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Mitigating Construction Risks: Nuclear Power Plants and their Environment

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Abstract: *In this paper, we would like to assess the issue of construction risks in a nuclear power plant and the possibility of mitigating these risks through a real-time monitoring system. In our research, we are concerned with the determination of the risks of deep construction activities and their impact on a specific nuclear site. We will also investigate possible risk mitigation activities that can be used in the nuclear power plant environment and their effectiveness. In some respects, the risk analysis applied to construction projects differs from the risk analysis applied to nuclear installations. For nuclear installations, the risk as such is primarily nuclear risk. In view of this, for investments involving a nuclear installation, the risk analysis to be carried out must be carried out at two separate levels. The first level is the traditional construction risk analysis, and then on a second level, each risk item should be classified from a nuclear risk point of view. In this study, the nuclear exposure of construction risks will be presented.*

Keywords: *real-time monitoring, geotechnical and building monitoring system, risk, construction risk, nuclear power plant safety*

1. INTRODUCTION

Risk analysis is a fundamental prerequisite for ensuring the safe construction and operation of any facility—especially in the nuclear sector. Before construction begins, a comprehensive risk analysis must be conducted, detailing all risk factors associated with the structure or construction complex. This includes each phase of construction and the specific risks they entail.

The purpose of the risk analysis is to clearly and transparently identify critical locations and high-risk construction steps, while also proposing appropriate mitigation strategies. When construction involves existing or aging structures, this analysis becomes even more critical. It must anticipate potential issues throughout the entire construction period, assess their likelihood, and estimate the potential severity of resulting damage.

For nuclear installations in particular, the risk analysis must include a risk matrix that lists each identified risk element along with feasible risk-reduction measures. Following the implementation of these measures, the risk analysis must be updated, and a revised risk index calculated to reflect the new risk levels.

To effectively reduce risk, the deployment of real-time building movement and geotechnical monitoring systems at key locations is essential. Without these monitoring systems, reliable risk reduction is not achievable. Their primary function is to safeguard both the structural integrity of the facility and the surrounding natural environment.

In today's construction landscape, especially within the nuclear industry, this level of risk management is indispensable. Construction activities—including increased traffic, heavy machinery operation, and deep excavation—inevitably impact both the built and natural environments. Proactive, data-driven risk analysis and monitoring are crucial to managing these impacts safely and sustainably.

2. WHAT TYPES OF IMPACTS CONSTRUCTION PORJECTS HAVE ON THEIR ENVIRONMENT AND WHAT SHOULD AND CAN BE PROTECTED:

Protecting the natural environment: As well as protecting the built environment, we must not forget to protect the natural environment. Today, with water quality in constant decline, the depletion and loss of agricultural land and the destruction of wildlife, it is impossible to start a construction project without taking into considering the protection of the natural environment, especially in the case of an operational and planned nuclear installation.

Protection of the built environment: During the design phase of any technical installation, be it a flood protection dam, a building, a structure, a bridge, an infrastructure (roadway, railway track, etc.), the structural solutions chosen and the materials used predetermine the maximum load-bearing capacity of the structure. In many cases this also defines the maximum possible displacement of the structure. Other engineering structures designed and constructed in the immediate vicinity of these engineering structures will create additional new load-bearing effects. In all cases, the excess load is applied to the existing structure ('built environment'). Accurate quantification of this excess load is essential for the safe operation of existing structures.

Provide information during the construction, maintenance and operation period: A structure movement and geotechnical monitoring system, properly set up during the design phase of a construction project will allow the impact on the built and natural environment to be accurately measured during the construction period. If necessary, construction technology modifications can be made to protect the built and natural environment. A continuous picture can be obtained at the end of the construction period:

- of the movements and subsidence that occur;
- of the stresses that develop, the new equilibrium situation;
- of the movements and stresses over time.

During the construction period, the results measured by the monitoring system are those that will be aggregated at the moment of commissioning and will represent the "0" status of the structures during the operational period. Thus, giving an accurate picture of the real initial state of the installation.

3. TYPES OF CONSTRUCTION IMPACTS

The movements that occur during a construction project have an impact on the environment of the project site. For any movement that occurs, it is true that it may extend beyond the property boundary.

Possible movements can be classified into the following types:

- Surface settlement: In the case of a stable system, if a change is made somewhere, it is likely to cause instability again and time is needed to re-establish stability. The natural and built environment in the immediate vicinity of a construction project is assumed to be stable until construction starts. In any case, the start of a construction project will lead to a new situation, with decreases and increases in tension, which will result in a new equilibrium state. Changes in the rest stress of the ground environment can cause subsidence, to the extent of which depends on the properties of the soils and the degree of intervention in the environment.
- Sinking of the groundwater level: A significant proportion of nuclear sites are located near rivers or lakes. Groundwater levels and changes in groundwater levels are significantly influenced by the water level of nearby rivers or lakes.
- Displacement of deep excavation support: There is a situation where construction activities are taking place in the immediate vicinity of an existing operating nuclear power plant unit, and where significant earth displacement is expected during the deep foundation and underground construction of the unit to protect the boundary structures. During the excavation, the boundary structures of the excavation pit will be subjected to continuously increasing stresses. The increase in tension may cause deformation of the boundary structures, resulting in displacements and stress redistribution in the surrounding soil mass.

In the event of an unforeseen construction situation or accident, there could be a significant shift in the support of the deep excavation pit, which could lead to a major reduction in groundwater levels and subsidence.

These resulting movements have an impact on the environment:

- Uneven subsidence of buildings/structures;
- In rare cases, even subsidence of buildings/structures;
- Sinking of some wall sections/walls of surrounding buildings/structures;
- Reduction in resistance to cracking;
- Deformation of utilities, structures running below the surface, local subsidence.

4. GEOTECHNICAL AND BUILDING MOVEMENT MONITORING SYSTEM AS A GUARDIEN OF THE ENVIRONMENT

When selecting a monitoring system, it is essential to establish exactly what the purpose of the measurement is, what conclusions are to be drawn from the measurement results during processing, and what exactly is to be measured.

In engineering practice, we can divide the elements that can be measured into three broad categories:

- Movement measurements: Settlement measurement; Tilt measurement; Torsion measurement; Deflection measurement.
- Tension measurements: Earth pressure measurement; Pore water pressure measurement.
- Variation over time of all the above measurements.

The precise definition of the measurement objective also determines the type of measuring instruments to be used in the building movement and geotechnical monitoring system.

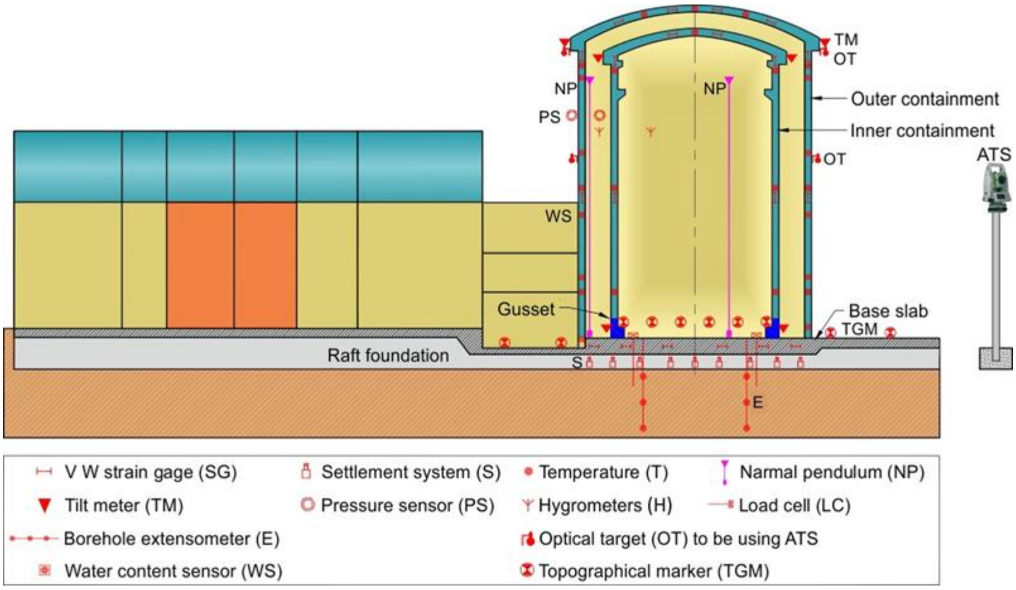

Figure 1 Instrumentation location plan of a Nuclear Power Plant[17]

5. REQUIREMENTS FOR INSTRUMENTS

To ensure the effectiveness of a monitoring system—particularly within nuclear installations—it is essential to define the technical requirements and prioritization criteria for all instruments used. The following aspects must be taken into account:

Each instrument must meet clearly defined requirements for accuracy, resolution, precision, and measurement deviation. These parameters must align with the safety-critical demands of nuclear environments, where even small inaccuracies can have significant consequences.

In nuclear facilities, real-time monitoring is mandatory. Measured data must be processed and displayed immediately upon collection, ensuring that changes—such as settlement at monitoring points—are visible without delay. This allows for immediate response to potential issues and supports continuous situational awareness.

Instrument Lifetime and Environmental Suitability environment:

Indoors or outdoors, Above ground or underground, Above or below groundwater levels, Exposure to aggressive environmental conditions, such as corrosive groundwater or chemically active soil.

These factors significantly influence the selection of materials, protective casings, and maintenance requirements.

All measurement data must be collected, stored, and transmitted according to the monitoring system's data management protocol. This includes reliable and secure transmission to designated servers for processing, analysis, and archiving, ensuring compliance with cybersecurity and operational standards.

6. ELEMENTS OF A BUILDING MOVEMENT AND GEOTECHNICAL MONITORING SYSTEM

As with any construction project, there are specific points and structural elements to be measured and monitored in the case of nuclear power plants.

Figure 1 shows the proposed features and measurement points that are required for the safe long-term operation of a nuclear power plant.

They can provide data on the condition of structural elements, installed materials and their changes in condition during operation. These proposed measurement tools go beyond the current research topic, which is the possibility of reducing construction risks by using real-time building movement and geotechnical monitoring systems.

Among the elements of the overall monitoring system, I would like to highlight and discuss those that facilitate safe construction investments and construction works on the site of nuclear power plants and other nuclear facilities.

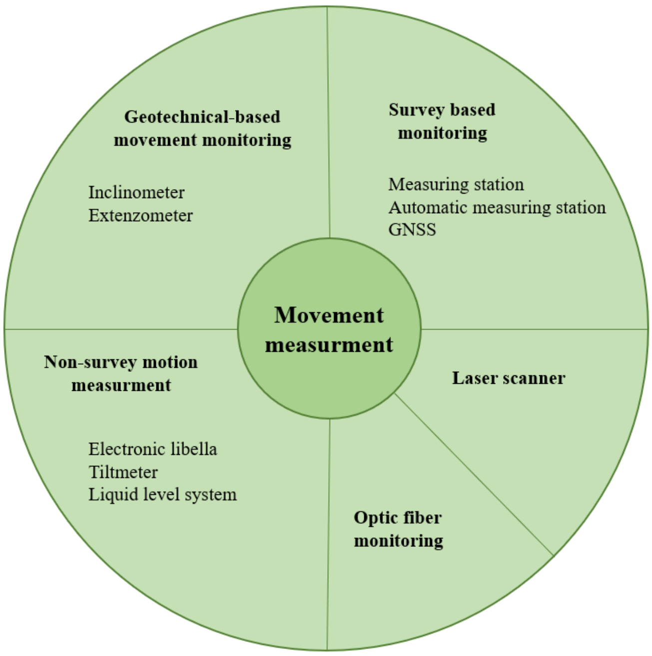

Figure 2 Movement monitoring systems [own figure]

As summarised in the previous chapter, several types of movement can be measured by specialised instruments.

Stresses, stress changes and displacements must be measured to monitoring soil-structure interaction.

Several monitoring measurement systems can be distinguished for the measurement of displacements and deformations, which should be combined to design each monitoring system.

The displacement and deformation monitoring system group:

1. Survey based monitoring system: conventional survey based movement measurement is suitable for measuring buildings, nodes with appropriate frequency. The result of the measurement is the displacement in X,Y,Z direction of the measurement point. In the case of an automatic measuring station fixed measuring points are installed. Measurement with an automatic measuring station gives a real-time result of the position of the measuring points in the X,Y,Z direction. We also include satellite displacement measurements, which can control the position of predefined fixed points on structures.

During the measurement, the fixed measurement points must be freely visible. That is, the measurement can only be carried out outdoors. Indoor use is not possible. Measurement results are subject to a manufacturer's specified margin of error and processing time, which can sometimes be several days.

2. Non-survey based motion measurement: the principle of non-survey based motion measurement works on two basic principles:
   Tilt measurement based on the displacement of a level to determine the displacement of structures and structural elements from the water level. The displacement from the water level determines the position of the structural element under test. The tiltmeter or liquid levelling system is a device based on the displacement of a level, which can measure the deformation or tilting of a structure after it has been installed in a horizontal position. All of these devices provide real-time measurement results.
   Displacement measurements based on changes in distance, where the change in distance between fixed structural elements provides the basis for the displacement value of the structural elements.
3. Geotechnical-based movement measurement: geotechnical movement measurements can detect displacements in the ground environment or in underground structures, such as expected settlement, slope slides, possible dam failures, sooner than their actual occurrence, since these processes are the consequence of the shear strength depletion of the soil environment. The stress and strain changes in the soil environment are determined on the basis of the measurement. Based on this information, the deformation and failure of the soil environment ("surface settlement", " slope slide", etc.) can be predicted. As a consequence, a continuous monitoring system significantly increases the safety of a given construction technology. This includes inclinometers, extensometers, all of which can provide real-time measurement results.
4. Laser scanner: The continuous development of computers allows the spread of laser scanners and the expansion of their field of application. There are no restrictions on the frequency of the survey. The disadvantage of the survey is that the device has to be installed in a fixed position in indoor spaces, in case it is used for real-time motion measurement. As a result, a separate installed laser scanner is required in each survey room, which has a significant cost implication.
5. Optical cables: motion measurements with optical cables are a significant trend in the registration of movements and displacements, which no longer only give good results in research, but also prove their proper functioning at actual test sites. The measurement is based on the variation of the speed and quality of the signal transmitted by the optical cable in the receiver unit. Since the wavelengths are precisely defined for each cable, the wavelength variation can be detected even with minimal displacement or deformation, which gives the displacement of the structure on the order of micrometers. The direction of measurement is significant and is constantly evolving. The results provided by the measurements are real-time.

7. ELEMENTS OF THE STRESS MEASUREMENT

In addition to deformation and displacement, the other major area to measure is stress measurements.
To determine the stresses in the soil mass, the pressure cell can be placed individually, or borehole pressure cell system can be used. The borehole cell continuously records the pressure in the soil environment at 45° offsets over 360°, thus allowing the determination of the stress ellipsoid in the soil, i.e., the actual stress field. In all cases, the evolution of displacements and deformations is preceded by a change in the value of the stresses. In other words, stress changes in soils predict the expected displacements in the soil mass, their direction and their value.

The stress values in soils are used as a baseline for the displacements in soils. Both the individually placed pressure cell and the borehole cell can provide real-time results and can be used as part of a real-time monitoring system.

Accurate determination of the stress field in the soil is complemented by a piezometer, a monitoring device for measuring the pressure caused by groundwater, which can also provide real-time data. The three instruments, the pressure cell, borehole cell and piezometer, can together measure the stress field in the soil at the measuring point in 360° in X,Y,Z directions, giving an accurate picture of the soil stress.

In order to continuously analyse the soil-structure interaction, it is worthwhile to install monitoring elements for the direct measurement of stresses in new structures under construction during the design and construction phase. These structural stress gauges can also be placed on existing structures to monitor the effect of stress increments on the existing structure.

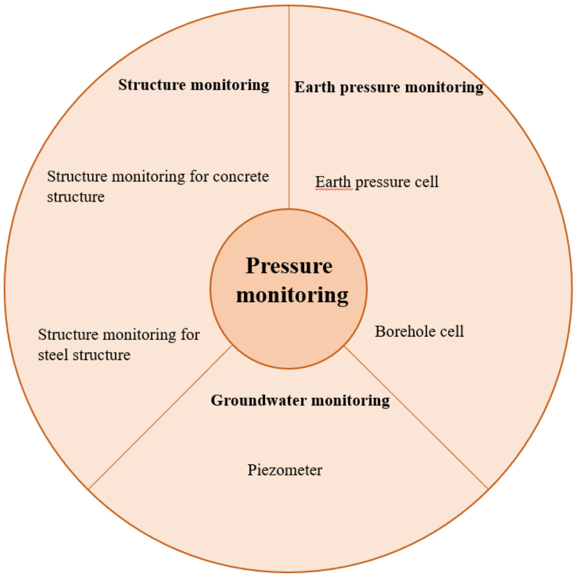

Figure 3 Stress measuring instruments [own figure]

In other words, for existing structures we can determine stresses indirectly. A stress measuring device placed on the test section of concrete structures can determine the stress values acting on the structure from displacements between two fixed points.

Measuring devices can also be fixed on steel structures. As in the case of concrete structures, it is also possible to determine stress values indirectly from displacement measurements for steel structures.

In both cases, the frequency of measurements can be determined and programmed. Real-time measurement results can be determined with the instruments.

8. DATA MANAGEMENT, APPLICATION AND ALERTING

The consistent management of some measurement tools is essential for setting up a real-time monitoring system.

The measurement results of each measuring instrument must be compiled in a single interface, at a uniform scale and in a single system, so that safe, informed decisions can be made when evaluating the measurement results obtained.

The data measured by the measuring instruments must be transmitted to a central datalogger, which collects all the results and sends them to the central secure server. The measurement results are stored here and the evaluation and display are synchronised.

International practice shows that the data measured by the monitoring system are stored on 3 independent protected servers.

One of the 3 protected servers is owned by the Client, the other by the Contractor and the third by the Independent Operator who operates the monitoring system.

The data stored on the servers can only be modified by entering a simultaneous authorisation password.

When designing the monitoring system, it is essential to define the criterion levels for each measurement point of the building that will serve as milestones for the operation of the monitoring system. In the case of an existing installation, it is important to note that the recording of the "0" condition is considered as the critical activity. Therefore, a significant period of test operation of at least 1 year is required, which corresponds to the recording of the "0" state before the actual construction works start. The reason for the one-year interval is to record the temperature and groundwater periodicity accordingly.

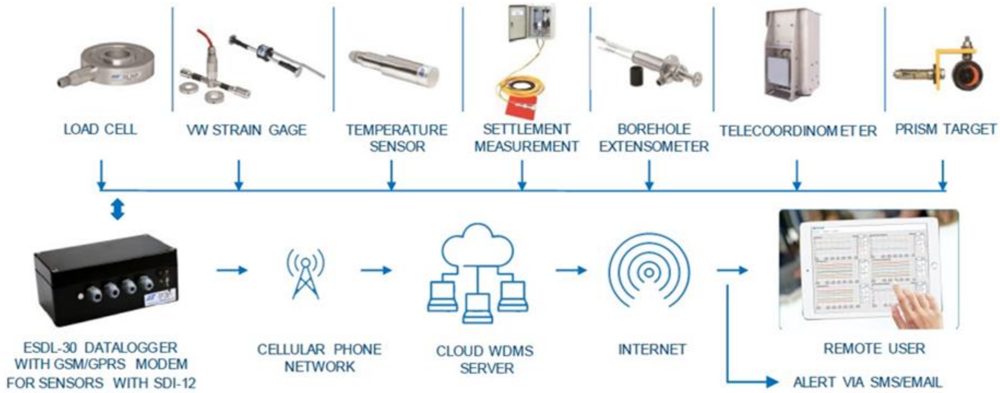

Figure 4 S Transmission, display of measured results [17]

By thoroughly defining the "0" condition and the associated temperature and groundwater cyclicity curves, the level of false alarms can be minimized. The results are displayed on a geoinformatics system prepared for the study facility.

For each measurement type and point, the specified alarm levels shall be indicated.

When the alert levels are reached, the geoinformatics system shall issue an automatic alert.

The elements of the monitoring system shall be defined in such a way that their measurement results can be managed in a geoinformatics system.

9. CONCLUSIONS

Safety is the highest priority for nuclear installations and must never be compromised. However, construction-related risks can occasionally lead to unforeseen events that may jeopardize nuclear safety.

To mitigate these risks, real-time monitoring must be implemented for all interventions and construction activities across the entire nuclear facility. This includes geotechnical monitoring and the tracking of structural movements during construction.

All components of the monitoring system must be mutually compatible, and their data should be managed within a centralized geoinformatics system. The monitoring data must also be integrated into a unified alert system, with clearly defined Action Plans corresponding to each alert level.

For any risk items that retain a medium to high risk level even after mitigation measures are applied, it is recommended to prepare a supplementary safety Action Plan. Intervention strategies should be developed as part of the monitoring plan, since certain safety measures may require additional instrumentation, which should be incorporated into the overall monitoring framework from the outset.

Because structural movements typically lag behind ground movements, geotechnical monitoring is essential for maintaining and improving safety.

An integrated monitoring system is a critical element of both nuclear facilities under construction and those already in operation. Such a system enables the early detection and control of any triggering events, ensuring safe operation throughout the facility’s entire lifecycle.

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