Client: Nederlandse Aardolie Maatschappij

Arup Project Title: Groningen 2013

Structural Upgrading Strategy

REP/229746/ST001

Issue | 29 November 2013

Job number 229746
External ref EP201311204034

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Introduction

This report provides a summary of the structural upgrading strategy for existing buildings in the Groningen area. This report is one of the required studies outlined in the letter of Minister Kamp to the Dutch Parliament of 11 February 2013. This report is issued - as requested by NAM - as input for the Winningsplan, which is to be submitted on 1st December 2013 by NAM.

An undesirable effect of gas extraction is induced earthquakes, causing damage to buildings. As these induced earthquakes are increasing in number and size, the possible risk to life safety is a growing concern. NAM commissioned Arup to develop a structural upgrading strategy, underpinned by extensive studies. The objective of this strategy is to reduce risk to life safety by implementing structural upgrading measures to buildings.

The Netherlands has a history in managing risks such as flooding. Over the past centuries, the Dutch have developed strategies to cope with such risks, many of which have found their way into (building) legislation. However, the possible risk to life safety caused by induced earthquakes is new to the Dutch. Unlike in other EU-countries, the Netherlands has limited experience with seismic hazard and associated risk to life safety and no legislation enforcing seismic design requirements has been put in place to cope with this risk. Consequently, the buildings in the Groningen area are not specifically designed to resist earthquakes.

Seismic risk to life safety is a function of the seismic hazard, the exposure to the hazard, and the vulnerability of buildings in the region to seismic ground motion. Structural upgrading measures are proposed to reduce the vulnerability of the buildings to seismic ground motion. The proposed structural upgrading measures have different levels of complexity depending on the expected amplitude of the seismic ground motion and the particular building structure. The measures therefore range from mitigating unstable chimneys to structurally strengthening entire walls and building foundations. In case structural upgrading is practically or economically unfeasible, demolition may be the ultimate measure.

Over the last year much research and many investigations have been undertaken to better understand the seismic risk in the region. These studies have identified important influencing variables for the seismic hazard and building vulnerability. For these variables limited information is available at this stage and the influences of some of these variables are still not fully understood. Consequently, the prediction of seismic hazard, building vulnerability and the overall seismic risk are done under high uncertainties. Because of these uncertainties it is too early to roll out a definitive upgrading program and a phased approach is proposed.

Seismic Risk

A first indication of the risk to life safety can be gained from the earthquake scenario-based risk assessment study which has been undertaken for the Groningen region. This risk assessment provides an estimate of the potential building damage and casualties that could occur in earthquake scenario events with magnitudes between M_w=3.6 and M_w=5, which potentially could occur in the region in the future.

An earthquake scenario of $M_w \geq 5$ is estimated to have a probability of occurring of less than 10% in the next 10 years[1]. The smaller magnitude earthquakes have higher probabilities of occurring in the Groningen area.

A M_w=5 earthquake scenario event is currently estimated to cause between 5 (50th percentile) and 100 (84th percentile) fatalities. The mean estimate of the number of fatalities is between these two values.

The Seismic Risk study also considered a potential M_w=3.6 earthquake scenario event, the same magnitude as the August 2012 Huizinge event. The 50th and 84th percentile fatality estimates for M_w=3.6 were 0 and 1, respectively, and the estimated total number of injuries were 0, and less than 25, respectively. It can be seen that the numbers of injuries estimated using the 84th percentile PGA values appear to be high, compared with no reported injuries in the Huizinge earthquake. Similarly, damage estimates for the 84th percentile give significantly higher numbers of extensively damaged and collapsed buildings than were actually observed in the Huizinge earthquake (in which there were no extensively damaged or collapsed buildings). The 84th percentile results overestimate what was observed in the case of one earthquake, which puts into context the 84th percentile fatality estimates for the M_w=5 earthquake scenario, reported above. On the other hand, the possibility of such levels of fatalities cannot be discounted in case a M_w=5 would occur in the future.

Upgrading Strategy

Arup developed an upgrading strategy that meets the following criteria:

1. The ability to cope with the current uncertainties by (a) gathering relevant data to reduce uncertainties and (b) adopting a flexible approach to adjust to new developments.
2. A realistic contribution to lowering risk to life safety as quickly as possible by using the proposed strategy as further explained below.

The most important elements of the proposed strategy are:

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[1] NAM indicates: *"The 'Report to the Technical Guidance Committee (TBO) on Production Measures; Part 1: Depletion Scenarios and Hazard Analysis' reports that although considerable progress was made in the understanding of the seismic hazard, significant uncertainty remains at present. The predictions of the seismic hazard range are believed to be conservative and NAM has initiated a further data acquisition program to obtain additional field data, and a studies program to reduce the uncertainty. A* $M_w \geq 5$ *earthquake scenario in this report is estimated to have a probability of occurring of less than 10% in the next 10 years.*

Further data gathering and further studies in the next years will be executed in order to reduce the uncertainty range and may well in the future further reduce the hazard. For example, it is expected that geomechanical studies, explicitly modelling faults, can demonstrate a physical upper bound to the maximum magnitude."

1. ***A stepped implementation*** starting with (1) strengthening or removing higher risk building elements (falling hazard), (2) improving the integrity of buildings and (3) improving strength and/or ductility of buildings. By implementing the upgrading interventions in steps a balance is sought between the cumulative risk reduction, the impact of the interventions on the buildings and environment, the speed of implementation and the capacity of resources needed for implementation.
2. ***Prioritisation based on minimising risk to life safety.*** Not all buildings can be screened and addressed at the same time. It is therefore proposed to start with the buildings that are likely to cause most casualties in case of a heavy earthquake, using the following considerations:
    a. Seismic hazard: priority is given to areas of highest seismic hazard working from the central area of the gas field where the seismic hazard is highest to the outside where the seismic hazard is lowest.
    b. Building vulnerability: rapid visual screenings/assessments are being undertaken to assess the vulnerability of all buildings with assessments starting in the highest seismic hazard areas. The relative vulnerability of buildings is then used to set priorities for further assessment and implementation of structural upgrading measures. Rapid visual assessments are also used to identify and prioritise buildings with elements that pose immediate life safety risk.
    c. Building exposure: building importance class defined in accordance with current Eurocodes is also used to prioritise work on higher importance buildings (e.g. hospitals, first responder buildings, schools, elderly homes) by addressing these via a separate work stream.
3. ***Constant monitoring and continuing research and investigations*** to reduce uncertainties in the level of seismic hazard in the region, improve the understanding of the vulnerability of the buildings in the region, further develop structural upgrading measures and help to define an acceptable level of seismic risk to life safety. The results of the research and investigations are expected to contribute to the development of the NPR (Nationale Praktijk Richtlijn).
4. ***Starting with pilot projects (pilot 1 and 2)***, having two benefits:
    a. An increase in the research pace needed to reduce uncertainties quickly and to prevent future disruptions in execution.
    b. An immediate positive/mitigating effect on the risk to life safety for the people participating in the pilot.

The proposed structural upgrading strategy is subject to progressive insights and will be updated periodically. It forms the basis for current thinking and discussions and is aimed to form a framework for work that has already commenced and for the large scale implementation of the structural upgrading strategy and management of the risk from induced seismicity in the Groningen region.

Implementation

In addition to an extended research program it is proposed to NAM to continue with the pilot projects (Pilot 1 and 2), which consist of:

1. Screening 1700 buildings in Pilot 2 on vulnerability and exposure;
2. Implementing temporary measures for those buildings identified during surveys in Pilot 2, needing urgent actions due to severely impaired integrity;
3. Consider implementing temporary measures for those buildings identified during surveys in Pilot 2, based on their typology;
4. Implementing step 1 measures for those building elements identified during surveys in Pilot 2;
5. Implementing step 2 measures for at least 5 houses before the end of 2014 (Pilot 1) and investigating the effect of these measures on building vulnerability;
6. Implementing step 1 and 2 measures for all buildings in Pilot 2 before the end of 2016 (scope of Pilot 2 depends on progressive insights, results of inspections, and findings from Pilot 1); and
7. A regular evaluation of the pilot projects (Pilot 1 and 2) before the roll-out of the complete program after 2016.

1 Introduction

This report provides a summary of the proposed structural upgrading strategy for existing buildings in the Groningen region. It is one of the studies for building damage reduction as outlined in the letter of Minister Kamp to the Dutch Parliament of 11 February 2013.

Arup has been appointed by Nederlandse Aardolie Maatschappij B.V. (NAM) to carry out consultancy services in relation to induced seismicity hazard and risk assessment, and the design of structural upgrading measures for buildings in the Groningen region of the Netherlands.

Arup is a global firm of professional consultants. This report has been commissioned by NAM, and produced using information, instructions and directions from NAM. However the findings reached are the product of our independent professional judgement, on the basis of our scientific knowledge at the date of writing this report.

This report forms part of a wider scope of services related to the structural upgrading strategy for buildings in the Groningen region, described in a series of reports by Arup (2013). The strategy is supported by three studies:

- Structural Upgrading Study [1];
- Seismic Risk Study [2]; and
- Implementation Study [3].

The location and extent of the study area is shown in Figure 1.

Preventive structural upgrading for existing buildings is applied in several seismic regions around the world, mostly on the initiative of building owners, but also backed up with local or national legislation.

The Groningen situation is unique as (and for this reason examples from other regions cannot simply be copied):

- The earthquakes are caused by gas extraction, known as induced earthquakes;
- There is very limited knowledge and experience in the Dutch building industry in the design and construction of earthquake resistant buildings and the structural upgrading of existing buildings; and
- Most of the building stock in Groningen consists of unreinforced masonry (URM) including specific details common in Dutch building practice (i.e. cavity walls), which in general, without special design features, has a relative poor response to earthquakes.

The strategy has been developed in consultation with NAM over the last months and incorporates feedback from the Technische Begeleidingscommissie Bovengrond (TBB).

This strategy is based on current available data and should be considered preliminary. It will also be updated on a regular basis when more information and knowledge becomes available.

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure 1 Groningen region location plan.

2 Strategy

2.1 Elements of the Strategy

The strategy has the following elements, as illustrated in Figure 2:

- **Stepped implementation** approach for risk reduction with screening/assessments and steps of interventions;
- **Prioritisation** by seismic risk;
- (extended) **Studies** to reduce uncertainties; and
- **Implementation pilots** to test technical feasibility (Pilot 1) and operational implementation (Pilot 2).

The elements of Figure 2 will be further explained in the following sections. The stepped approach (step 1, 2, 3) is further explained in section 7.

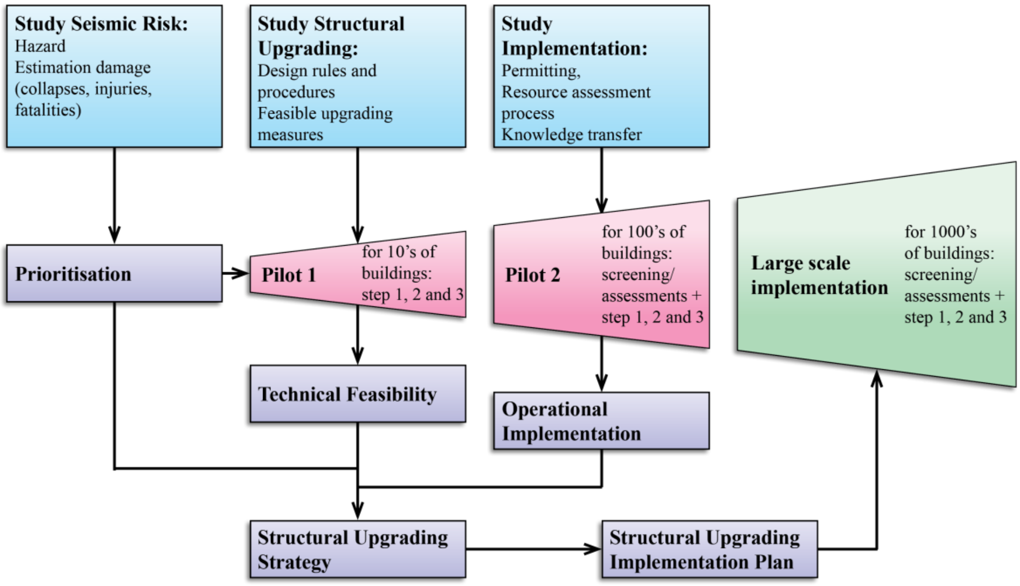

Figure 2 Elements of the strategy and their relations (numbers are indicative)

2.1.1 Study Seismic Risk

The Seismic Risk Study aims to quantify potential building damage and casualties for a specific area caused by the seismic hazard resulting from induced earthquakes.

In the context of the upgrading strategy, seismic risk is an important parameter to prioritise the implementation of studies, implementation of pilots and large scale implementation.

The summary of results for the study seismic risk is outlined in section 4 of this report.

2.1.2 Study Structural Upgrading

The Structural Upgrading Study aims to develop design guidance for structural upgrading of the Groningen region building stock within the context of Dutch building practice and the available regulatory framework. This design guidance takes the format of design rules and protocols for so-called 'typical' buildings (e.g. terraced houses), representative of a large proportion of buildings, and design procedures for unique buildings (e.g. office buildings) or those of special importance (e.g. hospitals or schools).

The design guidance to be developed is aimed at life safety. This protection of life is incorporated by performance requirements in the design codes.

The focus of the study has been on buildings constructed from unreinforced masonry (URM) which were not originally designed for seismic resistance and are particularly susceptible to seismic action, as is indicated by the fragility curves of URM buildings when compared with buildings of other materials.

The summary of the structural upgrading study is outlined in Section 5 of this report.

2.1.3 Study Implementation

The Implementation Study aims to develop a methodology for large scale implementation. An initial large scale implementation scenario ('N') has been selected and has been the basis for management, scoping, programming, planning, information management and prioritisation.

The summary of results for the study implementation is outlined in Section 6 of this report.

2.1.4 Prioritisation

Given the extent of the area and the number of buildings in this area, a prioritisation approach has been developed. The process has three basic steps:

- **Identification**: to identify the buildings with the highest potential seismic risk, based on the seismic hazard, exposure, structural vulnerability and/or the consequences of failure in an earthquake (based on desk top studies and field survey's). These methods of identification are pre- and post-earthquake inspections (FEMA 154 and ASCE 41-13) using different screening and assessment standards.
- **Performance evaluation:** to quantify the gap between the current and the required structural performance; and
- **Structural upgrading:** to achieve the required performance in an effective way using conventional and innovative upgrading measures.

Summary of results for the prioritisation are outlined in Section 6.3 of this report.

2.1.5 Implementation

Before large scale implementation is undertaken, two implementation pilots are intended to validate the design & execution impact on the proposed risk reduction and structural upgrading measures.

- **Pilot 1:** small scale testing:
    - **Phase 1:** screening/assessments;
    - **Phase 2:** preliminary design;
    - **Phase 3:** execution (incl. detailed design);
- **Pilot 2:** large scale testing:
    - **Phase 1:** screening/assessments;
    - **Phase 2:** preliminary design;
    - **Phase 3:** execution (incl. detailed design).
- **Large Scale Implementation:** full scale structural upgrading works:
    - **Phase 1:** screening/assessments;
    - **Phase 2:** preliminary design;
    - **Phase 3:** execution (incl. detailed design).

Pilot 1 is intended to validate the technical feasibility of the proposed design procedure and structural upgrading measures. Pilot 2 is intended to validate the operational implementation. Thereafter, large scale implementation is the full scale roll-out of the structural upgrading works.

2.2 Relationship of the Different Elements and other Studies/activities

The relationships between the different elements of the strategy are shown in Figure 2. Studies will overlap in time, but basic progression is from left to right, starting with the seismic risk study and finishing with the implementation study. The implementation pilots tie in with this sequence.

There are several relationships with other studies and activities not undertaken by Arup. These parallel studies provide important input to this study:

- **Definition of seismic hazard** by KNMI and subsurface experts (incl. NAM): the seismic hazard input used by Arup is provided by NAM.
- **Definition of the safety level** by NEN. NEN is to propose the safety level to the government. For now, Arup uses internationally accepted safety levels for existing buildings.

- **Development of national design guidance** (NPR and National Annex to Eurocode 8) on the structural upgrading of existing buildings by NEN.

2.3 Knowledge Management and Learning

The studies and implementation pilots are to learn how to undertake large scale implementation in an effective and timely manner.

As the context is unique it is assumed that the implementation process is not a linear process, but cyclic, with defined feedback loops.

There are multiple ways of learning:

Feedback loops: The process builds up in small steps with a cyclic character. New learning and insights resulting from the different steps in the studies and implementation pilots give feedback to assumptions of previous steps;

Scaling: The implementation pilot process builds up to deal with an increasing scale. The first implementation pilot will focus on 10’s of buildings; followed by the second implementation pilot which will possibly focus on 100’s of buildings.

Extended research and investigations: see section 5.4.3.

Market consultation: During Pilot 1 various market parties will be actively consulted.

Results from all pilots will be documented and used to update the Structural Upgrading Strategy and plan.

This process will lead to a refinement of the knowledge base starting with an approximate approach, than leading to more refinement with associated verification and validation.

3 Seismic Risk Assessment

3.1 Introduction

This section of the report provides a summary of the earthquake scenario-based seismic risk assessment undertaken to investigate the risk to buildings and the building occupants in the Groningen region. A full description of the seismic risk study is provided in a separate report titled, ‘Seismic Risk Study – Earthquake Scenario-Based Risk Assessment’.

Potential building damage estimates (and subsequently the potential casualty estimates for the building occupants) are sensitive to the level of ground shaking (e.g. measured in PGA) expected at each building location. A given magnitude of earthquake that can potentially occur in the future can produce a range of possible PGAs at each building location. Therefore, to answer questions like, “how many buildings are expected to be damaged in a M_w=5 earthquake?”, a range of possible outcomes, some more likely than others, must be considered. The probability distribution of these outcomes describes how likely each of them are to occur, given the scenario earthquake event.

There are many different ways of describing such a probability distribution. The ‘median’ describes the value which has a 50% chance of being exceeded (and a 50% chance of not being exceeded) given the occurrence of the scenario earthquake event. Other ‘percentile’ values can also be reported. For example, the 16th percentile is exceeded with 84% probability (100% minus 16%), and is therefore likely (although not certain) to be a low estimate of what would occur in an earthquake, while the 84th percentile is exceeded with only 16% probability (100% minus 84%), and therefore is likely (although not certain) to be a high estimate. These particular percentiles (16th and 84th) are often reported, as they represent the median minus and plus one standard deviation from the median.

The ‘mean’ is what would be obtained if a representative number of possible scenario earthquake events were observed, and the average calculated. For a skewed probability distribution (in which disproportionately large values are possible but with a very small probability), the mean is larger than the median, i.e. the mean value has less than 50% chance of being exceeded. Estimates of building damage in earthquakes have a skewed probability distribution so the mean is much larger than the median. Nevertheless, the “median” and the “mean” are commonly used measures to represent possible values from a probability distribution. By themselves, however, the ‘median’ and the ‘mean’ are not adequate to describe what could potentially occur even in a single scenario earthquake – and a range of possible results provides the best understanding.

3.2 Seismic Hazard

For the earthquake scenario based risk assessment, four earthquake scenarios have been considered:

- A magnitude M_w=3.6 earthquake;
- A magnitude M_w=4 earthquake;

- A magnitude M_w=4.5 earthquake; and
- A magnitude M_w=5 earthquake.

An earthquake scenario of $M_w \geq 5$ is estimated to have a probability of occurring of less than 10% in the next 10 years[2].

The earthquake scenario risk assessment results presented in this report provide an estimate of what could happen in single possible future earthquakes of a given magnitude. The scenario assessments do not provide an estimate of the cumulative damage that could potentially arise from all possible future induced earthquakes during the life of the gas field and after.

3.3 Building Exposure

For this risk assessment, a study area has been defined that extends over a region covering the full extent of the Groningen gas field. A database has been compiled for all buildings in this study area along with the simplified engineering characteristics for each building including their potential vulnerability to earthquake damage (referred to as fragility functions), the use of the building, and the number of occupants (during the day and the night). There are approximately 275,000 buildings in the study area with a total population of approximately 500,000 of which approximately 200,000 people in the city of Groningen.

3.4 Building Vulnerability

For each of the earthquake scenarios the distribution of ground shaking hazard in terms of peak horizontal ground acceleration (PGA) has been determined. The distribution and amplitude of the ground shaking is then used to estimate the amount of potential damage to buildings using fragility functions that are assigned to each of the buildings in the study area. Building damage is then classified into five damage states: slight (DS1), moderate (DS2), extensive (or substantial to heavy) (DS3), complete (or very heavy) (DS4) and collapse (or destruction) (DS5). The distribution and numbers of buildings damaged (to each damage state) is estimated.

Appropriate fragility functions were initially selected from a literature review of functions for similar typologies of buildings, based on empirical damage statistics from international earthquakes, and were calibrated for Dutch building stock based on data collected in the 1992 Roermond earthquake. Multiple sets of

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[2] NAM indicates: *"The 'Report to the Technical Guidance Committee (TBO) on Production Measures; Part 1: Depletion Scenarios and Hazard Analysis' reports that although considerable progress was made in the understanding of the seismic hazard, significant uncertainty remains at present. The predictions of the seismic hazard range are believed to be conservative and NAM has initiated a further data acquisition program to obtain additional field data, and a studies program to reduce the uncertainty. A* $M_w \geq 5$ *earthquake scenario in this report is estimated to have a probability of occurring of less than 10% in the next 10 years.*

Further data gathering and further studies in the next years will be executed in order to reduce the uncertainty range and may well in the future further reduce the hazard. For example, it is expected that geomechanical studies, explicitly modelling faults, can demonstrate a physical upper bound to the maximum magnitude."

fragility functions were used to assess the sensitivity of the analysis results to the assumed functions.

3.5 Discussion of Results

3.5.1 Building Damage Estimates

The numbers of buildings estimated to be damaged to different damage states (DS1 to DS5) in each of the four main earthquake scenarios (M_w=3.6, 4, 4.5 and 5) using median PGA earthquake ground motion input values are summarised in Figure 3.

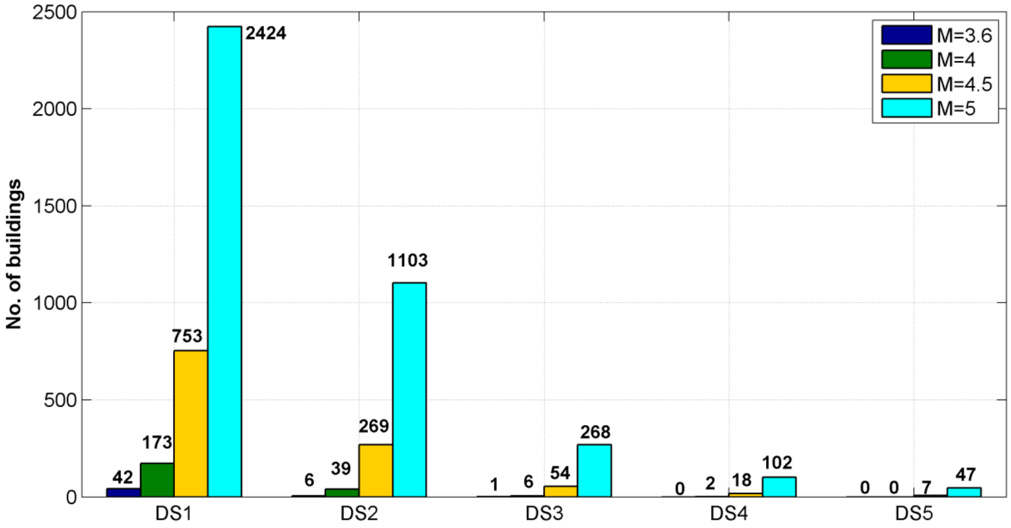

Figure 3 Number of damaged buildings for different damage states and earthquake magnitude using median (50th percentile) PGA values.

The number of buildings that will potentially be damaged is expected to increase significantly with increasing magnitude of the earthquake. For a M_w=4 earthquake scenario, it is expected that more than a hundred buildings will be slightly damaged, tens of buildings will be moderately damaged and less than 10 buildings will be extensively damaged. In the event of a larger magnitude earthquake, such as the M_w=5 earthquake scenario, it is expected that more than a thousand buildings will be slightly or moderately damaged, hundreds of buildings extensively to completely damaged and approximately 50 buildings estimated to collapse.

3.5.2 Casualty Estimation

There is a strong correlation between the level of building damage and the expected number and severity of injuries. Therefore the number of buildings in each damage state and the population in each of the buildings can be used to estimate the potential number and severity of casualties in an earthquake scenario. Casualties are classified into four levels: SL1 injuries require basic medical aid; SL2 injuries require greater medical care but are not life threatening; SL3 injuries are life threatening if not treated; and SL4 injuries in which an individual is mortally injured or instantaneously killed.

The number of potential casualties that are estimated to be caused by each of these scenario earthquakes is also expected to increase significantly with increasing magnitude. The numbers of casualties estimated to occur in each of the four main earthquake scenarios (M_w=3.6, 4, 4.5 and 5) are summarised below in Figure 4. For a M_w=4 earthquake scenario, it is expected that 2 or 3 people will be injured. In the event of a larger magnitude earthquake, such as the M_w=5 earthquake scenario, it is expected that more than a hundred people will potentially be injured with almost ten life threatening injuries or direct fatalities.

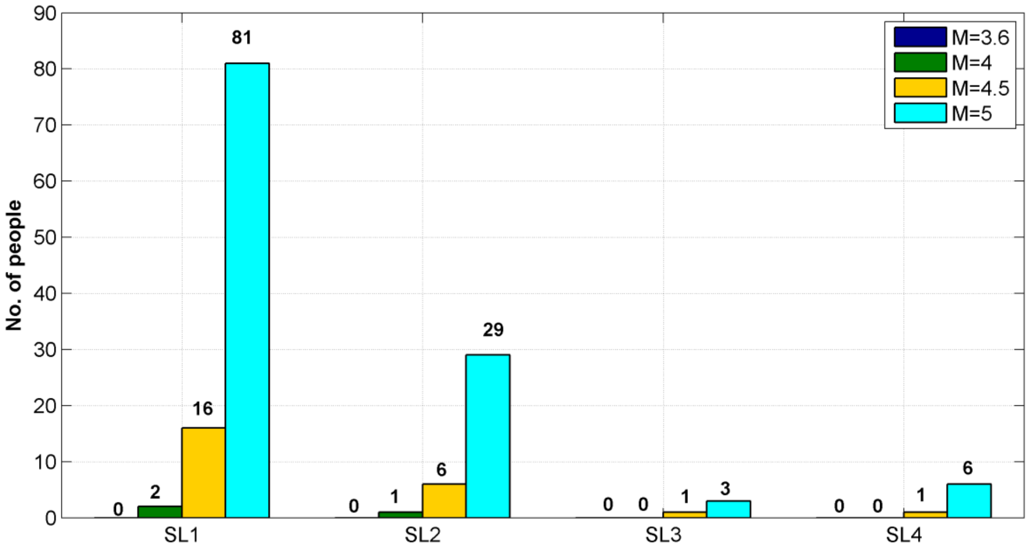

Figure 4 Number of injured people for different severity levels and earthquake magnitude using median (50th percentile) PGA values.

3.5.3 Risk Assessment Sensitivity Analyses

It is emphasised that these risk assessment results are preliminary and work is still in progress. There are very significant uncertainties in the input parameters to the risk assessment calculations. There are significant uncertainties in the seismic hazard ground motion PGA values, the fragility functions assigned to the buildings and therefore the estimation of the amount of potential building damage and also uncertainty in the estimation of casualties given the expected levels of building damage. Considerable effort is on-going through research and development tasks to reduce the uncertainty in all these areas.

In order to investigate the potential impact of these large uncertainties on the risk assessment calculation results a series of sensitivity analyses have been undertaken and the findings from these sensitivity analyses are summarised in this report. The sensitivity analyses include investigation of the effect of the uncertainty and spatial variability of the seismic hazard ground motion PGA values. Sensitivity analyses have also been undertaken to investigate the effect of assigning different fragility functions to account for the uncertainty in the performance of the Groningen region building stock under seismic ground shaking. In particular, the effect of use of alternative fragility functions to account for the potential effect of smaller magnitude earthquakes and shorter duration ground shaking on the expected level of building damage has been investigated.

The number of buildings that will potentially be damaged is expected to increase significantly with increasing seismic hazard ground motion PGA value. The numbers of buildings estimated to be damaged to different damage states (DS1 to DS5) in each of the four main earthquake scenarios (M_w=3.6, 4, 4.5 and 5) using uniformly higher 84th percentile PGA ground motion input values (rather than the median or 50th percentile PGA values) are summarised below in Figure 5. The estimated numbers of damaged buildings using this uniformly higher level of PGA is significantly higher as expected but cannot be considered unrealistically high and discounted at this stage. These analyses do serve to emphasise how sensitive the results are to changes in input values. The "mean" of the number of collapsed buildings and fatalities is in between the 50th percentile and 84th percentile values, due to the skewed nature of the probability distribution (high-consequence low-probability events skew the mean estimates above the median).

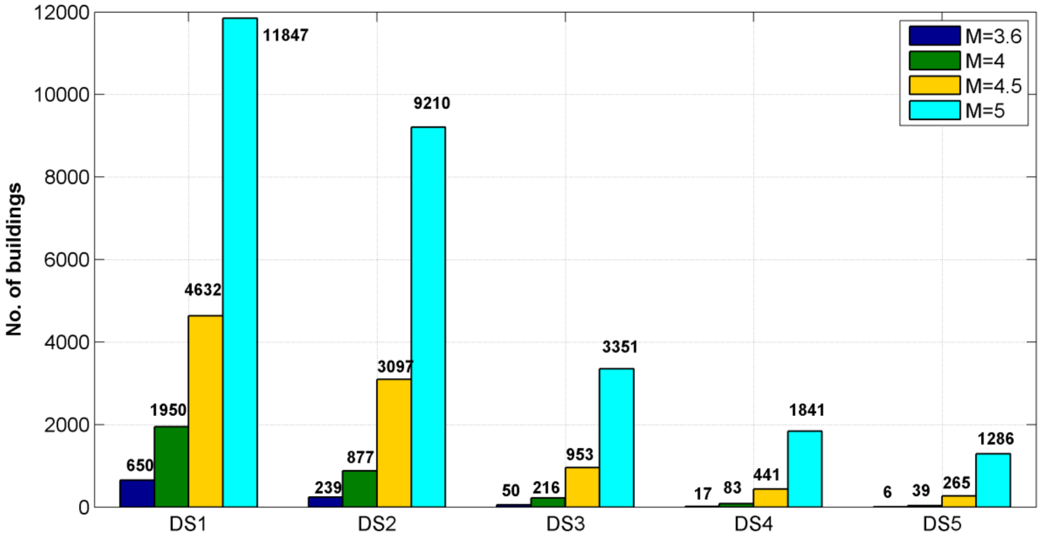

Figure 5 Number of damaged buildings for different damage states and earthquake magnitude using 84th percentile PGA values.

The numbers of potential casualties that are estimated to be caused by each of the scenario earthquakes but using the uniformly higher 84th percentile PGA ground motion input values (rather than the median or 50th percentile PGA values) are summarised below in Figure 6. It can be seen that the numbers of damaged buildings and numbers of injuries estimated using the 84th percentile PGA values appear to be high. The number of damaged buildings and numbers of injuries estimated for a M_w=3.6 earthquake scenario can be compared with the numbers of damaged buildings observed following the Huizinge earthquake of August 2012. For example the M_w=3.6 scenario earthquake building damage estimate includes approximately 50 extensively damaged building and even 6 collapsed buildings. In the actual event there were no extensively damaged or collapsed buildings. The M_w=3.6 scenario earthquake injury estimate includes over 20 injuries including a potential fatality. Again, in the actual event these injuries did not occur, but it cannot be discounted that they would occur in a future event.

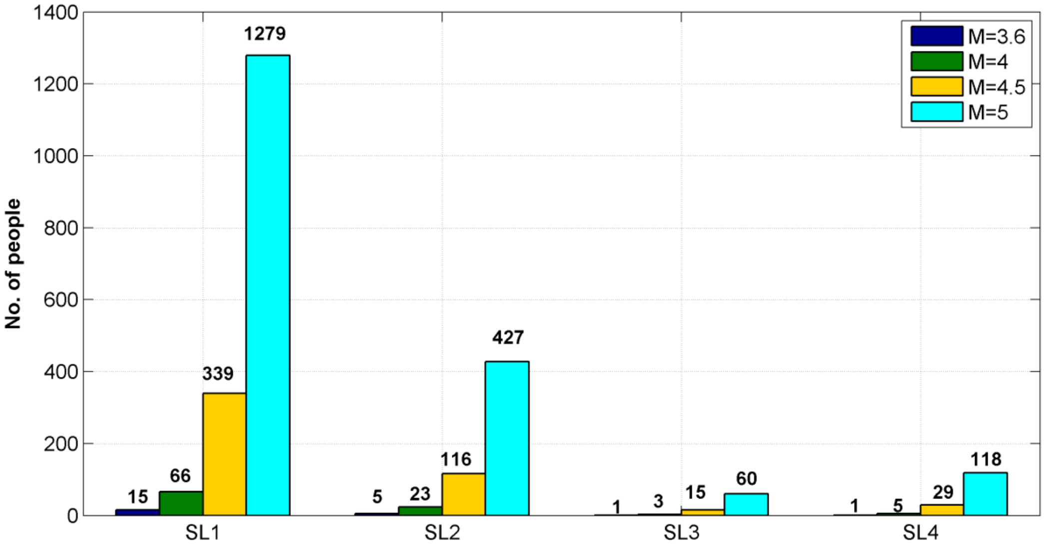

Figure 6 Number of injured people for different severity levels magnitude (84th percentile PGA values).

It is emphasised throughout this summary report that there is considerable uncertainty in the analyses and therefore it can be expected that there will be significant uncertainty in the estimated numbers of potentially damaged buildings and numbers of potential casualties presented for different earthquake scenarios. It is therefore recommended that the range of results be considered as providing a good indication of the possible levels of damage and numbers of casualties that could occur in future earthquakes in the Groningen region.

The scenario earthquake risk assessment using the median PGA values as input are considered to provide a reasonable estimate of the potential building damage and number of casualties. These median results appear to be consistent with the levels of damage and casualties resulting from similar magnitude tectonic earthquakes elsewhere in the world. However, median PGA values by their very nature mean that the ground shaking could be higher or lower in future earthquakes and therefore it is important to look at a more conservative estimate of the potential building damage and number of casualties.

If the variability of the input ground motion is used (i.e. possible higher or lower PGA values are considered) and the range of possible fragility functions are used then the estimated levels of damage and casualties are significantly higher. These building damage and casualty estimates represent a possible outcome from a M_w=5 earthquake scenario. It is likely that the values will be less than these values but on the other hand they cannot be discounted at this stage.

3.5.4 Risk Management

The findings from this risk assessment study can be used for informing risk management decisions. Unreinforced masonry buildings constitute 75% to 85% of the building stock in the Groningen region but it is not only the older unreinforced masonry buildings but also the newer unreinforced masonry buildings that contribute most to the risk. Severe injury and potential loss of life is predominantly associated with building collapse and therefore structural upgrading of buildings particularly the unreinforced masonry buildings for collapse prevention should form a key component of the risk management strategy.

The risk assessment results can also be used to inform the prioritisation of risk management activities. Priority should be given to buildings in highest risk areas (high hazard x high exposure x high vulnerability) along with buildings of high importance (e.g. hospitals), high occupancy (e.g. schools), and high cultural value (e.g. churches and museums) as well as facilities where there may be secondary hazards (e.g. chemicals storage facilities) and facilities where systems failure might have adverse cascading impacts (e.g. failure of electrical distribution or water supply).

The Arup earthquake scenario based risk assessment only provides an estimate of damage to buildings and associated casualties due to earthquake ground shaking. Other hazards and risks, for example those associated with earthquake induced failure of dykes and subsequent flooding or fire following damage to gas utilities, have not been considered as part of this study and it is recommended that the wider risk management strategy for the Groningen region covers these issues.

4 Structural Upgrading

4.1 Introduction

To reduce risk to life safety in a seismic event to as low a level as reasonably practical, the structural upgrading study focusses on developing design guidance for structural upgrading of the Groningen region buildings stock within the context of Dutch building practice and the available regulatory framework.

The objective of the Structural Upgrading Study is to develop design guidance for structural upgrading of the Groningen region building stock within the context of Dutch building practice and the available regulatory framework. This design guidance takes the format of design rules and protocols for so-called ‘typical’ buildings (e.g. terraced houses), representative of a large proportion of buildings, and design procedures for unique buildings (e.g. office buildings) or those of special importance (e.g. hospitals or schools).

The design guidance to be developed is aimed at life safety. This protection of life is incorporated by performance requirements in the design codes.

The focus of the study has been on buildings constructed from unreinforced masonry (URM) which were not originally designed for seismic resistance and are particularly susceptible to seismic action, as is indicated by the fragility curves of URM buildings when compared with buildings of other materials.

4.2 Study Approach

At present, structural upgrading measures for the protection of life safety have been studied and developed to concept design level for buildings, on the basis of a seismic hazard generating peak ground acceleration at surface (PGA) of up to 0.5g. It should be noted that field instrumentation equipment is being installed and additional research and investigations are being performed to improve the reliability of the seismic design data.

This study assesses the performance of selected buildings representing typical, damaged, historical, and other buildings. To date, 16 buildings have been assessed:

- Eight typical buildings of six sub-typologies:
    - terraced house
    - semi-detached house
    - detached house
    - labourer’s cottage
    - mansion
    - villa
- Four damaged buildings;
- One historic church; and
- Three other buildings:
    - one school
    - two utility buildings

Modal response spectrum analyses have been used for all selected buildings as this is the default analysis method recommended by the seismic design codes. For the church a non-linear mechanism-based approach has been used, as this approach shows good prediction of failure mechanisms in historic buildings. For two typical sub-typologies – the detached house and the terraced house - further analysis methods have been used to investigate the sensitivity of the outcomes to the analysis methodology. These include the lateral force analysis, the equivalent frame method, the non-linear macro element method and the non-linear time-history analysis. The detached house and the terraced house are representative of respectively the less vulnerable and more vulnerable sub-typologies in typical buildings.

For all buildings studied ties between walls, floors and the roof, and floor stiffening were assumed. This takes into account upgrading levels 2 and 3 (as defined on page v) as a significant number of buildings may not have these ties and have flexible floors. Whether these two upgrading levels are needed in all buildings will be the subject of additional investigations.

4.3 Discussion of Results

4.3.1 Seismic building performance

Relative performance

Although the number of typical buildings studied is limited, the following factors are seen to influence building performance:

- Wall openness (e.g. windows and doors);
- Wall type; and
- Building mass (which is a function of mass of floor construction and number of storeys).

Based on the Modal response spectrum analyses, two groups are distinguished:

- The **more vulnerable** typical building sub-typologies, comprising terraced houses and semi-detached houses; and
- The **less vulnerable** typical building sub-typologies, comprising detached houses, labourer’s cottages, mansions and villas.

The **more vulnerable** typical building sub-typologies are directional in their structural configuration and performance and are particularly vulnerable in the direction parallel to the front and rear façades. These façades are relatively open.

This wall openness originates from a design methodology commonly used to design these buildings for resistance to wind load on the gables, which resulted in relatively narrow masonry piers per terraced house to resist lateral loads in that direction. In this group all the buildings are three storey buildings and all walls are cavity walls. Buildings with relatively light floors perform better compared to buildings with relatively heavy floors.

The **less vulnerable** typical building sub-typologies are non-directional. In this group most buildings are two-storey buildings and most buildings have solid walls. Again, buildings with relatively light floors perform better compared to buildings with relatively heavy floors.

Buildings with shop fronts, though not explicitly studied, are expected to perform similarly to more vulnerable typical building sub-typologies based on similar structural arrangements of load-bearing members.

Note that the differentiation in more and less vulnerable buildings has not yet been made in the fragility curves used in the Seismic Risk Study. At present, the fragility curves represent a statistical representative estimate for all buildings with a differentiation only according to age. When more information becomes available about relative vulnerability this will be taken into account in the Seismic Risk Study.

Life safety performance

When upgrading measures 2 and 3 are assumed to be implemented on the buildings studied, the threshold for partial collapse (Damage State 4 = DS4), such as wall failure, is used to assess life safety performance (probability of casualties from DS4 is relatively low).

The Modal response spectrum analyses show partial collapse (DS4) at PGA's smaller than 0.1g. This is not consistent with the experience at the Huizinge earthquake where maximum observed component PGA's of 0.08g were measured and the only damage observed was cracks in walls (DS1 and DS2).

Non-linear analyses show partial collapse (DS4) for PGA's between 0.15g to 0.5g dependent on building sub-typology and non-linear analysis method. For the sub-typologies studied – terraced houses and detached houses - partial collapse was observed at PGA's of respectively 0.3g and 0.5g on the basis of sophisticated non-linear time history analyses. Using more simple non-linear pushover analysis, partial collapse was observed between 0.16g and 0.24g on the detached house sub-typology.

Definite conclusions about structural upgrading beyond level 3 is difficult, although these preliminary results show that the threshold where upgrading beyond level 3 is needed is tentatively between 0.15g and 0.5g. To be more confident the non-linear analyses need calibration with physical laboratory tests.

4.3.2 Design methodology

In the absence of a regulatory framework for seismic design in the Netherlands, international guidance/codes have been reviewed and a methodology has been developed that combines the applicable Eurocode 8 and the American Society of Civil Engineering (ASCE) approaches. ASCE 41-13 Seismic Evaluation and Retrofit of Existing Buildings is currently in draft form and expected to be released early in 2014. It represents the state-of-the-art of engineering knowledge in the assessment of URM structures under seismic action. This is an area in which the Eurocode 8 does not incorporate the most up to date guidance. Earthquakes in the Groningen area are induced and of much smaller magnitude and duration than the large tectonic earthquakes on which the guidance in ASCE

41-13 has been based. Consequently, research into the background data and test results of ASCE 41-13 has been undertaken to test the applicability to the Dutch building stock and additional research has been identified (i.e. rocking mechanisms and out-of-plane stability of slender walls) to develop specific guidance to be applicable in the Groningen region.

4.3.3 Analysis methodology

Several analysis methodologies have been investigated as part of the study to test their validity and accuracy to different building typologies. The aim in each case has been to strike an appropriate balance between accuracy and speed of assessment. From the study it is concluded that different methodologies may be used for different building typologies.

For low levels of PGA or when performance requirements are linked to no or negligible damage (DS0 and DS1) a **linear-elastic analysis** can be used in an accurate way.

For larger PGA’s and with the acceptance of significant damage (DS4) for performance requirements associated with life safety, a **non-linear analysis** can take into account the non-linear more ductile response of the building and is required in order to achieve more accurate results and hence better insight in required upgrading measures. This is especially the case when the analysis is for a special building or is representative for a typology or sub-typology, representing a larger proportion of buildings.

For larger PGA’s an alternative approach is to use a linear-elastic analysis, together with ductility factors based on material, (sub) typology or failure mode. These ductility factors are not available for the Groningen building stock, while currently codified ductility factors give limited ductility for URM buildings or building parts. After calibration through physical and numerical non-linear testing, a linear analysis methodology that takes into account the representative ductility of the Groningen building stock may provide a more efficient overall procedure. This methodology may be more appropriate for general, large-scale deployment within the engineering community. Development of such simplified method may take one to three years.

4.3.4 Structural upgrading measures

The results from the analyses and assessments determine the requirement for upgrading measures. Feasible preliminary structural upgrading measures and options suitable for local implementation have been developed for each building investigated. These measures have been proposed as being appropriate to prevent life-threatening damage and are developed taking due consideration of local capabilities, social disturbance and aesthetic sensitivity. Seven levels of permanent upgrading measures have been characterised within the study. Commencing at level 1, the upgrading levels have been set out in order of the most effective solutions that can be deployed most rapidly to reduce risk most quickly whilst minimising impact for inhabitants. Complexity, duration and impact on inhabitants increase with increasing intervention level.

When intervention is required this will be a mix of different permanent and temporary upgrading measures.

Permanent upgrading measures – intervention levels:

- **Level 1**: Mitigation measures for higher risk building elements (potential falling hazards);
- **Level 2**: Tying of floors and walls;
- **Level 3**: Stiffening of flexible diaphragms;
- **Level 4**: Strengthening of existing walls;
- **Level 5**: Replacement and addition of walls;
- **Level 6**: Foundation strengthening; and
- **Level 7**: Demolition.

Temporary upgrading measures have also been identified for specific building types for rapid risk reduction, for example terraced houses, semi-detached houses and shop front buildings which have been identified as being more vulnerable. Temporary upgrading measures are exterior to the building and provide lateral support to the building (e.g. steel “bookend” frames). Temporary upgrading is to be considered for these buildings to mitigate short-term risk until permanent solutions are available.

A key consideration under investigation is the seismic hazard threshold below which no intervention is required. The determination of this threshold is under development and will be investigated based on analyses and physical testing. The current expectations are that this threshold will be for PGA’s of 0.1g to 0.2g, based on observation in other countries with comparable URM building stock.

5 Uncertainty Reduction

5.1 Sources of model Uncertainty

In a traditional approach, there are three main sources of uncertainty in estimating the number of buildings that may need structural upgrading and assessing the extent of structural upgrading required:

1. The **model for seismic action** contains uncertainties relating to:
    - Amplitude of the peak earthquake ground motions and its geographical distribution;
    - Characteristics of expected earthquake ground motions, including their frequency content and durations;
    - Local ground conditions and their effects on seismic accelerations and characteristics of the earthquake ground motions; and
    - Treatment of transient nature of induced seismic hazard, its correlation with gas production, and its interpretation with respect to code requirements;
2. The **model for seismic resistance** contains uncertainties relating to:
    - Structural analysis methodology;
    - Information/knowledge on the buildings and material properties;
    - Allowable ductility that may be taken into account for Dutch building stock;
    - The effect of ground motion duration on seismic performance;
    - Vulnerability – a lower-bound threshold of acceleration for which no seismic upgrading is required;
    - Vulnerability – differences between individual buildings within each typology and the representativeness of individual analysis models for assessing the total population; and
    - Quantitative effect of structural upgrading measures.
3. The **target safety level** depends on:
    - A balanced view on the probability of occurrence of different levels of earthquake ground motion, and the expected consequences of their occurrence for new and existing buildings; and
    - Tolerance of the local community to risk from induced earthquake ground motion.

The variables in Figures 7 and 8 have been identified as the most important, from the point of view of reducing uncertainty and therefore make the biggest impact on the level of intervention required.

5.2 Approach to Uncertainty in Respect to new and existing Buildings

For the design of new to build buildings the current uncertainty can be integrated into the models and specific seismic design criteria can be adopted which minimize the impact of the uncertainties. Consequently, specific design for seismic action might add a maximum of 5–10% of the new build value. For existing buildings the structural upgrading measures might cost more than 50% of the current building value, and indirect impacts associated with implementing structural upgrading may add to this. Consequently, the reduction of uncertainty is more important for existing buildings, than buildings that will be built in the future.

5.3 Implications of Model Uncertainties

Depending on the selected value of the variables, the measures needed for a specific building might vary from no measures to all measures up to levels 6 (see section 3.4). Taking conservative (pessimistic) assumptions may result in too many interventions with intervention levels that are higher than needed. Taking optimistic assumptions may result in not enough interventions at the right intervention levels to assure the safety level that is assumed. Selected values to date have been based on conservative assumptions and available information.

The influence of the uncertainty on the total number of buildings requiring upgrading is illustrated in Figures 7 and 8. The number of buildings requiring each level of structural upgrading depends on a number of variables as shown in the figures. The figures show the influence of various variables on the number of required lighter interventions (level 1-3, see Figure 7) respectively on the number of required stronger interventions (level 4-7, see Figure 8).

The values in Figures 7 and 8 at the ‘100%’ position indicate the baseline value; any change in this value will result in an increase or decrease in the relative number of structural interventions required in the area. For example: if all houses have a threshold vulnerability level of 0.1g, intervention levels 1to 3 may be required for the baseline number of buildings. If the vulnerability level is 0.2g, intervention levels 1-3 may be required for approximately 60% of the baseline.

Each bar on Figures 7 and 8 should be interpreted as a reasonable range of possible values for each parameter following further study, current knowledge or preliminary studies that have already been conducted. Each of these values should be interpreted as possible lower and upper bound values that will be explored further in uncertainty reduction studies. The figures should not be interpreted as meaning that the lower values on each plot will necessarily be obtained.

It should also be noted that each variable is varied in isolation; the effect of varying multiple parameters (e.g. reducing the seismic hazard and increasing the vulnerability) is not considered in the figures.

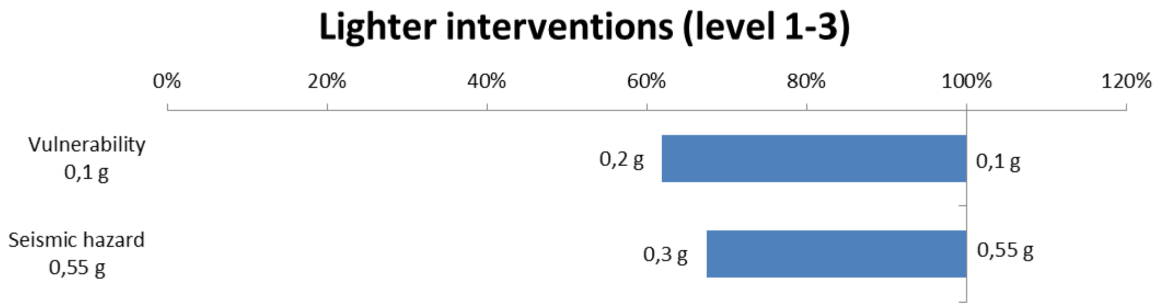

Figure 7 Influence of factors on the number of light interventions.

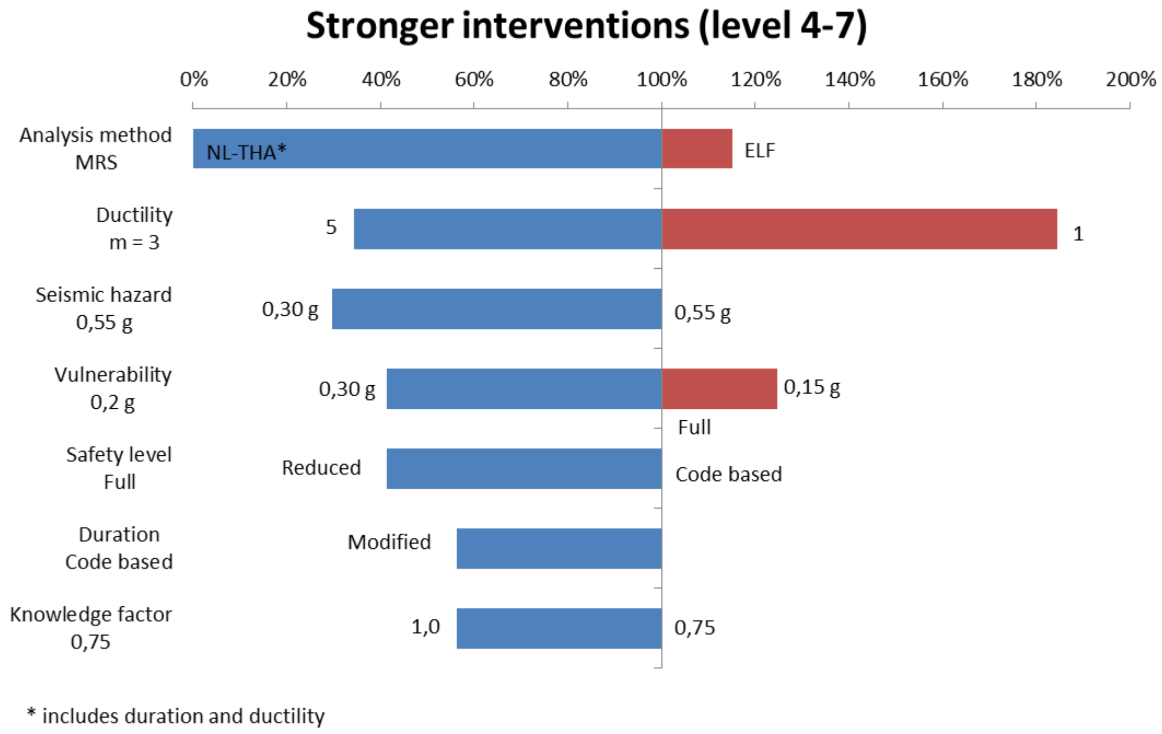

Figure 8 Influence of various factors on the number of heavy interventions.

For several variables limited information is available at this stage and the influences of some of these variables are still not fully understood. Consequently, the predictions of seismic hazard, building vulnerability and the overall seismic risk are done under high uncertainties. Because of these uncertainties it is too early to roll out a definitive upgrading program and a phased approach is therefore proposed.

5.4 Reduction of Model Uncertainties

The reduction of model uncertainties by an extension of existing seismic risk and structural upgrading studies is proposed to be undertaken in three different ways:

- Increasing representativeness of analytical models of local situation;

- Calibration of models with physical laboratory tests and/or field measurements; and
- Increasing basic knowledge on specific influencing factors.

5.4.1 Increasing Representativeness within Analytical Models of Local Situation

The reduction of the uncertainties in the analytical seismic action and building resistance/fragility models will increase with more accurate local seismic action, local building stock and local soil representations.

5.4.2 Calibration of Models with Physical Laboratory Tests and/or Field Measurements

The modeling methodologies and model assumptions need to be verified by physical calibration of the models and their assumptions. This can be done by physical laboratory test and/or field measurements.

Laboratory test that are suggested, include:

- Shaking table tests to achieve knowledge about the total building response;
- Dynamic tests on building elements; and
- Material testing.

Field measurements that are suggested, include:

- Earthquake motion;
- Soil settlement; and
- Damage measurements to the houses.

5.4.3 Increasing Basic Knowledge on Specific Influencing Factors

The following studies by Arup to reduce model uncertainty are currently underway:

- **Duration:** Non-linear finite element calculations on 3-D models of total buildings, non-linear single degree of freedom models and non-linear cavity wall models;

- **Structural analysis methodologies**: comparison between dynamic linear and dynamic non-linear methodologies;
- **Building soil-structural interaction**; and
- **Structural building element studies**, such as cavity walls.

To reduce model uncertainties in seismic action, seismic resistance and target safety level is it recommended to undertake additional research and investigations. For the seismic resistance/vulnerability, the aim of this research and investigations is to better understand the influencing factors and the influence of different levels of structural upgrading and specifically the different types of upgrading.

In the short term the following research / investigations are proposed:

- **Improve structural analysis and model methodologies**: extended comparisons to find a feasible methodology with the right balance of time/knowledge requirements and accuracy for assessment of forces and/or damage;
- **Calibration of models by laboratory testing** using scale or full scale physical models for total buildings, building parts and material testing. These studies aim to calibrate the analysis methodologies and model assumptions;
- **Calibration of models using field measurements** of ground motion, related building damage and ground settlement on real buildings in Groningen;
- **Improve fragility curves** for local building stock: production of a methodology to produce fragility curves using analytical non-linear models in combination with laboratory testing;
- **Building / soil structural interaction**;
- **Duration**: Extension of non-linear finite element calculations on 3-D models of total buildings, non-linear single degree of freedom models;
- **Testing of specific building elements or structural upgrading measures** by using non-linear dynamic and static model approaches in combination with physical laboratory tests;
- **Building stock variability** study to improve understanding in-plan and elevation geometry, material properties and detailing; and
- **Ground motion characteristics and local ground conditions.**

6 Implementation

6.1 Introduction

The main objectives for this implementation study are to develop:

- a methodology to reduce risk to an acceptable level within an acceptable time frame;
- a programme that is supported by authorities;
- a programme that is generally socially acceptable; and
- a programme that is flexible.

The assessments of seismic hazard, building vulnerability and the overall seismic risk have been done under high uncertainties. Because of these uncertainties, it is too early to implement a definitive upgrading program and a phased approach with periodic reviews is therefore proposed.

A prioritised approach has been developed as outlined in the structural upgrading strategy. Prioritisation is predominantly conducted on the basis of seismic risk, followed by pragmatic considerations. Seismic risk is composed of seismic hazard, building vulnerability and exposure. Pragmatic considerations include; commencing implementation per town, starting within their centres, owner consent, and permitting process.

6.2 Key Elements of the Implementation Study

Key elements of the proposed implementation methodology have been summarized below.

1. **Building inspection process**
    - Importance class I and II buildings (Eurocode 8), are proposed to be inspected in parallel in two different work streams;
    - Rapid Visual Screenings (RVS) are proposed for class II buildings starting in the core of the hazard area and then moving outwardly. The RVS is an external inspection method in accordance with the FEMA 154 (International) method, which has been modified for the local situation; and
    - ASCE 41-13 surveys are proposed to be performed for class III and IV buildings and for selected class II buildings. This international survey method consists of a desk study, a detailed in-house inspection followed by potential detailed design and engineering of structural upgrading measures.

2. **Mitigating risks in a prioritized manner, based on different implementation steps**
    - Step 1 focusses on designing and executing intervention measures to mitigate urgent risks as well as intervention measures to mitigate high risk building elements (such as damaged chimneys or parapets);
    - Step 2 focusses on improving the structural integrity of buildings (i.e. tying floors and walls and stiffening diaphragms);
    - Step 3 focusses on potential further intervention levels to improve strength and / or ductility of buildings;

3. **Permit and tender process:**
    - To develop an effective planning permission process, consultation with planning permission agencies of relevant municipalities is proposed. Consultations are currently underway with the planning agency of Loppersum; and
    - The tendering process is to be further developed in the implementation plan. Within the overall procurement strategy a focus on local firms is proposed (architects, engineers, suppliers, contractors and other third parties).

4. Program, cost and resources:

- As part of the implementation study, a preliminary program has been developed focusing on the coming 3 years; and
- Due to commercial and market sensitivities all information pertaining to costs and resources has been removed from this report. This information has been provided to NAM directly.

5. Scope for implementation study

- Currently the seismic hazard levels for the Groningen region have been determined by Shell P&T and the expected threshold level below which no interventions are required have been determined by Arup.
- Both the PGA distribution (hazard) and the threshold level currently have high uncertainties. The exact scope of the implementation works can therefore not be defined at this stage and will require further studies to help reduce these uncertainties.
- To get an understanding for ‘order of magnitude’ of the scope of large scale implementation, an initial scenario ‘N’ was adopted as the basis for this study.
- Given the current uncertainties, the scenario ‘N’ scope described in this report is not a prediction of the future and can be expected to change as uncertainty reduction studies progress.
- Parameter uncertainties are illustrated in Figures 4 and 5.

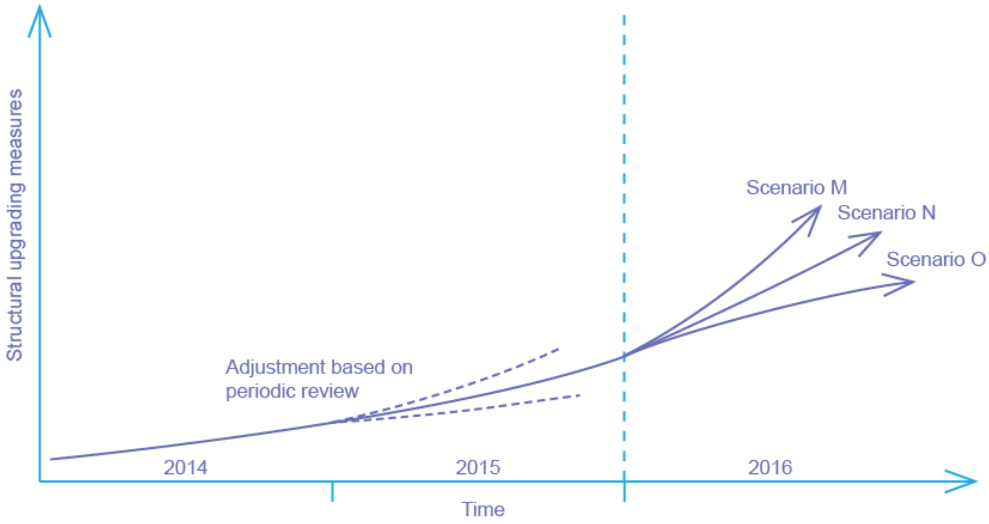

Figure 9 Large scale implementation scenarios

6. **Proposed next steps:**

In addition to an extended uncertainty reduction program it is proposed to NAM to continue with the pilot projects (Pilot 1 and 2), which consist of:

1. Screening 1700 buildings in Pilot 2 on vulnerability and exposure;
2. Implementing temporary measures for those buildings identified during surveys in Pilot 2, needing urgent actions due to severely impaired integrity;
3. Consider implementing temporary measures for those buildings identified during surveys in Pilot 2, based on their typology;
4. Implementing step 1 measures for those building elements identified during surveys in Pilot 2;
5. Implementing step 2 measures for at least 5 houses before the end of 2014 (Pilot 1 and investigating the effect of these measures on building vulnerability;
6. Implementing step 1 and 2 measures for all buildings in Pilot 2 before the end of 2016 (scope of Pilot 2 depends on progressive insights, results of inspections, and findings from Pilot 1); and
7. A periodical evaluation of the pilot projects (Pilot 1 and 2) before the roll-out of the complete program in 2016.

6.3 Prioritisation

Given the aforementioned objectives and the extent of the relevant area, it is not considered feasible to immediately carry out full scale structural upgrading measures to all buildings in this area. Moreover, the prediction of seismic hazard, building vulnerability and the overall seismic risk are done under high uncertainties. Because of these uncertainties it is too early to unroll a definitive upgrading program and a phased approach is therefore proposed.

A prioritised approach has therefore been developed in the implementation study. Prioritisation is predominantly conducted on the basis of seismic risk, followed by pragmatic considerations such as the accessibility of buildings and grouping buildings geographically to allow more efficient assessment.

Prioritisation has been based on minimising risk to life safety. Not all buildings can be screened and addressed at the same time. It is therefore proposed to start with the buildings that are likely to cause most casualties in case of a heavy earthquake, using the following considerations:

1. **Seismic hazard:** priority is given to areas of highest seismic hazard working from the central area of the gas field where the seismic hazard is highest to the outside where the seismic hazard is lowest.

2. **Building vulnerability:** rapid visual screenings/assessments are undertaken to assess the vulnerabilities of all buildings with assessments starting in the highest seismic hazard areas. The relative vulnerability of buildings is then used to set priorities for further assessment and implementation of structural upgrading measures. Rapid visual assessments are also used to identify and prioritise buildings with elements that pose urgent life safety risk.
3. **Building exposure:** building importance class defined in accordance with current Eurocodes is also used to prioritise work on higher importance buildings (e.g. hospitals, first responder buildings, schools, elderly homes). The classification has been modified to the local situation in Groningen, as outlined in Appendix B. Table 2 describes the different importance classes which have been defined for this study.

6.4 Implementation Methodology

6.4.1 Implementation Steps

Based on the assessments to date, the recommendation is to start with the following structural upgrading measures as soon as possible in the area of highest seismic hazard initially:

1. Strengthening or removing higher risk building elements (falling hazard);
2. Improving the integrity of buildings; and
3. Improving strength and/or ductility of buildings.

6.4.2 Work Streams, Screenings and Assessments

Two separate work streams have been defined as part of the proposed implementation methodology, one for normal buildings (importance class II per Eurocode 8) and one for important buildings (importance class III and IV as per Eurocode 8, see figure 10).

For the initial area, external Rapid Visual Screenings (RVS) will be performed to all class II buildings in accordance with the FEMA 154, which has been modified to allow for the local situation. This screening method will not be applied to class III and IV buildings as it is aimed at quickly identifying high risks and the prioritisation process within the largest group of buildings (class II).

ASCE 41-13 assessments are proposed to be performed on all Pilot 2 and class III and IV buildings, which will consist of an in-house survey (tier I) followed by a potential risk mitigation and then a structural upgrading proposal as required. For similar houses (e.g. terraced houses) the assessment can become less extensive.

Since there are uncertainties about the hazard and vulnerability of buildings it is proposed to temporarily limit the screenings and assessments to the area in which permanent measures are estimated to be needed in any credible scenarios. As uncertainties are still high, the area definition is not fixed and will be adjusted as and when new knowledge becomes available.

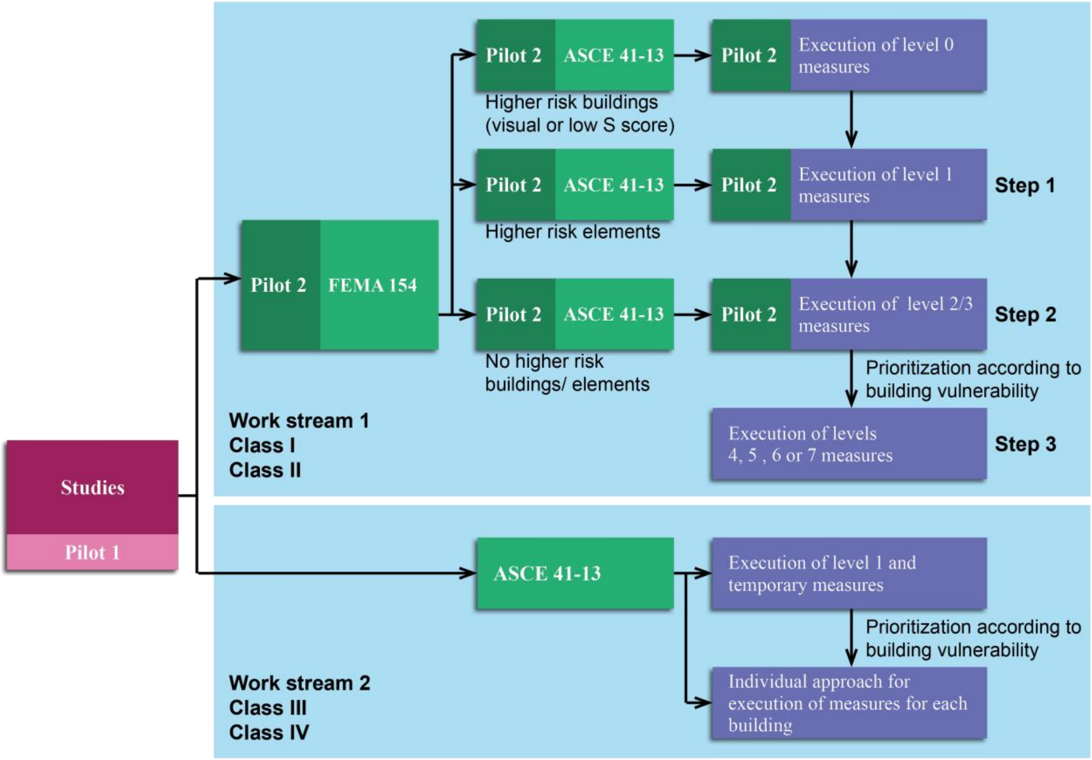

Figure 10 Work streams, screenings, assessment and prioritisation

The initial area to be considered for screening and assessments has been based on the ‘contour maps’ received from NAM (Shell P&T) and has been defined differently for different classes of buildings:

- Class I buildings (barns and sheds) will not be considered due to their relative low importance (except for large buildings with live stock);
- Class II buildings (approx. 47,500 buildings);
- Class III buildings (approx. 500 buildings); and
- Class IV buildings (less than 100 buildings).

The above-mentioned area and total numbers will be reviewed regularly and may increase or decrease.

To reduce the risk level quickly, work stream 1 will be executed in three steps for different interventions levels. Step 1 focusses on designing and executing intervention measures to mitigate urgent risks as well as intervention measures to mitigate high risk building elements (such as damaged chimneys or parapets). Step 2 focusses on designing and executing intervention measures to improve structural integrity within buildings (i.e. tying floors and walls and stiffening diaphragms). Step 3 focusses on potential further intervention levels to structurally upgrade buildings. Each step will start with a pilot phase (during pilot 2) to test the feasibility of execution of measures.

Since the variation of buildings in work stream 2 is higher and the repetition is lower, an individual approach will be used to execute the proposed risk mitigation or structural upgrading measures to these buildings (or group of buildings).

6.4.3 Permit Application

The process of permit application and granting is a critical element within the program. Permit application will be based on the drawings and calculations that are developed in the detailed design phase. Execution cannot start before a permit is granted (if required). It is therefore recommended to start consultations with the affected municipalities as soon as possible, to make agreements on the permit application process such as the instalment of a central permit agency for the Groningen 2013 program. Consultation with the relevant permitting agencies has started on this subject within the core hazard area (Loppersum).

6.4.4 Building Owner Consultation

Building owner consent is an essential part of the execution phase. Without this any proposed risk mitigation or structural upgrading works cannot be undertaken. It is therefore suggested to liaise with building owners on the proposed interventions as early as possible in the design process (after concept design).

6.5 Time schedule and Organisation

6.5.1 Time Schedule

A preliminary and indicative 'master planning' has been drawn up for implementing the 'Groningen 2013 Programme'. Indicative turnaround times and milestones of the main activities are provided below in Table 1.

Table 1 Time line activities start.

Activity	Milestone start	Description
Continued studies	started	
Pilot 1		
- **houses (class II)**	started	Design started
- **historic and other buildings (class III and IV)**	started	Design started
Initial design guideline (intervention levels 1 and 2)	started	Q1 2014
Pilot 2		
- **rapid visual screening**	started	
- **ASCE 41-13 surveys**	started	
- **level 0 measures (temporary)**	Q2 2014	
- **level 1 measures (mitigation HRBE)**	Q1 2014	
- **level 2/3 measures**	2015	
Large scale implementation	2015 / 2016	

The above-mentioned time line is indicative and has been developed by calculating resources needed.

6.5.2 Organisation

It is recommended to develop a standalone project organisation for the implementation of the entire program, whereby the structure and functioning of the organisation stems from the proposed implementation methodology described in this implementation study. Consideration for this new project organisation are:

- Focus total organisation on programme scope
- A dedicated organisation for the programme scope within the NAM organisation;
- Local presence, visibility in the area; and
- Fine tuning of organisation, systems, procedures, resourcing, etc., to the specific requirements of the Implementation works.

It is recommended to consider options integrally, including legal and financial (tax) issues.

References

[1] REP/229746/SU003 Structural Upgrading Study, Arup, Amsterdam (29-11-2013).

[2] REP/229746/SR001 Seismic Risk Study – Earth quake Scenario-Based Risk Assessment, Arup, Amsterdam (29-11-2013).

[3] REP/229746/IS001 Implementation Study, Arup, Amsterdam (29-11-2013).