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Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting

FINAL INDEPENDENT EVALUATION

Evaluated Document: Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, Revision 2, NEK and WorleyParsons, 18. July 2014

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1.0 Executive Summary

An independent evaluation of the technical report Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting was made. The aim of the technical report was to estimate the capacity of NEK's safety-related structures, systems, and components (SSC) to resist possible fault displacements at the site. In the study, NEK and WorleyParsons (WP) anticipated that the Essential Service water (ESW) underground infrastructure was most sensitive to the possible permanent surface deformations. Therefore, the technical report focused on estimating the capacity of the ESW piping to accommodate permanent ground deformation in the case of a fault event. The seismic resistance of the ESW piping system was checked for a ground motion with peak ground acceleration PGA=0.6 g, i.e. twice the design SSE ground motion. The results of deterministic analysis performed in the evaluated report indicate that there is a high probability that the integrity of the pipe of intake train A, pipe welds and pipe flanges will be preserved during an earthquake with an intensity of 2×SSE. However, as stated in the evaluated report, there have been some open items left regarding the qualification (for 2×SSE loading) of flanged bolts, MC heat exchanger nozzle and pipe supports, which are constitutive parts of the ESW system. Therefore, based on the result of the evaluated study, the ESW piping system as a whole has not been qualified for the 2×SSE loading yet. Additional separate analyses of these components are needed to estimate their seismic capacities.

It should be noted that, according to the results of the probabilistic fault displacement hazard analysis PFDHA, which represents an input for the study, the fault displacement corresponding to a return period comparable to a ground motion PGA=0.6 g is smaller than 1 mm, which has no engineering significance and which is negligible compared to the hazard for seismic ground motion. Thus, it was concluded that the fault displacement hazard estimated in the PFDHA does not have a significant impact on seismic and nuclear safety of the NEK, which is controlled by the seismic ground motion.

The independent evaluation was performed, using an iterative procedure, in several steps until the final report was issued by NEK and WP. The conclusion of the independent evaluation is that the procedure used in the evaluated report and the results presented in the report are adequate. The document is ACCEPTABLE. There is a very high probability that the NEK's safety-related structures, systems, and components (SSC) are able to resist possible fault displacements at the site. However, as stated before, for the 2×SSE loading, the ESW piping system as a whole has not been qualified yet.

2.0Introduction

Recent geotechnical, geological, and seismological evaluations for the Krško Nuclear Power Plant (NEK) region have shown that the Libna fault may be considered a capable fault. NEK was expected to perform an analysis of the impacts that the potential fault displacements at the existing plant site would have on the nuclear safety and propose measures, if needed, to improve the means to successfully mitigate the potential consequences. A probabilistic fault displacement hazard analysis (PFDHA) was performed by Paul C. Rizzo Associates [NEK2] to assess the fault displacement hazard for the NEK site. The surface offsets for fault events with return periods of 10^6 and 10^7 years were estimated at approximately 0.002 m and 0.020 m, respectively. Based on the information provided in the PFDHA, the potential impact of fault displacement hazard on NEK's safety-related structures, systems, and components (SSC) was evaluated by NEK and WorleyParsons [NEK1]. The aim of this work is an independent evaluation of the report [NEK1]. Note that the PFDHA report [NEK2] has not been evaluated by the team performing this independent evaluation. It is assumed that the surface offsets have been correctly estimated.

The technical report [NEK1] estimates the capacity of NEK's safety-related structures, systems, and components (SSC) to resist possible fault displacements at the site. In accordance with IAEA requirements, the potential impact of fault displacement hazard on NEK's SSCs was evaluated based on the information provided in the PFDHA.

NEK's safety-related SSCs are designed to resist earthquake loading. The majority of SSCs are installed within the Main Complex (MC) structures, which are on a common foundation slab. The only exceptions are the Bunkered Building 1 (BB1), the Essential Service Water Intake Structure (ESWIS),

and the ESW underground infrastructure. It is anticipated that the ESW underground infrastructure is most sensitive to the possible permanent surface deformations. Therefore, the report [NEK1] focused on estimating the capacity of the ESW piping to accommodate permanent ground deformation in the case of fault event.

The evaluated study [NEK1] has been extended beyond the original scope which is visible also from the title "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting". The seismic resistance of the ESW piping system was checked for ground motions with peak ground accelerations PGA=0.3 g and PGA=0.6 g, i.e. the design SSE ground motion and twice the design SSE ground motion, respectively. They represent a much stronger seismic action than the possible fault displacement corresponding to a comparable return period for SSE.

The aim of this work is an independent evaluation of the report [NEK1]. Initially, the evaluation team was composed of the FGG members, specialized in earthquake engineering, structural engineering and geomechanics. Later on, when the scope of the study was extended and the analysis of the pipeline became the main issue, a specialist in mechanical engineering joined the evaluation team.

3.0 Documentation – References

3.1 NEK Documents

[NEK1] Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, Revision 2, NEK and WorleyParsons, 18.7.2014.

[NEK2] Probabilistic Fault Displacement Hazard Analysis Krško East and West Sites, Proposed Krško 2 Nuclear Power Plant, Rev. 1, Project N. 11-45-46, Paul C. Rizzo Associates, 13. May 2013.

[NEK3] NPP Krško Seismic Design Verification based on "Probabilistic Fault Displacement Hazard Analysis Krško East and West Sites, Proposed Krško 2 Nuclear Power Plant", NEK ESD-TR-10/13, Revision 0, NEK and WorleyParsons, 13.6.2013.

[NEK4] NEK response on FGG preliminary opinion on "NPP Krško Seismic Design Verification based on »Probabilistic Fault Displacement Hazard Analysis Krško East and West Sides, proposed Krsko 2 Nuclear Power Plant«, Rev.0, 17. June 2013" , Krško Nuclear Power Plant, July 12th, 2013.

[NEK5] Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, Revision 1, NEK and WorleyParsons, July 2013.

[NEK6] NEK and WP response to FGG comments on "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting", Draft Rev.1, July 2013", Krško Nuclear Power Plant, November 19, 2013.

[NEK7] Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, Revision 1, NEK and WorleyParsons, 20.11.2013.

[NEK8] Delovni sestanek FGG – NEK, Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, NEK, 16.12.2013.

[NEK9] NEK response on FGG comments on "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, Rev.1, 20. November 2013", Krško Nuclear Power Plant, April 22, 2014.

[NEK10] Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, (*draft*) Revision 2, NEK and WorleyParsons, Version April 2014.

[NEK11] Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, (*draft*) Revision 2, NEK and WorleyParsons, Version 5. June 2014.

[NEK12] NEK response on FGG comments on "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, Rev.2, WP and NEK, April 23, 2014 and draft revised version sent by D.Celarec on 5. June 2014", Krško Nuclear Power Plant, June 17, 2014.

3.2 Authorized Institution Documents

[FGG1] FGG preliminary opinion on NPP Krško Seismic Design Verification based on »Probabilistic Fault Displacement Hazard Analysis Krško East and West Sides, proposed Krsko 2 Nuclear Power Plant« Rev.0, 17. June 2013, University of Ljubljana, FGG, 26. 6. 2013.

[FGG2] FGG comments on Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, Draft Rev.1, 12. July 2013, University of Ljubljana, FGG, 17.7. 2013.

[FGG3] FGG comments on Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, Rev.1, 20. November 2013, University of Ljubljana, FGG, 23.12. 2013.

[FGG4] FGG comments on Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting, NEK ESD-TR-10/13, *(draft)* Rev.2, WP and NEK, April 23, 2014 and draft revised version sent by D.Celarec on 5. June 2014, 10. 6. 2014.

3.3 Other Documents

[FS1] Review of document: "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting", NEK ESD-TR-10/13, Rev. 1. Letter number: ESDTR10/13-LNMS-NEK-001, University of Ljubljana, Faculty of Mechanical Engineering, Laboratory for Numerical Modelling and Simulation, 29.1.2014.

[FS2] Review of document: "Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting", NEK ESD-TR-10/13, Rev. 2 draft. Letter number: ESDTR10/13-LNMS-NEK-002, University of Ljubljana, Faculty of Mechanical Engineering, Laboratory for Numerical Modelling and Simulation, 12.6.2014.

4.0 Acceptance Criteria

Acceptance criteria are based mainly on the following documents:

ASCE Standard 4-98, Seismic analysis of safety-related nuclear structures and commentary, ASCE, 1999.

ASME Boiler and Pressure Vessel Code, Section III, Appendix F, Winter 1972 Addenda.

ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Subsection ND, Edition 1972.

ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Subsection ND, Edition 1998 with 2003 Addenda.

5.0Description of Evaluation Process

5.1 Description of current status

A Probabilistic Fault Displacement Hazard Analysis (PFDHA) [NEK2] was performed following the suggestions in SSG-9 [30] for the East and West sites, which are being considered for the Krško 2 NPP. The site of the existing NPP is between the two investigated sites. According to PFDHA, a surface displacements of engineering significance (i.e. on the order of 5 centimeters or higher) the mean annual probabilities of exceedance are less than 10^{-7} for the East site and less than 10^{-8} for the West site. Low estimated fault displacements for the selected return periods indicate that surface fault displacement of engineering significance is highly unlikely at the Krško site. In any case, the probability of occurrence of such a surface fault displacement is much lower than the mean annual probability of exceedance for the SSE earthquake (10^{-4}, return period 10000 years) which controls the seismic design.

Considering the results of the Probabilistic Fault Displacement Hazard Analysis [NEK2], it can be concluded that this hazard is negligible compared to the hazard due to the seismic ground motion. The design and seismic assessment of Krško NPP is based on SSE, which corresponds to mean annual probability of exceedance of 10^{-4}.

In spite of this obvious conclusion, NEK and WP decided to perform an analysis aimed at demonstrating the capability of the NEK's safety-related structures, systems, and components (SSC) for accommodation of potential surface fault displacements.

The majority of the Seismic Category I structures, with exception of Diesel Generator Building (DGB), Bunkered Building 1 (BB1), and Essential Service Water Intake Structure (ESWIS), are located on a common foundation. The strong foundation and high-strength shear walls without openings in the exterior underground walls help the embedded portions of the foundation to resist forces transferred to the structure from ground deformation. Such a design enables the Main Complex (MC) to move relative to the ground as a nearly rigid body without a structural collapse or failure of operability. It is assumed that a potential surface fault displacement cannot endanger the MC. The same applies to BB1, DGB and ESWIS, which are all very stiff structures.

BB1 and DGB are connected to the MC only by electrical cables installed in underground cable ducts. The ESWIS is located around 100 m south of the MC. The Essential Service Water (ESW) buried piping consists of supplying pipes from the ESWIS to the MC and a system discharge from the component cooling heat exchangers to the Sava River. Two independent loops (trains) A and B are installed, each providing cooling water to one component cooling heat exchanger. Only one loop is necessary for safety operation at a time, while the other one is redundant. The piping system is considered to be the vulnerable part of the NPP, for which the seismic assessment has to be made.

5.2 Required status

It is required to check if the essential service water (ESW) piping system is able to accommodate the potential surface fault displacements in addition to the seismic action related to ground motion corresponding to twice the SSE ground motion, i.e. the ground motion with peak ground acceleration PGA = 0.6 g, combined with other loadings (internal pipeline pressure, gravity loading and thermal loads). Since, according to PFDHA, the potential surface fault displacement at a return period comparable to 2*SSE ground motion is negligible, the actual outcome of the study is an assessment of the piping system in the case of ground motion corresponding to 2*SSE.

5.3 Acceptance criteria description

The methodology of assessment should be consistent with the state-of-the-practice and in accordance with relevant standards and codes. The computational procedure should be comparable to the original design.

5.4 Evaluation

The first version of the document submitted to independent evaluation was NPP Krško Seismic Design Verification based on "Probabilistic Fault Displacement Hazard Analysis Krško East and West Sites, Proposed Krško 2 Nuclear Power Plant" [NEK3]. In this document it was assumed that the displacement due to possible surface faulting will be accommodated only by the ESW piping expansion joints (couplings). FGG prepared a preliminary opinion on this document in June 2013 [FGG1], questioning some of the assumptions used in the analysis.

NEK responded [NEK4] to the FGG comments and prepared a draft revised version (draft Rev.1) of the document with a modified title Assessment of capacity of the NEK to resist permanent ground deformations due to potential surface faulting [NEK5], where substantial modifications have been made, compared to the initial document. The new document was reviewed by FGG [FGG2]. In this review, it was stated "The evaluated study tries to demonstrate not only that the impact of the surface fault displacement hazard is negligible, but also, as a byproduct, that the ESW piping is capable to survive the DEC (i.e. 2xSSE) ground motion in combination with the thermal effects and with permanent ground settlements. For this demonstration a very simple analysis was performed, which was based on a large number of crude approximations. Many of them are conservative, but some of them may be unconservative." Based on the evidence presented in the evaluated study, it was not possible to approve the "byproduct" of the evaluated study, i.e. that the ESW piping is capable to survive the DEC (i.e. 2xSSE) ground motion in combination with the thermal effects and with permanent ground settlements.

NEK responded [NEK6] to the new FGG comments and prepared a revised version (Rev.1) [NEK7] of the document in November 2013. The most important changes made in Rev.1 were: (a) an analysis of intake train A was performed using a 3D model. An earthquake with PGA = 0.6 g was considered; (b) Joint displacements in the couplings due to the effects of seismic wave propagation were estimated; (c) a fault displacement is assumed to be accommodated by several couplings, since distributed fault displacements are expected at the NEK site in the case of a fault event. In order to discuss the methods used and the results presented in the report, and to accelerate the iterative reviewing procedure, a meeting of authors and reviewers was organized on 16th December 2013. Based on the conclusion of this meeting [NEK8], FGG prepared a new set of comments [FGG3].

In parallel, another independent review of Revision 1 was prepared by the Faculty of Mechanical Engineering [FS1]. The review was focused mainly on the analysis of intake piping of ESW Train A. The conclusion of this review was: »In general, the methodology and types of analyses, proposed in [the evaluated report] are correct. Majority of the assumptions and results are also correct. But some important details need to be resolved …, and some analyses are missing, thus the evaluated document is NOT ACCEPTABLE.«

A new version of the document (draft Revision 2) was prepared by NEK and WP in April 2014 [NEK10], together with the response [NEK9] to the FGG review. (Note that the Rev. 1 of the report was independently reviewed also by the Faculty of Mechanical Engineering, University of Ljubljana, as stated above, and that the new revision, i.e. draft Revision 2, includes also the changes due to that review.) Once again, the new version was substantially changed and extended. Several changes were made due to repeated analysis to account for more conservative seismic and model parameters. Two new sections were included in Appendix II, related to Seismic analysis of intake train A of ESW pipeline for 2×SSE. These are Plastic analysis of local 3D model of pipe segment and elbow at the penetration to the MC, and Flange analysis. Before the review of the document of 23. April has been concluded, a new version of the document was submitted in an e-mail by D.Celarec on 5. June 2014 [NEK11].

FGG prepared a review of the draft Revision 2 on 10. June 2014 [FGG4]. In addition to the three FGG reviewers, who have independently checked all versions of the technical report, a reviewer from the Faculty of Mechanical Engineering, who is an expert for analysis of pipelines was engaged for reviewing the new sections included in Appendix II, Revision 2 of the evaluated document. The FGG team prepared 8 comments, mainly suggesting improved description of the work and its results, and requesting some additional explanations. The new reviewer prepared a thorough review of the new

sections and formulated a number of comments, mainly related to Section 6 of Appendix II (Elastic-plastic analysis - local 3D model). Based on this review, it was concluded:
"Provided that bolts are replaced as recommended, there is a high probability the evaluated pipeline will keep its functionality during and after an earthquake with PGA intensity of 0.6 g. However, when analyzing ESW pipeline, several new open items regarding the ESW system qualification appeared during the work on the project. Some of them are successfully resolved (closed), see Attachment II, but a few remain. All those remaining items are not qualified to the 2xSSE loading conditions yet. These items are:
1) Discharge piping of ESW Train A,
2) Piping supports inside MC of both, intake and discharge Train A piping,
3) Flange bolts on both pipings,
4) Train A heat exchanger inlet and outlet nozzles.
As a consequence, the ESW system as a whole is not qualified to the 2xSSE loading conditions yet. In order to qualify it, additional analyses are needed."

The draft Revision 2 was reviewed independently also by the Faculty of Mechanical Engineering [FS2]. Majority of the issues exposed in the review of Revision 1 [FS1] have been satisfactorily settled by NEK, the main hindrance, however, remains: »If the ESW system as a whole is to be qualified to 2xSSE loads, mentioned structural elements (heat exchanger nozzles and pipe supports) need to be qualified as well.«
NEK took into account the comments of the reviewers , [FGG4] and [FS2], and prepared a new draft of Revision 2, together with the response to reviewers [NEK12]. After some additional comments made by reviewers and discussions between authors and reviewers by e-mail and phone, the final version of Revision 2 [NEK1] was prepared by NEK and WP. This is the document under evaluation.

The Revision 2 of the evaluated document [NEK1] contains 103 pages. It consists of the main part and 2 appendices. In the Introduction, the history of NPP Krško site investigations before and after construction is first described. Important analyses and investigations, relevant for seismic input, are briefly summarized. Then, in two short sub-sections, experiences with permanent ground deformations are described and the conclusions of the recent PFDHA [NEK2] are summarized, respectively. A short description of the NEK structural design is presented in Chapter 2. In three sub-sections seismic classification and layout of structures, key attributes of NEK to resist seismic motions and permanent ground deformations, and description of underground cable ducts and ESW piping are presented. The main part of the report is Chapter 3, where the assessment of capacity of the ESW piping to accommodate fault displacements is discussed. In Section 3.1, the assessment of capacities of couplings in the case of SSE is made. Several conservative assumptions were used in analyses. Soil-pipe interaction was neglected. The simplified calculation was aimed at determining the limiting train. The results of the calculations provided in Section 3.1 show that train B is limiting over train A in terms of accommodating permanent ground displacements. A stress analysis of intake train A was performed in order to evaluate seismic behaviour during a ground motion with intensity of 2×SSE. In contrast to the simplified case considered for SSE, the internal stresses and fault displacement capacities of intake train A were estimated considering soil-pipe interaction using 3D models of the pipe. Loads considered in the analysis of the 3D model of intake train A are dead-weight, internal pipeline pressure, operating thermal load, and earthquake with the intensity 2×SSE. The results are presented in Section 3.2 and in Attachment II.

Conclusions are summarized in Chapter 4. The results indicate that effects of ground motion on the evaluated pipeline are much more important than those due to the fault displacement hazard at the NEK site. The results of deterministic analysis indicate that there is a high probability that pipe of the intake train A, pipe welds and pipe flanges will keep their integrity and functionality during a ground motion with PGA intensity of 0.6 g. On the other hand, there are some open items left regarding the qualification of flanged bolts, MC heat exchanger nozzle, and pipe supports for 2×SSE ground motion effects. Additional analyses are necessary before these parts, and the ESW piping system as a whole, could be possibly qualified for the 2×SSE loading.

In Attachment I, the seismic displacements (relative to the ground, for SSE) of the Main Complex (MC) and ESWIS are calculated for two locations at which the ESW piping connects to the ESWIS and for four locations at which the piping enters and exits the MC. The results of seismic analyses of buildings performed in previous projects were used as the input for the calculations.

An important conclusion, which is related to the original aim and scope of the study, is that a fault event, which is expected to cause a fault displacement equal to the estimated displacement capacity of ESW pipeline, has a return period much higher than the return period of a ground motion with PGA= 0.6 g (2×SSE) which is more than 10000 years. According to the results of the PFDHA [NEK2], the fault displacement corresponding to a return period comparable to a ground motion with 0.6 g is smaller than 1 mm, which is negligible compared to the hazard for seismic ground motion. Thus, it can be concluded that the fault displacement hazard estimated in the PFDHA [NEK2] does not have a significant impact on seismic and nuclear safety of the NEK.

The review was performed by the three FGG reviewers, which have independently checked all versions of the technical report. In addition, a reviewer, who is an expert for analysis of pipelines, was engaged for reviewing the new sections included in Revision 2 of the evaluated document, related to the detailed analysis of the intake train A. The methodology, used for the assessment, the assumptions, the results of calculations, and their implications for the seismic safety of NEK, were extensively discussed between the authors and the reviewers in an iterative procedure which led to the final version of the document. Some more details of whole review process are documented in the review comments and authors' responses (see references). In our opinion, the methodology, the description of the work and the results presented in the evaluated document are acceptable.

6. Suggestions, Recommendations and Required NEK Document Changes

6.1 Suggestions

None

6.2 Recommendations

In order to qualify the pipeline system, some actions and additional analyses are needed, as described in the evaluated document. Since quite specialized analyses will be necessary, they should be performed within a new project.

6.3 Required NEK Document Changes

None

7. Final Independent Evaluation Conclusion

The evaluated document is ACCEPTABLE. This conclusion applies to the methodology and results presented in the evaluated document. Note that the pipeline system has not been qualified yet.