Risk Assessment of Falling Hazards in Earthquakes in the Groningen region

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Editors Stuart Hardie and Jan van Elk

General Introduction

To date, NAM's hazard and risk assessment has focused on the potential risk to people in the Groningen region from building collapse during earthquakes due to failure of the structural elements of buildings. However, non-structural elements of buildings, such as chimneys, parapets, and gables, can also fail during earthquakes, posing a potential falling object risk to people inside buildings and outside in the area close to building facades. Consequently, a falling hazards risk assessment has been carried out for induced earthquakes in the Groningen region, focusing on the non-structural (particularly masonry) elements of buildings. The falling hazards risk assessment was carried out for NAM by TTAC Limited, and is based on an earlier risk model developed to assess earthquake related rockfall risk in Christchurch, New Zealand, which was extensively peer reviewed and used for government decision making. The Groningen falling hazards risk assessment is considered fit for purpose given the objectives of characterizing falling object risk across the region, supporting prioritization of the structural upgrading program, and helping to develop some practical guidelines for managing falling object risk. Quality assurance of the risk assessment has been carried out by TTAC and Arup, and the methodology has been reviewed with the Scientific Advisory Committee.

In the Groningen falling hazards risk assessment, 160,000 buildings across the region were surveyed (using an internet based survey), on which 120,000 potentially hazardous objects were identified where the objects pose a risk to publicly accessible space, are located above a door, or could fall through the roof of a building. The majority of these objects were assessed to have very low levels of risk, with 97% (approximately 117,000 objects) having an individual risk (IR) contribution of less than 10^{-6} per year. Of the remaining objects, 3600 (3%) have IR between 10^{-5} and 10^{-6} per year, and less than 100 (<0.1%) have individual risk between 10^{-4} and 10^{-5} per year. No objects were assessed with an IR above 10^{-4} per year. The objects with IR >10^{-6} per year are mainly masonry objects (particularly chimneys and gables) located in the area of highest seismicity (Loppersum and surrounding area).

Moving forwards, the results from the Groningen falling hazards risk assessment are available to the National Coordinator Groningen and the Centrum Veilig Wonen to help with the prioritization and management of falling object risk in the region. Integration of falling objects into the NAM hazard and risk assessment program is planned in 2016, so that building collapse risk and falling object risk will be assessed using the same methodology and the same seismic hazard (at present, the falling hazards risk assessment uses the KNMI October 2015 seismic hazard as input). Further scientific/peer reviews of the falling hazard risk methodology are also planned in 2016.

Title	**Risk Assessment of Falling Hazards in Earthquakes in the Groningen region**	**Date**	March 2016
		Initiator	NAM
Authors	Tony Taig Florence Pickup	**Editors**	Stuart Hardie Jan van Elk
Organization	TTAC Limited	**Organization**	NAM
Place in the Study and Data Acquisition Plan	Study Theme: Falling Object Risk Comment: This study provides an assessment of the falling object risk posed to people in the Groningen region from the failure of non-structural elements of buildings such as chimneys, parapets and gables.		
Directly Linked Research	1. Consequence model for building collapse risk (inc. out of plane failure) 2. Structural upgrading of buildings 3. Risk metrics		
Used Data	• October 2015 KNMI seismic hazard assessment • Empirical evidence on the fragility of non-structural masonry elements during earthquakes, and on people injured by falling masonry • Population data: inside buildings from NAM exposure database; and outside buildings from Locatus “footfall” measurements in Groningen city		
Associated Organization	Arup		
Assurance	Quality assurance by TTAC and Arup; methodology reviewed with Scientific Advisory Committee; further scientific/peer reviews planned in 2016		

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Executive Summary

Introduction

This report presents the results of a risk assessment for falling non-structural building elements as a result of induced earthquakes in the Groningen region. The assessment was carried over the period October 2014 to January 2016.

The scope of the assessment covers all buildings within the 0.1g contour of the KNMI 2013 map of the 475 year return period peak ground acceleration (PGA). Buildings were surveyed and hazardous objects assessed individually for the municipalities of Appingedam, Bedum, Delfzijl, Eemsmond, Groningen, Haren, Hoogezand-Sappemeer, Loppersum, Menterwolde, Oldambt, Slochteren, Ten Boer, Veendam and Winsum.

Background

Non-structural masonry components of buildings such as chimneys, parapets and gables are prone to fail in earthquakes, and have been widely observed to collapse under shaking well below that required to cause structural collapse of buildings. The associated falling debris has caused fatalities, both inside and outside buildings. To date in the Groningen region, potential falling hazards or "High Risk Building Elements" have been identified via the Rapid Visual Screening (RVS) process, involving visits to properties and external inspection. The RVS process has worked outwards from Loppersum, where seismicity is highest. Parallel inspections are also now taking place in the city of Groningen, for example for schools and other buildings where larger numbers of people might be at risk.

Purpose

The purpose of this assessment is to support risk-based prioritisation of areas for inspection of falling hazard objects, and to help develop practical rules to inform decision making about potential falling hazard objects.

This assessment is not intended for making decisions on individual objects and buildings, which requires further local knowledge both of the hazardous object and of the situation in which it is located.

Risk Metrics and Scope

In the discussions about risk the following definitions are used:

- **Local Personal Risk (LPR):** risk of fatality to an (imaginary) person in a specific location/risk area from specified hazards, assuming the person is present in the risk area 100% of the time. Unit is probability of fatality/year.
- **Community Risk (CR):** risk to a total community from specified hazards. CR in an area at risk from a falling hazard object is equal to the product of the LPR and the average number of people present in that specific area. This is a summation over everyone in a defined community. Unit is fatalities/year.

- **Individual risk (IR):** risk to a real individual from specified hazards, taking into account the time the individual spends at different locations/risk areas. IR is a summation over all at-risk locations of the product of the LPR at each location and % of time spent at that location. Unit is probability of fatality/year.

LPR, CR and IR can all be defined in relation to a single hazard or to any specified set of hazards. Throughout this study they are defined in relation to individual potential falling hazard objects. For the avoidance of doubt the terms OCR (Object-related Community Risk), and OIR (Object-related Individual Risk) are used to make this clear. Unless otherwise stated, the terms CR and IR are used throughout this study to mean OCR and OIR.

Community Risk (CR) has been used from the outset of this assessment as the risk metric of choice for prioritising objects for upgrade, because it takes into account both the level of risk individuals face and how many people are affected by the risk.

Local Personal Risk (LPR) is used as an intermediate step in the risk calculations. Note that the NEN NPR 9998 is based on a requirement for local personal risk inside buildings to be smaller than 10^{-5} per year (LPR<10^{-5}).

Individual Risk (IR) is used by Commission Meijdam, which was established by the Netherlands government to provide advice on risk policy in relation to induced earthquakes in the Groningen region. The Commission issued its final advice to Government in December 2015, as this study was nearing completion. The advice recommended that individuals should not face earthquake fatality risk higher than 10^{-5} per year (IR<10^{-5}).

In light of the Commission Meijdam recommendations, we have extended our risk model to include calculation of Object-related Individual Risk (OIR[1]) as well as of Object-related Community Risk (OCR). The results and our observations on them are presented in this report.

How to use the different risk metrics calculated in this report to prioritise objects and buildings for inspection and upgrade is outside the scope of this report. No presumptions are made in this study as to the basis on which objects should be prioritised for inspection or upgrade. Results are provided in terms of the numbers of objects in different bands of risk to help understand the implications of different possible prioritisation policy choices.

Risk Assessment Approach

The risk assessment methodology is developed from that used by GNS Science New Zealand for the modelling of rock fall impact on houses following the Christchurch earthquakes of 2010/11. The model estimates the Community Risk (CR) to people in and around buildings resulting from three particular exposure pathways:

- Passers-by exposed to debris falling outside buildings;
- Building occupants running out into falling debris, and;
- Debris falling through building roofs onto people inside.

[1] OIR is referred to as OIA (objectgebonden individueel aardbevingsrisico) in the Commission Meijdam advice

Such a model requires information on;

1. How often earthquakes of different characteristics occur at a given location;
2. The likelihood of given debris being generated from a given building component in a given earthquake;
3. Where the debris falls, and the likelihood of someone present in that area being killed by it;
4. The probability of a given person being present, and/or the number of people present, in the area where debris falls, and;
5. The number and characteristics of different non-structural elements on specific buildings that could present a significant hazard to life in the event of earthquakes.

The report explains the risk model that has been developed for this study, covering items (1) to (4) of this list. It then describes an extensive survey of falling hazard objects in the region which was carried out using Google Street View and other internet tools to address item (5), and the checks and sensitivity studies carried out on both survey and risk assessment results.

In addition to evaluating the fitness for purpose of the assessment, the checks and uncertainty studies carried out provide insight into the factors not included in the risk model which need to be taken into account in making decisions about upgrades for individual buildings or objects. The uncertainty associated with the results is around a factor of ten in either direction from the mid-range estimates presented throughout this report. Object fragility and assumptions about people's risk exposure make similar contributions to that uncertainty.

Risk Assessment Results

An overview of the results of the risk assessment in terms of numbers of different objects within different bands of Object-related Community Risk (OCR) and Object-related Individual Risk (OIR) is provided in Table ES.1.

Community Risk (OCR) fatalities/year	Individual Risk (OIR), probability of fatality/year					Totals
	$10^{-5}<OIR\leq10^{-4}$	$10^{-6}<OIR\leq10^{-5}$	$10^{-7}<OIR\leq10^{-6}$	$10^{-8}<OIR\leq10^{-7}$	$OIR\leq10^{-8}$	
$OCR>10^{-4}$	0	1	5	1	0	**7**
$10^{-5}<OCR\leq10^{-4}$	42	97	88	26	0	**253**
$10^{-6}<OCR\leq10^{-5}$	2	3319	1677	357	47	**5402**
$10^{-7}<OCR\leq10^{-6}$	1	140	21959	4624	598	**27322**
$10^{-8}<OCR\leq10^{-7}$	0	8	2284	35500	6011	**43803**
$OCR\leq10^{-8}$	0	1	485	4366	38579	**43431**
Totals	**45**	**3566**	**26498**	**44874**	**45235**	**120218**

Table ES1: Objects Identified and Assessed, by OCR and OIR Band.

Note – it is possible for objects to have OIR greater than OCR in this assessment, as the generic assumptions used in calculating OIR are based on a "representative person" and are somewhat conservative (tend to overstate occupancy), whereas the OCR estimates use more realistic estimates of the average numbers of people present in an at-risk area.

The results of the assessment can be summarised as follows;

1. Approximately 160,000 buildings were surveyed, and 120,000 potentially hazardous objects identified which were capable of falling into publicly accessible space, or were situated above a doorway, or were capable of falling from height onto a roof.
2. Risk has been assessed in terms of Object-related Community Risk (OCR) and Object-related Individual Risk (OIR) for each individual object surveyed. The risk estimates are considered uncertain within about a factor of 10 in either direction.
3. In terms of Community Risk, numbers of objects are assessed as falling in risk bands as follows;
    a. OCR ≥ 10^{-5}/year — about 260;
    b. 10^{-5} > OCR ≥10^{-6}/year — about 5,400;
    c. 10^{-6} > OCR ≥ 10^{-7}/year — about 27,000;
    d. OCR < 10^{-7}/year — the remainder (about 87,000).
4. Chimneys, parapets and gables account for the majority of such higher OCR cases.
5. Higher OCR cases predominantly involve exposure via running out of doorways and objects falling from an elevated height through roofs rather than objects falling onto people in public space outside buildings.
6. The numbers of objects assessed in different bands of occupancy-adjusted individual risk (OIR) are
    a. OIR ≥ 10^{-5}/year — 45;
    b. 10^{-5} > OIR ≥ 10^{-6}/year — about 3,600;
    c. 10^{-6} > OIR ≥ 10^{-7}/year — about 27,000;
    d. OIR < 10^{-7}/year — the remainder (about 90,000).
7. Objects with the highest levels of OIR shown in Table ES1 (in excess of 10^{-5}/year) are found only in the highest seismicity Municipalities of Loppersum, Appingedam, Ten Boer and Bedum. Objects with highest OCR (in excess of 10^{-5}/year) are distributed more widely, including in areas of high population/low seismicity such as the centre of Groningen.

Conclusions and Recommendations

We conclude that the risk assessment methodology is fit for its intended purpose, of prioritising areas for inspection on the ground prior to upgrade decisions, and of helping to develop simple rules for upgrade prioritisation. It should not be used in support of decisions on whether an individual object or building requires upgrade.

The study does not investigate the influence of different seismic hazard maps and the influence of local soil conditions. Both could have a significant influence on absolute numbers and distribution.

We recommend that the risk assessment now be used for its intended purpose, and that tools to support decision making for individual objects/buildings should be developed based on this assessment along with the insights developed into the other local factors (not currently modelled) which substantially influence risk. Further work is required (planned by NAM in 2016) to provide probabilistic risk assessments for falling hazards on a comparable basis to current assessments for collapse risk (e.g. the NAM hazard and risk assessment).

1 Introduction

Falling debris from non-structural building components such as masonry chimneys, parapets, gables and dormers is well recognised as a potentially significant hazard in earthquakes, particularly when large populations of masonry buildings are involved. This report presents the results of risk assessment for such falling hazards as a result of induced earthquakes in the Groningen region. It is based on research and analysis carried out during 2014 and 2015.

The risk assessment methodology is developed from that used by GNS Science New Zealand for the modelling of rock fall impact on houses following the Christchurch earthquakes of 2010/11. The model estimates the Community Risk (CR) to people in and around buildings resulting from three particular exposure pathways;

- Passers-by exposed to debris falling outside buildings
- Building occupants running out into falling debris, and
- Debris falling through building roofs onto people inside.

Both the model itself, and the surveyed building features on which the risk assessment is based, provide rough approximations rather than definitive assessments for individual buildings.

The purpose of the assessment is to help prioritise areas for more detailed, on the ground inspection and evaluation, and to support the development of general rules that can be applied in such prioritisation.

This risk assessment is not intended, and is not suitable, for making definitive decisions about individual buildings and building elements.

The report provides;

- **Section 2**, an overview of the risk assessment approach and model;
- **Section 3**, a description of the Falling Hazards Survey used to collect data on potentially hazardous objects for specific buildings;
- **Section 4**, a summary of the checks made on fitness for purpose and uncertainty associated with the results;
- **Section 5**, an overview of the results and;
- **Section 6**, conclusions and recommendations.

2 Risk Assessment Approach

This section provides an overview of the risk model used for this assessment, covering in turn

- The nature of falling hazard risk, and how best to measure it;
- An overview of the main elements of the model, and;
- How the model has been applied in practice in the Groningen region.

2.1 The Nature of Falling Hazard Risk and Appropriate Risk Metrics

The model considers risk arising via three particular exposure pathways;

- Passers-by exposed to debris falling outside buildings;
- Building occupants running out into falling debris, and;
- Debris falling through building roofs onto people inside.

For the second and third exposure pathways, the risk is to building occupants. For the first pathway, the risk is generally distributed across the community.

In the discussion of risk in this study, the following risk metrics are used:

- **Local Personal Risk (LPR):** risk of fatality to an (imaginary) person in a specific location /risk area from specified hazards, assuming the person is present in the risk area 100% of the time. Unit is probability of fatality/year.
- **Community Risk (CR):** risk to a total community from specified hazards. CR in an area at risk from a falling hazard object is equal to the product of the LPR and the average number of people present in that specific area. This is a summation over everyone in a defined community. Unit is fatalities/year.
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In light of the Commission Meijdam recommendations, we have extended our risk model to include calculation of Object-related Individual Risk (OIR[2]) as well as of Object-related Community Risk (OCR). The results and our observations on them are presented in this report.

How to use the different risk metrics calculated in this report to prioritise objects and buildings for inspection and upgrade is outside the scope of this report.

2.2 The Risk Model Approach

2.2.1 Basis

The model builds on a similar model used to predict the risk from rock fall and cliff collapse in Christchurch New Zealand, which has been extensively peer reviewed and has been relied on by central and local government to support decisions on which homes are safe to re-occupy and which should be permanently removed from the market by Government purchase[1].

2.2.2 Approach

The approach is illustrated in schematic form in Figure 1 and is explained in outline below.

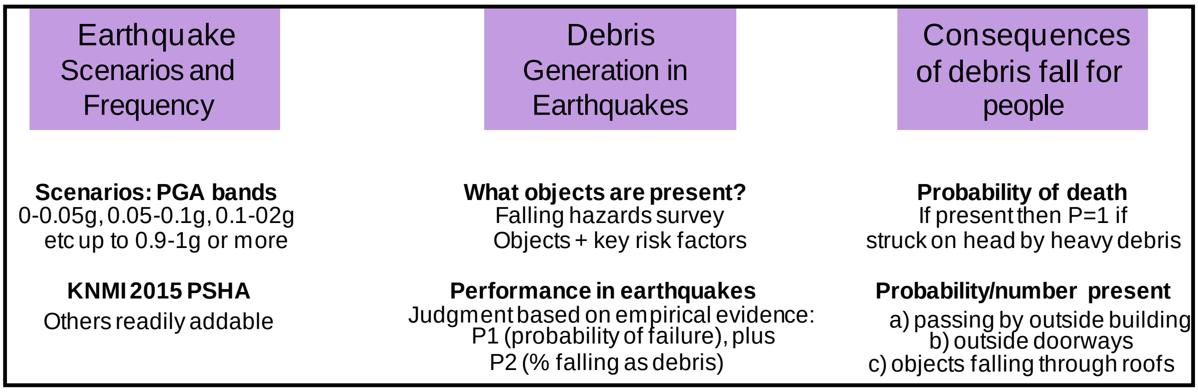

Figure 1: Overview of Risk Assessment Approach

The risk model considers the full range of possible earthquake severity, by dividing ground motion into shaking scenarios based on 0.1g increments of peak ground acceleration (PGA). The KNMI seismic hazard assessment model[2] is used to provide input as to the frequency with which these earthquake scenarios are expected to occur.

The objects present and their characteristics significant for risk (notably their dimensions and their situation in relation to where people might be at risk) were collected in the parallel Falling Hazards Survey which is described in Section 3.

The model is described in greater detail, step by step, in Appendix 1.

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[2] OIR is referred to as OIA (objectgebonden individueel aardbevingsrisico) in the Commission Meijdam advice

2.2.3 Probability and extent of damage

The probability and extent of damage to chimneys, parapets and gables is estimated using judgment informed by extensive study of the performance of such elements in earthquakes, focusing in particular on areas with large populations of broadly North European style masonry buildings. Other types of potentially hazardous objects, such as balconies and canopies, for which less data is available, are treated by analogy with the performance of objects for which more data is available.

The extensive study of the performance of elements in earthquakes is presented in Appendix 2.

2.2.4 Probability of failure

Failure throughout this study is taken to mean “Damage such that some part of the object falls as debris from the building”.

An overall probability of failure for each earthquake scenario (PGA band) is estimated, along with the proportion of such failures that would involve different damage states. A key feature of this approach is that object damage states are defined in terms of the percentage of object volume that falls to the ground, which correlates directly with the risk of fatality to a person present.

The derivation of failure probabilities is presented in more detail in Appendix 3.

2.2.5 Probability of fatality

The consequences of object failure are assessed based on a model of fatality which makes three simple assumptions;

1. if the head is struck by heavy debris, a person dies, but otherwise they do not;
2. for the highest (worst) damage state, objects fall through the air in an orientation that maximises the area impacting on the ground, and thus the probability of killing someone present, and;
3. for all other damage states, the area impacting on the ground is scaled from that in (2) pro rata to the percentage of object volume falling in each damage state.

These assumptions are discussed further in Appendices 1 and 6; they together provide a good approximation to the fatality forecast from a more complex model derived from literature surveys and empirical data on injuries caused by falling masonry. This enables the probability of fatality for a person present in an at-risk area is to be determined by simple geometry as the ratio of the cross-sectional area of the object as it falls, to the area at risk.

The average number of people present is determined from the estimated footfall past the building (for people walking past outside), or from the internal population of the building (for people running out of doorways into falling debris, and for people indoors struck by objects falling through building roofs).

2.3 Practical Application of the Risk Model

2.3.1 Model parameters and assumptions

Object-related Community Risk (OCR) for each exposure route is calculated by multiplying the LPR by the average number of people present in the at-risk area.

The Local Personal Risk (LPR) for each exposure route for each object is calculated by multiplying a Standardised Local Personal Risk (SLPR) for an object of that type at the given PGA contour by the cross-sectional area of the whole object, divided by the area of the space at risk. The area at risk (see Appendix 1) is taken as;

- 3m x facade length for people walking past outside the building[3];
- 10m^2 for people at risk outside a doorway, and;
- The plan area of the building for people at risk from objects falling through the roof.

Earthquake frequency, failure probabilities and probabilities of fatality are combined to calculate a Standardised Local Personal Risk (SLPR) for each type of object considered in the assessment at each contour of PGA on the KNMI seismic hazard map[4]. This is the annual probability, summed over all possible object damage states and earthquake scenarios, that a person present in the at-risk area would be killed by an object just large enough to fill that area (i.e. to guarantee fatality) if the whole object fell into it.

The average number of people present in the risk area is estimated from;

- Footfall data or estimates for people walking past outside the building (explained further in Appendix 5);
- Internal population plus simple assumptions about the proportions who would run outside so as to coincide with debris falling, for people outside doorways, and;
- Internal population for people indoors at risk from objects falling through the roof.

Object-related Individual Risk (OIR) for each exposure route is calculated by multiplying the appropriate LPR by the percentage of the time for which a reference individual is assumed to be present at each location. For exposure via the latter two pathways (objects falling above doorways or through roofs) this is simply the time for which the reference individual is assumed to be inside the building. For the first pathway (objects falling into public space outside buildings), the reference individual is assumed to spend 1% of their time in the at-risk area for each at-risk facade of the building.

[3] Note – our research shows that the risk is concentrated within 3m of facade walls for falling non-structural objects, even for tall buildings. We therefore use 3m as the basis for risk estimation. There is a possibility that in some cases the range might extend to 5m, so this risk is applied in all cases where the public can approach within 5m of a building facade. Thus anyone within 5m of a facade is treated as "at risk", to include a margin of safety, whereas the level of risk is calculated assuming the risk is concentrated within 3m of the facade. We recognise that these assumptions will tend to overstate risk slightly outside building facades.

[4] The KNMI 1 in 475 year PGA contour map published in October 2015 (see reference 2). The values of exceedence frequency at each such contour were obtained from a simulation of the KNMI PSHA model carried out in October 2015.

2.3.2 Tools

The survey results were prepared in Excel spreadsheets with typically around 5000 buildings per sheet. The risk assessment was applied by extending beyond the data fields in the survey spreadsheet to carry out calculations of Local Personal Risk (LPR), then of Object-related Community Risk (OCR), via each of the three exposure pathways considered, and finally of Object-related Individual Risk (OIR). Compromises had to be struck between achieving a reasonable computation time for the spreadsheets on the one hand, and both;

- automating the spreadsheet to reduce effort and error in applying the risk assessment, and;
- preserving maximum functionality to enable sensitivities to be explored.

The compromise arrived at is documented in a procedure for applying the risk assessment model to the survey spreadsheets (available as a companion document), which covers;

- reading in PGA (for the new KNMI 2015 map) contours, internal building populations and revised footfall estimates from other source files;
- dealing with buildings for which data was missing;
- assigning objects to fragility classes (based on filtering and manual entry of categories);
- applying the appropriate formulae to calculate LPR and OCR, depending on the recorded hazardous object characteristics, and;
- setting up results tabs including aggregated outputs by street, specific to the Municipality or Wijk being assessed.

2.3.3 Process

This process enabled the risk assessment to be applied by a team of three people in about a week to the 23 survey files. A standardised inputs sheet was developed to reduce errors in inputting key data and assumptions and to facilitate modifying them and carrying out sensitivity studies. “Debugging” and checking of the spreadsheets took several weeks longer, to deal with the combination of survey errors that were revealed in the risk assessment process and slips made during the application of the risk assessment process itself.

2.3.4 Challenges of the tools and process

Given the time and resources available to the survey and risk assessment team the process followed is considered fit for purpose to produce an assessment whose provenance roughly matched that of the survey data on which it was based. That process does not, however, provide a sustainable way in which to manage a database of falling hazard objects and carry out analyses on it. For example, to carry out the sensitivity studies reported in Section 4, it was necessary for each scenario analysed to paste a fresh set of inputs into each of 23 spreadsheets, wait for them to calculate (taking several minutes on a fast machine for the larger Municipalities), then paste results into a separate spreadsheet for analysis.

2.3.5 Priorities for improvement

A clear priority once the risk assessment results have been assimilated and a clear path for their application and use has been determined should be to migrate the spreadsheet files in which the data and results are delivered in parallel with this report into a database, ideally linked to GIS, to facilitate ongoing data management and analysis. The survey results require validation against current, higher resolution building information than can be obtained via Google Street View (on which the available photographs are relatively low resolution, and at the time of this study were typically 6 years old or older, before any significant conclusions can be drawn on individual buildings or objects.

2.4 Further information

More detail is provided in Appendices 1 to 6 as follows:

- **Appendix 1:** The Falling Hazards Risk Model;
- **Appendix 2**: Performance of Falling Hazard Objects in Earthquakes;
- **Appendix 3:** Fragility Assumptions for the Falling Hazards Risk Model;
- **Appendix 4:** Occupancy Assumptions for OIA Calculation;
- **Appendix 5:** Estimation of At-Risk Population Outside Buildings;
- **Appendix 6:** Injury Impacts of Falling Masonry.

3 Survey

This section provides an overview of the Survey and its statistics.

3.1 Pilot studies for limited areas

Pilot studies in Bedum and Groningen Centrum demonstrated the feasibility of a desk-based survey using readily available internet data sources (Google Street View and Google Earth) to identify and characterise non-structural building elements with potential to fall into streets, above doorways or onto roofs in earthquakes.

The strength of this approach is that it enables information directly relevant to risk (object dimensions and location in relation to doorways, public spaces and roofs through which objects might fall) to be collected quickly for large numbers of buildings by people without specialist expertise. The weaknesses of the approach are that;

1. some buildings cannot be viewed in Street View (the primary information source) as they are either obscured or were built since the latest Street View photographs were taken), and;
2. local features important for risk, both of the hazardous objects themselves and of the pathways by which people could be exposed to risk, cannot generally be assessed from Street View photographs.

3.2 Full scale survey

A full scale survey was devised and initiated in June 2015, taking advantage of the availability of university students and recent graduates to carry out the work during the summer vacation.

The scope of the survey was initially set at “All buildings within the 0.1g PGA contour on the KNMI 2013 map, with the exception of ‘Nietverblijfsobjecten’ of plan area less than 10m^2”. This comprised over 280,000 buildings, which was clearly beyond what could be achieved in a few months’ work. The scope was thus reduced by agreement with NAM to exclude buildings without an address (largely outbuildings, sheds, garages etc.), and the remaining 194,000 buildings (approx.) were prioritised by agreement with NAM based on the combination of seismicity plus size of population potentially exposed to risk. The prioritisation and associated numbers of buildings to be surveyed are shown in Table 1. The scope area is shown by the red line on Figure 2, along with the more recent contours of 1 in 475 year PGA based on the 2015 update of the KNMI seismic hazard assessment, which are shown in blue on Figure 2.

All buildings within the High and Medium priority Municipalities as shown in Table 1 were surveyed individually. This set includes;

- Loppersum and each of the surrounding Municipalities (selected based on their relatively high seismicity);
- the whole of the city of Groningen (selected based on its high population plus, in the central urban areas, on the high population of potentially hazardous objects such as parapets, Dutch Gables and chimneys situated above public spaces where large numbers of people are often present), and;
- the Municipalities of Eemsmond, Haren, Hoogezand-Sappemeer, Menterwolde, Oldambt and Veendam which are the next highest seismicity areas.

The survey format and data collected, the recruitment and training of the survey team, and checking and QA of the survey outputs, are described in more detail in Appendix 7.

Municipality	**Total number of buildings**	**Number of addresses**	**Number of buildings without address**	**Number of buildings with address**	**Survey Priority Category**
Aa en Hunze	5378	3519	2034	3344	Low
Appingedam	7752	6764	2620	5132	High
Assen	8	5	4	4	Low
Bedum	6144	5095	1734	4410	High
Bellingwedde	42	8	34	8	Low
De Marne	5326	3439	2084	3242	Low
Delfzijl	18169	14165	6928	11241	High
Eemsmond	12910	8377	5448	7462	Medium
Groningen	64036	112576	8700	55336	High
Grootegast	8	4	4	4	Low
Haren	12184	9842	4279	7905	Medium
Hoogezand Sappemeer	20092	19015	6535	13557	Medium
Leek	853	449	405	448	Low
Loppersum	8029	5100	3310	4719	High
Menterwolde	9338	5885	3809	5529	Medium
Noordenveld	4300	2818	1782	2518	Low
Oldambt	25689	19854	9017	16672	Medium
Pekela	8268	5815	3122	5146	Low
Slochteren	13562	7329	6718	6844	High
Ten Boer	3994	3375	898	3096	High
Tynaarlo	23291	15617	9306	13985	Low
Veendam	16809	14687	4722	12087	Medium
Winsum	9191	6606	2979	6212	High
Zuidhorn	8550	6169	3030	5520	Low
Total	**283923**	**276513**	**89502**	**194421**	

Sub-Totals by Priority Category

Survey Priority Category	**Total number of buildings**	**Number of addresses**	**Number of buildings without address**	**Number of buildings with address**
High	130877	161010	33887	96990
Medium	97022	77660	33810	63212
Low	56024	37843	21805	34219
Total	**283923**	**276513**	**89502**	**194421**

Table 1: Municipalities, Building Counts and Survey Priorities

Note: Buildings within the 0.1g Contour. (Excluding 'Nietverblijfsobject' < 10m² in floor area)

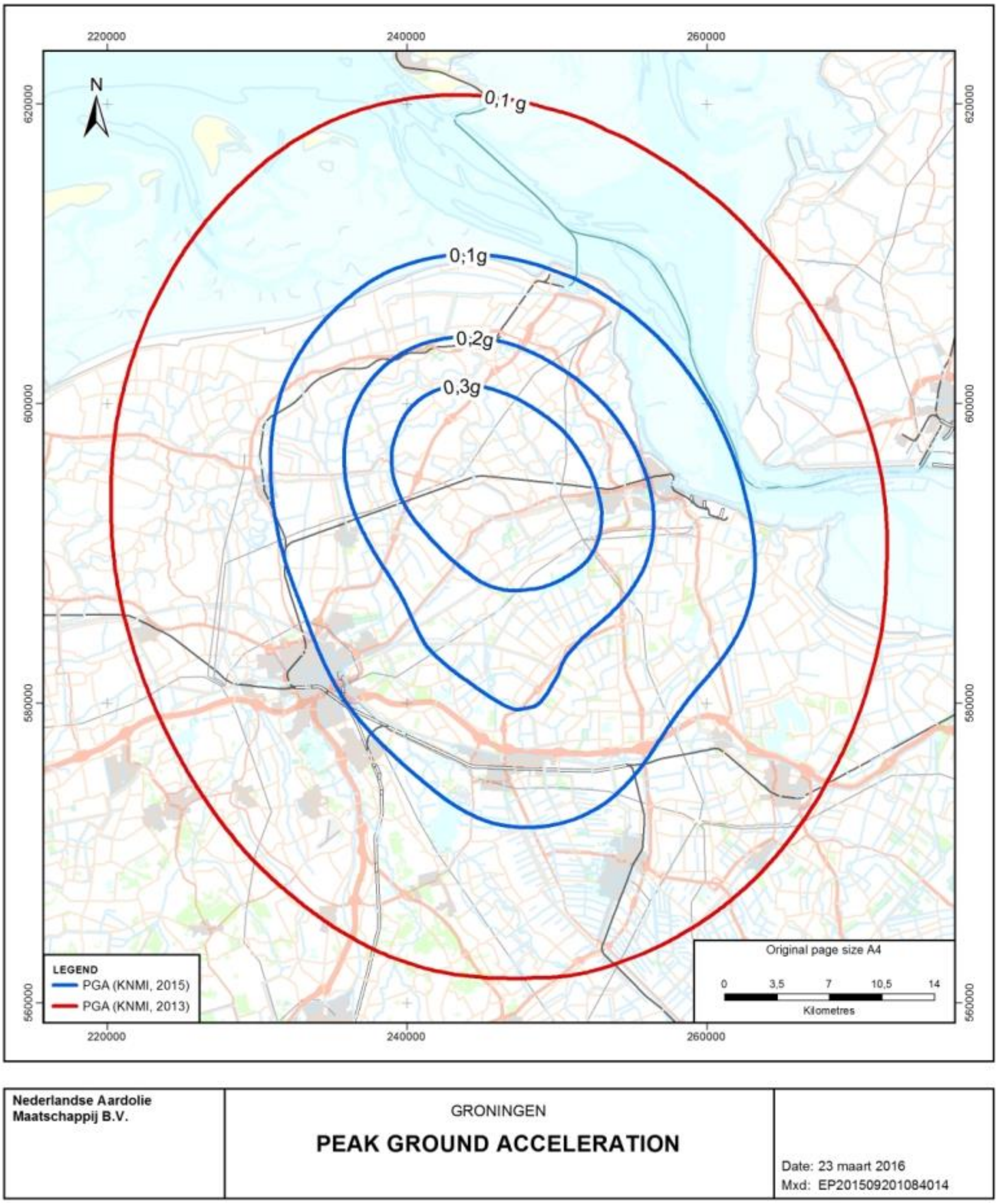

Figure 2: Risk Assessment Scope Area (red line) and PGA contours based on 2015 KNMI hazard assessment (blue lines)

Low priority Municipalities were not surveyed building by building; a risk assessment is carried out for them based on the anticipated object numbers and performance deduced for buildings of similar age, type and seismicity from the assessments for high and medium priority Municipalities.

Table 2 provides an overview of the numbers of objects identified, by type and location.

Object Type	G00	G01	G02	G03	G04	G05	G06	G07	G08	G09	APP	BED	DEL	LOP	SLO	TEN	WIN	EEM	HAR	HOS	MEN	OAM	VEN	TOTAL
Chimney	1058	2192	1891	873	440	384	2076	488	763	766	1325	1613	3182	2241	2132	1168	2322	3539	3122	3688	2092	6310	3706	**47371**
Decorative feature	231	23	34	14	10	37	16	5	2	20	8	34	12	27	14	15	19	52	21	7	13	65	27	**706**
Pinnacle	85	40	2	3	13	3	16	1	5	0	8	14	19	23	12	7	11	35	5	3	1	49	8	**363**
Parapet	1047	853	732	581	295	459	513	147	344	357	126	148	286	139	110	85	120	224	152	244	73	256	266	**7557**
Balustrade	371	224	328	201	218	77	429	164	77	331	107	60	132	16	86	67	31	120	160	189	31	531	335	**4285**
Free standing wall	30	39	37	53	11	192	139	30	24	155	59	49	126	60	82	65	79	48	44	69	4	85	27	**1507**
Gable	444	587	603	395	174	323	645	272	881	1590	785	973	2204	1026	1672	608	1287	1574	1460	2395	1542	4414	2285	**28139**
DG parapet	250	98	21	19	18	43	48	8	2	0	23	14	7	18	9	10	15	26	15	8	5	28	24	**709**
DG gable	250	98	21	19	18	43	48	8	2	0	23	14	7	18	9	10	15	26	15	8	5	28	24	**709**
Dormer	486	239	223	84	63	317	89	2	23	4	30	40	50	42	10	8	53	88	40	152	20	107	74	**2244**
Canopy - supported	188	114	43	69	39	93	182	44	55	148	55	23	95	43	41	29	44	56	62	179	17	40	24	**1683**
Canopy - unsupported	1335	760	1092	992	225	761	751	748	407	930	342	299	1258	161	318	45	319	424	717	576	246	472	827	**14005**
Balcony	255	93	182	171	64	56	561	200	27	201	276	49	184	33	27	11	34	71	87	282	30	340	238	**3472**
Bay window	567	282	161	241	124	98	226	29	9	12	19	8	72	5	1	11	3	31	45	22	2	45	21	**2034**
Large glass area	62	50	29	37	28	64	18	41	4	11	8	12	43	13	8	7	11	11	9	18	4	23	26	**537**
Sign – vertical	509	47	15	47	8	61	22	15	10	23	18	20	65	39	12	16	24	38	30	65	12	54	31	**1181**
Sign – horizontal	368	159	39	49	45	236	84	87	73	78	72	59	128	26	46	25	50	90	86	166	49	270	121	**2406**
Industrial object	1	2	1	1	1	7	4	3	4	2	0	12	10	2	3	3	1	4	2	9	1	3	1	**77**
Walkway	1	3	0	1	3	3	2	0	0	8	6	2	8	0	0	0	1	0	0	1	0	0	0	**39**
Other	22	8	6	1	1	2	4	7	3	8	0	0	3	0	0	4	1	2	0	0	15	9	12	**108**
Flagpole	229	69	31	52	8	57	66	15	4	13	13	38	123	35	41	24	16	39	38	61	11	75	28	**1086**
TOTAL OBJECTS	**7789**	**5980**	**5491**	**3903**	**1806**	**3316**	**5939**	**2314**	**2719**	**4657**	**3303**	**3481**	**8014**	**3967**	**4633**	**2218**	**4456**	**6498**	**6110**	**8142**	**4173**	**13204**	**8105**	**120218**
TOTAL BUILDINGS	**4514**	**5530**	**6920**	**4096**	**2681**	**3348**	**6809**	**3999**	**6006**	**11482**	**5133**	**4410**	**11242**	**4717**	**6844**	**3096**	**6213**	**7446**	**7905**	**13556**	**5527**	**16668**	**12087**	**160229**

Table 2: Objects Identified in Falling Hazards Survey – Overview

***Key: Groningen Wijken**: G00 - Binnenstadt; G01 – Schilder- en Zeeheldenwijk; G02 - Oranjewijk; G03 - Korrewegwijk; G04 - Oosterparkwijk ; G05 - Oosterpoortwijk; G06 - Herewegwijk en Helpman; G07 - Stadsparkwijk; G08 - Hoogkerk; G09 – Noorddijk*

***Key: Other Municipalities**: APP – Appingedam; BED – Bedum; DEL – Delfzijl; EEM – Eemsmond; HAR – Haren; HOS – Hoogezand-Sappemeer; LOP – Loppersum; MEN – Menterwolde; OAM – Oldambt; SLO – Slochteren; TEN – Ten Boer; VEN – Veendam; WIN – Winsum*

3.3 Statistics

Summary statistics for the survey of High and Medium priority Municipalities include;

- 160,000 buildings surveyed in just over 4 months by a team of 20 surveyors;
- 120,000 potentially hazardous objects identified, with the largest numbers comprising chimneys (47,000), gables (29,000 including Dutch Gables), canopies (16,000) and parapets (8,000);
- Were these hazardous objects to collapse in an earthquake;
    - just over 2/3 could fall within 1m of a doorway;
    - just under 2/3 could fall into publicly accessible space in front of or around building;
    - just under 4% could fall from height onto the roof of an occupied building.

3.4 Further information

Further information on the Survey and its results is provided in Appendix 7.

4 Checking, Accuracy and Sensitivity

The Falling Hazards Survey on which this assessment is based was by design a rapid, once-through, internet-based scan of buildings. The risk model used to convert the objects identified in the Survey into risk estimates is a simple, empirical tool. It has been recognised from the outset of this project that there would inevitably be inaccuracies and omissions from the Survey, and that the simple assumptions made in the risk model and in its large-scale spreadsheet implementation would be more or less appropriate for different objects and buildings.

This section of the report provides an overview of the activities carried out and their findings on;

- Survey and risk assessment accuracy checking, and;
- Sensitivity studies to explore the impact of key uncertainties in the risk model.

4.1 Survey and Risk Assessment Accuracy Checking

Checking processes were adopted;

- In the course of surveying buildings;
- On completion of surveys for high priority Municipalities, to peer check 20% of all objects surveyed (and extend any changes made to similar buildings nearby);
- On completion of the survey for a Municipality, to check 2% of all objects surveyed within TTAC Ltd;
- By Arup, to check 10% of the 2% of buildings and objects TTAC had checked;
- To address buildings for which data could not be obtained via the survey, and;
- "Sense checks" addressing the degree to which risk assessment results appeared to be either over or underestimating risk for specific objects/buildings.

4.1.1 During the survey

In the course of surveying, every surveyor indicated their own confidence rating in their assessment for every building and object recorded. This allowed them to ask a colleague to check their assessment. Every such request was reviewed by the survey Project Manager on a daily basis, leading to numerous clarifications and updates of the guidance for surveyors.

4.1.2 After the survey – self check by TTAC

The checks carried out by TTAC on completion of the survey identified a significant percentage of recorded objects that were not considered hazardous at all, but also a significant percentage (7-8%) that had been missed. Several of the higher risk such objects had the potential to fall from height onto a roof. Of the fields completed in the survey, that for footfall proved particularly difficult to complete accurately.

4.1.3 After the survey – check by Arup

Much the most significant finding of the Arup checks on the survey outputs was of a further 7-8% of missed objects that had not been picked up by the TTAC checks. The top 5 such objects in terms of OCR all had the potential to fall from elevated height onto a roof. It was recognised that Survey practice in respect of such objects had evolved significantly in the course of the Survey, and that this could be an area of significant weakness.

4.1.4 Check buildings that could not be surveyed

About 10% of all the buildings within scope of the survey could not be surveyed because they were obscured or not yet built when Street View photos were taken. A TTAC surveyor carried out a study in which a sample of over 200 such buildings was surveyed via the RVS reports rather than via Street View. This provided confidence that the missed buildings appeared broadly similar to other buildings of a similar age and type in terms of both the numbers of hazardous objects present and the likely risk per object.

4.1.5 Sense checks

"Sense checks" started by examining objects assessed as higher risk, concluding that most were appropriately assessed but that perhaps 15-20% of assessments were conservative (tending to overstate risk, leading to the possibility of "False positives" being identified as "high risk" objects when they should not be so). This was generally because the simple general assumptions built into the model for both object fragility and for people's exposure to risk tended to provide risk estimates on the high side in a significant percentage of real situations.

4.1.6 Dealing with false negatives – underestimation of risk

The only further issue identified in the sense checks as capable of providing "False negatives" (systematically understating risk) was the under-assessment of footfall around public use buildings such as schools and churches.

In response to the findings of these checks;

- A small team of surveyors was given additional training in estimating numbers of people walking up and down sections of streets, and carried out a separate exercise to estimate footfall on each street in the region, taking into account the presence of shops and other "footfall magnets" such as schools, bus and train stations, sports/leisure facilities etc. Their results were read back into the survey files and were used in place of the initial surveyors' footfall estimates in the subsequent risk assessment, except for buildings in Groningen Centrum where directly surveyed footfall data was available;
- All roads in the high priority Municipalities with more than 5 buildings were re-surveyed with a particular focus on objects elevated above roofs. This increased the stock of such objects recorded in the survey from 2,803 to 4,335;
- All objects rated as low footfall around public use buildings in the high priority Municipalities were re-surveyed. Footfall ratings were adjusted in 671 out of 2,388 cases;
- The fragilities assumed for gables and parapets were reviewed and were adjusted (downward for gables and upward for parapets) in order better to reflect the engineering judgment.

The conclusion drawn from all the above was that the checking process had succeeded in identifying issues with potential significantly to affect the results of the risk assessment.

The most important issues with potential to generate “False negatives” (higher risk objects that failed to be identified as such) related to objects missed or miss-assessed during the Survey, and were able to be corrected by selective re-surveying within the H priority Municipalities. It is recognised that the results may accordingly be less complete and accurate for the medium priority Municipalities.

4.1.7 Dealing with false positives - overestimation of risk

The issues tending to generate “False positives” (objects incorrectly assessed as high risk) were more difficult to deal with in a simple model with access to limited information on objects, their condition, their situation and the use of public space around them. The sense checks carried out, though, enabled a wide range of important local factors to be identified which should provide extremely useful in developing guidance for on-the-ground inspection and decision making on upgrades for individual objects.

Several of the local situational factors identified in the sense checking process involved a tendency for the simple model assumptions to over-estimate risk for larger buildings in particular, for reasons such as;

1. Assumptions about people running out of doorways – the model effectively assumes every building occupant has the same chance of being outside each doorway as debris is falling. This cannot be the case for many larger buildings because, for example;
    a. The buildings may have multiple exits (people cannot run out of all of them simultaneously), and;
    b. People will be unable to get to the exits in time, and even if they do;
    c. Congestion around exits would slow down escape.
2. The location of hazardous objects in relation to areas where people are exposed – the model assumes, for example, that any object with any part of it within 1m of a doorway exposes anyone running out of that doorway to risk for every object damage state. For a large building with a doorway to one side of a gable, the model assumes every damage state exposes someone running out to risk, whereas this may only be the case for the most extreme damage state of total collapse.
3. For objects falling through roofs from height, a fairly common situation e.g. in schools is that a large building will have a main entrance in a lower outbuilding or hallway, which could be at risk from an object falling through the roof. The model assumes all parts of the building are equally occupied, whereas in such situations the entrance way is likely to be unoccupied for most of the time.

4.2 Sensitivity Studies

Sensitivity studies were carried out to explore the impact of the uncertainties in the risk model on the numbers of higher OCR objects. These sensitivity studies took the form of simple recalculation of the risk spreadsheets for each Municipality under each of a number of scenarios corresponding to different parameters being varied around the base case. The results have no statistical significance; the parameter ranges explored are not extremes, or 10-90% confidence limits but what we regard as plausible ranges within which we would hope (but by no means be certain) to find that the true values for the Groningen region would lie.

4.2.1 Scenarios

The scenarios modelled are;

- **Scenario 1**: Lower fragility, masonry objects (chimneys, parapets, gables)
- **Scenario 2:** Higher fragility, masonry objects (chimneys, parapets, gables)
- **Scenario 3:** Lower exposure assumptions
- **Scenario 4:** Higher exposure assumptions
- **Scenario 5:** Lower fragility AND seismicity assumptions
- **Scenario 6:** Higher fragility AND seismicity assumptions
- **Scenario 7:** Lower fragility, other objects (balconies, canopies, glazing etc)
- **Scenario 8:** Higher fragility, non-conventional objects
- **Scenario 9:** Lower risk – All Assumptions simultaneously
- **Scenario 10:** Higher risk – All Assumptions simultaneously

The parameters varied, and the values used for higher, lower and base case assumptions are shown in Table 3. To provide an indication of the combined effect of uncertainties in seismicity and object fragility we made a simple assumption that the KNMI estimates of frequency of earthquakes in our lowest shaking band (0.05-0.1g) should be quite accurate, as the associated frequency is high enough to be directly testable against experience. The frequency was assumed to be uncertain within +/- 10% for this band. At the other extreme, there is clearly much greater uncertainty as to the frequencies estimated for the rare events in our top shaking band (>0.9g). We assumed that frequencies for this band were uncertain by x/÷ 5, and interpolated smoothly between these assumed uncertainties for top and bottom bands to estimate uncertainty for the intermediate PGA bands.

4.2.2 Results

The results are shown in Figure 3 in terms of the numbers of objects assessed with OCR $\geq 10^{-5}$ per year. Note that in Figure 3 the lower end of the bar for “All uncertainties” is actually zero objects, which could not be displayed on the logarithmic scale shown.

These sensitivity studies were completed before the Commission Meijdam final advice had been issued. Subsequent to that advice, calculations of object-related individual risk (OIR) were also incorporated into the risk assessment. Various minor refinements to the calculations were made in the course of that work. The sensitivity studies thus;

1. did not include OIR, and;

2. contain values of OCR that may differ slightly in some cases from the final values used in the study.

We are confident (because of the relatively simple relationship between OCR and OIR) that the sensitivity study findings can be applied to OIR as well as OCR. We are also confident that any small changes in OCR values as a result of changes made subsequent to the completion of the sensitivity studies do not significantly affect their findings.

	Parameter	**Low case**	**Base case**	**High case**
Object Fragility	***Failure probabilities for masonry chimneys, parapets & gables***	Lower end of range proposed for Groningen region	Centre of range (geometric mean)	Higher end of range proposed for Groningen region
	Failure probabilities for canopies, balconies	0.03 x those for comparator masonry objects	0.1 x those for comparator masonry objects	0.3 x those for comparator masonry objects
Seismicity	***Frequency of shaking in 0.05-0.1g PGA band***	KNMI(2015) / 1.1		KNMI(2015) x 1.1
		varying smoothly up to	KNMI 2015	*varying smoothly up to*
	Frequency of shaking in >0.9g PGA band	KNMI(2015) / 5		KNMI(2015) x 5
Exposure - people passing outside building	***Width of at-risk zone used in risk calculation***	3m	5m	5m
	Footfall	All footfall categories moved down 1	Standard footfall table for categories 1-10	All footfall categories moved up one
Exposure - building occupants running outside	***Area at risk outside doorway***	15m2	10m2	10m2
	% occupants who try to run out in earthquake	30%	70%	80%
	% people running out whose timing coincides with debris falling	1%	5%	10%
Exposure - objects falling through roofs	***Probability an object falling from height penetrates right through to ground level***	0.3	1	1

Table 3: Parameters Varied for Sensitivity Studies

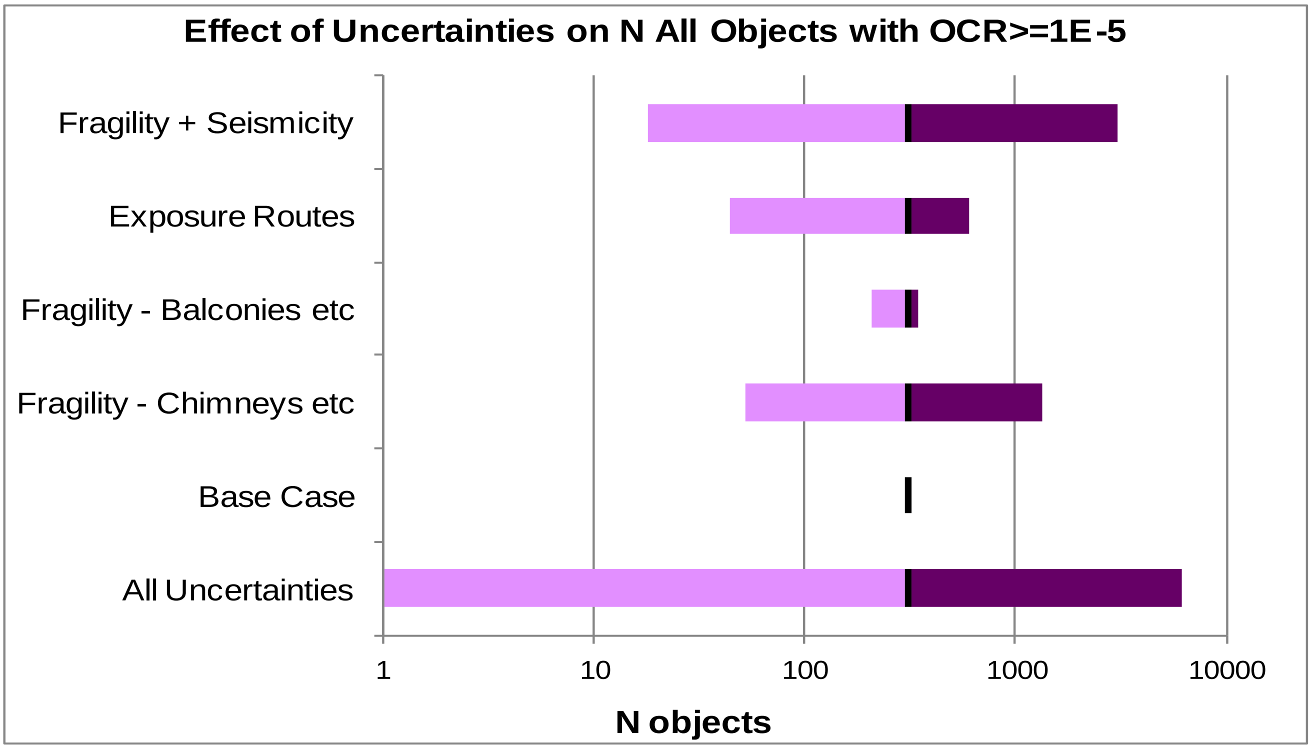

Figure 3: Impact of Uncertainties on Numbers of Objects with OCR≥10^{-5}/year

4.2.3 Conclusions

Our conclusions from the sensitivity studies are as follows:

1. The overall uncertainty in the results is about an order of magnitude (factor of 10) in either direction in OCR, with the uncertainties to the lower side somewhat greater than those to the upper side.

2. The uncertainty in numbers of higher OCR objects is somewhat greater, varying from zero with all uncertainties taken into account up to several thousand at the higher end.

3. The inclusion of uncertainty in seismicity as well as object fragility does not make as big a difference as might be expected. This is because to some extent these uncertainties cancel each other out – at low shaking there is high uncertainty in object fragility but low uncertainty in shaking frequencies, while for rare, severe shaking events there is high uncertainty in shaking frequency but little uncertainty in fragility (most non-structural masonry objects can be relied on to fail).

4. Exposure assumptions are of similar impact to fragility assumptions to the lower side of the base case, but of lesser potential impact to the higher side. This is consistent with the observation made in the sense checks above that in many cases the simple exposure assumptions in the model produce results that tend to overstate risk – effectively the model assumptions have been pitched nearer to the higher than to the lower end of the range of reasonable assumptions.

5. The generally low assumed fragilities of balconies, canopies and large areas of glass relative to masonry objects mean that the results are relatively insensitive to variation of assumed fragilities around their base case values. Given the lack of direct evidence behind these assumed low fragilities (they are judgments based on a workshop held with Arup Groningen staff, as described in the companion Risk Model report) we are less confident in the robustness of this conclusion than in our other conclusions.

4.2.4 Observations on methods and tools

As a final observation on the sensitivity studies, we note that the current configuration of the risk model (as a series of spreadsheets built on the survey outputs) is extremely unwieldy for routine risk assessment. For each of the ten scenarios modelled here, it was necessary to paste a new set of input values into each of 23 spreadsheets, recalculate (taking several minutes per spreadsheet for the larger Municipalities on a fast computer), then paste the results into separate spreadsheets to enable simple comparisons to be presented such as those shown in Figure 2.

It is not practically possible, with the model as currently configured, to carry out the kind of "simultaneous variation of multiple inputs" exploration of uncertainty and sensitivity that we would prefer. The spreadsheet approach worked well for collecting survey information but does not provide a sustainable basis for maintaining and using the model – there is too much manual processing required both to set up and to maintain and vary assumptions within the spreadsheets. They could be more highly automated, but the price would be even slower and more unwieldy calculation.

4.3 Further information

The work carried out to check the quality of the survey and the risk assessment outputs, and the sensitivity studies carried out on those outputs, is described in more detail in Appendix 8.

5 Risk Assessment Results

Results are presented first for the High and Medium priority Municipalities which were surveyed and risk assessed building by building. A brief assessment of risk for the low priority Municipalities is then provided.

5.1 High and medium priority municipalities

A brief overview of the results in aggregate for all the buildings surveyed is provided below.

5.1.1 Object-related community risk

By object type

Table 4 provides an overview of the numbers of hazardous objects identified, broken down in bands of Object-related Community Risk (OCR = Local Personal Risk x Average Number of People in the at-risk area).

Object Type	Total	OCR $\geq 10^{-4}$	$10^{-5} \leq$OCR$<10^{-4}$	$10^{-6} \leq$OCR$<10^{-5}$	$10^{-7} \leq$OCR$<10^{-6}$	OCR$<10^{-7}$
Chimney	47371	0	35	1580	11563	34193
Gable	28139	0	45	1944	7299	18851
Canopy unsupported	14005	0	4	59	437	13505
Parapet	7557	1	71	735	3131	3619
Balustrade	4285	0	17	196	1246	2826
Balcony	3472	0	0	7	108	3357
Sign - horizontal	2406	1	2	28	230	2145
Dormer	2244	0	22	290	1350	582
Bay window	2034	0	0	3	24	2007
Canopy supported	1683	1	2	10	104	1566
Free standing wall	1507	0	6	266	742	493
Sign - vertical	1181	0	0	2	53	1126
Flagpole	1086	0	0	0	0	1086
DG parapet	709	0	15	81	325	288
DG gable	709	0	4	51	237	417
Decorative feature	706	3	9	60	220	414
Large glass area	537	1	10	49	167	310
Pinnacle	363	0	11	39	73	240
Other	108	0	0	2	5	101
Industrial object	77	0	0	0	3	74
Walkway	39	0	0	0	5	34
Total	**120218**	**7**	**253**	**5402**	**27322**	**87234**
% of all objects		0.01%	0.21%	4.5%	22.7%	72.6%

Table 4: Overview of Hazardous Objects by OCR Band

Note: Dutch Gables (DG) are each considered as 2 features (a parapet and a gable)

In terms of Community Risk, numbers of objects are assessed as falling in risk bands as follows;

a. OCR $\geq 10^{-5}$/year about 260;

b. 10^{-5} > OCR $\geq 10^{-6}$/year about 5,400;

c. 10^{-6} > OCR $\geq 10^{-7}$/year about 27,000;

d. OCR < 10^{-7}/year the remainder (about 87,000).

The largest numbers of objects assessed as lying in the higher OCR bands are parapets and similar structures (balustrades and free standing walls), chimneys and dormers. Risk depends on both size and fragility thus;

- Gables also appear in substantial numbers among the higher risk objects (larger, though somewhat less fragile than chimneys);
- A relatively high proportion of decorative stonework and pinnacles (assumed similar fragility to chimneys but often larger) appear as higher risk, and;
- A relatively high proportion of large glass features (assumed similar fragility to modern gables) appear as higher risk.

By exposure pathway

Table 5 provides an overview of the numbers of objects in the three highest OCR bands shown in Table 4 (i.e. those with OCR ≥ 10^{-6}/year), broken down by the predominant hazard exposure pathway for each object.

Object Type	Above doorways		Above public space		Above roofs	
	Total objects	Number with OCR≥10^{-6}	Total objects	Number with OCR≥10^{-6}	Total objects	Number with OCR≥10^{-6}
Chimney	30109	652	27367	77	4776	886
Gable	14515	1378	17966	74	1187	537
Canopy-unsupported	12704	46	7346	16	6	1
Parapet	5255	540	6390	225	218	42
Balustrade	2759	167	3306	45	50	1
Balcony	2326	7	2567	0	1	0
Dormer	1793	236	1995	74	4	2
Canopy-supported	1399	13	1025	0	2	0
Bay window	1365	3	1893	0	0	0
Sign – horizontal	1309	24	2244	5	17	2
Free standing wall	1101	204	685	23	72	45
Sign – vertical	561	2	1138	0	1	0
DG gable	528	33	651	19	9	3
DG parapet	514	57	651	34	15	5
Flagpole	500	0	1049	0	4	0
Decorative feature	475	50	613	20	11	2
Large glass area	390	40	436	17	4	3
Pinnacle	174	23	335	19	26	8
Other	63	1	90	1	4	0
Industrial object	24	0	54	0	17	0
Walkway	15	0	36	0	0	0
Total	**77879**	**3476**	**77837**	**649**	**6424**	**1537**
% Objects ≥ 10^{-6} Within exposure pathway		4.5%		0.8%		23.9%

Table 5: Objects with OCR≥10^{-6}/year, by Exposure Pathway

Note: total objects in Table 5 add to more than the totals in Table 4 as some objects expose people to risk via more than one pathway.

Examined by exposure pathway, a higher proportion of objects falling through roofs fall into the higher risk bands in comparison with objects above doorways and (in particular) objects above public space.

This is because of the higher occupancy of the space involved – people at risk from objects falling through the roof are typically, in a house, spending 60-70% or so of their time at home, whereas the probability of someone being present outside a building is relatively low except in busy shopping areas and other places where people congregate outdoors.

Most of the higher risk objects involve risk exposure for building occupants (either running out of doors when the ground shakes, or being struck by objects falling through the roof), rather than risk exposure for passers-by outside. Less than 1% of objects had OCR associated with passers-by in excess of 10^{-6} fatalities per year.

This result arises because of the generally very low occupancy by people of the space outside buildings. Only in busy town and city centre streets does the occupancy of space associated with passers-by reach levels high enough for the risk to approach that associated with similar objects above doorways or falling through roofs.

As a proportion of all of the relevant objects in potentially hazardous situations, objects elevated above roofs appear about 5x as likely to involve OCR at or above the 10^{-6} level as are objects above doorways, which are in turn about 5x as likely to involve OCR at such a level as are objects above publicly accessible space.

By location

Table 6 and Figures 4 and 5 show where the higher risk (OCR$\geq 10^{-6}$/year) objects are, by Municipality (or Wijk for the city of Groningen).

In Figure 4 the commonly occurring objects are grouped according to assumed fragility as follows;

- 'Chimneys & similar' includes decorative stonework and pinnacles;
- 'Parapets & similar' includes parapets on Dutch gables, balustrades and free-standing walls;
- 'Gables & similar' includes Dutch gables (excluding the parapet part above the roof line), and;
- 'Other' includes balconies, canopies, bay windows, large glass areas and signs

Table 6 and Figures 4 and 5 show that, while the majority of the objects with OCR above 10^{-6}/year are in the highest seismicity Municipalities of Loppersum and the "ring" of Municipalities around it, there is a significant minority in the city of Groningen (particularly in G00 – the central part of the city). Some important points need to be made about these higher OCR objects in areas of relatively low seismicity;

1. They derive their risk rating from a combination of relatively low seismicity and individual risk, in combination with large numbers of people exposed to risk. Many of them are large buildings such as schools, shops, apartment blocks and churches which either have large average internal populations or have large external falling hazards putting busy public spaces at risk.
2. The sense checks carried out on the model results (Section 4) suggest that the simple model assumptions;
    a. Tend to overestimate risk associated with running out of doorways (for larger buildings in particular);
    b. Tend to overestimate risk associated with objects falling through roofs, while;
    c. Tend to underestimate risk associated with objects falling into public spaces, particularly those where people tend to congregate outdoors.
3. The risk in such areas of low seismicity does not result from exposure to shaking at around the PGA levels on the 1 in 475 year KNMI contour map (0.08g for all of the CR>10^{-6}/year objects in G00 for example). It results largely from the significantly less frequent (more rare) events involving larger shaking.

Object Type	G00	G01	G02	G03	G04	G05	G06	G07	G08	G09	APP	BED	DEL	LOP	SLO	TEN	WIN	EEM	HAR	HOS	MEN	OAM	VEN
Chimney	58	21	12	42	17	8	14	4	1	40	395	60	143	307	67	163	12	90	2	144	6	4	5
Decorative feature	29	0	2	2	2	8	3	1	0	0	5	2	2	7	1	3	1	1	0	2	0	0	1
Pinnacle	14	3	0	1	0	2	3	0	0	0	3	2	4	9	2	4	0	3	0	0	0	0	0
Parapet	167	99	3	30	26	34	21	2	8	29	64	23	61	59	31	30	4	28	4	39	4	10	1
Balustrade	25	5	0	9	15	0	2	10	0	5	24	3	20	3	21	24	1	14	4	25	1	1	1
Free standing wall	4	2	0	23	1	28	0	5	0	9	51	5	51	45	15	16	1	6	5	5	0	0	0
Gable	33	3	0	16	4	3	2	1	0	154	462	93	288	443	98	227	38	83	6	27	3	3	2
DG parapet	37	10	1	0	3	2	0	0	0	0	13	0	2	8	0	5	3	7	2	2	1	0	0
DG gable	18	4	0	0	2	0	0	0	0	0	15	0	1	7	0	5	1	1	0	1	0	0	0
Dormer	63	17	9	1	2	2	8	0	0	0	25	15	15	39	7	7	4	51	2	38	2	4	1
Canopy-supported	0	0	2	0	2	1	0	0	0	1	1	0	3	1	0	0	0	1	0	1	0	0	0
Canopy-unsupported	16	1	2	0	0	3	0	2	0	0	6	1	10	4	15	0	0	1	0	2	0	0	0
Balcony	0	0	0	0	0	0	0	0	0	0	4	0	0	2	0	0	0	0	0	1	0	0	0
Bay window	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large glass area	6	4	6	1	2	12	3	1	0	0	5	1	7	2	0	1	2	6	1	0	0	0	0
Sign – vertical	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sign – horizontal	6	0	3	0	1	3	0	0	0	1	8	0	3	0	2	0	0	1	0	3	0	0	0
Industrial object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walkway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flagpole	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**481**	**169**	**70**	**125**	**77**	**106**	**57**	**26**	**9**	**239**	**1081**	**205**	**610**	**936**	**259**	**485**	**67**	**293**	**26**	**291**	**17**	**22**	**11**

Table 6: Falling Hazard Objects with OCR ≥10^{-6}/year, by Municipality/Wijk

***Key: Groningen Wijken**: G00 - Binnenstadt; G01 – Schilders- en Zeeheldenwijk; G02 - Oranjewijk; G03 - Korrewegwijk; G04 - Oosterparkwijk ; G05 - Oosterpoortwijk; G06 - Herewegwijk en Helpman; G07 - Stadsparkwijk; G08 - Hoogkerk; G09 – Noorddijk*

***Key: Other Municipalities**: APP – Appingedam; BED – Bedum; DEL – Delfzijl; EEM – Eemsmond; HAR – Haren; HOS – Hoogezand-Sappemeer; LOP – Loppersum; MEN – Menterwolde; OAM – Oldambt; SLO – Slochteren; TEN – Ten Boer; VEN – Veendam; WIN – Winsum*

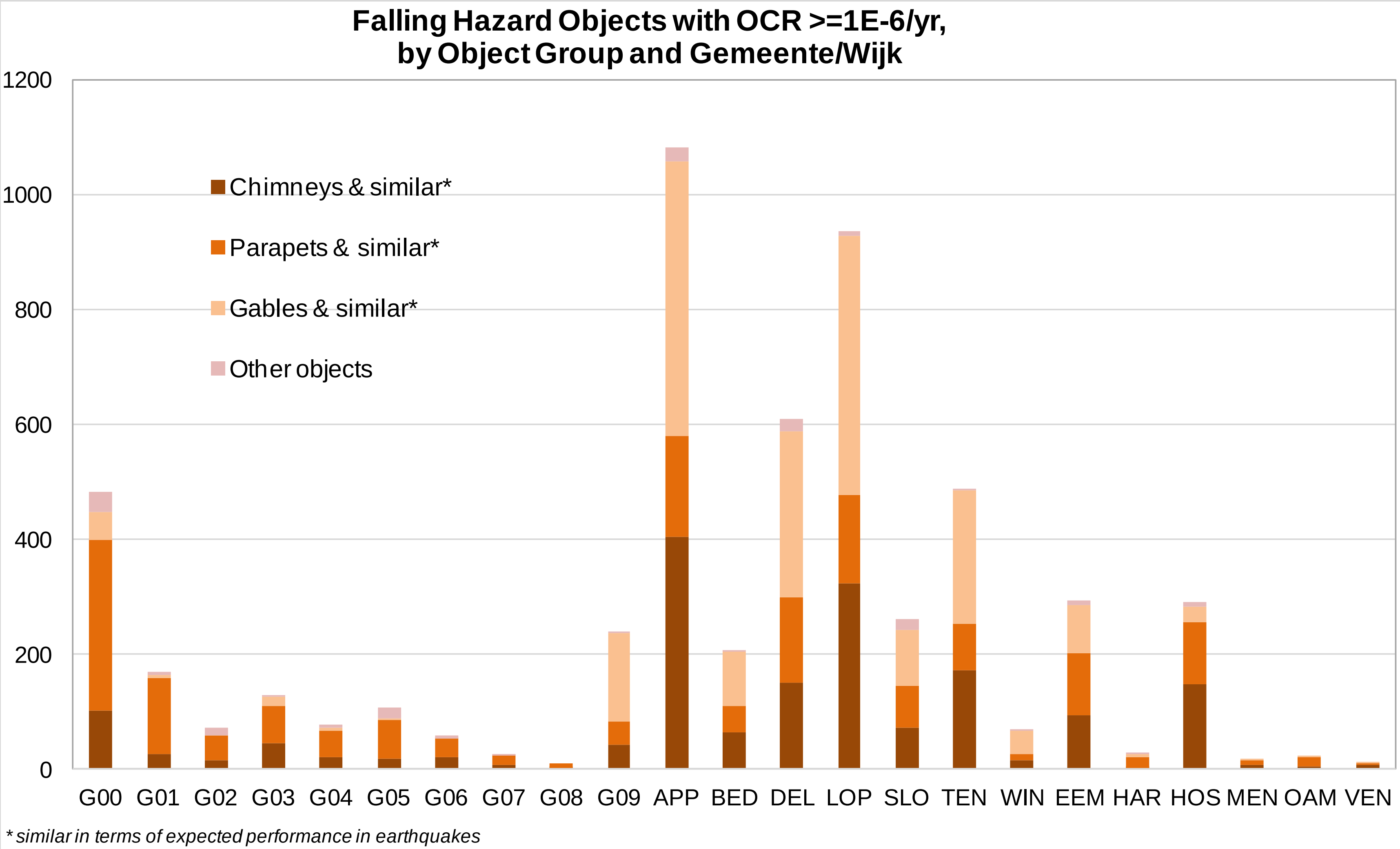

Figure 4: Falling Hazard Objects with OCR≥10^{-6}fatalities/year, by Municipality/Wijk and Object Group

Key: As for Table 6

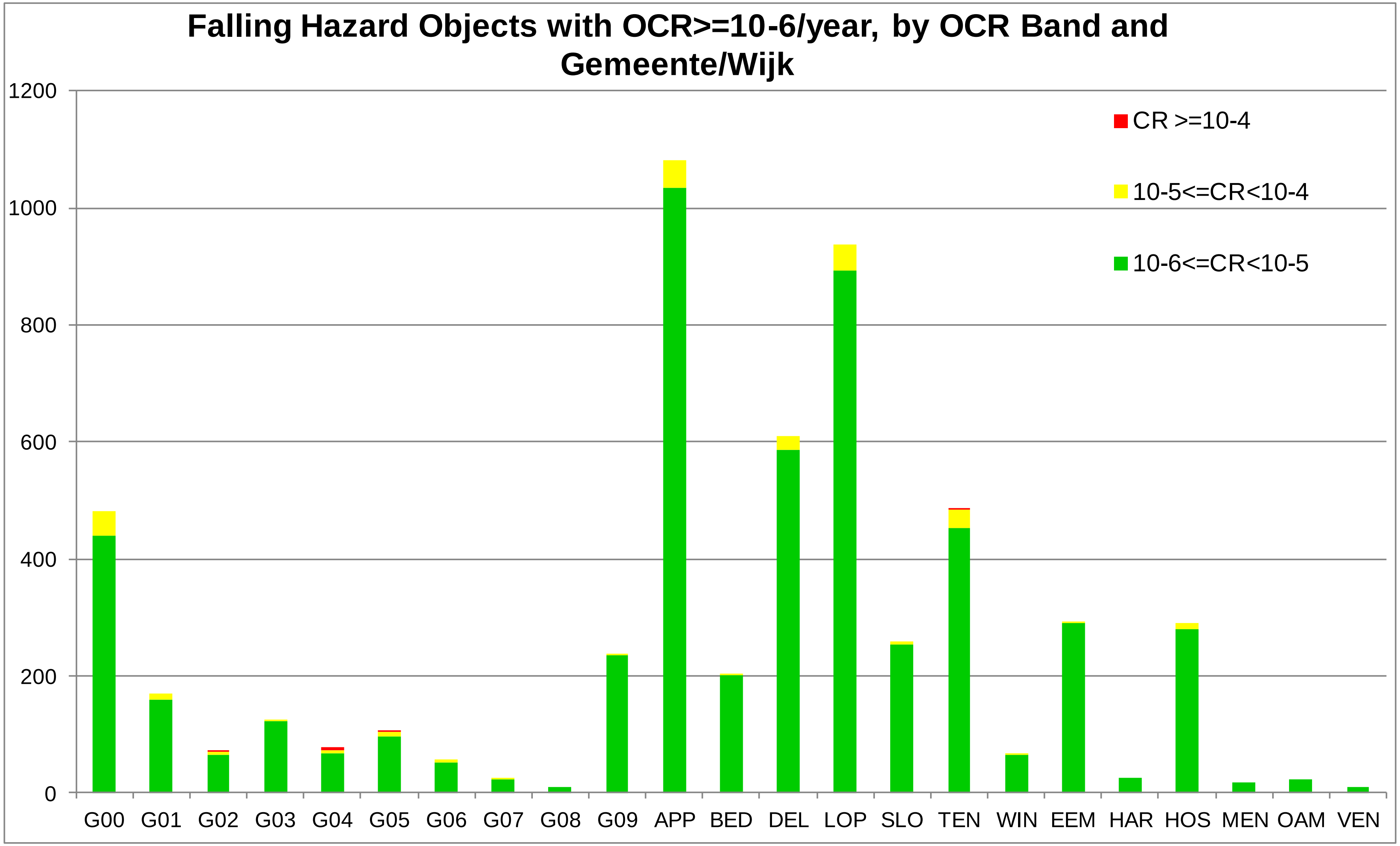

Figure 5: Falling Hazard Objects with OCR≥10^{-6} fatalities/year, by Municipality/Wijk and OCR band

Key: As for Table 6

5.1.2 Individual risk

By object type

Occupancy assumptions to be used for the calculation of OIR are discussed and proposed in Appendix 4. OIR has been calculated based both;

1. on the actual likely occupancy of buildings used as shops, workplaces, schools etc. (20%), and;
2. on the basis proposed by Commission Meijdam for the comparison of OIR with risk norms (assuming 100% occupancy of all buildings which are regularly occupied for a large proportion of the time).

All results presented here are those calculated on the latter basis.

Table 7 provides an overview of objects by OIR band, analogous to the OCR version in Table 4.

Object Type	**Total**	**OIR ≥ 10^{-4}**	**10^{-5}≤OIR<10^{-4}**	**10^{-6}≤OIR<10^{-5}**	**10^{-7}≤OIR<10^{-6}**	**OIR<10^{-7}**
Chimney	47371	0	8	1113	10906	35344
Gable	28139	0	20	1583	8496	18040
Canopy unsupported	14005	0	0	1	96	13908
Parapet	7557	0	8	298	3010	4241
Balustrade	4285	0	0	111	1144	3030
Balcony	3472	0	0	1	25	3446
Sign - horizontal	2406	0	0	0	11	2395
Dormer	2244	0	5	165	1394	680
Bay window	2034	0	0	0	5	2029
Canopy supported	1683	0	0	1	27	1655
Free standing wall	1507	0	0	189	735	583
Sign - vertical	1181	0	0	0	1	1180
Flagpole	1086	0	0	0	0	1086
DG parapet	709	0	2	34	263	410
DG gable	709	0	0	24	134	551
Decorative feature	706	0	0	17	125	564
Large glass area	537	0	0	2	71	464
Pinnacle	363	0	2	26	53	282
Other	108	0	0	1	1	106
Industrial object	77	0	0	0	1	76
Walkway	39	0	0	0	0	39
Total	**120218**	**0**	**45**	**3566**	**26498**	**90109**
% of all objects		0.00%	0.04%	3.0%	22.0%	75.0%

Table 7: Overview of Falling Hazard Objects by OIR Band

The majority of these higher OCR objects are in the highest seismicity areas of Loppersum and the surrounding Municipalities, but a substantial minority are in lower seismicity, more highly populated areas (in particular the centre of Groningen).

The numbers of objects assessed in different bands of occupancy-adjusted individual risk (OIR) are

a. OIR $\geq 10^{-5}$/year 45;

b. 10^{-5} > OIR $\geq 10^{-6}$/year about 3,600;

c. 10^{-6} > OIR $\geq 10^{-7}$/year about 27,000;

d. OIR < 10^{-7}/year the remainder (about 90,000).

By exposure pathway

Table 8 provides an overview of the numbers of objects in the three highest OIR bands shown in Table 7 (i.e. those with OIR $\geq 10^{-6}$/year), broken down by the predominant hazard exposure pathway for each object.

Object Type	Above doorways		Above public space		Above roofs	
	Total objects	**Number with OIR≥10^{-6}**	**Total objects**	**Number with OIR≥10^{-6}**	**Total objects**	**Number with OIR≥10^{-6}**
Chimney	30109	442	27367	17	4776	662
Gable	14515	1088	17966	32	1187	483
Canopy-unsupported	12704	1	7346	0	6	0
Parapet	5255	270	6390	9	218	27
Balustrade	2759	109	3306	2	50	0
Balcony	2326	1	2567	0	1	0
Dormer	1793	167	1995	1	4	2
Canopy-supported	1399	1	1025	0	2	0
Bay window	1365	0	1893	0	0	0
Sign horizontal	1309	0	2244	0	17	0
Free standing wall	1101	142	685	9	72	38
Sign vertical	561	0	1138	0	1	0
DG gable	528	22	651	0	9	2
DG parapet	514	33	651	1	15	2
Flagpole	500	0	1049	0	4	0
Decorative feature	475	16	613	0	11	1
Large glass area	390	1	436	0	4	1
Pinnacle	174	26	335	2	26	0
Other	63	0	90	1	4	0
Industrial object	24	0	54	0	17	0
Walkway	15	0	36	0	0	0
Total	**77879**	**2319**	**77837**	**74**	**6424**	**1218**
% Objects >= 1E-6		3.0%		0.1%		19.0%

Table 8: Objects with OIR ≥10^{-6}/year, by Exposure Pathway

By location

Table 9 and Figures 6/7 provide the counterparts of Table 6 and Figures 4/5, showing numbers of objects in different risk categories broken down by Municipality/Wijk, with risk now measured as OIR rather than OCR.

There is a marked contrast between where the objects in the higher OCR bands shown in Table 5 and those in the higher OIR bands shown in Table 7 are located. Objects with OIR greater than 10^{-5}/year are confined to Loppersum, Appingedam, Ten Boer and Bedum, with none at all in Groningen City or even in Delfzijl. This is because the seismicity is insufficiently high outside the highest seismicity areas to generate levels of individual risk (adjusted for occupancy) at this level.

The distribution of objects with OIR greater than 10^{-6}/year is also heavily skewed towards Loppersum and the surrounding Municipalities, though the higher seismicity parts of Groningen City (in particular G09 – Noorddijk, the furthest North East and highest seismicity Wijk) do have some objects with OIR at or above this level.

Object Type	**G00**	**G01**	**G02**	**G03**	**G04**	**G05**	**G06**	**G07**	**G08**	**G09**	**APP**	**BED**	**DEL**	**LOP**	**SLO**	**TEN**	**WIN**	**EEM**	**HAR**	**HOS**	**MEN**	**OAM**	**VEN**
Chimney	8	8	6	29	24	5	7	0	0	34	305	27	122	234	31	126	4	63	2	82	3	0	1
Decorative feature	0	0	0	0	0	2	0	0	0	0	3	0	0	6	1	1	1	1	0	2	0	0	0
Pinnacle	0	0	0	0	0	1	0	0	0	0	3	0	4	7	2	5	0	5	0	1	0	0	0
Parapet	3	4	3	6	1	7	0	0	0	23	54	17	39	49	29	22	0	19	0	24	3	3	0
Balustrade	0	0	0	1	1	0	0	0	0	5	24	1	8	3	18	21	0	6	0	23	0	0	0
Free standing wall	1	0	0	22	0	19	0	1	0	2	48	2	21	40	8	19	0	3	1	2	0	0	0
Gable	2	1	0	4	2	1	0	0	0	148	447	67	156	430	56	187	22	58	1	19	0	2	0
DG parapet	2	2	0	0	0	0	0	0	0	0	12	0	1	7	0	5	0	5	0	2	0	0	0
DG gable	1	1	0	0	0	0	0	0	0	0	12	0	0	7	0	2	0	1	0	0	0	0	0
Dormer	1	0	0	2	0	2	0	0	0	0	20	8	14	36	5	6	0	47	0	28	0	1	0
Canopy - supported	0	0	0	0	0	02	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Canopy - unsupported	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Balcony	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Bay window	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large glass area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	1	0	0	0	0	0	0
Sign – vertical	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sign – horizontal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial object	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walkway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flagpole	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**19**	**16**	**9**	**64**	**28**	**37**	**7**	**1**	**0**	**212**	**929**	**122**	**365**	**821**	**150**	**395**	**28**	**208**	**4**	**183**	**6**	**6**	**1**

Table 9: Falling Hazard Objects with OIR≥10^{-6}/year, by Municipality/Wijk

***Key: Groningen Wijken**: G00 – Binnenstadt; G01 – Schilder- en Zeeheldenwijk; G02 - Oranjewijk; G03 - Korrewegwijk; G04 - Oosterparkwijk ; G05 - Oosterpoortwijk; G06 - Herewegwijk en Helpman; G07 - Stadsparkwijk; G08 - Hoogkerk; G09 – Noorddijk*

***Key: Other Municipalities**: APP – Appingedam; BED – Bedum; DEL – Delfzijl; EEM – Eemsmond; HAR – Haren; HOS – Hoogezand-Sappemeer; LOP – Loppersum; MEN – Menterwolde; OAM – Oldambt; SLO – Slochteren; TEN – Ten Boer; VEN – Veendam; WIN – Winsum*

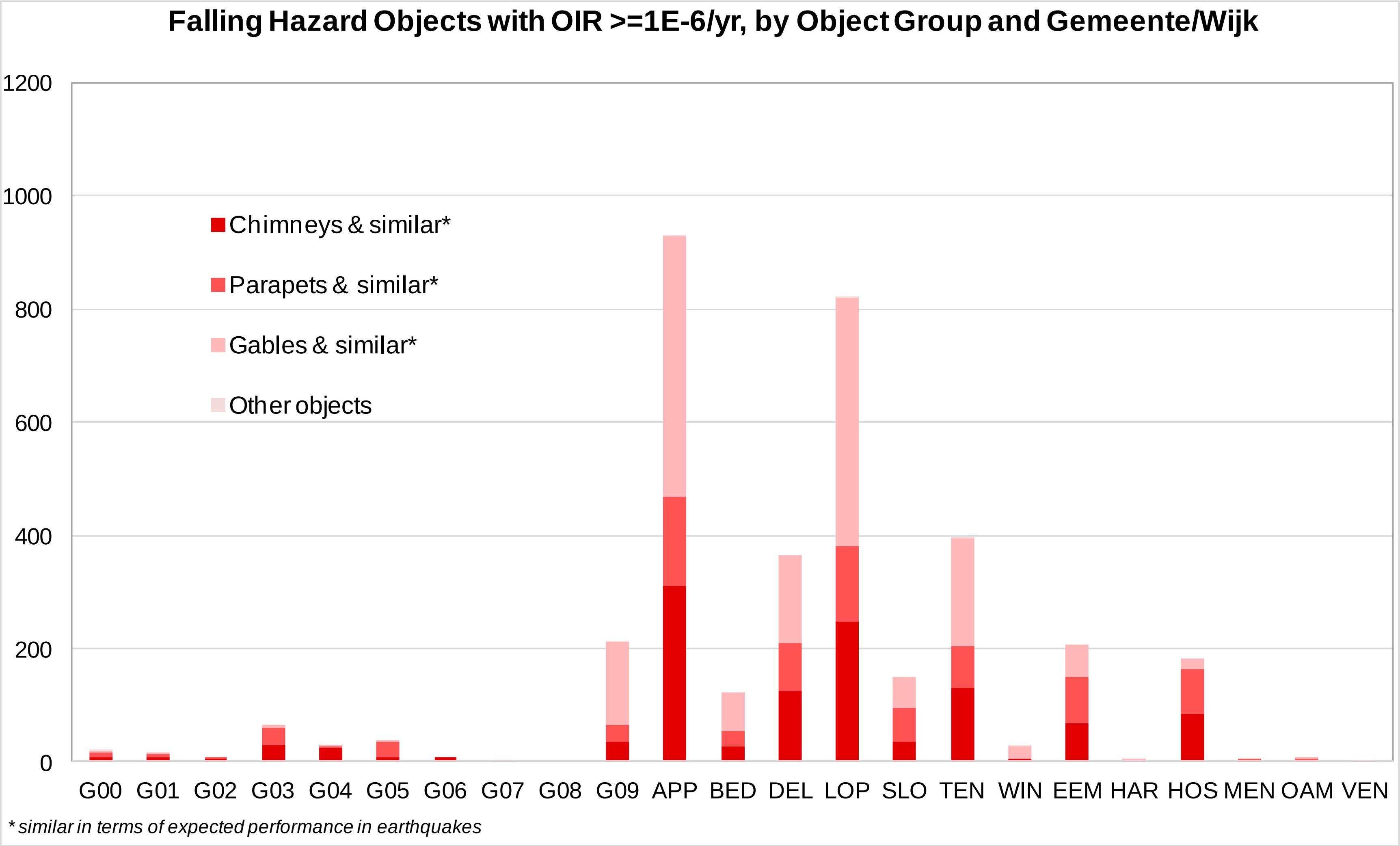

Figure 6: Falling Hazard Objects with OIR≥10⁻⁶/year, by Municipality/Wijk and Individual Risk (OIR) Band

Key: As for Table 8

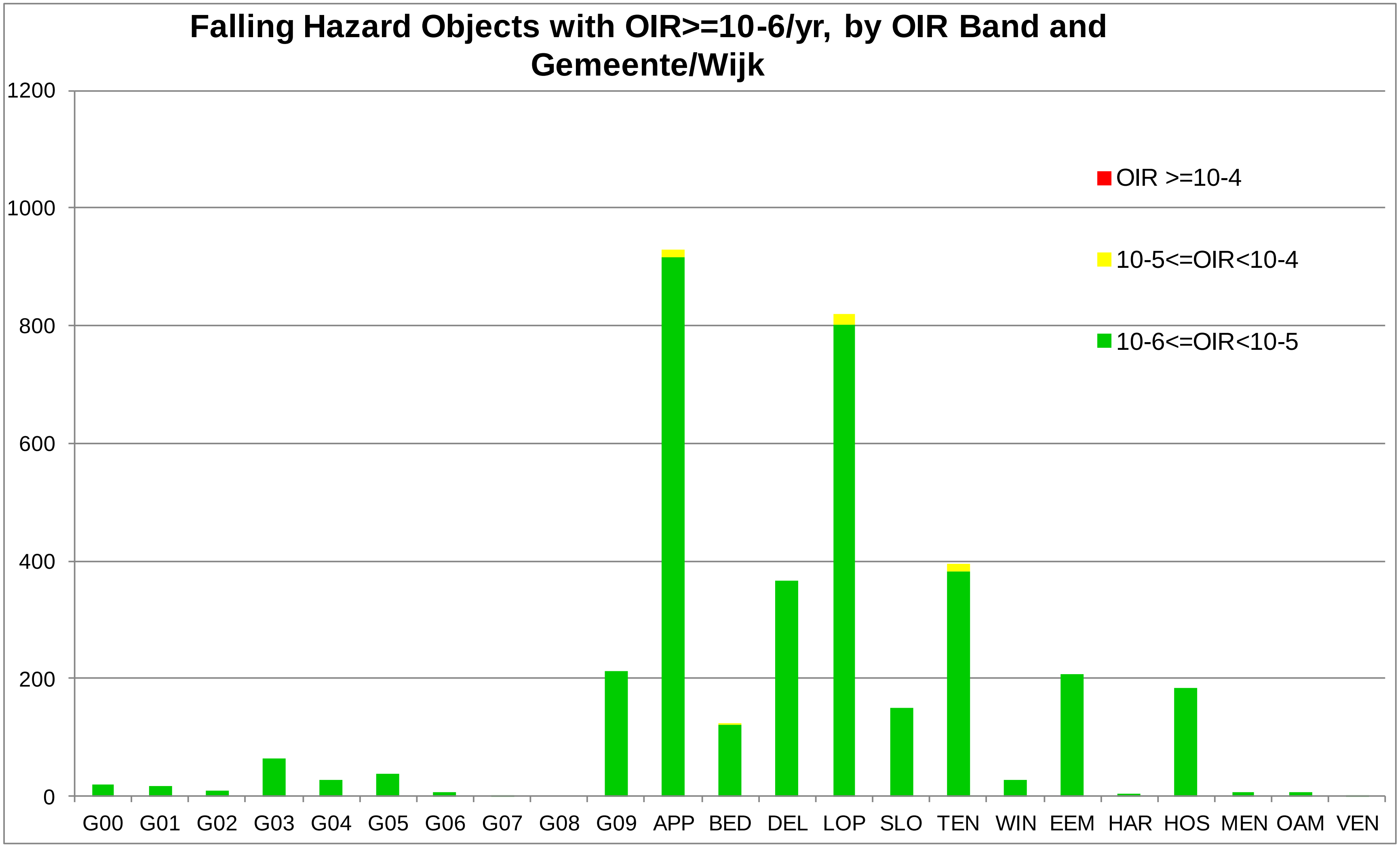

Figure 7: Falling Hazard Objects with OIR≥10^{-6}/year, by Municipality/Wijk and OIR Band

Key: As for Table 8

5.1.3 Results by Community and Individual Risk Bands

Table 10 shows a breakdown of all identified falling hazard objects by bands of both Community and Individual Risk (OCR and OIR).

Community Risk (OCR) fatalities/year	**Individual Risk (OIR), probability of fatality/year**					**Totals**
	$10^{-5}<OIR\leq10^{-4}$	$10^{-6}<OIR\leq10^{-5}$	$10^{-7}<OIR\leq10^{-6}$	$10^{-8}<OIR\leq10^{-7}$	$OIR\leq10^{-8}$	
$OCR>10^{-4}$	0	1	5	1	0	**7**
$10^{-5}<OCR\leq10^{-4}$	42	97	88	26	0	**253**
$10^{-6}<OCR\leq10^{-5}$	2	3319	1677	357	47	**5402**
$10^{-7}<OCR\leq10^{-6}$	1	140	21959	4624	598	**27322**
$10^{-8}<OCR\leq10^{-7}$	0	8	2284	35500	6011	**43803**
$OCR\leq10^{-8}$	0	1	485	4366	38579	**43431**
Totals	**45**	**3566**	**26498**	**44874**	**45235**	**120218**

Table 10: Falling Hazard Objects Identified, by OCR and OIA Band

Note – it is possible for objects to have OIR greater than OCR in this assessment, as the generic assumptions used in calculating OIR are based on a "representative person" and are somewhat conservative (tend to overstate occupancy), whereas the OCR estimates use more realistic estimates of the average numbers of people present in an at-risk area.

5.2 Low Priority Municipalities

A simple assessment of falling hazard risk has been made for the Municipalities further from the areas of significant seismicity by combining

- Numbers of buildings assigned a given PGA contour on the KNMI map, with
- Average objects per building for that contour (from the assessment for high & medium priority Municipalities), and
- Proportion of objects with OCR ≥10^{-6}/year for that contour (from the high/medium assessment).

The other Municipalities involved and associated numbers of buildings by PGA contour are shown in Table 11.

	PGA Contour (1 in 475 year exceedence, KNMI 2015)			
Survey Segment	**0.06**	**0.04**	**0.02**	**Totals**
Aa en Hunze	0	3235	108	3343
De Marne	1183	2059	0	3242
Pekela	0	5146	0	5146
Tynaarlo	1267	12575	143	13985
Zuidhorn	682	4838	0	5520
Other Municipalties*	0	2978	4	2982
Total	**2450**	**17869**	**251**	**20570**

** Assen, Bellingwedde, Grootegast, Leek and Noordenveld combined*

Table 11: Building Numbers by Municipality and PGA Contour

Note that the set of buildings in Table 11 is defined based on the numbers within the 0.1g contour on the KNMI 2013 map of 1 in 475 year exceedance PGA, whereas the PGA contours and numbers of buildings shown in the table are defined based on the October 2015 PGA map.

Statistics on number of buildings, number of objects, proportions of objects in different OCR bands and average OCR were taken from the aggregates for buildings on the 0.06 and 0.04g contours from all of the Municipalities covered in the individual risk assessments described in the previous section. The relevant parameters and the results of their combination with the building numbers from Table 9 are shown in Table 10.

Object Type	**Estimated values for**	
	N objects present	**N objects with OCR≥10^{-6}**
Walkway	0	0.0
Other	0	0.0
Industrial object	1	0.0
Pinnacle	33	0.0
DG parapet	42	0.1
DG gable	42	0.0
Free standing wall	53	0.4
Bay window	54	0.0
Decorative feature	73	0.2
Sign - vertical	75	0.0
Canopy - supported	91	0.0
Large glass area	123	0.1
Flagpole	124	0.0
Dormer	130	0.2
Sign - horizontal	229	0.0
Balcony	298	0.0
Balustrade	587	0.4
Parapet	671	1.3
Canopy - unsupported	1126	0.0
Gable	7813	0.3
Chimney	14445	1.0
Total	**26010**	**4.0**

Table 12: Assessed Risk for low Priority Municipalities

Parallel calculations have not been carried out for individual risk. The number of identified objects in the surveyed Municipalities on the 0.06 and 0.04g PGA contour with OIR≥10^{-6}/year was less than 10% of that with OCR≥10^{-6} fatalities/year, suggesting that the expected number of objects with OIR≥10^{-6}/year among the low priority Municipalities is less than 1.

6 Conclusions and Recommendations

Our conclusions are;

1. This risk assessment is fit for its dual purposes of;
    a. Prioritising areas for on-the-ground inspection of falling hazards, and;
    b. Helping develop simple rules for when objects do or do not require upgrade.
2. The risk assessment should not be used to make upgrade decisions at the level of individual buildings, because of the many local factors relating not only to the object but also its situation and the use of space around it which are of major importance for risk and cannot currently be incorporated into the model.
3. In terms of Community Risk, numbers of objects are assessed as falling in risk bands as follows;
    a. OCR $\geq 10^{-5}$/year about 260;
    b. 10^{-5} > OCR $\geq 10^{-6}$/year about 5,400;
    c. 10^{-6} > OCR $\geq 10^{-7}$/year about 27,000;
    d. OCR < 10^{-7}/year the remainder (about 87,000).
4. The objects in the higher OCR bands (a) to (c) above are dominated by parapets, chimneys, gables and other stone or masonry elements with assumed similar fragility characteristics.
5. The majority of these higher OCR objects are in the highest seismicity areas of Loppersum and the surrounding Municipalities, but a substantial minority are in lower seismicity, more highly populated areas (in particular the centre of Groningen).
6. The numbers of objects assessed in different bands of individual risk (OIR) are
    a. OIR $\geq 10^{-5}$/year 45;
    b. 10^{-5} > OIR $\geq 10^{-6}$/year about 3,600;
    c. 10^{-6} > OIR $\geq 10^{-7}$/year about 27,000;
    d. OIR < 10^{-7}/year the remainder (about 90,000).

7. The higher OIR objects in band (a) above are concentrated in Loppersum and the highest seismicity areas of the Municipalities surrounding it. There are no identified objects in band (a) (≥10^{-5}/year OIR) in the city of Groningen.

8. Falling hazard risk to building occupants (via running outside during earthquakes or objects falling from height through roofs) accounts for a larger proportion of higher risk objects than does the risk of hazards situated above publicly accessible space where people walking or standing outside buildings would be at risk. This is because of differences in occupancy of the space involved.

9. The quantitative results of this risk assessment should be regarded as being uncertain by about a factor of ten in either direction (perhaps somewhat more in the downward than the upward direction). Object fragilities and assumptions about people's risk exposure contribute roughly equally to this uncertainty; both will need to be addressed if the uncertainty is to be reduced.

10. The 'sense checks' carried out in the course of this work have made good strides towards identifying the local factors that cannot currently be treated in the risk model but which would need to be taken into account in collecting more detailed information via inspection or other means, and making upgrade decisions on individual buildings.

Our recommendations are;

1. The findings of the assessment should now be used;
    a. to inform prioritisation of areas for on the ground inspection prior to upgrade decisions, and;
    b. to help develop simple rules to guide decisions on upgrading requirements.

2. Tools to support local decisions on upgrade need to be developed taking into account not only the risk as assessed here, but also the many local factors (relating to objects themselves, their location and the use of space around them) which have been identified as important for risk.

3. If the model is to be used as a basis for quantified risk assessment to complement the overall picture of risk developed for collapse risk by the NAM Hazard and Risk programme, further work is required (planned by NAM in 2016) to address the uncertainties in the model (relating both to objects and their fragility, and to people's exposure to risk in different situations) in order to generate results approximately equivalent to those developed for collapse risk.

7 References

[1] C Massey, M McSaveney et al "Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Life Safety Risk from Rockfalls (Boulder Rolls) in the Port Hills (2012)", GNS Science report 2012/123 (plus companion report GNS 2012/124 on cliff collapse)

[2] B Dost & J Spetzler, "Probabilistic Seismic Hazard Analysis for Induced Earthquakes in Groningen; Update 2015", KNMI Netherlands, October 2015