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# On the Reasons and Extent of NEK's Seismic Instrumentation Upgrade

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## ABSTRACT

Nuclear Power Plant Krško (NEK) is designed so that, if the Safe Shutdown Earthquake (SSE) occurs, all structures, systems, and components important to safety remain functional. Furthermore, all structures, systems, and components of the nuclear power plant necessary for continuous operation without undue risk to the health and safety of the public, shall be designed to remain functional within applicable stress and deformation limits when subjected to the effects of the vibratory motion of the Operating Basis Earthquake (OBE) in combination with normal operating loads. In NEK, appropriate instrumentation is provided to monitor strong seismic ground motions at the site and seismic response of the NEK's structures so that the seismic response of the safety related structures, systems and components can be evaluated promptly after an earthquake. The function of strong motion seismic instrumentation system is to detect significant (strong motion) earthquakes at the plant site, record and manage (analyse and store) acceleration data, perform OBE and SSE exceedance evaluation and, ultimately, report to plant operator during and after an event. Since the establishment of NEK, the strong seismic motion monitoring instrumentation has been upgraded three times. The last and the most extensive upgrade was performed in 2022, when the system was completely replaced by new one. New system was extended with several new ground motion accelerometer locations on free field and inside safety related buildings in order to ensure full compliance with up-to-date regulatory guidelines for the industry (i.e., both new Bunkered Buildings, new Dry Storage Building, and new locations at Main Nuclear Island). The free-field accelerometers close to the Main Island (accelerometers A1) was relocated to being immediately adjacent to another free-field accelerometer (A2) to avoid signal disturbances during earthquake due to effect of seismic response of nearby structures (at close vicinity) on recorded ground motion at the location of accelerometer A1. The set of free field accelerometers is completed by the down-hole accelerometer A9, which has been installed following the requirements of the latest regulatory guide at the time (RG 1.12 rev. 3). Obsolescence and operational and maintenance issues were also a very important reasons for the old system replacement. Specifically, the old system was occasionally subject to false triggering due to impacts of electric discharges on the outdoor signal and triggering lines during lightning strikes, and negative effects of electro-magnetic radiation on in-housed lines. Another deficiency was the exposure to the effects of radiation and high temperatures that could have caused system malfunctions due to the recorder's failure inside the reactor and intermediate building, respectively. In the new system: (1) optical connections between the outdoor recorders in main control cabinet in the Main Nuclear Island

are used to avoid lightning impacts; (2) electrical lines between the accelerometers and recorders are designed and installed following up-to-date electro-magnetic compatibility qualification code requirements to avoid electro-magnetic interference; and (3) all in-housed recorders are relocated from the accelerometer locations into the main control cabinet. The reason for last requirement is to avoid negative radiation and environmental effects on the recorders. The entire system was seismically and EMC qualified. The replacement of the seismic monitoring system began in mid-2022 with the installation of cable trays, temporary relocation of free field accelerometer, installation of new free field accelerometers and a downhole accelerometer, and it was finally completed with the installation of a new cabinet in the main control room, testing and commissioning during the outage the same year.

## 1 INTRODUCTION

Earthquakes are present almost worldwide and are a risk for most human construction. In nuclear power plants, the resulting risk is controlled by state laws that provide a high level of safety against earthquakes in comparison with other industries.

The design of nuclear power plants is executed taking into consideration the effects of the largest expected earthquake in the plant area. Such earthquake is defined as the Design Basis Earthquake (DBE) and the plant should be able to safely shutdown in case it happened. This is also called Safe Shutdown Earthquake (SSE). The half level of SSE is called Operating Basis Earthquake (OBE) and represent the maximum earthquake that can happened at the plant without requiring a shutdown. Every plant located at seismic area should be designed to withstand in its lifetime: 5 Operating Basis Earthquake (OBE) and 1 Safe Shutdown Earthquake (SSE).

In a nuclear power plant, appropriate seismic instrumentation must be provided to ensure that the seismic response of the safety related plant structures, systems and components can be evaluated promptly after an earthquake. The seismic instrumentation must be able to process the earthquake records and provide results to plant operator within a short time (< 4 hours) after an earthquake occurs.

During the operation of the Nuclear Power Plant Krško (NEK), the strong seismic motion monitoring instrumentation was upgraded three times. The last upgrade was performed during Outage 2022 in order to ensure compliance with up-to-date regulatory guidelines and to repair obsolescence and operational and maintenance issues of the old system. This paper briefly describes new seismic instrumentation of NEK and presents the reasons and extent of the its last upgrade.

## 2 DESCRIPTION OF SEISMIC INSTRUMENTATION

### 2.1 Configuration of the system

The purpose of the Seismic Monitoring System (SMS) is to continuously measure seismic activity at the NPP and, when the system is activated (triggered), it monitors, records, and stores the data for the subsequent OBE and SSE evaluation and analysis. In addition, an immediate annunciation in MCR and report to plant operator is provided when the system is triggered.

Considering the fact that seismic instrumentation system has to provide accurate information on seismic event and the response of Category I structures, the seismic instrumentation system itself is classified as Seismic Category I. Sensing instruments are placed at the representative points in the plant. The types, number and locations of the instruments are selected to comply with the US NRC Regulatory Guide 1.12, "Instrumentation for Earthquakes" [1] and standard ANSI/ANS-2.2-1997 "Earthquake Instrumentation Criteria for Nuclear Power Plants" [2].

After the systems' upgrade in year 2022, NEK is monitoring 17 critical plant locations with the following accelerometers (see Figure 1): two (2) free surface accelerometers (located far from main structures), one (1) subsurface (20 m downhole) accelerometer, and fourteen (14) in-housed accelerometers. The locations are determined on the basis of the dynamic analysis of Main Island buildings (Reactor Building, Auxiliary Building, Intermediate Building), Diesel Generator Buildings, Essential Service Water Intake Structure, Bunkered Buildings 1 and 2 and Dry Storage Building, and requirements of US NRC Regulatory Guide 1.12. Each accelerometer is measuring seismic motions in three (3) perpendicular directions (North-South, East-West, Vertical).

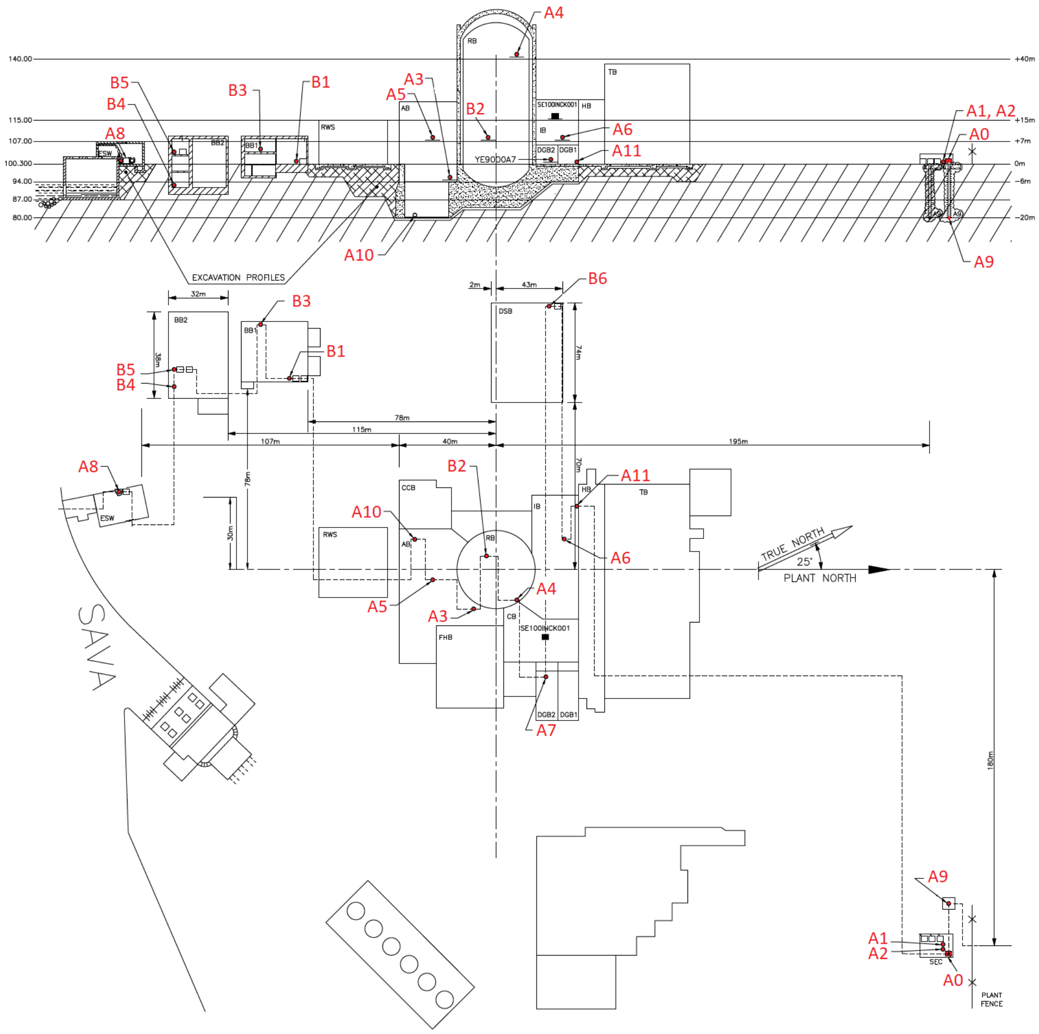


Figure 1: Locations of accelerometers at NEK site.

The configuration of main parts of the system is schematically shown on Figure 2. Eight accelerometers in-housed in the Nuclear Island (see item No. 2, Figure 2), as well as six field accelerometers in-housed in ESWIS, BB1, BB2 or DSB buildings and the two installed at the free surface (item No. 3, Figure 2) are placed in a protective stainless-steel housing which protects accelerometers from the environment. The downhole accelerometer is functionally equivalent to the rest except that it is inserted in protective torpedo-shaped housing (see item No. 4 on Figure 2). The downhole accelerometer is installed in a 20 m deep borehole. Unlike the free-surface and in-housed accelerometers, the downhole accelerometer measures acceleration at the level equivalent to the bottom of Main Complex foundation, defines the amplification factor between surface and soil layer at the foundation level and avoids potential human induced noise present at free surface.

Each of the accelerometers is permanently monitored by the seismic recorder which is connected to either in a field station (item No. 3 on Figure 2) or the central cabinet (Item No. 1 on Figure 2). The recorders store an event file when the signal detected by corresponding acceleration exceeds over a set trigger threshold. Each of the seismic recorders (one per accelerometer) stores this event file in its own SD memory card and transfer it to the PC inside the central cabinet. The event files can be viewed on the PC regardless of where they originated or are stored. The SD cards may be swapped or data may be backed up to the PC SSD or any external server. Essential for post analysis is the time synchronisation between all the recorders which is guarantee by the GPS time signal broadcasted among the recorder's network.

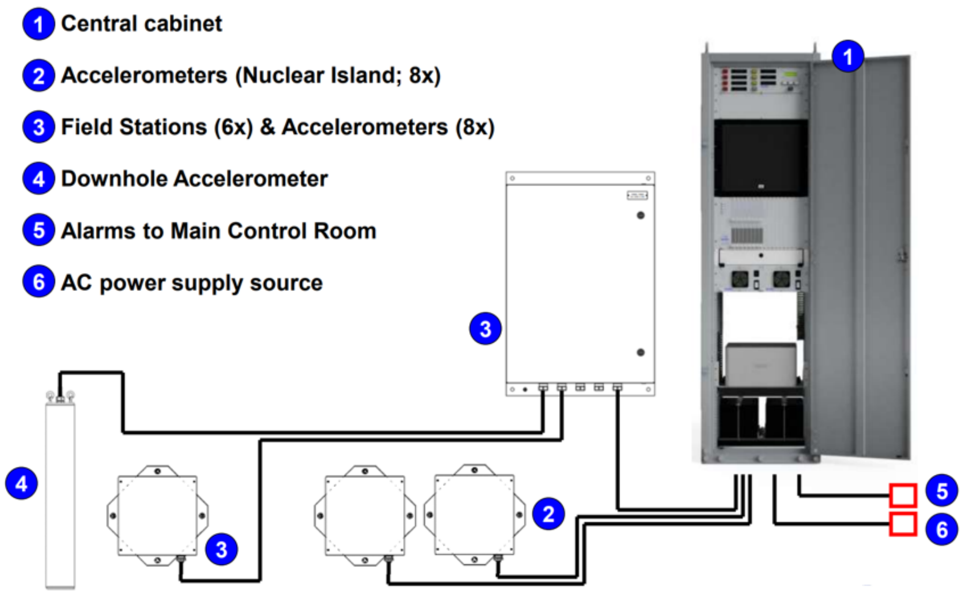


Figure 2: Locations of accelerometers at NEK site.

## 2.2 OBE exceedance check

The accelerometers are in function continuously and measure any earthquake motions and structures' movements (memory length of 3 months). If a seismic motion with a peak ground acceleration greater than 0.01g is detected at any accelerometer location on the free field (accelerometers A1, A2) or 20 m below the surface (accelerometer A9), the »SE SYSTEM TRIGGERED« alarm is triggered in the main control room. In such a case, all measurements are permanently recorded, the analysis of seismic event is automatically performed (calculation of acceleration and velocity spectra and cumulative absolute velocity), and the OBE exceedance is checked.

OBE exceedance set points are determined in accordance with USNRC Reg Guide 1.166, Rev. 1, Feb. 2020, "Pre-Earthquake Planning, Shutdown, and Restart of a Nuclear Power Plant Following an Earthquake" [3], ANSI/ANS-2.23-2016, "Nuclear Power Plant

Response to an Earthquake [4], and EPRI 3002005284, "Guidelines for Nuclear Power Plant Response to an Earthquake", 2015 Technical Report [5], respectively. The criteria for determining the exceedance of the OBE, based on data recorded at the free field, is a threshold response spectrum ordinate check and a cumulative absolute velocity (CAV) check. OBE exceedance is confirmed if the data recorded at the free field locations (2 on the free surface and 1 at depth of 20 m below ground) exceed:

- the corresponding 5% damped OBE design response spectral acceleration in any one of the three directional components, two horizontal and one vertical, for frequencies between 2 to 10 Hz **OR** the corresponding 5% damped OBE response spectral velocity in any one of the three directional components for frequencies between 1 and 2 Hz,

  **AND**

- CAV check,

where, for each component of the free field ground motion of the seismic event, the CAV calculated as follows:

1. the absolute acceleration, in g units, time history is divided into 1 second intervals,
2. each one second interval that has at least one exceedance of 0.025 g is integrated over time,
3. all the integrated values are summed together to arrive at the CAV.

The CAV check is exceeded if any of the CAV of the three orthogonal directions is greater than 0.16 g-second.

If the response spectrum limits and the CAV limits are exceeded than the OBE is declared and plant shut down is required.

When a new event file is generated, it undergoes an Event Check. An Event Check evaluates the data for any RSA/RSV/CAV exceedance. In case of OBE exceedance (SSE disabled for KRSKO), an alarm is generated and sent to the MCR. All calculation results after an event are included in an event report.

## 3 REASONS FOR SYSTEM UPGRADE

The current system has been upgraded in year 2022. The upgrade was driven by the needs for improved functionality of the system and extension of the system to new Seismic Category I structures. By replacing the previous SE system, the problems of false activation and dysfunctionality of the system were also eliminated. The new system was designed taking into account all negative effects causing false triggering and fails in functionality that have been recognized, such as problems related to inconsistent grounding solutions, effects of transient phenomena during electrical discharges, electromagnetic effects, and effects of increased radiation and temperatures.

### 3.1 Extension of the system to new locations

The new SE system is designed in accordance with USNRC RG 1.12, rev. 3, standard ANSI/ANS-2.2-2016 and special requirements from USAR 3.7.4, rev. 25 [6]. The criterion regarding the location of seismic instruments states that it is necessary to equip all structures Seismic Category 1 with seismic instruments at the base and elevation, if it exists. This requirement, which was met for all existing buildings, must also be followed in case of newly built Seismic Category I buildings, such as Bunkered Building 1, Bunkered Building 2 and Dry Storage Building. In building BB1, accelerometer was already installed on the foundation; it was necessary to additionally install an accelerometer on the first floor (Emergency Control Room elevation). In the BB2 building, it was necessary to install an accelerometer at the base elevation as well as at the top elevation. In the DSB building, it was necessary to install the accelerometer at the foundation mat.

An additional criterion regarding the availability of seismic instruments states that all free field instruments (two at the free surface and one downhole) must be available for inspection purposes immediately after a seismic event. The downhole accelerometer, which did not meet this requirement, was redesigned and replaced as well in accordance with mentioned regulatory requirements.

### 3.2 False triggering and fails in functionality

Before the systems' upgrade, the recorder, which contains electronic parts sensitive to radiation, and associated accelerometer installed in reactor building were exposed to the radiological conditions of the reactor building. Fails in communication between the central system in the MCR and the recorder appeared frequently, which caused an alarm on the SE system and the inoperability of the measurement in the reactor building. To fix the problem, a reset of the recorder was usually required, which was done remotely from the MCR or locally at the reactor building recorder location. The effects of radiation caused partial or complete fail of the recorder two times, which required partial replacement of electronic parts or complete replacement of the recorder. The recorder in the reactor building needed to be moved permanently outside the RB building, while the existing location for the corresponding accelerometer was kept. This action also meets ALARA criteria from USNRC RG 1.12, rev. 3.

In the past, the recorder with an integrated accelerometer installed in Intermediate Building at elevation 107 was exposed to high temperatures of up to 50° C. High temperatures affected functionality of the batteries and often caused their failures. It was realized that location of the Intermediate Building, El. , was not suitable for the recorder and its battery, so it was decided that the recorder needs to be moved permanently outside the Intermediate Building, El. 107, to the central cabinet in the Main Control Room, while the existing location for the corresponding accelerometer was retained.

The obsolescence and the operational and maintenance issues were also a very important reasons for the old system replacement. Specifically, the old system was occasionally subject to false triggering due to impacts of electric discharges on the outdoor signal and triggering lines during lightning strikes, and negative effects of electro-magnetic radiation on in-housed lines. In the old system, the most frequent false triggers were: activation of accelerometer noise test, random triggering of the system caused by random secondary (slave) accelerometers, triggering of the system during electrical discharges (despite the protective elements on the lines, inductions occur in the system), and occurrence of system trouble alarm, based on either AC loss, DC loss, communication problem, missing information, reaper stopped, unknown recorder, and operation ignored. The reasons for false activations of the old SE system have been eliminated by a complete replacement of the system and replacement of all cable connections using appropriate design and materials.

The new SE system is designed and built considering all recognized negative impacts at individual locations of the accelerometers and by consistently taking into account the equipment newest manufacturer's technology.

## 4 SCOPE OF MODIFICATION

The scope of seismic instrumentation system upgrade project included: the dismantling of the existing seismic system, the installation of 18 new accelerometers (17 NEK's accelerometers and one accelerometer as part of national seismological network), one central cabinet, one free field container, one borehole for underground sensor and 6500 m of cables and 450 m of conduits.

The implementation of the new system was performed in 3 phases, with the first two phases being implemented before the Outage 2022 (i.e., On Line 32). In the first phase during the OL 32, starting few months before Outage 22, the activities that didn't have impact to the existing system were performed, including the installation of selected components, conduits and cables as well as termination of the cables (where possible). In the phase 2 during the OL 32, starting one month before Outage 22, the existing free surface accelerometers A2 and A0, located in the free surface container, and downhole accelerometer A9 were dismantled. At the same time the entire container was replaced by new one, and all sensors except those in-housed in Diesel Generator Building El. 100, Auxiliary Building El. 94, and Reactor Building Els. 107 and 140 were implemented. As required by Technical Specification (LCO 3.3.3.3) [7] 2/3 free-field accelerometers (A1, A2, and (downhole) A9) must be operable continuously. This requirement was followed by having in function two free surface accelerometers, i.e., accelerometer A1 at its original location (close to Main Complex), which also acted as master sensor, and accelerometer A2 which was temporarily relocated to alternative free surface location. During the outage, the accelerometer A2 was not acting as a master sensor (could not triggered the system) but it was in function to record any seismic event. In case of seismic event, the recorded data could have been downloaded for the purposes of further analysis. In phase 3, during the Outage 22, complete seismic instrumentation system was replaced including central cabinet in Main Control Room. During the phase 3 activities, it was necessary to provide a minimum temporary configuration for seismic monitoring. For that purpose, existing selected accelerometers were kept at several locations. In addition to the accelerometer at the temporary free surface location (sensor A2), the following additional were in function all time during the outage: Auxiliary Building El. 94 (A3), Diesel Generator Building 2 El. 100, and Essential Service Water Intake Structure, El. 100. During the outage period, the performed activities were: disconnection of all existing cables and conduits, removal of the existing cabinet and accelerometers, installation of new cabinet and sensors, new cable pulling and termination, testing and start-up.

## 5 CONCLUSIONS

The new Seismic Monitoring System is in full accordance with the Reg. guide 1.12, Rev 3. Additional sensors at new locations on the main nuclear Island and other buildings were installed. The new instrumentation has enhanced performance: the measuring range is increased up to 4 g, the data recording and storage capacities are extended, the frequency range is wider and the sampling rate is extended. Also, the ALARA principles are followed with the upgraded system. Other advantages are: the seismic monitoring is extended to new buildings (Bunkered Building 1, Bunkered Building 2, Dry Storage Building), the existence of the redundancy of sensors on the free surface (A1 and A2 are at the same location), the power supply is unified, the system is more reliable (resistant to discharges and electro-magnetic influences), and the unfavourable effect of increased temperature (intermediate Building, El. 107) was eliminated.

## ACKNOWLEDGMENTS

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