Preliminary Monitoring Results Fraeylemaborg, Slochteren

İhsan Engin Bal
Eleni Smyrou
Dimitris Dais
Hanze University of Applied Sciences
Research Centre NoorderRuimte

25.01.2019

1. **Scope**

   Fraeylemaborg in Slochteren was subject to some level of structural damage, a fact that was correlated to the recursive induced earthquakes occurring in the region due to the gas extraction activities. There has been a tiltmeter monitoring at the basement of the structure since 2014, and an accelerometer-based structural health monitoring since March 2018. This short memo provides preliminary results of these monitoring activities and tries to correlate the findings to the recent earthquakes and to the damages observed on the structure.

2. **Tiltmeter Monitoring**

   The tiltmeter is at the basement of Fraeylemaborg, placed in 2014. Company StabiAlert is the producer of the sensors and they collect the data in their servers. The existing monitoring scheme is presented in below figure.

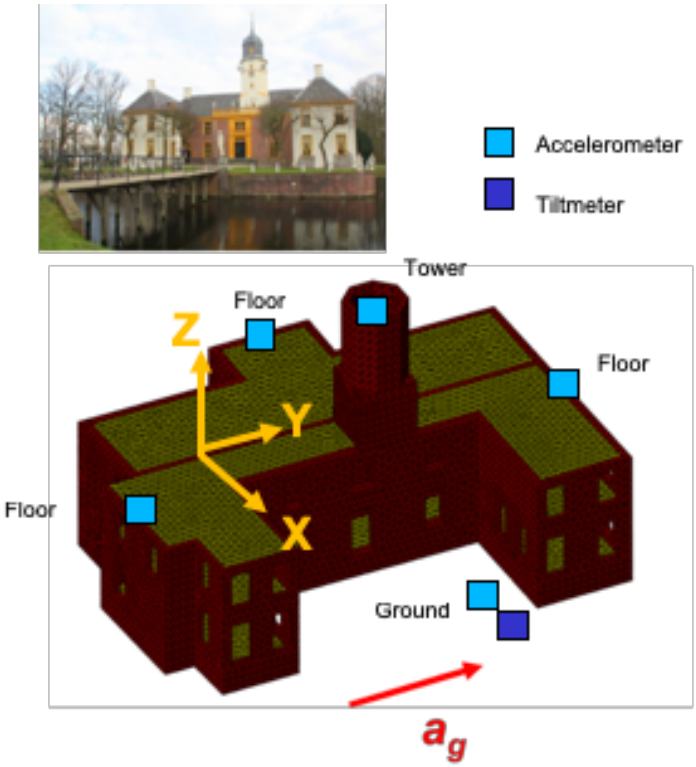

Figure 1. Location of the sensors and the sign convention at Fraeylemaborg

The tiltmeter data have been examined in two ways, as i) high-frequency (HF) data, and ii) low frequency (LF) data. The HF data is recorded in the server only if a certain threshold of vibration is exceeded. This threshold algorithm is defined by StabiAlert.

Since the starting time of the recording, 4 actual earthquakes have been recorded in the tiltmeter at Fraeylemaborg. These are given in the below table.

Table 1. Earthquake events detected by the tiltmeter at Fraeylemaborg since 2015

Event Date	Event Time (UTC)	Event Time (Local)	Magnitude (M_{Ln})	Lat.	Lon.
2016-02-25	22:26:30	23:26:30	2.4	53.184	6.781
2016-09-02	13:16:00	15:16:00	2.1	53.218	6.844
2017-04-26	13:56:49	15:56:49	2.0	53.210	6.713
2017-05-27	15:29:00	17:29:00	2.6	53.211	6.834

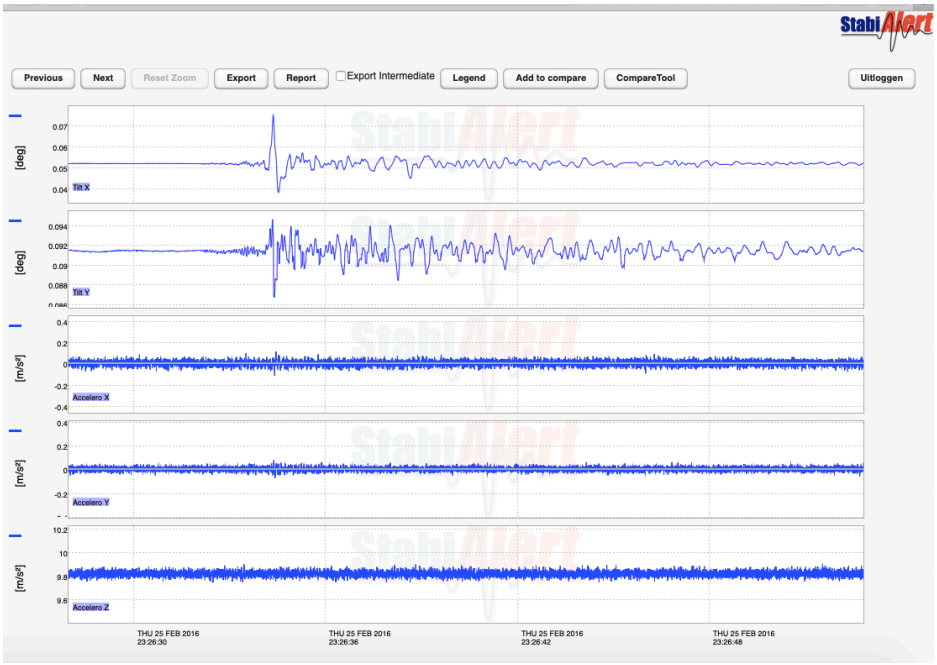

Figure 2. Tilt and acceleration readings from the event on 2016-02-25

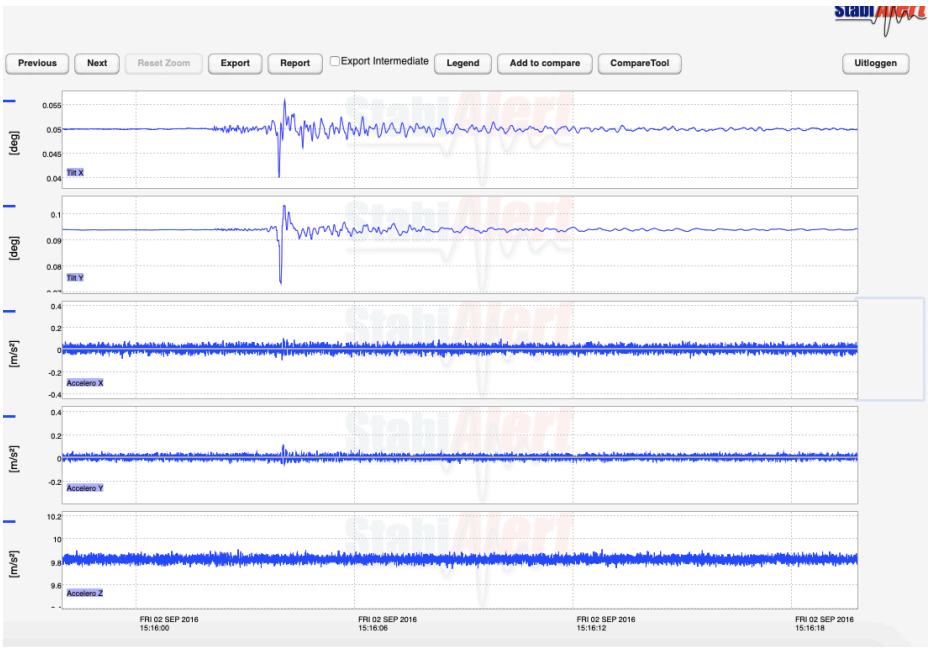

Figure 3. Tilt and acceleration readings from the event on 2016-09-02

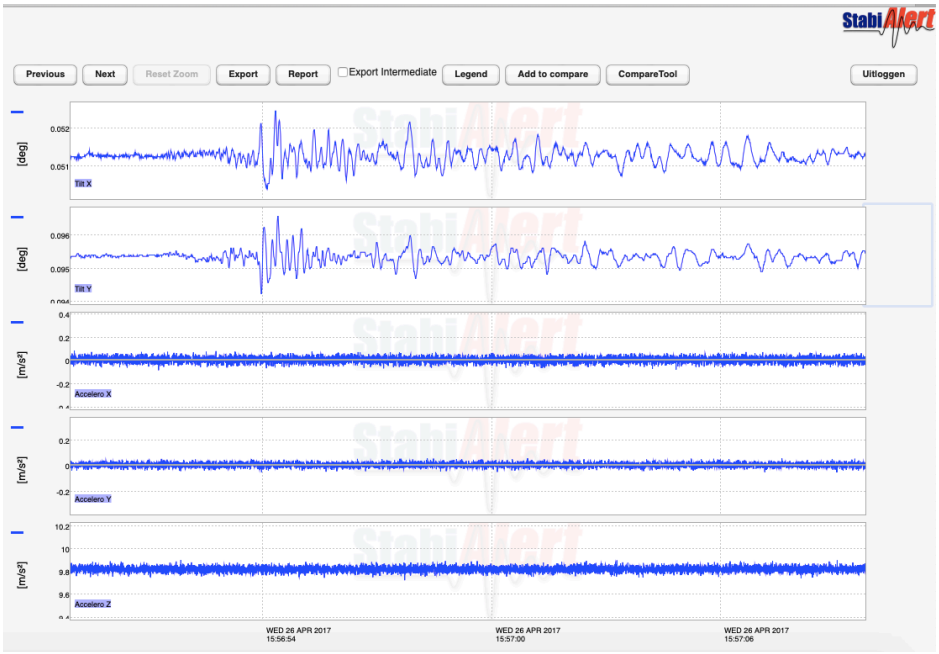

Figure 4. Tilt and acceleration readings from the event on 2017-04-26

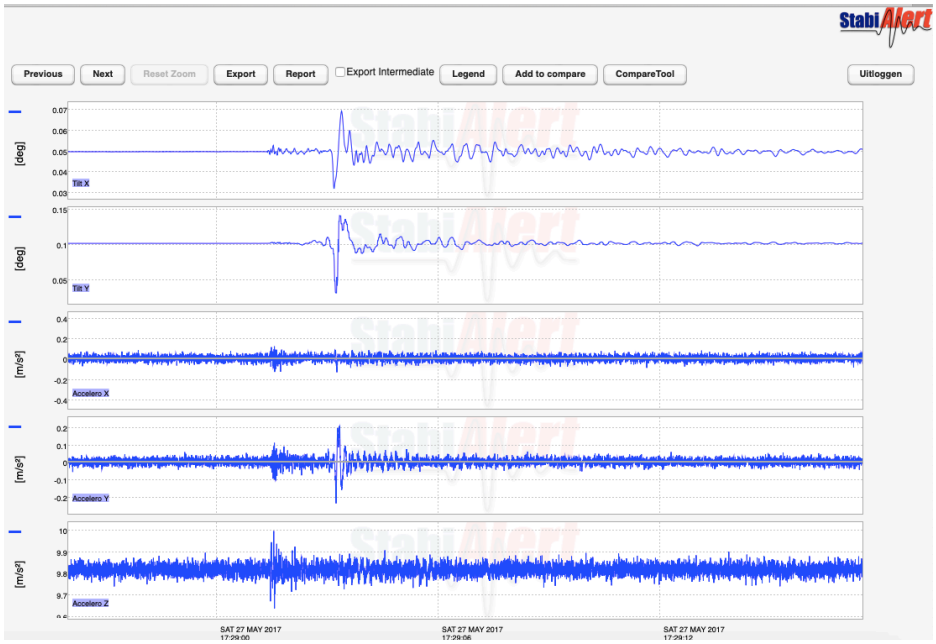

Figure 5. Tilt and acceleration readings from the event on 2017-05-27

It can be seen in Figure 2 to Figure 5 that the tilt values during the earthquake come back to the original rotational position right at the end of the earthquake. In other words, it seems at first glance that the earthquake motion does not leave a significant level of residual deformation or damage. However, further analysis and insights to the data have proven that the correlation of the damage to the tilt values is not a straight-forward issue, as explained below.

A small earthquake of 1.9 magnitude occurred in 8th of August 2018 in Appingedam, 13km far from Fraeylemaborg. Cracks have developed at window-corners after the earthquake. The earthquake was so small that the tiltmeter was not even triggered. The same earthquake was recorded by the accelerometers in the building because they record continuously, without the trigger mechanism. However, this small earthquake was also not visible at the accelerometer next to the tiltmeter at the base. Further filtering and processing the accelerometer data resulted the plots in Figure 6 and Figure 7. The accelerometer data show that the earthquake was received and affected the building during the shaking.

More interesting results can be seen when the tiltmeter data of 15 days before and after the earthquake are analysed. Although the tilt values do not provide insights regarding the damage on the building for such small earthquakes, for the seconds during the shaking, they do provide very valuable information for the hours and days following the earthquake. It can clearly be seen in Figure 8 that the tilt values fluctuate between the daily maxima and minima before the earthquake. There important things happen in the following days after the earthquake, as shown in Figure 8:

1. The average tilt position starts increasing, meaning that the monitored location of the structure starts leaning.
2. Leaning keeps increasing for the 5 days following the earthquake, very slowly, stabilizing at the end and creating a new average position. This new average position has higher tilt values than the average before the earthquake, meaning that some residual deformation and damage occurred in the meanwhile.
3. The difference between maxima and the minima in the daily changes decreases (smaller fluctations), a fact that can be explained by high stresses developing in the soil and in the structural elements.

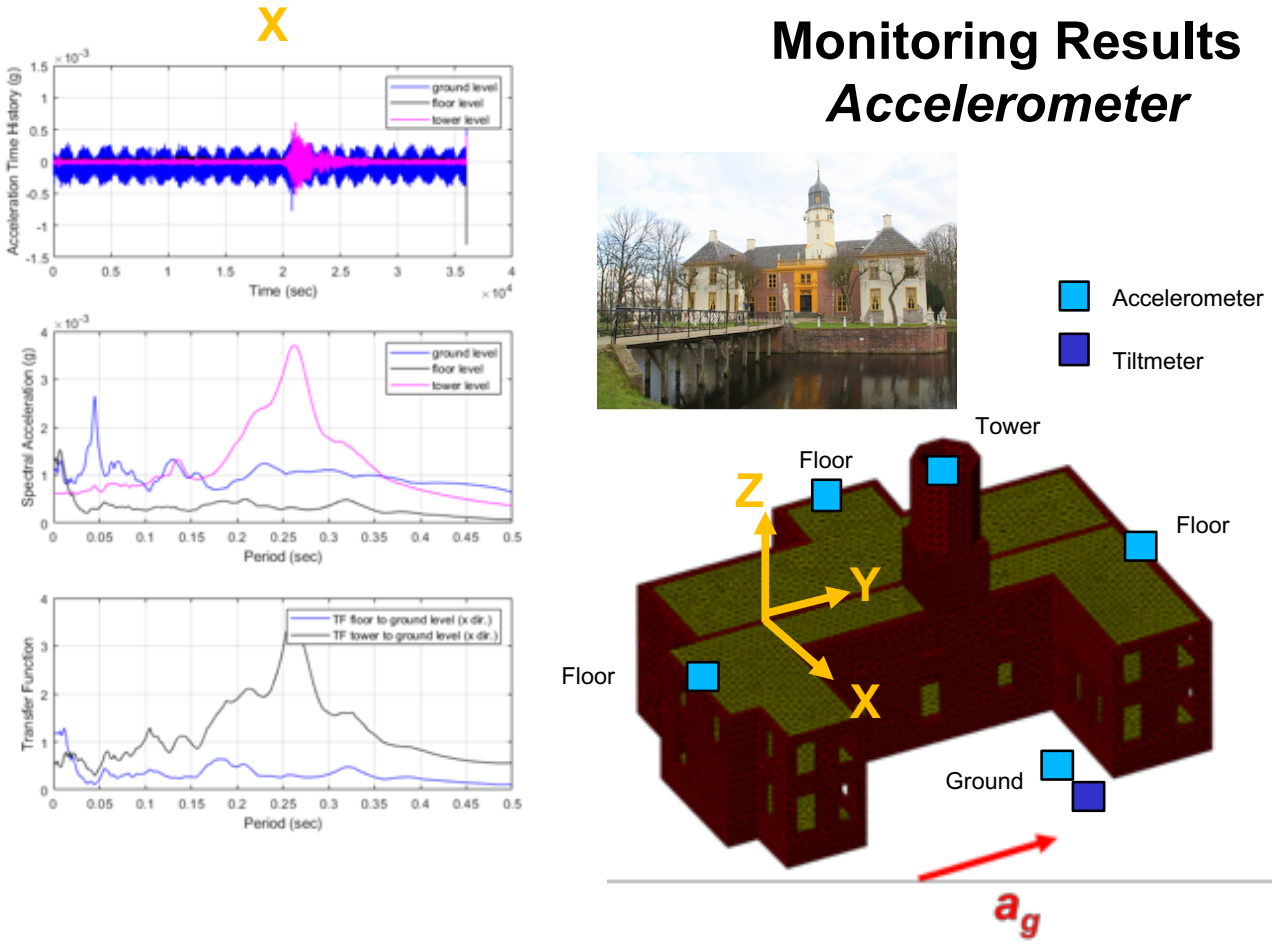

Figure 6. Accelerometer recordings, response spectra and transfer functions in X direction from 08-08-2018 Appingedam Earthquake (MLn1.9)

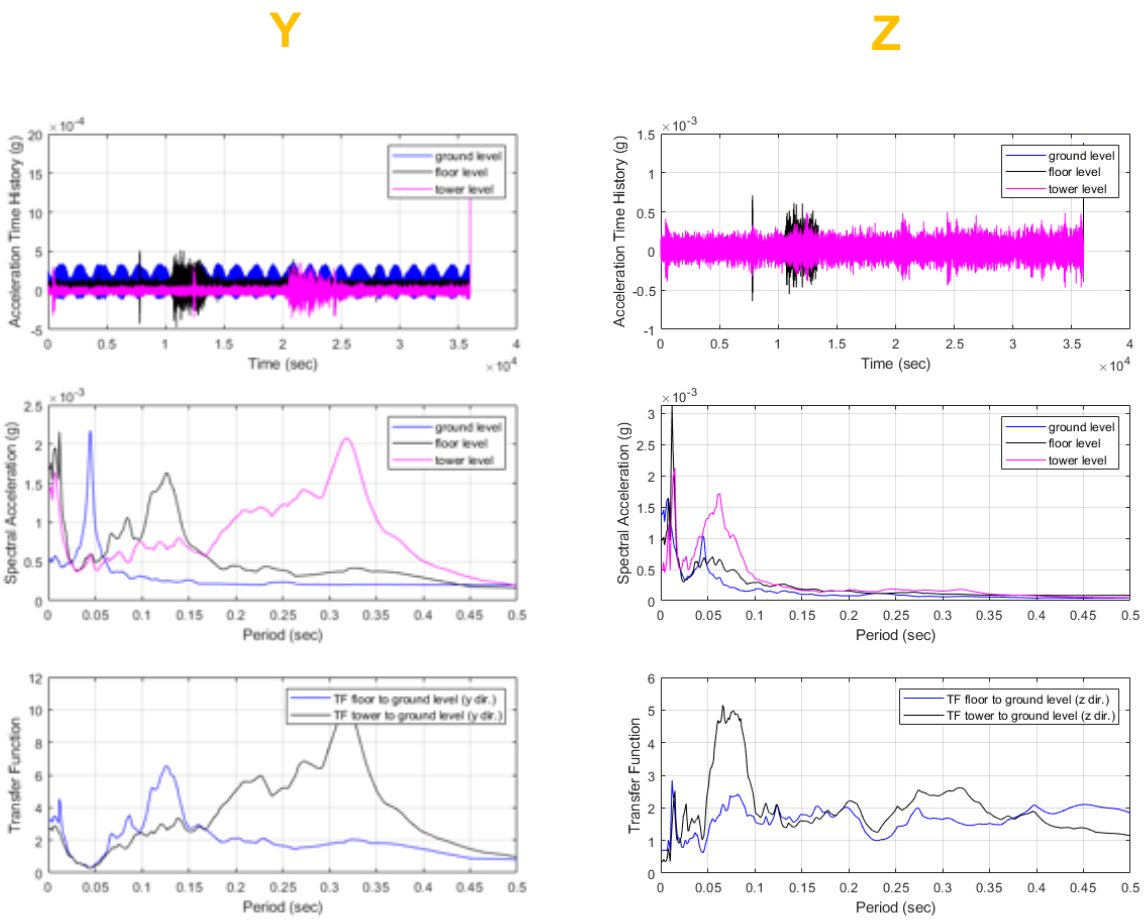

Figure 7. Accelerometer recordings, response spectra and transfer functions in Y and Z direction s from 08-08-2018 Appingedam Earthquake (M_{Ln}1.9)

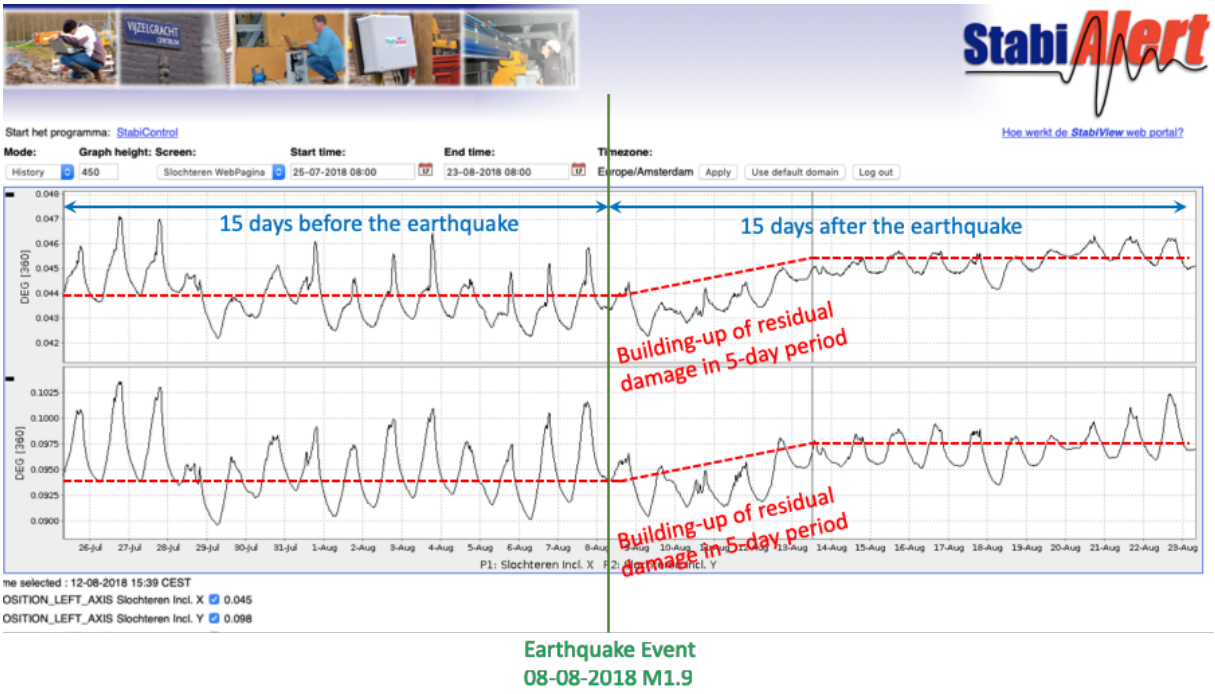

Figure 8. Tiltmeter data from the base of Fraeylemaborg, 15 days before and after the 08-08-2018 Appingedam Earthquake

3. Summary of Conclusions

Conclusion from the monitoring activities so far are summarized below:

- Even small and distant earthquakes affect the structure

- The effect of the small and distant earthquakes do not manifest themselves immediately, but a damage procedure takes place in approximately 5 days following the earthquake

- Soil and the structure run into higher stress values the days following the earthquake, limiting the daily fluctuations of movements and eventually resulting residual damage