Qualification program of an instrumentation system for measuring nuclear power plant settlements

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1 INTRODUCTION

A level indicator system was installed in 1984 at the Caorso Nuclear Power Plant, for automatic and remote monitoring of foundation settlements.

Before discontinuing previous optical surveying activities, a qualification program was developed to validate the continuous records provided by the level indicator system. Some of the results of this program, presently under way, are presented herein, i. e. the comparison of the automatic and optical settlement data, and the geotechnical evaluation of the maximum settlement recorded by the system during the 1985 refueling of the plant.

The level indicator system is finally shown to provide a basis for the development of an expert system that can perform an automatic, continuous and real-time foundation safety control of the plant.

2 SITE INFORMATION

The Caorso Nuclear Power Plant, with an 880 Mwe BWR (Mark 2) reactor, is the largest in activity in Italy and is in operation since 1981. Plant construction started in 1971 at a Po river valley location 70 kilometers east of Milan. The ground level, initially at El. +41.5 meters, was raised to El. +48.0 meters in an area of about 300 by 500 meters by a fill. The plant layout is presented in Figure 1.

The design soil profile (Figure 2) presents (from the surface) a top clayey layer, removed during construction, an alluvial sandy gravel layer of about 18 meters thickness (Formation B), a silty clay layer of about six meters thickness (Formation C), and dense sand and gravel layers down to large depth (Formation D). Several layers of clay of various thickness can be distinguished in Formation D.

From an hydrogeological point of view, the subsoil comprises two acquifers: an upper one (Formation B) with piezometric level around El. +40.0 meters, and a lower one (Formation D) where the groundwater table has an average value around El. +39.0 meters.

Foundation elevations for the Main Buildings were more than seven meters below the average groundwater table in the upper acquifer, and dewatering activities were hence required for construction. The dewatering system consists in a plastic diaphragm of cement-bentonite,

deepened to Formation C, and deep wells operated inside the diaphragm.

3 OBSERVED AND PREDICTED SETTLEMENTS

The heavy buildings of the plant and the massive soil embankment have produced large settlements. The settlements measured at four monuments on the Reactor Building foundation are shown in Figure 3 and indicate an average of approximately 35 centimeters. The average settlements of the other buildings vary in the range 20-35 centimeters.

Only five centimeters of settlement have been recorded since June 1977, after the end of construction activities, and the settlement trend (Figure 3) is due to the consolidation of the cohesive Formation D4, as confirmed by the almost uniform average settlement of the plant buildings.

An additional few centimeters of settlement are predicted for the next 30 years. The long-term settlements predicted for the four monuments of the Reactor Building are shown in Figure 4: the settlement data have been back fitted for a period of nine years, adopting the methodology outlined in a companion paper (Biondani et al., 1987), and the long-term settlements have been forecasted through a statistical analysis of the results.

4 AUTOMATIC INSTRUMENTATION SYSTEM

A system of level indicators has been recently installed on the Main Buildings of the plant to monitor in a continuous and automatic way the settlements of the foundations. The system was already presented in detail (Mirone et al., 1985), and only its main features are summarized in the following.

The level indicator system is based on the principle of communicating vessels and gives electrical signals proportional to the elevation difference between the vessels (CISE, 1985). Each level indicator consists of a cilindrical vessel in which the position of a float, balanced by a counterweight, is indicated by an agular transducer mounted on a pulley (Figure 5). The level indicators are connected by horizontal channels.

Series of instruments installed at various buildings can be related to one another by adjacent pairs of instruments, and a vessel placed on a fixed benchmark, founded on a pile, allows direct monitoring of absolute settlements. The signals of the transducers of the 32 instruments (Figure 6) are conveyed to a central reading unit located in the control room of the plant.

The level indicator system is integrated by a remotized and automated piezometric system of Casagrande and Wellpoint piezometers, installed at El. +10.0 meters in Formation D and El. +24.0 meters in Formation B.

5 QUALIFICATION PROGRAM

Before discontinuing optical survey activities, a qualification program has been undertaken and is presently under way for purposes of validating the new automatic system.

Settlements measured by both optical survey and automatic level indicators are related to a single point on which a monument and a level indicator were installed. The results obtained up to now have indicated a good comparison of the two sets of settlement data.

Figure 7(c) presents the comparison for the Reactor Building between the weekly level indicator records (shown as lines in the diagram) and the monuments readings, available on a three-month base (shown as symbols in the diagram).

A similar comparison was performed with reference to a parallel optical survey conducted in the second half of 1985. Some results are presented in Figure 8 for different locations on the Diesel and Reactor Buildings.

The level indicator system has also provided continuous settlement records during the refueling of the plant that occurred in the same period. Comparison with numerical settlement predictions has indicated the accuracy of the level indicator system for settlement monitoring.

The numerical evaluation has been performed using D'Appolonia in-house computer program DAPSET. The soil profile used in the analysis is a simplification of Figure 2. The soil properties have been correlated to the results of in-situ investigations and to literature values. The settlement obtained in correspondence of the filling with water of the Reactor Building pools, resulting in the load diagram shown in Figure 7(a), was estimated of the order of 4 millimeters: the highest settlement readings during September-October 1985, then recovered in December (Figure 7(c)), reflects this prediction.

Oscillations in level indicator records are due to movements of the piezometric surface inside the diaphragm, as an effect of dewatering activities.

This issue is evident in Figure 7, where piezometric levels are compared to settlement values: piezometric levels inside Formation B (Figure 7(b)) show an average value around El. +31.0 meters, and the amplitude of oscillations produce consistent fluctuations in the level indicator records (Figure 7(c)).

The qualification program was based so far on available measurements in a period of about one year, starting from mid-1985.

The qualification program will support the validation of settlement data with an analysis of possible relations between load variations and foundation tilts, and with a statistical correlation between groundwater levels and level indicator records.

6 EXPERT SYSTEM FOR SITE CONTROL

The automated instrumentation systems described in Section 4 provide information on the geotechnical behavior of the site in the form of a large amount of data. Thus, data interpretation and decision making are of major concern in the monitoring process.

The interpretation of stored data leads to an evaluation of the site response to changes in loads and groundwater levels, comparing the actual behavior of soil and structures with the design assumptions, and updating the design predictions, if necessary.

These tasks can be performed by the use of Knowledge Based Expert Systems (KBES), computer programs able to solve complex problems not only using algorithmic procedures but also heuristic, decisional

factors and a wide and specialized knowledge (Cremonini et al., 1986). In developing a decision process, KBES's use models of human reasoning, thus applying to the problem typical artificial intelligence techniques.

By using knowledge derived from theoretical analyses for the evaluation of the time-related settlement and from the continuous monitoring of groundwater levels, the KBES may judge if detected value match the expected behavior. Whenever the response is negative, the KBES states the amount of the mismatch and performs a search of possible causes. Finally, it plans about the actions which should be taken to restore the design situation. Such a system is under development for the subject site.

Figure 9 shows a flow chart of the typical activities related to instrumentation monitoring applications, and the aspects handled by the expert system under development.

7 CONCLUDING REMARKS

The qualification program developed for the automatic system for continuous control of foundation settlements installed at the Caorso Nuclear Power Plant has been presented.

The qualification program, started in 1985 and presently under way, has allowed a preliminary validation of the level indicator records. This instrumentation system, together with the remotized piezometric system, represents a relevant example of geotechnical data monitoring and processing.

The concept of an expert system to integrate the monitoring system for a real time control of the site behavior has been introduced; such a system is presently under development for the site.

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Cremonini, M. G., G. Ferro, R. D. Jenkins and G. Righetti, 1986, "Applications of Monitoring Systems in Structural and Geotechnical Engineering", 2nd ICOSM, Venice, Italy.

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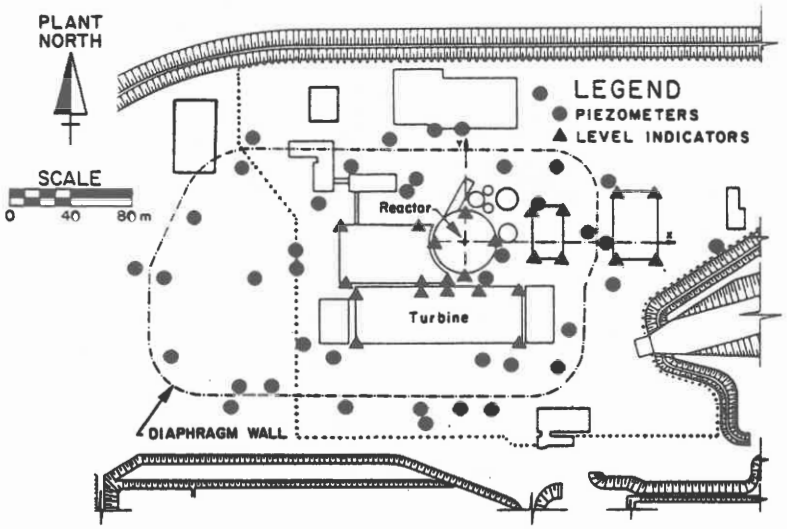

FIGURE 1 - PLANT LAYOUT

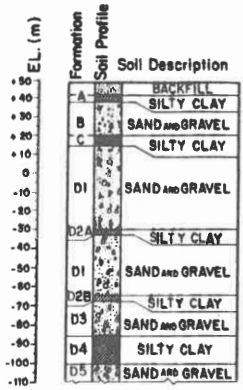

FIGURE 2 - SOIL PROFILE

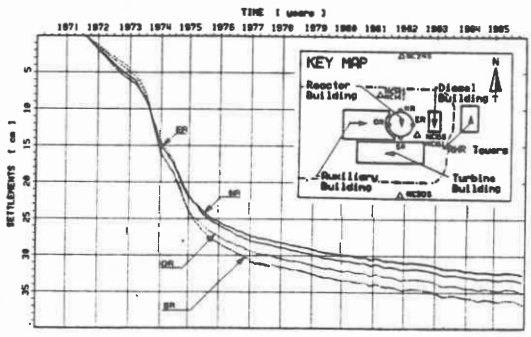

FIGURE 3 - OBSERVED SETTLEMENTS

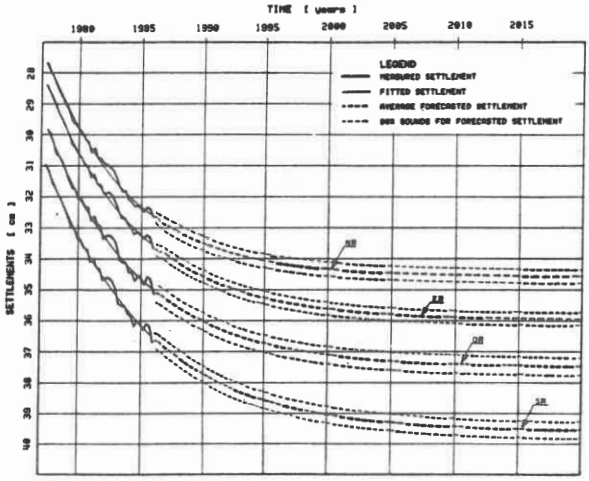

FIGURE 4 - PREDICTED SETTLEMENTS

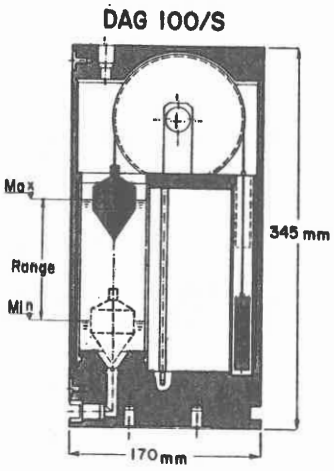

FIGURE 5 - LEVEL INDICATOR

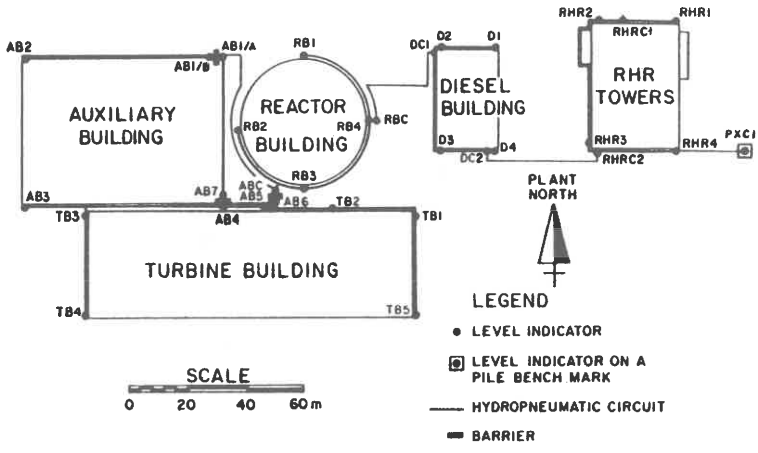

FIGURE 6 - LEVEL INDICATOR SYSTEM LAYOUT

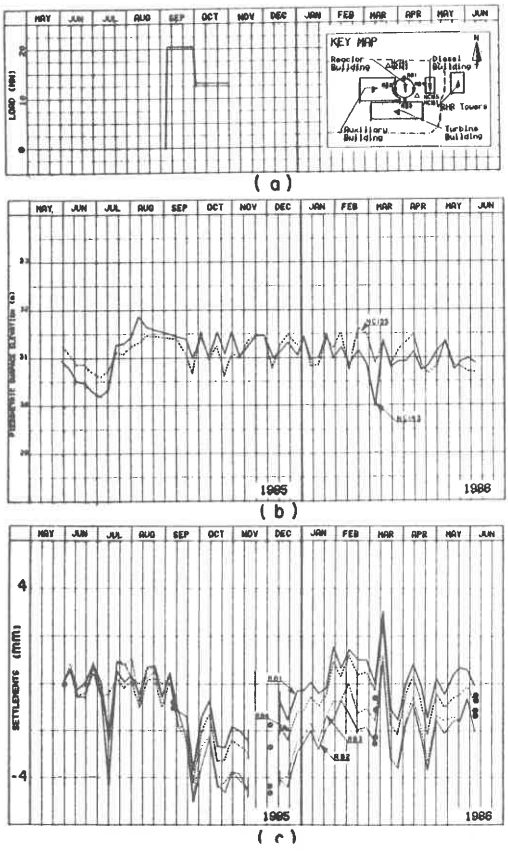

FIGURE 7 - COMPARISON OF SETTLEMENT MEASURES (c) WITH REFUELING SURCHARGES (a) AND PIEZOMETRIC LEVELS (b)

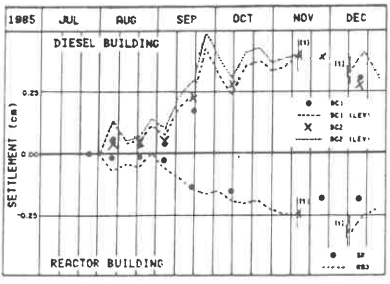

FIGURE 8 - COMPARISON OF SETTLEMENT MEASURES

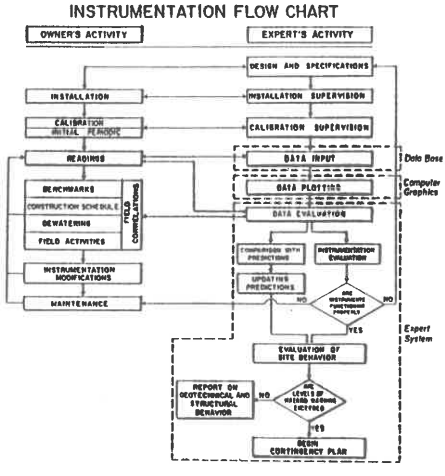

FIGURE 9 - ACTIVITY RELATED TO INSTRUMENTATION MONITORING (AFTER CREMONINI ET AL, 1986)