Monitoring, assessment and diagnosis of Fraeylemaborg in Groningen, Netherlands

Dimitris Dais[1,2], Eleni Smyrou[3], Ihsan Engin Bal[4], and Jelle Pama[5]

Abstract. Fraeylemaborg is a noble house in an earthquake-striken area of the Netherlands due to the induced seismicity events in the region. The structure is located in the middle of the town of Slochteren which gave its name to the largest gas field in the world upon its discovery in 1959. The gas extraction has caused small-magnitude shallow earthquakes during the last decade, damaging not only the residential inventory but also the historical structures in the area. The main building of Fraeylemaborg sits on an artificial island surrounded by water channels, rendering the problem of earthquake response even more complicated. A small part of the main structure on the island was built in the 14th century, while the construction of additional parts and morphological alterations had taken place until the 18th century. The structure has been subjected to several small magnitude earthquakes causing damages on the load bearing system. An extensive renovation and repair of damages took place in recent years, however the latest seismic events imposed again damage to the structure. This paper presents a project of monitoring, assessment and diagnosis of problems for the Fraeylemaborg, the most important "borg" of the region, underlining the particularities of the induced seismicity problem. The FE model has been calibrated by using ambient vibration tests. Combination of earthquake and soil settlement loads have been applied on the calibrated model. The paper develops scenarios that help in explaining the reasons behind the damages on this structure during the recent shallow and low-magnitude induced seismicity earthquakes.

Keywords: seismic response, induced seismicity, structural monitoring, ambient vibration tests

1 Introduction

Groningen is the largest gas field in Europe and 10th in the world. Due to the extensive gas extraction induced earthquakes of relatively "larger" magnitude have been recorded in the very last decade. The building stock in the region comprises single- and two-storey unreinforced masonry (URM) houses constructed with no seismic considerations.

Figure 1. Fraeylemaborg

[1,2] PhD candidate at Newcastle Univ., UK, and researcher at Hanze Univ. of Applied Sciences Groningen, Netherlands, d.dais@pl.hanze.nl
[3] Associate Professor, Hanze University of Applied Sciences Groningen, Netherlands, e.smyrou@pl.hanze.nl
[4] Professor, Hanze University of Applied Sciences Groningen, Netherlands, i.e.bal@pl.hanze.nl
[5] University Lecturer Structural Design, Hanze University of Applied Sciences Groningen, Netherlands, j.pama@pl.hanze.nl

open bended shape of the vertical rod of the wall anchors (Fig. 2d) evidence movement of the retaining wall followed by the soil beneath and resulting in differential displacements and settlement of the structure. These observations led to the hypothesis that soil movements initiated by earthquake events, not the seismic loading itself, inflicted damage, correlating thus the damage patterns with the deformability of the foundation [3].

Table 1. The main events recorded in the Groningen region after the Huizinge event (2012).

Place	Date	Lat [°]	Lon [°]	Depth [km]	M	PGA [cm/s^2]
Huizinge	16-08-2012	53.345	6.671	3	3.6 (M_L)	85
Zeerijp	08-01-2018	53.363	6.751	3	3.4 (M_L)	114
't Zandt	13-02-2014	53.357	6.782	3	3.0 (M_L)	71
Zandeweer	05-11-2014	53.374	6.678	3	2.9 (M_L)	82
Slochteren	27-05-2017	53.211	6.834	3	2.6 (M_L)	34

For validating the aforementioned hypothesis, a detailed 3-D numerical model (Fig. 3) was constructed utilizing the Finite Element software Abaqus [4]. Solid 10-node quadratic tetrahedron elements (C3D10) were used. The structural elements, i.e. the clay brick walls and wooden floors, were modeled as solid homogenous members with isotropic elastic properties.

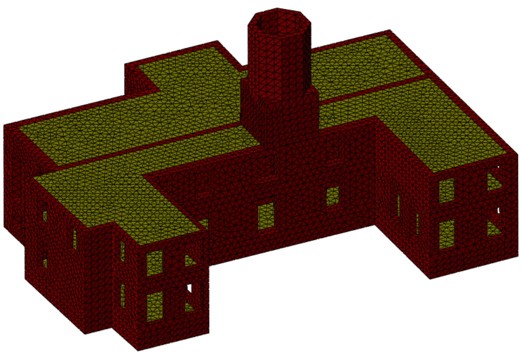

Figure 3. The 3-D numerical model in Abaqus (the clay brick walls in maroon color, wooden floor in green).

Figure 4. Locations of the accelerometer sensors during ambient vibration measurements. The blue arrows indicate the direction the sensors recorded.

A rather simple experimental study was carried out to obtain some rough material properties of the existing structure: Six bricks retrieved during the previous restoration works were subjected to compression tests. Their