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TNO report

TNO2020 R11464 | Final report

Status of the TNO Model Chain Groningen per October 1, 2020 and recommendations for the public Seismic Hazard and Risk Analysis 2021

Date	October 1, 2020
Author(s)	
Copy no	
No. of copies	
Number of pages	17 (incl. appendices)
Number of appendices	
Sponsor	
Project name	
Project number	

Samenvatting

Status TNO Modelketen Groningen
De TNO Modelketen Groningen is in staat vanaf 2021 de jaarlijkse Seismische Dreigings- en Risico Analyse (SDRA) in het publieke domein uit te voeren. Behoudens acceptabele numerieke verschillen is de TNO Modelketen erin geslaagd de NAM HRA 2019 en 2020 resultaten te reproduceren. De technische status van de TNO Modelketen per 1 oktober 2020 omvat de componentversies van het Seismologisch Bronmodel (SSM) V5 en V6, het Grondbewegingsmodel (GMM) V5 en V6 en de Schademodellen (DM) V5, V6, V7, volgens de gangbare NAM versie-benaming.

Aanbevolen modellen in de publieke SDRA Groningen 2021
Om het publieke karakter van de toekomstige SDRA's te benadrukken, heet deze analyse "publieke SDRA Groningen jjjj", waarbij jjjj het jaar is waarin het corresponderende gasjaar begint. Door de modulaire opzet van de TNO Modelketen Groningen kunnen verschillende modelcomponenten worden gecombineerd – en daarom moeten geschikte componenten worden gekozen die het beste aansluiten bij het voorspellende karakter van de publieke SDRA Groningen 2021.

- TNO adviseert de implementatie van SSM V6 met een spanningsafhankelijke (hyperbolische tangens) b-waarde, zonder taper, doch inclusief ETAS. Daarnaast herhaalt TNO haar eerder advies om de Mmax-verdeling te herzien.
- Momenteel is een actualisatie van het GMM (V7) in voorbereiding door NAM. Omdat het geactualiseerde model, noch de documentatie op het moment van schijven beschikbaar is, adviseert TNO GMM V6 te gebruiken in de publieke SDRA Groningen 2021. Recente TNO analyse heeft echter geleid tot vragen met betrekking tot de wenselijkheid van het al dan niet ontbreken van een correlatiestructuur in de siterespons. TNO beveelt ten zeerste aan om deze kwestie in de geplande GMM expertmeeting te bespreken en op te lossen in de actualisatie van het GMM.
- TNO stelt voor om het Kwetsbaarheids- en Gevolgmodel (FCM) in het DM V7 aan te passen voor gebruik in de publieke SDRA Groningen 2021. Deze aanpassingen omvatten, maar zijn niet beperkt tot, het vergroten van de modelonzekerheid voor metselwerkgebouwen en verschillende verschuivingen van parameters voor specifieke kwetsbaarheidsklassen en consistentie in de gebouw-tot-gebouw variabiliteit.
- TNO stelt voor om de NAM Exposure Database V7 met de uitgevoerde actualisatie te gebruiken. Hiermee kan regionaal het aantal gebouwen dat niet aan de veiligheidsnorm voldoet worden bepaald in de publieke SDRA Groningen 2021.
- Tot slot wordt aanbevolen een nieuwe, unieke, versiebenaming te hanteren voor de gebruikte modelcomponenten in de publieke SDRA Groningen 2021.

Summary

Status TNO Model Chain Groningen
The TNO Model Chain Groningen is equipped to execute the yearly Seismic Hazard and Risk Analysis (SHRA) in the public domain from 2021 onwards. Barring acceptable numerical differences the tool has been successful in reproducing the NAM HRA 2019 and 2020 results. The technical status of the TNO Model Chain per October 1, 2020 includes the versions of the Seismic Source Models (SSM) V5 and V6, the Ground Motion Models (GMM) V5 and V6, and the Damage Models (DM) V5, V6, V7, following the common nomenclature in NAM HRA's.

Recommended models in the public SHRA Groningen 2021
To emphasize the public character of the upcoming SHRA's, this analysis is called: "public SHRA Groningen yyyy", in which yyyy is the year in which the corresponding gas year begins. As a result of the modular setup of the TNO Model Chain Groningen different model components can be combined – and hence, appropriate components must be chosen that best comply with the forecasting nature of the public SHRA Groningen 2021.

- TNO recommends implementation of SSM V6 with a stress-dependent (hyperbolic tangent) b-value, yet without a taper, but including ETAS. In addition, TNO reiterates its advice to review the Mmax-distribution.
- An update of the GMM (V7) is currently being prepared by NAM. Because neither the updated model nor the documentation is available at the time of writing, TNO recommends to use GMM V6 in the public SDRA Groningen 2021. Recent TNO analysis has, however, led to questions regarding the desirability of the absence of a correlation structure in the site response. TNO strongly recommends to discuss this issue in the planned GMM expert meeting and to resolve it in the GMM update.
- TNO proposes to adjust the DM V7 Fragility and Consequence model (FCM) for use in the public SHRA 2021. These adjustments involve, but are not limited to, increasing the model uncertainty for masonry buildings and several shifts of fragility parameters for specific vulnerability classes, and consistency in building-to-building variability.
- TNO proposes to use the NAM Exposure Database V7 with the upgrades carried out in 2020. In this way, the public SHRA 2021 can determine the number of buildings that do not meet the safety norm in a regional sense.
- Lastly, it is recommended to adopt a new, unique version designation for the used model components in the public SHRA Groningen 2021.

Contents

Preface

The yearly Probabilistic Seismic Hazard and Risk Assessment (HRA) of the Groningen gas field has traditionally been provided by the field operator NAM (e.g. NAM, 2019; 2020). The Dutch government decided in 2018 to cease production as fast as possible, to gradually opt-out NAM's involvement, and to outsource the Seismic Hazard and Risk Analysis (SHRA) in the public domain (EZK, 2018). The first public SHRA will take effect in 2021 for the Operational Strategy for the gas year 2021-2022 (EZK, 2020a). Meanwhile, TNO had independently rebuild and implemented the NAM HRA models and had been successful in reproducing similar output using similar input (TNO, 2019). Hence, the TNO Model Chain Groningen is the best-equipped candidate to deliver the SHRA executed in the public domain from 2021 onwards (TNO, 2020a; 2020b). The analysis by TNO for gas year 2021-2022 is called "public SHRA Groningen 2021" and in Dutch "publieke SDRA Groningen 2021".

As requested by the Ministry of Economic Affairs and Climate (EZK, 2020b), current report describes the status of the TNO Model Chain per October 1, 2020 including TNO's recommendations for model components in the public SHRA Groningen 2021. The scope is twofold: (i) supply an inventory of the input datasets, the state-of-art model components and output deliverables that form the basis of the current version of the TNO Model Chain; and (ii) give an overview of the recommended model choices that need to be made to run the public SHRA Groningen 2021 for the "Vaststellingsbesluit gasjaar 2021-2022". As scientific knowledge on induced seismicity and associated hazard and risk continuous to evolve, alternative models may need to be developed and/or implemented for usage in the TNO Model Chain Groningen, focusing on induced seismicity after ceasing gas production.

This report contains two chapters:
- Chapter 1 (Technical Status) describes the capabilities of the TNO Model Chain Groningen using the current and past versions of the different model components, data input, and deliverables.
- Chapter 2 (Recommendations) gives an outline of the suggested model components and the model choices that need to be made to successfully execute the public SHRA Groningen 2021 with the TNO Model Chain.

1 Technical Status per October 1, 2020

The TNO Model Chain Groningen is subdivided into three main model components: Seismic Source Model (SSM), Ground Motion Model (GMM), and the Damage Model (DM). Currently the Model Chain includes the following versions[1] of these models:

- Seismic source models (SSM): V5, V6
- Ground motion models (GMM): V5, V6
- Damage models (DM): V5, V6, V7
- Exposure database (EDB): V5, V6, V7.

In the following these models are described in more detail. Most model versions can be combined in the Hazard and Risk Analysis (HRA), although some combinations are impossible (e.g. GMM V6 no longer includes a duration equation, which is needed by the Fragility and Consequence model of DM V5).

TNO made an extensive comparison between the Model Chain Groningen and the NAM HRA based on version V5 of all the underlying model components (TNO 2019; 2020a). For quality control, these have been evaluated by KEM (2020a; 2020b) and the Model Chain code has recently been reviewed by Tessella (2020). These V5 versions were previously used by NAM (2019) in the HRA 2019. NAM (2020) used SSM V6, GMM V6 and DM V7 for the HRA 2020 for gas year 2020/2021 on which TNO’s advice to the Minister is applicable (TNO, 2020c). For the more recent models (SSM V6, GMM V6, DM V7) TNO (2020d) has made a successful comparison with the NAM HRA 2020 and considers the current Model Chain suitable for the public Seismic Hazard and Risk Analysis (SHRA) Groningen 2021.

Abovementioned models require input that must be provided by external parties:

- Seismic Source model input:
  - Catalogue of induced earthquakes (KNMI, 2020)
  - Static: reservoir thickness, compressibility, fault data (NAM)
  - Dynamic: past and future reservoir pore pressure corresponding to the required production scenario (NAM)
- Ground motion model parameters and site-response region geometry (NAM).
- Fragility and Consequence model parameters (NAM, TNO)
- Extraction of the Exposure Database (NAM, EZK)

TNO has all model parameters for the aforementioned model versions currently available in the Model Chain. Any updates to models, such as the GMM, DM or updates of the Exposure Database require that new model input files are provided to TNO in a compatible format.

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[1] Nomenclature is here according to NAM’s version numbering. Note that for the SSM, model version designations are not assigned by the model developers (Bourne and Oates, NAM), but are rather used informally. V5 refers to the SSM used for the HRA 2019, V6 refers to the SSM used for the HRA 2020.

1.1 Technical status SSM

The TNO Model Chain Groningen implemented SSM V5 and SSM V6 independently from NAM, based on the scientific and mathematical description of the models (Bourne and Oates, 2018; 2019; Bourne et al., 2019). Comparisons with the results obtained by NAM showed that although based on the same logic as derived from the reports, the software implementation details result in a slightly different spatiotemporal forecast. As an additional assurance step, TNO has therefore also implemented 'duplicates' of NAM's implementation of SSM V5 and SSM V6. These result in identical forecasts (within numerical accuracy) compared to those obtained by NAM when the same calibration result is used (TNO, 2019; 2020d).

Because of the modular setup of the SSM in the TNO Model Chain Groningen, different model components can be combined within the SSM (Figure 1). All combinations are possible configurations of the SSM and can be calibrated with observed seismicity. The obtained calibration can then be convolved with a future gas production scenario to obtain a seismicity forecast.

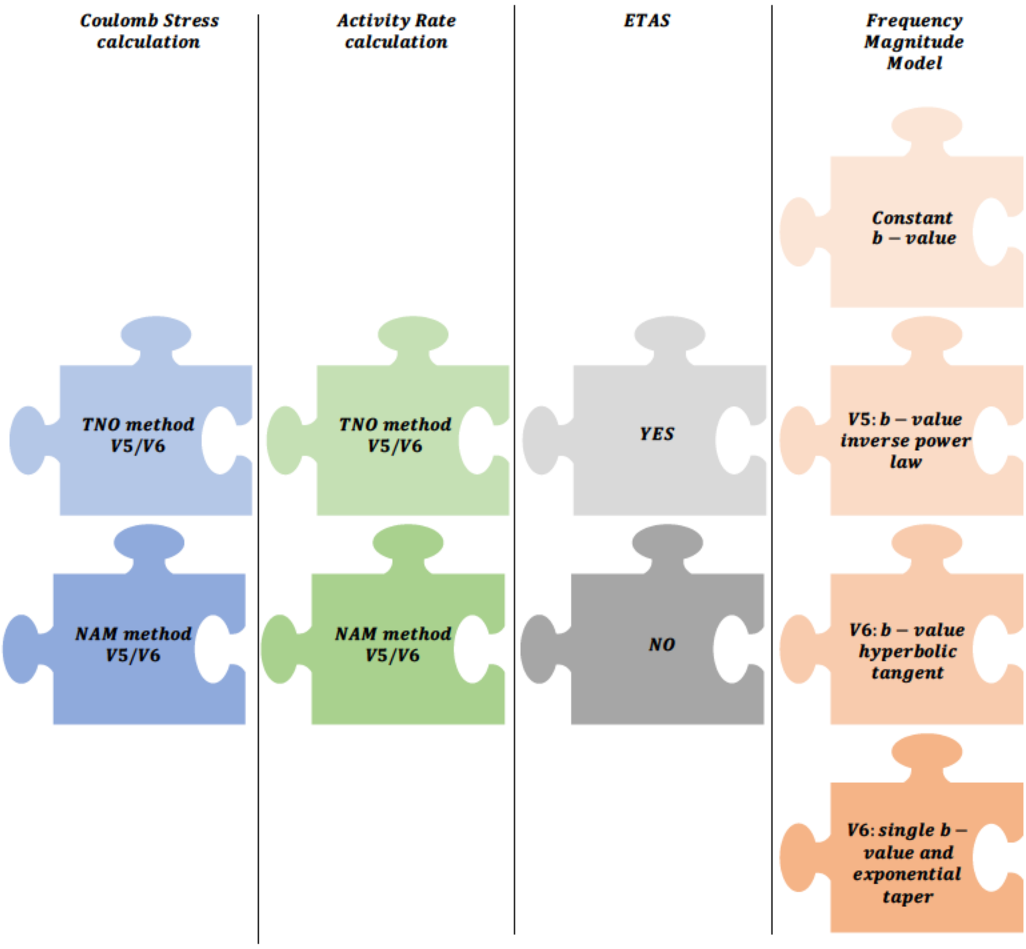

Figure 1 Modular setup SSM components

1.1.1 *Coulomb stress calculation*

Both V5 and V6 source models use smoothed "Coulomb stress" fields[2] as predictors/covariates for activity rate and magnitude-frequency distribution. These stress covariate fields are obtained from the static and dynamic reservoir properties through a series of data conditioning steps (Bourne et al., 2019). Apart from algorithmic steps related to the discretization of the faults, the conditioning steps include free parameters. An important difference between the V5 and V6 models of NAM is that NAM has moved from choosing a single realization of conditioning parameters (best fit for activity rate) to two realizations of parameters (best fit for activity rate, and a separate best fit for magnitude distribution). As an alternative, TNO prefers using a posterior distribution of conditioning parameters obtained from Bayesian inference from the observations[3] (TNO, 2020a), see also Table 1.

Table 1 Treatment of stress field conditioning parameters in V5 and V6 implementations of NAM and TNO.

SSM version	NAM	TNO
"V5" (HRA 2019)	1 realization for both activity rate and magnitude distribution (maximum likelihood)	posterior distribution from Bayesian inference
"V6" (HRA 2020)	1 realization for activity rate, and 1 realization for magnitude distribution (maximum likelihood)	posterior distribution from Bayesian inference

1.1.2 *Activity Rate calculation*

The Activity Rate modules are very similar. However, the NAM method calculates the activity rate for a single Coulomb Stress field, whereas the TNO method does so for an ensemble of Coulomb Stress fields.

1.1.3 *ETAS*

The Epidemic-Type Aftershock Sequence (ETAS) model can be turned on or off independent of other modelling choices.

1.1.4 *Frequency-Magnitude Model*

The TNO Model Chain Groningen implements all Frequency-Magnitude models present in the V5 and V6 versions of the SSM. In addition, a simple 'constant b-value' model is available.

[2] Although the stress covariate calculation is based on an expression for Coulomb stress at the faults, the conditioning steps that include smoothing and averaging lead the numerical values of the covariate field away from anything that is to be interpreted as Coulomb stress. The covariate field is often referred to as "Coulomb stress" nonetheless.
[3] The general advantage of using posterior distributions rather than point estimates is that uncertainties/variabilities are accommodated and the result is more robust to variations in the input data (e.g., this prevents discontinuities due to mode switching as a result of new observations).

1.2 Technical status GMM

The TNO Model Chain Groningen implemented GMM V5 and GMM V6 independently from NAM, based on the scientific and mathematical description of the models (Bommer et al., 2017; 2019).

Comparisons with the V5 results obtained by NAM initially showed a systematic difference in the obtained results. After analysis of NAM's software implementation, provided to TNO by SodM for the purpose of in-depth comparison, this difference was found to be due to an incorrect[4] implementation of the period-to-period correlations in the NAM software. For the purposes of the comparison, TNO (2020c) therefore implemented the option to follow the period-to-period correlation method used by NAM. With this option enabled, the TNO and NAM codes yield results identical to within a relative tolerance of 10^{-6} and an absolute tolerance of 10^{-8} (used when numbers are very close to zero).

In terms of technical implementation, the difference between GMM V5 and V6 is solely a change of input tables. The in-depth comparison with the NAM results for GMM V5 therefore translate directly to V6 as well. The results obtained in the recent HRA 2020 comparison confirms this (TNO, 2020c).

Currently, GMM V7 is still being developed. Implementation of GMM V7 into the TNO model chain has therefore not started. If the documentation and parameter files are supplied to TNO before 31 December 2020, it may be possible for TNO to realize the technical implementation before the public SHRA Groningen 2021 needs to be performed.
This implementation will be possible if the update only concerns:

- Change of input tables, and/or
- Addition/removal of GMM_{median} and/or Phi_{ss} logic tree branches.

TNO cannot guarantee technical implementation of GMM V7 before the public SHRA 2021 needs to be performed, if the update concerns other modelling aspects, such as, but not limited to:

- Change in functional form of mathematical expressions
- Change in model logic and/or (correlation) structure.

[4] The NAM software implemented the period-to-period correlations not only for the ground motions at reference level, but also for the amplification/attenuation functions of the site response, in contrast to the specification by Bommer et al. (2019).

1.3 Technical status DM

The TNO Model Chain Groningen implemented DM V5, V6, and V7 independently from NAM, based on the scientific and mathematical description of the models (Crowley and Pinho, 2017; 2020; Crowley et al., 2019).

Comparisons with the V5 results obtained by NAM initially showed a systematic difference in the obtained results (TNO, 2019). Analysis showed that there were differences between the values extracted from the V5 description report (Crowley and Pinho, 2017) and the parameter files used by NAM. After confirming that the parameter files used by NAM contained the correct values, and that the values in the report contained errors (Crowley, pers. comm.), the comparison was repeated using a consistent parameter set. The TNO and NAM codes yield identical results within numerical accuracy (TNO, 2019).

The update from DM V5 to V6 consists of a change in the functional form for the intensity measure calculation, and updated parameter files. The model structure and logic is otherwise unchanged.

The update from DM V6 to V7 consists of updated parameter files. The model structure and logic is otherwise unchanged.

The in-depth comparison with the NAM results for DM V5 therefore translates to DM V6 and DM V7 as well. The results obtained in the recent HRA 2020 comparison confirm this (TNO, 2020c).

1.4 Technical status EDB

The NAM Exposure Database (EDB) is an extract of the building stock database and contains information specific for Hazard and Risk Modelling (Arup, 2020). The TNO Model Chain implemented the EDB V7 with upgrades carried out in 2020. The next version/s of the EDB (V7.1) is to be delivered February/March 2021 (Arup, 2020).

2 Recommendations for the public Seismic Hazard and Risk Analysis (SHRA) Groningen 2021

Based on the available knowledge as of October 1, 2020, TNO recommends the following (versions of) models, logic tree weights and modelling choices as most suitable for use in the public SHRA Groningen 2021. In addition, TNO recommends to adopt a new, unique version designation for the used model components in the public SHRA Groningen 2021.

2.1 Recommended SSM

TNO recommends the use of the TNO implementation of SSM V6, including ETAS, and using the V6 hyperbolic tangent b-value model. This approach best honors the distribution and density of faults in the Groningen field, uses a full posterior distribution of stress covariate fields and is better in line with the NPR NEN webtool and TNO's advice for the HRA 2020 (TNO, 2020c).

TNO recommends including the most recent observations until the day TNO receives the request by the Minister of EZK to perform the public SHRA Groningen 2021. Source model calibration should be performed by TNO, within the same Quality Assurance system that applies to the entire TNO Model Chain Groningen. This approach maximizes the amount of work done in the public domain, increases traceability and reproducibility, and reduces the dependency of the SHRA result on external inputs.

TNO (2020c) has demonstrated that a tapered Frequency-Magnitude model cannot be calibrated reliably on an earthquake catalogue of the size that is available for Groningen and leads to a biased estimation of seismic hazard and risk. In fact, the taper location and its hypothesized stress-dependence cannot be resolved from the observations and therefore should to be treated as epistemic uncertainty, in a similar fashion to Mmax. Therefore TNO recommends the following update in the logic tree branch weights for the public SHRA Groningen 2021:

	NAM HRA 2020	public SHRA 2021
Stress-dependent b-value, no taper	20%	100%
Constant b-value, stress-dependent taper	80%	0%

In addition, we reiterate our advice (TNO, 2020c) to review the Mmax-distribution (values and weights) in the logic tree through an expert elicitation process. This would also be an excellent opportunity to discuss the necessity and desirability of a supplementary (stress-dependent) taper branch point in the logic tree.

2.2 Recommended GMM

TNO recommends the use of GMM V6 in the public SHRA Groningen 2021. However, TNO (2019, 2020c) previously raised questions on the inconsistency of the period-to-period correlation between the documented V6 specification by Bommer et al. (2019) and the actual implementation by NAM in the HRA 2020.

On the one hand, the original specification prescribes a period-to-period correlation of the ground motion variability at the North Sea base reference level, and does not specify any period-to-period correlation for the site response (i.e., to the site-to-site variability). On the other hand, the NAM implementation applies the reference level correlation structure to the site response as well. As a result, the period-to-period correlation for ground motions at the surface is much less for a literal implementation of Bommer et al. (2019) than for the implementation by NAM. Recently, NAM (pers. comm. September 21, 2020) confirmed the inconsistency between their code and Bommer et al. (2019).

TNO has studied the effect of the period-to-period correlation implementation consistent with Bommer et al (2019) and found that this leads to more than 20% reduction in local personal risk for all vulnerability classes relative to the implementation according to NAM. For the vulnerability classes with the highest risk, a reduction up to 40% is observed in the center region. An important cause for the reduction is that the intensity measure used in the V6 and V7 fragility models is defined as the average of the spectral accelerations at 10 spectral periods. This averaging reduces the variability in the intensity measure relative to the variability of the contributing periods. However, this reduction effect is stronger if the variation of the ground motions for the individual periods are less correlated. The literal implementation of Bommer et al. (2019) therefore leads to lower variability in the intensity measure, which ultimately leads to a lower risk.

However, the lack of correlation structure in the site response effectively compromises the generic correlation structure (according to Baker and Jayaram (2008)) imposed at the reference level. TNO questions whether this is an intended effect and strongly recommends the discussion and resolution of this issue in the upcoming GMM workshop with NAM (planned in November 2020) for version V6 and/or the future version V7.

Since no documentation for NAM GMM V7 is yet available, the question of implementing period-to-period correlation at North Sea base level and/or surface level remains open. Hence, TNO cannot judge the suitability of the GMM V7 update for use in the public SHRA 2021.

2.3 Recommended FCM

TNO proposes to adjust the DM V7 Fragility and Consequence model (FCM) in the public SHRA Groningen 2021. The following adaptations are based on the advice given in TNO (2020c) and studies of the FCM in the typology project TNO (2020e):

1. Increase of the model uncertainty for all unreinforced masonry vulnerability classes (with code starting with URM) from 0.27 to 0.35.
2. The shift of upper branch fragility parameters to the middle branch for the vulnerability classes: URM1F_B, URM1F_HA, URM1F_HC, URM3L, URM3M_U, URM3M_B, URM4L.
3. Apply a 15% shift of the median SaAvg towards lower values, for the fragility of vulnerability classes: URM5L, URM6L, URM7L, URM8L.
4. Implement building-to-building variation consistently (setting $\sigma_{BB} = b_1\beta_{BB} = b_1 * 0.3$) for all typologies not modified in the transition from V6 to V7.
5. The shift of upper branch consequence to middle branch for all vulnerability classes which have been modified in V7 fragility from V6. These are the vulnerability classes: URM1F_B, URM1F_HA, URM1F_HC, URM3L, URM3M_U, URM3M_B, URM4L.

These adaptations lead to a higher risk compared to the original V7 FCM parameters of Crowley and Pinho (2020). After considering the advice of TNO (2020c), NAM's response, and a meeting with NAM on September 21, 2020, the above adaptations are believed necessary for the following reasons:

Ad 1) For the model uncertainty NAM has assumed that the numerical models are superior and therefore the $\beta_q = 0.1$ value from FEMA can be taken. While TNO acknowledges that the 3D MDOF FEM models for index buildings are indeed of high quality, the approach followed to derive fragility functions is to match simplified SDOF models to these MDOF models. Fragility functions directly derived from the MDOF models show more variability than those derived from SDOF models. In addition, the many modeling assumptions made in the MDOF models are generally not validated by the more realistic shaking table tests. These uncertainties lead to larger variability as well. TNO (2020f) demonstrated that using $\beta_q = 0.25$, which FEMA recommends for average models, leads to agreement of MDOF vs SDOF derived fragility functions.

Ad 2) In the development of the fragility functions NAM discovered that fragility curves resulting directly from MDOF models are in general more fragile than those of the SDOF models by 15% for masonry buildings. Therefore a 15% shift to lower values of the intensity measure is applied by NAM. However, this is then used for the upper branch fragility parameters rather than the middle branch (best estimate). The main reason for this provided by NAM is that shaking table tests show consistent underestimation of displacement capacity and refers to Table 4.6 in Crowley et al. (2019). Table 4.6 is about EUC Build 6 showing an ultimate displacement of 99 mm and the blind prediction models show 41 mm displacement. TNO acknowledges the underestimation observed in this specific case; however this case is not directly a basis of the fragility functions. EUC Build 6 test is somewhere in between vulnerability classes URM3L and URM4L and in the MDOF models for URM3L index buildings ultimate displacements of 50 mm, 98 mm, 161 mm, and 123 mm are found. For the URM4L index buildings ultimate displacements of 99mm and 109 mm are found. These ultimate displacements are directly transferred to the SDOF models and the median of the fragility curves. Most of these models have a similar or even larger ultimate displacement than the EUC Build 6 test. Therefore it is recommended to use the median shift on the middle branch rather than the upper branch of the logic tree.

Ad 3) These vulnerability classes have not been modified by NAM in the transition from V6 to V7. However, the type of construction is such that they resemble the other vulnerability classes described in Ad 2) where a 15% median shift of the SaAvg has been applied. Considering the construction similarities it is necessary to apply this shift here as well.

Ad 4) For the vulnerability classes modified in V7 from V6, NAM uses the building-to-building variation $\beta_{BB} = 0.3$ on the SaAvg intensity measure, and the building-to-building variation $\sigma_{BB} = b_1\beta_{BB}$ on the displacement capacity in the fragility functions. b_1 is a parameter in the fragility functions which is often larger than 1 making $\sigma_{BB} > \beta_{BB}$. For the vulnerability classes, which are not modified from the V6 model, this is not carried out, meaning the building-to-building variability is too low if $b_1 > 1$. For consistency, these vulnerability classes should be treated in the same manner.

Ad 5) In the V7 consequence model NAM used the consequence parameters originally derived for the middle branch (best estimate) now for the upper branch. One reason NAM provides for doing so is that in comparing the loss of life for NAM's Groningen vulnerability classes with the European PAGER database, a significant higher probability of loss of life is found for the Groningen vulnerability classes. TNO acknowledges this. However, Groningen homes were not constructed with earthquake reliability in mind. It is not recommended to use a general European database in favor of elaborate FEM models of buildings in the Groningen region. Another reason provided by NAM is that the MDOF models are conservative and lead to collapse well before shaking table tests lead to collapse. Here, it must be noted that the consequence model describes probability of loss of life conditional on a certain collapse state. It is irrelevant if a certain collapse state is observed in a model at lower earthquake intensities than in a test. What is important for the consequence model is the debris coverage conditional on a collapse state. There is not sufficient information to conclude that the debris coverage from the MDOF simulations is overestimated.

2.4 Recommended EDB

TNO proposes to use the NAM Exposure Database V7 with upgrades carried out in 2020 (Arup, 2020). It is noted that for a number of buildings the vulnerability class is not exactly known in the NAM Exposure Database, because each building can belong to multiple vulnerability classes according to different probability weights. Also, buildings can have prior damage in which case they are more fragile than assumed in the vulnerability classes. Therefore an SHRA based on this type of exposure database can only be used in a regional sense, not for individual buildings. Only through actual inspection, vulnerability class and damage state can be precisely determined and statements about individual buildings be made. This is carried out in the TNO typology based project TNO (2020e).

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Signature

Utrecht, October 1, 2020	TNO
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