Dear Referee #2,

We would like to thank you for your constructive comments. We agree with most of the suggestions and, therefore, we will modify the manuscript to take on board your comments. In the following, we recall comments and we reply to each of the comments in turn (outlined by "**<Authors' reply>"**).

Please note that the line numbers of changes are indicated and correspond to the revised manuscript with marked changes.

Referee #2:

1. General comments

The paper proposes a method to derive improved and accurate fragility curves for nuclear plants subject to seismic activity by adopting non-stationary GEV for the engineering demand parameter. The capacity of the structure is simulated allowing for parametric uncertainties. The premise of the proposed method is novel and reasonable. The analysis is rigorous and encompasses major requirements of uncertainty quantification. The results indicate that the usage of the method presented may provide better vulnerability assessment in nuclear plant safety analysis by a significant margin. The paper may benefit from improved clarity of presentation, particularly in the final computation of fragility curves (FC) and presentation of results.

"**<Authors' reply>"** we are grateful to referee #2 for his/her analysis. The following document provides details on how we improve the different aspects, which consists in:

- Improving the quality of the figures;
- Adding a technical appendix on the double-penalisation procedure as well as a synthetic case to illustrate its effectiveness;
- Adding details on the dynamic simulations and on their analysis to derive the fragility curves;
- Clarifying the added value of our approach with respect to the literature.

2. Specific comments: Methods

The choice of whether to use GEV is done using AIC or BIC measures. The benefit to using a non-stationary GEV may be demonstrated by showing improved goodness of fit or other custom measures as applicable. Fig.5 and 9 may be locations to include such a comparison.

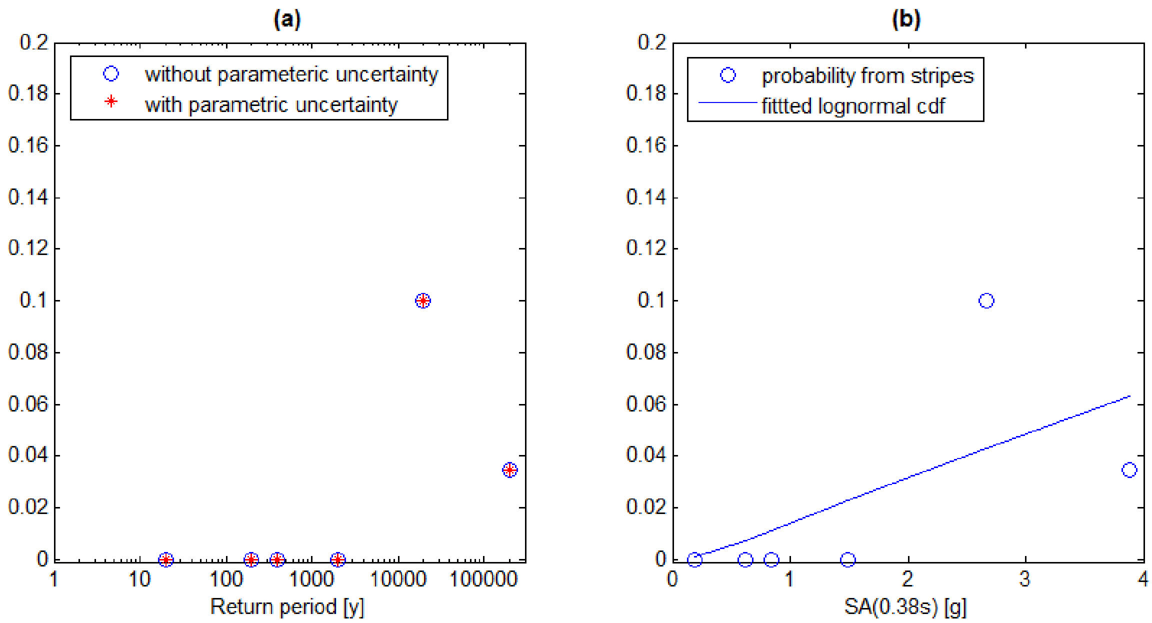
"**<Authors' reply>"** We agree with referee #2 that we should better emphasize the benefit of a non-stationary formulation. We propose to evaluate the chi-squared test (as described for instance by Panagoulia et al., 2014: Sect. 2). In our case, the very low p-value (<0.1%) provide strong evidence against the null hypothesis "the model is stationnary".

References

Panagoulia, D., Economou, P., & Caroni, C. (2014). Stationary and nonstationary generalized extreme value modelling of extreme precipitation over a mountainous area under climate change. Environmetrics, 25(1), 29-43.

The derivation of the fragility after arriving at demand and capacity may be done more explicitly. The nonlinear structural analysis section describes a scaling range with 6 steps. One might expect a few data points on the FC rather than a continuous curve based on this. A fit may be done after this and superimposed on the same graph. The absence of this plot may be due to the usage of a different method. The GEV fit appears to be for the EDP but is also mentioned as the fit for FC. Clarity here may improve readability considerably.

<Authors' reply> We thank referee #2 for his/her on-point comment regarding FC derivation methods. What the reviewer describes here pertains to the derivation of FC using multi-stripe analysis or incremental dynamic analysis (Baker, 2015; Vamvatsikos & Cornell, 2002): multiple ground-motion are scaled at the same IM value, and statistic on the exceedance rate of a given EDP value may be extracted at each IM step. In our present study, the conditional spectrum method leads to the selection and scaling of ground motions with respect to SA(0.38s), which correspond to the fundamental modal of the structure. However, the fragility analysis is focused on the pipeline component (located along the structure), which appears to be more susceptible to PGA: therefore, PGA is chosen as IM in the present fragility analysis. For this reason, it is not feasible to represent probabilities at 6 levels of PGA (as shown in Figure 3, there is a variability around the 6 scaling levels). In this case, current approach for FC derivation are the 'regression on the IM-EDP cloud' (i.e., least-squares regression, as demonstrated by Cornell et al., 2002) or the use of GLM regression or maximum likelihood estimation (Shinozuka et al., 2000). For illustration purposes, we propose to add a figure showing the probabilities at the 6 selected return periods (which may be associated to unique values of SA(0.38s), but not of PGA).



New Figure 3. (a) Damage probabilities directly extracted from the 6 scaling levels (or return periods); (b) Damage probabilities w.r.t. the 6 SA(T*) levels, and fitted lognormal cumulative distribution function.

From Figure 3, two main observations can be made: *(i)* the multiple stripe analysis does not emphasize any different between the models with and without parametric uncertainty, and *(ii)* the FC directly derived from the 6 probabilities does not provide a satisfying fit.

We propose to add in the manuscript a small paragraph similar to the one written above, briefly summarizing the various FC derivation methods.

References

Baker, J. W. (2015). Efficient analytical fragility function fitting using dynamic structural analysis. Earthquake Spectra, 31(1), 579-599.

Cornell, C.A., Jalayer, F., Hamburger, R.O., & Foutch, D.A. (2002). Probabilistic basis for 2000 SAC federal emergency management agency steel moment frame guidelines. Journal of Structural Engineering, 128(4), 526-533.

Shinozuka, M., Feng, M., Lee, J., & Naganuma, T. (2000). Statistical analysis of fragility curves. Journal of Engineering Mechanics, 126(12), 1224-1231.

Vamvatsikos, D., & Cornell, C.A. (2002). Incremental dynamic analysis. Earthquake Engineering & Structural Dynamics, 31(3), 491-514.

The same ambiguity arises in the plots of partial effects (Figs. 6,10,11). The structural variables appear to have a partial effect on the demand parameter. This seems counter-intuitive conventionally. The GEV appears to be used not just for demand in that case, this may be better presented.

We agree with referee #2 that there is some ambiguity on that aspect. Similarly as for the previous comment, we propose to better clarify in the introduction (lines 39-41) that we focus on the derivation of an appropriate statistical model for demand parameter based on which we derive the FC. The introduction will also be completed by referring to alternatives like multi-stripe analysis or incremental dynamic analysis.

The convolution of the probability density of capacity around the pre-defined damage states and the 1-CDF of the demand on the structure by different levels of ground motion would produce points on the FC. The procedure is detailed in [1]. This may be used as a starting point to show how FC derivation is different here.

Thank you for this valuable reference. As far as we understand the suggested study, Rota and co-authors account for the uncertainty on the structure by deriving the statistical law of the different damage states (Fig. 11 of their paper). In our study, we considered a fixed threshold *th* for defining the damage state (here fixed at *th*=775 kN). Combining the proposed approach with the one of Rota and co-authors is clearly worth investigating. It should however be underlined that the translation is not direct, because we actually performed dynamic numerical simulations, whereas Rota and co-authors based their procedure on pushover analyses. Analysing how to make this link may deserve further developments. We propose to add a reference to this study in lines 55-60 (when describing limit (4) in the introduction) and to discuss this aspect in the discussion section.

Return period for a non-stationary model requires transformation which may be of significance in some cases. See [2]. This may be of no effect considering the order of scaling, but it may be of use to include/discuss.

"**<Authors' reply>"** Thank you for this suggestion and reference, which was included in the discussion section Sect. 5.

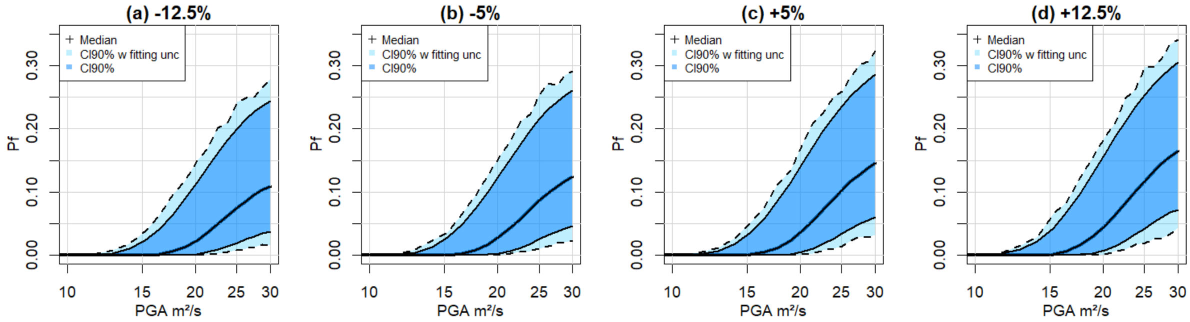
3. Readability

The paper may benefit from an appendix or a different section for detailed methods after describing the main results.

The partial effects may be consolidated in one section, the fragility curves being in another.

"**<Authors' reply>"** Thank you for this suggestion. Sect. 4.X (X=1,2) are now subdivided in as follows: Sect. 4.X.1: Model selection; Sect. 4.X.2: Partial effects; Sect. 4.X.3: FC derivation.

The variation of the fragility curves based on the choice for parameters such as e4 may be better presented in measures of percentage changes.
“<Authors’ reply>” Thank you for this suggestion, which has been taken into account. New Figure 14 should be presented as follows.



New Figure 14. FC considering different thickness e4 s: (a) -12.5% of the original value; (b) -5%; (c) +5%; (d) +12.5%. Uncertainty bands are provided by accounting for epistemic uncertainty only (dark blue) and by accounting for the fitting uncertainty as well (light blue).

The method used by Wood et al. (line 97) could’ve included with more detail for completeness.
“<Authors’ reply>” On the one hand, adding details (in a new appendix) on the double penalisation approach is clearly necessary, because it is a key ingredient of the proposed procedure. On the other hand, adding too many details on developments (that we did not perform), might hamper the readability of the paper. This may be the case for the AIC formulation for GAM models; the interested reader can easily find such details in the indicated reference.

The paper may benefit from a tabular presentation of results, especially the effect of structural parameters on FC as this may be of key significance for a practitioner.
“<Authors’ reply>” Thank you for this suggestion. We now present the effect of the structural parameters on FC using the following new Table 3.

Table 3. Influence of the geometrical/mechanical parameters on the GEV parameters, μ and lσ of the GEVsmo2 model

Variable	Influence on μ	Influence on lσ
E_{IC}	Linear (decreasing)	-
ξ_{RPC}	-	Non-linear (non-monotone)
ξ_{RC}	Non-linear (non-monotone)	Non-linear (decreasing)
e_1	Linear (increasing)	-
e_2	-	-
e_3	Linear (decreasing)	-
e_4	Linear (increasing)	-
e_5	Linear (increasing)	Non-linear (non-monotone)
e_6	Non-linear (non-monotone)	-
ξ_{SL}	-	-

Figure quality may be improved. Consider using vector graphics. x-axis of Fig. 5 requires uniformity and units may be placed in brackets.
“**<Authors’ reply>”** Thank you for these suggestions that will be take into account.

[1] Rota, M., A. Penna, and G. Magenes. "A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses." Engineering Structures 32.5 (2010): 1312-1323.

[2] Salas, Jose D., and Jayantha Obeysekera. "Revisiting the concepts of return period and risk for nonstationary hydrologic extreme events." Journal of Hydrologic Engineering 19.3 (2014): 554-568.

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