Terraced House – Practical application of NZSEE principles in the Netherlands

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ABSTRACT: The Groningen onshore gas field, which is the largest in Europe, is situated in the north of the Netherlands and has been operational since the 1960s. As gas has been extracted from the field, the pressure has decreased, which has resulted in induced earthquakes that are felt at the surface due to their relatively shallow depth. Because the Groningen region has not historically been seismically active, buildings in the region have not been designed to resist earthquake loading and are particularly vulnerable given their age, materials and construction method.

The building stock in the Groningen region is now being assessed by NAM, who own the licence to extract the gas. The scope of this task is huge. There are close to 150,000 buildings located above the reservoir, which may all require structural assessment and, where required, strengthening to levels prescribed in Dutch guidelines. Currently, the focus of the structural assessment is on 25,000 addresses located above the centre of the reservoir.

The approach to date of Dutch consultants engaged to assess existing buildings has been either to undertake complex NLTHAs of the buildings, which are expensive, time-consuming and require a high level of engineering competence, or to use elastic methods that result in substantial structural upgrading measures. BICL(NL) identified areas where the assessment process could be improved. These primarily focussed around simplifying how surface demands are prescribed and how building capacity is assessed.

This paper describes the application of the newly-revised NZSEE guidelines to the assessment of a terraced house typical of Dutch construction, and discusses more broadly the concepts underlying a New Zealand approach to addressing this complex issue.

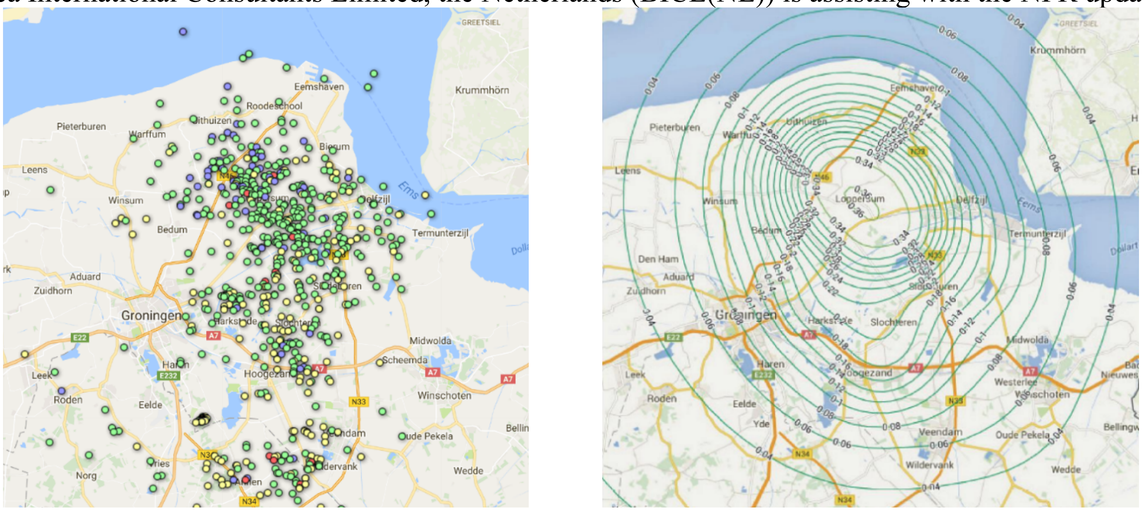
1 CONTEXT

The Groningen onshore gas field was discovered in 1959 and production began in 1963. The gas field, which is located in the north of the Netherlands, is the largest in Europe and one of the largest in the world. Figure 1 presents the location of the Groningen gas field within the Netherlands, and its relative size compared to other petrochemical fields. Nederlandse Aardolie Maatschappij BV (NAM), a joint venture between Royal Dutch Shell and ExxonMobil, owns the licence to extract the gas.

Figure 1: Location and relative size of the Groningen gas field (Stratfor, 2014).

The recoverable volume of gas was approximately 2,800 billion cubic metres, 60% of which has since been extracted. The original reservoir pressure was 350 bar; as gas has been extracted the pressure has reduced, which has resulted in earthquakes as the underlying rock formations consolidate. Over the past three decades, as reservoir extraction has continued, these induced earthquakes have increased in frequency and magnitude. Figure 2 (a) presents the location of historic earthquakes in the Groningen region.

The induced earthquakes are felt strongly at the surface due to both their relatively shallow depth and the soft soil overlying the reservoir. Furthermore, because the Netherlands is not susceptible to tectonic earthquakes, seismic design provisions have not historically been required for structures and as a result, the building stock in the Groningen region is typically of unreinforced masonry (URM) construction and therefore particularly vulnerable to earthquake loading. The Netherlands has no National Annex to Eurocode 8 (CEN, 2004) as it was believed that tailoring Eurocode 8 to the Dutch situation, where a distinction may need to be made between tectonic and induced earthquakes, would require a thorough study (NEN, 2015). Instead, the 'Dutch Practical Guideline' (NPR9998) has been prepared and published to provide timely guidance to stakeholders involved in the construction of new buildings, as well as the assessment of existing structures (NEN, 2015). Figure 2 (b) presents the seismic hazard map from NPR9998:2015 for the Groningen region. The NPR has a number of inconsistencies and omissions when compared to modern seismic design standards from developed countries, which can complicate the assessment procedure. The NPR is currently being revised for publication mid-2017 to address a number of these inconsistencies and to improve the technical content based on increased knowledge. Beca International Consultants Limited, the Netherlands (BICL(NL)) is assisting with the NPR update.



(a) Historic earthquakes (KNMI, 2017). **(b) Seismic hazard map (NEN, 2015).**

Figure 2: Seismicity in the Groningen region.

NAM is undertaking an assessment of the building stock in the Groningen region against induced earthquakes. There are approximately 150,000 buildings in the region, with approximately 25,000 addresses located within the 0.2g contour presented in Figure 2 (b). The buildings are being assessed to the NPR; where buildings are found to be deficient, structural upgrading measures are to be implemented. The scale of the task is huge.

The previous assessment methodology was primarily based around nonlinear time history analyses (NLTHA) of representative building typologies using finite element models of the building superstructure, foundation and soil substructure up to 30m deep. Experienced engineers are required to undertake NLTHA; the process is also labour intensive and the output accuracy is sensitive to modelling assumptions and input accuracy. For these reasons, the methodology was not achieving the target number of assessments (5,000 per year).

BICL(NL) identified areas where the assessment process could be improved. The assessment procedures are general; however, in the context of this paper they are presented as applied to a typical Dutch terraced house.

2 TERRACED HOUSE

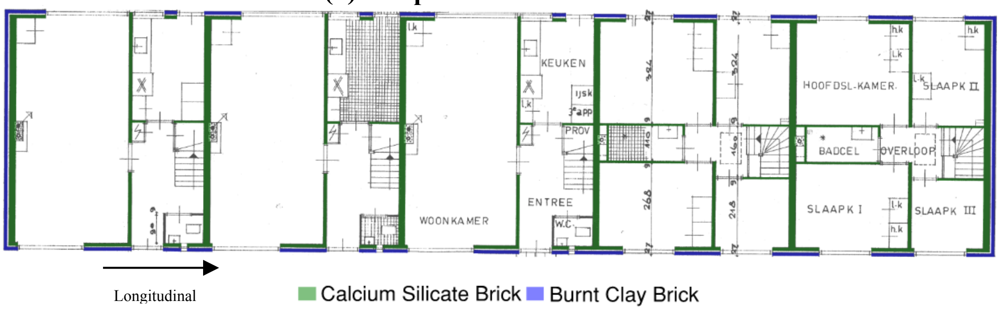
The ‘Type K’ building is a terraced house designed in 1967 by Martini Architecten. The building containing five units (house addresses) was specifically examined in this investigation; however, other versions exist with fewer units. The Martini Type K (MTK) building is typical of Dutch construction. The dwelling is located in the town of Loppersum, which has the highest seismic hazard in the region, as shown in Figure 2 (b).

As shown in Figure 3, the MTK is a two-storey URM building. It is rectangular in plan; each unit is approximately 7.7 m by 6.3 m and includes a one-storey storage unit constructed adjacent to the rear façade.

The exterior walls are of cavity brick construction. The interior brick leaves provide the gravity and lateral support to the structure. This inner leaf is constructed from calcium silicate bricks that are approximately 90 mm thick. The exterior leaf is primarily for weather-tightness and aesthetics. This leaf is constructed from burnt clay bricks that are approximately 100 mm thick. Interior partition walls are constructed from a single leaf of calcium silicate bricks. The foundation system is comprised of shallow reinforced concrete strip footings beneath the walls, and discrete masonry piers supporting the timber floor at Ground Level. The attic and Level 1 floors are in-situ 100 mm thick reinforced concrete two-way slabs. The ground floor is constructed from timber flooring supported by timber joists and bearers.

(a) Architectural elevation of front façade.

(b) Perspective of front facade.



(c) Plan showing lateral load resisting system.

Figure 3: Martini Type K dwelling.

A detailed building inspection was not undertaken specifically for this assessment; however, the building details were derived from available drawings and an inspection report by others.

3 ASSESSMENT

A Detailed Seismic Assessment (DSA) was undertaken on the MTK dwelling using a 'New Zealand approach', following the methodology presented in 'The Seismic Assessment of Existing Buildings' (NZSEE, 2016). This document has been developed over the last 40 years, culminating in the 2016 version of the 'NZSEE' guidelines. The document is the product of world-leading seismic assessment research and practice in New Zealand and abroad, the vast experience gained during the Christchurch earthquakes, and during reconnaissance missions to major earthquakes around the world. As such, it is well suited to application to the Dutch situation.

The approach described in the NZSEE guidelines contrasts starkly with the NLTHA approach, in that it promotes understanding of structural load paths and nonlinear building behaviour in *sufficient* detail to allow quantification of seismic capacity. Another defining characteristic of the NZSEE guidelines is the separation of the demand from the capacity, which, given the seismic hazard in the region is being revised, simplifies the future re-assessment of building vulnerability. The guidelines promote the use of nonlinear assessment procedures with simple analysis techniques, these provide a balance between the uncertainties on the input parameters and the inherent uncertainties in these simpler forms of analysis. To this end, the guidelines recommend the use of, at least initially, a Simplified Lateral Mechanism Analysis (SLaMA). A SLaMA is a simplified technique for determining the probable inelastic deformation mechanisms and their lateral strength and displacement capacity by examining the load paths, the hierarchy of strength, the available displacement capacity and the manner in which mechanisms might work together.

The SLaMA process, as applied to the MTK building, is presented schematically in Figure 4. The first stage was to identify load paths and potential critical structural weaknesses (CSWs), such as diaphragm to wall connections, parapets, gables and/or chimneys and irregularities in plan or elevation. Symmetry within the system was identified next; geometry is repeated between the units, so the problem could be simplified. The URM walls were then subdivided further into either pier, spandrel or rigid elements; this process is often termed an 'equivalent frame analysis'. Once a load takedown was performed, Section C8 of the NZSEE guidelines was applied to determine the respective strength and failure mode of the piers and spandrels. A sway index could then be computed to determine the hierarchy of strength in the system, and therefore the likely failure mode. Once the failure mode is identified, the nonlinear behaviour of the critical elements is computed individually, then combined and converted to an equivalent single degree of freedom system. The building capacity can then be compared to the demand spectra in acceleration-displacement space. The secant stiffness can be used to represent an equivalent system, such that a capacity to demand ratio can be computed.

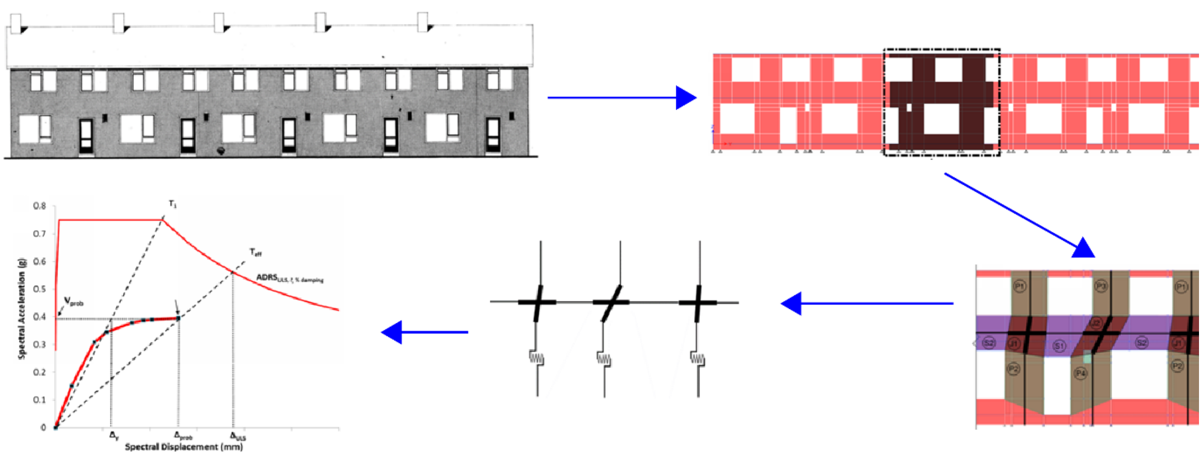


Figure 4: Schematic of SLaMA process for Martini Type K building.

One of the key vulnerabilities of URM buildings is out-of-plane (OOP) failure of the walls. The NZSEE guidelines promote the use of the Nonlinear Kinematic Analysis (NLKA) method for assessing the OOP capacity of URM walls. The NLKA method is based on the principle of virtual work; therefore, the probable failure mechanism of the wall must be known to determine a solution. The probable failure

mechanism – or crack pattern – is related to the support conditions and geometry. The NLKA method is a displacement-based assessment method, which is able to account for the non-linear behaviour of masonry walls as they displace OOP when subjected to inertial face-loads resulting from earthquake acceleration.

One way to undertake a NLKA is to generate a number of charts relating slenderness ratios, overburden ratios and boundary conditions to a Basic Performance Ratio (BPR). This is the approach presented in Appendix C8C of the NZSEE guidelines. The BPR is the seismic coefficient at which the displacement capacity of the wall equals the acceptance criteria, it must be divided by factors relating to the seismic hazard, spectral shape, magnification, etc. However, when generating these charts for a specific building, such as was the case for MTK, these factors are known and can be included such that the 'BPR' is instead peak ground acceleration (PGA). The charts can then be used to rapidly assess, and present, the performance of many walls of similar typology within a building.

4 RESULTS

The most important outcome of the assessment is an understanding of the overall building behaviour, in terms of the likely progressive failure mechanism. The relative vulnerability is more important than the absolute loading at which they occur, because it is the means by which structural intervention can be targeted to improve overall building performance. The progressive failure mechanisms of the MTK building are presented in Figure 5. As is typical of URM buildings of this typology, the MTK is vulnerable to OOP failure of the gable end and level one partition and perimeter walls.

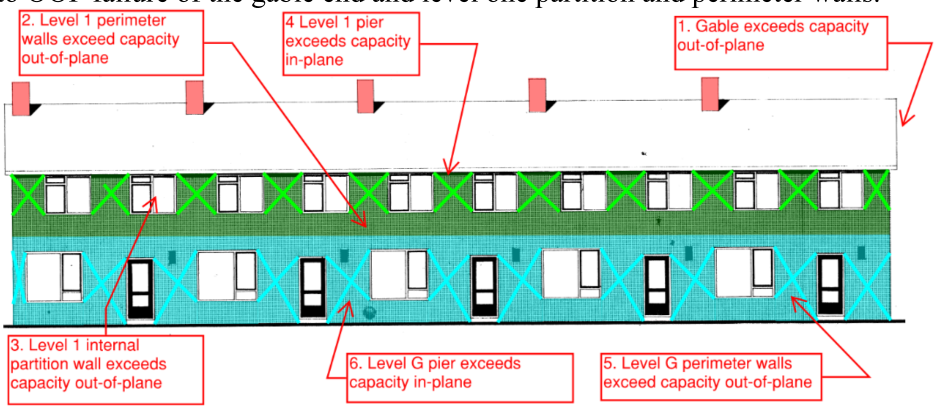
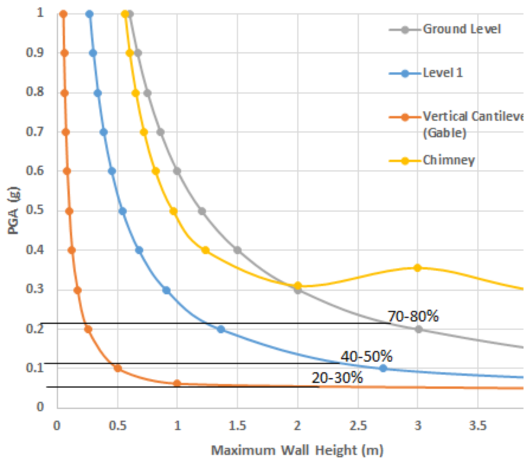


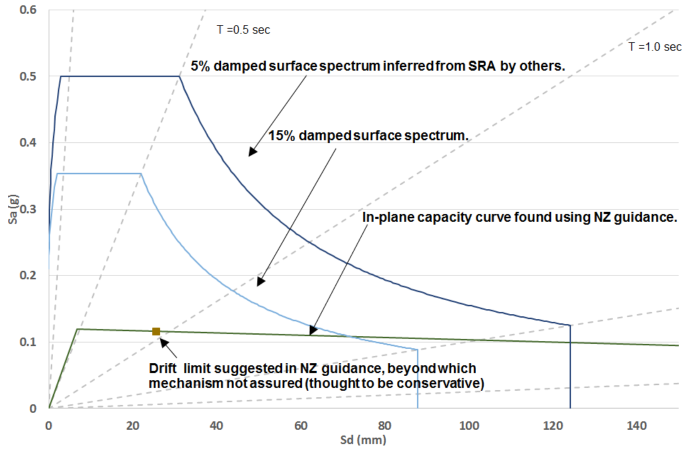
Figure 5: Progressive failure mechanisms in the MTK building during an earthquake.

Figure 6 (a) presents the OOP capacity of the URM walls of the MTK building; all walls in the building were able to be assigned to four general categories. Because of the magnification of acceleration that occurs with height within a structure, the gable end walls were particularly vulnerable, followed by the level one perimeter walls. The chimneys are relatively squat and were found to have sufficient capacity.

Once the OOP deficiencies are addressed, the primary in-plane failure mechanism is the level 1 piers, which fail by way of rocking. Pier rocking is a relatively stable failure mode, which allows the building to displace whilst maintaining vertical and horizontal load carrying capacity. The capacity of the building is presented in Figure 6 (b) against the design acceleration-displacement response spectrum (ADRS). The design response spectrum prescribed by NPR9998 (NEN, 2015) when using the 'general' provisions (not a site specific analysis) is onerous; furthermore, the spectral shape is not compatible with displacement-based methods in that is it missing the constant-velocity portion. Hence, a design response spectra was inferred from a site response analysis (SRA) undertaken by others to the 'alternative' provisions, which allow a reduction in demand. The Eurocode 8 spectral shape was used (CEN, 2004).



(a) Out-of-plane.



(b) In-plane.

Figure 6: Assessed capacity of the Martini Type K building,

Rocking URM piers are capable of sustaining large horizontal displacements before becoming unstable; however, as the instability limit is approached the uncertainty on the capacity increases. Hence, the NZSEE guidelines suggest a displacement limit, beyond which the rocking mechanism cannot be assured. This displacement limit is presented in Figure 6 (b) and represents the Ultimate Limit State (ULS); however, NPR 9998 requires the performance to be assessed at the Near Collapse (NC) limit state to comply with an individual risk level of $1x10^{-5}$. Hence, a greater displacement, which is known with decreased certainty, is acceptable. Acceptance criteria for the NC limit state, for use in the Netherlands, is being prepared currently for the NPR update.

The conceptual structural upgrading measures were designed to be pragmatic and minimally invasive to reduce the impact on building occupants and expedite the works. It was proposed to improve the seismic performance of the MTK building in two ways, with direct strengthening, which increases capacity, and indirect strengthening to decrease demand. The proposed structural upgrading measures are typical of those implemented in New Zealand. The direct strengthening aims to introduce a diaphragm at roof level, the URM walls are then positively connected to this, and the other existing reinforced concrete diaphragms at the other levels. In doing so, the building is tied together to promote 'box-like' behaviour, whilst introducing more favourable boundary conditions to increase URM wall OOP capacity. The indirect strengthening removes the chimneys (which are unused) to reduce the seismic mass and eliminate the fall hazard. It is also recommended that the heavy clay tiles on the roof be replaced with a light-weight alternative.

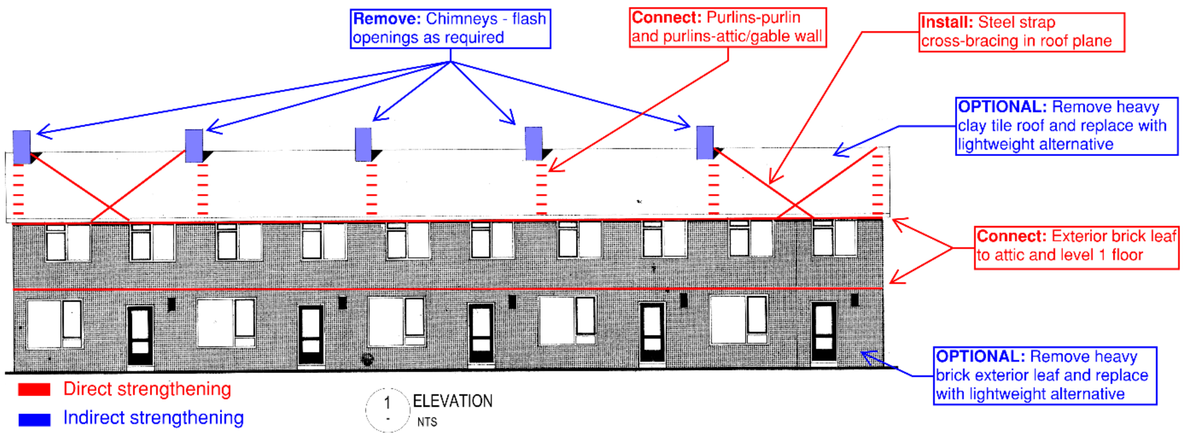


Figure 7: Conceptual structural upgrading scheme.

5 SUMMARY

This paper presented an introduction to induced seismicity in the Groningen region of the Netherlands. The application of a practical 'New Zealand approach', using NZSEE guidelines, to the seismic assessment of a typical URM terraced house was presented. This approach is pragmatic, efficient and able to be undertaken by suitably qualified engineers; it is ideally suited to the rapid seismic assessment of a large building stock.

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