NAM

Assurance Meeting on Exposure, Fragility and Fatality Models for the Groningen Building Stock

Presentations **Participants Workshop**

Letter and Report **Assurance Panel**

Date March 2018

Editors Jan van Elk & Dirk Doornhof

General Introduction

On 21st and 22nd February 2018, NAM organised, under the auspices of the Ministry of Economic Affairs and Climate, an Assurance Meeting on Exposure, Fragility and Fatality Models for the Groningen Building Stock at Schiphol Airport, Amsterdam.

Objective of the Meeting

To assure the following elements of the Groningen Risk Assessment:

1. The building typologies classification and the process used to combine inspection data and inference rules in the development of the Exposure Model
2. The experimental and numerical modelling programmes used in the development of the Fragility Model, and the underlying methodology behind the latter
3. The use of numerical and empirical data for the development of the Fatality Model
4. The implementation of the above models, and associated uncertainty, in the risk engine

The assurance scope will focus on fatality risk estimation, rather than non-life threatening structural and non-structural damage.

Meeting Format

In the meeting, the attendees will have the following roles:

1. **Development Team**. The study programme and the models developed by this team were subjected to the assurance. The team prepared pre-read documents and make these available to the Assurance Team at least one month prior to the meeting and present their work.
2. **Assurance Team**. Experts asked to assure the study programme and the models developed. The assurance team prepared a report with opinion of the work and suggestions for further work. Table 1 lists the members of the assurance team.
3. **Domain Experts**. Experts potentially presenting their views on one or more of the Assurance Meeting topics and taking part in the discussions. These experts have not been involved in the study programme and the development of the models subject to the assurance.
4. **Observers**. Experts in other fields (e.g. hazard modelling) with an interest in the assurance process. Representatives of the regulator, SodM, will be invited to attend as observers.

Some of the Assurance Team also performed assurance on the studies for the development of the exposure, fragility and fatality models in October 2015.

The Assurance Team

The assurance team was chosen from internationally recognised experts in the field.

External Expert	Affiliation	Main Expertise Area
Jack Baker (Chair)	Stanford University, USA	PSHA, Fragility Development and Risk Analysis
Matjaz Dolsek	University of Ljubljana, Slovenia	Structural Modelling, Fragility Development and Risk Analysis
Paolo Franchin	University of Rome "La Sapienza", Italy	Structural Modelling, Fragility Development and Risk Analysis
Ron Hamburger	Simpson Gumpertz and Heger, USA	Structural Modelling and Performance Assessment of Structures
Ihsan Engin Bal	Hanze Hoogeschool, Groningen	Structural Modelling and Performance Assessment of Structures
Marco Schotanus	RUTHERFORD + CHEKENE, USA	Structural Modelling and Performance Assessment of Structures
Nico Luco	United States Geological Survey, USA	PSHA, Fragility Development and Risk Analysis
Dimitrios Vamvatsikos	NTUA, Greece	Structural Modelling, Fragility Development and Risk Analysis

Table 1: The Assurance Team

The Domain Experts were selected from local experts involved with seismic assessment of buildings in Groningen. Representatives from the Ministry of Economic Affairs and Climate, the regulator (SodM), National Coordinator Groningen (NCG), TNO, Exxonmobil and EBN were present as Domain Experts.

Timing and Place

The meeting was held:

> Wednesday 21st February and Thursday 22nd February 2018, plenary sessions with Development Team, Assurance Team, Domain Experts and Observers. During these session, the Development Team and selected Domain Experts made presentations to the Assurance Team. These formed the basis for discussions.
>
> Friday 23rd February 2018 morning, a session exclusive to the Assurance Team was held. The Development Team was available to the Assurance Team to provide clarifications upon request for Assurance Team (if required).

Preparation and Agenda

Technical reports were made available to the Assurance Team and the Domain Experts one month prior to the event. Domain Experts were asked to indicate, up to two weeks prior to the event, if they would be interested in delivering a presentation at the meeting. A proposal for the meeting agenda was submitted by the Development Team to the Assurance Team, two weeks ahead of the event. The Assurance Team prepared the final agenda for the plenary sessions.

Wednesday 21st February

Start	End	Topic	Speaker
09:00	09:30	Welcome and Introduction Request by Minister and Life Safety Norm in The Netherlands	Ruud Cino
09:30	10:30	Risk metrics Overview of NAM's Hazard and Risk Assessment programme Objectives and Meeting format	Thijs Jurgens Jan van Elk
10:30	11:00	*Coffee break*	
11:00	11:20	Seismological model	Stephen Bourne
11:20	11:40	Ground Motion model	Julian Bommer
11:40	12:00	Hazard modelling and results + Risk Engine	Stephen Bourne
12:00	13:00	Groningen Building Stock and Exposure Database	Rinke Kluwer
13:00	14:00	*Lunch*	
14:00	14:30	Experimental testing programme for URM materials characterisation at TU Delft	Jan Rots
14:30	15:30	Experimental testing programme for URM components and structures at Eucentre and LNEC	Guido Magenes
15:30	16:00	*Coffee break*	
16:00	16:30	Experimental testing programme for RC structures at Eucentre	Rui Pinho
16:30	17:00	Verification and calibration of numerical models using test data	Rui Pinho
17:00	18:00	Discussion	All

Thursday 22nd February

Start	End	Topic	Speaker
09:00	09:30	Summary of first impressions/feedback from Review Panel	Jack Baker
09:30	10:15	Numerical modelling of Groningen buildings using Finite Element Analysis (with LS-Dyna software)	Richard Sturt
10:15	11:00	Numerical modelling of Groningen buildings using the Applied Element Method (with ELS software)	Andrea Penna
11:00	11:30	*Coffee break*	
11:30	13:00	Exposure, Fragility and Consequence models	Helen Crowley
13:00	14:00	*Lunch*	
14:00	14:30	Overview of risk results	Stephen Bourne
14:30	15:00	Discussion	All
15:00	15:30	*Coffee break*	
15:30	16:30	Final discussions	All
16:30	17:00	Closure	Jan van Elk

The current document

The current document contains:

- A general instruction providing information on the objectives, agenda and other specifics of the meeting. This section also introduces the Assurance Panel
- An Assurance Letter sent to the Ministry of Economic Affairs and climate by the Assurance Panel
- An Assurance Report prepared by the Assurance Panel
- All presentations used in the discussions during the meeting.

NAM

Title	**Assurance Meeting on Exposure, Fragility and Fatality Models for the Groningen Building Stock**		**Date**	March 2018
			Initiator	NAM
Autor(s)	Jack Baker (Chair), Matjaz Dolsek Paolo Franchin, Ron Hamburger Ihsan Engin Bal, Marco Schotanus Nico Luco, Dimitrios Vamvatsikos	**Editors**	Jan van Elk and Dirk Doornhof	
Organisation	Assurance Panel	**Organisation**	NAM	
Place in the Study and Data Acquisition Plan	Study Theme: Exposure, Fragility and Fatality Models Comment: On 21st and 22nd February 2018, NAM organised under the auspices of the Ministry of Economic Affairs and Climate an Assurance Meeting on Exposure, Fragility and Fatality Models for the Groningen Building Stock at Schiphol Airport, Amsterdam. The current document contains: ■ A general instruction providing information on the objectives, agenda and other specifics of the meeting. This section also introduces the Assurance Panel ■ An Assurance Letter sent to the Ministry of Economic Affairs and climate by the Assurance Panel ■ An Assurance Report prepared by the Assurance Panel ■ All presentations used in the discussions during the meeting.			
Directliy linked research	(1) Modelling Seismic Building Response (2) Experiments on buildings (3) Risk Assessment			
Used data				
Associated organisation	NAM			
Assurance	Assurance Panel			

27 April 2018

Mr. Jan van Herk
Ministry of Economic Affairs and Climate Policy
Bezuidenhoutseweg 73
2594 AC The Hague
The Netherlands

Dear Mr. van Herk:

Under the auspices of the Ministry of Economic Affairs and Climate, the NAM convened a panel consisting of the undersigned experts in structural engineering, earthquake engineering and risk analysis to review the NAM Research Team's Version 5 exposure, fragility, and fatality models for the Groningen building stock. Our review included the project reports associated with these models, and presentations from the research team on 21 and 22 February 2018 at the World Trade Center conference facility at Schiphol Airport. Some members of our panel also reviewed previous versions of these models in 2015. Our review focused on the selection of building archetypes, and the development of the fragility models and consequence functions for these archetypes. Attached with this letter is a report of our assessment from this Version 5 model review.

In general, we found this work to meet, and in many cases advance, international state-of-the art in structural testing and modeling, and prediction of consequences. They are suitable for the purpose of assessing Local Personal Risk from induced seismicity in the Groningen field. The attached report includes some recommendations for refinements and opportunities for future development, but these issues do not impact the fundamental appropriateness of these models for their intended purpose.

Sincerely,

Jack Baker (Chair)
Ihsan Engin Bal
Matjaz Dolsek
Paolo Franchin
Ronald Hamburger
Nicolas Luco
Marko Schotanus
Dimitrios Vamvatsikos

Review report: Exposure, fragility, and fatality models for the Groningen building stock

27 April, 2018

Jack Baker (Chair), Ihsan Engin Bal, Matjaz Dolsek, Paolo Franchin, Ronald Hamburger, Nicolas Luco, Marko Schotanus, Dimitrios Vamvatsikos

Introduction and Scope

This report summarizes the findings from the Assurance Panel, tasked with reviewing the Version 5 exposure, fragility, and fatality models for the Groningen Risk Assessment effort.

We reviewed these models to judge their suitability to evaluate Local Personal Risk. We understand that these models may have additional utility for other purposes, but have not performed a comprehensive review of their suitability for those other purposes.

We understand our scope of work to consist of review of:

1. The building typologies classification and the process used to combine inspection data and inference rules in the development of the Exposure Model;
2. The experimental and numerical modeling programs used in the development of the Fragility Model, and the underlying methodology behind the latter;
3. The use of numerical and empirical data for the development of the Fatality Model;
4. The implementation of the above models, and associated uncertainty, in the risk engine.

The assurance scope focuses on fatality risk estimation, rather than non-life threatening structural and non-structural damage.

Our review relied upon analysis reports provided by the NAM Research Team, as well as presentations made during an Assurance Workshop that took place on February 21 and 22, 2018 at the World Trade Center conference facility at Schiphol Airport. The subset of materials we reviewed that most directly relate to this report are:

- “Induced Seismicity in Groningen: Assessment of Hazard, Building Damage and Risk” Dated November 2017;
- “Report on the v5 Fragility and Consequence Models for the Groningen Field” Dated October 2017;
- “A Probabilistic Model to Evaluate Options for Mitigating Induced Seismic Risk” Draft manuscript received 9 February 2017.

While we carefully reviewed this information, we have not independently verified surveys or analysis results. We also note that results from the study expressed in terms of Local Personal

Risk for individual structures were not compared to acceptability of the same structure based on an assessment in accordance with NPR 9998, the Dutch Standard for "Assessment of buildings in case of erection, reconstruction and disapproval – basic rules for seismic actions: induced earthquakes" and that review of the Standard was beyond our scope.

Findings

The basic approach to risk evaluation properly follows the commonly accepted international framework for such studies. In general, we found this work to meet, and in many cases advance, the international state-of-the art in defining structural fragility and consequences informed by structural testing and modeling. The project team is world-class, and includes well-qualified experts in all aspects of the project scope. In some ways this project will be a model for future seismic risk assessments worldwide.

Assessing life safety risk in Groningen is extremely difficult, given the complete lack of empirical data on earthquake-induced structural collapses or fatalities for the region. This makes the modeling more challenging than in other regions where past deadly earthquakes provide observational constraints. The project team is well aware of this challenge, and has carefully thought about the many necessary extrapolations.

The goal of linking from gas extraction, to earthquake occurrence, to ground motion, to building exposure, to structural collapse and ultimately life safety, is an ambitious one. The interfaces between these models have been handled with more care than is standard, and care has been taken to identify and track uncertainties associated with the component models.

In the following subsections, we comment on specific model components this Panel reviewed.

Exposure model

The exposure model developed for the region is extremely detailed given the size of the region. The use of national databases, combined with inspections, local engineering expertise and other data sources, is appropriate and ensures utilization of all plausibly relevant data. It is appropriate that efforts have emphasized developing index buildings for the building stock contributing most to risk.

In general, the developed data and building archetypes are well suited for the purposes of identifying potentially vulnerable buildings and evaluating Local Personal Risk. It appears that the exposure models have utility for other purposes as well (e.g., later identification of buildings that may be identified for retrofit), though we have not considered those purposes in detail.

Fragility model

The overall testing and modeling effort underlying the fragility model is frankly incredible. The testing program is very substantial, with care taken to replicate typical construction details and as-built conditions in experimental specimens, and to identify and quantify potential failure

modes of the buildings. The combination of material, component and full-scale tests is extremely extensive.

The iterative development of numerical models, with software chosen based on suitability for the given objectives, builds substantial confidence that potential failure mechanisms are well characterized. The LS Dyna modeling is very sophisticated and not often employed even in regions of high natural seismicity. The application of Applied Element Method to masonry, coupled with supporting experimental tests, is pioneering. The use of parallel model development quality assurance is beyond best practices in almost any application; the only analog to this that the Panel knows of is in assessment of nuclear power plant risk.

The conversion of detailed numerical models into simplified single-degree-of-freedom (SDOF) models is understandable, given the wide range of building types to be studied, and the high computational cost of the detailed models. The consideration of soil-structure-interaction, and ground motion duration effects, could be important, given the somewhat unique circumstances present in Groningen.

Fatality model

The choice to use empirical models to predict fatalities, with only supplementary consideration of theoretical or numerical simulations, is appropriate. Prediction of fatalities is an extremely difficult problem to address numerically, so utilizing past observations from elsewhere in the world is the best available path to solving this problem. The empirical data utilized to establish potential fatality rates appears appropriate for the considered building typologies, given the fact that there are only a handful of empirical relationships available for this purpose.

Recommendations

While our review of the models is positive, there are several issues that we recommend the project team further address moving forward.

The mapping of detailed multi-degree-of-freedom (MDOF) structural models into simplified SDOF models is a challenging aspect of the process that needs care. The project documentation should include dynamic analysis validation results, such as those presented at the in-person meeting with the Panel; a comparison of SDOF and MDOF model pushover curves should also be provided. The specific approach to fit SDOF backbones, and choice of hysteresis models could be refined, but these choices did not appear to have impacted drift predictions for the cases we saw, and so ultimately these refinements may not impact Local Personal Risk estimates significantly.

For validation of the SDOF-based fragility functions, we suggest that the project team develops a fragility function directly for one MDOF model, for comparison with a corresponding SDOF-based function. A good candidate building would be the URM4L archetype that governs the risk

in the area, or a ductile building where the impact of the SDOF conversion is likely to be the largest.

The project would benefit from an evaluation of end-to-end interfaces and epistemic uncertainties. While the individual model components appear to have been well-studied and reviewed, a systematic study of the model interfaces, and the epistemic uncertainties associated with each model, would be beneficial. At present, the risk analysis includes consideration of some epistemic uncertainties (e.g., maximum possible earthquake magnitude, building fragility), but not others such as earthquake source model parameters and building inventory. As we deem the confidence intervals on Local Personal Risk estimates to be important, a systematic uncertainty study, and resulting expanded logic tree, is recommended. Additionally, the metrics used to quantify epistemic uncertainties could be improved relative to the current tornado diagram representation.

Finally, while the model sub-components are well documented, there is an opportunity to produce some aggregated model predictions for review, and for comparison of models against external data sources. An internal comparison of fragility functions for all architypes would be useful to evaluate whether the relative fragilities of the various buildings are ordered consistently with engineering judgement. Some suggested external comparisons are:

- Compare fragility models to empirical fragility functions for similar construction types from elsewhere in the world.
- Compute fatality rates as a function of ground shaking intensity (by combining the fragility and fatality models), and compare the results to empirical models (from, e.g., PAGER) for similar construction types.
- Compute regional predictions of the numbers of fatalities from the M>3 earthquakes that have happened in the past in Groningen (with the anticipation that the predictions would be of essentially zero fatalities).

These comparisons would not be done with the implication that the external models are "correct" for application in Groningen, or that the comparisons should result in close matches. After all, the anticipation is that the extensive testing and modeling program has produced fragility functions that are better suited for Groningen than any alternatives. Rather, the goal of these comparisons would be to provide general confirmation of the reasonableness of the results, and a benchmark to evaluate any differences; for example, if the Groningen fragilities for unreinforced masonry buildings suggest lower collapse probabilities than masonry fragilities from elsewhere in the world, would that relative difference make sense given what is known about Groningen construction methods?

Opportunities for future refinement

The insights established by the Version 5 models provide a foundation for even further exploration of risks and potential mitigation actions in Groningen. In this section we offer thoughts on potential opportunities for extension of the work scope, which may be useful if the project undertakes further stages of study.

Reduce conservatism

It appears that the project effort has appropriately aimed to characterize expected performance of the buildings, rather than taking a conservative view as is the case with building code analysis. There are, however, potentially a few subtle sources of conservatism remaining (i.e., sources that might result in overestimation of Local Personal Risk), which might be refined in future efforts:

- The large numbers of cycles of loading during testing and analysis may be producing conservatism in damage predictions relative to behavior under the very short duration shaking anticipated in Groningen. To some extent this may indirectly account for impacts of cumulative damage or pre-existing damage to buildings, but nonetheless some further evaluation of this issue may yield further insights.
- It has been assumed that the experimental buildings are near collapse at termination of the tests, but they may possibly have substantial remaining capacity.
- The ground motions used for analysis may be stronger in the demands they produce than actual ground motions that could be observed in Groningen. This is addressed to some extent by the use of vector ground motion intensity measures. But now that more is known about the ground motions contributing to risk, some follow-up study using hazard-consistent ground motions would offer the opportunity to better understand this issue.
- Take advantage of any further shake table tests as an opportunity for assessing the fidelity of the models and the currently employed fragility functions. Perform blind predictions (e.g., before and after knowing the material properties), perhaps sending the results to an independent third party before the test, and assess the fidelity of the models with an eye for improving the uncertainty bounds employed in the relevant fragilities.

Further refine structural modeling

As noted above, the structural modeling effort is in general extremely strong given the scope of study. Nonetheless, there are opportunities to further explore the impact of modeling assumptions on calculated risks. A few opportunities identified by the Panel include:

- Split building typologies and corresponding fragilities for critical cases (e.g., separate one- and two-story unreinforced masonry buildings, or separate older and newer variants of broadly defined typologies).
- Consider the impacts of including foundation flexibility in MDOF models, with an eye to differential settlement.
- Introduce a refined representation of soil-structure interaction in the SDOF model. Frequency dependence of stiffness and damping can be described for the purpose of time-domain analysis through a lumped-parameter model (LPM). Even with a relatively simple LPM the frequency-dependent coupled rocking-sway dynamic impedance can be described in the frequency range of interest. Care should then be taken to the way foundation input motion is applied, while incorporating the effective SDOF model height could be considered to better understand any issues of overturning moment coupled with foundation rotation.

- Consider the role of non-structural elements on structural response and life safety - in particular, internal masonry partitions.
- Consider developing simplified MDOF models as an alternative to SDOF models. Simplified structural models are capable of predicting various failure modes that can cause fatalities, but they are not as computationally demanding as refined Finite Element Models.

Study sensitivities in fatality models

There is an opportunity to better understand the implications of the fatality model, with respect to assumptions associated with that model. Parameters that could be explored include:

- Percent of time that occupants spend inside versus outside of the building;
- Percent volume loss associated with building collapse modes;
- Considered radius around the exterior of buildings;
- Combined impacts of exterior debris from adjacent buildings.

Extend project scope

Finally, there are topics that are not the current focus of the NAM modeling effort, but that could be well addressed by the models that NAM has developed. We recommend that these topics would benefit from study by the project team.

- Develop fragility functions and fatality models for retrofitted buildings, to evaluate benefits and necessary levels of retrofits for risk reduction. There seem to be some planned experiments with strengthening works, thus their outcomes could be useful for this purpose.
- Assess index buildings according to NPR. Parallel analyses using NPR and the NAM fragility functions, especially of the experimentally tested buildings, will help reconcile any differences in assessment results and support informed decision-making in cases where the two approaches result in different outcomes.
- The developed models could be utilized to quantify aggregate risk measures (i.e., group risk) rather than individual Local Personal Risk. This scope extension would require further refinements to address issues such as correlation of damage states of buildings, and spatial correlation of ground motions.
- Explore the potential impacts of cumulative damage or pre-existing damage to buildings mentioned above.