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Implementation Study

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Executive Summary

Introduction

This report presents the results of an implementation study conducted by Arup for the Nederlandse Aardolie Maatschappij (NAM) to undertake preventive structural upgrading works to buildings in the Groningen region of the Netherlands.

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).

- Structural Upgrading Strategy [1];
- Seismic Risk Study [2];
- Structural Upgrading Study [3]; and
- Implementation Study (this report).

The implementation study is in support of the required studies outlined in the letter of Minister Kamp to the Dutch Parliament of 11 February 2013.

Objectives and reasoning behind the Implementation Study

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 [1], 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.

[1] NAM indicates: *"As the work on the quantification of the seismic hazard is still ongoing and as the forecasted maximum magnitude is expected to be lowered by the geomechanical work, a phased approach with periodic reviews is supported."*

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 [4]) and importance class III and IV buildings (Eurocode 8), are proposed to be inspected in parallel in two different work streams (see Table 2);
   - 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 [5] 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 have 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.

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 of 1700 buildings (the village of Loppersum has been selected) 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

1 Introduction

1.1 Background

The Nederlandse Aardolie Maatschappij (NAM) commissioned Arup in 2013, to develop a structural upgrading strategy for existing buildings in the Groningen region. Supporting this strategy, this report presents the implementation study to undertake preventive structural upgrading works in this region. The location and extent of the study area is shown in Figure 1.

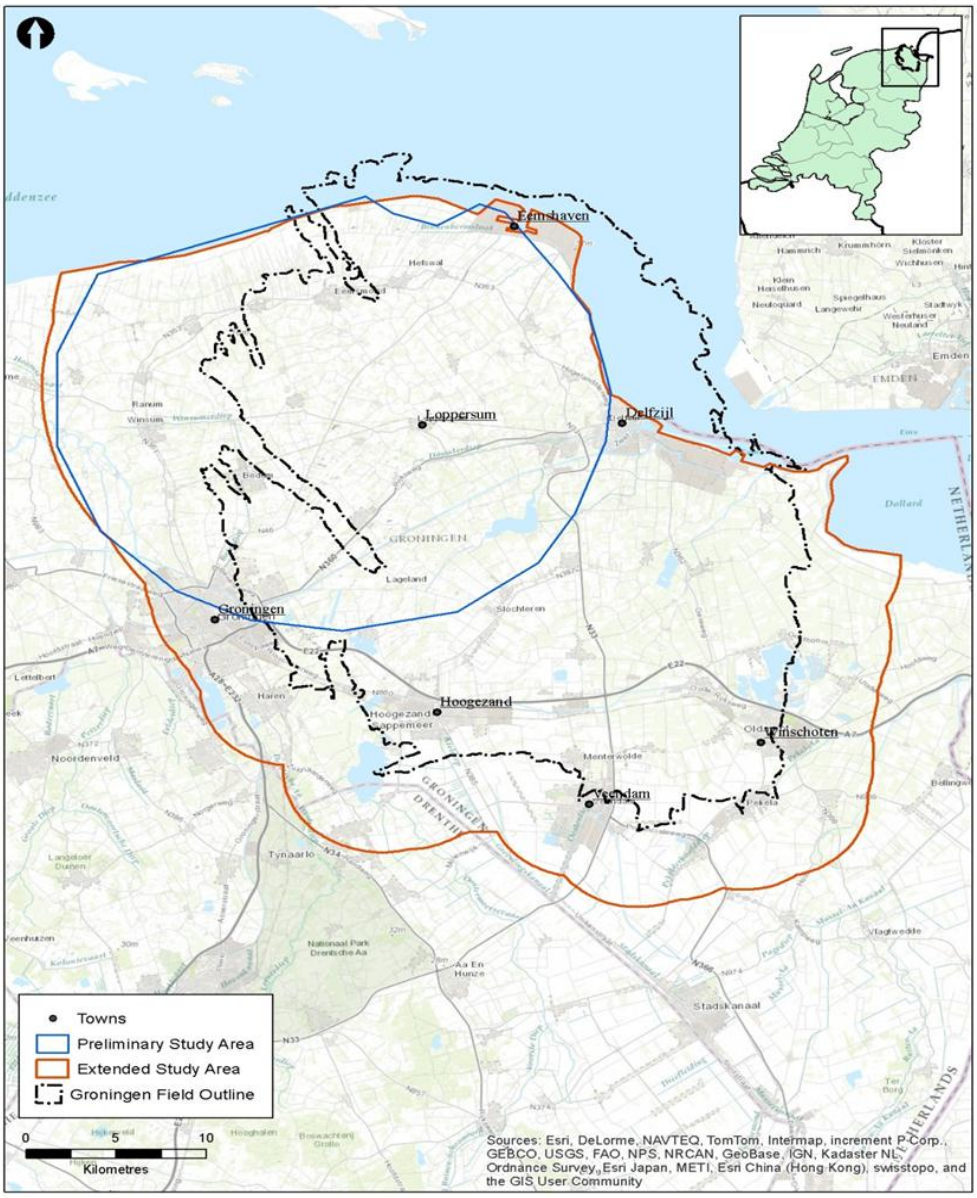

Figure 1 Groningen region location plan.

This report is in support of the required studies outlined in the letter of Minister Kamp to the Dutch Parliament of 11 February 2013. As requested by NAM, it is also being issued at this stage as input for the ‘Winningsplan’, which will be submitted by NAM on the 1st of December 2013. This report is therefore an intermediate presentation of the implementation study.

In support of the structural upgrading strategy, this implementation study provides an approach for the ‘implementation’ of risk mitigating and structural upgrading measures to existing buildings in the affected region of Groningen.

Preventive structural upgrading of 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 context is unique as:

- 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 related to the Dutch context (i.e. cavity walls), which in general, without special design features, has a relative poor response to earthquakes.

1.2 Important elements of the Structural Upgrading Strategy in relation to the Implementation Study

The overall Structural Upgrading Strategy is aimed at reducing risk levels quickly while uncertainty reduction activities progress through continued research and investigations.

The Structural Upgrading Strategy consists of, ‘studies’ and ‘implementation’. These are partially overlapping, which means implementation reduces the risk levels while uncertainty reduction studies and tests are continued, as explained in more detail below.

1.2.1 Studies

As part of the wider scope of services to develop the structural upgrading strategy for buildings in the affected Groningen region, the following three study areas have been identified.

1. Seismic Risk Study;
2. Structural Upgrading Study; and
3. Implementation Study (this report).

Further information on these studies can be found in the study reports and the Structural Upgrading Strategy as found in the reference list. See also Figure 2.

1.2.2 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.

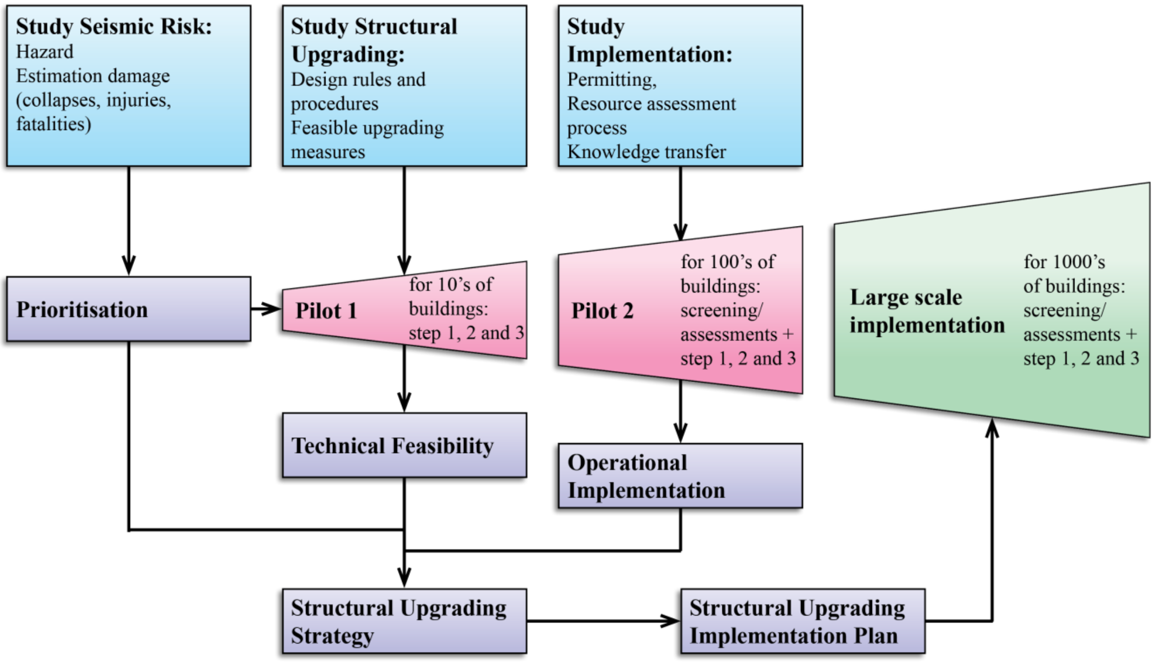

Figure 2 Elements of the strategy and their relations (numbers are indicative).

1.3 Current Seismic Hazard and Threshold Levels

The seismic hazard in the Groningen area has been defined by the probabilistic seismic hazard analysis (PSHA) conducted by Shell P&T. A map was developed for the level of peak ground acceleration (PGA) associated with a 2% probability of exceedance in the next ten years (see Figure 3). This is approximately equivalent to the design basis earthquake ground motion in Eurocode 8 which corresponds to a 10% probability of exceedance in 50 year hazard level (return period of 475 years).

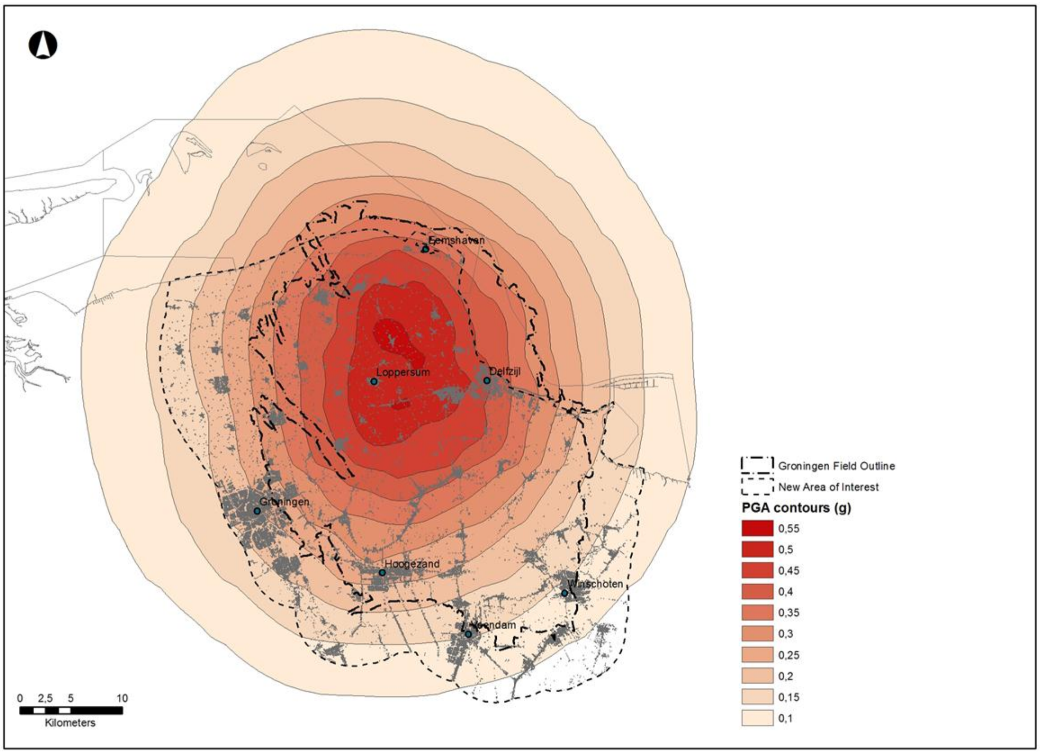

Figure 3 PGA contour map according to Shell P&T with a return period of 475 years.

There are a number of uncertainties associated with the probabilistic seismic hazard scenario analysis. These uncertainties could be expected to affect the overall level of expected PGA across the whole field and not its distribution (i.e. the contours remain a similar shape but with different values). The relative order, in which works can be carried out are therefore not expected to change.

However, the overall outcome of building assessments and upgrading measures required may change as intervention is only required for a minimum threshold level of PGA.

Based on current preliminary findings from the structural upgrading and risk assessment studies, the threshold level above which structural upgrading measures are expected is between 0.1 and 0.2 g PGA.

Both the PGA distribution (hazard) and the threshold levels have high uncertainties. Based on current knowledge, higher and lower PGAs and upgrading thresholds are possible. The exact scope of the implementation study can therefore not be defined at this stage and will require ongoing studies to reduce these uncertainties.

1.4 Implementation Methodology

Given the current uncertainties and the extent of the area (and number of buildings in this area), the implementation methodology is based on a prioritisation approach. 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 surveys); These method of identification is based on **pre- and post-earthquake inspections (FEMA 154 and ACSE 41-13)** using different screening and assessment standards.
- **Performance evaluation:** to quantify the gap between the estimated current and required structural performance; and
- **Structural upgrading:** to actually achieve the required performance in an effective way by using conventional and innovative upgrading measures (the process for this is mentioned in section 1.2.2)

2 Current Uncertainties

2.1 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 to risk for the area concerned.

Please also see Seismic Risk Study Section 7.2 with regards to current uncertainties.

The variables in Figures 4 and 5 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.

2.2 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 4 and 5. 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 4) respectively on the number of required stronger interventions (level 4-7, see Figure 5).

The values in Figures 4 and 5 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 4 and 5 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. Further information about how each figure was generated is provided in Appendix B.

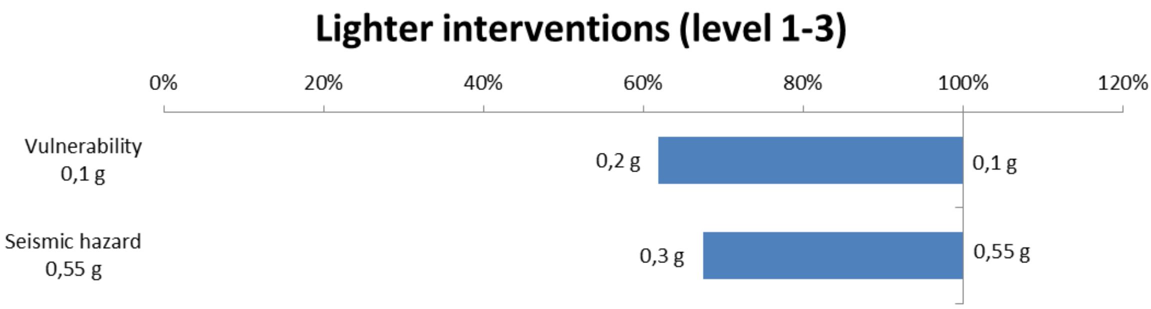

Figure 4 Influence of factors on the number of light interventions.

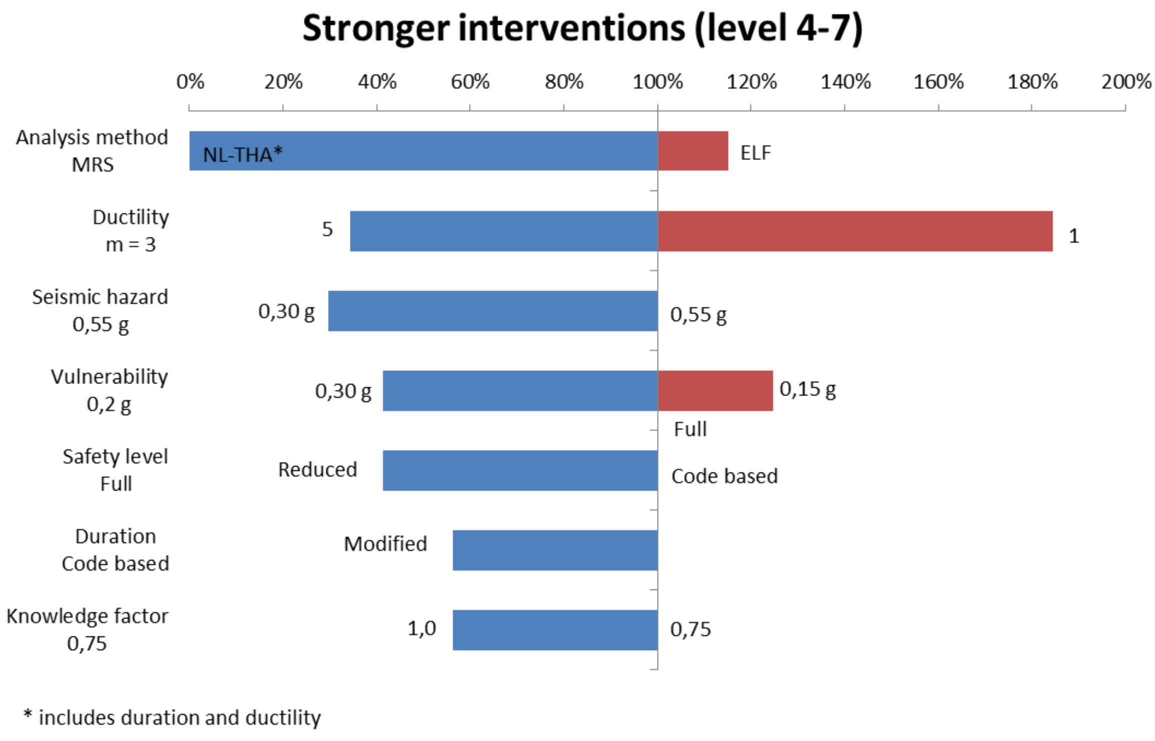

Figure 5 Influence of various factors on the number of heavy interventions.

2.3 Recommendations in dealing with uncertainties at this stage

The aforementioned has shown that limited information is available at this stage for several variables and that the influences of some of these variables are large. For instance, the initial results from non-linear analysis show that considerable reductions in intervention levels 4 to 6 may be possible. 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 risk based approach is therefore proposed.

3 Implementation Study Scope

This implementation study describes the methodology for large scale implementation of risk reducing measures as well as preventive structural upgrading measures to buildings in the affected Groningen region. Large scale implementation is expected to start after Pilots 1 and 2 have commenced. Given the current uncertainties with regards to hazard and threshold levels, large scale implementation has been developed on an initial scenario 'N' basis.

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.

3.1 Objectives

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.

Table 1 further informs on the main objectives of this implementation study.

Table 1 Objectives of the implementation study.

Objective	Further clarification
Methodology to reduce risks to an acceptable level	An 'acceptable level' will be defined in the expected national guidelines (NPR) and NEN norm. Until the NPR is available, guidance outlined in international codes are proposed to be used allowing measures to be determined based on objective criteria.
The programme is supported by authorities	Authorities concur with the proposed studies, the measures to be implemented and the implementation process.
The programme is generally socially accepted	The process of implementation, including prioritisation, is considered logical, accurate and fair.
The programme is flexible	The programme starts with a step wise approach that is prioritised on the basis of available knowledge on hazard, vulnerability and exposure. This prioritisation minimises the chance of carrying out unnecessary implementations as more research is carried out and can be adjusted if necessary due to updated information. The prioritisation strategy reduces the total risk level in the area as quick as possible.

3.2 Scenario 'N' basis for Implementation Study

The implementation study looks at large scale implementation; following pilots 1 and 2 (see Figure 3). As per section 1.2.2, Pilots 1 and 2 are aimed at technical and operational validation of the implementation works and are expected to become the focus of works undertaken in 2014 and 2015. Depending on the results from Pilots 1 and 2 and the proposed uncertainty reduction studies, large scale implementation is currently expected to start in 2016.

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 implementation works associated with scenario 'N' described in section 3.3 are not a prediction of the future and can be expected to change as uncertainty reduction studies progress. Other scenarios with a larger or smaller scope, such as scenarios 'M' or 'O' illustrated in Figure 4, may therefore also be possible.

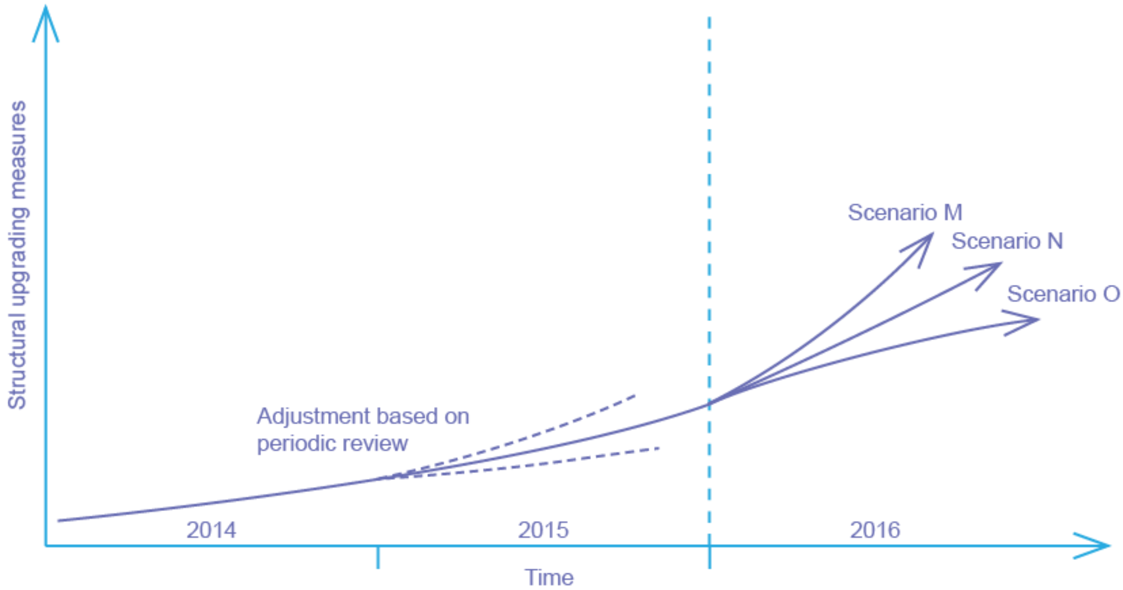

Figure 4 Large Scale Implementation Scenarios

3.3 Initial Scenario 'N'

The large scale implementation scope considered within the initial scenario 'N' has been based on the proposed prioritisation strategy and an initial area that may increase or decrease as more information becomes available on seismic hazard and threshold levels. This scenario includes the following contour areas:

- importance class I buildings (barns and sheds) will not be considered due to their relative low importance (except for large buildings with live stock);
- importance class II buildings within the PGA > 0.3g area (approx. 42,300 buildings);
- importance class III buildings within the PGA > 0.25g area (approx. 500 buildings); and
- importance class IV buildings within the PGA > 0.2g area (less than 100 buildings).

It is proposed to review the large scale implementation scope periodically. Larger contour lines have been selected for class III and IV buildings, given the importance class requirements of Eurocode 8. Table 2 informs on these importance classes used in Eurocode 8.

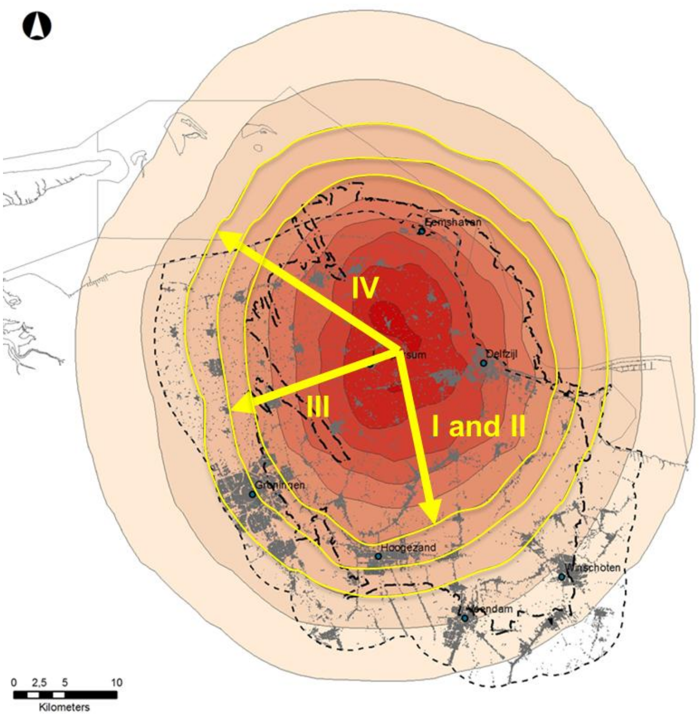

Figure 5 Scenario 'N' areas for class I/II, III and IV buildings.

Table 2 Importance classes according to Eurocode 8

Importance class EC8	Definition	Included buildings
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection	Fire stations, police stations, ambulance posts, hospitals, power plants,
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse	Buildings recognized in the Risicokaart Nederland (e.g. schools, day care centres, assembly halls, cultural institutions, large restaurants)
II	Ordinary buildings, not belonging in the other categories.	BAG* premises with addresses that are not part of EC8 categories III and IV (e.g. dwellings)
I	Buildings of minor importance for public safety	BAG* premises without addresses (e.g. agricultural buildings, barns and garden sheds)

*Basisregistratie Adressen en Gebouwen

The breakdown of the preliminary numbers of class II, III and IV buildings for scenario 'N' are shown in Tables 3, 4 and 5 below, in order to get a feel for the order of magnitude. In Appendix A, the development of these numbers is explained.

Table 3 Class II buildings.

Building	Number of buildings	Number of adresses	Mean surface area [m2]*
Detached	15.600	15.600	177
Semi-detached	8.100	8.100	120
Terraced	13.800	14.500	107
Flat and apartment	600	5.500	83
Commercial and Industrial	700	800	724
Agricultural	1.000	1.000	903
Miscellaneous	?	2.000	400
Total	42.300	47.500	169

Sources used: Location of emergency services (Imergis, December 2012) and production facilities (BAG & Hoogspanningsnet)

* Following the Dutch definition *Gebruiksoppervlakte (GBO)*

Table 4 Class III buildings.

Building	Description, examples	Number of adresses	Total surface area [m2]*
Residential	Housing for target groups, e.g. elderly	688	176.000
Shopping	Large shopping buildings	52	71.000
Sports		20	70.000
Education	Primary schools, secondary schools	124	199.000
Horeca	Hotels, restaurants	7	26000
Offices		11	7.000

Building	Description, examples	Number of adresses	Total surface area [m2]*
Industrial	Factories, storage	49	134.000
Health	Nursing homes	20	44.000
Prisons etc		1	3.000
Meeting functions	House of prayer, day care, large bars	127	85.000
Other	Cultural, transformation house	35	10.000
Total		**1.134 (504 buildings)**	**825.000**

Sources used: Nationale risicokaart, (Interprovinciaal Overleg, September 2013), BAG (Kadaster, Juli 2013)

* Following the Dutch definition *Gebruiksoppervlakte (GBO)*

Table 5 Class IV buildings.

Building	**Number of buildings**	**Total surface area [m2]***
Ambulance posts	3	350
Fire stations	16	8.000
Police stations	10	12.000
Hospitals	2	470.000
Power plants	4	n/a
NAM gas distribution station	> 20	n/a
Transformer, switching and distribution stations	> 17	n/a
Total	> 72	

Sources used: Location of emergency services (Imergis, December 2012) and production facilities (BAG & Hoogspanningsnet)

* Following the Dutch definition *Gebruiksoppervlakte (GBO)*

3.4 Structural Upgrading and Intervention Levels

The Structural Upgrading Study has identified the requirement for upgrading interventions depending on the level of seismic hazard at the building location and its seismic resistance. The proposed upgrading interventions reduce risk, and are based on a balance between speed of implementation and minimizing disruption.

Seven permanent intervention levels have been characterised within the aforementioned study that form the basis for the structural upgrading works described in this implementation study. There is a step change in time and complexity between one level of intervention and the next.

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.

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.

4 Implementation Methodology

4.1 Work Breakdown Structure

The following section informs on the proposed work break down structure for the implementation works. The process is outlined in Figure 6.

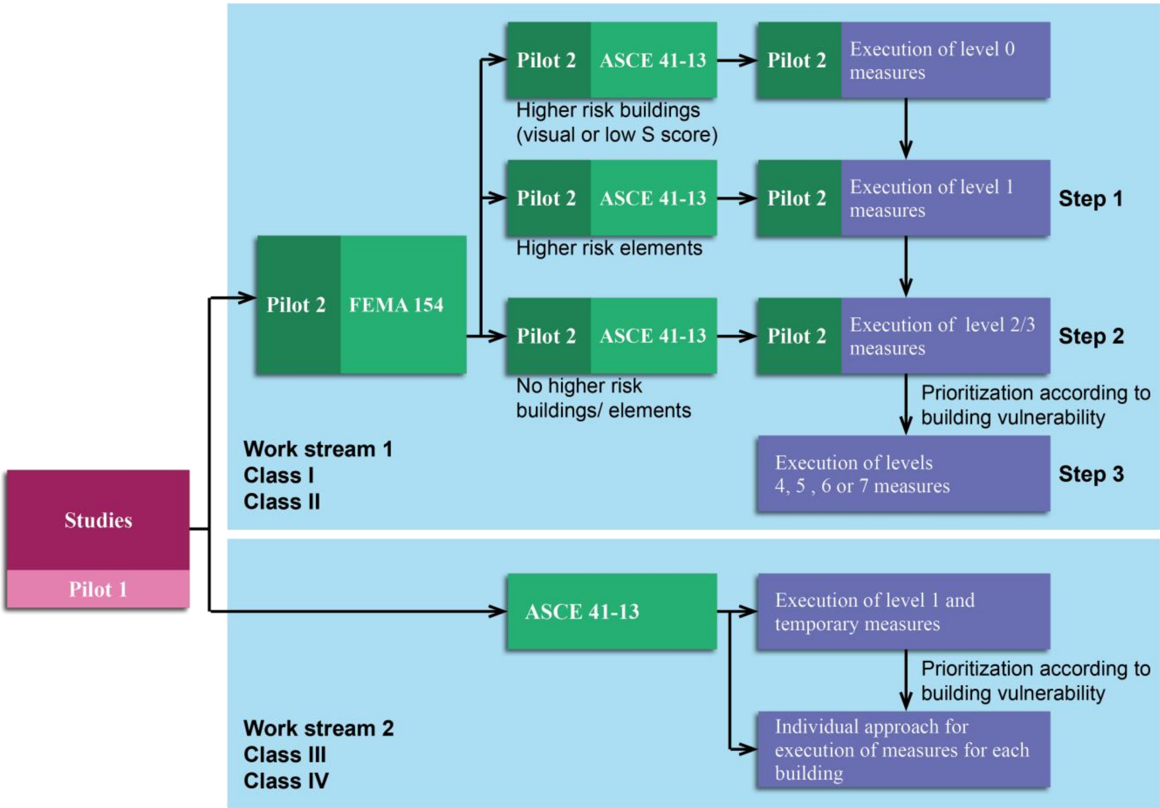

Figure 6 Break down structure for implementation based on prioritisation approach.

As per Figure 8, two work streams have been identified to undertake the proposed implementation works. The differences and characteristics of each work stream are informed on in Table 6.

Table 6 Differences and characteristics between work streams.

Work Stream	**Importance Class (Euro code 8)**	**Characteristics**
Work Stream 1	Class I and II	Mainly houses, normal importance Limited amount of typologies of houses Large scale High repetition Standard design solutions Relatively ‘simple’ measures to implement
Work Stream 2	Class III and IV	Important post-earthquake function or severe consequences if building would fail during an earthquake Many different typologies of buildings Smaller scale Less repetition Individual design solutions More complex measures to implement

The two different work streams make it is possible to develop a specific implementation approach in accordance with the characteristics of buildings (as per the importance classes in Euro code 8).

Work stream 1:

Consecutive steps for executing intervention levels are proposed in section 4.4.5.1. This approach makes it possible to initially focus on the implementation of measures that reduce the general risk level as quickly as possible. The steps correspond with the intervention levels described in Section 3.4.

Work stream 2:

Work Stream 2 requires a building-specific approach, since the variation in building types is higher than in Work Stream 1. For all class III and IV buildings an ASCE 41-13 assessment has been proposed, starting in the town of Loppersum during Pilot 2. Prioritisation of execution is proposed to be based on the outcomes of the ASCE assessments. For all class III and IV buildings, a building-specific plan is proposed how to structurally upgrade the building and, if necessary, how to reduce risks quickly. If possible, buildings will be grouped by building characteristics or function.

4.2 Prioritisation

Given the objectives mentioned in section 2.1 and the extent of the area and the number of buildings in this area, a prioritisation approach has been developed. 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 (see Figure).

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

4.3 Inspection Methodologies

4.3.1 Introduction

Building inspection is a trade-off between speed and accuracy of information. A very cursory and rapid survey may not identify the highest risk buildings, whereas a more detailed survey may mean that too much time is spent on each building and progress on risk reduction through upgrading the highest risk buildings is slow. The approach to this trade-off is typically a multiple stage screening process, in which initial rapid visual screening is used to identify highest priority buildings for more detailed assessment and structural upgrading.

In the United States, this screening procedure is documented through several publications from the American Society for Civil Engineers (ASCE) and the Federal Emergency Management Agency (FEMA):

- FEMA 154: Rapid Visual Screening of Buildings for Potential Seismic Hazards. This documents a form-based, external-only seismic assessment. It is calibrated on typical building typologies in the US, and also makes use of knowledge about when seismic design codes were introduced in various states. It also identifies when falling hazards (such as chimneys and parapets) are present; and

- ASCE 31-03: Seismic Evaluation of Existing Buildings. This covers three levels of seismic assessment, Tier 1 to Tier 3, of increasing levels of detail. Tier 1 assessment is essentially check-list based, with limited numerical calculations, while Tiers 2 and 3 are based on quantitative calculations;

- ASCE 41-06: Seismic Rehabilitation of Existing Buildings. This includes more detailed quantitative guidance on assessing different types of buildings, and also documents the design of seismic rehabilitation works; and

- FEMA 547: Techniques for the Seismic Rehabilitation of Existing Buildings. This guide is used to identify appropriate seismic retrofit options when seismic deficiencies have been identified by assessment. It also documents advantages and disadvantages of each method.

ASCE 41-13 is due to be published in January 2014. This new version combines and updates the evaluation and rehabilitation guidelines currently contained in ASCE 31-03 and ASCE 41-06.

In this study, rapid visual screening based on a modified FEMA 154 approach and detailed seismic assessment based on the ASCE 41-13 (draft version) are recommended.

4.3.2 Rapid Visual Screening

Rapid visual screening identifies high risk building elements and high risk buildings and also ranks buildings for further (internal) assessment.

The FEMA 154 screening methodology was specifically developed for the US building stock and makes use of knowledge of seismic design codes that were in place at the time a given building was constructed. It gives an indication whether a given building is adequate with regard to seismic safety. The outcome of the FEMA 154 rapid visual screening (RVS) is a building score, S, which relates to the probability of collapse in the “Maximum Considered Earthquake” (which is the basis of seismic design in US building codes). This building score has been used for the Groningen area, but has not yet been calibrated. Therefore this building score can only give a relative indication of the building vulnerability within the pool of buildings that have been surveyed.

The Structural Upgrading study has identified a number of particularly vulnerable building types; those buildings with a high percentage of openings in walls are particularly vulnerable. Therefore, a modified version of FEMA 154 is adopted here for the rapid visual screenings. The modified procedure is detailed in Appendix B.

The RVS procedure is aimed at identifying the following:

- Class II buildings which pose an urgent life safety risk (due to pre-existing damage or state of repair);
- External higher risk building elements, such as chimneys and parapets. If required, this information will be passed on to contracting teams responsible for removal of these high-risk elements; and
- A building score, *S*, will be calculated for each building. In-house surveys (as required) will be carried out based on relative S scores. Meaning that higher risk buildings will be dealt with first.

4.3.3 Internal Assessment (ASCE 41-13)

In order to properly assess a building’s seismic performance, it is also necessary to assess buildings from the inside, and in more detail than is undertaken in a rapid visual screening (external).

The ASCE 41-13 assessment is proposed to be used for internal surveys of buildings. This comprises a number of checklists which are used to identify deficiencies in the building that could compromise its seismic safety. The assessment includes structural components (such as ensuring that there is a complete load-resisting system that can withstand the seismic forces) and non-structural components (such as large pieces of heavy equipment) are anchored to the floor.

The ASCE 41-13 assessment consists of three tiers. Tier 1 is an in-house survey which is proposed to be performed for every building. Tier 2 is a ‘deficiency only evaluation’, tier 3 a full evaluation of the whole structure of the building. For the Groningen 2013 programme tier 2 and tier 3 are combined in ‘detailed design’. In this report the ‘ASCE 41-13 Tier 1 survey’ is referred to as the ‘ASCE 41-13 survey’.

Throughout the Pilot 1 and 2 assessment programmes, the applicability of ASCE 41-13 to Dutch building stock will be re-evaluated, and lessons from on-going structural upgrading studies will be incorporated into the assessment guidelines to be used in Groningen.

4.3.4 Prioritisation of Inspections

Priorities are proposed to be determined by a desk study, utilising information that has already been collated in the building database and the PSHA results discussed in Section 1.3.

Inspection teams are proposed to be assigned to both work streams 1 and 2, which makes it possible to control the relative priority assigned to (for example) important buildings with moderate seismic hazard and normal importance buildings with high hazard. Since there are significantly fewer buildings in the higher importance work stream (work stream 2), this will also allow short term risk reduction to be made on the buildings with an important post-earthquake function or other severe consequences of failure in an earthquake.

Rapid visual screening is not proposed for class III and IV buildings. Instead, assessments are proposed to proceed directly to in-house assessments. This decision was made for several reasons:

- Risk reduction for these buildings is a high priority, and their importance warrants more detailed assessment from the beginning;
- The rapid visual screening approach is calibrated for class II buildings, and may not give a good estimate of seismic risk for class III and IV buildings; and
- Class III and IV buildings are likely to require significant time for rapid visual screening and this time is better spent on an overall in-house building assessment.

Rapid visual screening (for class II only) and in-house assessment, if required, are proposed in order of decreasing seismic hazard (see Figure 7), such that buildings with a higher probability of experiencing an earthquake will be screened (and if appropriate, further assessed and upgraded) in the short term.

Since it is not possible to obtain an accurate assessment of building vulnerability before individual building screening is carried out, the building age has been selected as a proxy for vulnerability. This assumes that older buildings have a higher collapse risk than newer buildings. Later stages of screening and assessment can then be used to establish building-specific vulnerability estimates

To combine seismic hazard and the vulnerability based on age, screening is proposed to take place from highest to lowest hazard, carried out from the centre of towns to their perimeter. The assumption is that buildings in the centre are the oldest, as the towns are likely to have grown outwards from their historical centre as they have developed. Therefore, it is proposed to give seismic hazard implicitly the highest weight, but within built-up areas over which the seismic hazard is approximately constant, age (and therefore vulnerability) is also taken into account. This philosophy is shown in Figure 7 below.

The prioritisation of inspections is proposed to be reviewed periodically. If new criteria are found that impact the currently proposed process, such as for instance building type vulnerability, then the aforementioned process can be altered.

4.4 Execution Methodology

The outcome of the ASCE 41-13 survey is the start of the execution phase, which consists of the following activities:

1. Design;
2. Building owner consultation
3. Permit application process
4. Tendering; and
5. Construction.

4.4.1 Design Methodology

The design process consists of three phases

1. **Concept design:** For class II buildings design is proposed to be based on the design guidelines of standard upgrading measures that will be developed as a result of the Structural Upgrading Study. For class III and IV buildings concept design is proposed to be developed for each building on an individual basis. Concept design describes the type of measures that have to be executed for each building at a generic level.
2. **Detailed Design:** Following concept design, detailed design is proposed to be developed to the level of tender and permit application documents (for those buildings requiring a building permit) or to the level of a 'work description' document if no building permit is required.
3. **Working stage drawings:** Depending on the complexity of a building or the complexity of upgrading measures, detailed design will be elaborated into working stage drawings.

4.4.2 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).

4.4.3 Permit Application Process

The process of permit application and granting of permits is a critical element within the programme. Permit applications will be based on the drawings and calculations that are developed in the detailed design phase. For structural upgrading measures requiring a building permit, execution cannot start before the permit is granted.

However, there are currently several issues within the permit application process that need to be resolved with planning permission agencies at earliest.

- How permit application is undertaken in lieu of a regulatory frame work against which structural upgrading measures can be assessed;
- Clarify as of which intervention levels (measures) building permits are required; and
- Clarify if a fast track process can be developed for urgent cases.

Consultation on this subject has just started within the core hazard area (Loppersum) with the relevant permitting agencies.

When the aforementioned permitting issues have been clarified with the relevant permitting agencies (such as Bouw- en woningtoezicht and Monumenten zorg), the following actions are also recommended:

- There are several municipalities within the contour line areas proposed in Figure 5. Each municipality has its own permit agency responsible for permitting. To make the permit process more efficient, it is recommended that consultations with the municipalities about installing and mandating a central permit agency for the entire region for the Groningen 2013 programme are started at earliest;
- Train permit assessors on international guidelines (Eurocode and ASCE) used to develop structural upgrading measures, as well as the NPR guide line as soon as this is made available;
- The scale of the foreseen structural upgrading process provides permitting process opportunities, such as:
    1. Agree with permit agency on standard and accelerated procedures;
    2. Apply for permits based on agreed standard formats;
- Bundle permit applications for typical houses as much as possible; and
- Automate the permit application process as much as possible.

4.4.4 Tendering

High involvement of (local) engineering firms, architects, contractors, suppliers and other construction industry affiliated parties is recommended during the implementation of upgrading measures during Pilots 1 and 2. An effective tendering process for both Pilots is currently being developed in consultation with NAM.

Following this implementation study a detailed contracting strategy will be developed in the Implementation plan for the Large Scale Implementation works.

4.4.5 Construction

4.4.5.1 Work stream 1

In Work Stream 1, consecutive steps have been identified for execution, which makes it possible to focus on implementing measures that reduce the general risk level as quickly as possible in a stepped manner. The consequence of implementing intervention levels in a stepped manner is that inhabitants can be inconvenienced over a longer period of time (as not all measures can be implemented at once). The steps correspond with the intervention levels as described in Section 3.4:

Step 0 Execution of temporary measures for high risk buildings. High risk buildings can be identified in the rapid visual screening (class II) or the internal ASCE 41-13 surveys (class II, III and IV). If a high risk building is identified, immediate actions should be undertaken in view of life safety. Actions could include implementing temporary measures such as bracing or temporarily relocating the building's occupants.

Step 1 Execution of intervention level 1 measures, can be applied to reduce high risk building elements such as slender chimneys or damaged parapets. These elements can be identified as part of the rapid visual screening (class II) or the in-house surveys as part of the ASCE 41-13 assessment for class II, III and IV buildings.

Step 2 Execution of intervention level 2 measures (floor-wall tying) and level 3 measures (stiffening of diaphragms). From the current preliminary results of the structural upgrading strategy [REP/229746/SU003] it is assumed that level 2 and 3 measures can significantly affect the resilience of buildings. In the ASCE 41-13 assessment buildings can be identified for which level 2 and 3 measures are necessary.

Step 3 Due to the current uncertainties relating to seismic hazard and the vulnerability of the building stock, measures associated with intervention levels 4-6 for class II buildings are anticipated to start when these uncertainties have been reduced through further studies. Note that ideally steps 4-6 should be executed in one procedure for each building to minimise disturbance to inhabitants. Execution is proposed to be prioritised in order of building vulnerability as identified in the ASCE 41-13 assessment.

Implementing steps 0-2 is proposed to start while studies to reduce uncertainties are further progressed.

Pilot 2

To test the implementation methodology for work stream 1 as described above, Pilot 2 is proposed to be performed. Pilot 2 consists of the following elements:

1. Testing the developed systems, procedures and tools for rapid visual screening. The test started in October 2013 and will be performed to the approximate 1700 houses in Loppersum;
2. Testing the developed method for the ASCE 41-13 surveys for the high risk class II buildings identified in the RVS. Starting Q1 2014;

3. Testing the developed ASCE 41-13 surveys method for all class II buildings in Loppersum for large scale implementation step 2/3. Starting directly after the ACSE 41-13 survey for the high risk buildings; and
4. Testing the design, permit, tender and execution process for temporary measures and intervention levels 1, 2 and 3 for class II buildings in Loppersum.

These elements are shown in Figure 8.

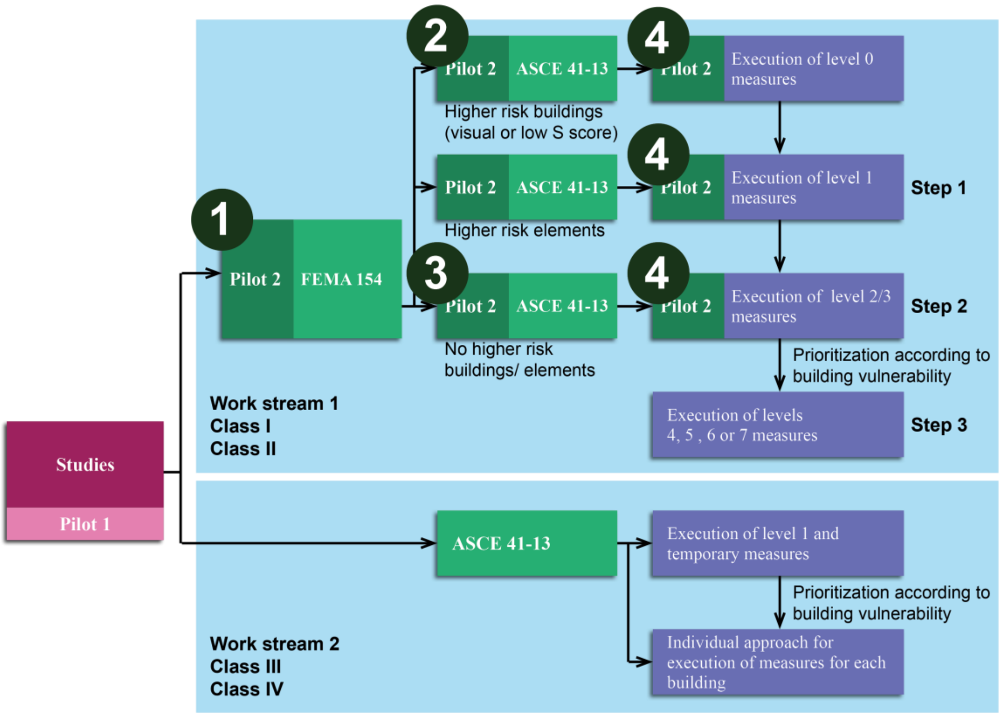

Figure 8 Elements of Pilot 2.

Note: *Pilot 1 forms part of the uncertainty reduction studies, which is proposed to commence before Pilot 2 execution works start. As such, the intervention levels 2 and 3 that are proposed to be undertaken during Pilot 2 will be technically tested on buildings during Pilot 1*

4.4.5.2 Work Stream 2

In comparison with work stream 1, variance in building types in work stream 2 is higher, standard design solutions are not applicable and repetition is less (or even absent). Developing standard steps for implementing upgrading measures for buildings in Work stream 2 is therefore not possible. However, urgency to reduce risk levels is even higher because of the importance of these buildings. Therefore a more individual approach is proposed for the class III and IV buildings.

On the basis of the ASCE 41-13 survey, measures to reduce high risks quickly may be required. Parallel an individual design for each building will be developed to structurally upgrade the building. If possible buildings should be grouped like for example schools and elderly homes.

4.5 Information Management

Because of the quantity and variety of buildings involved in the proposed structural upgrading strategy, it is recommended to develop a strongly automated process to facilitate an effective implementation process.

The following is currently recommended in this regard:

- A well-defined information management system to also assist the quality management strategy for the structural upgrading strategy;
- Develop a core database system in which all data is collected;
- Develop an information management system that combines easy-to-access and easy-to-use systems through a technical automation system , whereby professional support capabilities are provided for the structural upgrading strategy programme;
- At the same time flexibility will also be required to manage the processes that come with construction works. This way quality can be managed on the level of the overall programme as well as on the detailed level of measures to be implemented in an individual building at a given moment in execution; and
- All processes are recorded as information is added during the design and construction stages for further archival.

4.6 Monitoring Risk Reduction

Using the aforementioned information management system, the proposed step wise reduction of risks can be quantified and monitored. For instance, when risk mitigating or structural upgrading measures have been implemented on a building, this can then be logged in the overall data base and provide an updated risk assessment outcome (or risk map). New results from studies and their subsequent impact on the proposed strengthening measures can also be monitored, thereby providing an insight into the extent to which the overall risk to the Groningen region has been reduced over time.

4.7 Owner/ Community Engagement

Owner / Community engagement is expected to critically influence the success of implementation, as owner approval is required to carry out activities in their building (ASCE 41-13 survey, construction works).

To enhance this engagement the following should at least be considered:

- Prioritisation is risk based and therefore explainable (logical). Highest risks are reduced first, similar cases are treated similarly;
- People should actively be informed about the programme, the planning of execution and the consequences for their personal situation.
- Consultations with authorities are proposed to discuss the information and communication process with inhabitants and the permit application process.

4.8 Social Return

In order to achieve the objective that the ‘programme is generally socially accepted’, it is recommended to have a significant part of the works performed by local/regional companies and people (providing these people and parties have the required knowledge and skills to perform the works).

It is recommended to draft a social return policy for the entire structural upgrading strategy as part of the future implementation plan. Potential considerations are:

- Use a minimum level of local personnel as a requirement in construction contracts;
- Use social return as a selection criterion in tenders;
- Enabling inhabitants to combine the execution of measures with maintenance works or the execution of sustainability measures.

5 Programme (Time schedule)

5.1 Indicative Programme

In line with the prioritisation methodology described in Section 4.2, an indicative program for the currently foreseen structural upgrading works has been developed (see below Figure 9).

This indicative time schedule is predominantly aimed at the currently foreseen Pilot 1 and 2 works in 2014 and 2015. Periodical review sessions are intended to balance the scheduled works with the latest status of important parameters (such as the seismic hazard and threshold levels).

This indicative program is based on the implementation methodology described in Section 4.

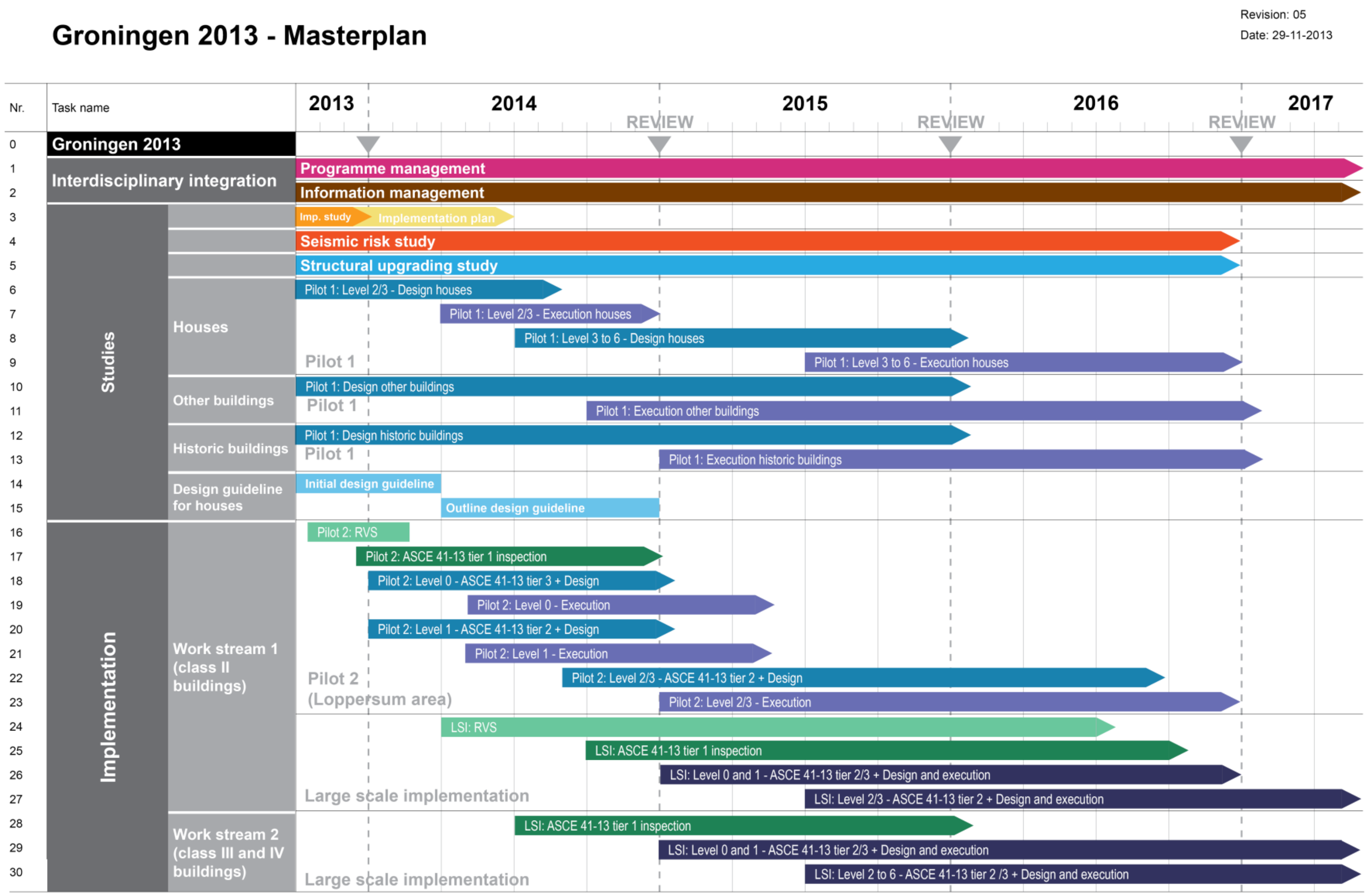

Figure 9 Time Schedule

5.2 Program Uncertainties

The following factors have been identified that influence the time schedule significantly:

- Start and scope of large scale implementation works in relation to more refined information becoming available on current uncertainties over the next 1-3 years;
- Cooperation of building owners is necessary to carry out activities in the building;
- Lead times for permit application and granting depend heavily on cooperation of permit agencies;
- Availability of resources; and
- Availability of temporary housing. Temporary housing may be necessary for the execution of step 3 (intervention levels 4-6) and might be needed (on a smaller scale) for the execution of step 2 (intervention levels 2 and 3).

6 Perspective on Organisation

6.1 Management of Structural Upgrading Works

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.

6.2 Structuring the Organisation

It is recommended that the organisation structure matches the activities defined in the Implementation Plan. Within the organisation it is recommended that responsibilities are assigned to dedicated teams and / or individuals focussing on main processes such as:

- Pilot 1 works;
- Pilot 2 works;
- Large Scale Implementation works;
- The permit application process;
- Safety, Health and Environment (SHE);
- Information management;
- Legal team;
- Process & Quality Assurance ; and
- Communications.

7 Conclusions and Recommendations

Conclusions

Given the objectives of this implementation study and the extent of the area affected by induced earthquakes (considered in scenario ‘N’), it is not considered feasible to immediately carry out full scale structural upgrading measures to all buildings in this area. Moreover, the predictions of seismic hazard, building vulnerability, overall seismic risk and scenario ‘N’ have been done under high uncertainties. Because of these uncertainties, it is too early to implement a definitive upgrading program and a phased approach is therefore proposed;

Prioritisation is risk based. This means that rapid visual screenings (RVS) are performed working from the core of the hazard area towards the outer borders. ASCE 41-13 assessments should be performed based on the outcomes of the RVS. Structural upgrading measures can be executed, as required, based on the outcomes of the ASCE 41-13 assessments; and

Further studies are expected to reduce current key uncertainties in the coming three years. The implementation strategy proposed in this report has focussed on this period (2014-2016). During this three year period, the total scope of the Large Scale Implementation programme is expected to become more refined also with regards to the expected costs and time schedule. During this three period, periodical review sessions are proposed to allow the scope of the implementation works to be balanced with the latest findings from the uncertainty reduction studies and Pilots 1 and 2.

Recommendations

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 periodical evaluation of the pilot projects (Pilot 1 and 2) before the roll-out of the complete program after 2016.

References

[1] REP/229746/ST001 Structural Upgrading Strategy, 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/SU003 Structural Upgrading Study, Arup, Amsterdam (29-11-2013).

[4] Eurocode 8 (EN 1998) Design of structures for earthquake resistance, European Standard (English version)

[5] ASCE/SEI 41-13 (2014), Seismic Evaluation and Retrofit of Existing Buildings, American Society of Civil Engineers, Reston, Va

Appendix A

Classification and Determination of Buildings

A1 Eurocode 8 Classes

Eurocode 8 classifies buildings in four importance classes depending on:

- The consequences of collapse for human life;
- Their importance for public safety and civil protection in the immediate post-earthquake period;
- The social and economic consequences of collapse.

A2 Eurocode 8 in the Dutch Context

There is no Dutch national annex for Eurocode 8 providing definitions for importance classes. The building counts for importance classes have been obtained by interpreting the general descriptions in the Dutch context. For this, data from a number of sources have been combined in GIS (Geographical Information System) software.

A3 Selection Criteria

Table 8 shows how the available has been used to interpret the Eurocode 8 definitions in the Dutch context. Using these selection criteria, the number of buildings within each PGA contour has been assessed.

Table 7 Interpretation of Eurocode 8 definitions in Dutch context.
*Basisregistratie Adressen en Gebouwen

Importance class	Eurocode 8 definition	Selection criteria applied
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection	Fire stations, police stations, and ambulance depots from open source data provided by Imergis and hospitals from the Risicokaart Nederland.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse	Vulnerable objects as defined by the Risicokaart Nederland, excluding hospitals.
II	Ordinary buildings, not belonging in the other categories.	Buildings from the BAG* with an address that are not part of EC-8 categories III and IV (e.g. most residential and commercial buildings).
I	Buildings of minor importance for public safety	All buildings from the BAG without an address (e.g. barns, sheds and garages).

A4 Building Data and Addresses (Kadaster, June 2013)

Building data (such as contours) and corresponding address information are obtained from the Basisadministratie Adressen en Gebouwen (BAG). The BAG is the official and explicit recording of all buildings and addresses in the Netherlands. For the purpose of assigning Eurocode 8 importance classes, building outlines with an address and outlines without an address are being distinguished.

A5 EC8 Class IV Buildings

Location of fire stations, police stations and ambulance depots (Imergis, December 2012)

Through the ArcGIS online web map service, the location of all fire stations, police stations and ambulance posts in the Netherlands is available (see Figure 10).

Production facilities (BAG & Hoogspanningsnet)

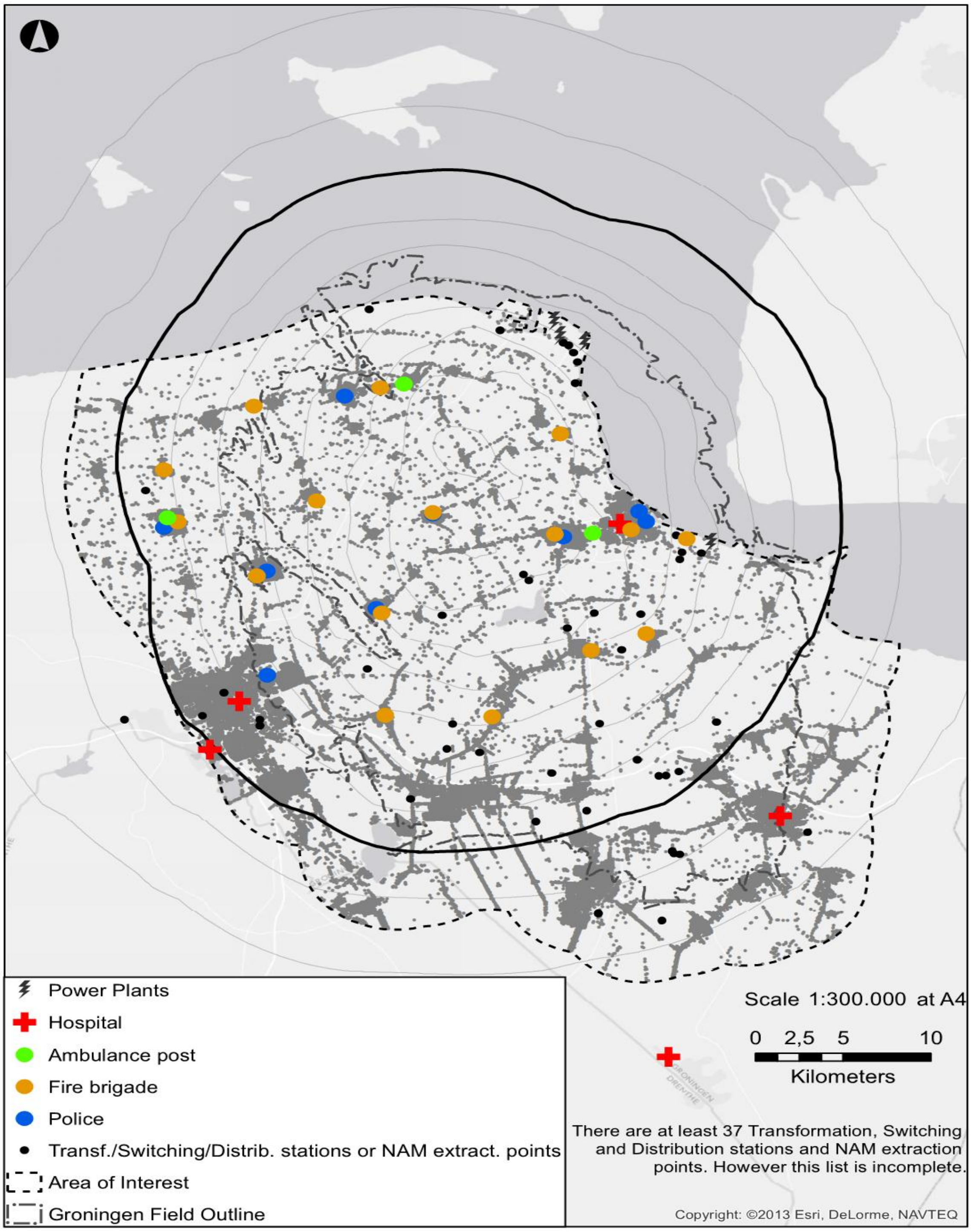

Figure 10 Class IV buildings

A6 EC8 class III buildings

Vulnerable objects with regard to disasters (Interprovinciaal Overleg, September 2013)

The Risicokaart Nederland (Risk map Netherlands) is an interactive map and informs people about risks of 18 types of disasters in their environment. This map also features the location of vulnerable objects, i.e. buildings where either many people could be present or where people are present that are not self-rescuing (patients, elderly, children).

The following vulnerable objects, with corresponding selection criteria, can be distinguished within the study area (see Figure 11):

1. Residential buildings:
   - Housing, > 10 persons;
   - Elderly home, > 10 persons;
2. Buildings with a lodging function:
   - Hotel, > 10 persons;
   - Guest house/night accommodation, > 10 persons;
   - Day care (children / disabled people), > 50 persons;
3. Buildings with an educational function:
   - School (students < 12 years), > 10 persons;
   - School (students > 12 years), > 250 persons;
   - Children day care, > 10 persons;
4. Health care buildings:
   - Hospital, > 10 persons;
   - Nursing home, > 10 persons;
5. Industrial buildings:
   - Factory, 250 - 500 persons;
   - Transit warehouse, storage, > 1,000 m2;
6. Garages:
   - Garages (storage and parking only), > 1,000 m2;
7. Public buildings:
   - Theatre, music hall, cinema’s, auditorium, 250 - 500 persons;
   - Museum, library, 250 - 500 persons;
   - Community centre, > 250 persons;
   - Religious building, > 250 persons;
   - Exhibition centre, > 500 persons;

- Sports hall, stadium, > 250 persons;
- Indoor swimming pool;
- Shopping mall, 500 - 1,000 persons;
- Temporary building > 50 persons.

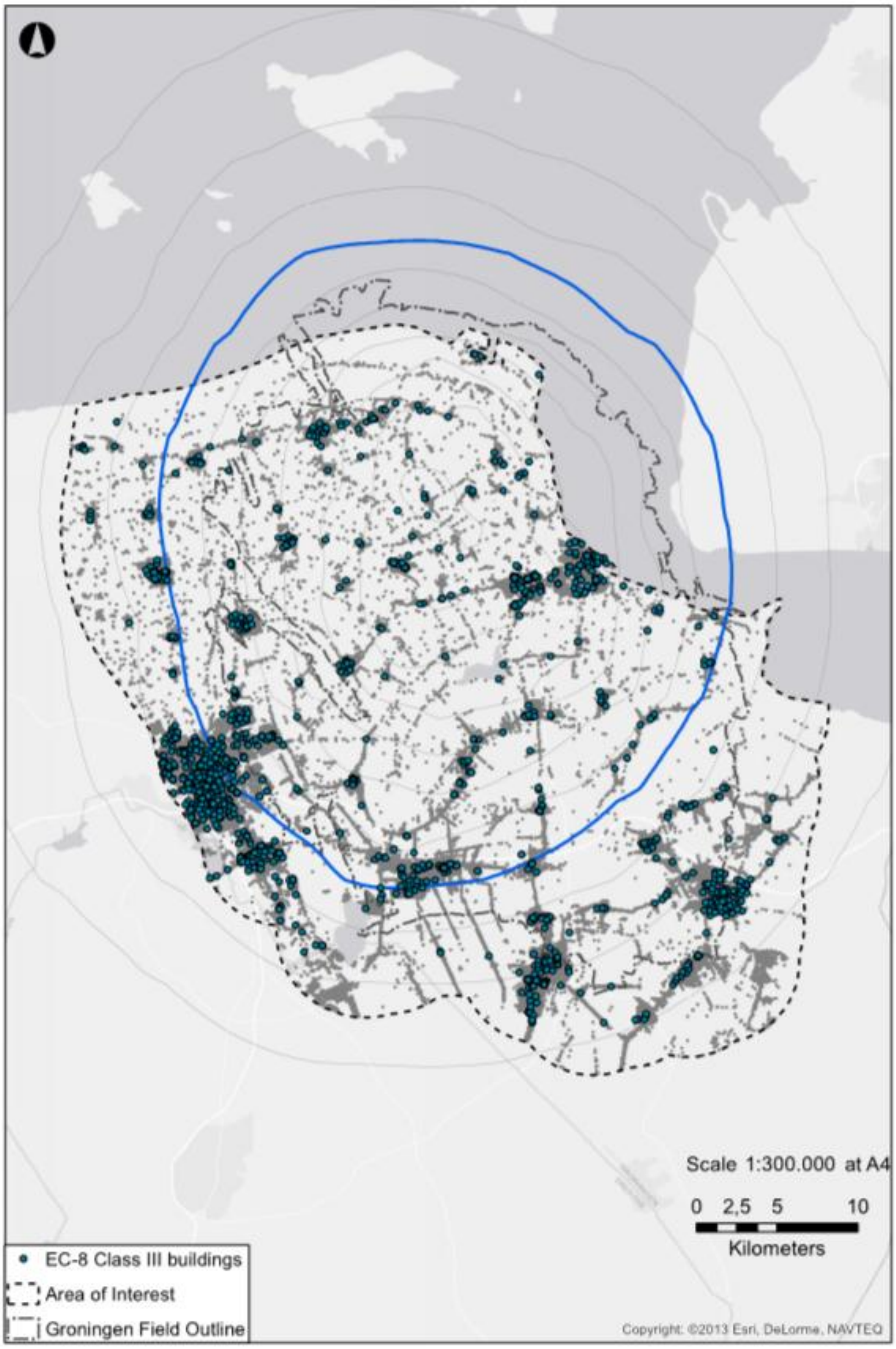

Figure 11 Class III buildings.

Table 8 Class III buildings.

Building	Number
Elderly home / nursing home, > 10 persons	26
Community centre, > 250 persons	10
Pub, discotheque, restaurant, > 500 persons	7
Pub, discotheque, restaurant, 250 - 500 persons	22
Day care (children / disabled persons), > 50 persons	11
Factory, > 500 persons	6
Factory, 250 - 500 persons	9
Garage (for storage and parking only), > 1,000 m2	1
Church, > 250 persons	44
Prison, > 10 persons	2
Hotel, > 50 persons	15
Hotel, 10 - 50 persons	9
Room rental, > 4 persons	1
Camping site / marina, > 250 persons	0
Office, > 500 persons	8
Children day care, > 10 persons	22
Clinic (policlinic, psychiatric clinic, ...), > 10 persons	17
Warehouse, storage > 1,000 m2	39
Museum, library, > 500 persons	0
Museum, library, 250 - 500 persons	2
Pension/night accommodation, > 50 persons	7
Pension/night accommodation, 10 - 50 persons	17
School (students < 12years), > 10 persons	134
School (students > 12 years), > 500 persons	6
School (students > 12 years), 250 - 500 persons	14
Sports hall, stadium, > 1,000 persons	2
Sports hall, stadium, 250 - 1,000 persons	15
Station building, 250 - 500 persons	0
Housing, shelter, > 10 persons	11
Exhibition building, > 500 persons	2
Theatre, music hall, cinema, auditorium, > 500 persons	2
Theatre, music hall, cinema, auditorium, 250 - 500 persons	2
Temporary building, > 50 persons	1
Nursing home, > 10 persons	5
Shopping mall, > 1,000 persons	4
Shopping mall, 500 - 1,000 persons	9
Homes (commercial) with non-self-rescuing inhabitants, > 10 persons	12
Swimming pool	10
Total	504

A7 Disclaimer

The counts of the various building types as presented in this study have been compiled from different sources and are meant to give an impression of the number of buildings. They cannot be considered as definitive figures.

Appendix B

Implications of Modelling Uncertainties

B1 Implications of modelling uncertainties

This appendix gives more details on the assumptions behind the “tornado plots” shown in Section 2.3 in the discussion of the implications of modelling uncertainties.

The “baseline” assumptions are the following:

- Seismic hazard follows the Shell P&T map with a peak value of 0.55g;
- Threshold PGA level (vulnerability) for which level 1-3 interventions are required is 0.1g;
- Threshold PGA level (vulnerability) for which level 4-7 interventions are required is 0.2g;
- Ductility factor for in-plane URM masonry wall checks is approximately m=3;
- Analysis method is modal response spectrum (MRS) analysis;
- Required safety level for existing construction is as required for new construction (i.e. 100% of new building requirements);
- Duration effect on seismic resistance (for stronger intervention measures) is not taken into account;
- Knowledge factor (that reduces seismic resistance) is 0.75.

The baseline numbers of buildings for Levels 1-3 and Levels 4-7 interventions are calculated from the Shell P&T map, based on counting the number of buildings in the building database within the threshold vulnerability levels noted above.

Each of the items in the list above is varied in turn, and the relative effect on the baseline number of buildings is evaluated. It is assumed that the seismic hazard contours are adjusted uniformly; for example, considering the peak hazard value of 0.55g reducing to a value of 0.3g, all the contours are multiplied by a factor 0.3/0.5 = 60%, and the number of buildings within the threshold vulnerability contour are evaluated.

The following sensitivities are evaluated:

- Seismic hazard peak value decreases to 0.3g (i.e. all hazard contours multiplied by 60%);
- Threshold PGA level (vulnerability) for which level 1-3 interventions are required increases to 0.2g;
- Threshold PGA level (vulnerability) for which level 4-7 interventions are required increases to 0.3g or decreases to 0.15g;
- Ductility factor for in-plane URM masonry wall checks increases to m=5 (i.e. vulnerability for stronger interventions multiplied by 5/3) or decreases to m=1 (i.e. vulnerability for stronger interventions multiplied by 1/3);

- Analysis method is non-linear time history analysis (NLTHA) or equivalent lateral force method (ELF), which are assumed to remove the need for any stronger interventions (for NLTHA) and to multiply the vulnerability level for stronger interventions by 85% (for ELF);
- Required safety level for existing construction is 67% of new construction (i.e. hazard levels multiplied by 0.67);
- Duration effect on seismic resistance such that vulnerability could be multiplied by 0.75;
- Knowledge factor can be increased to 1.0 (i.e. vulnerability can be increased by 1.0/0.75 = 4/3).

Each of these values should be interpreted as possible lower and upper bounds of 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 and the effect on the baseline response is evaluated. The effect of varying multiple parameters (e.g. reducing the seismic hazard and increasing the vulnerability) is not considered in the tornado plots.

Appendix C

Glossary

Glossary

General

Accelerogram: A record of acceleration versus time during an earthquake obtained from an accelerometer.

Accelerometer: An instrument used to measure ground accelerations caused by an earthquake.

Aleatory Variability: This is the natural randomness in a process. For discrete variables, the randomness is parameterised by the probability of each possible value. For continuous variables, the randomness is parameterised by the probability density function.

Attenuation: Decrease in seismic motions with respect to distance from the epicentre, depending on both geometric spreading and the damping characteristics of the ground.

Capacity: The amount of force or deformation an element or component is capable of sustaining.

Casualty classification: Severity levels (SL) are defined as:

SL 1: injuries that require basic medical aid and could be administered by paraprofessionals. They would need bandages or observations;

SL 2: injuries requiring a greater level of medical care and use of medical technology (x-rays or surgery) but not expected to progress to a life threatening status;

SL 3: injuries posing immediate life threatening conditions if not adequately treated; and

SL 4: instantaneously killed or mortally injured.

Collapse: For a given structure type, more than one failure mechanism can be identified as leading to collapse of different extents or parts of the total building envelope. Earthquake induced collapse of a masonry building is defined as failure of one or more exterior walls resulting in partial or complete failure of the roof and/or one or more floors. For an in-situ concrete building collapse is defined as failure of one or more floors or complete failure of part of the framed structure. For a steel frame building collapse refers to failure of the roof or one or more floors due to instability of the frame. For a multi-storey building, collapse refers to more than 50% volume reduction resulting from failure of the roof and one or more floors of the building.

Damage: Non-rehabilitating structural or aesthetic change following a seismic event.

Damage state classification: DS0: no damage;

DS1: negligible to slight damage (no structural damage, slight non-structural damage);

DS 2: moderate damage (slight structural damage, moderate non-structural damage);

DS 3: substantial to heavy damage (moderate structural damage, heavy non-structural damage);

DS 4: very heavy damage (heavy structural damage, very heavy non-structural damage); and

DS 5: destruction (very heavy structural damage).

Damping: A measure of energy dissipation. Damping in a structure is typically defined in terms of percent of critical damping.

Deformation: The amount by which an element or component changes from its initial shape.

Design Earthquake: A theoretical earthquake against which the building will be assessed.

Design Life: The period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.

Eurocode (EC): Standard suite of structural design guidance adopted across the European Union.

Focal Depth: The conceptual "depth" of an earthquake. If determined from high-frequency arrival-time data, this represents the depth of rupture initiation (the "hypocentre" depth).

Focus: See Hypocentre.

Free Field Ground Motion: The motion that would occur at a given point on the ground owing to an earthquake if vibratory characteristics were not affected by structures and facilities.

Frequency of Exceedance: The frequency at which a specified level of seismic hazard will be exceeded at a site or in a region within a specified time interval.

Geometric Mean: This is a type of mean or average, which indicates the central tendency or typical value of a set of numbers. The geometric mean of two numbers is given by the root square of the product of the numbers. Many GMPEs are derived for the Geometric Mean.

Ground Motion Prediction Equation (GMPE): Also known as “attenuation relationships”, these correlations estimate the ground motion due to an earthquake of a given magnitude at a specific distance. It can also consider the tectonic regime, fault characteristics, focal depth and soil conditions.

Hypocentre: Point in the earth where the seismic disturbance (earthquake) originates. Also known as focus.

In-Plane: In the direction parallel to the plane created by the element's largest dimensions.

KNMI: Koninklijk Nederlands Meteorologisch Instituut.

Large Seismic Event: A seismic event of M5.5 or greater.

Longitudinal Direction: Direction which is parallel to the plane created by the largest two dimensions of an element.

Magnitude: A logarithmic scale of earthquake size, based on seismograph records. A number of different magnitude scales exist, including Richter or local (M_L), surface wave (M_S), body wave (m_b) and duration (M_d) magnitudes. The most common magnitude scale now used is moment magnitude (M_W), which measures the size of earthquakes in terms of the energy released.

Masonry Pier: Vertical element between openings in a masonry wall.

Modal Response: An analytical tool for assessing the dynamic response of a structure's response to vibration (typically taking into account the structures mass and stiffness).

Mode: The specific behaviour of a structure under a defined frequency.

NPR: Nationale Praktijkrichtlijn (Dutch national codes of practice).

NEN: Nederlands Normalisatie-Instituut

NAM: Nederlandse Aardolie Maatschappij

Non-Linear Analysis : Analysis which accounts for deformations in an element or yielding of the material.

Out-of-Plane: In the direction perpendicular to the plane created by the element's largest dimensions.

Peak Ground Acceleration (PGA): The maximum absolute value of ground acceleration displayed on an accelerogram; the greatest ground acceleration produced by an earthquake at a site.

Probabilistic Seismic Hazard Analysis (PSHA): An assessment of the seismic hazard at a given site, taking into account in a probabilistic framework the seismic sources in the area, how often earthquakes of different magnitudes are produced by those sources, what the expected shaking at the site would be under different magnitudes (see “attenuation”) and all the uncertainties in each of these aspects.

Reference Period: A period of time over which a probability calculation is made; for example a reference period for seismic hazard may be the design life of the structure.

Response Spectrum: The plot of structural period against peak response (absolute acceleration, relative velocity or relative displacement) of an elastic, single degree of freedom system, for a specified earthquake ground motion and percentage of critical damping. Relative motions are measured with respect to the ground.

Return Period: The inverse of the annual frequency of occurrence. For example, the ground motion which has a 1% chance of being exceeded at a given point each year has a return period of (1/0.01) or 100 years.

Seismic Action: See Base Shear.

Seismic Hazard: The frequency with which a specified level of ground motion (for instance 20% of ground acceleration) is exceeded during a specified period of time.

Seismic Response: The behaviour of the structure with regards to the base shear and modal response.

Seismicity: The frequency and size of earthquake activity of an area.

Serviceability Limit State (SLS): The combination of loads which relate to the assessment of the building for the functioning or appearance of the structure or comfort of people.

Site Response: The behaviour of a rock or soil column at a site under a prescribed ground motion.

TNO: Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Dutch organisation for applied scientific research).

Transverse Direction: Direction which is perpendicular to the plane created by the largest two dimensions of the element.

Ultimate Limit State (ULS): The combination of loads which relate to the assessment of the building for the safety of people, structure or contents.

Uniform Hazard Response Spectrum (UHRS): This is a multi-parameter description of ground motion that can be generated from a probabilistic seismic hazard assessment. It is composed of a number of points which each have an equal likelihood of being exceeded in a given time period.

Unreinforced Masonry (URM): Masonry which does not contain any additional element to strengthen the masonry beyond masonry units and mortar.

Unusable: A damage state whereby a building cannot be used for its primary function – e.g. for residences, the building is not safe to occupy and for hospitals the facilities cannot be used for post-earthquake treatment.

Viscous Damping: Dissipation of seismic energy considered to be proportional to velocities in the structure. Commonly used as a mathematical model to represent sources of energy dissipation that are not explicitly accounted for in the modelling of structural elements, such as cracking in partitions or radiation energy into the soil.

Wall Ties: Objects which connect one leaf of masonry to another object (typically the internal masonry leaf).

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Capacity Assessment Method: Design method in which elements of the structural system are chosen and suitably designed and detailed for energy dissipation under severe deformations while all other structural elements are provided with sufficient strength so that the chosen means of energy dissipation can be maintained.

Damage Limitation (DL): Structure is only lightly damaged, with structural elements prevented from significant yielding and retaining their strength and stiffness properties. Non-structural components, such as partitions and infills, may show distributed cracking, but the damage could be economically repaired. Permanent drifts are negligible. The structure does not need any repair measures.

Elastic Response: Behaviour of the structure when subject to the design spectrum for elastic analysis.

Lateral Force Method: A simplified linear-elastic analysis method which applies a horizontal load to each storey. This method is only applicable to buildings which are regular in elevation and is within a limiting fundamental period.

Modal Response Spectrum Analysis: A linear-elastic analysis method which applies lateral load depending on the combined modal responses of the specific structure. This method is applicable to buildings which do not meet the Lateral Force Method criteria.

Near Collapse (NC): Structure is heavily damaged, with low residual lateral strength and stiffness, although vertical elements are still capable of sustaining vertical loads. Most non-structural components have collapsed. Large permanent drifts are present. The structure is near collapse and would probably not survive another earthquake, even of moderate intensity.

Non-structural Element: Architectural, mechanical or electrical element, system and component which, whether due to lack of strength or to the way it is connected to the structure, is not considered in the seismic design as load carrying element.

Significant Damage (SD): Structure is significantly damaged, with some residual lateral strength and stiffness, and vertical elements are capable of sustaining vertical loads. Non-structural components are damaged, although partitions and infills have not failed out-of-plane. Moderate permanent drifts are present. The structure can sustain after-shocks of moderate intensity. The structure is likely to be uneconomic to repair.

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Acceptance criteria: Limiting values of properties such as drift, strength demand and inelastic deformation used to determine the acceptability of a component at a given performance level (See also performance levels).

Collapse Prevention (S-5): Post-earthquake damage state in which the building is on the verge of partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral-force-resisting system, large permanent lateral deformation of the structure, and - to a more limited extent - degradation in vertical-load-carrying capacity. However, all significant components of the gravity-load-resisting system must continue to carry their gravity loads. Significant risk of injury due to falling hazards from structural debris might exist. The structure might not be technically practical to repair and is not safe for re-occupancy, as aftershock activity could induce collapse.

Damage Control (S-2): Midway point between Life Safety and Immediate Occupancy. It is intended to provide a structure with a greater reliability of resisting collapse and being less damaged than a typical structure, but not to the extent required of facility structure designed to meet the Immediate Occupancy performance level.

Demand: The amount of force or deformation imposed on an element or component.

Diaphragm: A horizontal (or nearly horizontal) structural element used to transfer inertial lateral forces to vertical elements of the lateral-force-resisting system.

Drift: Horizontal deflection at the top of the storey relative to the bottom of the storey.

Flexible Diaphragm: A diaphragm with horizontal deformation along its length twice or more than twice the average storey drift.

Fundamental Period: The natural period of the building in the direction under consideration which has the greatest mass participation.

Immediate Occupancy (S-1): Post-earthquake damage state in which only very limited structural damage has occurred. The basic vertical- and lateral-force-resisting systems of the building retain nearly all of their pre-earthquake strength and stiffness. The risk of life-threatening injury as a result of structural damage is very low, and although some minor structural repairs might be appropriate, these would generally not be required prior to re-occupancy. Continued use of the building will not be limited by its structural condition, but might be limited by damage or disruption to non-structural elements of the building, furnishings, or equipment and availability of external utility services.

Life Safety (S-3): Post-earthquake damage state in which significant damage to the structure has occurred but some margin against either partial or total structural collapse remains. Some structural elements and components are severely damaged but this has not resulted in large falling debris hazards, either inside or outside the building. Injuries might occur during the earthquake; however, the overall risk of life-threatening injury as a result of structural damage is expected to be low. It should be possible to repair the structure; however, for economic reasons this might not be practical. Although the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing prior to re-occupancy.

Limited Safety (S-4): Midway point between Life Safety and Collapse Prevention. It is intended to provide a structure with a greater reliability of resisting collapse than a structure that only meets the collapse prevention performance, but not to the full level of safety that the life safety performance level would imply.

Load Duration: The period of continuous application of a given load, or the cumulative period of intermittent applications of load.

Probability of Exceedance: The probability that a specified level of ground motion or specified social or economic consequences of earthquakes will be exceeded at a site or in a region during a specified period of time.

Rigid Diaphragm: A diaphragm with horizontal deformation along its length less than half the average storey drift.

Shear Wall: A wall that resists lateral forces applied parallel with its plane. Also known as an in-plane wall.

Stiff Diaphragm: A diaphragm that is neither flexible nor rigid.

Target Displacement: An estimate of the maximum expected displacement of the roof of a building calculated for the design earthquake.