Sensitivity of the Hazard and Risk Assessment for Production Scenario “Basispad Kabinet” to the inclusion of release of Tectonic Stresses

Addendum to:
Induced Seismicity in Groningen
Assessment of Hazard,
Building Damage and Risk
(November 2017)

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Contents

1 Introduction

From the 8th to 10th March 2016, a workshop was held in Amsterdam, where an expert panel was asked to advise NAM on the maximum magnitude (M_{max}) estimate for probabilistic seismic hazard and risk modelling in the Groningen gas field (Ref. 1).

Recently there has been a discussion on the treatment of earthquakes associated with triggering of the release of tectonic stresses in the hazard and risk assessment (Ref. 2). It is challenged whether the impact of release of tectonic stresses should be included in the hazard and risk assessment and claimed that the current treatment of potential release of these stresses leads to undue conservatism.

The current study provides a sensitivity assessment indicating the severity of this conservatism. The sensitivity is based on the V5 version of the hazard and risk model (Ref. 3) and the production scenario "Basispad Kabinet" (Ref. 4).

2 Representation of epistemic uncertainty in M_{max}

The distribution representing the epistemic uncertainty in the maximum magnitude was represented in the advice by the M_{max}-panel (Ref. 1) as a histogram (Fig. 2.1) consisting of seven intervals. For practical reasons, the seven-point representation provided by the panel was reduced to three points for the logic tree (Fig. 2.2 Tab. 2.1). The M_{max} values and associated probabilities on the three branches of the logic tree were chosen to exactly match the zero, first, second, third, fourth and fifth moments of the M_{max} distribution, as established by the M_{max} expert panel.

In appendix C of the hazard and risk assessment report for the production scenario "Basispad Kabinet" (Ref. 4), the sensitivity to the representation of the epistemic uncertainty in the M_{max} was investigated for the 24 Bcm/year production scenario used in the November 2017 hazard and risk assessment (Ref. 3). As preparation of the hazard and risk assessment using the 7-branch representation of the epistemic uncertainty of M_{max} is very computing intensive, it was, given the time-line, not possible to prepare this sensitivity for the new production scenario "Basispad Kabinet".

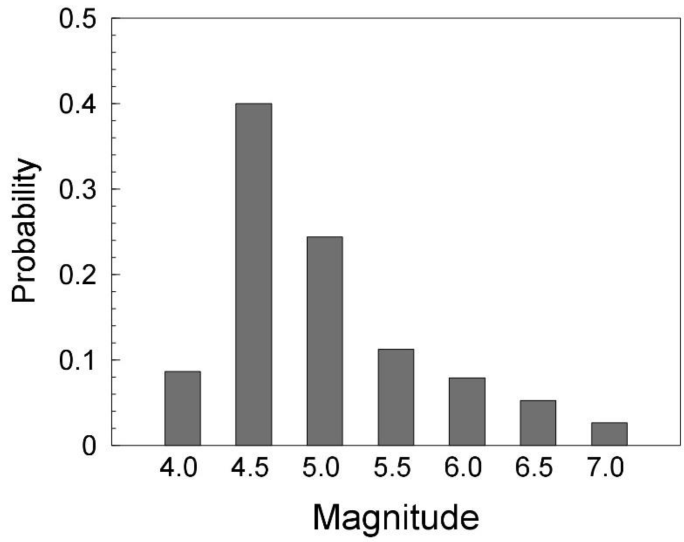


Figure 2.1 The distribution of the M_{max} as assessed by the M_{max}-experten panel.

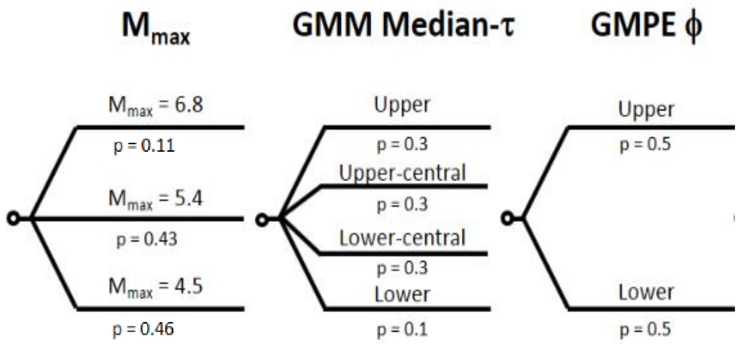


Figure 2.2 Logic tree used for assessing seismic hazard.

The 7-point and 3-point representation of the distribution for the M_{max} have been summarised in table 2.1 and figure 2.3.

7-point representation provided by the M_{max} Panel	
Moment Magnitude	Weight
4	0.08625
4.5	0.4
5	0.2375
5.5	0.1125
6	0.07875
6.5	0.0525
7	0.02625

3-point representation used in the hazard and risk assessment	
Moment Magnitude	Weight
4.5	0.46
5.4	0.43
6.8	0.11

Table 2.1 Moment magnitude and weights for the 7-point representation of the M_{max}-distribution provided by the M_{max} Panel and 3-point representation used in the hazard and risk assessment.

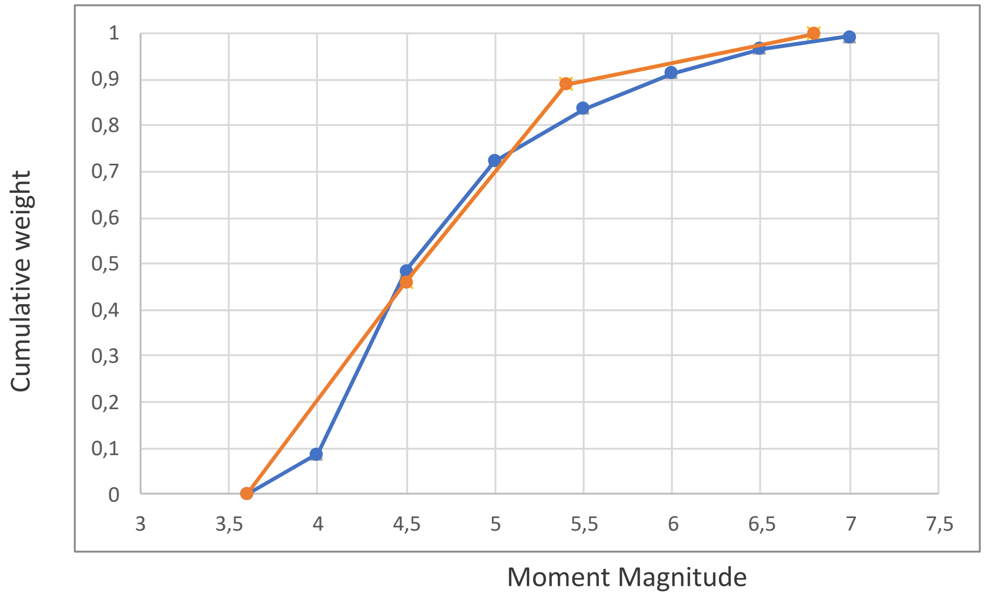


Figure 2.3 Moment magnitude and weights for the 7-point representation of the M_{max}-distribution provided by the M_{max} Panel and 3-point representation used in the hazard and risk assessment.

3 Seismicity Induced by Gas production and Triggering of Tectonic Stresses

The M_{max} advice of the panel was represented in a logic tree (Fig. 3.1), which incorporated apart from induced seismicity the possibility of triggering tectonic stresses on local faults.

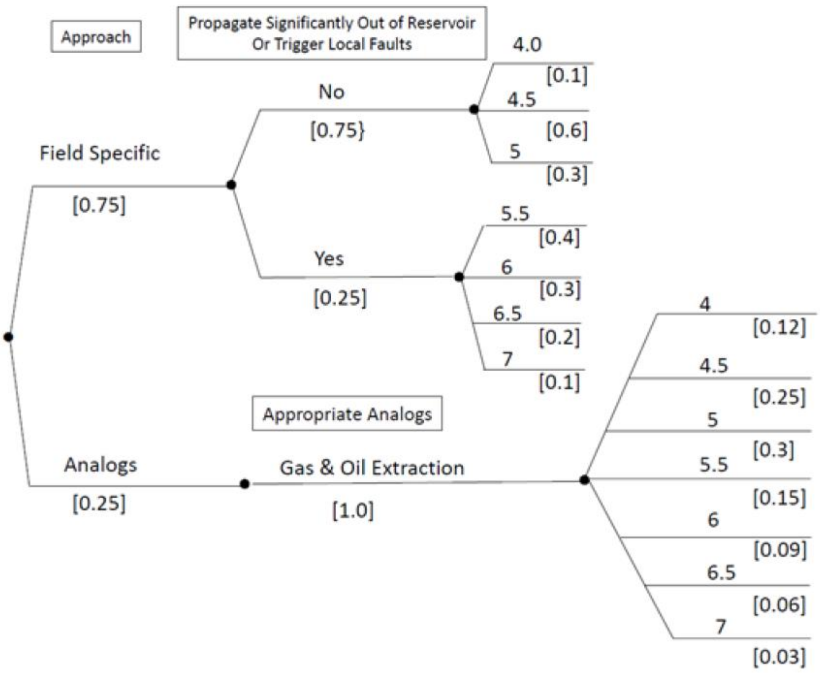


Figure 3.1 Figure taken from "Report from the Expert Panel on Maximum Magnitude Estimates for Probabilistic Seismic Hazard and Risk Modelling in Groningen Gas Field, 25 April 2016" with the logic tree provided by the assurance panel.

The logic tree provided by the assurance panel allows the distribution for the epistemic uncertainty in M_{max} to be partitioned in the M_{max} for earthquakes induced by the production of gas and the M_{max} for earthquakes that additionally trigger the release of tectonic stresses.

Including the possibility of release of tectonic stresses leads to an issue in the hazard and risk assessment, resulting from a lack of knowledge of faults at larger depth and these presence and distribution of the tectonic stresses. The predicted hypocentre location of such a triggered earthquake will have large uncertainty. Especially the uncertainty in the depth would be large. However, the depth would be larger than the 3 km depth of the induced earthquake hypocentres. Development of a ground motion prediction methodology (Ref. 5) for these deeper triggered earthquakes would be challenging and unconstrained by local field data.

In the hazard and risk assessment, it has therefore been chosen **not** to distinguish between hypocentre of induced and triggered earthquakes and treat all earthquakes as if these have a hypocentre at 3 km depth. This probably results in an over-estimation of the hazard impact of the earthquakes triggering tectonic stresses.

The distribution for the M_{max} for both induced and triggered earthquakes and for exclusively induced earthquakes have been summarised in Table 3.1 and Figure 3.2.

M_{max} distribution for induced and triggered earthquakes	
Moment Magnitude	Weight
4	0.08625
4.5	0.4
5	0.2375
5.5	0.1125
6	0.07875
6.5	0.0525
7	0.02625

M_{max} distribution for induced earthquakes only	
Moment Magnitude	Weight
4	0.1182
4.5	0.5479
5	0.3339

Table 3.1 Moment magnitude and weights for the M_{max} distribution of both induced and triggered earthquakes and for exclusively induced earthquakes.

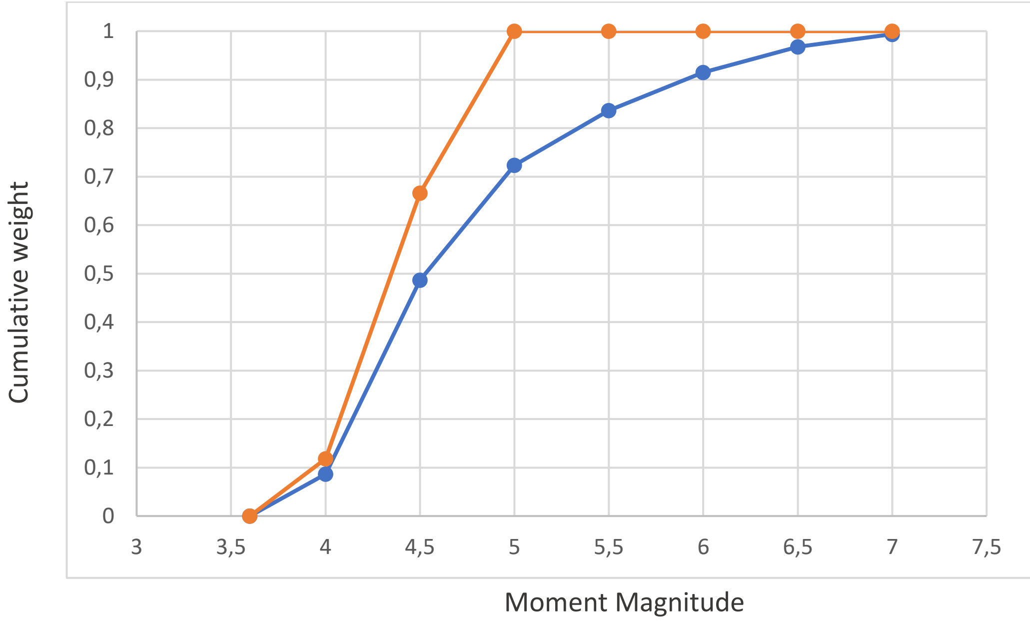


Figure 3.2 Moment magnitude and weights for the M_{max} distribution of both induced and triggered earthquakes and for exclusively induced earthquakes.

4 Hazard Assessment for the three sensitivities for the M_{max} distribution

Using the three different representations for the M_{max} distribution, hazard maps have been prepared. Figures 4.1a to c show the three hazard maps. These hazard maps are for the period of the five calendar years from 2018 to 2022 and a return period of 475 years.

Comparison of the two hazard maps 4.1a and 4.1b, based on the three-point and the seven-point representation of the M_{max} distribution for both induced and triggered earthquakes, shows that use of the three-point representation leads to a conservative (higher) assessment of the hazard. The largest PGA on the hazard map using the three-point representation is 0.158 g. This is some 6% larger than the largest PGA on the hazard map using the seven-point representation. The difference map between these sensitivities (Fig. 4.2a) shows that the PGA based on the seven-point representation of the M_{max} distribution is lower than that of the three-point presentation over the full Groningen field area. The histogram of the difference (Fig. 4.3a) indicates the reduction is overall in the range 0.002 to 0.008 g.

Comparison of the two hazard maps 4.1b and 4.1c, based on the M_{max} distribution for all earthquakes and only induced earthquakes, shows that the largest PGA of the hazard map for exclusively induced earthquakes is 7% lower than that for the hazard map for both induced and triggered earthquakes. This means that the conservativeness resulting from the treatment of earthquakes which additionally release tectonic stresses is some 10% (based on a comparison of the largest PGA on the hazard map). This forms an upper bound for the conservatism resulting from the treatment of the M_{max}.

These differences are in line with the sensitivity performed for the production scenario of 24 Bcm/year (Ref. 4). The difference map between these sensitivities (Fig. 4.2b) shows unsurprisingly that the PGA based on the M_{max} distribution for induced earthquakes is over the full Groningen field area smaller than that of for all earthquakes. The histogram of the reduction (Fig. 4.3b) indicates the reduction is overall in the range 0.003 to 0.017g.

a

M_{max} Distribution:
Three-point representation of the distribution for both induced and triggered earthquakes

b

M_{max} Distribution:
Seven-point representation of the distribution for both induced and triggered earthquakes

c

M_{max} Distribution:
Seven-point representation of the distribution for exclusively induced earthquakes

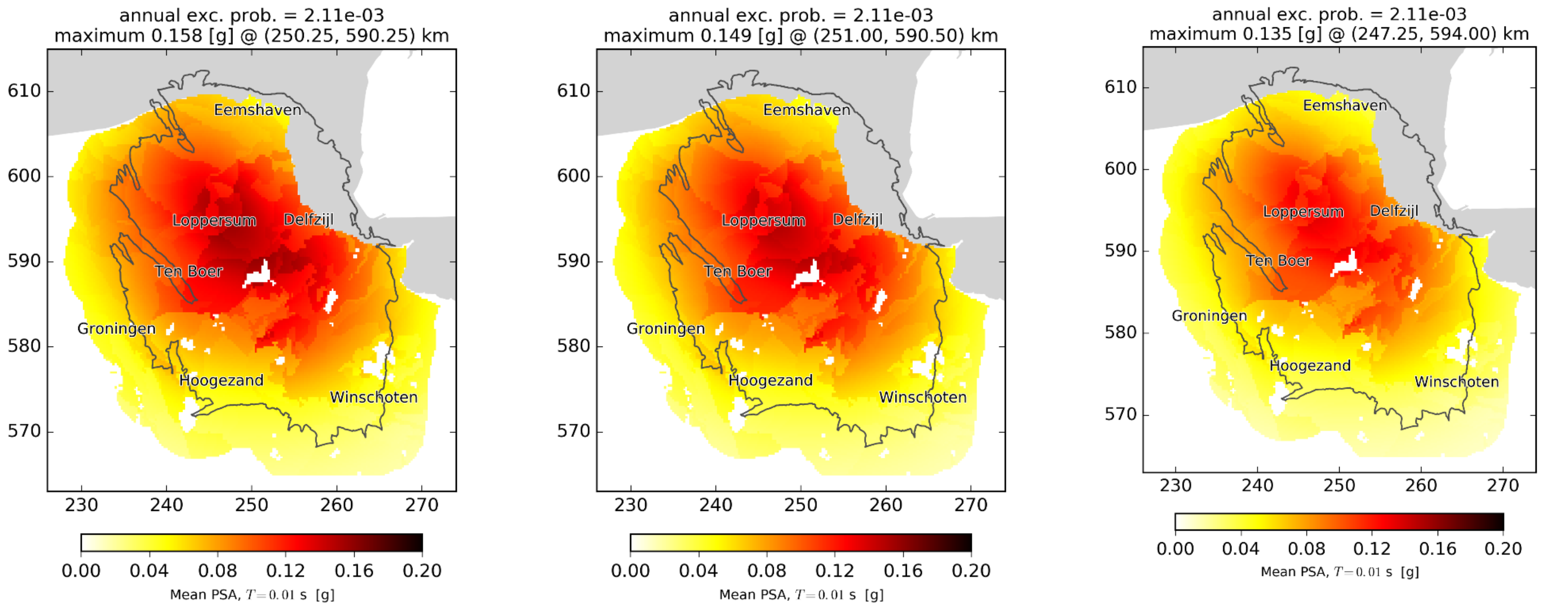
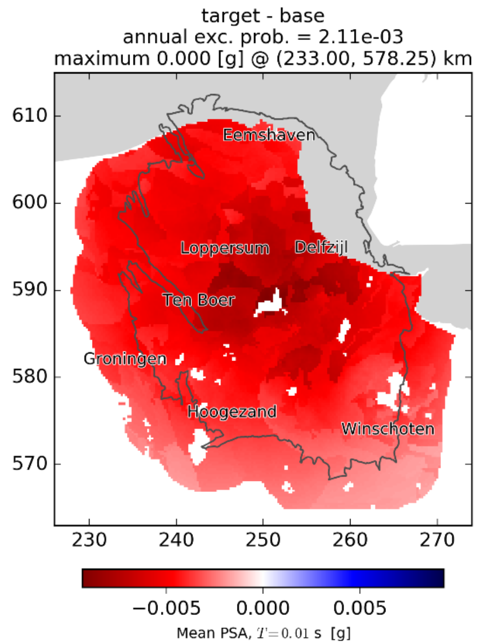


Figure 4.1a to c *Hazard Maps for three M_{max} sensitivities.*

a

PGA difference map:
Seven-point minus three-point representation of the distribution for both induced and triggered earthquakes



b

PGA difference map:
Seven-point representation of the distribution for both induced earthquakes only - Seven-point representation of the distribution for both induced and triggered earthquakes

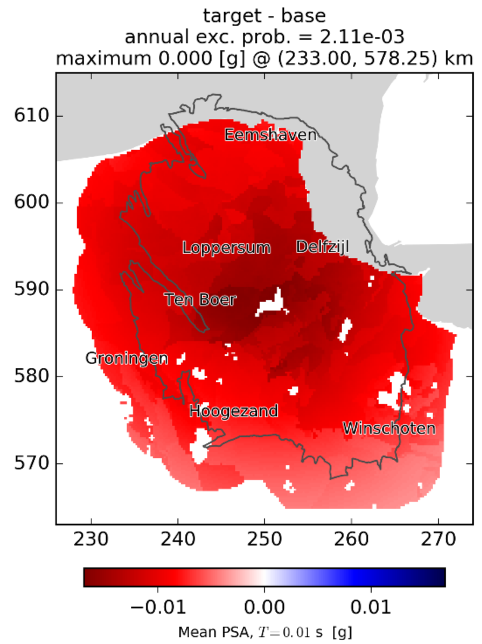
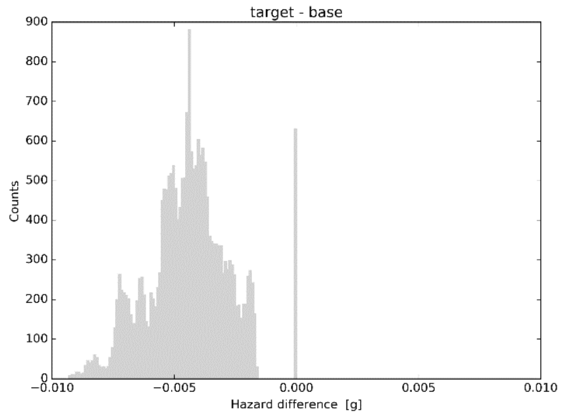


Figure 4.2a and b PGA difference maps.

a

PGA-difference histogram:
Seven-point minus three-point representation of the distribution for both induced and triggered earthquakes



b

PGA-difference histogram:
Seven-point representation of the distribution for both induced earthquakes only - Seven-point representation of the distribution for both induced and triggered earthquakes

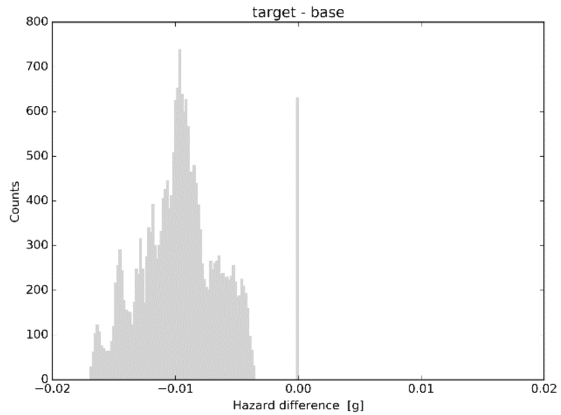


Figure 4.3a and b *PGA-difference histograms.*

5 Risk Assessment for the three sensitivities for the M_{max} distribution

The sensitivity assessment has been extended also to the risk assessment. The LPR-curves for the three sensitivities are shown in figure 5.1. The number of buildings above the 10^{-5}/year life safety norm for the 5-year period from 2018 to 2022 is shown in table 5.1.

Sensitivity	**Number of buildings above the 10^{-5}/year life safety norm for the 5-year period from 2018 to 2022**
Three-point representation M_{max} distribution of all earthquakes	1156
Seven-point representation M_{max} distribution of all earthquakes	955
Seven-point representation M_{max} distribution of induced earthquakes only	376

Table 5.1 The number of buildings above the 10^{-5}/year life safety norm for the 5-year period from 2018 to 2022.

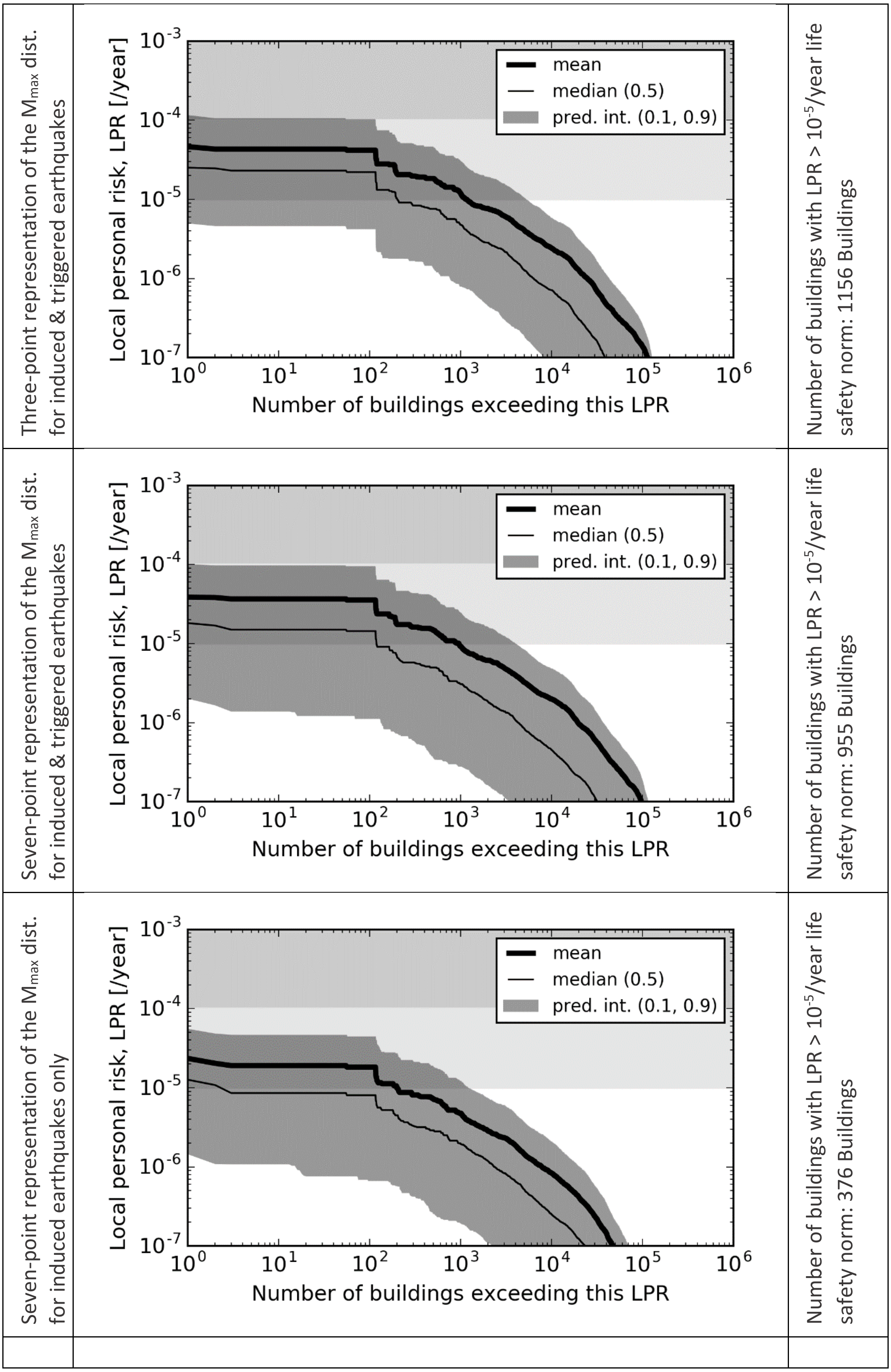


Fig 5.1 The LPR-curves for the three sensitivities for the 5-year period from 2018 to 2022.

6 Conclusions

- The three-point representation of the M_{max} distribution leads to a conservative (high) assessment of the hazard compared to the seven-point representation provided by the M_{max} -panel. In the new update of the Hazard and Risk Assessment (version 6), the seven-point representation of the M_{max} distribution, as provided by the M_{max} -panel, will be used.

- The conservativeness in the hazard assessment resulting from the treatment of earthquakes also releasing tectonic stresses is smaller than 10% of the PGA. In the new update of the Hazard and Risk Assessment (version 6) the treatment of earthquakes also releasing tectonic stresses will remain unchanged and the conservativeness will remain in the model.

References

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4. Seismic Risk Assessment for Production Scenario “Basispad Kabinet” for the Groningen field (Addendum to: Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017)
5. V5 Ground-Motion Model (GMM) for the Groningen Field - Re-issue with Assurance Letter, Julian J Bommer, Benjamin Edwards, Pauline P Kruiver, Adrian Rodriguez-Marek, Peter J Stafford, Bernard Dost, Michail Ntinalexis, Elmer Ruigrok and Jesper Spetzler, March 2018