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Static Reliability of Concrete Structures under Extreme Temperature, Radiation, Moisture and Force Loading

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ABSTRACT

The contribution presents some aspects of the static reliability of concrete structures under temperature effects and under mechanical loading. The mathematical model of a load-bearing concrete structure was performed using the FEM method. The temperature field and static stress that generated states of stress were taken into account. A brief description of some aspects of evaluation of the reliability within the primary circuit concrete structures is stated. The knowledge of actual physical and mechanical characteristics and chemical composition of concrete were necessary for obtaining correct results of numerical analysis.

KEY WORDS

Static reliability, primary circuit, concrete structure, temperature and mechanical loading, mathematical model, FEM method

INTRODUCTION

The nuclear power plant Dukovany (EDU) has been in use under reliable operation for more than 15 years. Within the programme Harmonisation which aim is to ensure high-quality and safe operation of this nuclear power plant at least until the year 2025 so for this reason there has been disposed a great number of tasks concerning various areas. Actual static reliability of concrete structures is besides others one of the problem of the power plant building part. Considering the fact that concrete structures have to be functional, safe and reliable for substantial time period after the operation of the nuclear power plant there have been worked out large-scale procedures and models for evaluation of particular - for the nuclear power plant reliability – dominantly important structural parts. The problems of evaluation of the concrete structure reliability are solved from the experimental and theoretical point of view.

EXPERIMENTAL PART

Concretes of the load-bearing structures of the primary circuit are affected not only by the mechanical stress but also by the moisture stress. Moreover, these concrete structures are also subjected to long-period influence of high temperatures during their lifetime. Due to the present temperature and moisture stresses, new crystalline formations inside the concrete structure can develop (e.g. 11 A-tobermorit) and so one part of evaluation works was focused on observations of the actual physically- mechanical characteristics of concrete. The experimental part of the works was especially concentrated on the following areas:

- Determination of the distribution of temperature field on the surface of the concrete structures which serves as the boundary conditions for temperature field (calculated by the means of mathematical models)
- Determination of the distribution of moisture field inside the concrete structures. It is used as the constraint condition for moisture field determination by the means of mathematical model
- Determination of the actual physically-mechanical characteristics
- Determination of the different degradation effects on the concrete structure of the primary circuit.

From the experimental tests of the steel and concrete samples and from the measurement in situ it is evident that

- temperatures of the concrete structure exceed 100^{o} C in some areas,

- the migration of moisture inside concrete demonstrates itself within the time of shut-down, which was found out by comparison of the moisture in the identical areas of the RC load-bearing structure,
- amount of boron was found in concrete by physically chemical tests,
- in the course of the nuclear power plant operation there have not appeared any substantial physically-mechanical characteristic changes of concrete within the observed structures of the primary circuit,
- the appearance of artificial radionuclides in the samples of concrete taken from the structure of the primary circuit was found. The radio nuclide content in the samples is so low that it does not influence the physically mechanical properties,
- the appearance of CSH-gels and 11-A-tobermorit in the samples of concrete that only demonstrates the present existence of the increased moisture and temperature at the time of its origin.

MODELLING OF THE STRUCTURE BEHAVIOUR

Consistently with the observation of the structure behaviour of all blocks of the nuclear power plant it was stated that all EDU blocks were considered as identically thermally stressed and that is why it is not necessary to distinguish the temperature stresses of the individual blocks. The differences of temperature about ±5 C in the extremely stressed areas cannot be considered as substantial.

Radiation loading

The detailed analysis of the radiation influence on the concrete structures reliability was carried out - detailed theoretical summary can be found in [4], [5]. According to the American standard ANSI/ANS-6.4-1985 [6] the radiation influence on the primary shielding is minimal on the condition that the density of the temperature flow of energy does not exceed 10^{10} MeV . cm^{-2} . s^{-1}= 16 W m^2. On the base of our calculations it is possible to neglect the influence of the internal sources of the temperature inside concrete initiated by the radiation on the temperature field values when it is solved by the FEM method.

Moisture loading

Considering the fact of random moisture migration inside the concrete structure, the influence of the moisture expansivity on the state of stress of the structure was neglected at simplifying modelling. Up today, there have not been available reliable time-dependent changes of the moisture during the tests.

Other types of loading

The limiting importance for the state of stress evaluation, function reliability and durability of the concrete structure has the distribution of the temperature field inside the concrete structure and by this generated the state of stress (of course, in the co-action with the mechanical, radiation and moisture stress). That is why we solved the problems relating with

- the specification of a mathematical model of the parts of the primary circuit structures, which are based on:
  1. definition of the boundary conditions of temperature field within the mathematical model of the primary circuit structures,
  2. theoretical analysis of the determination of the concrete structure referential temperature. The aim was to formulate the theory needed and to define the referential temperature field within the solved structures in dependence on their thickness,
  3. final solution of the problem considering the influence of random temperature sources inside concrete initiated by the absorption of neutron radiation and by the gamma emission,
  4. complementation of some missing data relating to geometry, material characteristics and the composition of some structural parts.
- application of the specified model for solution of the particular situation defined after the discussion with the nuclear power plant workers,
- evaluation of the actual static reliability of the concrete structures within the above stated situations.

Model of the Structure

Based on the experimentally obtained data (the boundary conditions of the temperature field), following amendments on the mathematical model of the primary circuit structures were carried out taking into account the comments issuing from the discussion with some EDU departments. Scheme of the used FEM model shows Fig. 1 and 2.

Following calculations were carried out:

- calculation of the temperature field distribution,
- calculation of the state of stress generated by the temperature field in the steady state,
- calculation of the mechanical state of stress under the static load,
- calculation of the total state of stress (under the temperature and static load).

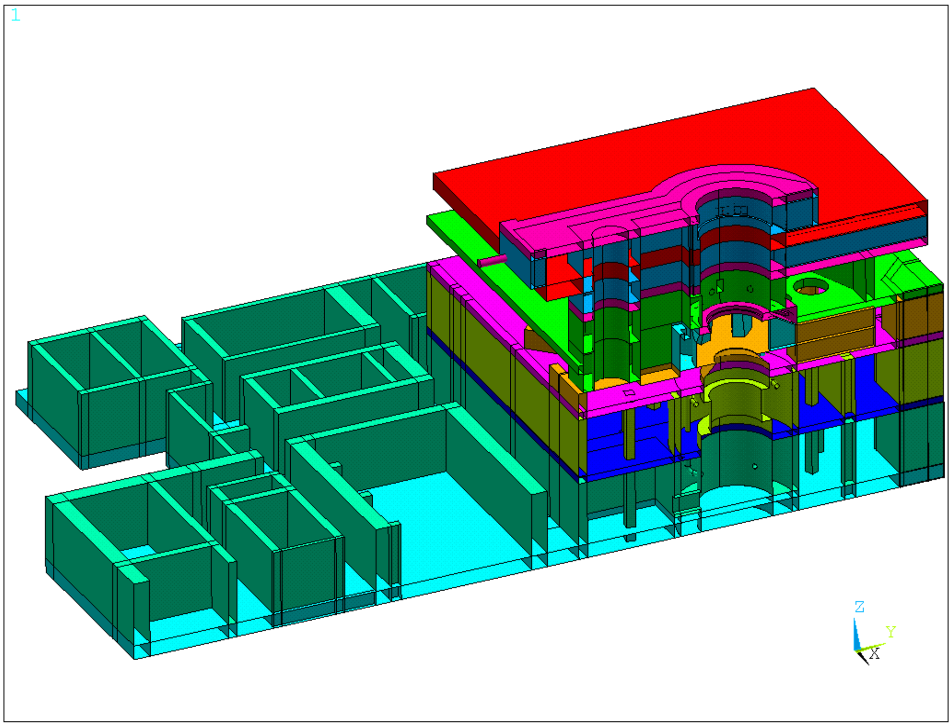

Fig. 1: Scheme of the whole concrete structure for FEM solution

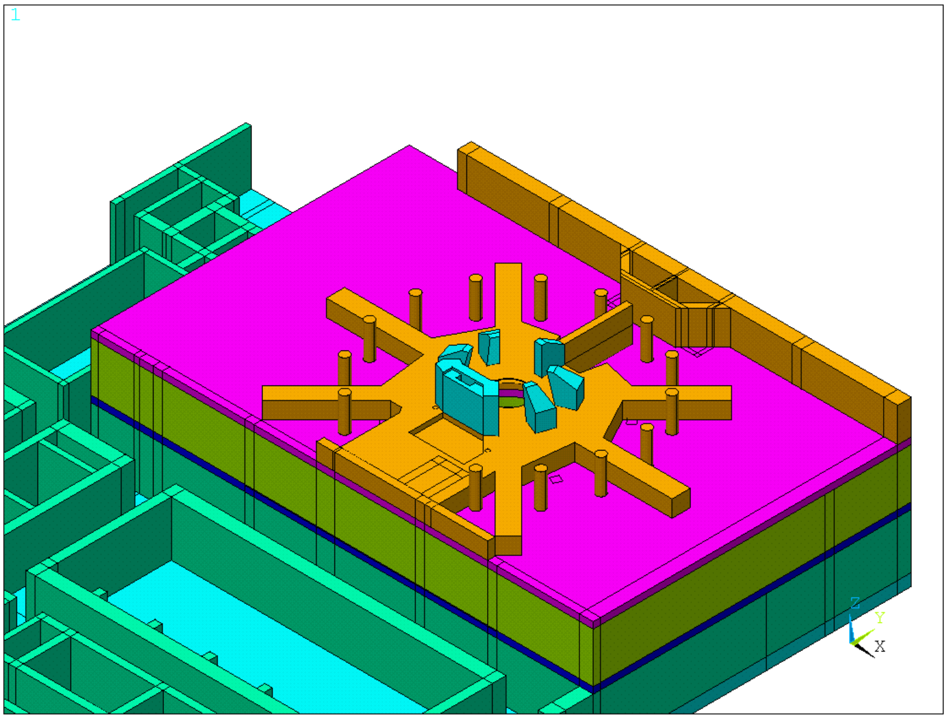

Fig. 2: Part of the FEM model of the structure – extremely stressed cantilevers on the level 7,65 m

The STANDARD design state was solved. This state introduces the standard operating situation that corresponds to the steady time-independent behaviour of the concrete structures during testing procedures when the influence of the reactor starting-up or shutting down operation is not substantial; temperature, radiation and moisture fields are stationary (time independent). This situation is defined by

- the boundary conditions of the measured temperature field,
- the dead load, the technology load (machinery parts loading the structures) and by the boron content of a reservoir,

- consideration of the creep influence on the state of stress generated by the temperature stress (the temperature loading is assumed as the long-terms one).

More information about the input data and solved alternatives are at [1], [2], [3].

The calculated temperature field distribution shows Fig. 3 and the field of principal stress σ_1 generated by temperature loading is in Fig. 4.

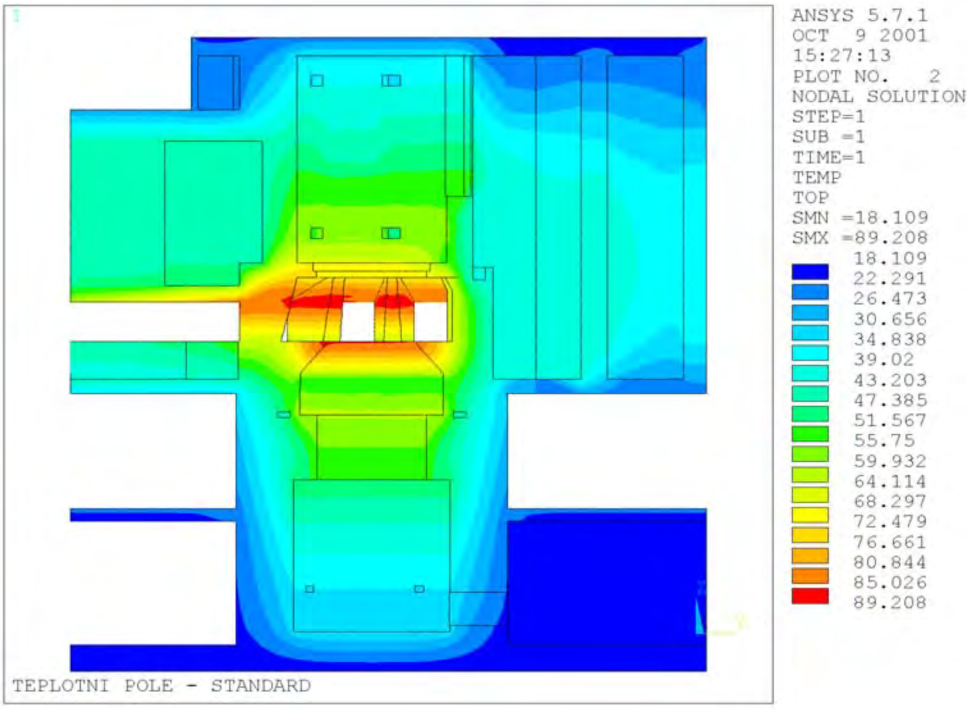

Fig. 3: Distribution of the temperature field on the concrete structures surface

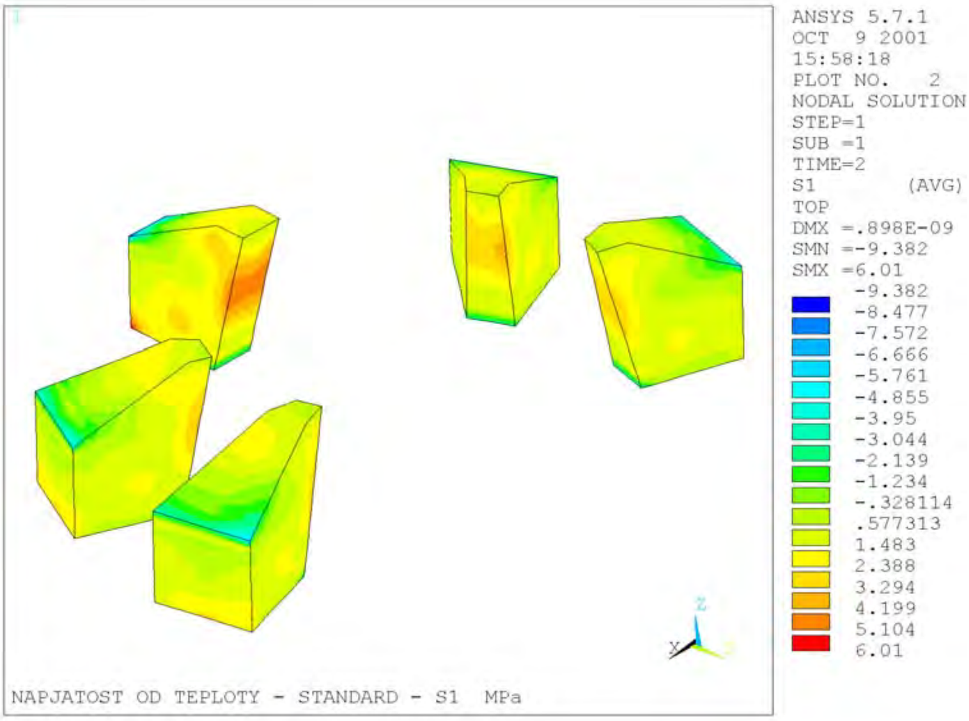

Fig. 4: Distribution of the principal stress σ_1 field on the extremely stressed cantilevers on the level 7,65 m caused by temperature field distribution in concrete structures

The calculated principal stress field σ_3 generated by temperature and force load is shown in Fig. 5.

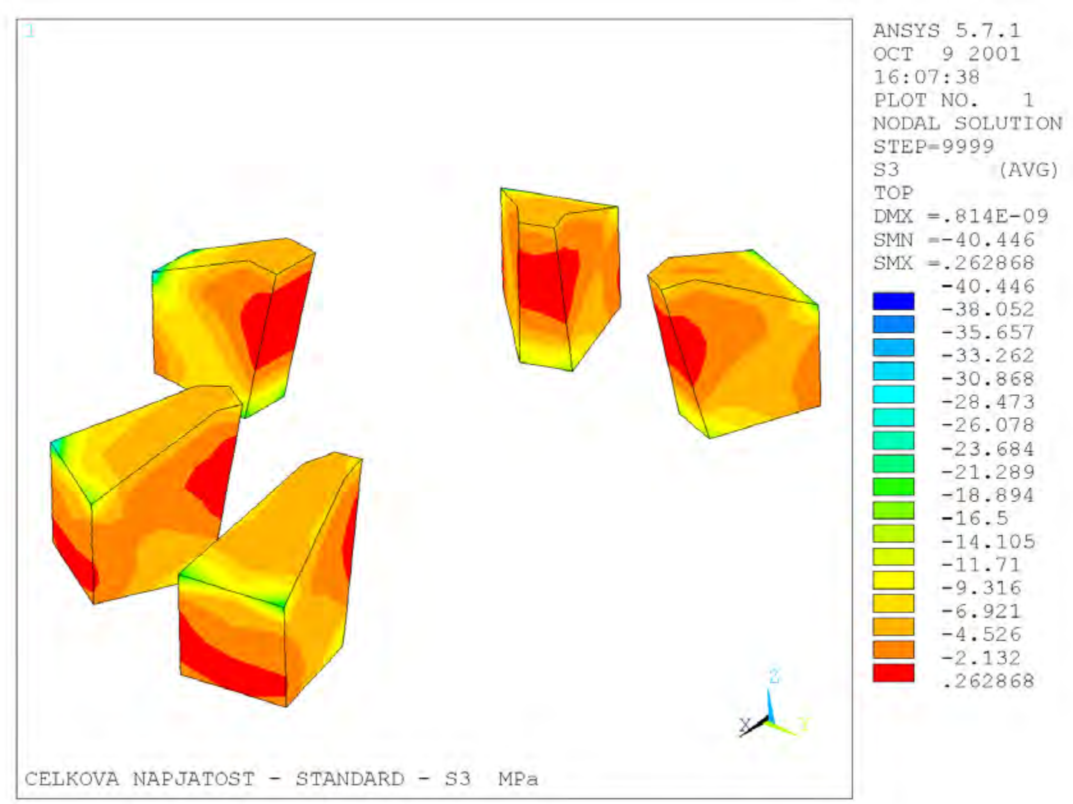

Fig. 5: Distribution of the principal stress σ_3 field on the extremely stressed cantilevers on the level 7,65 m (final state for load case STANDARD – influence of temperature and mechanical loads)

CONCLUSION

From the works that were carried out in the years 1998-2001, which dealt with the problems of the concrete structures reliability on the primary circuit, can be concluded:

- according to the carried out evaluation of the static reliability in accordance with the Czech standard ČSN 731201-86 at the steady temperature operating regime can be stated that all the structural parts meet the requirements of the calculated stresses for the load state STANDARD (dead load + technology + temperature in the steady operating regime)
- satisfactory compliance among the results of the numerical temperature field solution and measured values was found.

The results of numerical analyses can serve as the base for correct computing of time reliability and lifetime prognosis of the concrete load bearing structures.

It was confirmed that the set-up mathematical models would be possible simply to extend for the cases using the simulation method and for evaluation of the concrete structure reliability in which some of the input data are considered as random. At present, input statistic data are being gathered for application of these models. But the substantial complication may be – regarding the solved task extension- the time consumption of the calculation, but even this problem can be solved – [7], [8]. Application of the non-linear modelling is another sphere of the result accuracy specification.

Even though the concrete structures are extremely stressed by mechanical, temperature, moisture and radiation load, they must be highly reliable not only during the nuclear power plant operation but also after its closure. Therefore it is important and necessary to monitor regularly actual reliability of the structures and evaluate their durability. With the help of mathematical modelling is possible to verify and evaluate current or predicted reliability of the concrete structures; the modelling uses physically mechanical characteristics obtained from the monitoring and from accelerated loading of reference samples in time.

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