Urbanisation
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10

TNO report

TNO 2015 R11382

Monitoring Network Building Vibrations - Analysis Earthquakes 05-11-2014 (Zandeweer), 30-12-2014 (Woudbloem) and 06-01-2015 (Wirdum)

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Contents

1 Introduction

1.1 Background

In Groningen, so-called induced earthquakes occur, as a result of the extraction of natural gas. These earthquakes cause ground-borne vibrations that transfer to the foundations of buildings thus causing the building itself to vibrate. These vibrations may result in damage to the building.

To determine the effects of the induced earthquakes, NAM has set up a research program. Part of this research program is a monitoring network for building vibrations. In about 200 buildings a vibration sensor is installed, measuring continuously the building vibrations at foundation level. To gain insight in the vulnerability of the buildings in Groningen for particular vibration levels, this monitoring network also includes a damage survey. By surveying the damage in these buildings before and after an earthquake, a relation can be found between the building vibrations due to an earthquake and the damage in the buildings caused by that earthquake.

TNO has designed and built this monitoring network for building vibrations, including an IT infrastructure to handle, process and analyse the data (the vibration data centre). The set-up of this monitoring network is described in TNO-report 2015 R10501 “Monitoring Network Building Vibrations” [ref 01].

1.2 Purpose

During the period October 2014 to February 2015, a total of 3 earthquakes with a magnitude of M=2,5 or larger took place within the region of the monitoring network. According to the website of KNMI the characteristics of these earthquakes are:

1. Name: Zandeweer
- Date: 5th November 2014
- Time: 01:12h (UTC)
- Magnitude: M = 2,9
- Location epicentre (latitude/longitude): 53374 / 6678
- Location epicentre (X-Y): 240908 / 599397

2. Name: Woudbloem
- Date: 30th December 2014
- Time: 02:37h (UTC)
- Magnitude: M = 2,8
- Location epicentre (latitude/longitude): 53208 / 6728
- Location epicentre (X-Y): 244580 / 580985

3. Name: Wirdum
- Date: 6th January 2015
- Time: 06:55h (UTC)
- Magnitude: M = 2,7
- Location epicentre (latitude/longitude): 53324 / 6768
- Location epicentre (X-Y): 247004 / 593944

NAM has commissioned TNO to analyse the effects of this earthquake on the buildings of the monitoring network. These analyses comprise the transfer of ground-borne vibrations to building vibrations and the damage inflicted on the buildings due to the earthquake vibration.

1.3 Guide

This report describes the results of the analysis of the earthquakes.
Firstly, Chapter 2 provides a general description of the set-up of the monitoring network building vibrations. Subsequently, Chapter 3 gives an overview of the buildings for which the measured vibration velocity at foundation level has exceeded a preset trigger value.
The analysis of the building vibrations is given in Chapter 4 – 6. Chapter 4 describes the framework of this analysis, Chapter 5 presents an analysis of the building vibrations and Chapter 6 presents an analysis of the transfer of the ground borne vibrations to the building vibrations.
The analysis of the building damage, caused by the earthquake, is given in Chapter 7 – 9. Chapter 7 describes the framework of this analysis, Chapter 8 gives the results of the repetitive damage surveys and Chapter 9 the damage curves.
Finally, Chapter 10 to 12 give the conclusions, references and the signature.

1.4 Former reports

This report is a second report of the Monitoring Network Building Vibrations with an analysis of the effects of the earthquakes. The former report was:

- TNO report 2015R10604 “Monitoring Network Building Vibrations – Analysis Earthquake 30-09-2014 Garmerwolde” [ref 04].

2 Set-up of the analysis procedures of the monitoring network

The analysis procedure of the monitoring network is based on the path the vibrations travel from source to building. The path the vibrations travel comprises of (Figure 2.1):

1. Ground-borne vibrations caused by an earthquake which spread towards the surroundings.
2. Ground-borne vibrations which are transferred to the buildings and result in vibration loads on the building foundations.
3. Building vibrations which can cause damage.

The effects caused in the three steps are analysed separately.

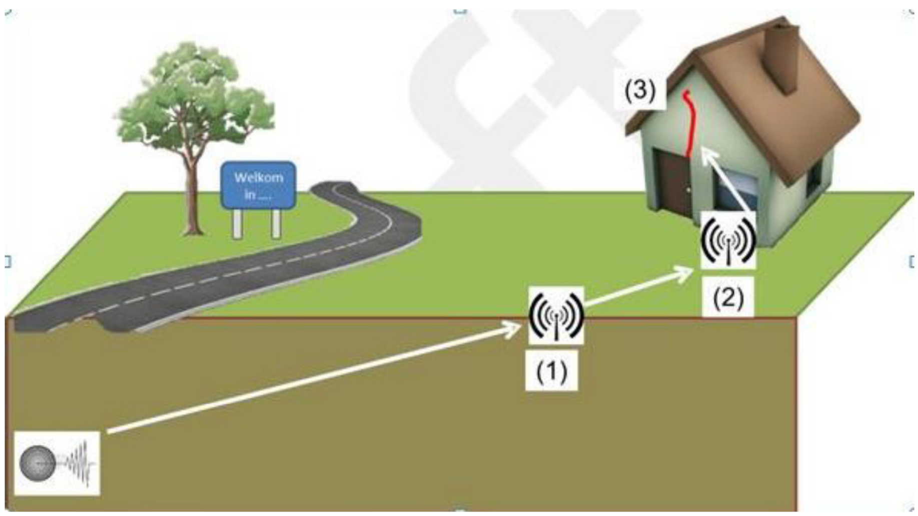


Figure 2.1: Illustration of the vibration path of an earthquake

<u>Ad 1: Ground-borne vibrations</u>
The ground-borne vibrations of step 1 are measured and analysed by KNMI via their own (separate) monitoring network, hence this effect is not part of the analysis procedure of this monitoring network. However, the ground-borne vibrations measured by KNMI do provide valuable input for step 2 and some data of the KNMI monitoring network is therefore included in the analysis.

<u>Ad 2: Vibration load on buildings</u>
Ground-borne vibrations are (probably) not transferred to the buildings one-to-one. The extent to which the ground-borne vibrations are transferred to buildings is characterised in practice by a transfer function. The transfer of vibrations depends on several factors, such as local soil conditions, type of foundation, etc.
To obtain insight into the transfer of the vibrations, vibration measurements are performed in about 200 buildings, at foundation level. Those measurements are then linked to the ground-borne vibrations measured or calculated by the KNMI in order to determine the transfer functions.
The buildings included in the monitoring network are selected such that they are representative for the majority of the buildings in Groningen.

Ad 3: Damage caused by vibrations

In the Netherlands there are no regulations for the determination of damage due to vibration loads on buildings. To ascertain the probability of building damage as a result of vibrations the SRB guideline A [02] provides damage curves. These damage curves show the relationship between the building vibration velocity and the probability of damage, for masonry in good and poor condition and for monuments, based on practical experience.

Although these damage curves can be used to establish the probability of damage for a particular vibration velocity, they provide no information on the severity of the damage.

After each earthquake above a magnitude M=2,5 a damage survey is carried out in the buildings that have a vibration level above a pre-set threshold (v=1 mm/s). The severity of the damage is classified in damage categories. By plotting the damage categories of the respective buildings against the vibration characteristics, new damage curves can be established in which the severity of the damage is related to the vibration characteristics on foundation level.

3 Buildings triggered by earthquakes

As mentioned in TNO-report “Monitoring Network Building Vibrations” [01] the monitoring network building vibrations includes a total of 203 buildings. 183 of these buildings are used for analysis, after an earthquake has occurred. The other 20 are public buildings.

NOTE: In the summer of 2015 the network is extended with more buildings. These extra buildings are not taken into account in this report.

The buildings for which the measured foundation vibration velocity (v_{max}) has exceeded 1 mm/s are analysed (see TNO-report “Monitoring Network Building Vibrations” [01]). This trigger level of 1 mm/s is based on the strictest limits of the SBR guideline for damage due to vibrations [ref 02].

During the Zandeweer, Woudbloem and Wirdum earthquakes, the building vibration velocity at foundation level (v_{max}) exceeded 1 mm/s in respectively 82, 22 and 36 buildings of the monitoring network. An overview of these buildings is given in tables 3.1, 3.2 and 3.3. These tables provide the following information:

- Building ID number
- Building type (see Annex A; Table A.1)
- Year of construction
- Foundation type
- Damage state (DS) at the most recent damage survey before the earthquake
- Maximum measured building vibration velocity at foundation level (v_{max}) during the earthquake (for definition V_{max} see Paragraph 4.2).
- The data the previous damage survey and the damage survey took place.

Additionally Figures 3.1, 3.2 and 3.3 show the maximum measured building vibration velocities at foundation level (v_{max}) of all buildings with respect to the epicentre of the earthquakes as given by KNMI (see Chapter 1.2).

Table 3.1: Buildings triggered by Zandeweer earthquake

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Zandeweer
[redacted]	7	1967	No piles	2	7,0	8-8-2014	8-12-2014
[redacted]	6	1934	Unknown	0	1,6	22-8-2014	18-2-2015
[redacted]	5	1904	No piles	1	2,6	10-9-2014	26-1-2015
[redacted]	9	1980	No piles	2	12,6	20-8-2014	9-12-2014
[redacted]	4	1890	No piles	1	3,4	19-8-2014	11-2-2015
[redacted]	6	1800	Unknown	1	2,9	18-8-2014	28-1-2015
[redacted]	7	1970	Piles	0	1,2	6-10-2014	3-2-2015
[redacted]	4	1905	No piles	0	1,5	18-8-2014	10-2-2015
[redacted]	4	1928	No piles	1	3,1	5-9-2014	7-11-2014
[redacted]	3	1994	Piles	0	2,3	8-8-2014	26-1-2015
[redacted]	4	1905	No piles	2	3,9	23-9-2014	11-2-2015
[redacted]	4	1918	Unknown	2	1,6	4-11-2014	20-2-2015
[redacted]	7	1959	No piles	1	2,4	27-8-2014	28-1-2015
[redacted]	8	1995	Piles	1	3,8	12-9-2014	7-11-2014
[redacted]	7	1952	Unknown	2	2,0	8-8-2014	28-1-2015
[redacted]	5	1933	No piles	1	1,5	7-8-2014	29-1-2015
[redacted]	3	2008	Piles	1	1,4	29-8-2014	18-11-2014
[redacted]	8	2002	Piles	0	1,7	8-10-2014	27-1-2015
[redacted]	5	1934	Unknown	1	2,2	11-9-2014	29-1-2015
[redacted]	4	1935	No piles	1	1.5	3-9-2014	13-11-2014
[redacted]	4	1920	No piles	1	1,4	21-8-2014	19-2-2015
[redacted]	6	1926	No piles	0	6,8	29-8-2014	9-12-2014
[redacted]	5	1912	No piles	1	1,9	8-8-2014	26-1-2015
[redacted]	4	1925	No piles	2	1,6	10-9-2014	13-11-2014
[redacted]	8	1991	Piles	1	2,7	25-8-2014	27-1-2015
[redacted]	9	1976	No piles	0	1,4	21-8-2014	18-2-2015
[redacted]	4	1870	No piles	2	1,4	3-9-2014	10-11-2014
[redacted]	8	2000	Piles	1	7,3	6-8-2014	8-12-2014
[redacted]	4	1800	No piles	1	6,6	11-8-2014	6-11-2014
[redacted]	7	1955	Unknown	2	2,3	3-11-2014	9-2-2015
[redacted]	8	1989	Piles	0	2,5	4-8-2014	27-1-2015
[redacted]	3	1990	Piles	1	2,1	24-7-2014	10-11-2014
[redacted]	5	1876	Piles + NP	2	1,1	15-7-2014	5-2-2015
[redacted]	7	1975	No piles	1	1,9	17-9-2014	18-2-2015
[redacted]	3	1985	Piles	1	1,9	22-7-2014	10-11-2014
[redacted]	3	1982	Piles	1	1,3	4-9-2014	13-11-2014
[redacted]	8	2007	Piles	1	1,8	13-8-2014	18-11-2014

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Zandeweer
[redacted]	8	1999	Piles	1	1,8	29-8-2014	6-11-2014
[redacted]	2	1983	Piles	0	1,3	16-9-2014	12-11-2014
[redacted]	2	1983	Piles	1	2,3	11-9-2014	11-11-2014
[redacted]	7	1964	No piles	1	1,4	23-7-2014	6-11-2014
[redacted]	6	1910	No piles	1	2,3	18-9-2014	28-1-2015
[redacted]	1	1994	Unknown	0	2,6	17-9-2014	12-11-2014
[redacted]	8	1997	Piles	0	3,9	4-8-2014	6-11-2014
[redacted]	7	1970	No piles	1	2,0	5-8-2014	6-11-2014
[redacted]	5	1906	Unknown	3	1,4	3-9-2014	10-2-2015
[redacted]	6	1896	No piles	1	1,1	12-8-2014	19-2-2015
[redacted]	7	1972	No piles	1	1,3	6-8-2014	29-1-2015
[redacted]	3	1999	Piles	1	1,3	28-8-2014	11-11-2014
[redacted]	8	1988	Piles	1	2,2	17-7-2014	10-11-2014
[redacted]	7	1969	No piles	1	1,0	7-8-2014	10-2-2015
[redacted]	4	1910	No piles	1	10,3	4-9-2014	9-12-2014
[redacted]	6	1890	No piles	1	1,7	21-8-2014	18-2-2015
[redacted]	3	1996	Piles	1	1,1	13-8-2014	18-11-2014
[redacted]	7	1962	No Piles	1	1,1	11-8-2014	6-07-2015*
[redacted]	6	1927	No piles	1	1,5	2-9-2014	18-11-2014
[redacted]	5	1929	No piles	2	1,5	14-7-2014	5-2-2015
[redacted]	5	1910	No piles	1	1,8	5-9-2014	18-2-2015
[redacted]	5	1932	No piles	1	11,4	14-8-2014	9-12-2014
[redacted]	6	1926	No piles	1	1,4	1-9-2014	19-2-2015
[redacted]	8	1995	Piles	0	1,7	6-8-2014	5-2-2015
[redacted]	8	2010	Piles	1	2,5	20-8-2014	13-11-2014
[redacted]	5	1870	Unknown	2	2,4	1-9-2014	27-1-2015
[redacted]	7	1956	No piles	1	1,2	12-8-2014	5-2-2015
[redacted]	8	1999	Piles	0	1,5	20-8-2014	19-2-2015
[redacted]	9	1979	No piles	1	4,2	11-8-2014	10-2-2015
[redacted]	8	1992	Piles	0	2,5	9-10-2014	29-1-2015
[redacted]	5	1936	No piles	1	5,6	17-9-2014	8-12-2014
[redacted]	6	1925	No piles	1	2,4	18-8-2014	27-1-2015
[redacted]	5	1938	No piles	2	1,1	26-8-2014	19-2-2015
[redacted]	3	1988	Piles	1	2,3	18-7-2014	6-11-2014
[redacted]	4	1889	No piles	2	1,9	9-9-2014	29-1-2015
[redacted]	3	1993	Piles	1	2,3	25-7-2014	7-11-2014
[redacted]	5	1938	No piles	1	2,9	15-9-2014	7-11-2014
[redacted]	5	1930	No piles	2	1,7	23-7-2014	10-11-2014
[redacted]	4	1800	No piles	1	1,3	16-9-2014	19-2-2015

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Zandeweer
[redacted]	8	2012	Piles	0	3,7	27-8-2014	10-2-2015
[redacted]	8	2000	Piles	1	1,4	22-9-2014	5-2-2015
[redacted]	4	1830	No piles	1	1,4	1-9-2014	3-2-2015
[redacted]	9	2008	No piles	1	2,7	25-8-2014	19-2-2015
[redacted]	4	1912	No piles	1	4,1	7-10-2014	3-2-2015
[redacted]	2	1983	Unknown	0	2,4	8-9-2014	12-11-2014

(*) Due to long term absence of building owner, the survey has been delayed

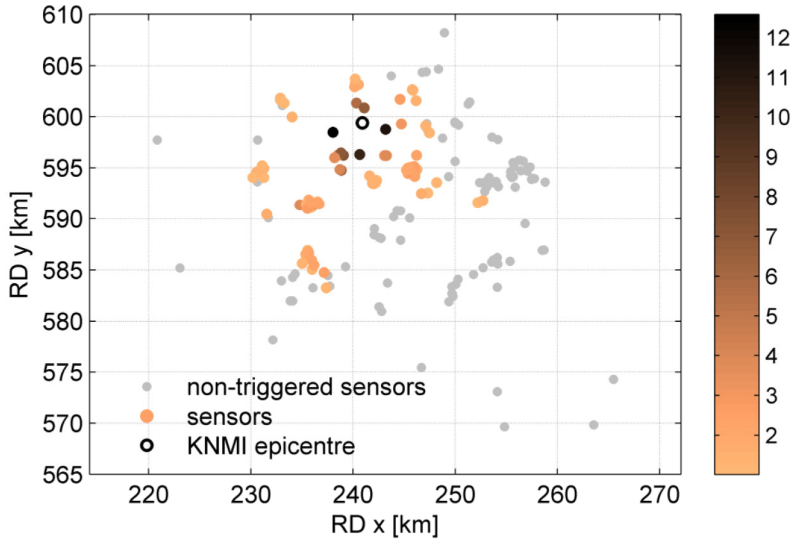


Figure 3.1: Overview of the maximum measured building vibration velocity at foundation level (v_{max} mm/s) with respect to the epicentre of the Zandeweer earthquake

Table 3.2: Buildings triggered by Woudbloem earthquake

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Woudbloem
[redacted]	9	1995	No piles	1	1,2	19-9-2014	20-2-2015
[redacted]	3	1992	Piles	1	2,2	12-11-2014	28-1-2015
[redacted]	8	1995	Piles	1	1,1	7-11-2014	26-2-2015
[redacted]	5	1936	No piles	2	3,6	3-9-2014	30-1-2015
[redacted]	3	1990	Piles	1	1,1	10-11-2014	28-1-2015

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Woudbloem
[redacted]	3	1985	Piles	1	1,2	10-11-2014	28-1-2015
[redacted]	8	1999	Piles	1	1,1	6-11-2014	26-2-2015
[redacted]	2	1983	Piles	1	1,0	11-11-2014	3-2-2015
[redacted]	8	2000	Piles	1	1,7	20-8-2014	26-2-2015
[redacted]	7	1970	No piles	1	1,0	6-11-2014	26-2-2015
[redacted]	3	1999	Piles	1	1,3	11-11-2014	28-1-2015
[redacted]	8	1988	Piles	1	1,4	10-11-2014	29-1-2015
[redacted]	5	1929	No piles	2	1,1	14-7-2014	5-2-2015
[redacted]	3	1988	Piles	1	1,0	6-11-2014	26-2-2015
[redacted]	8	1992	Piles	1	1,7	11-11-2014	28-1-2015
[redacted]	9	1996	No piles	1	8,6	15-8-2014	20-2-2015
[redacted]	1	1980	Unknown	1	1,2	12-9-2014	20-2-2015
[redacted]	2	1980	Unknown	1	1,2	8-9-2014	20-2-2015
[redacted]	1	1971	Unknown	1	9,2	15-9-2014	28-1-2015
[redacted]	2	1971	Unknown	1	6,6	9-9-2014	28-1-2015
[redacted]	3	2001	Piles	1	1,2	14-11-2014	30-1-2015
[redacted]	2	1964	Unknown	1	1,3	13-11-2014	3-2-2015

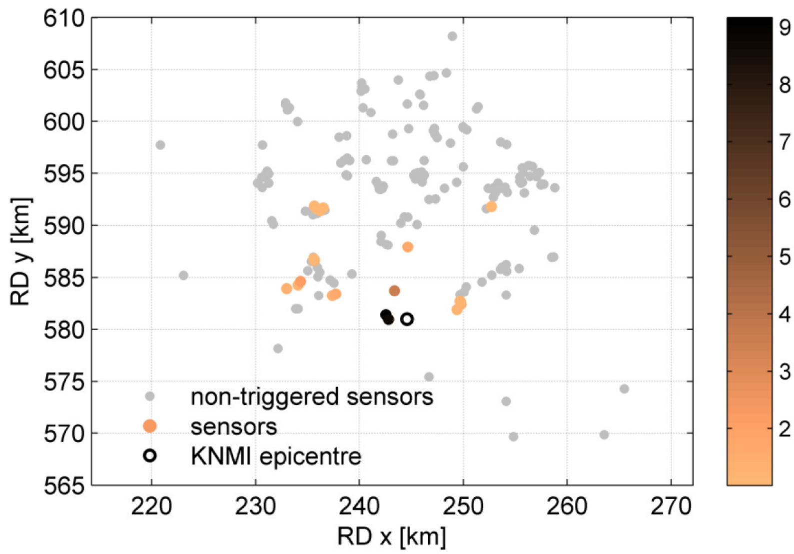


Figure 3.2: Overview of the maximum measured building vibration velocity at foundation level (v_{max} mm/s) with respect to the epicentre of the Woudbloem earthquake

Table 3.3: Buildings triggered by Wirdum earthquake

ID	Type	Year of construction	Foundation type	Damage state (DS; before earthquake)	V_{max} (mm/s)	Damage survey	
						Previous survey	Survey Wirdum
[redacted]	5	1904	No piles	1	3,6	10-9-2014	26-1-2015
[redacted]	4	1920	No piles	1	1,1	14-11-2014	11-2-2015
[redacted]	4	1890	No piles	1	1,1	19-8-2014	11-2-2015
[redacted]	6	1800	Unknown	1	3,6	18-8-2014	28-1-2015
[redacted]	3	1994	Piles	0	4,4	8-8-2014	26-1-2015
[redacted]	4	1905	No piles	2	1,4	23-9-2014	11-2-2015
[redacted]	7	1959	No piles	1	3,7	27-8-2014	28-1-2015
[redacted]	6	1930	No piles	1	3,1	13-8-2014	10-2-2015
[redacted]	8	1991	Piles	1	3,3	5-11-2014	27-1-2015
[redacted]	5	1933	No piles	1	1,2	7-8-2014	29-1-2015
[redacted]	8	2002	Piles	0	2,0	8-10-2014	27-1-2015
[redacted]	5	1934	Unknown	1	4,1	11-9-2014	29-1-2015
[redacted]	5	1912	No piles	1	3,3	8-8-2014	26-1-2015
[redacted]	8	1991	Piles	1	3,9	25-8-2014	27-1-2015
[redacted]	7	1955	Unknown	2	3,1	3-11-2014	9-2-2015
[redacted]	8	1989	Piles	0	3,2	4-8-2014	27-1-2015
[redacted]	4	1920	No piles	1	1,6	11-8-2014	9-2-2015
[redacted]	5	1876	Piles + No Piles	2	1,1	15-7-2014	5-2-2015
[redacted]	4	1925	No piles	1	1,2	13-11-2014	29-1-2015
[redacted]	6	1910	No piles	1	4,3	18-9-2014	28-1-2015
[redacted]	8	1993	Piles	1	4,1	7-11-2014	29-1-2015
[redacted]	7	1962	No piles	1	3,0	11-8-2015	06-07-2015*
[redacted]	5	1929	No piles	2	1,7	14-7-2014	5-2-2015
[redacted]	8	1995	Piles	0	2,9	6-8-2014	5-2-2015
[redacted]	8	2010	Piles	1	4,5	13-11-2014	29-1-2015
[redacted]	5	1870	Unknown	2	3,1	1-9-2014	27-1-2015
[redacted]	7	1956	No piles	1	3,0	12-8-2014	5-2-2015
[redacted]	8	1992	Piles	0	4,0	9-10-2014	29-1-2015
[redacted]	6	1925	No piles	1	3,4	18-8-2014	27-1-2015
[redacted]	4	1889	No piles	2	3,1	9-9-2014	29-1-2015
[redacted]	9	1986	No piles	1	1,6	13-8-2014	10-2-2015
[redacted]	5	1925	No piles	2	3,6	8-9-2014	26-1-2015
[redacted]	8	2000	Piles	1	1,7	22-9-2014	5-2-2015
[redacted]	9	1979	No piles	1	1,6	15-8-2014	9-2-2015
[redacted]	6	1842	No piles	1	1,5	6-8-2014	9-2-2015
[redacted]	4	1903	No piles	2	3,5	14-11-2014	27-1-2015
[redacted]	7	1974	No piles	1	1,5	31-7-2014	9-2-2015

(*) Due to long term absence of building owner, the survey has been delayed

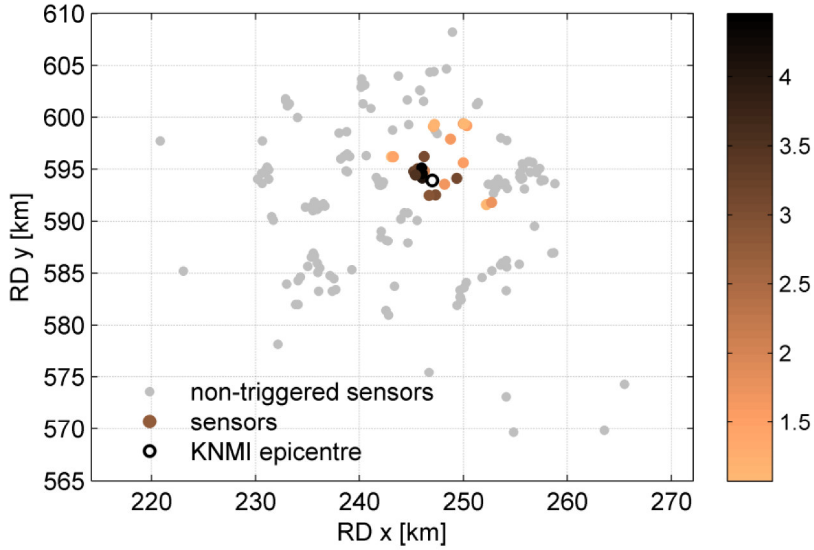


Figure 3.3: Overview of the maximum measured building vibration velocity at foundation level (v_{max} mm/s) with respect to the epicentre of the Wirdum earthquake

4 Framework analysis building vibrations

4.1 General

The building sensors measure building vibration accelerations at foundation level. Out of these measured accelerations the sensor systems calculate directly the vibration velocity and these calculated vibration velocities are used to determine if the pre set trigger, a vibration velocity of 1 mm/s, is exceeded.
After the pre set trigger is exceeded, the sensor system sends the originally measured vibration accelerations to the vibration data center (VDC). These originally measured accelerations are used for the analysis of the building vibrations.

4.2 Vibration characteristics

For each building the measured acceleration signal by the building sensor is analysed as follows (Figure 4.1):

- Two time-domain signals are calculated:
  - The raw measured acceleration signal a(t) is used after removal of the offset.
  - After filtering the signal is integrated to a velocity signal v(t).
- The frequency spectrum is calculated for the acceleration and the velocity signals.
- Individual signal characteristics are calculated for each of the three signal directions per sensor (two in horizontal direction (x and y) and one in vertical direction (z)):
  - Peak acceleration [a_{max}]; this value is used in international earthquake guidelines and is of interest for structural calculations. It is the maximum of $a_{x,\ max}$, $a_{y,\ max}$ and $a_{z,\ max}$.
  - Peak velocity [v_{max}]; this value is used in the Dutch guidelines (SBR ref [02]) for relations between building vibrations and the probability of damage. It is the maximum of $V_{x,\ max}$, $V_{y,\ max}$ and $V_{z,\ max.}$
  - Effective velocity [$v_{eff,max}$]; this value is mostly used to express a relation between the vibration and the hindrance for people (ref [03]).
  - Dominant frequency of acceleration [$f_{a,dom}$] and velocity [$f_{v,dom}$]; these values are of interest for the transfer of the ground-borne vibrations to the building vibrations.
  - The vectorial maximum of the acceleration ($|a(t)|_{max}$) and the velocity ($|v(t)|_{max}$) are calculated ($|a(t)| = \sqrt{(a_x(t))^2 + (a_y(t))^2 + (a_z(t))^2}$). These are absolute values of the acceleration and the velocity, independent from the orientation of the sensor.
- The Arias Intensity. For the x-channel this is given by $I_{A,x} = \frac{\pi}{2g}\int_0^T a_x(t)^2 dt$ with T the length of the time trace. The y- and z-channels are calculated in a similar way.
- The Total Arias Intensity. This is given by $I_{A,total} = I_{A,x} + I_{A,y} + I_{A,y}$.
- The Cumulative Absolute Velocity (CAV). For the x-channel this is given by: $CAV_x = \int_0^T |a_x(t)|dt$ and similar for the y- and z- channels.
- The Total Cumulative Absolute Velocity. This is given by $CAV_{total} = CAV_x + CAV_y + CAV_z$.

- The Standardized Cumulative Absolute Velocity CAV_{STD}. This is calculated in a similar fashion as the CAV but here the signal is divided into 1 second long sections and a section is only taken into account if there is a moment in the section where the absolute acceleration is above a certain threshold. Currently this threshold is set to 0.001g. This prevents the CAV_{STD} from keeping accumulating after the event contrary to the CAV can do.

The calculation of the Arias Intensity, CAV and CAV_{STD} is performed on the raw acceleration signal after offset removal. No filtering is applied. Tests show that results differ less than 1% for the current events. Larger events are likely to have a lower frequency content which is perhaps partly affected by the filter, so it has been chosen to perform the calculations on the unfiltered signal.

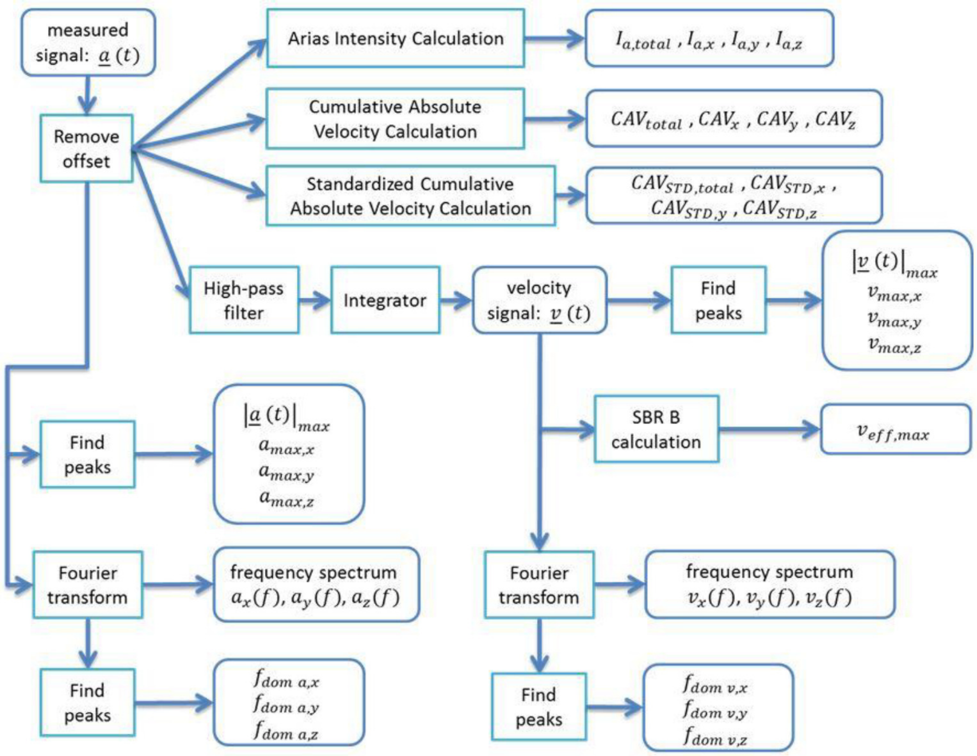


Figure 4.1: Flow chart for analysing signal characteristics

4.3 Transfer functions

There are three main sources of information along the chain from the epicenter of an earthquake to the exposed buildings, namely:

(i) the magnitude and location of the earthquake
(ii) the free-field signal characteristics at the KNMI instrument points
(iii) the foundation signal characteristics in the buildings.

The first two sources are covered by KNMI. KNMI has installed free-field sensors in a grid of 6 km within the area of the monitoring network, to measure the free field characteristics. The relationship between the vibration signal characteristics at the KNMI free-field points (ii) and the ones measured on the building foundations (iii) will be calculated as part of the monitoring network building vibrations. For each building, the KNMI free-field data at the KNMI point closest to the building and the measured foundation signals will be used to calculate the transfer function of the ground-borne vibrations to the building vibrations at foundation level.

For each building triggered the closest by KNMI free-field sensor has been selected. The signal from this free-field sensor has been analyzed in the same way as the signal from the building sensors (see Chapter 4.2).
Since the horizontal vibration components of the free-field sensors are given in the direction of the epicenter and perpendicular to that direction, these values cannot be compared to the horizontal components of the building sensors directly. The horizontal components of the free-field sensors have to be rotated to the x- and y-direction of the individual buildings.

The transfer of ground-borne vibrations to building vibrations will be determined for each of the individual signal characteristics, as a transfer factor: ratio between the comparable single-figures. This will be done for all three measuring directions.
As an example, the transfer factor for the peak velocity can be determined as follows:

- Peak ground velocity in three directions (i=1,2,3): $v_{max,ground\text{-}borne,i}$
- Peak foundation velocity in three directions (i=1,2,3): $v_{max,building,i}$
- Transfer factor in three directions (i=1,2,3): T_i

$$T_{v_{max},i} = \frac{v_{max,foundation,i}}{v_{max,ground-borne,i}}$$

NOTE: *At the moment this Paragraph was written the sensor network of KNMI was not yet finished and no sufficient data was available. It is possible that the final way in which the data will be provided to TNO will lead to some adjustments to the above mentioned analysis.*

5 Vibration characteristics

5.1 General

The vibration signals of the triggered buildings are recorded for a period of 30 s, about 10 s before and 20 s after the beginning of the signal from the earthquake. An example of such a vibration signal is given in Figure 5.1. Annex B of this report gives examples of the measured vibration acceleration signals of four buildings for each of the earthquakes Zandweer, Wirdum and Woudbloem. The same Annex also gives graphs with the distribution of the frequency of each signal.
Annex C gives the same information regarding the calculated vibration velocity signals and the distribution of the frequency of each signal.

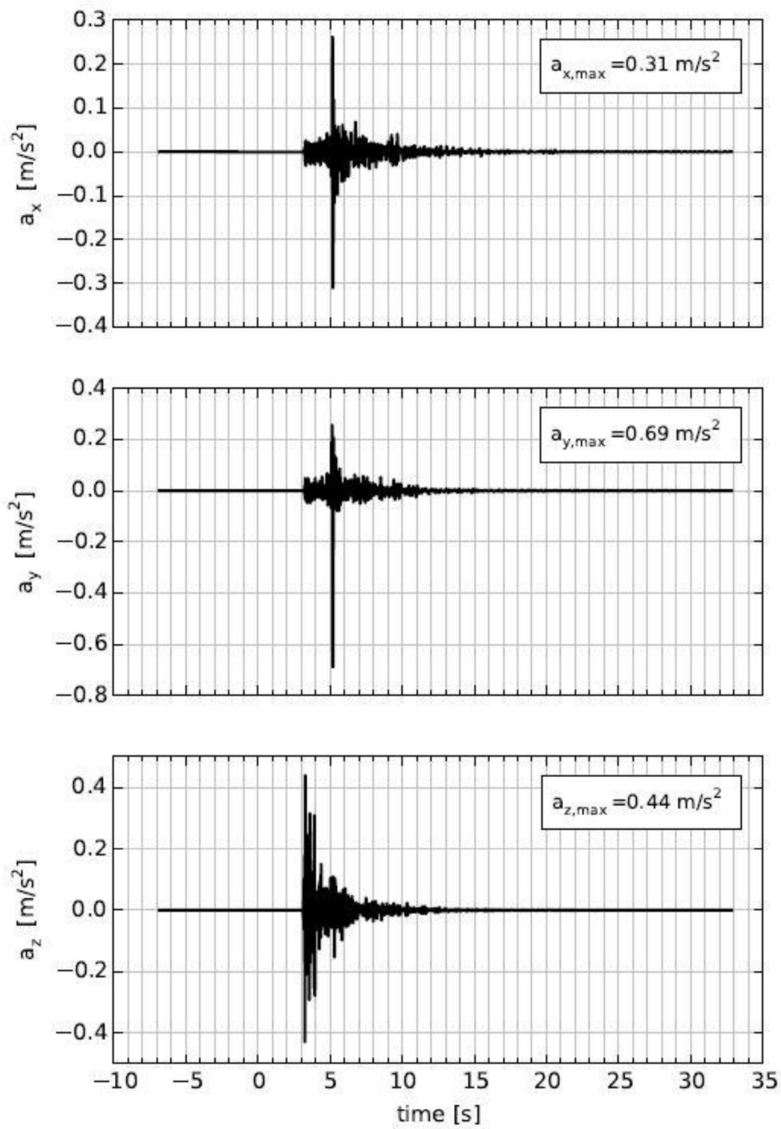


Figure 5.1: Example of a measured vibration acceleration signal from the Zandeweer event (ID[redacted]).

The calculated vibration characteristics regarding the acceleration are given in Annex D:

- Peak acceleration in three directions: $a_{x,max}$,$a_{y,max}$,$a_{z,max}$
- Peak acceleration: a_{max} = maximum of ($a_{x,max}$,$a_{y,max}$,$a_{z,max}$)
- Vectorial maximum of the acceleration: maximum of $|a(t)|$
- Dominant frequency of acceleration in three directions: $f_{a,dom,x}$,$f_{a,dom,y}$,$f_{a,dom,z}$

The calculated vibration characteristics regarding the velocity are given in Annex E:

- Peak velocity in three directions: $v_{x,max}$,$v_{y,max}$,$v_{z,max}$
- Peak velocity: v_{max} = maximum of ($v_{x,max}$,$v_{y,max}$,$v_{z,max}$)
- Vectorial maximum of the velocity: maximum of $|v(t)|$
- Dominant frequency of velocity in three directions: $f_{v,dom,x}$,$f_{v,dom,y}$,$f_{v,dom,z}$
- Peak effective velocity in three directions: $v_{eff,x,max}$,$v_{eff,y,max}$,$v_{eff,z,max}$
- Peak effective velocity: $v_{eff,max}$ = maximum of ($v_{eff,x,max}$,$v_{eff,y,max}$,$v_{eff,z,max}$)

The calculated vibration characteristics regarding the Cumulative Absolute Velocity are given in Annex F:

- Cumulative Absolute Velocity in three directions: CAV_x, CAV_y, CAV_z
- Total Cumulative Absolute Velocity: CAV_{total}
- Standardized Cumulative Absolute Velocity in three directions: $CAV_{STD,x}$, $CAV_{STD,y}$, $CAV_{STD,z}$
- Total Standardized Cumulative Absolute Velocity: $CAV_{STD,total}$

The calculated vibration characteristics regarding the Arias Intensity are given in Annex G:

- Arias Intensity in three directions: $I_{A,x}$, $A_{A,y}$, $A_{A,z}$
- Total Cumulative Arias Intensity: $I_{A,total}$

5.2 Zandeweer

The peak vibration acceleration of all triggered buildings in the Zandeweer earthquake is presented in Figure 5.2.
The peak vibration velocity of all triggered buildings in the Zandeweer earthquake is presented in Figure 5.3.

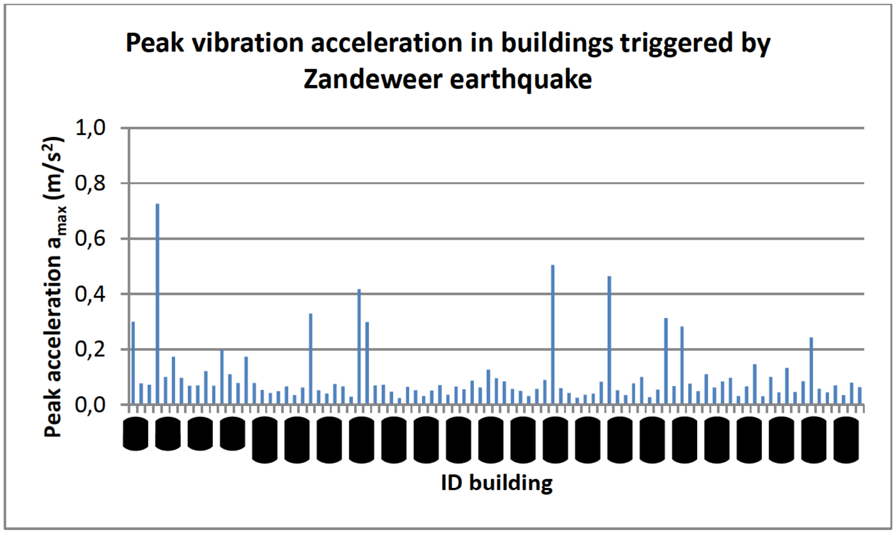


Figure 5.2: Peak acceleration of all buildings triggered by the Zandeweer earthquake

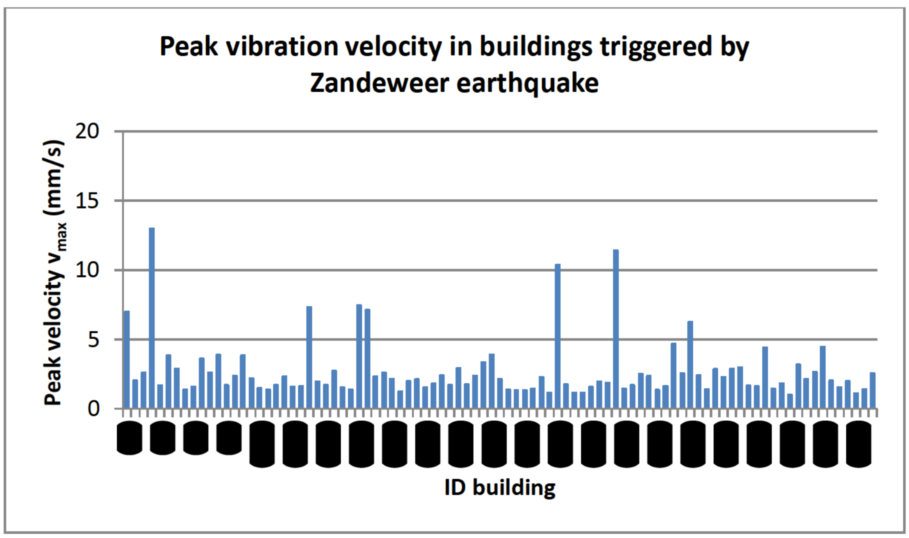


Figure 5.3: Peak velocity of all buildings triggered by the Zandeweer earthquake

The horizontal and the vertical component of the vibration of each building are compared, to see which direction gives the highest vibrations. This is done for both the peak acceleration (Figure 5.4) and the peak velocity (Figure 5.5). For the Zandeweer earthquake these two figures show that the horizontal component of the vibrations is mainly dominant over the vertical component, for both the acceleration and the velocity.

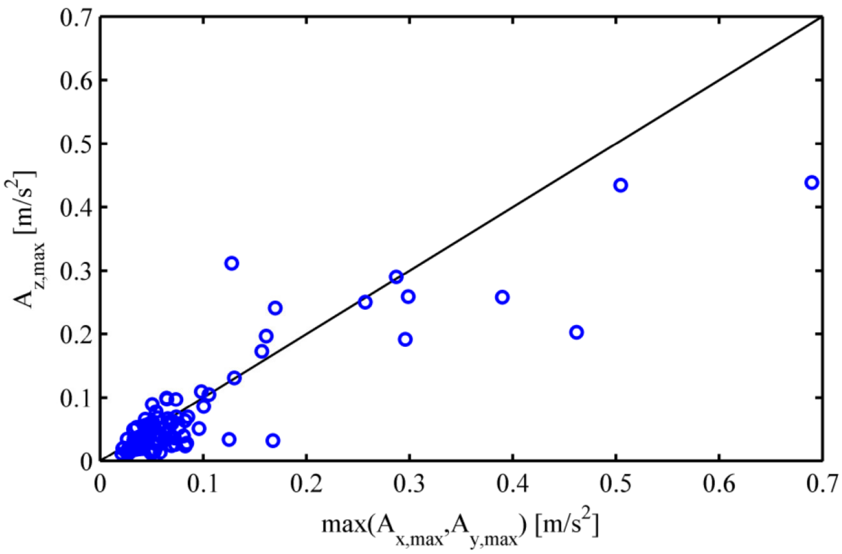


Figure 5.4: Horizontal versus vertical component of peak acceleration for all buildings triggered by the Zandeweer earthquake

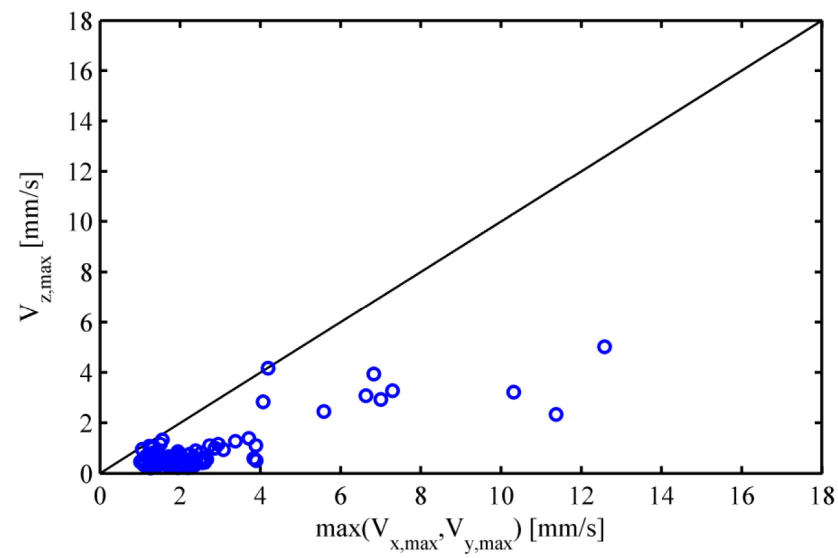


Figure 5.5: Horizontal versus vertical component of peak velocity for all buildings triggered by the Zandeweer earthquake

The peak acceleration and the peak velocity are compared to each other to look for the relation between these two characteristics. The results of this comparison are given in Figure 5.6. This Figure shows a rather linear relation between the peak acceleration and the peak velocity.

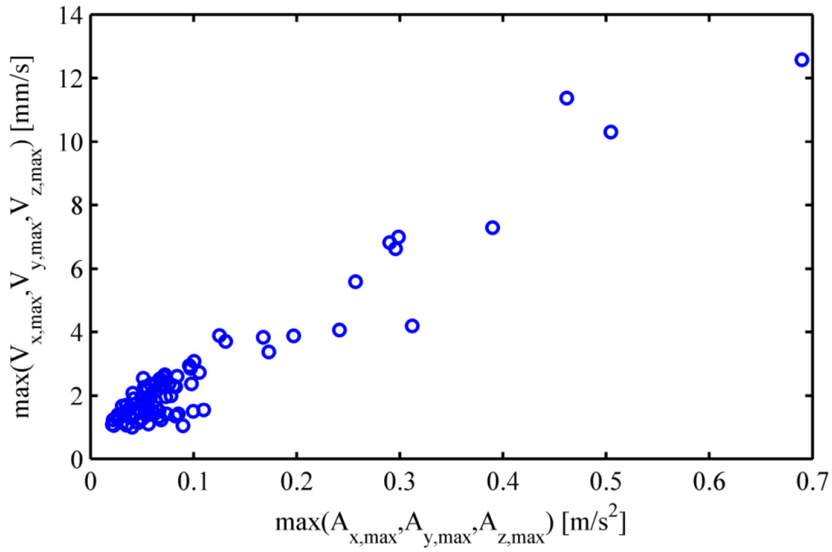


Figure 5.6: Peak acceleration versus the peak velocity for all buildings triggered by the Zandeweer earthquake

The distribution of the dominant frequency of the vibration accelerations is analysed to make it possible to compare the dominant frequency of the ground-borne vibrations with the ones of the foundations vibrations. The results of this analysis are given in Figures 5.7 – 5.9.

The frequency spectra of the measured acceleration signals (see Annex B) show no significant frequency content above 25 Hz for the x- and y-channels. For the z-channel there is no significant content above 40 Hz. As expected, the frequency spectra of the velocities (see Annex C) show a shift of the content to the lower frequencies with no significant content above 15 Hz for the x- and y-channels and above 25 Hz for the z-channel.

For the x- and y- channels, the dominant frequencies for acceleration are on average 5 Hz with a 95% upper bound of 10 Hz. For the z-channel the average dominant frequency is 11 Hz and the 95% upper bound is 17 Hz.

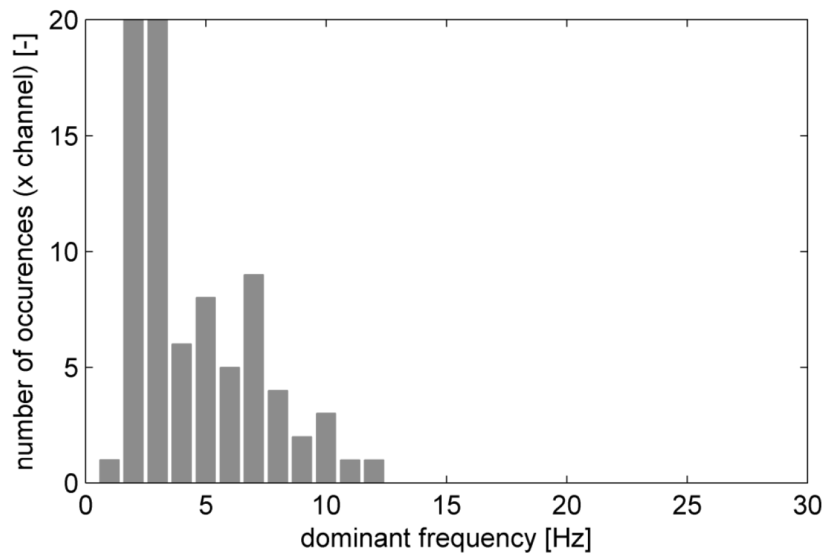


Figure 5.7: Distribution of dominant frequency of the vibration accelerations; x-direction for all buildings triggered by the Zandeweer earthquake

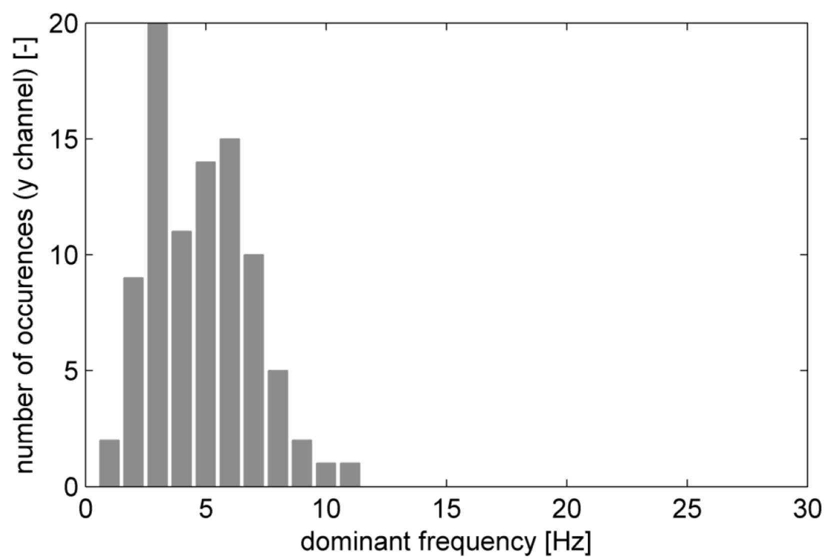


Figure 5.8: Distribution of dominant frequency of the vibration accelerations; y-direction for all buildings triggered by the Zandeweer earthquake

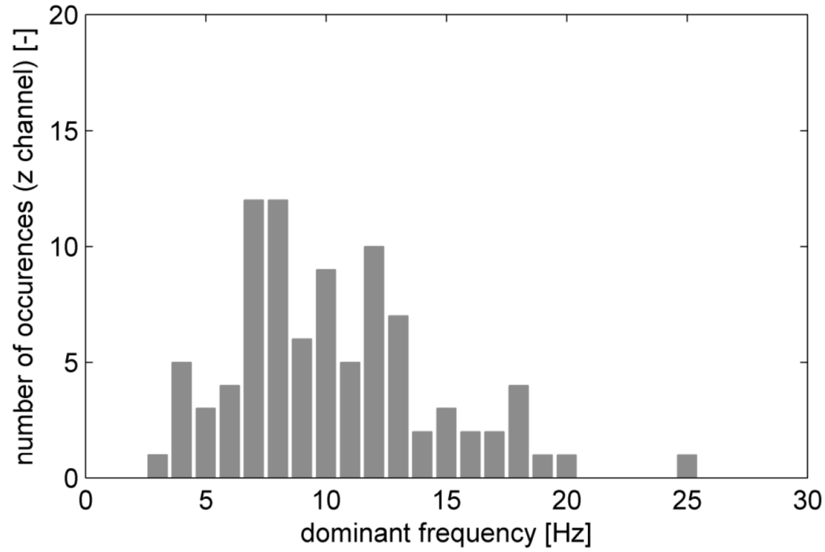


Figure 5.9: Distribution of dominant frequency of the vibration accelerations; z-direction for all buildings triggered by the Zandeweer earthquake

5.3 Woudbloem

The peak vibration acceleration of all triggered buildings in the Woudbloem earthquake is presented in Figure 5.10.
The peak vibration velocity of all triggered buildings in the Woudbloem earthquake is presented in Figure 5.11.

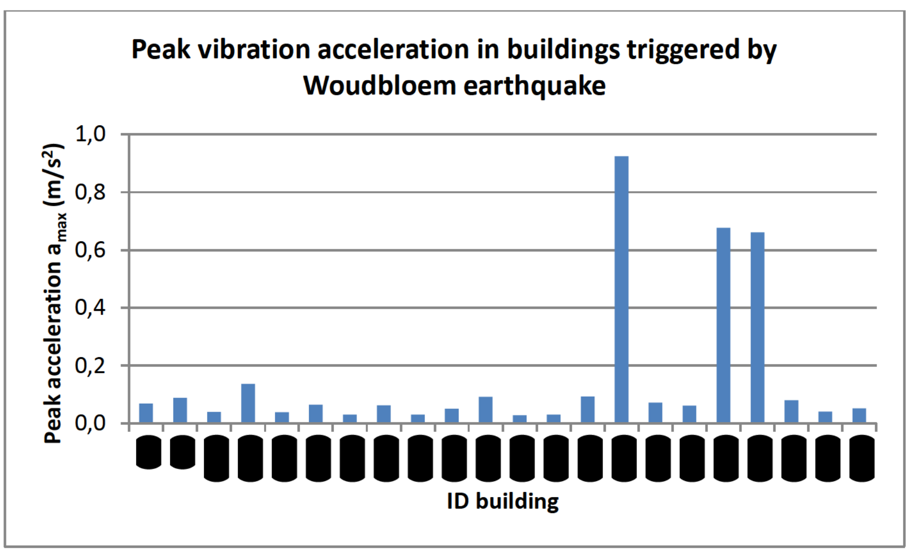


Figure 5.10: Peak acceleration of all buildings triggered by the Woudbloem earthquake

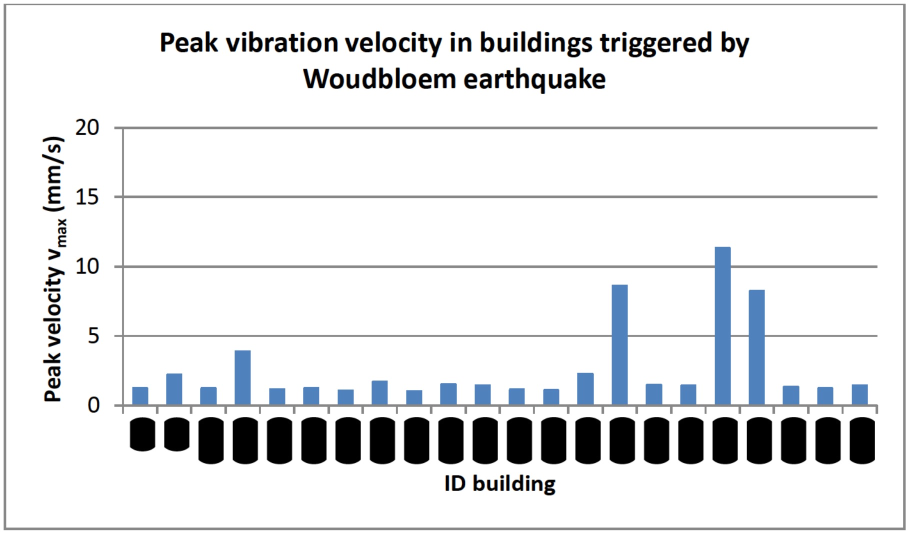


Figure 5.11: Peak velocity of all buildings triggered by the Woudbloem earthquake

The horizontal and the vertical component of the vibration of each building are compared, to see which direction gives the highest vibrations. This is done for both the peak acceleration (Figure 5.12) and the peak velocity (Figure 5.13). For the Woudbloem earthquake these two figures show that the horizontal component of the vibrations is mainly dominant over the vertical component, for both the acceleration and the velocity. However, three building show a rather different behaviour, with a dominant vertical component of the acceleration (ID[redacted], ID[redacted] and ID[redacted] the time signals and frequency content for these three ID's are presented in Appendices B2 and C2). Probably this is caused by the location of these three building nearby the epicenter of the earthquake (Figure 3.2).

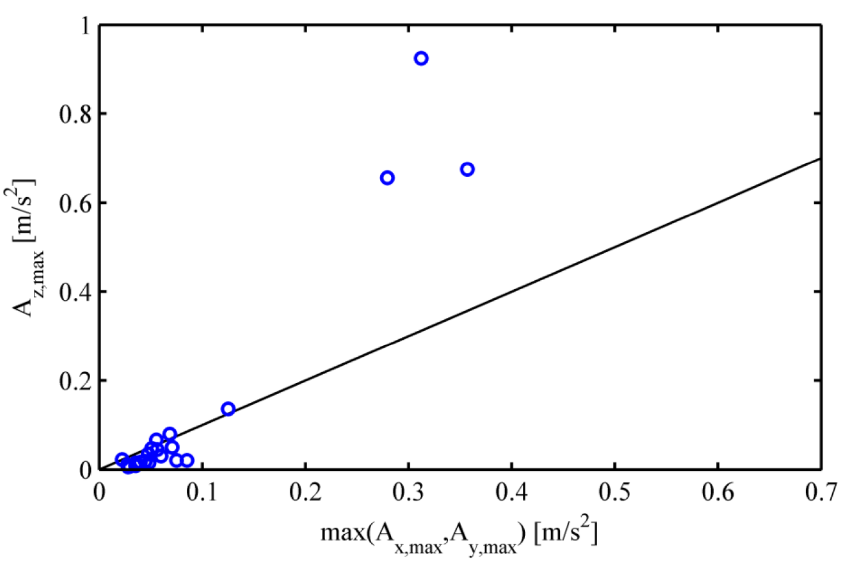


Figure 5.12: Horizontal versus vertical component of peak acceleration for all buildings triggered by the Woudbloem earthquake

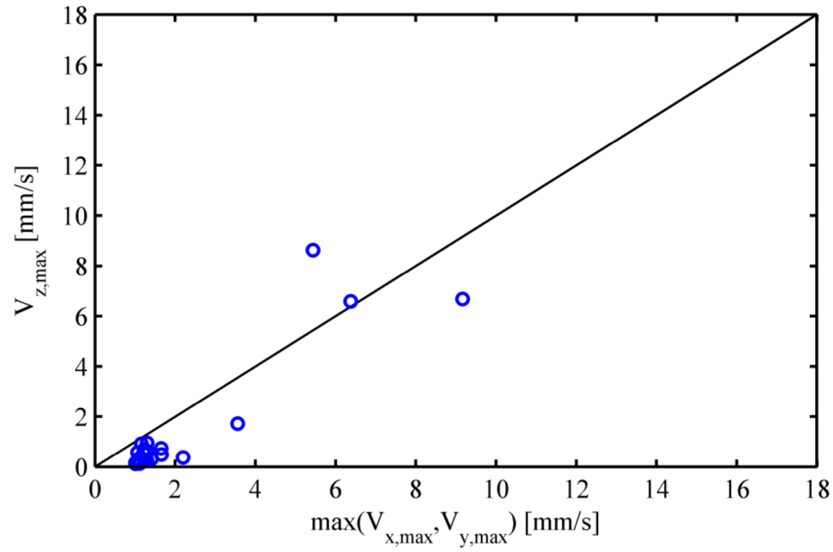


Figure 5.13: Horizontal versus vertical component of peak velocity for all buildings triggered by the Woudbloem earthquake

The peak acceleration and the peak velocity are compared to each other to look for the relation between these two characteristics. The results of this comparison are given in Figure 5.14. This Figure shows a rather linear relation between the peak acceleration and the peak velocity.

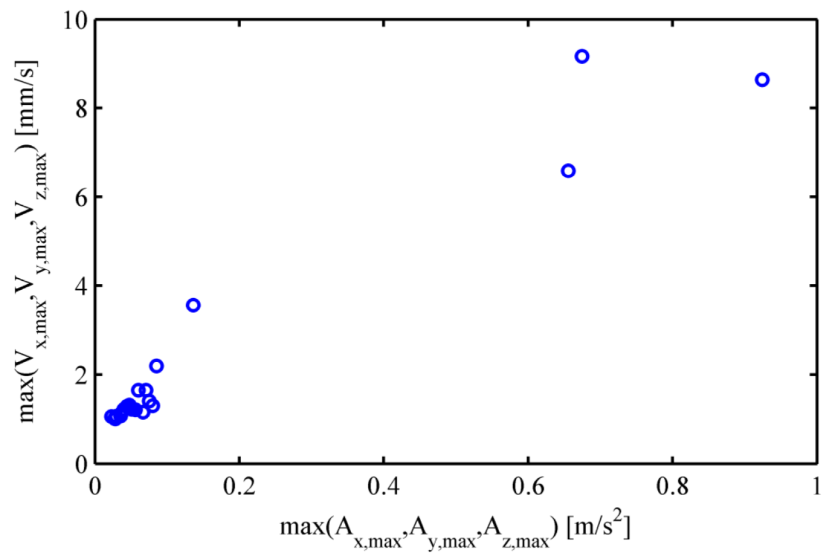


Figure 5.14: Peak acceleration versus the peak velocity for all buildings triggered by the Woudbloem earthquake

The distribution of the dominant frequency of the vibration accelerations is analysed to make it possible to compare the dominant frequency of the ground-borne vibrations with the ones of the foundations vibrations. The results of this analysis are given in Figures 5.15 – 5.17.

The frequency spectra of the measured acceleration signals (see Annex B) show no significant frequency content above 25-30 Hz for the x- and y-channels. For the z-channel there is no significant content above 40 Hz. As expected, the frequency spectra of the velocities (see Annex C) show a shift of the content to the lower frequencies with no significant content above 15 Hz for the x- and y-channels and above 25 Hz for the z-channel.

For the x- and y- channels, the dominant frequencies for acceleration are on average 6 Hz with a 95% upper bound of 11 Hz. For the z-channel the average dominant frequency is 15 Hz and the 95% upper bound is 17 Hz.

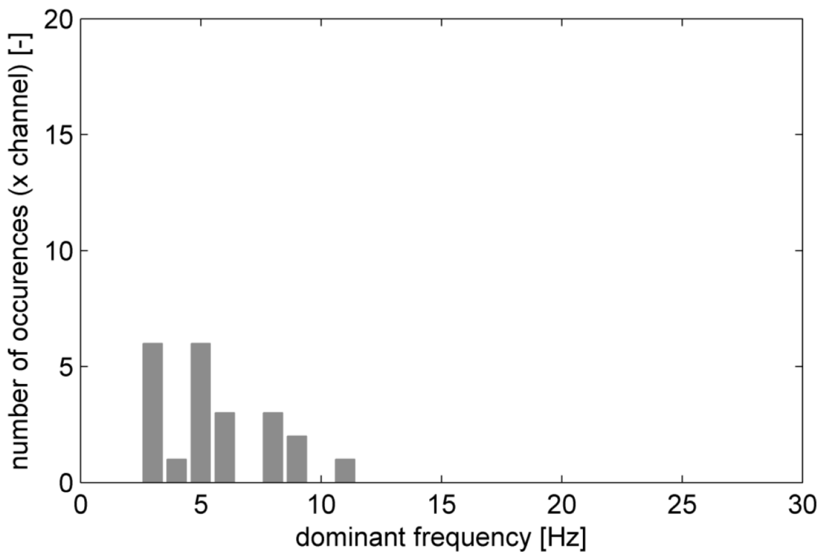


Figure 5.15: Distribution of dominant frequency of the vibration accelerations; x-direction for all buildings triggered by the Woudbloem earthquake

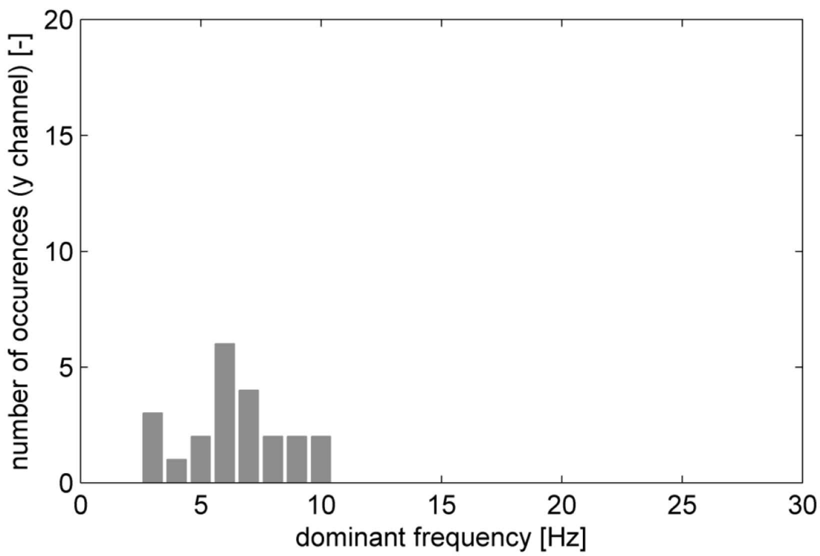


Figure 5.16: Distribution of dominant frequency of the vibration accelerations; y-direction for all buildings triggered by the Woudbloem earthquake

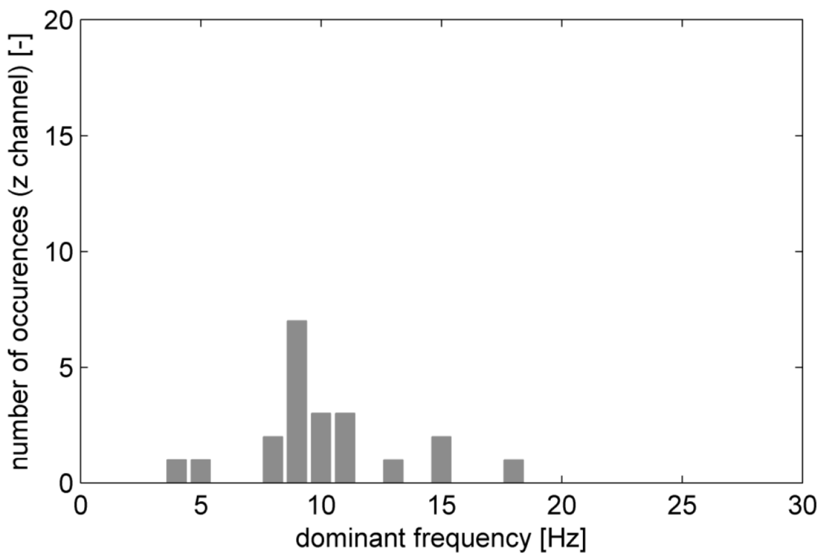


Figure 5.17: Distribution of dominant frequency of the vibration accelerations; z-direction for all buildings triggered by the Woudbloem earthquake

5.4 Wirdum

The peak vibration acceleration of all triggered buildings in the Wirdum earthquake is presented in Figure 5.18.
The peak vibration velocity of all triggered buildings in the Wirdum earthquake is presented in Figure 5.19.

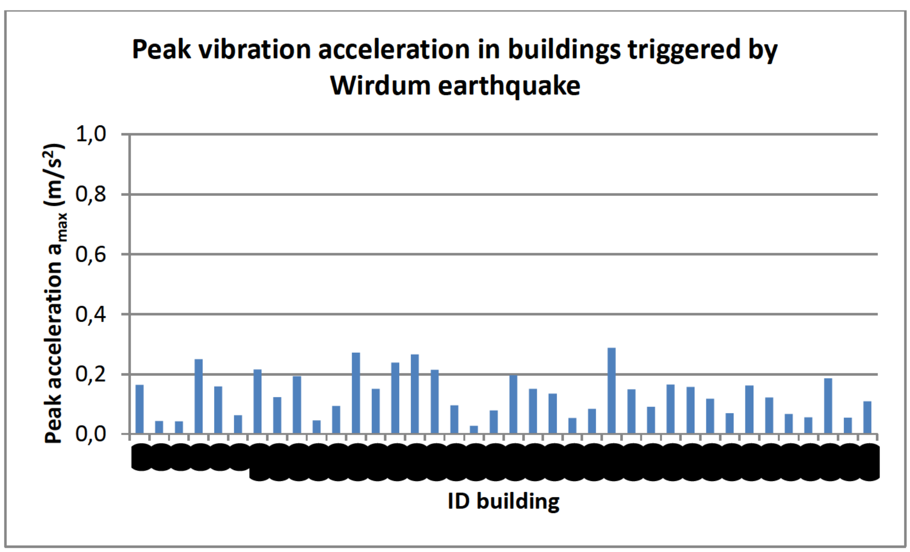


Figure 5.18: Peak acceleration of all buildings triggered by the Wirdum earthquake

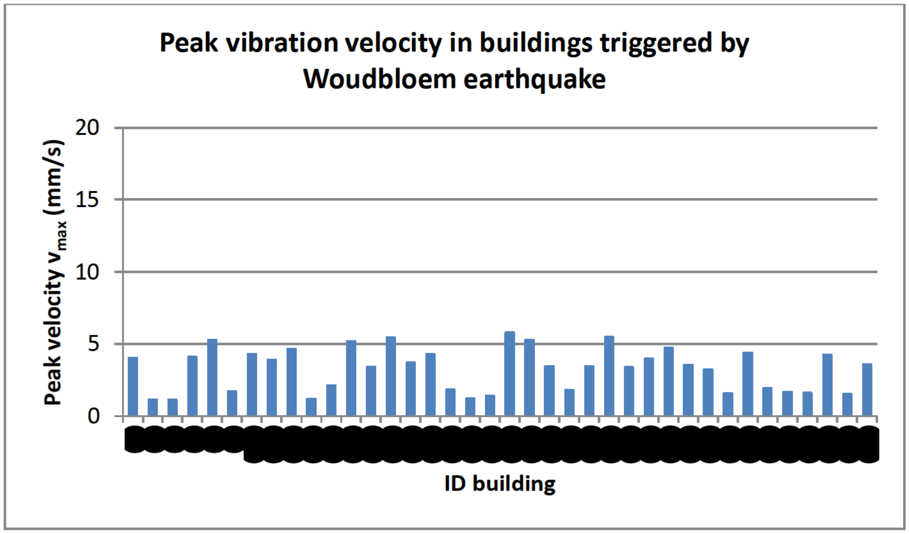


Figure 5.19: Peak velocity of all buildings triggered by the Wirdum earthquake

The horizontal and the vertical component of the vibration of each building are compared, to see which direction gives the highest vibrations. This is done for both the peak acceleration (Figure 5.20) and the peak velocity (Figure 5.21). For the earthquake Wirdum the horizontal accelerations mostly dominate the vertical accelerations with some exceptions. The horizontal velocities are dominant over the vertical velocities.

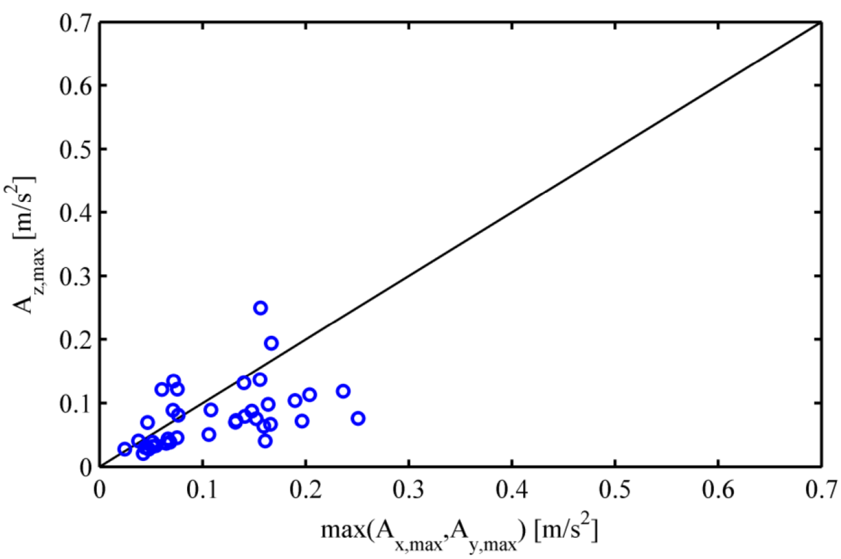


Figure 5.20: Horizontal versus vertical component of peak acceleration for all buildings triggered by the Wirdum earthquake

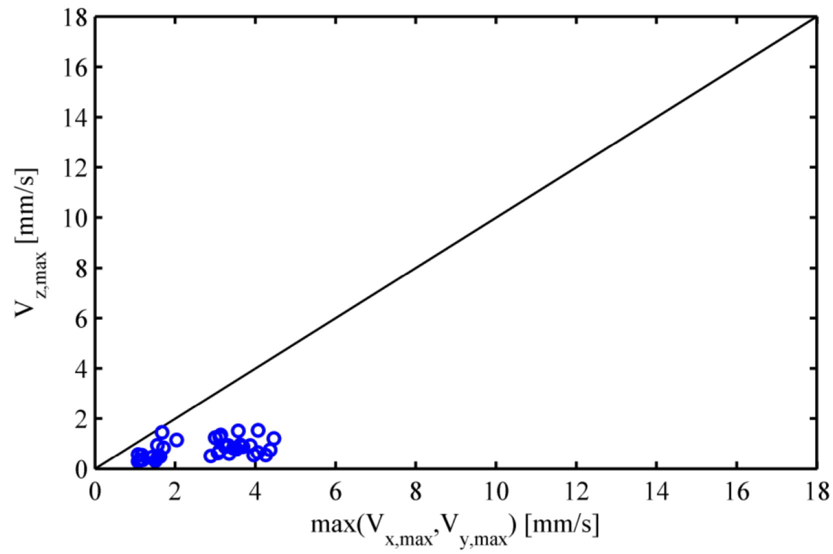


Figure 5.21: Horizontal versus vertical component of peak velocity for all buildings triggered by the Wirdum earthquake

The peak acceleration and the peak velocity are compared to each other to look for the relation between these two characteristics. The results of this comparison are given in Figure 5.20. This Figure shows a rather scattered correlation between the peak acceleration and the peak velocity.

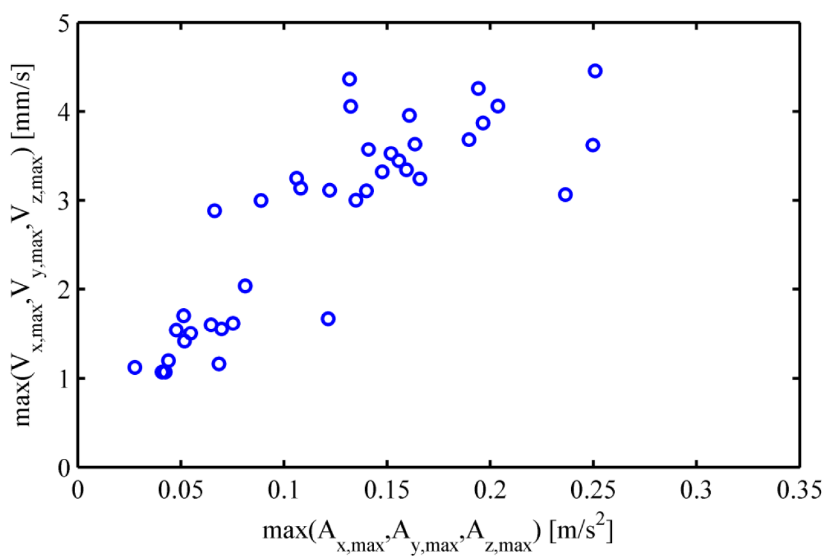


Figure 5.22: Peak acceleration versus the peak velocity for all buildings triggered by the Wirdum earthquake

The distribution of the dominant frequency of the vibration accelerations is analysed to make it possible to compare the dominant frequency of the ground-borne vibrations with the ones of the foundations vibrations. The results of this analysis are given in Figures 5.23 – 5.25.

The frequency spectra of the measured acceleration signals (see Annex B) show no significant frequency content above 25 Hz for the x- and y-channels. For the z-channel there is no significant content above 40 Hz. Several sensors (ID's [redacted], [redacted] and [redacted]) registered significant frequency content at higher frequencies above 40 Hz in the z-channel. In these sensors a vibration is visible after the main event with a different signature and this vibration is not the same for the different ID's. As expected, the frequency spectra of the velocities (see Annex C) show a shift of the content to the lower frequencies with no significant content above 15 Hz for the x- and y-channels and above 25 Hz for the z-channel.

For the x- and y- channels, the dominant frequencies for acceleration are on average 6 Hz with a 95% upper bound of 12 Hz. For the z-channel the average dominant frequency is 12 Hz and the 95% upper bound is 22 Hz.

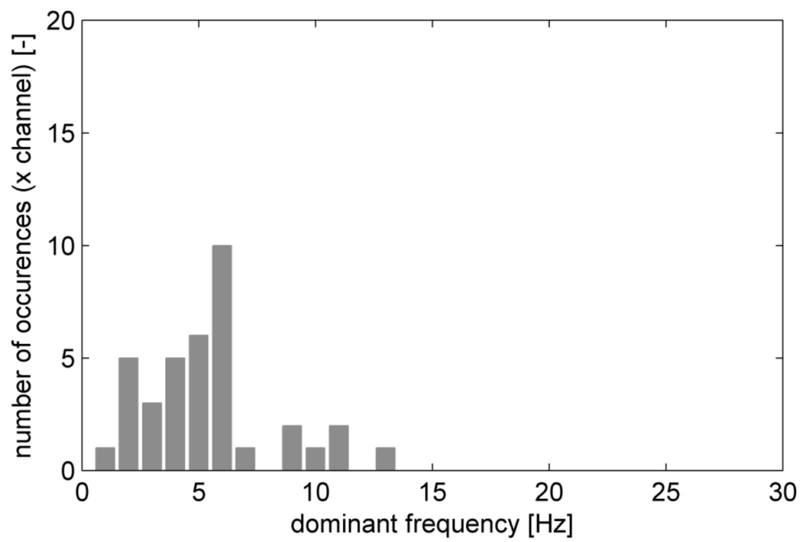


Figure 5.23: Distribution of dominant frequency of the vibration accelerations; x-direction for all buildings triggered by the Wirdum earthquake

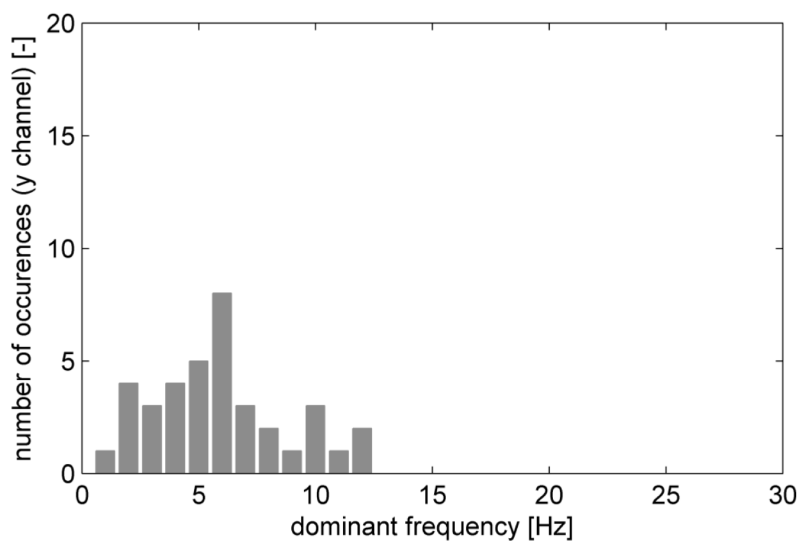


Figure 5.24: Distribution of dominant frequency of the vibration accelerations; y-direction for all buildings triggered by the Wirdum earthquake

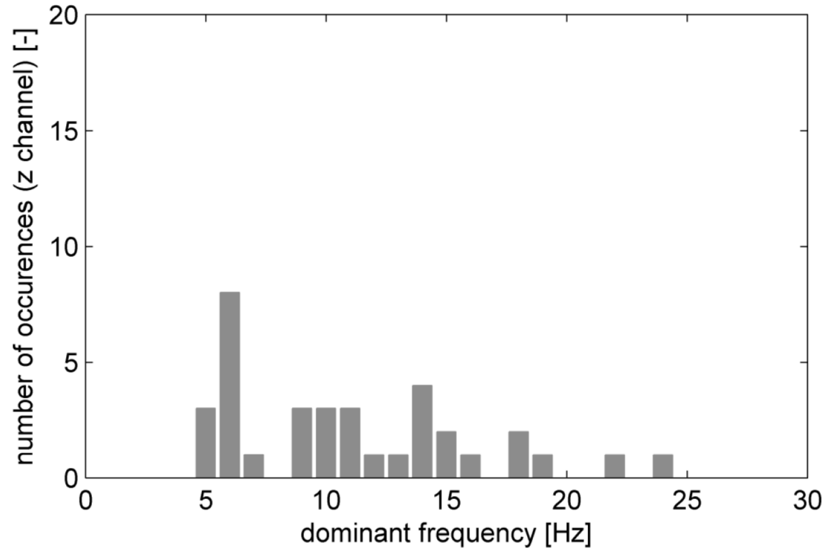


Figure 5.25: Distribution of dominant frequency of the vibration accelerations; z-direction for all buildings triggered by the Wirdum earthquake

6 Transfer functions

At the moment of the three earthquakes the sensor network of KNMI was not yet finished. Therefore no transfer functions could be calculated and no analysis could be executed about the influence of the building types or other factors.

7 Framework analysis damage of buildings

7.1 General

During the installation of the sensors, an initial damage survey of the buildings has been executed (see TNO-report “Monitoring Network Building Vibrations”; Chapter 11 (ref [01])). The main aim of this damage survey was to classify the initial damage in the buildings according to the EMS-98 “European Seismological Scale” (see Figure 7.1 and Table 7.1). This damage scale was used to comply with the setup of the fragility curves for the building stock in the Groningen region (see ARUP report “Seismic Risk Study Earthquake Scenario-Based Risk Assessment” dated 29 November 2013) and since this classification has been used in many other damage studies across Europe.

The initial building damage survey was limited to a survey of the cracks in the external parts of the building facades, because this information is sufficient for the categorisation of the building damage according to the EMS-scale.

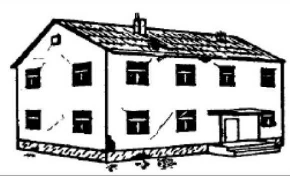
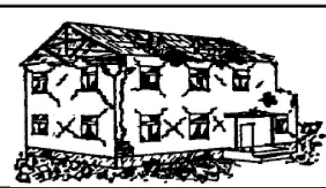
Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.

Figure 7.1: Classification of damage for masonry buildings (EMS-98)

Table 7.1: Defined damages state of buildings

Damage state	Description
DS 0	No damage
DS 1	Negligible damage (“non-structural”)
DS 2	Moderate damage (“slight structural”)
DS 3	Substantial to heavy damage (“structural”)
DS 4	Very heavy damage
DS 5	Destruction

7.2 Repetitive building survey

After an earthquake, all buildings triggered by that earthquake have been surveyed again, in a similar way as the initial damage survey. The registration form used for this repetitive damage survey is given in Annex H.

During this repetitive damage survey cracks that were already present have been examined:

- to see if the length and/or the width has been increased
- to see if they are repaired in the meantime
- to see if repaired cracks have cracked again.

Also new cracks are reported, in the same way as during the initial damage survey.

Based on the results of the repetitive damage survey the damage state of the buildings has been determined again.

7.3 Damage curves

Based on a comparison of the initial building damage state and the damage state after the earthquake, the effect of the earthquake on the individual buildings can be determined. Subsequently this effect can be related to the measured vibration level of the foundation during the earthquake.

The relation between vibration level and occurred damage can be characterized in different ways. In line with the SBR directive for vibration damage (ref [02]) the vibration level will be characterized by the peak velocity of the buildings. Therefore, damage curves have been setup based on the relation between the peak velocity of the building foundations and the damage state after the earthquake.

If sufficient data is available, also other damage curves will be made, based on other characterizations of the vibrations:

- Peak ground acceleration (KNMI; in line with the fragility curves)
- Peak acceleration
- Vectorial maximum of the acceleration
- Vectorial maximum of the velocity.

In the period between the previous damage survey and the current damage survey, other vibrations could have occurred in the buildings. This could be vibrations due to another earthquake, which took place in the intermediate period. This could also

be triggers other than an earthquake. If these have occurred, the building owners were asked for the reason for this trigger.
Other vibrations will affect the results. Either the recorded vibration level is too low for the damage state, or the damage state is not the result of the considered earthquake. The maximum measured building vibration levels in the period between the two damage surveys has been used for the damage curves.

8 Repetitive damage survey buildings

8.1 Peak vibration velocity per earthquake

In the period between the previous damage survey of the buildings and this repetitive damage survey several buildings were triggered by more than one of these three earthquakes. An overview of the vibration velocities of the triggered buildings with respect to the earthquakes is presented in Table 8.1.
In this table, the following information is provided:

- For each building the maximum vibration velocity at each earthquake is given. Building vibrations less than 1 mm/s (no trigger) are represented by "—" and buildings with no valid data available are represented by "+nan".
- For each building the normative vibration velocity for the repetitive damage survey is given ("Peak vibration velocity" in last column of table). This normative value is the maximum of the measured building vibrations.

At the time of the Zandeweer earthquake the repetitive damage survey for the Garmerwolde was ongoing. As a consequence a part of the triggered buildings by the earthquake of Zandeweer was already surveyed and reported in relation to the Garmerwolde earthquake (TNO report 2015 R10604 [ref 04]). In this report these buildings were taken into account as follows:

- If the vibration velocity as a consequence of the Zandeweer earthquake was larger than the vibration velocity as a consequence of the Garmerwolde earthquake, the survey is included in this report.
- If the vibration velocity as a consequence of the Zandeweer earthquake was smaller than the vibration velocity of the Garmerwolde earthquake, the vibration velocity of Zandeweer was not normative for the repetitive damage survey. These surveys are not included in this report and are marked with (*) in Table 8.1.

Table 8.1: Overview of vibration velocity per earthquake and peak vibration velocity

ID	V_{max} (mm/s)			Peak vibration velocity v_{max} (mm/s)
	Zandeweer	Woudbloem	Wirdum	
[redacted]	7,0	--	--	7,0
[redacted]	1,6	--	--	1,6
[redacted]	2,6	--	3,6	3,6
[redacted]	--	--	1,1	1,1
[redacted]	--	1,2	--	1,2
[redacted]	12,6	--	--	12,6
[redacted]	3,4	--	1,1	3,4
[redacted]	2,9	--	3,6	3,6
[redacted]	1,2	--	--	1,2
[redacted]	--	2,2	--	2,2
[redacted]	1,5	--	--	1,5
[redacted]	3,1	--	--	3,1
[redacted]	2,3	--	4,4	4,4

ID	V_{max} (mm/s)			Peak vibration velocity v_{max} (mm/s)
	Zandeweer	Woudbloem	Wirdum	
[redacted]	3,9	--	1,4	3,9
[redacted]	1,6	--	--	1,6
[redacted]	2,4	--	3,7	3,7
[redacted]	--	--	3,1	3,1
[redacted]	3,8 (*)	1,1	--	1,1
[redacted]	--	--	3,3	3,3
[redacted]	2,0	+ nan	+ nan	2,0
[redacted]	1,5	--	1,2	1,5
[redacted]	1,4	--	--	1,4
[redacted]	1,7	--	2,0	1,7
[redacted]	2,2	--	4,1	4,1
[redacted]	1,5 (*)	--	--	--
[redacted]	1,4	--	--	1,4
[redacted]	6,8	--	--	6,8
[redacted]	1,9	--	3,3	3,3
[redacted]	--	3,6	--	3,6
[redacted]	1,6 (*)	--	--	1,6
[redacted]	2,7	--	3,9	3,9
[redacted]	1,4	--	--	1,4
[redacted]	1,4 (*)	--	--	--
[redacted]	7,3	--	--	7,3
[redacted]	6,6 (*)	--	--	6,6
[redacted]	2,3	--	3,1	3,1
[redacted]	2,5	--	3,2	3,2
[redacted]	2,1 (*)	1,1	--	1,1
[redacted]	--	--	1,6	1,6
[redacted]	1,1	--	1,1	1,1
[redacted]	1,9	--	--	1,9
[redacted]	1,9 (*)	1,2	--	1,2
[redacted]	1,3 (*)	--	--	--
[redacted]	1,8 (*)	--	--	--
[redacted]	1,8 (*)	1,1	--	1,1
[redacted]	1,3 (*)	--	--	--
[redacted]	--	--	1,2	1,2
[redacted]	2,3 (*)	1,0	--	1,0
[redacted]	1,4 (*)	--	--	--
[redacted]	--	1,7	--	1,7
[redacted]	2,3	--	4,3	4,3
[redacted]	2,6 (*)	--	--	--
[redacted]	3,9 (*)	--	--	--
[redacted]	2,0 (*)	1,0	--	1,0

ID	V_{max} (mm/s)			Peak vibration velocity v_{max} (mm/s)
	Zandeweer	Woudbloem	Wirdum	
[redacted]	1,4	--	--	1,4
[redacted]	--	--	4,1	4,1
[redacted]	1,1	--	--	1,1
[redacted]	1,3	--	--	1,3
[redacted]	1,3 (*)	1,3	--	1,3
[redacted]	2,2 (*)	1,4	--	1,4
[redacted]	1,0	--	--	1,0
[redacted]	10,3	--	--	10,3
[redacted]	1,7	--	--	1,7
[redacted]	1,1	--	--	1,1
[redacted]	1,1	--	3,0	3,0
[redacted]	1,5	--	--	1,5
[redacted]	1,5	1,1	1,7	1,7
[redacted]	1,8	--	--	1,8
[redacted]	11,4	--	--	11,4
[redacted]	1,4	--	--	1,4
[redacted]	1,7	--	2,9	2,9
[redacted]	2,5	--	4,5	2,5 and 4,5 (**)
[redacted]	2,4	--	3,1	3,1
[redacted]	1,2	--	3,0	3,0
[redacted]	1,5	--	--	1,5
[redacted]	4,2	--	--	4,2
[redacted]	2,5	--	4,0	4,0
[redacted]	5,6	--	--	5,6
[redacted]	2,4	--	3,4	3,4
[redacted]	1,1	--	--	1,1
[redacted]	2,3 (*)	1,0	--	1,0
[redacted]	1,9	--	3,1	3,1
[redacted]	2,3 (*)	--	--	--
[redacted]	--	1,7	--	1,7
[redacted]	--	--	1,6	1,6
[redacted]	--	--	3,6	3,6
[redacted]	2,9 (*)	--	--	--
[redacted]	1,7 (*)	--	--	--
[redacted]	1,3	--	--	1,3
[redacted]	3,7	--	--	3,7
[redacted]	1,4	--	1,7	1,7
[redacted]	--	--	1,6	1,6
[redacted]	--	--	1,5	1,5
[redacted]	+ nan	--	3,5	3,5
[redacted]	1,4	--	--	1,4

ID	V_{max} (mm/s)			Peak vibration velocity v_{max} (mm/s)
	Zandeweer	Woudbloem	Wirdum	
[redacted]	2,7	--	--	2,7
[redacted]	--	8,6	--	8,6
[redacted]	--	--	1,5	1,5
[redacted]	4,1	--	--	4,1
[redacted]	--	1,2	--	1,2
[redacted]	--	1,2	--	1,2
[redacted]	--	9,2	--	9,2
[redacted]	--	6,6	--	6,6
[redacted]	--	1,2	--	1,2
[redacted]	--	1,3	--	1,3
[redacted]	2,4 (*)	--	--	N/A

(*) Vibration velocity Zandeweer is smaller than vibration velocity Garmerwolde
(**) Two surveys have been executed, one between Zandeweer and Wirdum and one after Wirdum.

8.2 Repetitive damage survey

The repetitive damage surveys have taken place from November 6th 2014 till February 26th 2015. The results of these repetitive damage surveys are given in Annex I. For each building this Annex provides the following information:

- The amount of cracks registered at the previous damage survey, for each of the three categories of crack width separately (category A < 1 mm; category B between 1 and 10 mm; category C > 10 mm).
- The amount of cracks with an increase in length and/or width, divided in cracks that remained in the same category of crack width and cracks which moved to a higher category.
- The amount of new cracks registered for each of the three categories of crack width A, B and C.
- Remarks regarding the repetitive damage survey.

Note:

The purpose of the initial survey was to detect and record major cracks in the buildings, in order to determine the damage state (DS) of the buildings. At that time it was not intended to execute a total survey, including also the smallest cracks.
During the first repetitive surveys question raised, mainly about small cracks, whether these crack were already present or were caused by the earthquake. For this reason it was decided to record also minor cracks. As a consequence of this decision the first repetitive surveys show much more cracks than the initial survey.

The repetitive damage survey of 94 buildings resulted in the following additional information:

- In the previous damage survey, a total amount of 749 cracks was reported for the 94 buildings. The repetitive damage survey has shown that 10 of these cracks have increased in width and/or in length.

- Most of the new reported cracks were relatively small and short and belong to crack width category A.
- A large part of the new reported cracks is located at the lintels and the sills of windows and doors.
- From overview photos of the facades, taken at the initial damage survey, it could be verified that several new reported cracks were already present at the initial damage surveys, but were not reported at that time.
- Based on the previous remark it is expected that more new reported cracks (at the first repetitive damage survey) were already present at the initial damage survey.

Based on the results of the repetitive damage survey, the damage state of the buildings after the Zandeweer/Woudbloem/Wirdum earthquakes has been categorized again. The results of the categorization of the previous damage state and the damage state after the Zandeweer/Woudbloem/Wirdum earthquakes are presented in Table 8.2.

Table 8.2: Categorization of the previous damage state and the damage state at the repetitive damage survey

ID	Peak vibration velocity v_{max} (mm/s)	Damage state (DS)	
		At previous damage survey	At repetitive damage survey
[redacted]	7,0	2	2'
[redacted]	1,6	0	1
[redacted]	3,6	1	1'
[redacted]	1,1	1	1'
[redacted]	1,2	1	1'
[redacted]	12,6	2	1
[redacted]	3,4	1	1'
[redacted]	3,6	1	1'
[redacted]	1,2	0	1
[redacted]	2,2	1	1
[redacted]	1,5	0	1
[redacted]	3,1	1	1
[redacted]	4,4	0	1
[redacted]	3,9	2	2'
[redacted]	1,6	2	2'
[redacted]	3,7	1	1'
[redacted]	3,1	1	1'
[redacted]	1,1	1	0
[redacted]	3,3	1	1'
[redacted]	2,0	2	1
[redacted]	1,5	1	1'
[redacted]	1,4	1	1
[redacted]	1,7	0	1

ID	Peak vibration velocity v_{max} (mm/s)	Damage state (DS)	
		At previous damage survey	At repetitive damage survey
[redacted]	4,1	1	1'
[redacted]	1,4	1	1'
[redacted]	6,8	0	0
[redacted]	3,3	1	1'
[redacted]	3,6	2	1
[redacted]	1,6	2	2'
[redacted]	3,9	1	1
[redacted]	1,4	0	1
[redacted]	7,3	1	1'
[redacted]	6,6	1	1'
[redacted]	3,1	2	2'
[redacted]	3,2	0	1
[redacted]	1,1	1	1
[redacted]	1,6	1	1'
[redacted]	1,1	2	2'
[redacted]	1,9	1	1'
[redacted]	1,2	1	1
[redacted]	1,1	1	1'
[redacted]	1,2	1	1
[redacted]	1,0	1	1'
[redacted]	1,7	1	1'
[redacted]	4,3	1	1'
[redacted]	1,0	1	1'
[redacted]	1,4	3	3'
[redacted]	4,1	1	1'
[redacted]	1,1	1	1'
[redacted]	1,3	1	1'
[redacted]	1,3	1	1
[redacted]	1,4	1	1
[redacted]	1,0	1	1'
[redacted]	10,3	1	1
[redacted]	1,7	1	1'
[redacted]	1,1	1	1
[redacted]	3,0	1	1’
[redacted]	1,5	1	1'
[redacted]	1,7	2	2'
[redacted]	1,8	1	1'
[redacted]	11,4	1	1'
[redacted]	1,4	1	1'
[redacted]	2,9	0	1

ID	Peak vibration velocity v_{max} (mm/s)	Damage state (DS)	
		At previous damage survey	At repetitive damage survey
[redacted](*)	2,5	1	1'
[redacted](*)	4,5	1	1'
[redacted]	3,1	2	2'
[redacted]	3,0	1	1
[redacted]	1,5	0	1
[redacted]	4,2	1	1'
[redacted]	4,0	0	1
[redacted]	5,6	1	1'
[redacted]	3,4	1	1'
[redacted]	1,1	2	2'
[redacted]	1,0	1	1
[redacted]	3,1	2	2'
[redacted]	1,7	1	1
[redacted]	1,6	1	0
[redacted]	3,6	2	2'
[redacted]	1,3	1	1'
[redacted]	3,7	0	0
[redacted]	1,7	1	1'
[redacted]	1,6	1	1
[redacted]	1,5	1	1'
[redacted]	3,5	2	2'
[redacted]	1,4	1	1'
[redacted]	2,7	1	1
[redacted]	8,6	1	1
[redacted]	1,5	1	1'
[redacted]	4,1	1	1'
[redacted]	1,2	1	1'
[redacted]	1,2	1	1'
[redacted]	9,2	1	1'
[redacted]	6,6	1	1
[redacted]	1,2	1	1
[redacted]	1,3	1	1

‘) = Increase of cracks (amount, length and/or width), but still in the initial damage state
*)= results from two repetitive damage surveys (Zandeweer and Wirdum)

9 Analysis repetitive damage survey

9.1 Normative vibration velocity

For the period between the previous and the repetitive damage survey, buildings triggered by an earthquake have been scanned for other triggers. In addition, building owners were asked for a possible explanation.
For some buildings, the vibration level caused by another source was higher than that caused by an earthquake. In case of a local vibration, such as mounting the sensor's cover lit, these registered vibrations are excluded for damage analysis. In case of a vibration for which it is likely that it resulted in a vibration of the whole building, it is taken into account for damage analysis.

An overview of buildings for which vibration velocities have been registered which exceeded the level of those registered during the earthquakes is given in Table 9.1.

Table 9.1: Buildings for which a vibration velocity is registered that exceeds the registered vibration velocity during an earthquake.

ID	Maximum registered vibration velocity vmax (mm/s)		
	Earthquake	Other triggers	Taken into account
[redacted]	1,6	1 trigger 1,9 mm/s, 1 trigger 6,5 mm/s Cause: train (goods transport)	6,5
[redacted]	1,2	3 triggers 2,7 < x < 8,7 mm/s Causes unknown. Sensor is placed close to door and owner mentions that slamming doors could be a possible cause. Because this is not an external cause and will not effect the whole building, these triggers are not taken into account.	1,2
[redacted]	3,4	1 trigger 4,7 mm/s; 3 triggers 20,1 mm/s Cause 4,7 mm/s: unknown Cause 20,1 mm/s: mounting cover lit on sensor	4,7
[redacted]	1,5	8 triggers 1,5 < x < 2,9 mm/s Causes unknown. However, building activities are present in surrounding area and therefore these triggers are taken into account	2,9
[redacted]	3,9	1 trigger 80 mm/s Cause: bump against sensor	3,9
[redacted]	3,7	1 trigger 8,0 mm/s Cause: building activities	8,0
[redacted]	3,1	1 trigger 5,4 mm/s; 1 trigger 36,9 mm/s Causes: mounting cover lit on sensor	3,1

ID	Maximum registered vibration velocity vmax (mm/s)		
	Earthquake	Other triggers	Taken into account
[redacted]	2,0	4 triggers 2,3 <x<5,8 mm/s; 1 trigger 39 mm/s; 1 trigger 140 mm/s Cause 2,3 < x < 5,8 mm/s: building activities Cause 39 mm/s: mounting cover lit on sensor Cause 140 mm/s: bump against sensor	5,8
[redacted]	1,5	21 triggers 1,5< x < 2,0 mm/s and 1 trigger 74 mm/s (z) Cause: traffic (speed bump) Cause 74 mm/s: unknown. Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account	2,0
[redacted]	1,7	5 triggers 2,3 < x < 4,7 mm/s Causes unknown	4,7
[redacted]	4,1	1 trigger 62 mm/s Cause unknown. Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account	4,1
[redacted]	1,4	2 triggers 1,4 mm/s and 1,5 mm/s, 1 trigger 7,6 mm/s Causes 1,4 and 1,5 mm/s: traffic Cause 7,6 mm/s unknown	7,6
[redacted]	6,8	1 trigger 20 mm/s Cause: building activities: Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account	6,8
[redacted]	1,4	4 triggers 1,6 < x < 6,3 mm/s Cause 1,6 mm/s: bump against sensor Other: causes unknown	6,3
[redacted]	3,2	1 trigger 24 mm/s and 1 trigger 89 mm/s Causes: mounting cover lit on sensor	3,2
[redacted]	1,6	1 trigger 2,2 mm/s Cause: unknown	2,2
[redacted]	1,2	1 trigger 1,9 mm/s (y) Cause: kicking shoes against wall nearby sensor. Because it is not expected that this was a vibration of the whole building, this level is not taken into account	1,2
[redacted]	1,7	26 triggers 1,6 < x < 3,6 mm/s Causes unknown	3,6
[redacted]	1,4	20 triggers 1,4 <x< 5,6 mm/s; 1 trigger 73 mm/s Cause 73 mm/s: unknown. Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account Causes other triggers: road construction activities	5,6

ID	Maximum registered vibration velocity vmax (mm/s)		
	Earthquake	Other triggers	Taken into account
[redacted]	1,1	12 triggers 1,1 < x < 1,3 mm/s 4 triggers 2 < x < 12 mm/s Causes up to 1,3 mm/s: unknown Causes >2 mm/s: mounting cover lit on sensor	1,3
[redacted]	1,3	1 trigger 22 mm/s Causes: mounting cover lit on sensor	1,3
[redacted]	1,0	330 triggers > 1 mm/s of which 13 triggers 2<x<3 mm/s and 3 triggers 3< x< 4 mm/s. 1 trigger 37 mm/s Cause 37 mm/s: unknown. Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account Causes other triggers: unknown. However, road construction activities have taken place in front of the building and therefore these vibrations are taken into account.	4,0
[redacted]	10,3	38 mm/s and 56 mm/s Cause 56 mm/s: unknown. Because it is not expected that this high level was a vibration of the whole building, this level is not taken into account cause 38 mm/s: mounting cover lit on sensor	10,3
[redacted]	1,7	5 triggers 1,8 < x < 3,2 mm/s Causes: unknown. However, building activities are present in surrounding area and therefore these triggers are taken into account	3,2
[redacted]	1,4	1 trigger 3,8 mm/s Cause unknown.	3,8
[redacted]	1,0	24 triggers 1 < x < 25 mm/s Causes: building activities. Information from owner clarifies that these activities were close to the sensor and most likely didn't result in a vibration of the whole building.	1,0
[redacted]	1,6	47 triggers 1,6 < x < 17,9 mm/s Causes: building activities Information from owner clarifies that these activities were close to the sensor and most likely didn't result in a vibration of the whole building.	1,6
[redacted]	1,3	2 triggers 2,5 mm/s and 3,2 mm/s Cause: bump against sensor	1,3
[redacted]	1,6	1 trigger 3,1 mm/s Cause: installation convertor for solar panels nearby sensor	1,6

ID	Maximum registered vibration velocity vmax (mm/s)		
	Earthquake	Other triggers	Taken into account
[redacted]	1,4	50 triggers 1,4 < x < 2,4 mm/s and 1 trigger 4,7 mm/s Cause: slamming doors nearby sensor. Because it is not expected that this was a vibration of the whole building, this level is not taken into account	1,4
[redacted]	9,2	10,0 mm/s Cause unknown	10,0

9.2 Damage curves

The damage curves of the Zandeweer/Woudbloem/Wirdum earthquakes are given for the four damage state categories (Figure 9.1 – 9.4). The horizontal axis in the figures shows the maximum registered vibration velocity in the period between the previous and the repetitive damage survey (see Table 8.1 and 9.1). The vertical axis shows the damage state categories according to the following scheme:

<u>Buildings categorized in DS 0 at previous survey</u>
- DS 0→DS 0 = remained in DS 0
- DS 0→DS 1 = damage stated increased to DS 1
- DS 0→DS 2 = damage stated increased to DS 2

<u>Buildings categorized in DS 1 at previous survey</u>
- DS 1→DS 0 = repaired to DS 0 and remained in DS 0
- DS 1→DS 1 = remained in DS 1
- DS 1→DS 1’ = remained in DS 1, but increase in amount and/or length and/or width of cracks
- DS 1→DS 2 = damage state increased to DS 2

<u>Buildings categorized in DS 2</u>
- DS 2→DS 1 = repaired to DS 1 and remained in DS 1
- DS 2→DS 2 = remained in DS 2
- DS 2→DS 2’ = remained in DS 2, but increase in amount and/or length and/or width of cracks
- DS 2→DS 3 = damage state increased to DS 3

<u>Buildings categorized in DS 3</u>
- DS 3→DS 3 = remained in DS 3
- DS 3→DS 3’ = remained in DS 3, but increase in amount and/or length and/or width of cracks

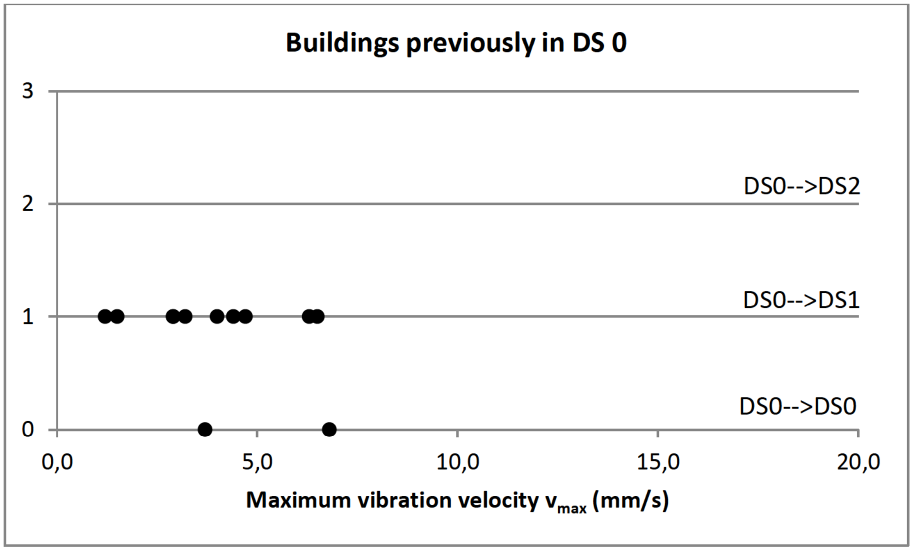


Figure 9.1: Damage state for buildings categorised in DS 0 at previous survey

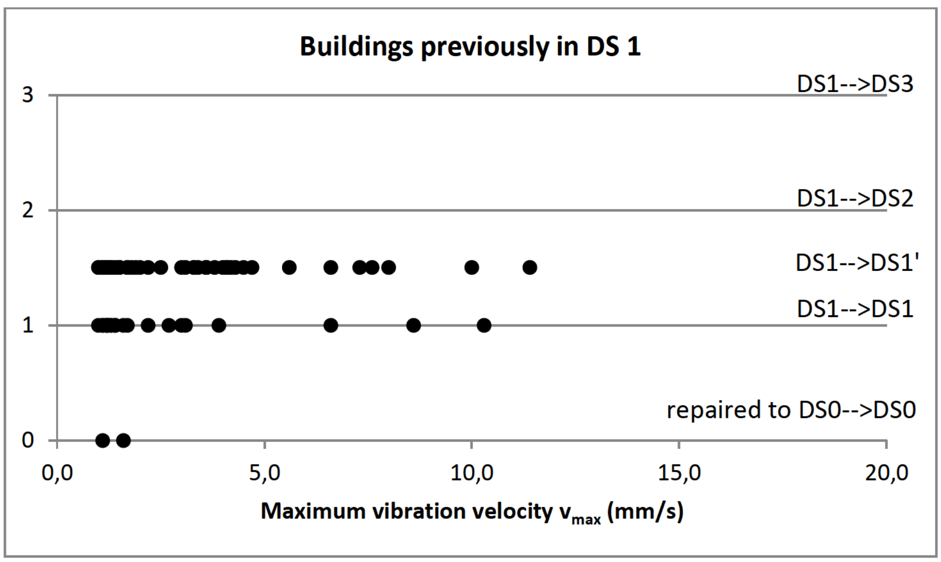


Figure 9.2: Damage state for buildings categorised in DS 1 at previous survey

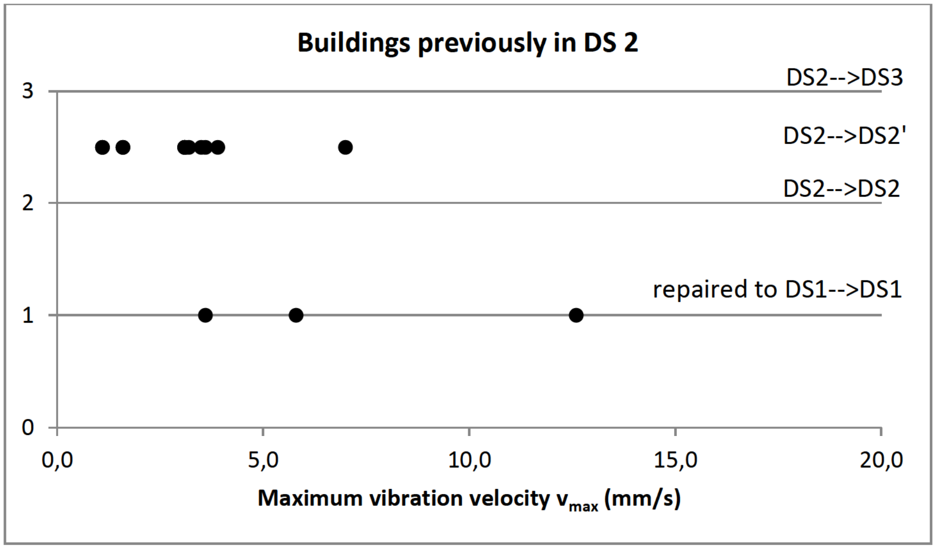


Figure 9.3: Damage state for buildings categorised in DS 2 at previous survey

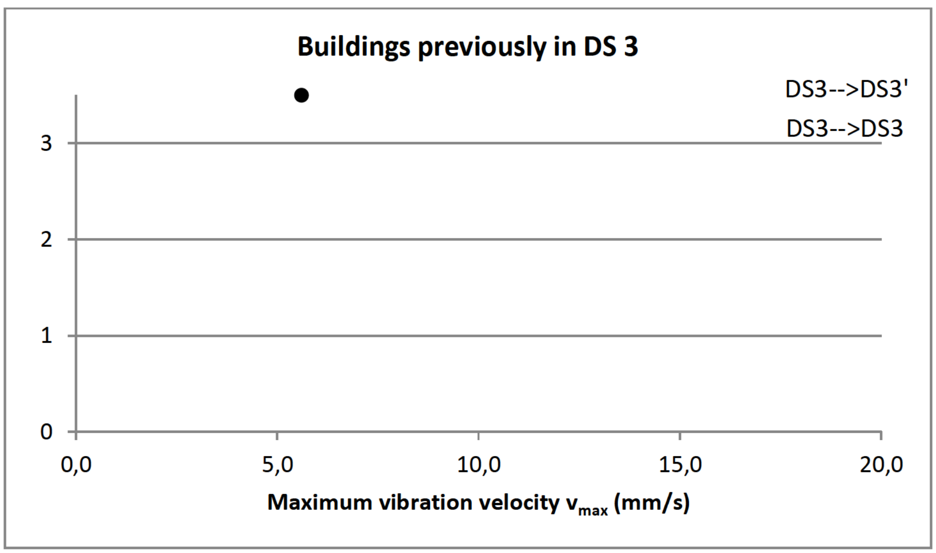


Figure 9.4: Damage state for buildings categorised in DS 3 at previous survey

9.3 Conclusions of damage curves

From the damage curves presented in the former Paragraph (Figures 9.1 – 9.4) the following conclusions can be drawn:

- Most of the buildings that were categorised in damage state DS 0, having no reported cracks, one or more new cracks were reported, as a result of which these are categorised into a higher damage state (all DS 1). As mentioned already in Chapter 8 several of the newly reported cracks were already present at the time of the initial damages survey. Because of this it could not be verified if these buildings were initially already in DS 1 or not.
- For all buildings categorized in damage state DS 1 and DS 2 the earthquakes didn't result in an increase of the damage state. This means that the missed

cracks at the initial or previous damage survey had no influence on the previous categorization of the damage state of the buildings.

- For two buildings in DS1 and three buildings in DS 2, substantial repair activities have taken place in the period between the repetitive damage survey and the previous survey. As a consequence, the damage state has “improved”.
- For more buildings repair activities have taken place in between the two surveys, but these were too limited in order to decrease the building’s damage state. However, for future analysis, information about repair and whether the repaired crack has cracked again can be interesting. This is only useful when information about the date of the repair activities (i.e. whether repair has taken place prior to the earthquake or after the earthquake) is available. Information about repair is given in tables 9.2 and 9.3.

Table 9.2: Repair activities with decrease in damage state

DS	ID	V_{max}	Cause	Date V_{max}	Repair info	Repair date
1→0	[redacted]	1,1	Woudbloem	30-12-2014	All cracks repaired, all repaired cracks didn't crack again, no new reported cracks	no info between 7-11-2014 and 26-2-2015
1→0	[redacted]	1,6	Wirdum	6-1-2015	All cracks repaired, all repaired cracks didn't crack again, no new reported cracks	no info between 13-8-2014 and 10-2-2015
2→1	[redacted]	12,6	Zandeweer	5-11-2014	11 (out of 13) existing cracks repaired, all repaired cracks didn't crack again. Two new reported cracks in non repaired parts (during initial damage survey, visibility was obstructed for these parts)	"damage repaired after initial damage survey" date initial damage survey: 2-8-2014
2→1	[redacted]	5,8	Other (unknown)	30-9-2014	8 (out of 9)existing cracks repaired, all repaired cracks didn't crack again. 1 new reported crack.	no info between 8-8-2014 and 28-1-2015
2→1	[redacted]	3,6	Woudbloem	30-12-2014	All cracks (29) repaired, 1 repaired crack cracked again (connection 2 facades). No new reported cracks	"damage repaired after initial damage survey" date initial damage survey: 3-9-2014

Table 9.2: Repair activities within damage state

DS	ID	V_{max}	Cause	Date V_{max}	Repair info	repair date
1→1'	[redacted]	4,1	Wirdum	6-1-2015	1 (out of 2) existing cracks repaired, repaired crack didn't crack again. 1 new reported crack	no info between 7-11-2014 and 29-1-2015

1→1	[redacted]	3	Wirdum	6-1-2015	1 (out of 5) exisiting cracks repaired, repaired crack didn't crack again. No new reported cracks	no info between 12-8-2014 and 5-2-2015
1→1'	[redacted]	10	Other (unknown)	30-9-2014	4 (out of 7) cracks repaired, repaired cracks didn't crack again. 7 new reported cracks (some of them already present during initial damage survey)	no info between 15-9-2014 and 28-1-2015
1→1	[redacted]	6,6	Woudbloem	30-12-2014	1 (out of 1) crack repaired, repaired crack didn't crack again. 1 New reported crack (already present during initial damage survey)	no info between 15-9-2014 and 28-1-2015
1→1	[redacted]	2,7	Zandeweer	5-11-2014	2 (out of 2) cracks repaired (connection facades), repaired cracks didn't crack again. 1 new reported crack.	no info between 25-8-2014 and 19-2-2015
2→2'	[redacted]	3,1	Wirdum	6-1-2015	8 (out of 19) cracks repaired, repaired cracks didn't crack again. 13 new reported cracks.	no info between 1-9-2014 and 27-2-2015

10 Conclusions

TNO has analysed the effects of the Zandeweer, Woudbloem and Wirdum earthquakes of November 5th 2014, December 30th 2014 and January 6th 2015 on the buildings of the monitoring network. The analysis has resulted in the following conclusions.

Building vibrations

1. In 106 buildings of the monitoring network the maximum building vibration velocity of the foundation has exceeded the pre-set trigger of 1 mm/s.

2. The maximum measured foundation vibration acceleration (a_{max}) is 0,73 m/s^2 (Zandeweer), 0,92 m/s^2 (Woudbloem) and 0,29 m/s^2 (Wirdum).

3. The maximum measured foundation vibration velocity (v_{max}) is 13,0 mm/s (Zandeweer), 11,4 mm/s (Woudbloem) and 5,8 mm/s (Wirdum).

4. The horizontal component of the vibrations is dominant over the vertical component, for both the acceleration and the velocity. Only in a few buildings the vertical component was dominant.

5. For the x- and y-direction of the buildings, the dominant frequencies are on average 5 – 6 Hz. The dominant frequency for the z-direction are on average 11 - 15 Hz.

6. At January 6th 2015 the sensor network of KNMI was not yet finished. Therefore no transfer functions could be calculated.

Repetitive damage survey

7. The analysis of the damage survey was executed for 94 buildings. The other building, all triggered only by the Zandeweer earthquake, were already analyzed for the Garmerwolde earthquake.

8. From 94 buildings, a total amount of 749 cracks was reported. At the repetitive damage survey only 10 of these cracks were increased in length or width.

9. The majority of the newly reported cracks were relatively small and short cracks of category A.

10. Several new reported cracks were already present at the initial damage surveys, but were not reported at that time. Therefore, the number of buildings that increased from damage state DS0 to DS1 cannot be determined exactly.

11. For all buildings that were initially (or at previous survey) categorized in damage state DS 1 and DS 2, the earthquakes didn't result in an increase of damage state. This means that the missed cracks at the initial damage

survey had no influence on the initial categorization of the damage state of these buildings.

12. At some buildings repair activities have taken place in the period between the repetitive damage survey and the previous damage survey. For a part of these buildings the damage state has decreased as a consequence of these repair activities.

11 References

[01] TNO-report 2015 R10501 “Monitoring Network Building Vibrations”

[02] SBR guide line A: “Trillingen: meet- en beoordelingsrichtlijnen. Schade aan gebouwen, 2002”

[03] SBR guide line B: “Meet- en beoordelingsrichtlijn. Hinder voor personen in gebouwen, 2002”

[04] TNO-report 2015 R10604 “Monitoring Network Building Vibrations – Analysis Earthquake 30-09-2014 Garmerwolde”

12 Signature

Name and address sponsor:

Nederlandse Aardolie Maatschappij
PO Box 28000
9400 HH Assen

Signature:

[redacted] [redacted]

[redacted]

Signature Research Manager Structural Reliability:

[redacted]

A Background information

Table A.1: Defined types of buildings

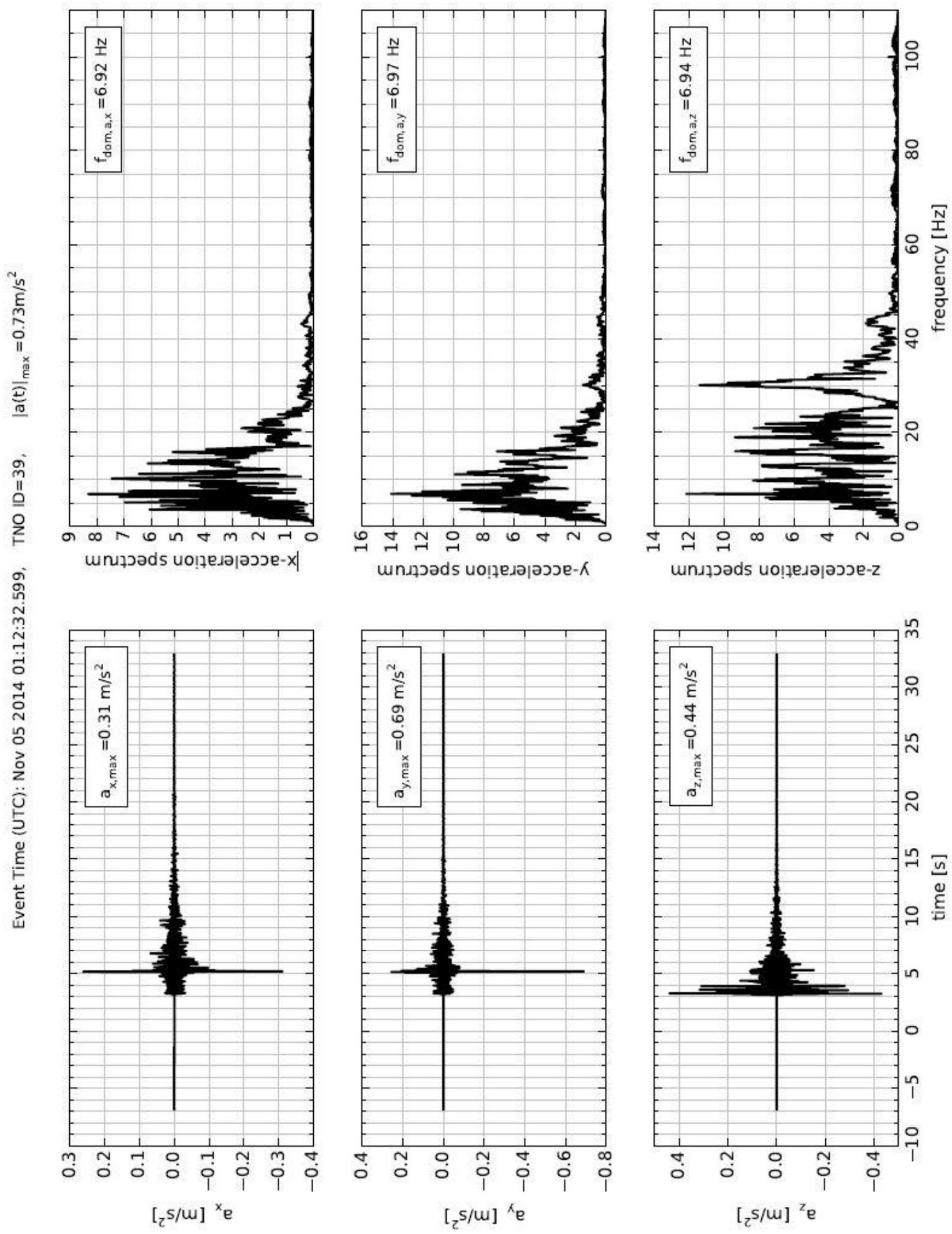
No.	Type of building	Foundation	Type of floor
1	Terraced building - corner	(Piles)[1]	(Concrete)[1]
2	Terraced building – no corner	(Piles)[1]	(Concrete)[1]
3	Semi-detached	(Piles)[1]	(Concrete)[1]
4	Detached <1940	No piles	Combination wood/concrete
5		No piles	Wood
6		No piles	Concrete
7	Detached 1941-1975	No piles	--
8	Detached >1975	Piles	Concrete
9		No piles	Concrete

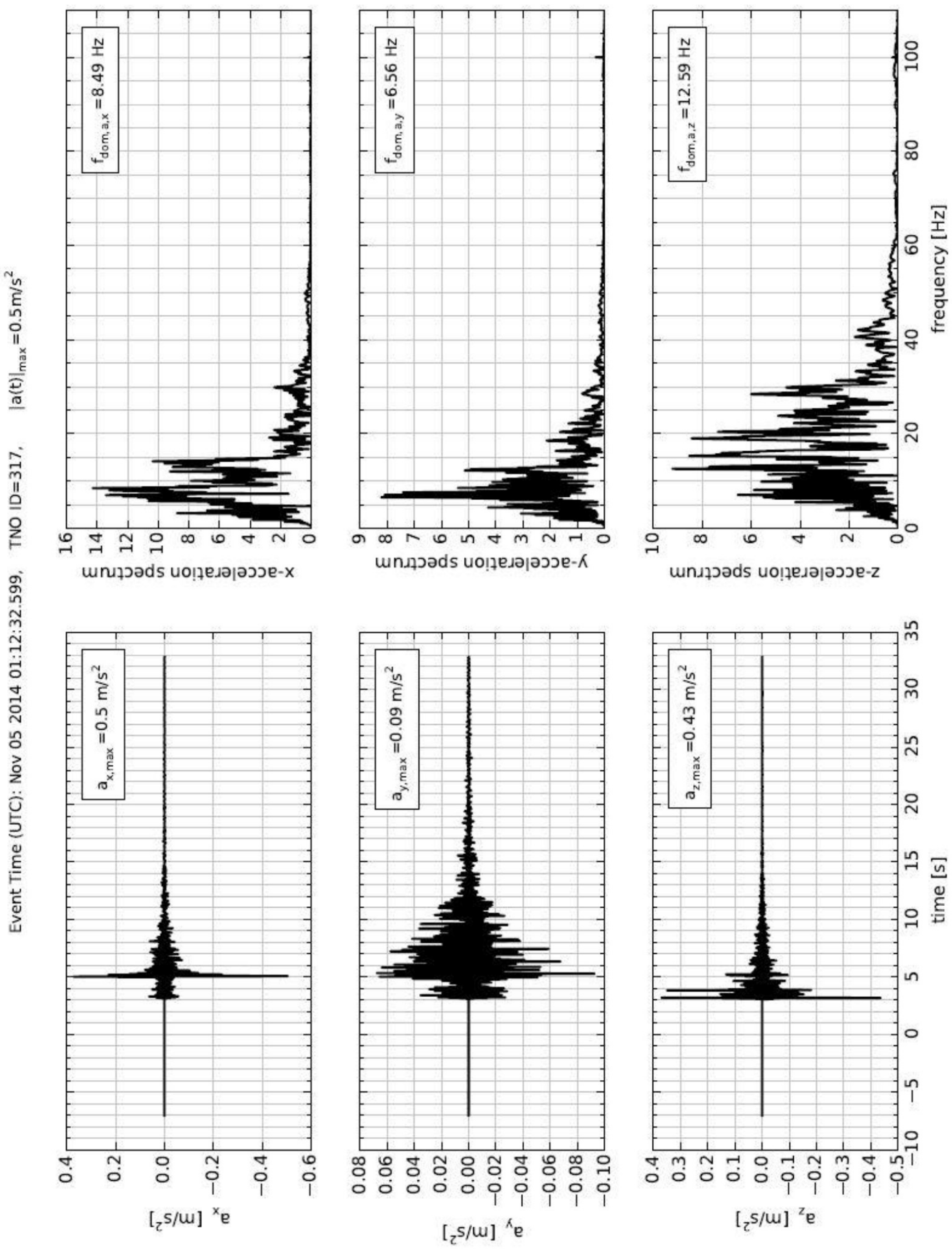
)[1] Not all buildings fulfil this pre-set properties (see TNO-report 2015 R10501 “Monitoring Network Building Vibrations” [01])

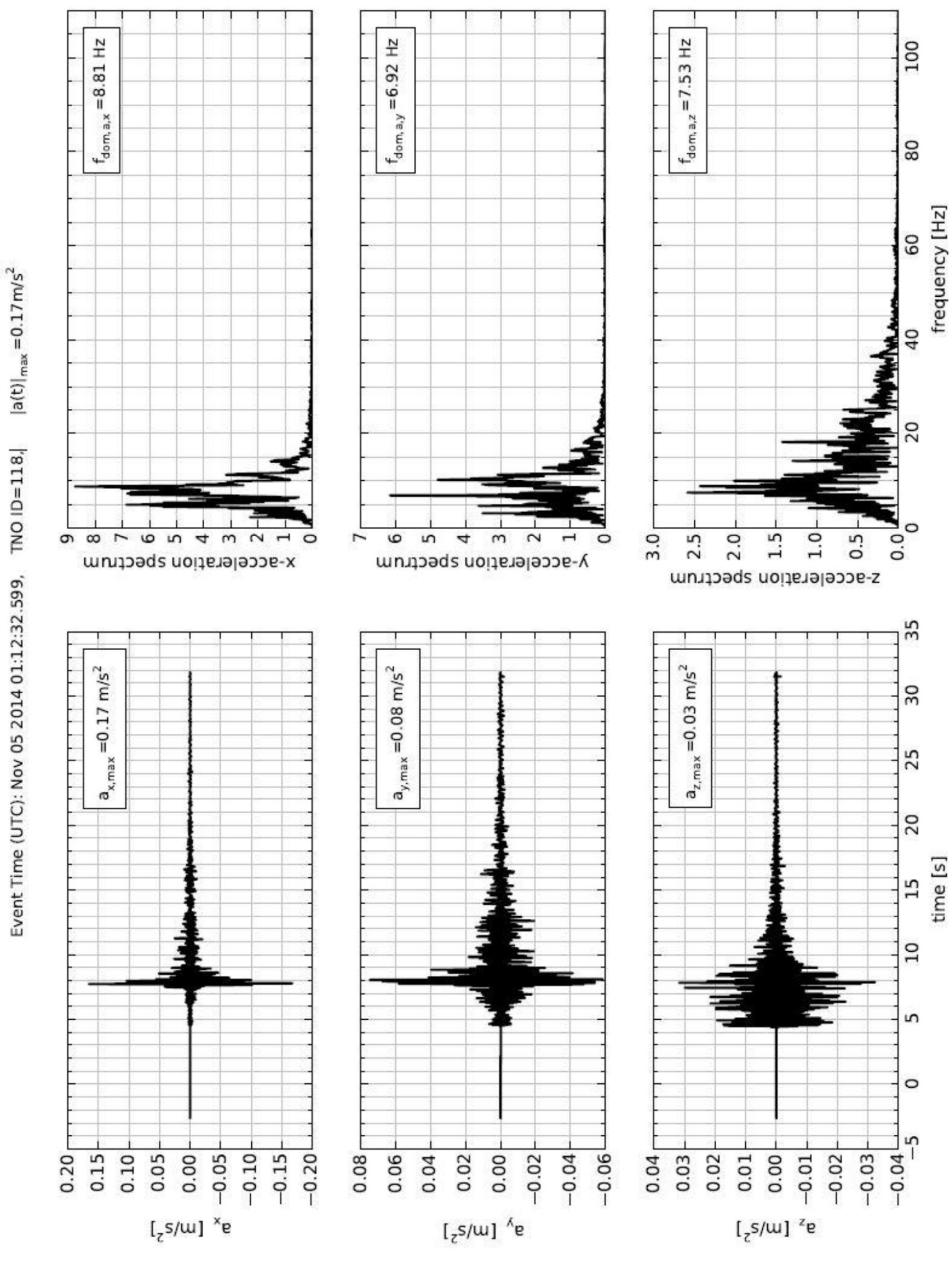
B Vibration signals – acceleration

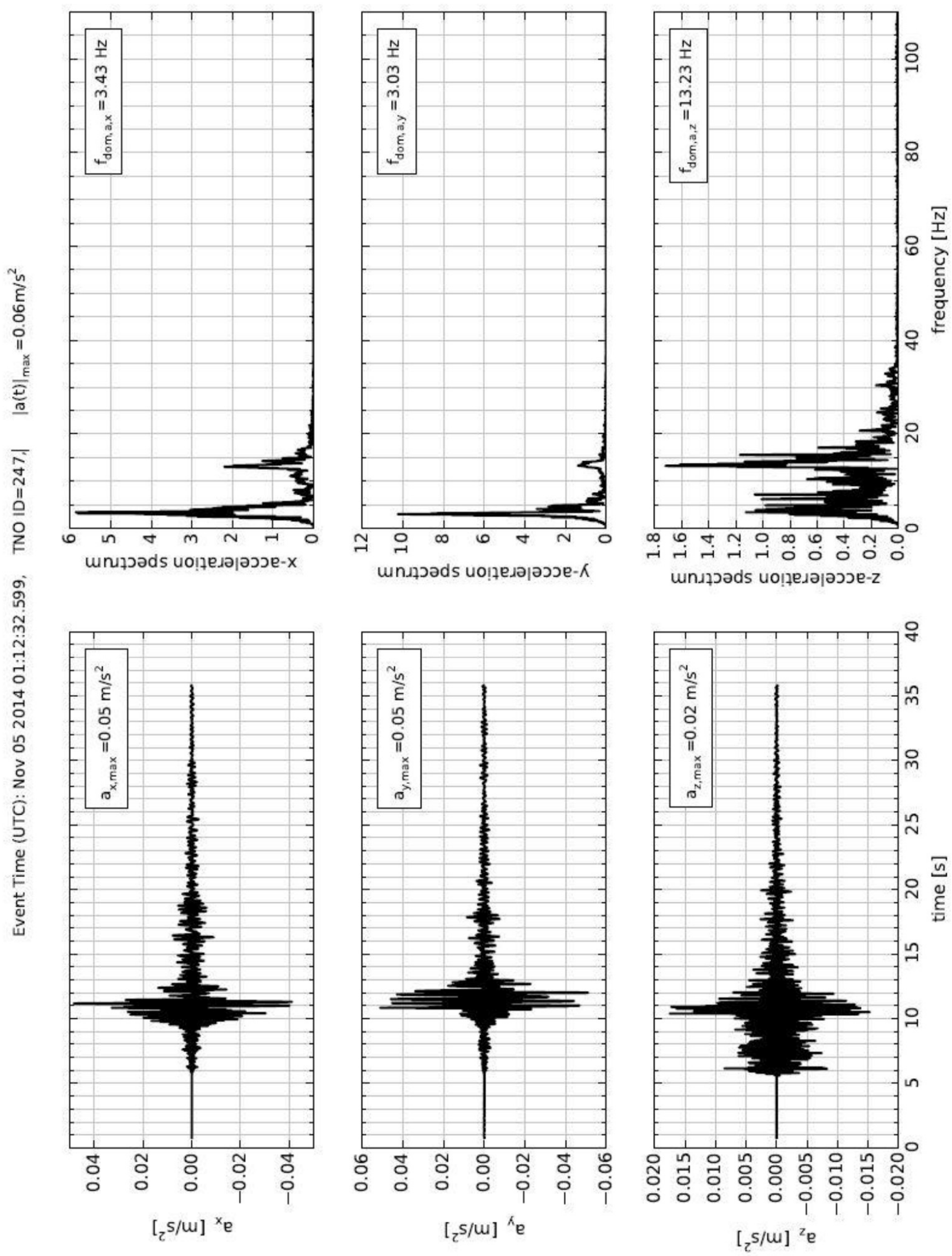
This Annex gives an example of the measured vibration acceleration signals. For four buildings, with different levels of acceleration, the following graphs are given:
- Measured acceleration (a_x, a_y, a_z)
- Distribution of the frequency ($f_{dom,a,x}$,$f_{dom,a,y}$,$f_{dom,a,z}$)

B.1 Selected acceleration signals Zandeweer

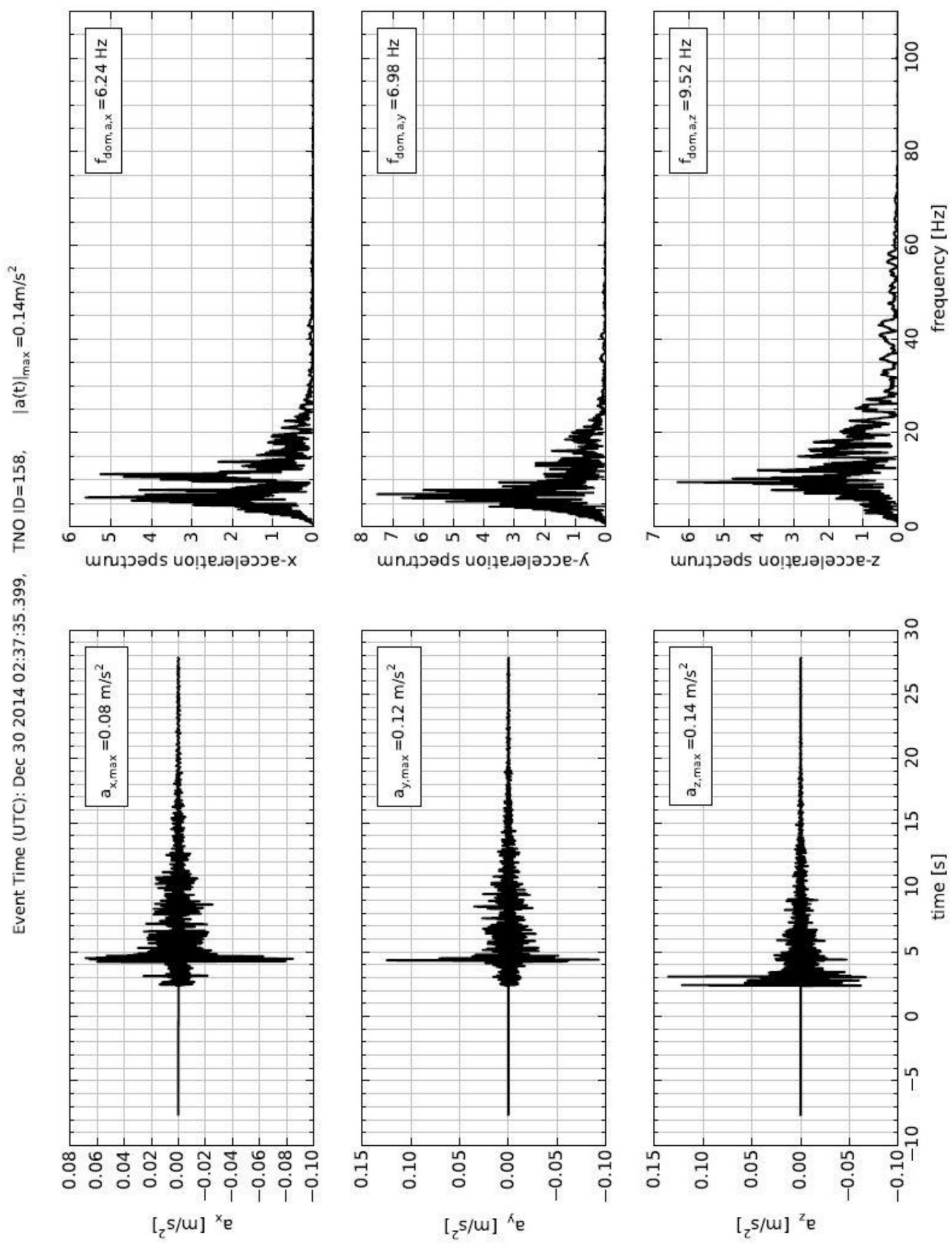


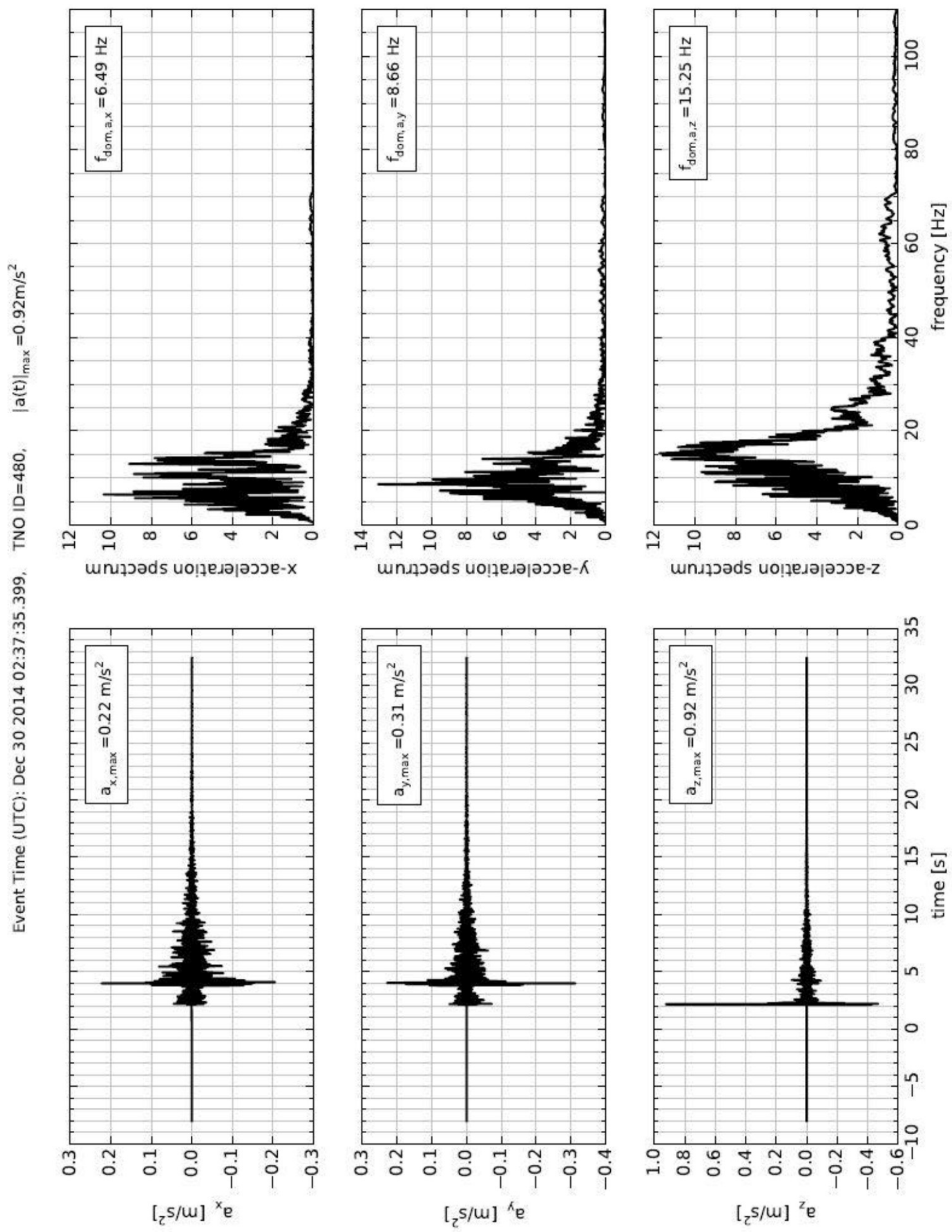

Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=317, |a(t)|max=0.5m/s2
ax,max =0.5 m/s2
ay,max =0.09 m/s2
az,max =0.43 m/s2
fdom,a,x =8.49 Hz
fdom,a,y =6.56 Hz
fdom,a,z =12.59 Hz
ax [m/s2]
ay [m/s2]
az [m/s2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

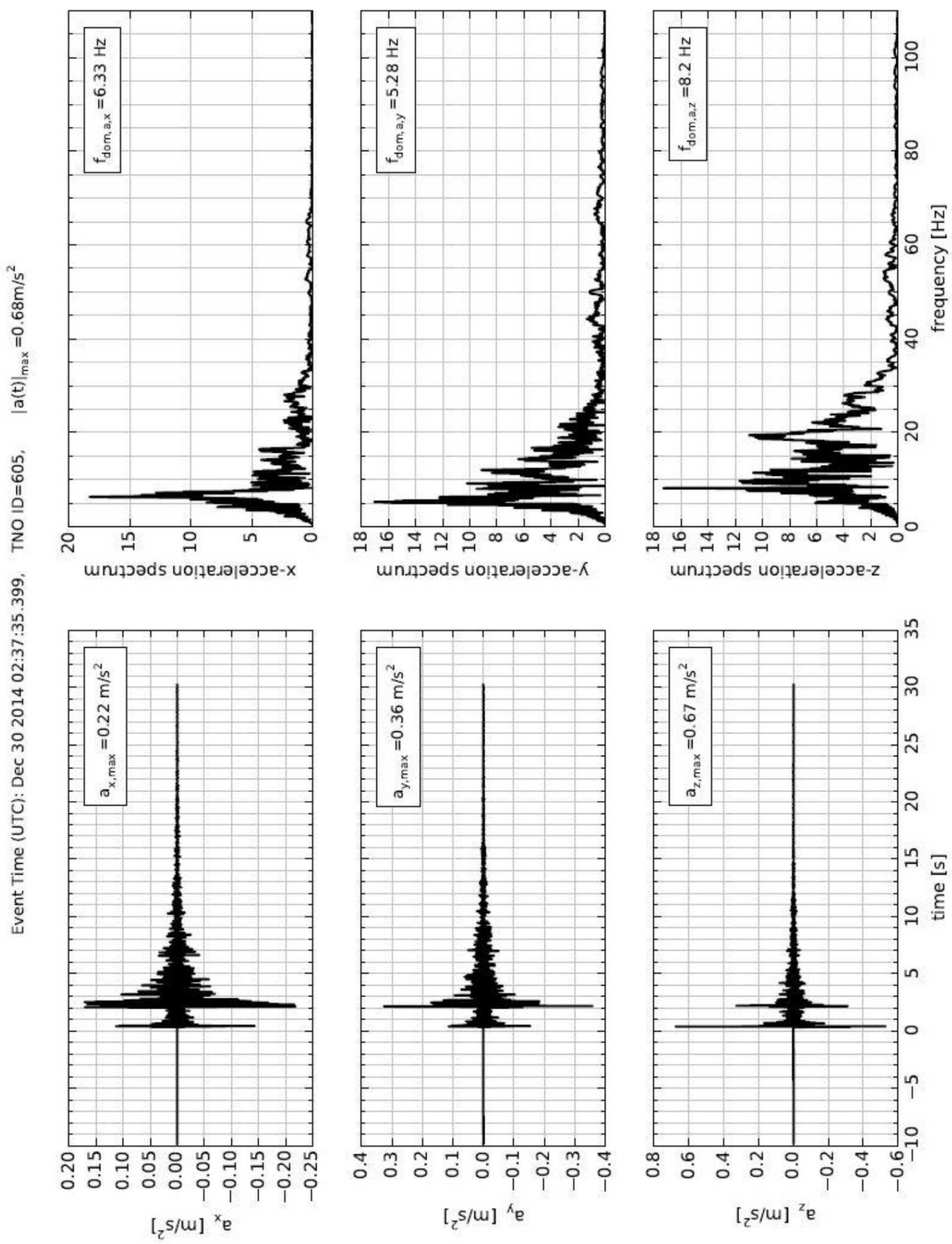

Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=118, |a(t)|max=0.17m/s²
a_x [m/s²]
a_x,max =0.17 m/s²
a_y [m/s²]
a_y,max =0.08 m/s²
a_z [m/s²]
a_z,max =0.03 m/s²
time [s]
x-acceleration spectrum
f_dom,a,x =8.81 Hz
y-acceleration spectrum
f_dom,a,y =6.92 Hz
z-acceleration spectrum
f_dom,a,z =7.53 Hz
frequency [Hz]

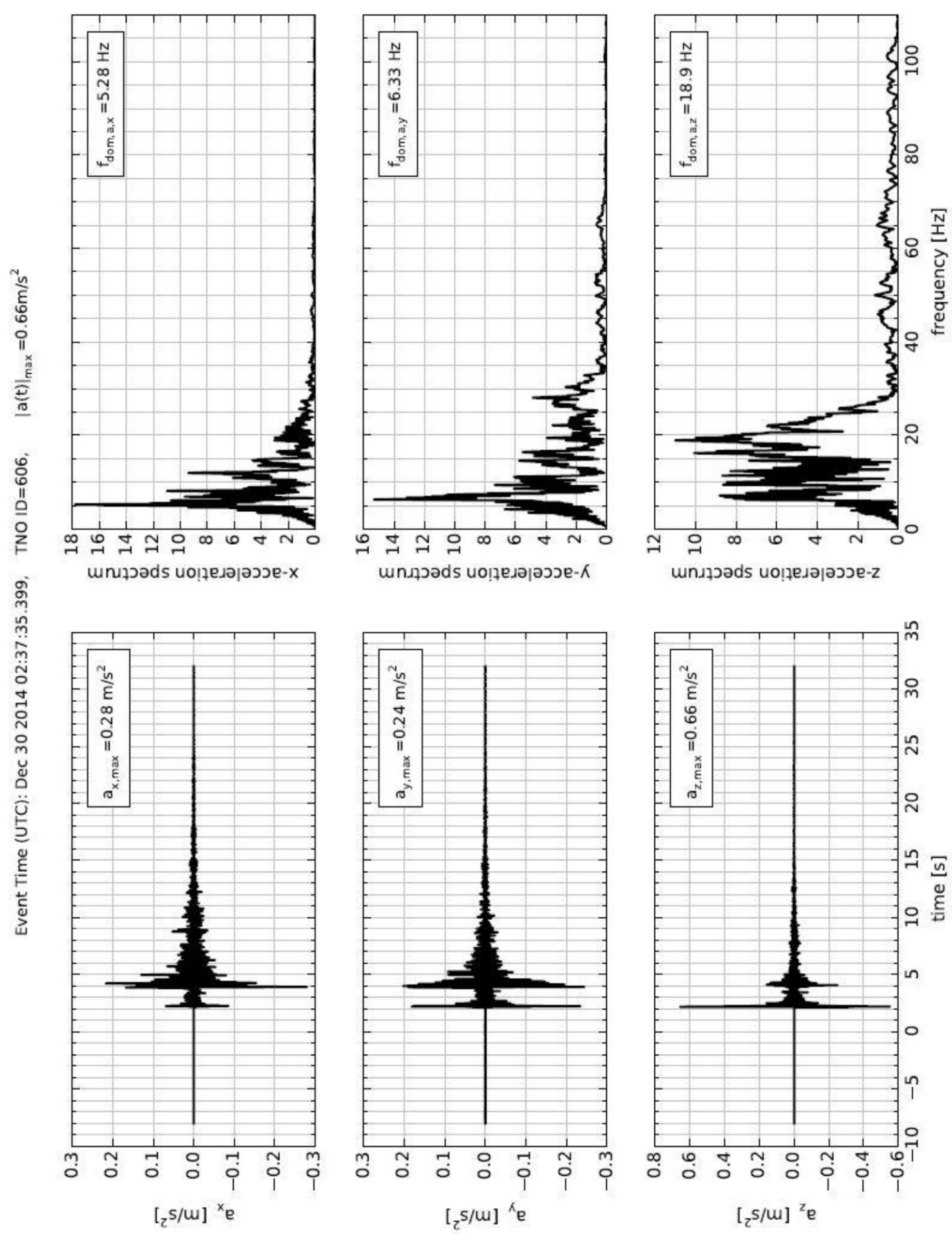

Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=247, |a(t)|max =0.06m/s²
$a_{x,max}$ =0.05 m/s²
$a_{y,max}$ =0.05 m/s²
$a_{z,max}$ =0.02 m/s²
$f_{dom,a,x}$ =3.43 Hz
$f_{dom,a,y}$ =3.03 Hz
$f_{dom,a,z}$ =13.23 Hz
a_x [m/s²]
a_y [m/s²]
a_z [m/s²]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

B.2 Selected acceleration signals Woudbloem

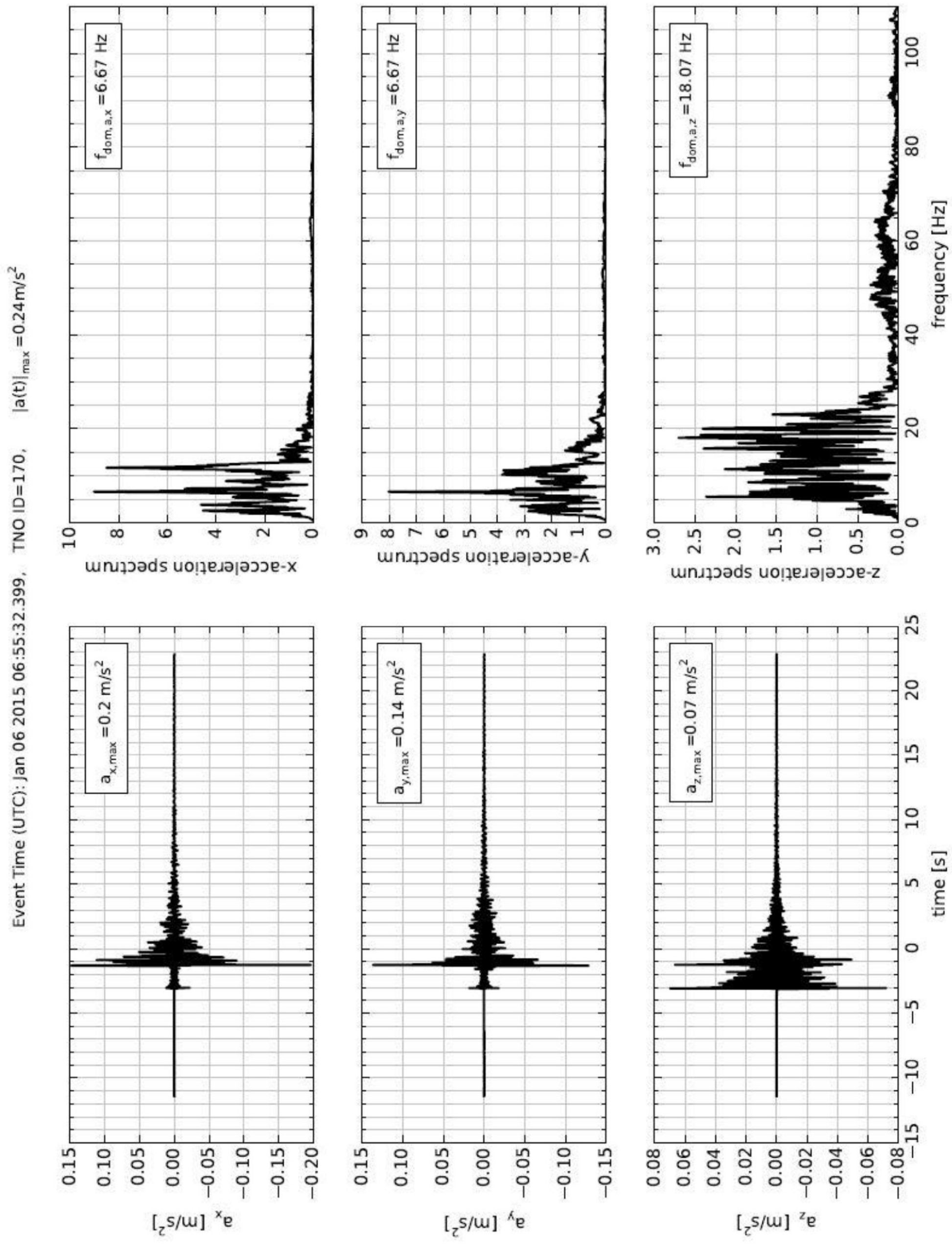


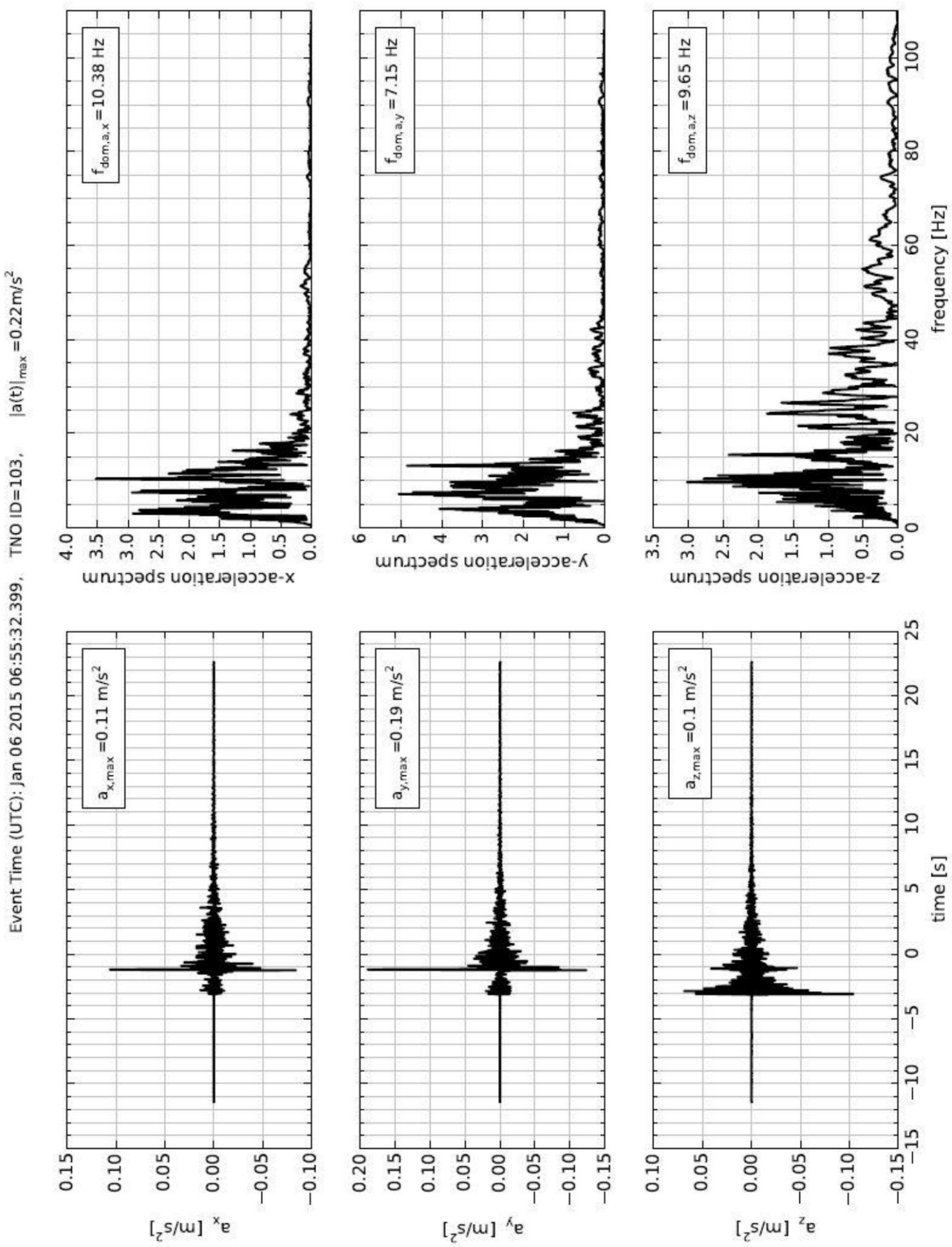

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=480, |a(t)|max =0.92m/s2
$a_{x,max}$ =0.22 m/s2
$a_{y,max}$ =0.31 m/s2
$a_{z,max}$ =0.92 m/s2
$f_{dom,a,x}$ =6.49 Hz
$f_{dom,a,y}$ =8.66 Hz
$f_{dom,a,z}$ =15.25 Hz
a_x [m/s2]
a_y [m/s2]
a_z [m/s2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

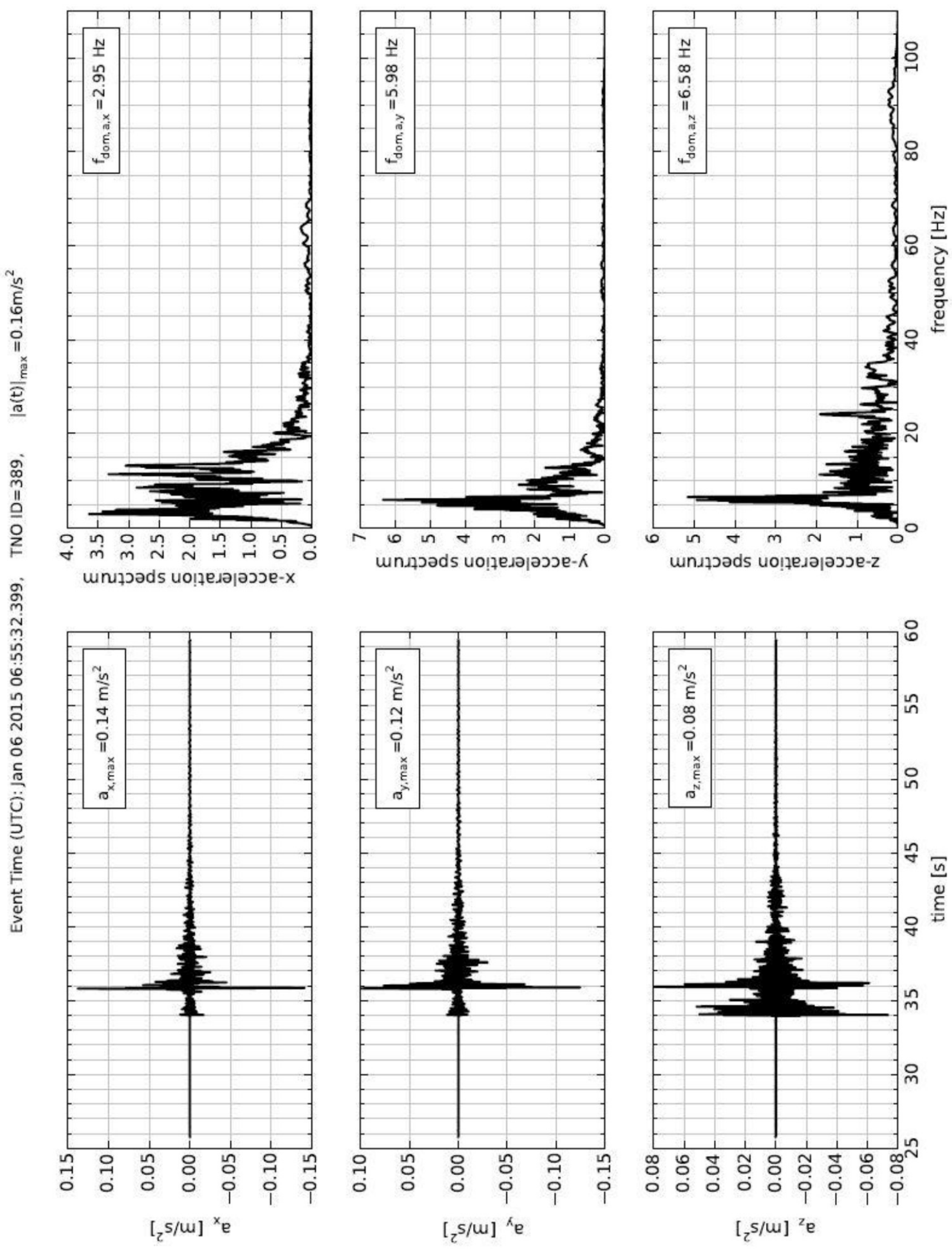

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=605, $|a(t)|_{max}$=0.68m/s^2
$a_{x,max}$=0.22 m/s^2
$a_{y,max}$=0.36 m/s^2
$a_{z,max}$=0.67 m/s^2
$f_{dom,a,x}$=6.33 Hz
$f_{dom,a,y}$=5.28 Hz
$f_{dom,a,z}$=8.2 Hz
a_x [m/s^2]
a_y [m/s^2]
a_z [m/s^2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

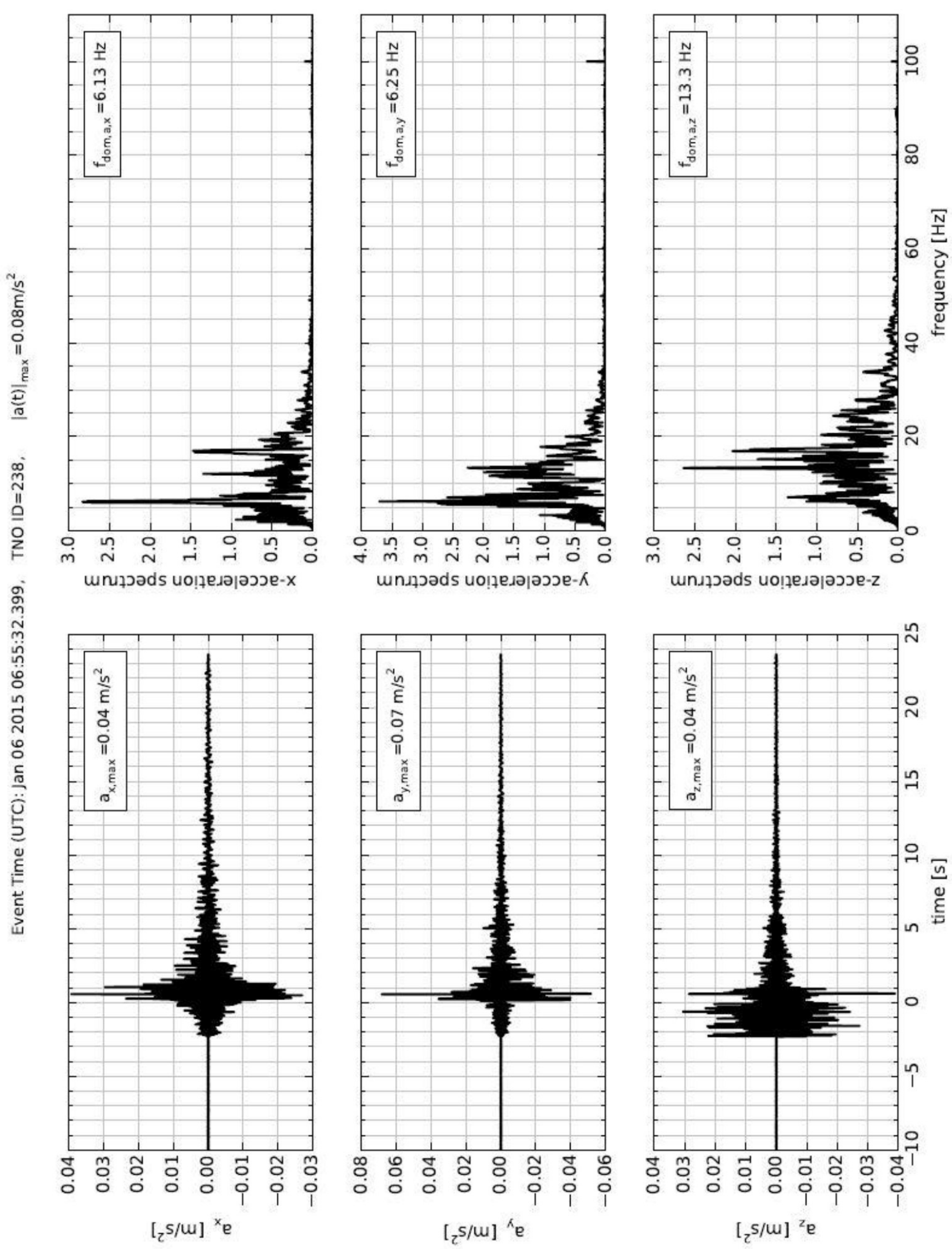

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=606, |a(t)|max =0.66m/s2
ax,max =0.28 m/s2
ay,max =0.24 m/s2
az,max =0.66 m/s2
ax [m/s2]
ay [m/s2]
az [m/s2]
time [s]
fdom,a,x =5.28 Hz
fdom,a,y =6.33 Hz
fdom,a,z =18.9 Hz
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
frequency [Hz]

B.3 Selected acceleration signals Wirdum




Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=103, |a(t)|max =0.22m/s2
ax,max =0.11 m/s2
ay,max =0.19 m/s2
az,max =0.1 m/s2
fdom,a,x =10.38 Hz
fdom,a,y =7.15 Hz
fdom,a,z =9.65 Hz
ax [m/s2]
ay [m/s2]
az [m/s2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]


Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=389, |a(t)|max =0.16m/s2
ax,max =0.14 m/s2
ay,max =0.12 m/s2
az,max =0.08 m/s2
fdom,a,x =2.95 Hz
fdom,a,y =5.98 Hz
fdom,a,z =6.58 Hz
ax [m/s2]
ay [m/s2]
az [m/s2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

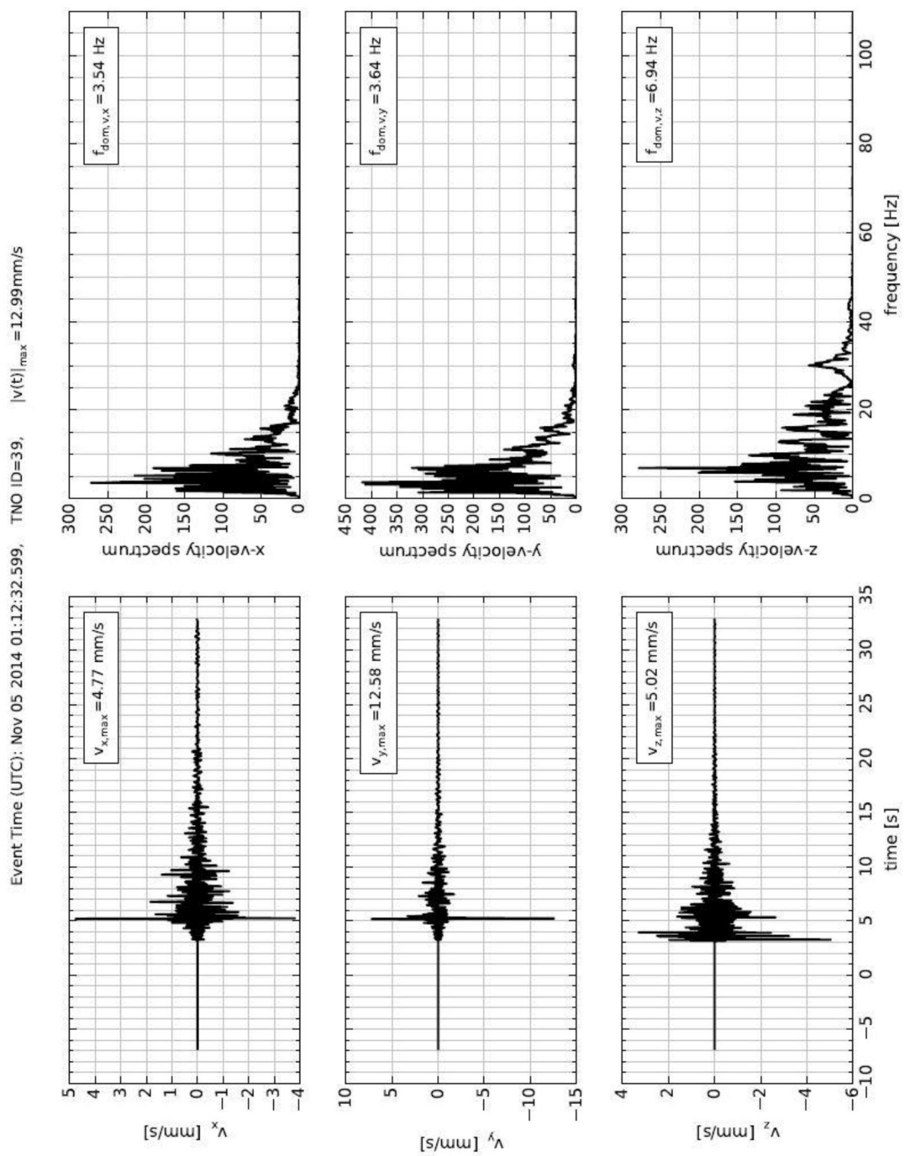

Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=238, |a(t)|max =0.08m/s2
ax,max =0.04 m/s2
ay,max =0.07 m/s2
az,max =0.04 m/s2
fdom,a,x =6.13 Hz
fdom,a,y =6.25 Hz
fdom,a,z =13.3 Hz
ax [m/s2]
ay [m/s2]
az [m/s2]
x-acceleration spectrum
y-acceleration spectrum
z-acceleration spectrum
time [s]
frequency [Hz]

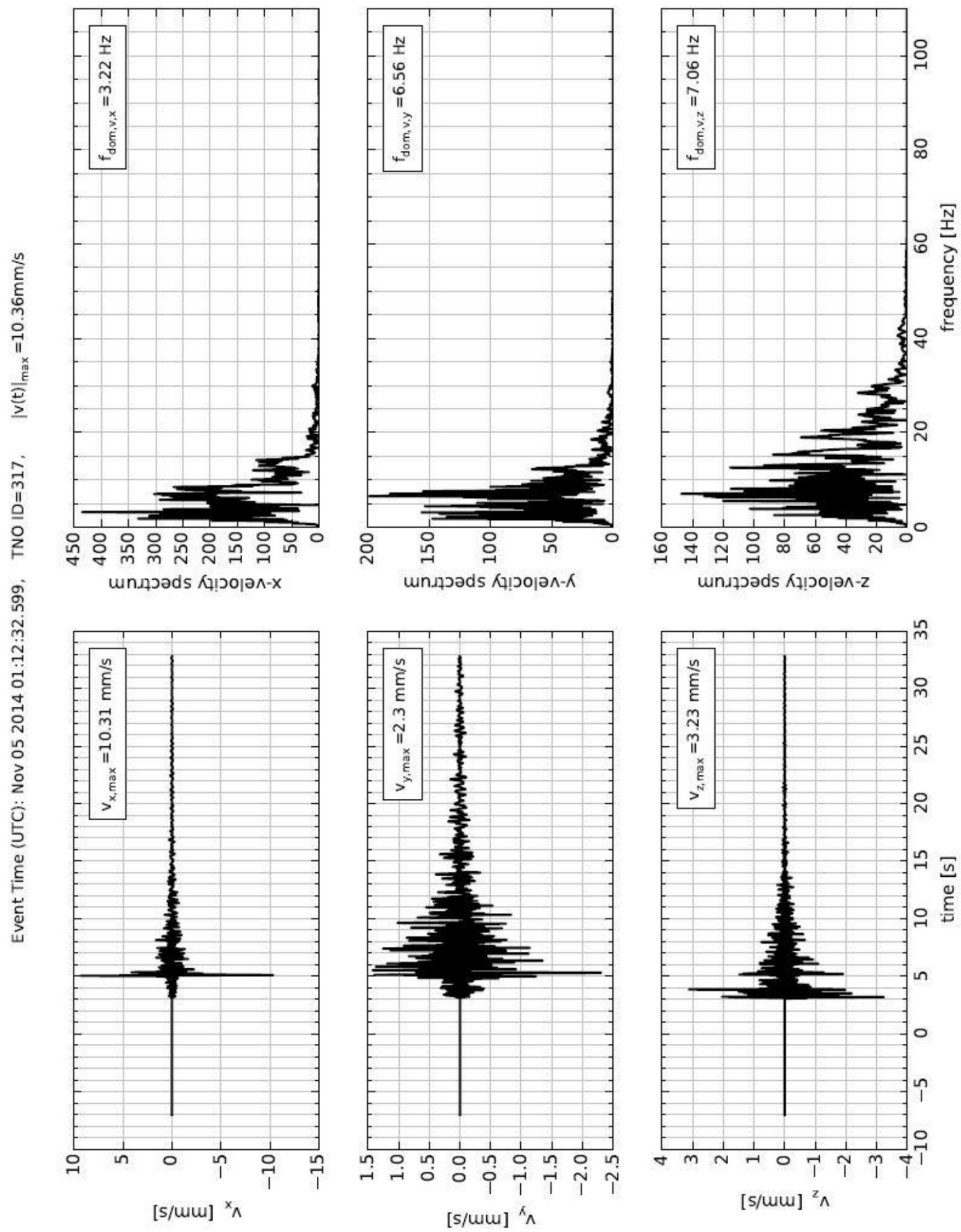
C Vibration signals – velocity

This Annex gives an example of the vibration velocity signals. For four buildings, with different levels of velocity, the following graphs are given:

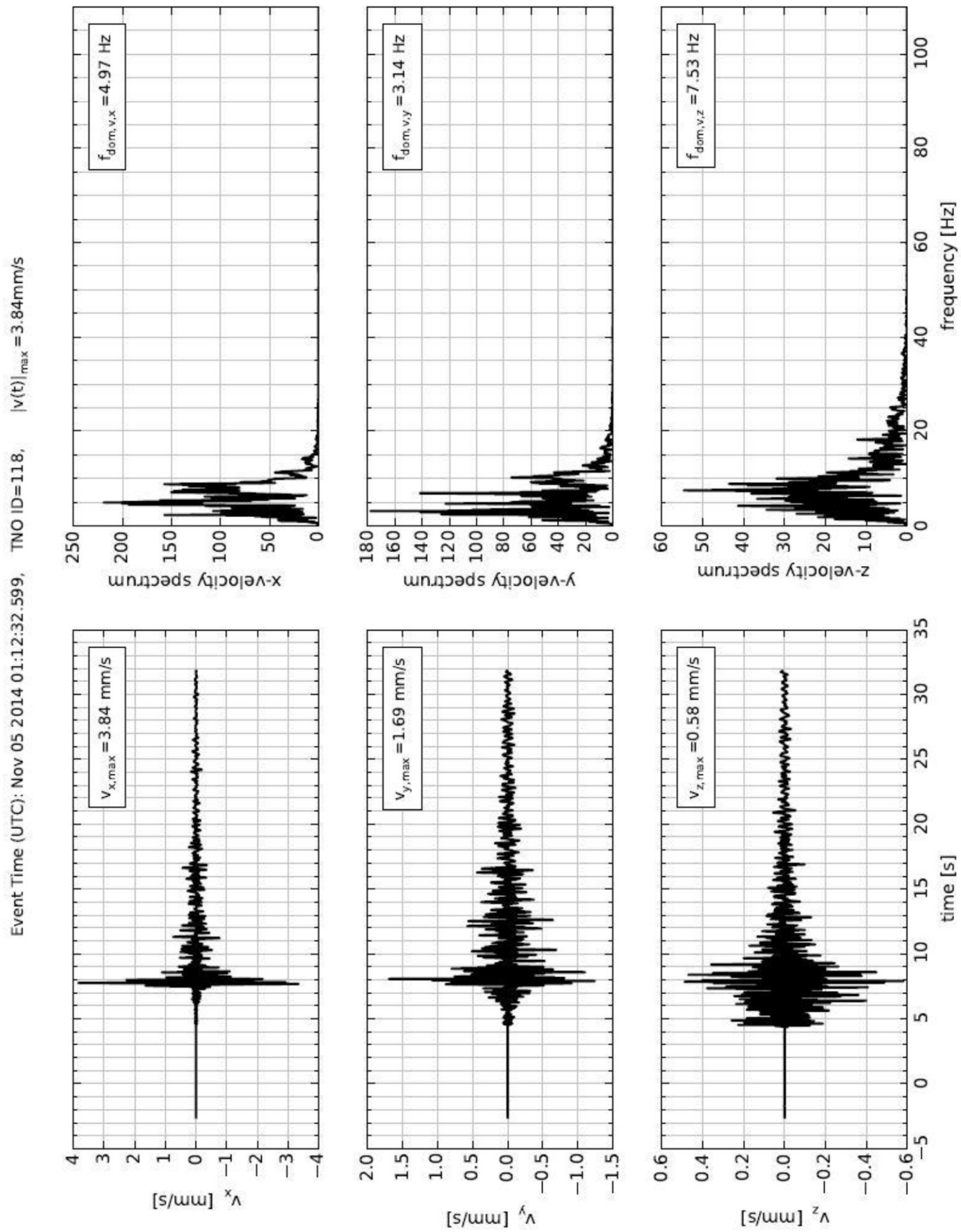
- Measured velocity (v_x, v_y, v_z)
- Distribution of the frequency ($f_{dom,v,x}$,$f_{dom,v,y}$,$f_{dom,v,z}$)

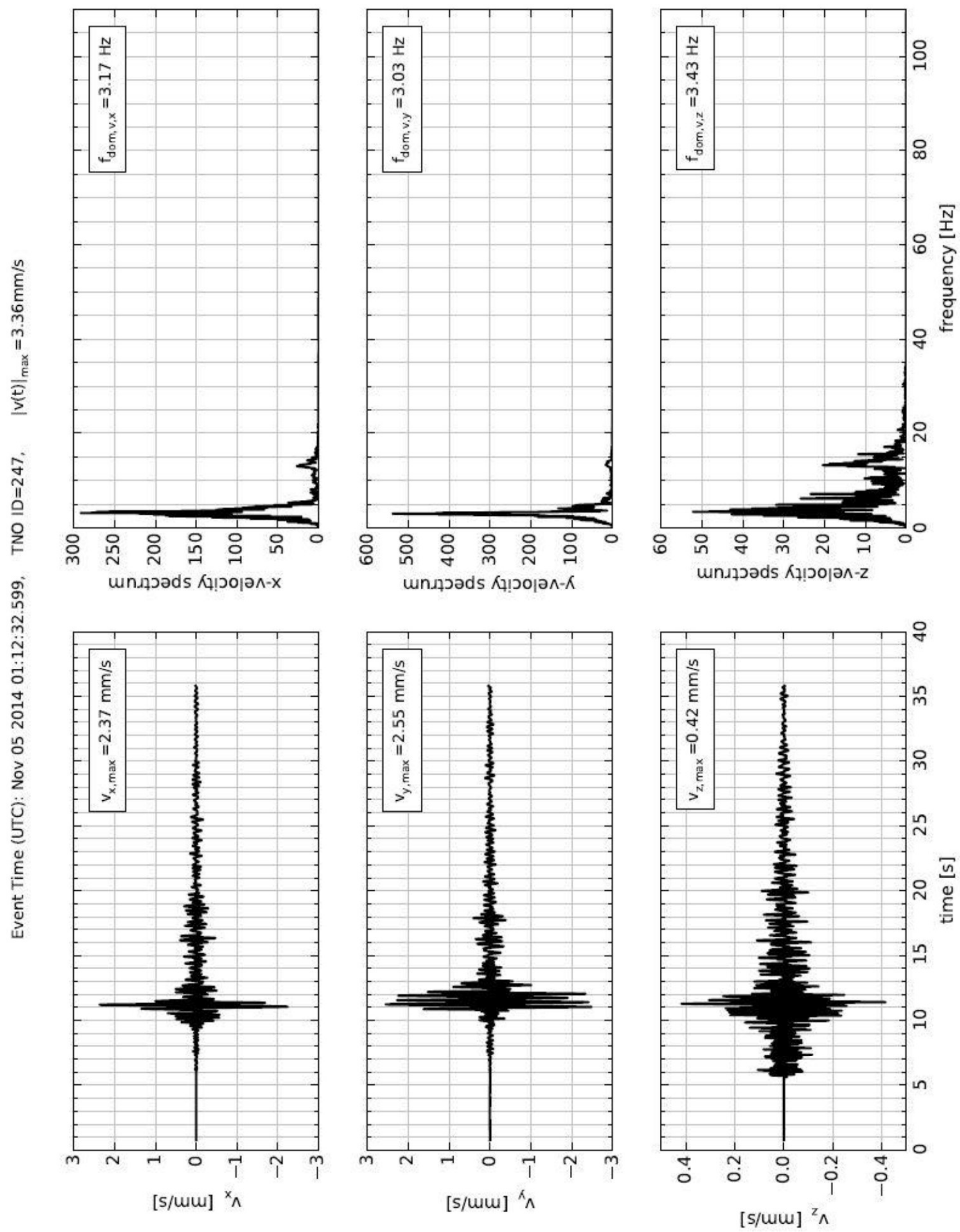
C.1 Selected acceleration signals Zandeweer



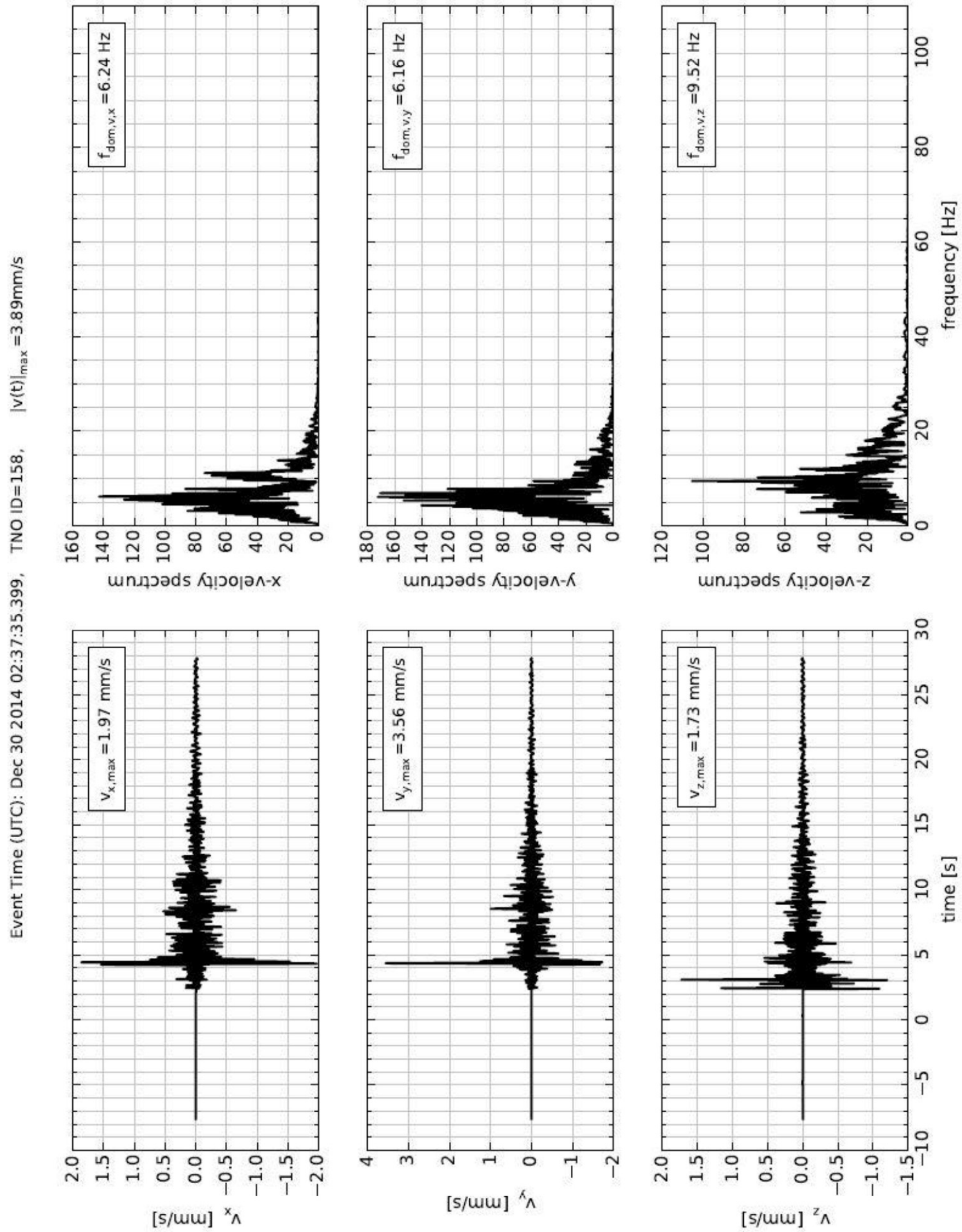


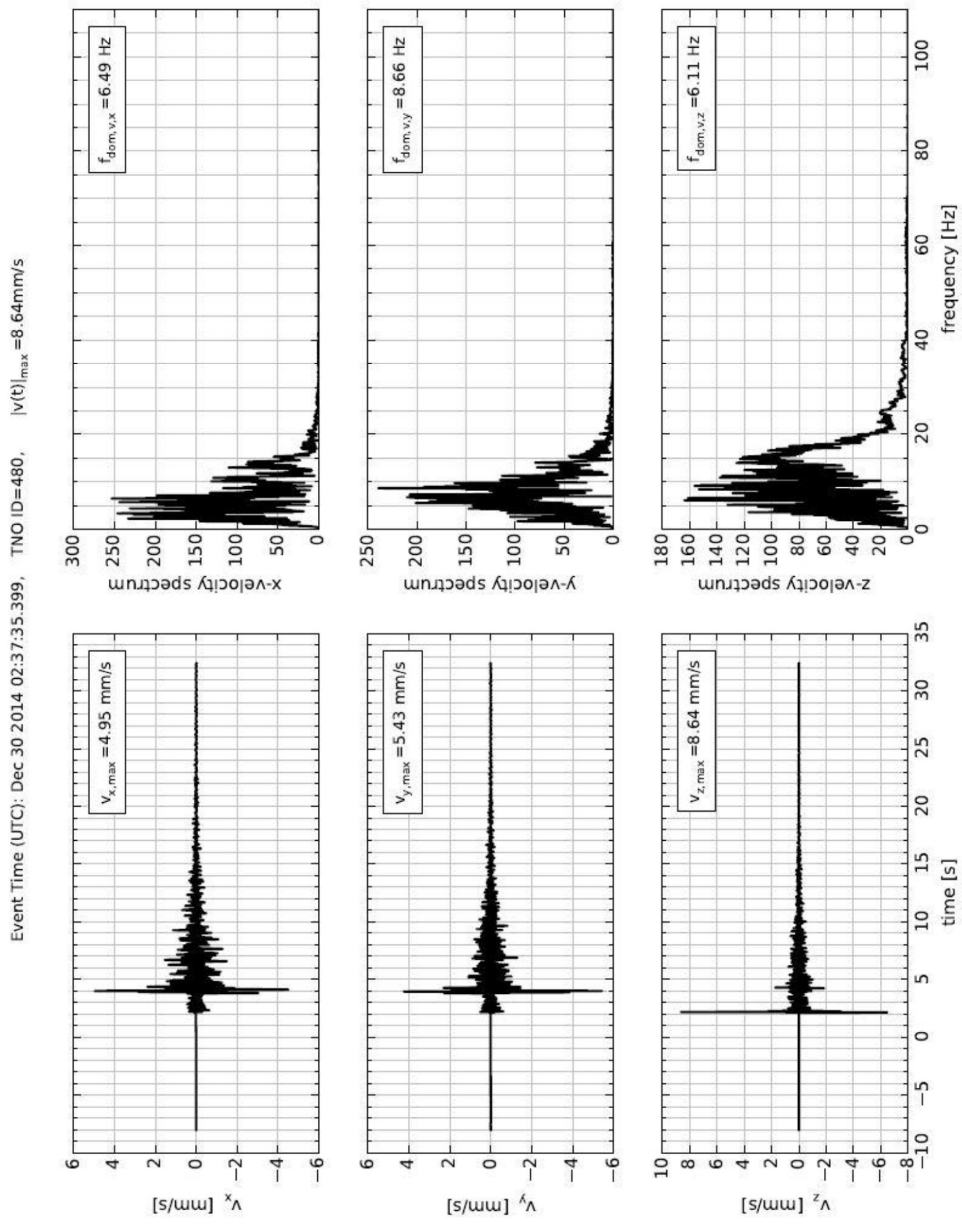
Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=317, |v(t)|max =10.36mm/s
vx,max =10.31 mm/s
vy,max =2.3 mm/s
vz,max =3.23 mm/s
vx [mm/s]
vy [mm/s]
vz [mm/s]
time [s]
fdom,v,x =3.22 Hz
fdom,v,y =6.56 Hz
fdom,v,z =7.06 Hz
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
frequency [Hz]

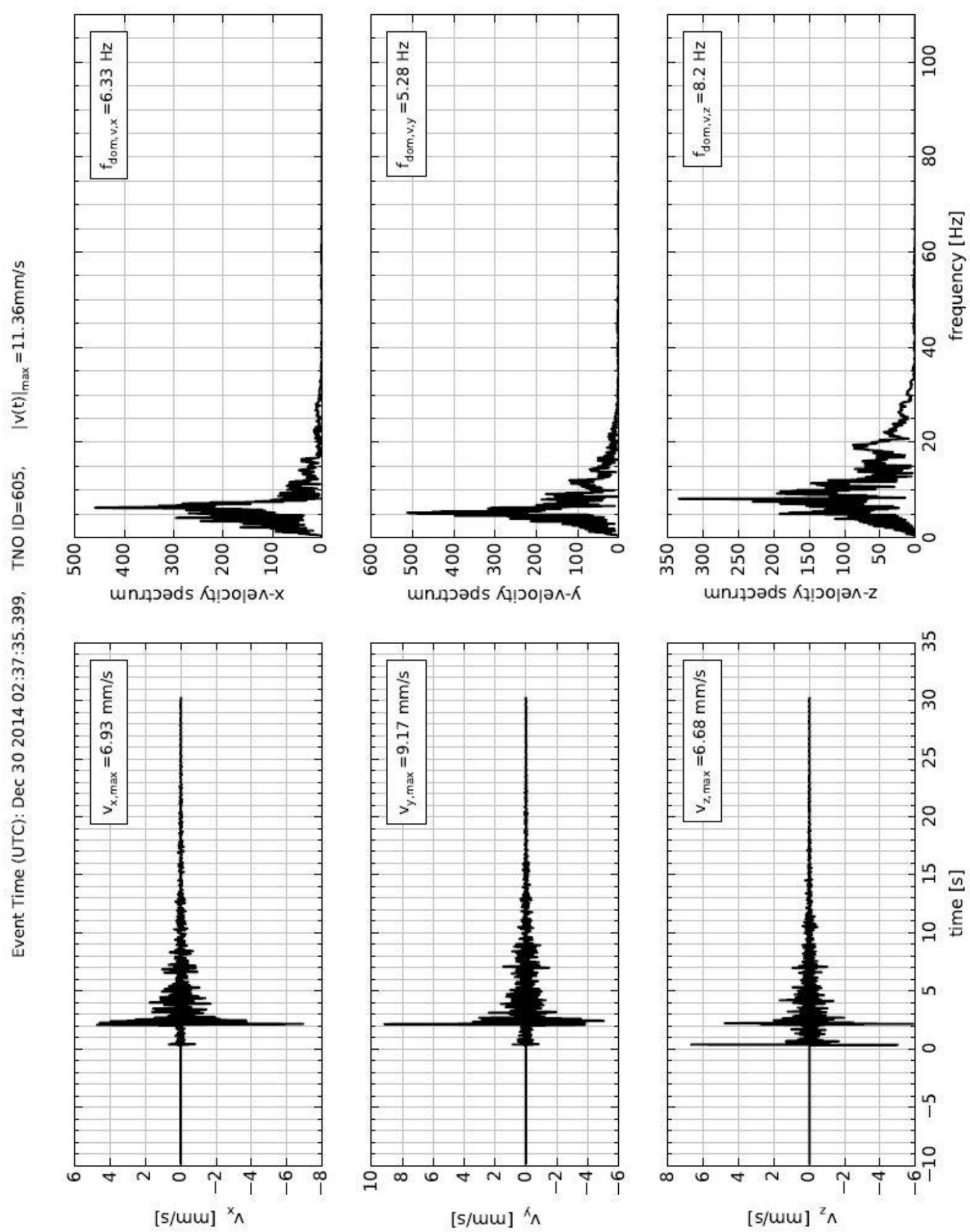

Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=118, |v(t)|max =3.84mm/s
vx,max =3.84 mm/s
vy,max =1.69 mm/s
vz,max =0.58 mm/s
vx [mm/s]
vy [mm/s]
vz [mm/s]
time [s]
fdom,v,x =4.97 Hz
fdom,v,y =3.14 Hz
fdom,v,z =7.53 Hz
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
frequency [Hz]

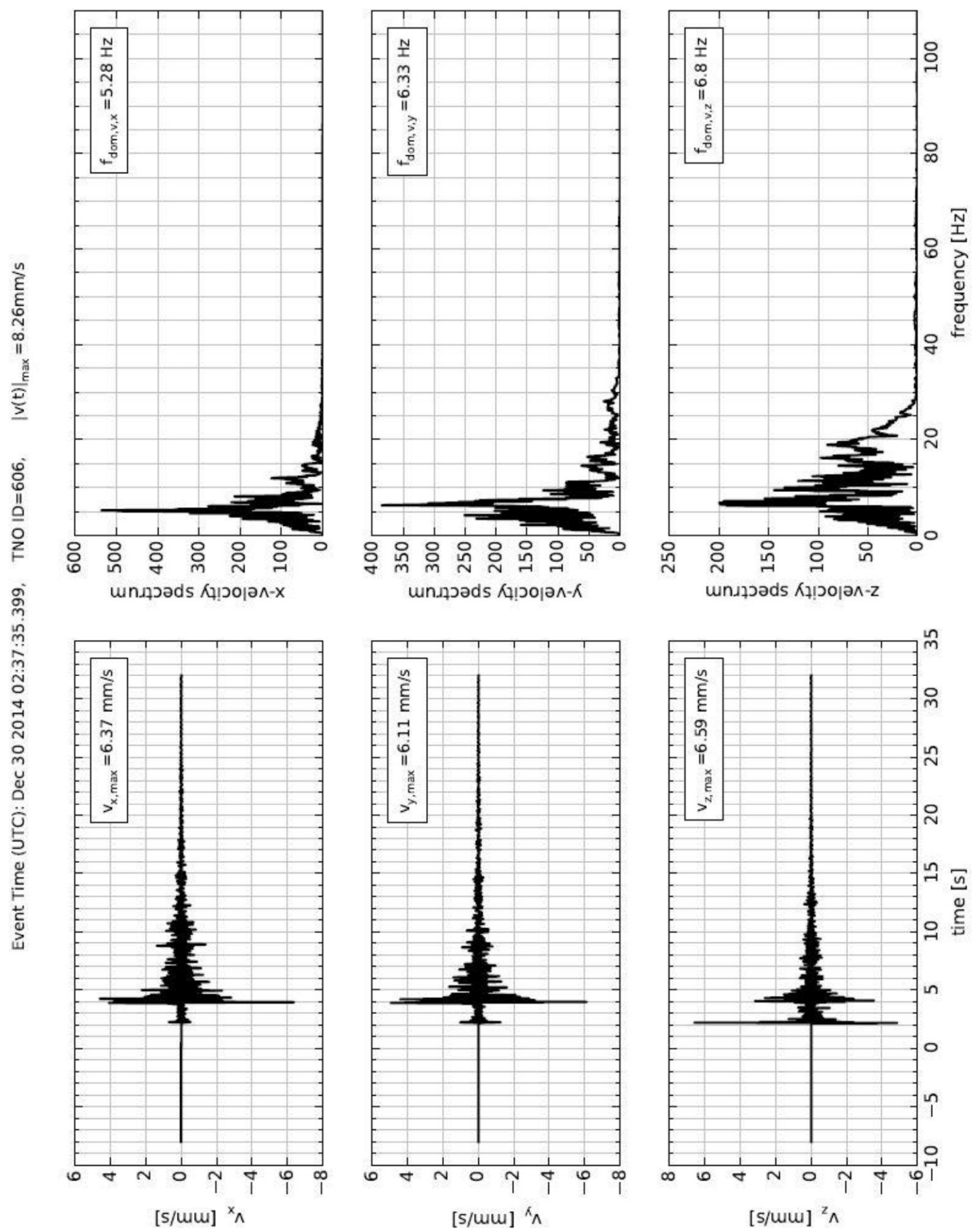

Event Time (UTC): Nov 05 2014 01:12:32.599, TNO ID=247, |v(t)|max =3.36mm/s
v_x,max =2.37 mm/s
v_y,max =2.55 mm/s
v_z,max =0.42 mm/s
f_dom,v,x =3.17 Hz
f_dom,v,y =3.03 Hz
f_dom,v,z =3.43 Hz
v_x [mm/s]
v_y [mm/s]
v_z [mm/s]
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
time [s]
frequency [Hz]

C.2 Selected velocity signals Woudbloem

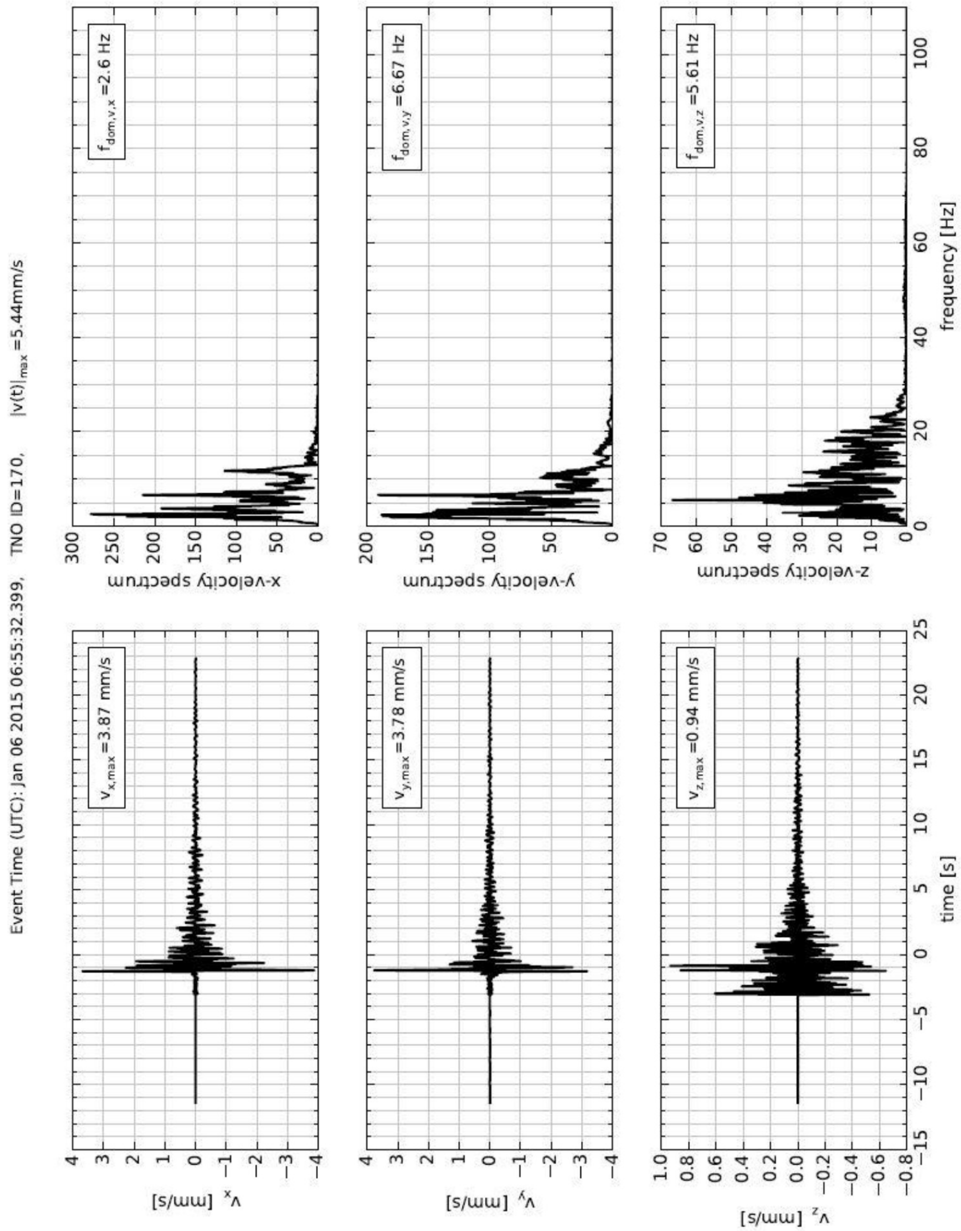


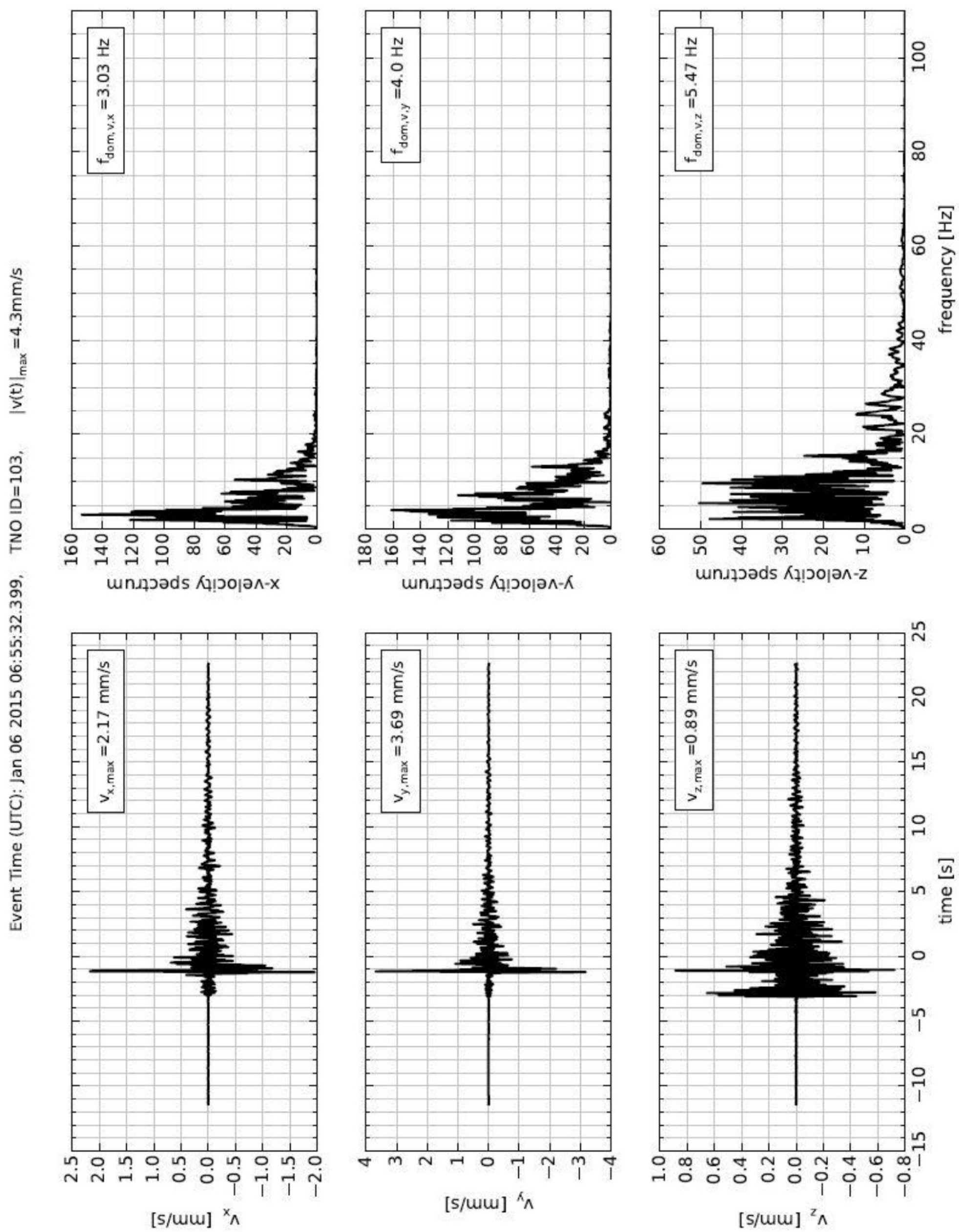

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=480, $|v(t)|_{max}$ =8.64mm/s
$v_{x,max}$ =4.95 mm/s
$v_{y,max}$ =5.43 mm/s
$v_{z,max}$ =8.64 mm/s
v_x [mm/s]
v_y [mm/s]
v_z [mm/s]
time [s]
$f_{dom,v,x}$ =6.49 Hz
$f_{dom,v,y}$ =8.66 Hz
$f_{dom,v,z}$ =6.11 Hz
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
frequency [Hz]

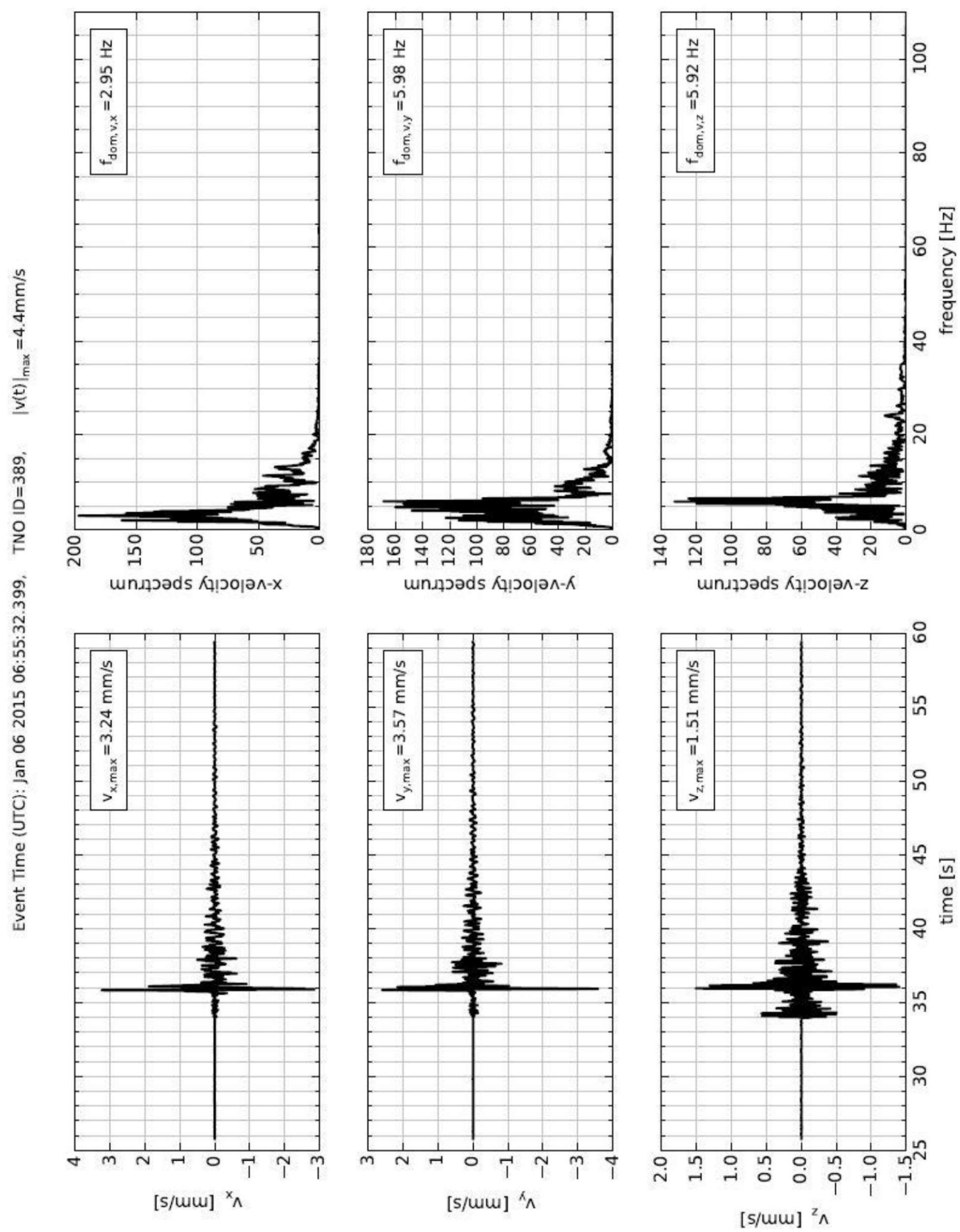

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=605, |v(t)|max =11.36mm/s
vx,max =6.93 mm/s
vy,max =9.17 mm/s
vz,max =6.68 mm/s
fdom,v,x =6.33 Hz
fdom,v,y =5.28 Hz
fdom,v,z =8.2 Hz
vx [mm/s]
vy [mm/s]
vz [mm/s]
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
time [s]
frequency [Hz]

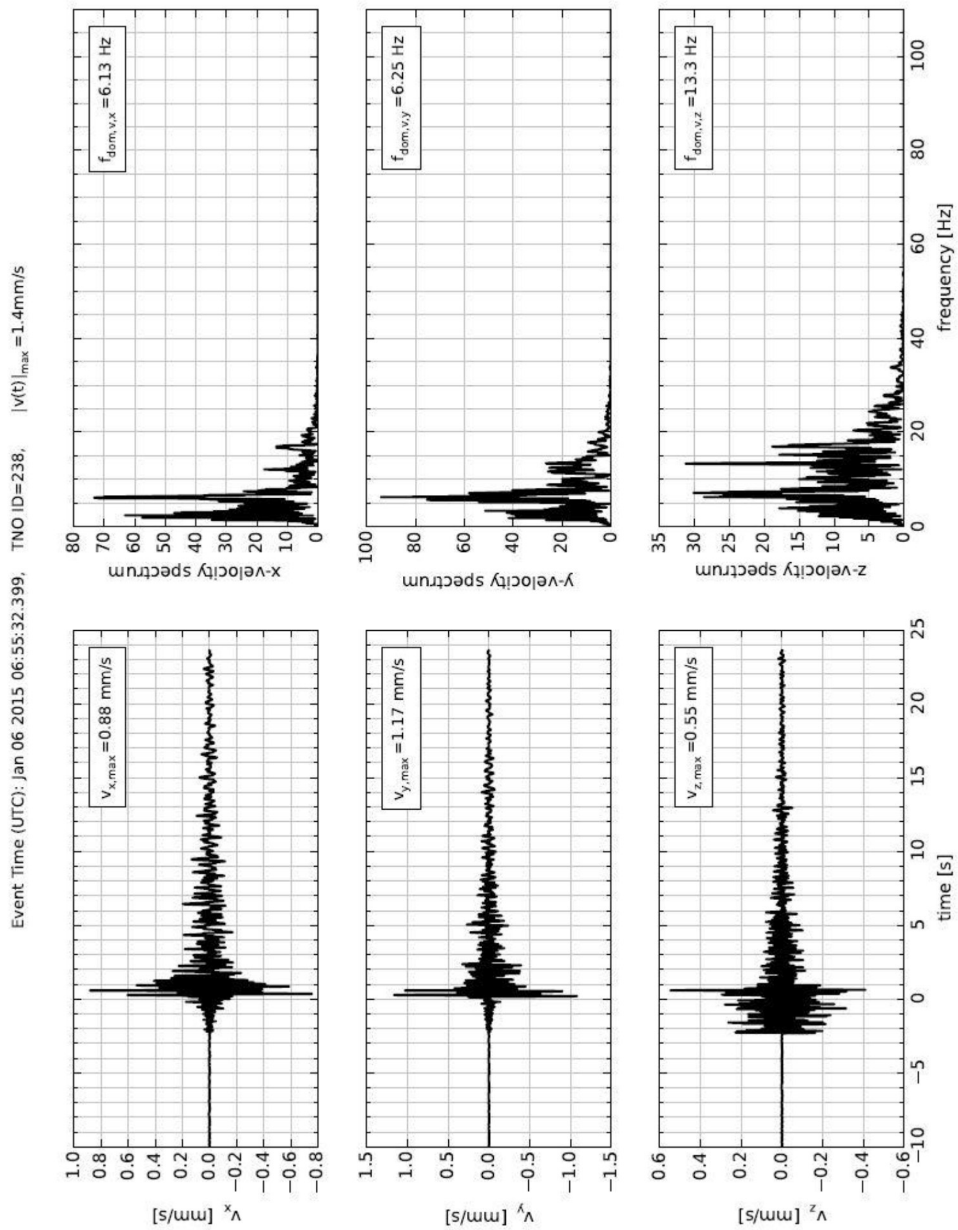

Event Time (UTC): Dec 30 2014 02:37:35.399, TNO ID=606, $|v(t)|_{max}$=8.26mm/s
$v_{x,max}$=6.37 mm/s
$v_{y,max}$=6.11 mm/s
$v_{z,max}$=6.59 mm/s
$f_{dom,v,x}$=5.28 Hz
$f_{dom,v,y}$=6.33 Hz
$f_{dom,v,z}$=6.8 Hz
v_x [mm/s]
v_y [mm/s]
v_z [mm/s]
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
time [s]
frequency [Hz]

C.3 Selected velocity signals Wirdum




Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=103, |v(t)|max =4.3mm/s
vx,max =2.17 mm/s
vy,max =3.69 mm/s
vz,max =0.89 mm/s
fdom,v,x =3.03 Hz
fdom,v,y =4.0 Hz
fdom,v,z =5.47 Hz
vx [mm/s]
vy [mm/s]
vz [mm/s]
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
time [s]
frequency [Hz]


Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=389, |v(t)|max =4.4mm/s
vx,max=3.24 mm/s
vy,max=3.57 mm/s
vz,max=1.51 mm/s
fdom,v,x=2.95 Hz
fdom,v,y=5.98 Hz
fdom,v,z=5.92 Hz
vx [mm/s]
vy [mm/s]
vz [mm/s]
x-velocity spectrum
y-velocity spectrum
z-velocity spectrum
time [s]
frequency [Hz]


Event Time (UTC): Jan 06 2015 06:55:32.399, TNO ID=238, |v(t)|max =1.4mm/s
v_x,max =0.88 mm/s
v_x [mm/s]
v_y,max =1.17 mm/s
v_y [mm/s]
v_z,max =0.55 mm/s
v_z [mm/s]
time [s]
f_dom,v,x =6.13 Hz
x-velocity spectrum
f_dom,v,y =6.25 Hz
y-velocity spectrum
f_dom,v,z =13.3 Hz
z-velocity spectrum
frequency [Hz]

D Vibration characteristics regarding acceleration

D.1 Characteristics Zandeweer

TNO ID	$a_{x,max}$ (m/s^2)	$a_{y,max}$ (m/s^2)	$a_{z,max}$ (m/s^2)	$\lvert a(t)\rvert_{max}$ (m/s^2)	$f_{a,dom,x}$ (Hz)	$f_{a,dom,y}$ (Hz)	$f_{a,dom,z}$ (Hz)
[redacted]	0.09	0.30	0.26	0.30	7.4	7.7	8.5
[redacted]	0.06	0.06	0.03	0.08	2.4	7.3	10.6
[redacted]	0.06	0.07	0.06	0.07	2.6	7.5	5.6
[redacted]	0.31	0.69	0.44	0.73	6.9	7.0	6.9
[redacted]	0.06	0.05	0.10	0.10	7.3	6.9	7.6
[redacted]	0.16	0.09	0.17	0.17	6.5	6.4	12.2
[redacted]	0.05	0.07	0.10	0.10	9.9	3.6	9.7
[redacted]	0.06	0.05	0.07	0.07	7.9	6.4	7.4
[redacted]	0.04	0.07	0.06	0.07	8.3	8.1	15.6
[redacted]	0.10	0.07	0.09	0.12	3.9	4.4	10.3
[redacted]	0.06	0.05	0.04	0.07	3.7	7.1	7.6
[redacted]	0.16	0.06	0.20	0.20	3.1	5.1	17.7
[redacted]	0.10	0.10	0.11	0.11	7.9	8.2	11.0
[redacted]	0.05	0.07	0.06	0.08	7.1	3.0	18.0
[redacted]	0.17	0.08	0.03	0.17	8.8	6.9	7.5
[redacted]	0.05	0.05	0.08	0.08	2.6	3.1	18.2
[redacted]	0.02	0.04	0.05	0.05	2.9	2.8	15.4
[redacted]	0.02	0.04	0.03	0.04	3.3	4.1	16.3
[redacted]	0.05	0.00	0.04	0.05	3.5	1.4	8.9
[redacted]	0.06	0.04	0.03	0.07	2.0	3.7	4.2
[redacted]	0.02	0.03	0.03	0.03	3.4	3.4	6.3
[redacted]	0.05	0.05	0.06	0.06	4.9	5.4	14.9
[redacted]	0.29	0.23	0.29	0.33	11.6	11.3	8.7
[redacted]	0.05	0.04	0.05	0.05	3.1	7.2	8.8
[redacted]	0.04	0.03	0.02	0.04	5.9	6.4	7.4
[redacted]	0.07	0.06	0.04	0.08	2.5	6.9	20.8
[redacted]	0.04	0.06	0.02	0.07	5.4	8.9	11.7
[redacted]	0.03	0.03	0.02	0.03	2.2	6.1	3.1
[redacted]	0.17	0.39	0.26	0.42	7.7	7.7	13.0
[redacted]	0.30	0.17	0.19	0.30	9.1	5.5	8.2
[redacted]	0.07	0.06	0.07	0.07	2.6	3.4	25.3
[redacted]	0.07	0.05	0.04	0.07	6.9	7.1	8.9
[redacted]	0.04	0.04	0.02	0.05	2.9	3.0	12.6

TNO ID	$a_{x,max}$ (m/s²)	$a_{y,max}$ (m/s²)	$a_{z,max}$ (m/s²)	$\|a(t)\|_{max}$ (m/s²)	$f_{a,dom,x}$ (Hz)	$f_{a,dom,y}$ (Hz)	$f_{a,dom,z}$ (Hz)
[redacted]	0.02	0.02	0.01	0.02	2.8	3.0	4.9
[redacted]	0.06	0.06	0.04	0.06	5.4	5.6	8.3
[redacted]	0.04	0.05	0.01	0.05	3.4	3.3	8.3
[redacted]	0.02	0.03	0.01	0.03	3.2	3.6	4.5
[redacted]	0.04	0.04	0.03	0.05	4.1	4.1	12.8
[redacted]	0.05	0.05	0.03	0.07	6.0	6.0	9.7
[redacted]	0.03	0.03	0.01	0.04	3.2	3.2	8.6
[redacted]	0.04	0.05	0.01	0.07	3.4	3.2	19.0
[redacted]	0.04	0.04	0.04	0.06	3.7	9.9	7.3
[redacted]	0.08	0.08	0.02	0.09	5.3	3.7	7.1
[redacted]	0.05	0.05	0.02	0.06	3.4	3.0	13.2
[redacted]	0.13	0.08	0.03	0.13	5.4	9.0	11.5
[redacted]	0.07	0.07	0.03	0.10	8.8	3.3	9.5
[redacted]	0.08	0.07	0.06	0.08	7.4	7.2	10.3
[redacted]	0.04	0.03	0.06	0.06	2.5	6.5	18.3
[redacted]	0.03	0.02	0.05	0.05	2.6	5.6	13.6
[redacted]	0.03	0.02	0.01	0.03	3.5	3.8	12.7
[redacted]	0.03	0.05	0.02	0.06	3.5	4.2	11.2
[redacted]	0.04	0.05	0.09	0.09	12.1	8.0	15.6
[redacted]	0.50	0.09	0.43	0.50	8.5	6.6	12.6
[redacted]	0.05	0.05	0.05	0.06	10.9	10.8	11.0
[redacted]	0.03	0.04	0.04	0.04	10.7	4.1	12.6
[redacted]	0.01	0.02	0.02	0.03	2.5	2.6	4.0
[redacted]	0.03	0.02	0.04	0.04	3.4	4.2	7.4
[redacted]	0.03	0.03	0.02	0.04	2.7	3.1	4.7
[redacted]	0.05	0.06	0.04	0.08	11.0	6.6	8.7
[redacted]	0.10	0.46	0.20	0.46	6.4	6.9	12.3
[redacted]	0.04	0.03	0.05	0.05	2.6	6.6	11.7
[redacted]	0.03	0.01	0.02	0.03	3.4	3.3	18.4
[redacted]	0.05	0.07	0.04	0.08	3.2	2.4	16.5
[redacted]	0.04	0.06	0.10	0.10	2.5	7.1	9.2
[redacted]	0.02	0.02	0.02	0.03	3.6	4.4	7.3
[redacted]	0.05	0.04	0.04	0.05	5.5	5.7	13.8
[redacted]	0.09	0.13	0.31	0.31	3.4	4.5	12.4
[redacted]	0.04	0.07	0.04	0.07	7.1	2.6	10.2

TNO ID	$a_{x,max}$ (m/s^2)	$a_{y,max}$ (m/s^2)	$a_{z,max}$ (m/s^2)	$\|a(t)\|_{max}$ (m/s^2)	$f_{a,dom,x}$ (Hz)	$f_{a,dom,y}$ (Hz)	$f_{a,dom,z}$ (Hz)
[redacted]	0.26	0.16	0.25	0.28	7.2	9.0	10.1
[redacted]	0.05	0.08	0.05	0.08	2.5	5.1	7.4
[redacted]	0.05	0.04	0.04	0.05	3.9	5.4	5.4
[redacted]	0.08	0.07	0.04	0.11	3.2	5.1	100.0
[redacted]	0.04	0.05	0.05	0.06	2.7	4.5	7.3
[redacted]	0.07	0.06	0.02	0.08	3.3	3.7	8.6
[redacted]	0.10	0.03	0.05	0.10	3.9	3.2	5.7
[redacted]	0.02	0.03	0.02	0.03	2.8	2.5	12.5
[redacted]	0.04	0.04	0.07	0.07	5.7	5.7	13.7
[redacted]	0.13	0.11	0.13	0.15	3.6	4.9	13.3
[redacted]	0.03	0.02	0.02	0.03	2.2	2.0	7.4
[redacted]	0.07	0.09	0.07	0.10	6.7	7.2	6.7
[redacted]	0.04	0.04	0.04	0.04	4.5	3.8	10.9
[redacted]	0.08	0.11	0.11	0.13	3.4	3.2	19.2
[redacted]	0.03	0.04	0.03	0.05	2.7	3.5	9.3
[redacted]	0.08	0.04	0.03	0.08	4.9	5.5	13.9
[redacted]	0.09	0.17	0.24	0.24	4.4	5.1	10.5
[redacted]	0.05	0.05	0.06	0.06	2.6	2.5	9.1
[redacted]	0.04	0.03	0.04	0.04	3.4	5.7	6.1
[redacted]	0.06	0.05	0.04	0.07	2.4	6.7	10.8
[redacted]	0.03	0.02	0.03	0.03	2.2	2.4	14.0
[redacted]	0.07	0.06	0.07	0.08	3.1	5.3	8.5
[redacted]	0.06	0.03	0.01	0.06	4.4	4.5	14.7

D.2 Characteristics Woudbloem

TNO ID	$a_{x,max}$ (m/s^2)	$a_{y,max}$ (m/s^2)	$a_{z,max}$ (m/s^2)	$\|a(t)\|_{max}$ (m/s^2)	$f_{a,dom,x}$ (Hz)	$f_{a,dom,y}$ (Hz)	$f_{a,dom,z}$ (Hz)
[redacted]	0.06	0.04	0.07	0.07	8.8	10.9	10.3
[redacted]	0.03	0.09	0.02	0.09	9.9	7.7	4.9
[redacted]	0.03	0.04	0.01	0.04	5.7	7.4	9.2
[redacted]	0.08	0.12	0.14	0.14	6.2	7.0	9.5
[redacted]	0.04	0.03	0.02	0.04	9.6	9.6	11.1
[redacted]	0.05	0.05	0.02	0.06	8.3	8.9	8.9
[redacted]	0.03	0.01	0.01	0.03	3.6	6.5	11.1
[redacted]	0.04	0.06	0.03	0.06	8.6	7.5	9.8
[redacted]	0.01	0.03	0.01	0.03	3.2	5.9	9.8
[redacted]	0.05	0.02	0.04	0.05	3.7	3.7	12.0
[redacted]	0.07	0.06	0.02	0.09	12.0	9.4	9.0
[redacted]	0.02	0.02	0.02	0.03	5.4	3.2	5.2
[redacted]	0.03	0.02	0.01	0.03	3.6	7.0	100.0
[redacted]	0.07	0.07	0.05	0.09	4.9	3.7	15.4
[redacted]	0.22	0.31	0.92	0.92	6.5	8.7	15.2
[redacted]	0.04	0.06	0.04	0.07	5.5	10.8	10.9
[redacted]	0.03	0.05	0.05	0.06	5.3	6.3	10.3
[redacted]	0.22	0.36	0.67	0.68	6.3	5.3	8.2
[redacted]	0.28	0.24	0.66	0.66	5.3	6.3	18.9
[redacted]	0.04	0.07	0.08	0.08	5.2	6.4	13.3
[redacted]	0.02	0.04	0.02	0.04	3.7	4.8	9.1
[redacted]	0.04	0.03	0.02	0.05	3.4	7.4	9.2

D.3 Characteristics Wirdum

TNO ID	$a_{x,max}$ (m/s^2)	$a_{y,max}$ (m/s^2)	$a_{z,max}$ (m/s^2)	$\|a(t)\|_{max}$ (m/s^2)	$f_{a,dom,x}$ (Hz)	$f_{a,dom,y}$ (Hz)	$f_{a,dom,z}$ (Hz)
[redacted]	0.07	0.16	0.10	0.16	3.2	5.8	5.7
[redacted]	0.02	0.04	0.02	0.04	6.6	10.0	10.0
[redacted]	0.02	0.04	0.04	0.04	33.5	33.5	14.1
[redacted]	0.10	0.16	0.25	0.25	6.1	4.0	33.8
[redacted]	0.13	0.09	0.07	0.16	6.0	6.7	11.6
[redacted]	0.04	0.05	0.03	0.06	5.0	8.6	5.9
[redacted]	0.11	0.19	0.10	0.22	10.4	7.1	9.6
[redacted]	0.08	0.06	0.12	0.12	2.5	3.4	19.0
[redacted]	0.11	0.16	0.06	0.19	6.6	5.6	9.4
[redacted]	0.02	0.04	0.03	0.05	5.9	6.3	14.7
[redacted]	0.08	0.00	0.08	0.09	6.7	1.4	6.8
[redacted]	0.19	0.20	0.11	0.27	11.3	11.3	14.9
[redacted]	0.15	0.06	0.09	0.15	4.1	12.2	11.2
[redacted]	0.20	0.14	0.07	0.24	6.7	6.7	18.1
[redacted]	0.12	0.24	0.12	0.27	13.5	12.5	16.7
[redacted]	0.15	0.17	0.07	0.22	6.5	6.6	6.7
[redacted]	0.08	0.07	0.05	0.10	7.5	7.4	15.7
[redacted]	0.02	0.02	0.03	0.03	2.7	3.0	6.5
[redacted]	0.04	0.07	0.04	0.08	6.1	6.3	13.3
[redacted]	0.17	0.15	0.19	0.20	5.6	6.6	59.2
[redacted]	0.13	0.09	0.07	0.15	5.5	5.5	14.9
[redacted]	0.05	0.07	0.13	0.14	3.4	2.6	6.0
[redacted]	0.03	0.05	0.04	0.05	6.6	4.9	5.3
[redacted]	0.07	0.06	0.04	0.08	2.7	2.9	18.8
[redacted]	0.14	0.25	0.08	0.29	5.9	6.6	96.0
[redacted]	0.08	0.14	0.13	0.15	6.7	6.8	24.8
[redacted]	0.07	0.06	0.09	0.09	3.7	3.7	6.8
[redacted]	0.12	0.16	0.04	0.17	6.6	7.5	10.2
[redacted]	0.04	0.16	0.14	0.16	4.8	4.9	7.6
[redacted]	0.05	0.11	0.09	0.12	9.2	2.5	6.1
[redacted]	0.02	0.05	0.07	0.07	11.5	4.8	12.8
[redacted]	0.14	0.12	0.08	0.16	2.9	6.0	6.6
[redacted]	0.05	0.06	0.12	0.12	2.0	8.2	11.8
[redacted]	0.02	0.06	0.04	0.07	4.3	10.2	15.0
[redacted]	0.05	0.04	0.03	0.06	9.7	9.8	10.2
[redacted]	0.13	0.15	0.08	0.19	4.2	10.7	10.7
[redacted]	0.05	0.02	0.03	0.06	4.8	3.9	22.4
[redacted]	0.04	0.11	0.05	0.11	2.7	5.0	6.0

E Vibration characteristics regarding velocity

E.1 Characteristics Zandeweer

ID	$v_{x,max}$ (mm/s)	$v_{y,max}$ (mm/s)	$v_{z,max}$ (mm/s)	$\|v(t)\|_{max}$ (mm/s)	$f_{v,dom,x}$ (Hz)	$f_{v,dom,y}$ (Hz)	$f_{v,dom,z}$ (Hz)
[redacted]	2.35	7.00	2.93	7.02	7.4	2.5	6.3
[redacted]	1.62	1.43	0.45	2.05	2.4	5.1	2.6
[redacted]	1.86	2.61	0.61	2.62	2.6	2.5	5.6
[redacted]	4.77	12.58	5.02	12.99	3.5	3.6	6.9
[redacted]	1.50	1.11	1.15	1.70	2.9	2.9	7.6
[redacted]	3.37	1.90	1.27	3.85	3.1	6.4	3.8
[redacted]	1.58	2.87	0.99	2.88	2.5	3.6	2.8
[redacted]	1.24	1.20	1.07	1.39	7.9	2.0	7.3
[redacted]	0.93	1.51	0.68	1.62	2.9	3.4	7.4
[redacted]	3.08	1.87	0.93	3.61	1.9	1.9	3.0
[redacted]	2.34	1.53	0.50	2.63	2.5	2.6	7.6
[redacted]	3.88	1.34	1.10	3.90	3.1	5.1	3.7
[redacted]	1.55	1.41	1.33	1.72	1.9	2.4	8.2
[redacted]	1.44	2.38	0.53	2.40	2.3	3.0	2.4
[redacted]	3.84	1.69	0.58	3.84	5.0	3.1	7.5
[redacted]	1.42	2.00	0.62	2.23	2.6	2.3	5.4
[redacted]	0.80	1.51	0.68	1.53	2.9	2.8	2.6
[redacted]	0.68	1.35	0.41	1.38	3.3	2.9	4.2
[redacted]	1.71	0.00	0.66	1.71	2.0	1.1	7.8
[redacted]	2.23	0.89	0.75	2.36	2.0	3.7	4.2
[redacted]	0.68	1.49	0.42	1.60	3.4	3.4	6.3
[redacted]	1.38	1.42	0.73	1.66	2.5	2.1	4.1
[redacted]	6.44	6.83	3.94	7.32	1.9	1.9	3.3
[redacted]	1.94	1.35	0.86	1.99	3.1	2.1	2.2
[redacted]	1.62	0.74	0.51	1.72	2.2	2.3	3.5
[redacted]	2.66	1.88	0.55	2.75	2.5	2.5	4.1
[redacted]	1.39	1.16	0.40	1.54	2.4	4.2	2.6
[redacted]	1.37	0.76	0.67	1.38	1.9	2.1	3.1
[redacted]	4.05	7.29	3.28	7.47	7.7	2.7	11.5
[redacted]	6.63	3.30	3.09	7.11	5.1	3.4	8.2
[redacted]	2.32	2.06	0.53	2.32	2.6	3.4	3.0
[redacted]	2.52	1.74	0.53	2.61	2.7	2.6	3.6
[redacted]	1.06	2.09	0.31	2.18	2.9	2.8	3.4

ID	$v_{x,max}$ (mm/s)	$v_{y,max}$ (mm/s)	$v_{z,max}$ (mm/s)	$\|v(t)\|_{max}$ (mm/s)	$f_{v,dom,x}$ (Hz)	$f_{v,dom,y}$ (Hz)	$f_{v,dom,z}$ (Hz)
[redacted]	0.99	1.09	0.34	1.25	2.8	3.0	3.2
[redacted]	1.92	1.58	0.58	2.00	2.5	2.4	2.9
[redacted]	1.18	1.93	0.23	2.13	3.4	2.5	3.4
[redacted]	0.91	1.32	0.40	1.56	3.2	3.0	2.9
[redacted]	0.83	1.75	0.34	1.83	4.1	3.2	4.0
[redacted]	1.71	1.81	0.40	2.41	3.4	3.1	4.2
[redacted]	1.09	1.34	0.31	1.73	3.2	3.2	3.3
[redacted]	2.03	2.27	0.25	2.94	3.4	3.2	3.3
[redacted]	1.07	1.41	0.75	1.77	3.7	2.6	7.3
[redacted]	1.61	2.29	0.35	2.39	2.6	2.4	6.4
[redacted]	2.37	2.55	0.42	3.36	3.2	3.0	3.4
[redacted]	3.89	1.72	0.50	3.90	5.4	3.5	5.5
[redacted]	1.11	1.97	0.44	2.16	3.0	3.3	2.4
[redacted]	1.34	1.36	0.82	1.38	3.0	7.2	7.4
[redacted]	1.11	0.80	0.49	1.34	1.8	1.9	7.2
[redacted]	1.26	0.86	0.56	1.33	2.6	2.0	3.3
[redacted]	1.27	0.80	0.21	1.48	3.5	3.8	2.8
[redacted]	1.20	2.20	0.23	2.31	3.5	3.5	3.1
[redacted]	0.67	1.05	0.94	1.15	3.2	3.4	6.8
[redacted]	10.31	2.30	3.23	10.36	3.2	6.6	7.1
[redacted]	1.74	1.21	0.55	1.77	2.5	1.9	3.1
[redacted]	0.66	1.11	0.39	1.15	3.7	2.2	3.2
[redacted]	0.57	1.07	0.40	1.16	2.5	2.6	4.0
[redacted]	1.53	0.66	0.40	1.60	3.4	4.2	3.6
[redacted]	1.40	1.47	0.50	1.97	2.5	3.1	4.7
[redacted]	1.84	1.29	0.50	1.89	2.4	3.1	2.8
[redacted]	1.80	11.37	2.34	11.43	6.4	2.5	4.2
[redacted]	1.43	0.62	0.71	1.47	2.6	2.6	2.6
[redacted]	1.70	0.50	0.29	1.72	3.4	3.3	2.9
[redacted]	1.77	2.50	0.52	2.52	2.6	2.4	3.6
[redacted]	1.39	2.37	0.60	2.38	2.5	2.5	4.3
[redacted]	0.65	1.23	0.28	1.36	3.6	3.4	3.2
[redacted]	1.47	1.35	0.65	1.64	2.6	2.9	2.7
[redacted]	2.79	4.19	4.17	4.70	3.4	3.5	12.4
[redacted]	1.32	2.53	0.80	2.58	2.1	2.6	2.5

ID	$v_{x,max}$ (mm/s)	$v_{y,max}$ (mm/s)	$v_{z,max}$ (mm/s)	$\|v(t)\|_{max}$ (mm/s)	$f_{v,dom,x}$ (Hz)	$f_{v,dom,y}$ (Hz)	$f_{v,dom,z}$ (Hz)
[redacted]	5.58	3.55	2.46	6.25	2.6	3.8	3.6
[redacted]	1.80	2.38	0.89	2.44	2.5	2.2	7.4
[redacted]	1.11	1.15	0.66	1.39	2.0	1.6	5.4
[redacted]	2.31	1.70	0.60	2.88	3.2	2.9	6.8
[redacted]	1.73	1.90	0.71	2.31	2.7	2.3	2.3
[redacted]	2.28	1.91	0.46	2.89	3.3	3.7	7.6
[redacted]	2.94	0.82	1.15	3.01	3.5	3.2	5.3
[redacted]	0.53	1.68	0.31	1.68	2.8	2.5	4.4
[redacted]	1.33	1.32	0.80	1.64	1.9	2.8	2.2
[redacted]	3.64	3.71	1.39	4.43	3.6	3.4	6.0
[redacted]	1.39	0.60	0.24	1.47	2.2	2.0	3.3
[redacted]	1.42	1.36	0.82	1.86	6.7	3.0	6.7
[redacted]	1.01	0.76	0.46	1.02	3.4	2.7	3.2
[redacted]	2.11	2.74	1.09	3.20	3.4	3.2	2.4
[redacted]	0.99	1.91	0.37	2.16	2.7	3.5	3.4
[redacted]	2.61	1.38	0.44	2.65	4.9	5.0	5.6
[redacted]	2.47	4.07	2.84	4.48	3.1	2.9	5.3
[redacted]	1.88	2.02	0.57	2.04	2.6	2.5	9.1
[redacted]	1.31	0.92	0.99	1.57	3.4	2.6	4.8
[redacted]	2.00	1.31	0.75	2.01	2.4	1.9	4.0
[redacted]	0.49	1.07	0.56	1.11	2.2	2.2	4.4
[redacted]	1.42	1.21	0.61	1.42	3.1	3.4	3.4
[redacted]	2.36	1.46	0.33	2.57	4.3	3.0	2.7

E.2 Characteristics Woudbloem

ID	$v_{x,max}$ (mm/s)	$v_{y,max}$ (mm/s)	$v_{z,max}$ (mm/s)	$\|v(t)\|_{max}$ (mm/s)	$f_{v,dom,x}$ (Hz)	$f_{v,dom,y}$ (Hz)	$f_{v,dom,z}$ (Hz)
[redacted]	1.16	0.87	0.93	1.24	2.3	3.6	10.3
[redacted]	0.78	2.19	0.37	2.23	4.0	5.1	4.9
[redacted]	1.11	0.74	0.13	1.23	4.9	7.4	5.1
[redacted]	1.97	3.56	1.73	3.89	6.2	6.2	9.5
[redacted]	1.07	0.76	0.30	1.15	2.7	2.6	7.0
[redacted]	1.24	0.94	0.25	1.24	3.3	3.4	7.0
[redacted]	1.07	0.40	0.18	1.07	3.4	3.0	3.8
[redacted]	1.09	1.65	0.50	1.71	2.7	2.2	9.8
[redacted]	0.36	1.01	0.12	1.03	3.2	3.3	5.5
[redacted]	1.32	0.77	0.62	1.52	3.7	3.7	11.2
[redacted]	0.94	1.41	0.32	1.44	3.3	3.7	9.0
[redacted]	0.57	1.06	0.58	1.13	5.2	3.2	5.2
[redacted]	1.01	0.66	0.16	1.09	3.6	3.0	4.4
[redacted]	1.65	1.58	0.73	2.27	4.9	3.7	3.7
[redacted]	4.95	5.43	8.64	8.64	6.5	8.7	6.1
[redacted]	0.82	1.21	0.56	1.47	5.5	6.0	10.9
[redacted]	0.70	1.23	0.70	1.42	5.3	6.3	6.6
[redacted]	6.93	9.17	6.68	11.36	6.3	5.3	8.2
[redacted]	6.37	6.11	6.59	8.26	5.3	6.3	6.8
[redacted]	0.95	1.30	0.96	1.32	5.2	6.4	6.6
[redacted]	0.64	1.22	0.29	1.22	3.7	3.3	4.3
[redacted]	1.29	0.67	0.26	1.42	3.0	2.3	6.0

E.3 Characteristics Wirdum

ID	$v_{x,max}$ (mm/s)	$v_{y,max}$ (mm/s)	$v_{z,max}$ (mm/s)	$\|v(t)\|_{max}$ (mm/s)	$f_{v,dom,x}$ (Hz)	$f_{v,dom,y}$ (Hz)	$f_{v,dom,z}$ (Hz)
[redacted]	1.95	3.63	0.92	4.04	2.5	2.6	5.7
[redacted]	0.41	1.07	0.30	1.16	2.7	2.6	6.4
[redacted]	0.48	1.07	0.57	1.13	4.4	1.8	4.8
[redacted]	2.44	3.62	0.96	4.09	3.1	4.0	4.4
[redacted]	4.36	3.02	0.76	5.30	2.0	2.7	6.7
[redacted]	1.02	1.42	0.47	1.71	5.0	4.4	5.9
[redacted]	2.17	3.69	0.89	4.30	3.0	4.0	5.5
[redacted]	3.11	2.36	1.27	3.91	2.5	2.3	5.3
[redacted]	3.34	3.33	0.60	4.66	2.6	5.6	5.6
[redacted]	0.70	1.20	0.36	1.21	5.9	3.1	6.4
[redacted]	2.04	0.00	1.16	2.14	2.6	0.9	6.8
[redacted]	3.51	4.06	1.54	5.18	2.5	2.5	4.3
[redacted]	3.32	1.38	0.93	3.41	2.2	2.2	3.0
[redacted]	3.87	3.78	0.94	5.44	2.6	6.7	5.6
[redacted]	2.59	3.07	0.63	3.70	2.4	2.8	4.2
[redacted]	3.04	3.24	0.89	4.31	2.6	1.8	3.5
[redacted]	1.05	1.62	0.49	1.84	3.3	1.8	3.2
[redacted]	0.63	1.13	0.37	1.22	2.7	3.0	6.5
[redacted]	0.88	1.17	0.55	1.40	6.1	6.3	13.3
[redacted]	4.00	4.26	0.55	5.78	2.6	2.9	5.6
[redacted]	4.06	3.57	0.66	5.26	2.0	1.8	6.0
[redacted]	1.81	3.00	1.24	3.48	3.4	2.6	6.0
[redacted]	1.01	1.70	0.85	1.83	2.6	3.1	5.3
[redacted]	2.88	1.93	0.52	3.46	2.7	2.9	3.6
[redacted]	3.79	4.46	1.22	5.48	2.6	2.3	5.6
[redacted]	1.70	3.11	0.73	3.38	2.5	2.5	6.1
[redacted]	3.00	2.38	1.25	3.97	3.7	3.7	6.5
[redacted]	3.02	3.96	0.55	4.74	1.9	1.9	6.3
[redacted]	1.61	3.44	0.83	3.56	2.5	2.5	7.6
[redacted]	1.05	3.14	1.35	3.22	3.2	2.5	6.1
[redacted]	0.42	1.56	0.95	1.58	2.2	2.3	12.8
[redacted]	3.24	3.57	1.51	4.40	2.9	6.0	5.9
[redacted]	1.25	1.67	1.46	1.95	2.0	1.9	7.8
[redacted]	0.57	1.60	0.51	1.68	2.5	3.6	4.5
[redacted]	1.55	0.77	0.42	1.61	2.7	2.4	10.2
[redacted]	3.53	3.51	0.79	4.25	4.2	3.0	4.1
[redacted]	1.51	0.60	0.32	1.54	3.0	3.9	3.9
[redacted]	1.51	3.25	0.93	3.59	2.7	2.6	6.0

F Vibration characteristics regarding Cumulative Absolute Velocity (CAV)

F.1 Characteristics Zandeweer

TNO ID	CAV_x [mm/s]	CAV_y [mm/s]	CAV_z [mm/s]	CAV_{total} [mm/s]	$CAV_{STD,X}$ [mm/s]	$CAV_{STD,y}$ [mm/s]	$CAV_{STD,z}$ [mm/s]	$CAV_{STD,TOTAL}$ [mm/s]
[redacted]	118.7	170.4	120.2	409.3	96.4	154.4	106.3	357.1
[redacted]	63.5	62.9	50.6	177.1	34.7	32.6	29.2	96.5
[redacted]	94.1	90.9	64.5	249.5	75.8	63.7	45.0	184.4
[redacted]	160.3	204.7	232.4	597.4	146.5	181.5	218.5	546.5
[redacted]	86.3	66.0	72.1	224.3	56.7	42.3	54.8	153.8
[redacted]	143.6	146.9	129.6	420.2	117.4	117.8	102.3	337.5
[redacted]	70.7	64.7	79.5	214.9	44.4	34.5	58.8	137.7
[redacted]	69.1	65.2	71.5	205.8	43.8	37.9	55.0	136.8
[redacted]	60.8	79.3	69.2	209.3	37.8	55.9	56.8	150.5
[redacted]	92.9	89.0	91.1	273.0	73.4	60.6	65.7	199.7
[redacted]	63.1	69.2	48.2	180.5	32.2	47.0	29.9	109.1
[redacted]	136.8	126.5	106.2	369.6	119.8	105.8	88.3	313.8
[redacted]	71.1	80.6	76.8	228.5	46.5	62.3	60.2	169.1
[redacted]	69.8	63.8	57.8	191.4	46.9	36.2	36.7	119.8
[redacted]	109.0	92.9	50.3	252.2	89.3	70.4	35.6	195.3
[redacted]	70.9	60.1	75.3	206.2	37.0	38.7	56.2	132.0
[redacted]	48.6	65.0	53.8	167.4	17.0	38.8	33.1	89.0
[redacted]	59.8	75.2	55.2	190.1	33.2	44.7	42.3	120.2
[redacted]	63.5	0.2	52.3	116.0	37.5	0.0	36.6	74.1
[redacted]	53.6	64.0	57.2	174.8	27.3	35.5	37.4	100.1
[redacted]	65.5	90.3	49.5	205.3	37.8	58.5	34.7	131.1
[redacted]	66.0	68.3	76.1	210.4	37.9	37.9	60.8	136.6
[redacted]	157.9	148.4	133.9	440.2	140.4	122.6	110.3	373.3
[redacted]	66.3	64.2	64.0	194.5	38.9	39.0	45.0	122.9
[redacted]	62.8	54.3	48.9	166.0	37.8	34.1	32.7	104.5
[redacted]	72.4	79.3	45.7	197.4	45.4	47.2	32.6	125.1
[redacted]	51.9	55.5	40.0	147.4	28.8	28.3	23.7	80.9
[redacted]	50.5	47.8	54.9	153.2	12.8	12.6	25.1	50.5
[redacted]	154.0	141.5	129.2	424.7	136.8	123.9	113.9	374.6
[redacted]	207.4	141.1	188.2	536.7	192.2	122.2	174.4	488.9
[redacted]	78.5	80.7	63.5	222.7	50.4	56.5	42.4	149.3
[redacted]	76.6	74.2	47.1	198.0	47.4	45.4	29.5	122.3
[redacted]	56.7	51.5	35.0	143.2	29.8	20.9	18.8	69.5

TNO ID	CAV_x [mm/s]	CAV_y [mm/s]	CAV_z [mm/s]	CAV_{total} [mm/s]	$CAV_{STD,X}$ [mm/s]	$CAV_{STD,y}$ [mm/s]	$CAV_{STD,z}$ [mm/s]	$CAV_{STD,TOTAL}$ [mm/s]
[redacted]	41.8	43.4	18.5	103.7	13.3	17.4	3.2	33.9
[redacted]	67.7	69.2	58.3	195.2	32.4	42.8	32.1	107.4
[redacted]	64.0	61.4	29.2	154.6	43.1	34.5	15.6	93.3
[redacted]	54.4	55.5	45.9	155.8	20.9	26.6	22.7	70.2
[redacted]	82.5	88.6	46.0	217.1	51.5	65.9	26.1	143.4
[redacted]	68.1	58.7	41.8	168.5	40.9	26.5	31.5	98.9
[redacted]	44.6	50.7	32.2	127.5	15.3	17.8	12.5	45.5
[redacted]	61.8	65.7	34.8	162.3	35.6	40.1	14.1	89.8
[redacted]	65.9	56.4	48.0	170.3	39.1	29.3	30.4	98.8
[redacted]	76.3	73.6	33.2	183.1	50.6	45.2	16.2	112.0
[redacted]	67.2	83.7	33.1	184.1	36.3	53.9	10.6	100.8
[redacted]	97.7	96.8	45.6	240.1	72.9	73.7	31.5	178.1
[redacted]	72.3	64.8	51.7	188.8	48.9	42.5	40.5	131.8
[redacted]	66.2	79.2	66.7	212.1	45.1	61.5	52.0	158.5
[redacted]	57.0	53.1	62.9	173.0	22.8	25.3	42.9	91.0
[redacted]	50.6	51.4	52.0	154.0	20.4	20.0	33.2	73.7
[redacted]	55.1	54.1	23.1	132.2	25.8	28.9	3.4	58.1
[redacted]	53.4	65.7	31.3	150.4	29.2	42.7	15.2	87.1
[redacted]	67.1	72.0	83.4	222.6	45.5	50.8	63.0	159.4
[redacted]	216.2	146.2	179.1	541.5	198.6	124.2	166.0	488.8
[redacted]	52.1	55.2	63.2	170.5	25.2	29.2	47.3	101.7
[redacted]	72.3	69.1	50.0	191.3	45.4	40.2	32.4	117.9
[redacted]	42.6	41.7	40.8	125.1	11.7	12.8	21.7	46.2
[redacted]	83.1	67.9	49.6	200.5	58.8	41.7	31.9	132.5
[redacted]	56.3	57.4	32.7	146.4	31.5	33.5	12.6	77.7
[redacted]	67.2	66.0	53.7	186.9	40.5	34.8	30.7	106.0
[redacted]	171.0	199.8	153.0	523.8	154.0	182.0	134.7	470.6
[redacted]	67.9	49.7	60.6	178.3	45.2	16.9	38.7	100.9
[redacted]	53.7	40.8	29.0	123.5	20.1	10.9	18.8	49.8
[redacted]	82.1	81.1	44.4	207.6	55.8	57.2	28.8	141.8
[redacted]	75.8	78.7	63.3	217.8	56.2	52.0	44.0	152.2
[redacted]	34.6	37.5	32.2	104.3	11.7	9.7	18.2	39.6
[redacted]	76.5	72.0	48.1	196.6	42.1	38.0	25.2	105.3
[redacted]	117.3	123.7	217.1	458.1	95.5	106.6	204.4	406.5
[redacted]	64.0	64.4	44.1	172.4	39.1	36.8	29.9	105.8

TNO ID	CAV_x [mm/s]	CAV_y [mm/s]	CAV_z [mm/s]	CAV_{total} [mm/s]	$CAV_{STD,X}$ [mm/s]	$CAV_{STD,y}$ [mm/s]	$CAV_{STD,z}$ [mm/s]	$CAV_{STD,TOTAL}$ [mm/s]
[redacted]	144.9	117.6	129.9	392.4	126.6	86.8	109.4	322.8
[redacted]	72.4	69.9	69.4	211.7	46.8	46.7	48.0	141.5
[redacted]	53.9	59.9	70.2	183.9	26.1	39.1	43.4	108.7
[redacted]	82.5	71.3	56.3	210.1	58.5	49.9	35.4	143.9
[redacted]	56.9	71.7	65.3	193.9	24.5	42.3	41.5	108.3
[redacted]	71.8	58.1	40.1	169.9	45.7	29.7	24.2	99.6
[redacted]	72.9	67.5	59.5	200.0	48.6	41.9	38.0	128.4
[redacted]	46.4	61.2	37.8	145.4	14.8	33.1	23.9	71.9
[redacted]	73.8	57.0	77.8	208.5	42.8	28.4	59.7	131.0
[redacted]	147.9	118.7	81.9	348.4	127.1	102.0	67.3	296.4
[redacted]	43.9	43.1	21.2	108.2	15.1	16.7	4.2	36.0
[redacted]	72.2	77.9	72.8	222.9	49.9	57.1	58.4	165.4
[redacted]	61.0	56.0	45.6	162.5	33.3	32.8	31.3	97.4
[redacted]	87.7	126.1	138.1	351.9	63.1	100.8	121.3	285.2
[redacted]	46.9	57.5	42.3	146.7	17.3	27.0	27.5	71.8
[redacted]	79.3	78.3	41.8	199.4	58.4	49.5	29.8	137.8
[redacted]	103.7	137.6	123.1	364.4	81.7	115.6	96.0	293.3
[redacted]	63.3	60.1	47.4	170.9	38.0	32.6	27.1	97.7
[redacted]	53.7	49.9	57.3	160.9	28.4	17.0	40.4	85.8
[redacted]	63.8	68.4	62.3	194.6	40.0	34.8	35.4	110.2
[redacted]	40.0	44.5	53.4	137.9	10.7	14.7	37.3	62.7
[redacted]	83.0	102.2	71.3	256.5	60.0	81.1	49.6	190.7
[redacted]	58.3	50.7	30.8	139.8	34.1	26.8	12.9	73.9

F.2 Characteristics Woudbloem

TNO ID	CAV_x [mm/s]	CAV_y [mm/s]	CAV_z [mm/s]	CAV_{total} [mm/s]	$CAV_{STD,X}$ [mm/s]	$CAV_{STD,y}$ [mm/s]	$CAV_{STD,z}$ [mm/s]	$CAV_{STD,TOTAL}$ [mm/s]
[redacted]	58.5	54.5	61.3	174.4	37.8	31.8	35.8	105.4
[redacted]	39.6	55.6	34.2	129.4	14.4	31.7	15.9	62.1
[redacted]	39.9	37.7	15.8	93.4	17.7	16.6	0.0	34.2
[redacted]	95.0	110.3	86.7	292.0	77.5	95.5	68.9	241.9
[redacted]	51.1	35.1	32.0	118.2	35.8	13.7	22.0	71.5
[redacted]	51.4	38.5	35.5	125.4	33.8	16.9	17.1	67.8
[redacted]	30.1	22.6	14.9	67.6	11.1	4.9	0.0	16.0
[redacted]	50.5	45.9	38.2	134.6	29.3	24.5	24.5	78.3
[redacted]	22.2	27.4	16.8	66.4	7.3	10.2	0.0	17.5
[redacted]	56.4	49.7	43.4	149.5	28.8	18.8	31.7	79.3
[redacted]	48.6	59.4	36.0	143.9	28.1	42.4	23.7	94.1
[redacted]	30.8	35.5	34.5	100.8	13.1	14.4	12.7	40.3
[redacted]	33.3	28.6	19.8	81.7	11.8	11.3	3.7	26.8
[redacted]	62.8	68.3	54.3	185.4	34.1	44.0	41.2	119.3
[redacted]	206.7	195.3	191.6	593.6	189.9	175.8	171.6	537.3
[redacted]	45.4	57.4	52.7	155.5	20.9	39.9	35.4	96.3
[redacted]	39.7	50.8	46.9	137.5	14.5	29.6	29.3	73.4
[redacted]	209.7	253.8	251.4	714.9	189.4	235.3	237.8	662.5
[redacted]	215.4	212.9	205.4	633.7	196.8	193.1	190.8	580.7
[redacted]	64.7	80.6	68.9	214.3	39.0	59.7	44.0	142.7
[redacted]	35.1	41.8	30.8	107.7	14.0	14.0	14.9	42.9
[redacted]	39.2	33.7	31.4	104.3	15.8	12.1	17.6	45.5

F.3 Characteristics Wirdum

TNO ID	CAV_x [mm/s]	CAV_y [mm/s]	CAV_z [mm/s]	CAV_{total} [mm/s]	$CAV_{STD,X}$ [mm/s]	$CAV_{STD,y}$ [mm/s]	$CAV_{STD,z}$ [mm/s]	$CAV_{STD,TOTAL}$ [mm/s]
[redacted]	84.1	105.6	75.7	265.4	57.7	81.9	55.4	195.0
[redacted]	28.6	32.6	30.6	91.9	15.4	17.6	19.4	52.4
[redacted]	46.9	76.1	43.1	166.2	19.5	34.9	22.9	77.2
[redacted]	55.2	75.0	85.5	215.7	40.8	57.4	71.5	169.6
[redacted]	78.6	66.1	62.6	207.2	58.1	48.1	47.2	153.4
[redacted]	45.7	47.2	39.9	132.7	28.6	24.3	24.6	77.5
[redacted]	59.9	76.9	61.9	198.7	49.1	59.2	50.6	158.8
[redacted]	65.1	62.0	69.1	196.2	49.2	47.9	55.8	152.8
[redacted]	71.9	92.9	37.1	202.0	56.6	73.5	25.1	155.1
[redacted]	34.7	39.8	38.0	112.4	13.1	22.3	25.5	61.0
[redacted]	57.5	0.2	65.3	123.0	42.3	0.0	49.8	92.1
[redacted]	105.1	100.2	79.6	284.9	83.3	82.2	65.1	230.6
[redacted]	73.4	54.6	55.3	183.3	59.4	37.8	38.8	136.0
[redacted]	93.5	78.9	56.7	229.2	75.8	66.7	46.9	189.4
[redacted]	66.8	90.6	54.7	212.1	52.8	78.1	43.8	174.7
[redacted]	96.9	79.0	57.2	233.1	78.7	63.7	48.0	190.4
[redacted]	35.5	42.7	36.0	114.2	16.9	25.3	23.5	65.7
[redacted]	28.7	30.5	28.0	87.2	10.0	10.3	20.1	40.4
[redacted]	38.8	51.3	40.5	130.6	16.9	31.1	26.8	74.7
[redacted]	90.1	86.2	46.8	223.1	72.1	68.1	36.2	176.4
[redacted]	82.4	63.3	41.3	187.0	61.5	49.6	32.6	143.6
[redacted]	54.1	63.8	71.6	189.5	33.4	47.1	57.7	138.3
[redacted]	41.2	44.8	59.7	145.7	20.9	24.3	46.4	91.6
[redacted]	71.0	63.7	36.9	171.6	52.6	45.1	22.7	120.4
[redacted]	84.8	101.0	112.8	298.6	59.2	76.9	43.1	179.3
[redacted]	72.6	83.9	76.3	232.8	51.9	62.5	53.6	168.0
[redacted]	55.4	47.5	51.1	154.1	39.4	29.5	40.3	109.1
[redacted]	65.9	84.8	43.8	194.5	49.2	66.5	34.7	150.3
[redacted]	56.6	67.0	61.2	184.7	42.7	48.0	44.8	135.5
[redacted]	47.3	68.3	61.8	177.3	29.2	52.2	49.1	130.5
[redacted]	30.5	40.4	60.9	131.8	7.9	19.8	50.4	78.0
[redacted]	56.4	62.2	65.8	184.4	39.5	47.3	53.4	140.2
[redacted]	41.8	56.1	34.5	132.4	27.5	35.6	24.6	87.7
[redacted]	26.6	37.1	43.5	107.3	9.9	23.0	34.1	67.0
[redacted]	37.2	44.5	38.0	119.8	17.0	22.8	27.7	67.6
[redacted]	75.7	76.9	64.6	217.3	57.9	64.3	53.2	175.4
[redacted]	34.6	37.4	41.5	113.4	12.7	11.0	30.7	54.4
[redacted]	39.3	54.0	43.8	137.1	22.4	36.1	26.6	85.2

G Vibration characteristics Arias Intensity (I_A)

G.1 Characteristics Zandeweer

TNO ID	$I_{A,X}$ [mm/s]	$I_{A,Y}$ [mm/s]	$I_{A,Z}$ [mm/s]	$I_{A,TOTAL}$ [mm/s]
[redacted]	0.37	1.51	0.72	2.60
[redacted]	0.09	0.09	0.06	0.24
[redacted]	0.19	0.19	0.11	0.49
[redacted]	1.08	2.97	3.23	7.28
[redacted]	0.21	0.10	0.19	0.50
[redacted]	0.50	0.43	0.62	1.55
[redacted]	0.11	0.13	0.22	0.47
[redacted]	0.11	0.10	0.19	0.40
[redacted]	0.07	0.15	0.17	0.39
[redacted]	0.21	0.15	0.21	0.56
[redacted]	0.10	0.10	0.06	0.26
[redacted]	0.61	0.29	0.44	1.33
[redacted]	0.17	0.17	0.27	0.61
[redacted]	0.10	0.10	0.09	0.29
[redacted]	0.65	0.23	0.07	0.96
[redacted]	0.09	0.09	0.17	0.34
[redacted]	0.03	0.07	0.09	0.20
[redacted]	0.05	0.09	0.07	0.21
[redacted]	0.08	0.00	0.08	0.16
[redacted]	0.07	0.08	0.07	0.22
[redacted]	0.06	0.14	0.05	0.25
[redacted]	0.10	0.09	0.17	0.36
[redacted]	1.10	0.73	0.77	2.60
[redacted]	0.08	0.08	0.11	0.27
[redacted]	0.08	0.06	0.05	0.19
[redacted]	0.14	0.15	0.07	0.36
[redacted]	0.05	0.07	0.04	0.16
[redacted]	0.04	0.04	0.04	0.12
[redacted]	0.89	1.32	1.13	3.34
[redacted]	1.71	0.56	1.53	3.81
[redacted]	0.13	0.13	0.13	0.39
[redacted]	0.13	0.12	0.06	0.31
[redacted]	0.06	0.07	0.03	0.16

TNO ID	$I_{A,X}$ [mm/s]	$I_{A,Y}$ [mm/s]	$I_{A,Z}$ [mm/s]	$I_{A,TOTAL}$ [mm/s]
[redacted]	0.04	0.04	0.01	0.08
[redacted]	0.09	0.10	0.07	0.25
[redacted]	0.08	0.08	0.02	0.18
[redacted]	0.04	0.05	0.03	0.13
[redacted]	0.11	0.13	0.05	0.29
[redacted]	0.12	0.09	0.05	0.25
[redacted]	0.04	0.05	0.02	0.10
[redacted]	0.09	0.11	0.02	0.22
[redacted]	0.09	0.07	0.06	0.22
[redacted]	0.15	0.13	0.03	0.31
[redacted]	0.13	0.24	0.02	0.40
[redacted]	0.39	0.23	0.06	0.68
[redacted]	0.13	0.15	0.07	0.34
[redacted]	0.12	0.15	0.15	0.42
[redacted]	0.06	0.05	0.11	0.21
[redacted]	0.05	0.04	0.08	0.16
[redacted]	0.07	0.05	0.01	0.13
[redacted]	0.06	0.10	0.02	0.18
[redacted]	0.09	0.11	0.26	0.45
[redacted]	3.12	0.53	1.99	5.64
[redacted]	0.06	0.07	0.12	0.25
[redacted]	0.09	0.07	0.06	0.22
[redacted]	0.03	0.03	0.04	0.09
[redacted]	0.12	0.07	0.05	0.23
[redacted]	0.07	0.08	0.02	0.17
[redacted]	0.11	0.09	0.07	0.26
[redacted]	0.64	2.04	0.85	3.52
[redacted]	0.09	0.04	0.11	0.24
[redacted]	0.05	0.02	0.03	0.10
[redacted]	0.13	0.14	0.06	0.33
[redacted]	0.13	0.14	0.15	0.42
[redacted]	0.02	0.03	0.03	0.07
[redacted]	0.11	0.09	0.07	0.27
[redacted]	0.32	0.47	3.30	4.09
[redacted]	0.08	0.11	0.07	0.26

TNO ID	$I_{A,X}$ [mm/s]	$I_{A,Y}$ [mm/s]	$I_{A,Z}$ [mm/s]	$I_{A,TOTAL}$ [mm/s]
[redacted]	0.73	0.36	0.84	1.93
[redacted]	0.12	0.12	0.13	0.37
[redacted]	0.06	0.06	0.12	0.25
[redacted]	0.17	0.13	0.07	0.37
[redacted]	0.07	0.10	0.11	0.28
[redacted]	0.13	0.08	0.05	0.26
[redacted]	0.22	0.07	0.09	0.38
[redacted]	0.04	0.08	0.03	0.15
[redacted]	0.10	0.07	0.22	0.39
[redacted]	0.59	0.35	0.31	1.26
[redacted]	0.04	0.03	0.01	0.08
[redacted]	0.14	0.16	0.19	0.49
[redacted]	0.07	0.06	0.06	0.19
[redacted]	0.17	0.31	0.52	1.01
[redacted]	0.04	0.08	0.04	0.15
[redacted]	0.19	0.11	0.05	0.35
[redacted]	0.25	0.61	0.70	1.56
[redacted]	0.09	0.08	0.07	0.25
[redacted]	0.05	0.05	0.08	0.18
[redacted]	0.08	0.09	0.08	0.26
[redacted]	0.03	0.03	0.07	0.14
[redacted]	0.12	0.19	0.13	0.44
[redacted]	0.11	0.07	0.02	0.20

G.2 Characteristics Woudbloem

TNO ID	$I_{A,X}$ [mm/s]	$I_{A,Y}$ [mm/s]	$I_{A,Z}$ [mm/s]	$I_{A,TOTAL}$ [mm/s]
[redacted]	0.08	0.05	0.12	0.25
[redacted]	0.04	0.13	0.03	0.19
[redacted]	0.05	0.05	0.01	0.11
[redacted]	0.28	0.36	0.28	0.92
[redacted]	0.08	0.04	0.03	0.14
[redacted]	0.08	0.06	0.02	0.17
[redacted]	0.03	0.01	0.00	0.04
[redacted]	0.07	0.07	0.05	0.20
[redacted]	0.01	0.02	0.01	0.04
[redacted]	0.07	0.04	0.07	0.17
[redacted]	0.09	0.13	0.04	0.26
[redacted]	0.02	0.03	0.02	0.08
[redacted]	0.03	0.02	0.01	0.06
[redacted]	0.10	0.11	0.12	0.33
[redacted]	1.42	1.56	3.57	6.55
[redacted]	0.05	0.10	0.08	0.22
[redacted]	0.03	0.08	0.07	0.18
[redacted]	2.06	2.63	3.99	8.68
[redacted]	1.77	2.13	3.43	7.32
[redacted]	0.08	0.14	0.15	0.36
[redacted]	0.03	0.04	0.02	0.09
[redacted]	0.04	0.03	0.02	0.09

G.3 Characteristics Wirdum

TNO ID	$I_{A,X}$ [mm/s]	$I_{A,Y}$ [mm/s]	$I_{A,Z}$ [mm/s]	$I_{A,TOTAL}$ [mm/s]
[redacted]	0.16	0.49	0.16	0.81
[redacted]	0.02	0.05	0.03	0.10
[redacted]	0.04	0.06	0.05	0.15
[redacted]	0.13	0.32	0.41	0.86
[redacted]	0.35	0.17	0.13	0.65
[redacted]	0.06	0.06	0.05	0.17
[redacted]	0.16	0.37	0.16	0.69
[redacted]	0.15	0.13	0.33	0.61
[redacted]	0.26	0.52	0.06	0.84
[redacted]	0.02	0.06	0.05	0.13
[redacted]	0.13	0.00	0.19	0.32
[redacted]	0.68	0.61	0.26	1.56
[redacted]	0.29	0.09	0.13	0.51
[redacted]	0.61	0.37	0.15	1.13
[redacted]	0.21	0.56	0.17	0.94
[redacted]	0.49	0.33	0.13	0.96
[redacted]	0.06	0.08	0.05	0.19
[redacted]	0.02	0.02	0.03	0.08
[redacted]	0.05	0.10	0.06	0.21
[redacted]	0.49	0.37	0.22	1.08
[redacted]	0.32	0.19	0.08	0.59
[redacted]	0.08	0.13	0.22	0.43
[redacted]	0.04	0.07	0.12	0.22
[redacted]	0.18	0.13	0.06	0.37
[redacted]	0.32	0.61	0.18	1.11
[redacted]	0.17	0.31	0.29	0.77
[redacted]	0.14	0.10	0.13	0.37
[redacted]	0.23	0.43	0.08	0.73
[redacted]	0.10	0.30	0.15	0.55
[redacted]	0.06	0.21	0.14	0.42
[redacted]	0.02	0.06	0.18	0.27
[redacted]	0.25	0.27	0.19	0.71
[redacted]	0.06	0.10	0.10	0.26
[redacted]	0.02	0.07	0.08	0.16
[redacted]	0.06	0.05	0.05	0.16
[redacted]	0.33	0.29	0.18	0.80
[redacted]	0.04	0.03	0.06	0.13
[redacted]	0.05	0.18	0.07	0.30

H Registration form for repetitive damage survey

Tabel voor herhalingsopname n.a.v. aardbeving				
Id - Postcode				
Naam				
Adres				
Woonplaats				
Aardbeving	locatie en datum	Vmax		mm/s
Aardbeving	Locatie en datum	Vmax		mm/s
Aardbeving	locatie en datum	Vmax		mm/s
Volgnummer herhalingsopname				
Datum herhalingsopname				
Uitvoerende(n)				
Bewoner of afgevaardige van bewoner aanwezig bij herhalingsopname?				
Ervaring bewoners bij aardbeving				
Heeft de aardbeving volgens de bewoner geresulteerd in een toename van de schade?				
Zijn er sinds vorige opname werkzaamheden in het huis uitgevoerd (verbouwing)?				
Zijn er sinds vorige opname werkzaamheden aan de buitengevel van het huis uitgevoerd?				
Zijn er sinds de vorige opname bijzonderheden in de directe omgeving gebeurd?				
Zijn er verder opmerkingen die van belang geacht worden?				

Tabel voor herhalingsopname n.a.v. aardbeving

Id - Postcode	
Naam	
Adres	
Woonplaats	

Volgnummer herhalingsopname				
Datum herhalingsopname				
Aardbeving	Locatie en datum	Vmax		mm/s
	Locatie en datum	Vmax		mm/s
	Locatie en datum	Vmax		mm/s

Gevel	Scheurnr.	Locatie	Scheurwijdte A=<1mm; B=1-10mm; C=>10mm	Foto scheur	W(ijder) / L(anger) / H(ersteld) / O(nveranderd)	Nieuwe scheurwijdte	Foto scheur
Bestaande scheuren							
Nieuwe scheuren							
Opmerkingen							

I Results repetitive damage survey

ID	previous damage survey			Repetitive damage survey				
	Amount of cracks			Amount of cracks increased		Amount of new cracks		
	Cat.A	Cat.B	Cat.C	In same category	In higher category	Cat.A	Cat.B	Cat.C
[redacted]	16	8	0	0	0	3	0	0
[redacted]	0	0	0	0	0	1	0	0
[redacted]	17	0	0	0	0	11	0	0
[redacted]	5	2	0	0	0	5	0	0
[redacted]	1	0	0	1	0	0	0	0
[redacted]	8	6	0	0	0	2	0	0
[redacted]	8	1	0	0	0	13	1	0
[redacted]	0	2	0	0	0	2	0	0
[redacted]	0	0	0	0	0	2	0	0
[redacted]	16	0	0	0	0	0	0	0
[redacted]	0	0	0	0	0	2	0	0
[redacted]	4	3	0	0	0	3	3	0
[redacted]	0	0	0	0	0	8	0	0
[redacted]	18	0	0	0	0	11	0	0
[redacted]	3	15	0	1	0	15	3	0
[redacted]	7	1	0	0	0	1	0	0
[redacted]	4	7	0	0	0	3	4	0
[redacted]	12	0	0	0	0	0	0	0
[redacted]	3	0	0	0	0	8	0	0
[redacted]	2	7	0	0	0	1	0	0
[redacted]	7	0	0	0	0	7	0	0
[redacted]	4	0	0	0	0	0	0	0
[redacted]	0	0	0	0	0	1	0	0
[redacted]	1	0	0	0	0	4	0	0
[redacted]	0	2	0	0	0	1	0	0
[redacted]	0	0	0	0	0	0	0	0
[redacted]	3	0	0	0	0	5	2	0
[redacted]	13	14	2	0	0	1	0	0
[redacted]	4	8	1	1	0	12	1	0
[redacted]	5	2	0	0	0	1	0	0
[redacted]	0	0	0	0	0	3	0	0
[redacted]	3	0	0	0	0	3	0	0
[redacted]	12	0	0	0	0	2	0	0
[redacted]	16	5	0	0	0	13	4	0

ID	previous damage survey			Repetitive damage survey				
	Amount of cracks			Amount of cracks increased		Amount of new cracks		
	Cat.A	Cat.B	Cat.C	In same category	In higher category	Cat.A	Cat.B	Cat.C
[redacted]	0	0	0	0	0	2	0	0
[redacted]	14	1	0	0	0	0	0	0
[redacted]	4	2	0	0	0	7	0	0
[redacted]	23	2	0	0	0	8	0	0
[redacted]	1	0	0	0	0	1	0	0
[redacted]	12	2	0	0	0	0	0	0
[redacted]	14	0	0	0	0	2	0	0
[redacted]	6	1	0	0	0	0	0	0
[redacted]	9	0	0	0	0	1	0	0
[redacted]	1	0	0	0	0	2	0	0
[redacted]	9	0	0	0	0	1	0	0
[redacted]	7	2	0	0	0	2	0	0
[redacted]	1	23	0	1	0	0	8	0
[redacted]	2	0	0	0	0	1	0	0
[redacted]	6	2	0	0	0	6	0	0
[redacted]	12	1	0	1	1	1	0	0
[redacted]	5	0	0	0	0	0	0	0
[redacted]	21	0	0	0	0	0	0	0
[redacted]	1	0	0	0	0	4	0	0
[redacted]	6	1	0	0	0	0	0	0
[redacted]	4	0	0	0	0	22	0	0
[redacted]	6	1	0	0	0	0	0	0
[redacted]	11	0	0	0	0	2	0	0
[redacted]	2	2	0	0	0	1	0	0
[redacted]	6	13	0	0	0	4	1	0
[redacted]	5	0	0	0	0	1	0	0
[redacted]	13	1	0	0	0	3	0	0
[redacted]	3	0	0	0	0	1	3	0
[redacted]	1	0	0	0	0	2	0	0
[redacted]	1	0	0	0	0	5	0	0
[redacted]	6	0	0	0	0	1	0	0
[redacted]	15	3	1	0	0	13	0	0
[redacted]	4	1	0	0	0	0	0	0
[redacted]	0	0	0	0	0	3	0	0
[redacted]	2	1	0	0	0	1	0	0
[redacted]	0	1	0	0	0	6	0	0

ID	previous damage survey			Repetitive damage survey				
	Amount of cracks			Amount of cracks increased		Amount of new cracks		
	Cat.A	Cat.B	Cat.C	In same category	In higher category	Cat.A	Cat.B	Cat.C
[redacted]	8	0	0	0	0	9	0	0
[redacted]	1	0	0	0	0	1	0	0
[redacted]	20	4	0	1	0	13	5	0
[redacted]	5	0	0	1	0	0	0	0
[redacted]	15	1	0	0	0	4	0	0
[redacted]	2	0	0	0	0	3	0	0
[redacted]	1	3	0	0	0	0	0	0
[redacted]	8	1	1	0	0	4	0	0
[redacted]	0	0	0	0	0	4	0	0
[redacted]	0	0	0	0	0	0	0	0
[redacted]	1	0	0	0	0	5	0	0
[redacted]	6	2	0	0	0	1	0	0
[redacted]	8	6	0	0	0	12	2	0
[redacted]	12	5	0	0	0	4	3	0
[redacted]	23	0	0	0	0	9	0	0
[redacted]	3	1	0	0	0	1	0	0
[redacted]	2	0	0	0	0	0	0	0
[redacted]	9	0	0	1	0	8	0	0
[redacted]	5	0	0	0	1	22	1	0
[redacted]	6	4	0	0	0	8	0	0
[redacted]	2	1	0	0	0	1	0	0
[redacted]	6	1	0	0	0	7	0	0
[redacted]	0	1	0	0	0	1	0	0
[redacted]	1	0	0	0	0	0	0	0
[redacted]	2	0	0	0	0	0	0	0

ID	Remarks
[redacted]	--
[redacted]	--
[redacted]	Five new cracks were already present at previous survey (seen on overview of facades)
[redacted]	--
[redacted]	Increased crack has become longer
[redacted]	--
[redacted]	One new crack was already present at previous survey (seen on overview of facades)

ID	Remarks
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	One new crack was already present at previous survey (seen on overview of facades); one crack has occurred in a repaired crack were at initial survey no crack was seen; all new reported cracks are present in barn
[redacted]	--
[redacted]	Four new cracks were already present at previous survey (seen on overview of facades)
[redacted]	Increased crack has become wider
[redacted]	--
[redacted]	Five new cracks were already present at previous survey (seen on overview of facades)
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	Three new cracks were already present at previous survey (seen on overview of facades)
[redacted]	--
[redacted]	--
[redacted]	New cracks mainly in plaster
[redacted]	--
[redacted]	--
[redacted]	New cracks (cat. B.) partially seen on overview of facades during previous survey, New cracks in façade 4 (2x cat. A.) not seen during previous survey due to vegetation
[redacted]	--
[redacted]	At least one new crack was already present at initial survey (seen on overview of facades); increased crack has become longer
[redacted]	New crack was already present at previous survey
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	Three new cracks (cat. A) and 1 new crack (cat. B). were already present during previous survey
[redacted]	One new crack was already present at previous survey (seen on overview of facades); one crack has occurred in a repaired crack were at initial survey no crack was seen; all new reported cracks are present in barn
[redacted]	--
[redacted]	--
[redacted]	Four new cracks were already present at previous survey (seen on overview of facades)

ID	Remarks
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	One increased crack has become wider
[redacted]	--
[redacted]	--
[redacted]	One increased crack has become longer, one slightly wider (new category)
[redacted]	--
[redacted]	--
[redacted]	Two new cracks were already present at previous survey (seen on overview of facades)
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	Three new cracks were already present at previous survey (seen on overview of facades), one new crack above roof (only visible when using stairs)
[redacted]	--
[redacted]	--
[redacted]	One new crack (B) was already present at previous survey but appears to be wider. One crack (B) not visible during previous survey due to vegetation
[redacted]	One new crack was already present at previous survey (seen on overview of facades); one crack has occurred in a repaired crack were at initial survey no crack was seen; all new reported cracks are present in barn
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--

ID	Remarks
[redacted]	Main part new cracks already present at previous survey. Increased crack has become wider
[redacted]	One increased crack has become slightly longer
[redacted]	One new crack was already present at previous survey (seen on overview of facades)
[redacted]	New cracks apply to joints between two walls
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	--
[redacted]	One new crack only visible from roof terrace, one crack already present at previous survey
[redacted]	--
[redacted]	One crack (B) not visible during previous survey due to vegetation
[redacted]	Two new cracks (B) were already present at previous survey (seen on overview of facades)
[redacted]	Two new cracks not visible during previous survey due to vegetation
[redacted]	--
[redacted]	--
[redacted]	New cracks mainly in plaster, increased crack has become slightly longer
[redacted]	One increased crack has become wider, main part of new cracks were already present at previous survey (seen on overview of facades)
[redacted]	--
[redacted]	--
[redacted]	Three new cracks were already present at previous survey (seen on overview of facades)
[redacted]	New crack applies to joint between two walls
[redacted]	--
[redacted]	--