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Naples, March 5th 2018.

Subject: review of the November 2017 version of the hazard and risk assessment (HRA) report, and the report on the v5 fragility and consequence models for the Groningen field, by NAM.

To whom may it concern,

as per your request, I give herein comments on the two documents in the subject. In particular, I've reviewed the full fragility and consequence report and chapter 7 (From Hazard to Building Damage and Risk of the HRA report). The comment arisen from the review are necessarily methodological as the documents do not have the level of detail necessary for a deeper technical review.

As a general comment, it results that the v5 fragilities are somewhat an improvement of what used for the 2016 winningsplan. The main improvements are: the calibration of the URM models on shake-table test results and nonlinear dynamic analysis; inclusion of the out-of-plane failure mechanisms in the URM models, checking for sufficiency of the intensity measures. Some of these issues address the comments provided by the scientific advisory committee (SAC) in 2016.

It is believed that the fragility modeling generally follows quasi-state-of-the-art practice, as such they are suitable for seismic risk assessment of Groningen. Nevertheless, there is a large number of simplifications, the necessity of which is not discussed herein, that do not render the results of the analysis suitable for other purposes. As discussed in the following, the main issue is the definition of the *index buildings* and variability of the risk within one of fifty-four classes of buildings, which appears not neither quantified nor controlled.

It results from the HRA report that 5%-10% of the buildings have metadata sufficient for them to be characterized structurally via inspections. Expert judgment and other criteria were used to infer information not available from inspections. It is not clear how this uncertainty is dealt with. Potentially, it might have a non-negligible effect on the risk assessment.

Individual buildings are assigned a probability they belong to a certain structural system. The way these probabilities are assigned is not codified, or at least not described in a way it is sufficient to gather consensus. Moreover, it is not clear how this is accounted for in the vulnerability assessment.

In general, the fragility modeling follows an index-building-based approach. It means individual buildings are defined so that they represent a sub-population of buildings exposed to seismic risk in Groningen. Although, some distributions of structural features are provided (note that distributions are given as absolute distributions not joint), it is not clear how index buildings are defined and what percentile/statistic of the sub-population they are (at some point they are defined as *median buildings* without any further specification). Note that this has significant consequences. The seismic risk assessment refers to the index building and it is not possible to quantify how much the fragility (then the risk) varies within the sub-population represented by the index building (although some additional variability was added to fragilities represent building-to-building variability). Thus, the risk assessment is not suitable to help the strengthening program (beyond ranking the riskiest sub-populations by ranking the risk coming from different index buildings). Also, the number of buildings not meeting the 10^{-5} local personal risk limits are difficult to identify in this context. (This is a legacy comment from the SAC.)

As it regards fragility modeling, the main simplification is the use of simplified single-degree-of-freedom (SDoF) systems to represent the response of index buildings for fragility development (usually the development of index buildings goes with detailed modeling of them). In any case, it seems that the choice of the hysteretic model has been overly simplistic, with only two models

considered (Takeda and multilinear Opensees elements; note that Takeda does not seem appropriate to represent URM where usually significant pinching or flag-shape behavior occur).

Whilst the reference multi-degrees-of-freedom systems are 3D models subject to 3D seismic actions it is not clear how these are rendered 1D SDoFs (see for example vertical ground motion component). Also, the validation of these models seems to be possibly significantly improved. For example, to purge it from conservative assumptions that bias the risk assessment.

The chimneys are modeled via PGA-dependent fragility curves, while they should be modeled together with the building they belong to. It seems it is not verified PGA is a sufficient intensity measure for these elements.

The ground motion intensity measure intervals for the cloud analysis seem unbalanced towards values that are from earthquakes much stronger than the Huizinge (2012) and Zeerjip (2018) earthquakes. As a consequence, it might be that the left tail of the fragility curves is not fitted properly and only follows the lognormal shape. This might impair the use of these fragility curves for expected damage assessment from these earthquakes.

Fragility functions are based on simulations of SDoF non-linear dynamics simulation using a sample of records. Moreover, risk assessment is based on Monte Carlo simulation. Whenever sampling is involved, uncertainty in estimation of the fragility parameters arises, this is neglected in the study. (Perhaps the authors believe it is negligible because the large number of records considered.)

Modeling uncertainty is taken from some US literature. It is not discussed the applicability of these values to the Groningen building stock. (Note that there is material to evaluate these factors specifically for the region of interest.) Moreover, it is not discussed how the inclusion of modeling uncertainty reflects on the results of the risk assessment and their interpretation.

The relationship of the numerical response of a simple SDoF system and loss of volume seems a critical issue in this risk assessment, it is missing the detail to gather consensus on the used

methodology and the consideration of uncertainty in this step of the analysis. (This is a legacy comment from SAC.)

The fragilities are structural only. The issue of fatality risk due to failure of non-structural elements within buildings, except chimneys, seems overlooked. Neither justification for this is given nor it is an expected future extension of the work.

Finally, keep in mind that the seismic fragilities developed neglect possible damage accumulation in subsequent event or seismic sequences. They reflect the hypothesis that any damaged building is instantaneously put back in to its pre-earthquake state after any event.

In general, there are several assumptions and working approximations were taken. Nevertheless, the effect of these approximations on the risk assessed and especially on the number of buildings exceeding the tolerable risk seems not quantified. (This is a legacy comment from SAC.)

Sincerely,

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