



# KEM-02 Results

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## Content of the presentation

- KEM02 scope
- Conclusions and recommendations research question 2
- Conclusions and recommendations research question 1

RQ2 first, since this has been the main part of KEM02

RQ3 just comprises recommendations based on RQ1 and RQ2 studies

## KEM02 scope

- In general:
  - Evaluation validation and improvement of the Site Amplification component of the GMM v5 and v6
  
- RQ1 (topics indirectly related to site amplification model):
  - Are research results available indicating that the effect of slopes or non-horizontal topography close to building can cause extra damage, caused by the fact they have different PGAs?
  - Is it possible that for slightly larger events “lateral spreading” occurs? This has been observed in the Meuse levees as a result of the Roermond earthquake. If so, what effect can be expected for infrastructures and building in Groningen?

## KEM02 scope

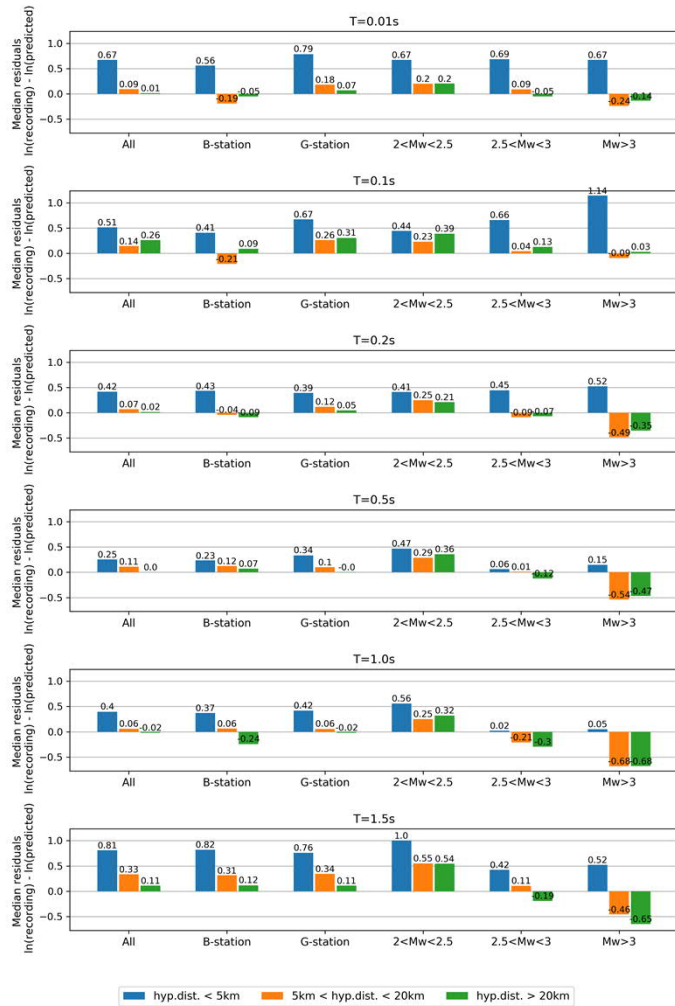
- RQ2 (topics directly related to site amplification model) :
  - Using the data newly collected after the NAM site response model was calibrated, test in a quantitative sense how well the different ground motion parameters (PGA, PGV, spectral accelerations) are forecasted by the model.
  - A residual analysis should analyze the spatial patterns and thus identify, if possible, geological/geotechnical conditions, where the model performs well or poorly.
  - This should lead to a recommendation if and how future validation of the data against the model (or models) may lead to improved uncertainty quantification and ultimately scientific and societal acceptance.

## Research question 2

## Research question 2 conclusions on model fit with data

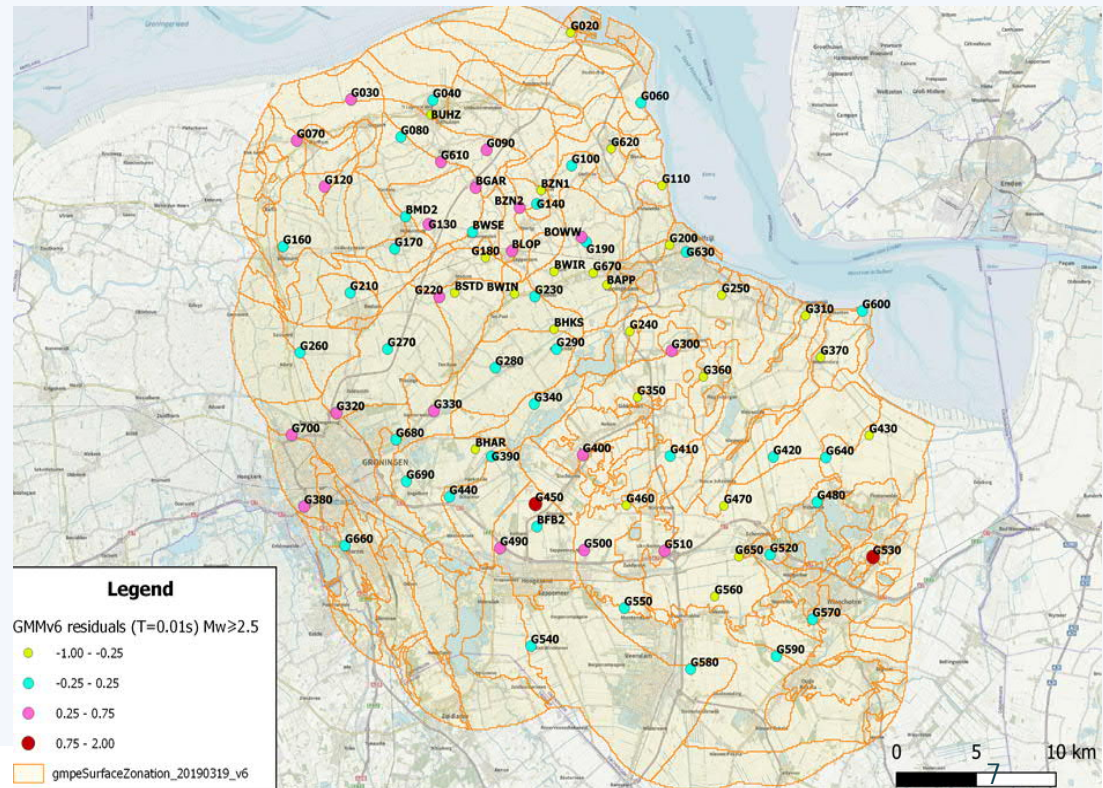
- The GMM v6 performs better than GMM v5 when compared with recordings. GMM v6 is only biased at short distances ( $< 5$  km) with an average factor, for all the examined spectral periods, of 1.8. The uncertainty range is large enough to cover this bias. However, the site amplification model of GMM v6 is not improved compared to GMM v5. The improved fit with recordings seem to be a direct result of the modified inversion process and it doesn't mean that the predictive capabilities of GMM v6 towards stronger ground motions have been proven.

Average median of residuals per subset, GMMv6



## Plots

- Left: categorized residuals per spectral period
- Right: average mapped PGA residuals



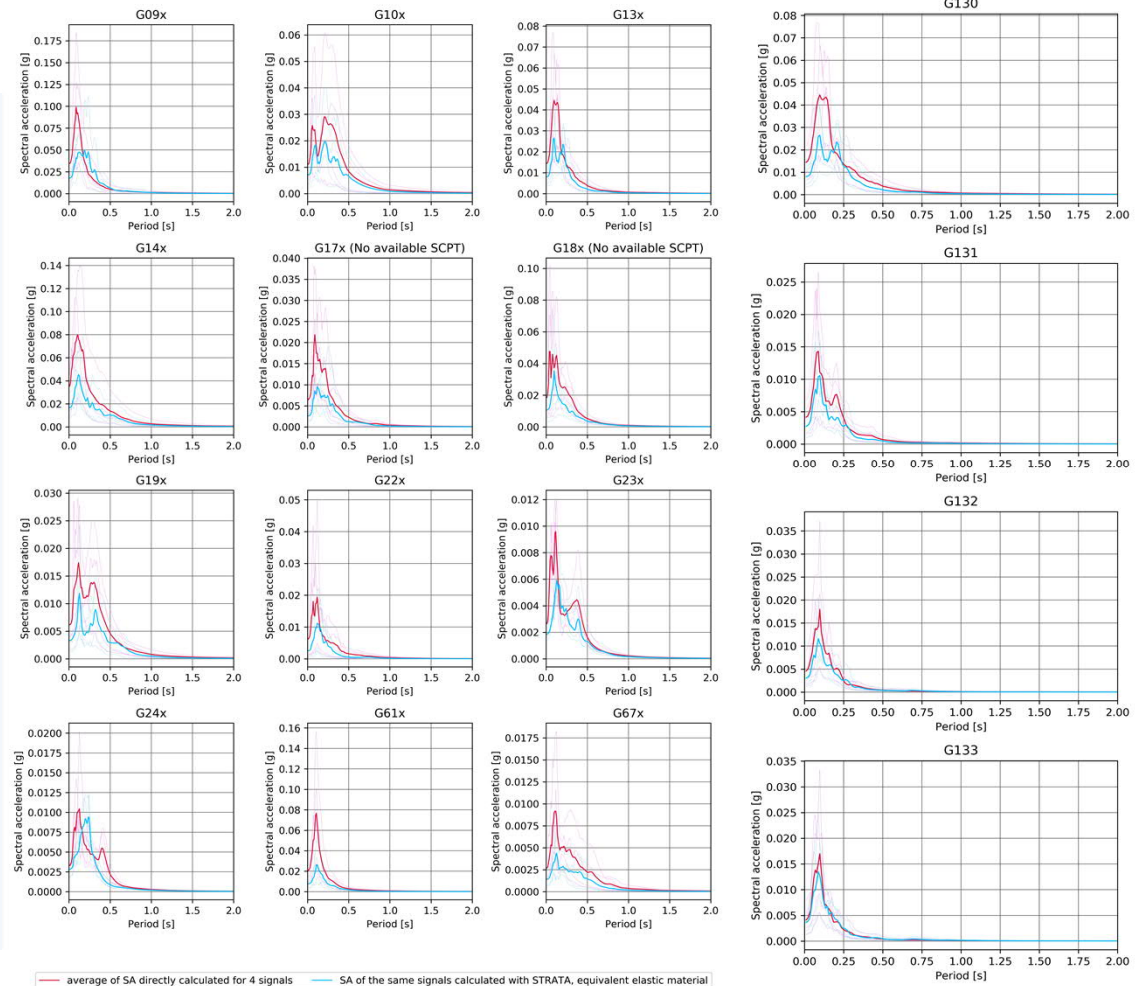
## Research question 2 conclusions on damping factor

The adopted soil damping is unrealistically high; this has been proven by direct site response calculations from 200 m depth upwards.

# Plots

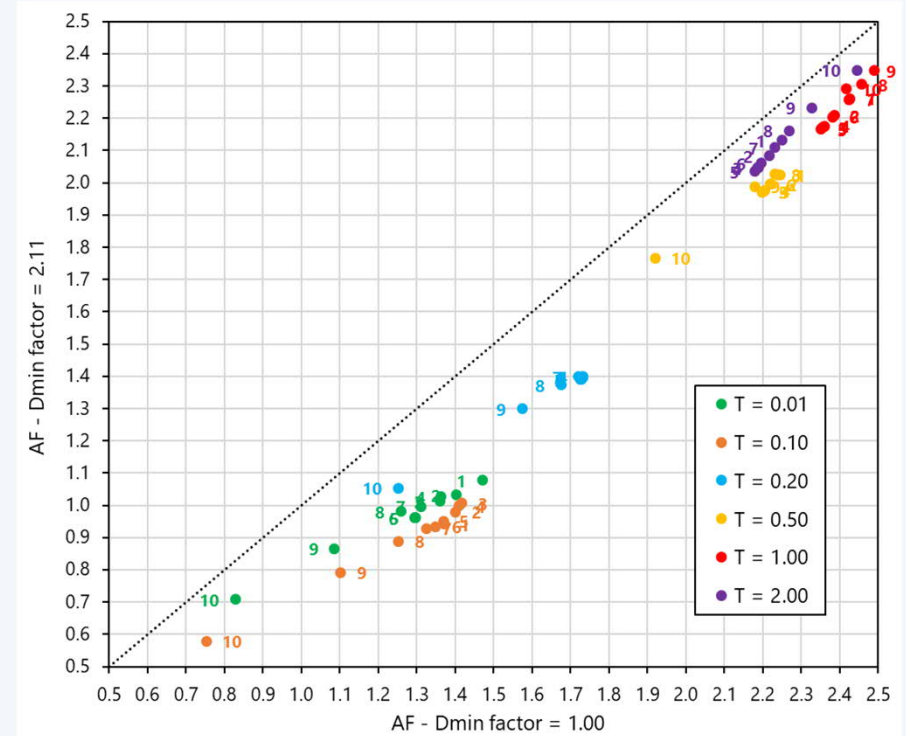
- Left: multiple stations
- Right: development with depth

Acceleration response spectra at 0m depth, Zeerijp



## Plots

- Effect of Dfactor for strong ground motions
- Numbers marking the dots relate to GMM FAS groups

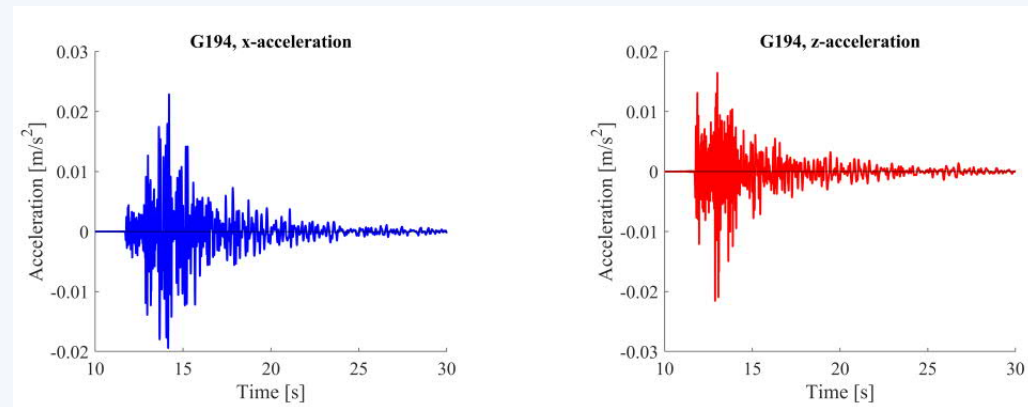


## Research question 2 conclusions on P-waves and S-waves

In the recorded signals there are both P- and S-waves identified which are not captured in the 1D model. At short epicentral distances P- and S-wave arrivals are partly mixed in recorded ground motions. This forms a risk towards upscaling to stronger ground motions, as the 2D model results show that other wave forms are important. A different scaling could apply to P- and S-waves, upon triggering the physical nonlinearity in the soil, potentially making the model non-conservative.

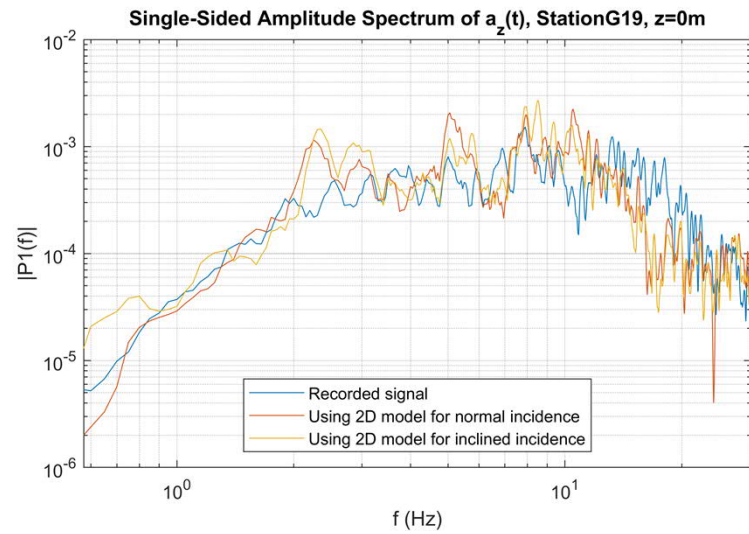
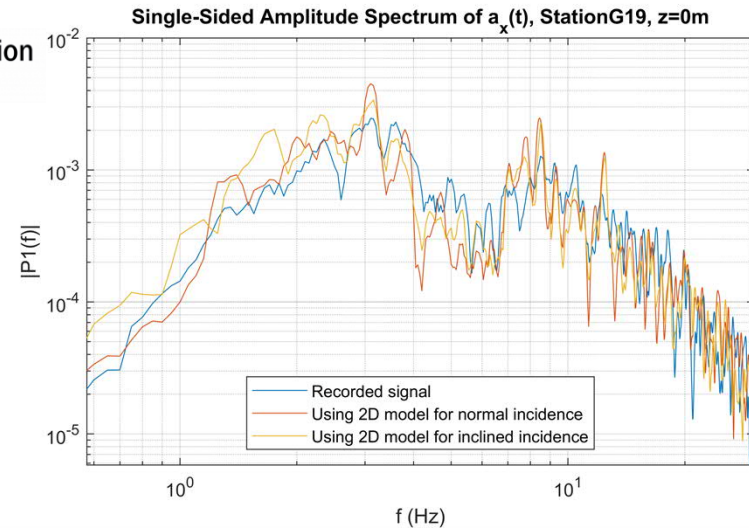
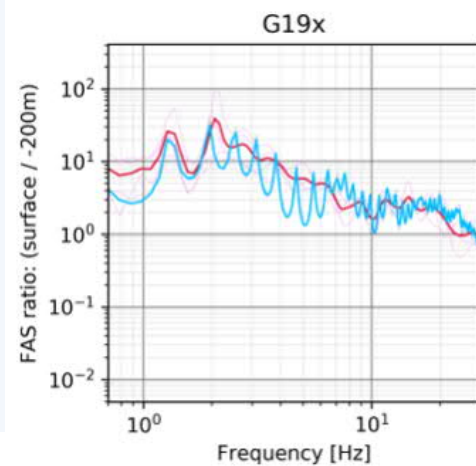
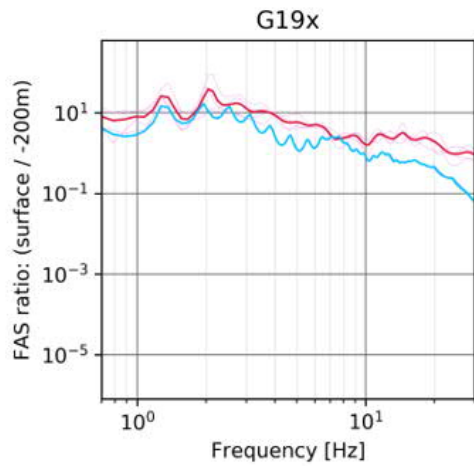
## Plots

- Recorded ground motion at G194 (200 m depth) for event Zeerijp 2018

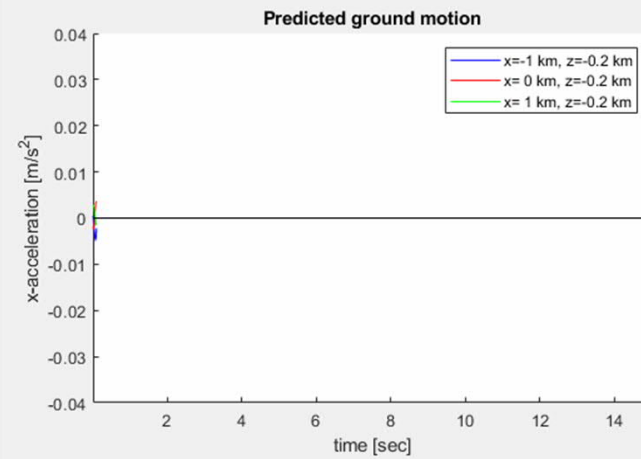
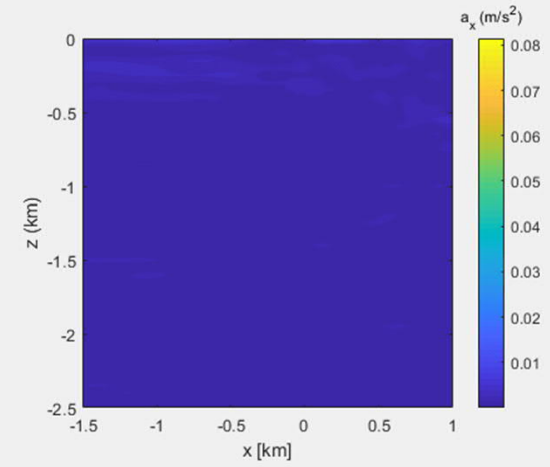


# Plots

- Left: 1D TF surface / -200 m from GMM v6 and GMM v6 with D-factor 1.0
- Right: 2D TFxx and TFzz



# Animation

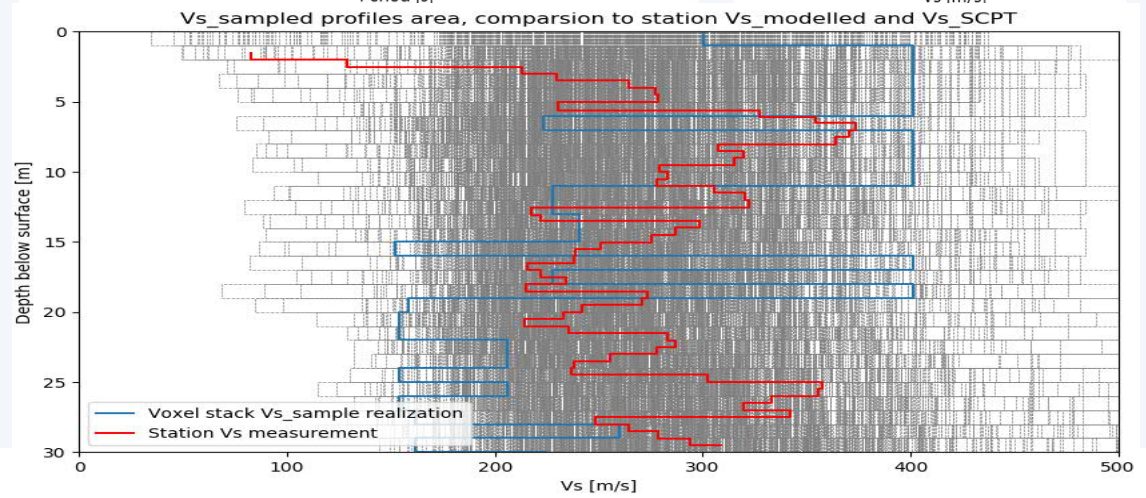
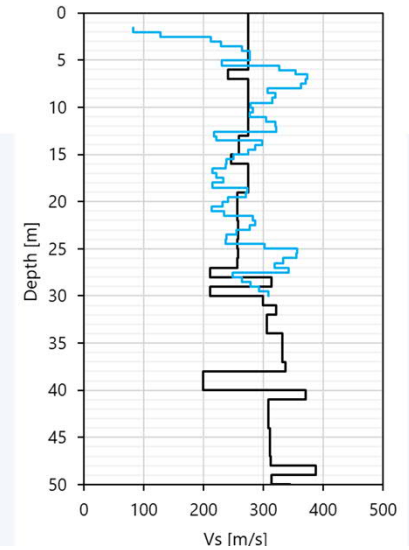
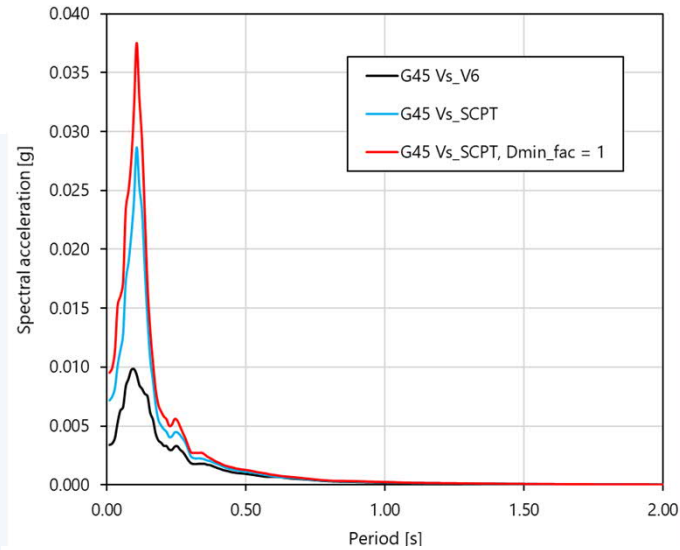


## Research question 2 conclusions on soft shallow soil layers

The presence of very soft soils in the top few meters is shown to lead to ground motion underprediction at local sites compared to the zone average of the ground motion model.

# Plots

- Top: soft top layer potential impact
- Bottom: G45 SCPT and zone sampled Vs profiles



## Research question 2 recommendations

- We recommend to lower the small strain damping compared to what is implemented in the GMM v5 and v6 site amplification simulations. Setting the applied D-factor to 1.0 is advised within the current site amplification model setup.
- The extensive CPT database available for Groningen could be used to identify locations that may show a site amplification characteristic which differs significantly from the zone average. The CPT, combined with CPT - Vs correlations could be used to perform this assessment, potentially limiting the need for many more SCPTs.

## Research question 2 recommendations

- Surface ground response spectra are concluded to be very sensitive to the shallow top (soft) layer, this is not necessarily true for the actual effective seismic demand on buildings. Effective foundation input motions will be less sensitive to thin shallow soft layers than the actual surface free field ground motions. This topic may need further consideration.

## Research question 2 recommendations

- Due to the above effect as well as other effects described in the main report, in the V6 GMM there are sites with positive bias (under-estimation of the ground motions) as well as negative bias (over-estimation of the ground motions). This means at those sites the probabilistic model does not exactly match. For the sites with negative bias, this is conservative and perhaps of lesser concern. For the sites with positive bias it is recommended to evaluate if the uncertainty in the GMM statistically covers the local sites' bias.

## Research question 2 recommendations

- In our research we have argued that the simultaneous contribution of the P- and S-waves to the ground surface motion cannot be disregarded once the distribution at the reference depth for the site amplification component is non-uniform. This is true both for the linear and nonlinear (strong earthquakes) regimes. In the latter case, the necessity to consider both waves simultaneously will be amplified due to the enhanced coupling due to the material nonlinearity. It is recommended to thoroughly investigate this.

## Research question 2 recommendations

- 2D or 3D nonlinear models that calculate how the P-wave and S-wave response scales up once non-linearity is triggered can be of added value here, but only if the nonlinear model parameters are well calibrated, see next section.
- Given the high sensitivity of the response to the amount of P- and S-wave damping, more investigation is needed to accurately determine the amount of damping in these waveforms. In the literature, there exist several advanced methods to identify the amount of damping on the basis of direct site investigation (direct measurements, like addressed in Versteijlen, (2018)). If 2D or 3D models will be used for further GMM development in the future it is recommended to substantiate the amount of damping based on these type of direct site investigations

## Research question 2 recommendations

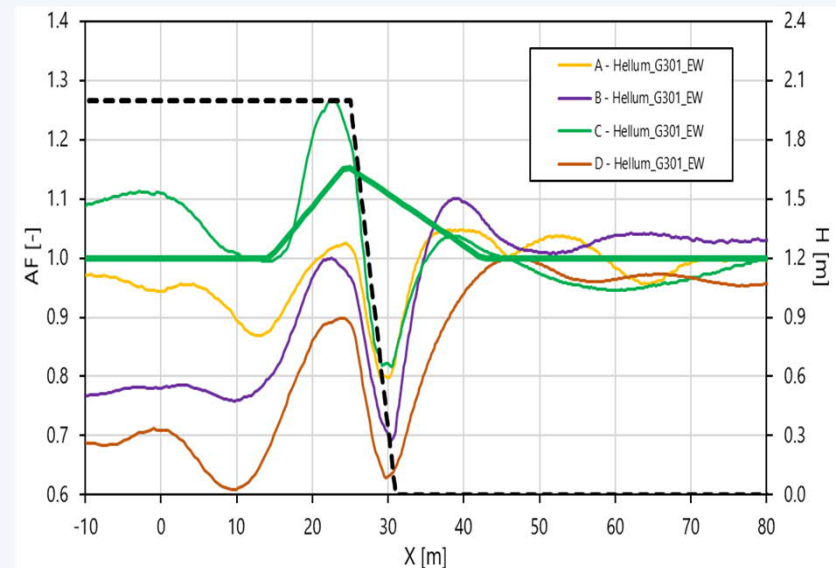
- Integrated models are preferred, combining source to surface in a single 2D or 3D model. We realize that such models may not very computationally efficient and can therefore not be used to perform a full probabilistic analysis. However, for model calibration purposes, especially in the upscaling to larger ground motions, these are of added value. At least a number of these integrated simulations should be carried out to be able to confirm whether the current 1D model is sufficiently accurate for larger ground motions. If not, these integrated simulations can serve to make the necessary adjustments to the current 1D model if it is to be retained.

## Research question 1

## Research question 1 conclusions

Topographic (de-)amplification, conclusions:

- Effect not captured by the current site response model
- Altered PGA's can be found at relatively small ground surface discontinuities Accounting for the phenomenon in a relatively simple manner goes at the cost of capturing correctly the physical complexity.



## Research question 1 recommendations

Topographic (de-)amplification, recommendations:

- Take this into account for damage assessments, or at least acknowledge its possible contribution.
- Possible extension towards higher spectral periods could be of added value to conclude if these effects can be excluded for HRA purposes
- Analyses for a wider variety of soil profiles and geometries could help to draw region-wide conclusions.
- The current seismic network cannot be used to validate calculated topographic amplification effects. However, even with a very dense localized network, soil heterogeneity and inherent variations in local ground motions probably prevent drawing strong conclusions



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# Backup

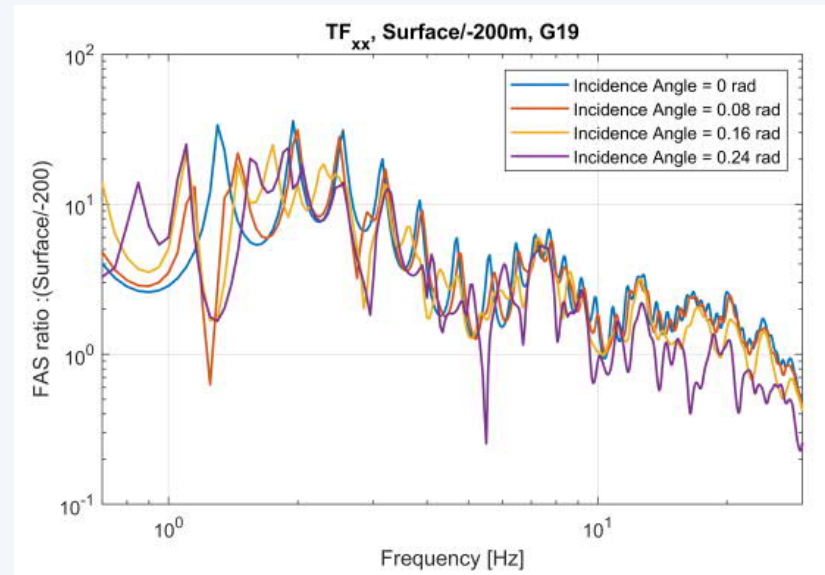
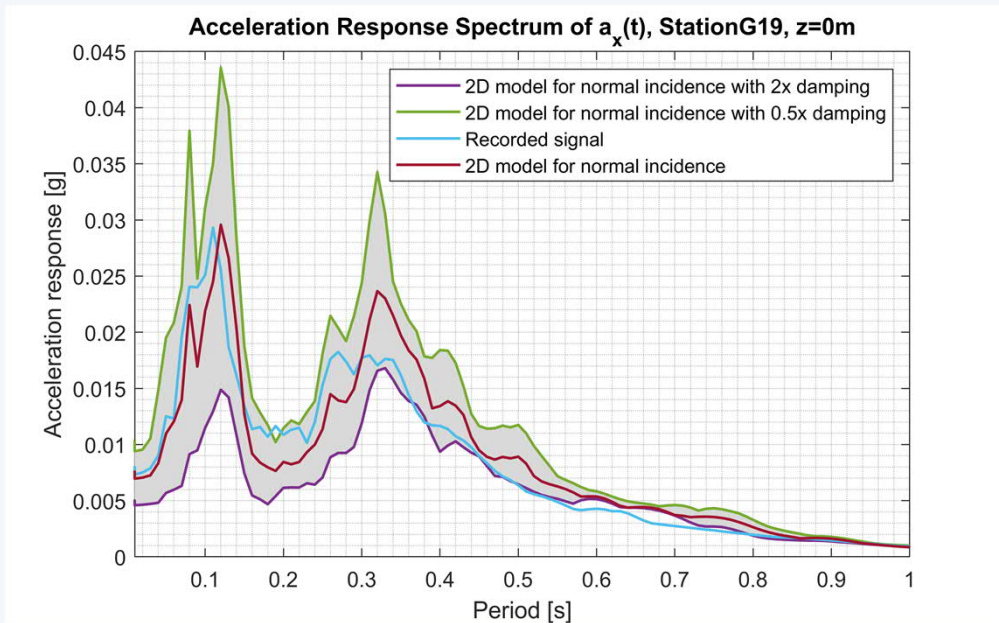


Figure 40:  $TF_{xx} (a_x|_{z=0}/a_x|_{z=-200m})$  for soil profile in G19.