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Creep of Pre-stressed Concrete Containment – comparing Measurements to Calculations

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ABSTRACT

The contribution is devoted to the comparison between the measured and calculated deformations and their changes in time of the containment structure of the Temelín NPP 1st and 2nd block. The two Temelín NPP blocks are of the VVER1000 type, containment consists of a pre-stressed reinforced concrete structure with a system of unbonded cables. The pre-stressing of the structure is important in terms of safety. Four independent measuring systems have been installed in the structure for monitoring the condition of pre-stressing, which measure strain, stress and pre-stressing forces of the structure in regular intervals. The contribution provides the results of measurements obtained using the systems within the period from the pre-stressing operation up to now. At present, the creep of containment concrete has the largest effect on tension changes. To forecast further developments of the pre-stressing, the calculation was made of the containment creeping, employing the finite element method. The calculation results are put in parallel with the values hitherto measured in the real structure.

KEY WORDS: containment, concrete, shrinkage, creep, power plant, measuring.

INTRODUCTION

One of the most important factors that influence loss of prestress anticipated in the designed prestressed structures is the effect of volume changes in concrete. Volume changes in the concrete may be divided into shrinkage, which is independent of the load, and creep, which depends on the loading. When a new structure is designed theoretical models are usually employed to determine values and time history of shrinkage and creep, based on experimental findings. The parameters and environment of each particular structure is taken into account through input parameters in the model. This contribution deals with a comparison of several commonly used models for concrete shrinkage and creep and also a comparison of calculated results for shrinkage and creep of a specific structure and measurements on the structure. The selected reference structure has been the containment structure of Unit 1 NPP Temelín where long-term measurements have been performed of deformation and prestressing forces.

CONTAINMENT STRUCTURE

The Temelin NPP is formed by two VVER 1000 MW units. The units of the VVER 1000 MW type have a PWR reactor and a containment of pre-stressed reinforced concrete. The containment consists of a cylindrical and a dome part. Connection between the cylindrical and dome parts is made with the help of a rigid ring beam in which the anchoring blocks of pre-stressing cables are placed. The wall thickness of cylindrical shell is 1.2m, the dome wall thickness is 1.1m. The containment structure is placed on the reinforced concrete slab at a level of +13.20m, thickness being 2.4m. This slab contains also supporting blocks of pre-stressing cables of the cylinder which are built-in there. The containment is made of concrete, grade B40 according to the Czech standards (CSN). The tightness of the containment is ensured by the steel liner of a thickness of 8 mm made of carbon steel.

A chart of the pre-stressing method is shown in Fig. 2. The cylindrical part of the containment is pre-stressed by 96 cables running in helical direction. The cable anchors are installed in the upper part of the ring beam, the bending of the cables takes place in the slab at a level of +13.20m. The dome part of the containment is pre-stressed by an orthogonal grid plan of pre-stressing cables formed by 36 cables. Always two cables are conducted against each other, anchors of one cable and bending of the other one are situated on one side. The anchoring blocks are installed from the ring beam side. The cables of the cylinder and dome parts are of the same structure and cross section. Cable preservation was made with grease during production, preservation of anchors was made after pre-stressing. The anchors are protected from climatic effects by means of the sheet covers installed. The pre-stressing unbonded cables are conducted in polyethylene tubes. Every cable is formed by 450 wires featuring a diameter of 5 mm. Low-relaxation wire was used for production, its yield point being 1620 MPa. The initial pre-stressing force according to the design is 10 MN.

The containment function was verified during the structure integrity test (SIT). The test carried out on both the 1st and 2nd units was implemented as a combined test. The function was tested for strength at an overpressure of 460 kPa, the function was tested for tightness at an overpressure of 400 kPa. The SIT of the 1st unit was carried out in 1998, the SIT of the 2nd unit was carried out in 2000.

In order to enable the inspection of the level of the containment pre-stressing, measurement systems are installed permanently on the structure, and these systems measure structure deformations and pre-stressing force in the cables. The measurement is carried out once a month. Inspection of the values measured is carried out at each measurement, a complete assessment is made once a year.

The following measurement systems are installed on the containment:

- NDS and SDM systems – these two systems consist of vibrating wire strain gauges fitted during concrete pouring into the containment walls. The sensors are of four types and measure concrete deformation, temperature and horizontal displacement in the middle of the height of the cylindrical part of the containment. The containment includes more than 240 sensors which are installed in it (246 on the 1st unit and 256 on the 2nd block).
- Hottinger system – this system is formed by strain-wire gauges stuck on the anchors of all cables of the cylinder and of the dome, i.e. 264 anchors measured. The sensors measure force in the anchor of the pre-stressing cables.
- MEM system – the system is formed by the sensors installed on the conduits of the pre-stressing cables. These sensors measure force in the cables by means of the magneto-elastic method. The sensors are placed on two cables of the cylinder and of the dome. The sensors on the dome cables are placed under the anchor and the cable bend. On cylinder cables they are placed under the anchor and at the middle of the cylinder height, on the 1st unit the sensors are installed in the lower part of the cylinder as well.

COMPARISON OF CREEPING MODELS

The containment at NPP Temelín is a standard and uniform one used for VVER 1000 units and was designed under Russian regulations. As part of calculations performed under Czech standards a new calculation was performed of the prestressing system, including prestress losses. In order to specify the effect of shrinkage and creep in respect to the employed concrete mixture, samples were collected in the course of concreting and made into test pieces. The tests pieces were used to conduct laboratory tests for shrinkage and creep values. The size of test pieces was 0.1m*0.1m*0.4m, while specimens for creeping measurements were placed into a frame and pressed by springs to the stress reaching to 30% of the concrete strength.

A comparison of values measured on the samples was performed both for a shrinkage and creep model under Czech national standards (CSN 73 1201 Design of concrete structures) and also under EC (CSN P ENV 1992-1-1 Design of concrete structures) and B3 model. Figures 3 and 4 demonstrate results of creep and shrinkage as obtained from the individual models, as well as results of samples measuring. Environmental parameters reflected the samples placement, i.e. indoor space with 50% humidity. The age of concrete at the moment of loading and the overall evaluated time corresponded to a cylindrical part of the concrete containment on Unit 1 – loading at the age of 1200 days and the overall evaluated time 16 000 days (i.e. ca. 44 years). The dimensions and the load corresponded to the test samples, all cross-section sides were anticipated as free, exposed to drying. The composition of concrete mixture is provided in the table below:

Component	1st Unit	2nd Unit
Cement [kg/m^3]	499	499
Aggregate (all fractions) [kg/m^3]	1700	1700
Water [l/m^3]	215	180

The development of shrinking demonstrates that the highest shrinking values have been reached in measurements of test specimens and B3 model. This is because they were relatively small elements placed indoors and the results were also influenced by the higher quantity of cement than usual for the given concrete class (quantity of cement is one of input parameters of B3 model). On the contrary, the smallest shrinking was found based on calculations under CSN and EC model. The results from the two models have also demonstrated a very good mutual agreement. The development of creep has demonstrated very good agreement between the individual theoretical models and measurements for creep (at the end of period). However, the individual methods provided different results in terms of different times of deformation growth – computations under CSN and EC provided a fast initial growth of creeping deformation followed by stabilization, while B3 model and measurements provided a gradual increase of deformation throughout the structure lifetime.

Figures 5 and 6 illustrate results of calculated shrinking and creeping under the theoretical models under CSN, EC and B3 using environmental parameters of the actual structure. In comparison to the earlier calculations the anticipated humidity was 80%, only one side of the cross-section exposed to drying and cross section area corresponded to a cylindrical part of the containment. In comparison with computations using laboratory parameters the shrinking values significantly decreased (to one half of the original level for EC model, tree times for CSN model and six times for B3 model), while the values of the creep deformation changed only to one half of the original level for all models.

COMPARISON OF COMPUTATIONS AND MEASUREMENTS

To compare results of measurements on the actual structure with the results of theoretical computations a simplified model of the containment has been developed. The model was created in the Abaqus system and it is illustrated in Fig. 7. The cylindrical and dome parts are modelled with shell elements, while solid elements were used to strengthen the structure in at the cylinder fixing and at the connection between the cylinder and dome. Concrete creep was introduced into the model as a visco-elastic material. The parameters of the visco-elastic material were set up using the B3 model for creep which simulates best the behaviour of the actual structure (compared to the other models, this model, similarly as the actual structure, provides a gradual increase of creep deformation). Compared to the actual structure, the models have used the following simplifying assumptions:

- Inlets and openings in the containment concrete wall are not included in the model.
- Prestressing cables are modelled with bar elements firmly connected to the shell wall (in the actual structure the cables are unbonded). The course of the prestressing force along the cable in the model includes losses of prestressing due to friction and changes in the prestressing force due to elastic deformation of the structure during prestressing. However, creep during prestressing was neglected.
- Elasticity modules for the concrete were determined in SIT tests and they corresponded to elasticity of the containment as a whole.
- The effect of concrete shrinkage was modelled as an alternative load with a temperature changing in time, while concurrent creep was taking into account.
- The load was applied once in two steps – loading with its own weight and loading with prestressing.
- The resulting level of deformation was determined as a sum of computed shrinkage, dead loading and loading by prestressing.

A comparison of computation results is shown in Figures 8 through 10. The measured values from 1st Unit containment were used while measurements on 2nd Unit provided similar results. The measured values were represented by average values and min/max of 95% quantile. Results of the computations are shown using two curves for the outer and inner surface. Beginning of s X and Y axes in the diagram has been selected at the end of containment prestressing. Figure 8 shows a comparison of deformation for the top dome section (the figure provides a curve for the circumferential direction, while in the meridian direction it is very similar). The comparison shows a very good agreement between the measurements and computations in the period after prestressing. Deformation from prestressing is lower in the calculation, due to the fact that concrete creep during prestressing was neglected in the computation (prestressing was performed in stages for a period of several months). The development of deformations for the cylinder is shown in Figure 9 (meridian direction) and Figure 10 (circumferential direction). Similarly as with the dome, the computed deformation during prestressing is lower. The computed deformation after prestressing in the circumferential direction corresponds with the measurements very well. In the meridian direction the computed creeping deformation is smaller (both for the period before prestressing , when loaded only with its own weight, and also after the prestressing). This fact will be a subject of further analyses.

CONCLUSION

This contribution seeks to demonstrate differences in individual computation methods for concrete shrinkage and creep and also differences between a theoretical model and behaviour of the actual structure. A comparison between individual computation methods for creep has shown no major differences between the methods in terms of creep values, however some differences were found in the time distribution of values between individual methods for creep computation. A comparison of results for shrinkage has shown differences between the individual methods, both in terms of values and their distribution in time. The size of concrete shrinkage is also strongly influenced by environmental parameters. A comparison of results from a computation model with measurements from the actual structure has shown that concrete shrinkage and creep may be very well described with models based on modern theories of concrete behaviour in time. The only significant deviations have been the lower computed values in the meridian direction on the cylindrical part. Once the deviation is analyzed and incorporated into the computation model the model may be used to analyze future behaviour of the containments of 1st and 2nd Unit at NPP Temelín.

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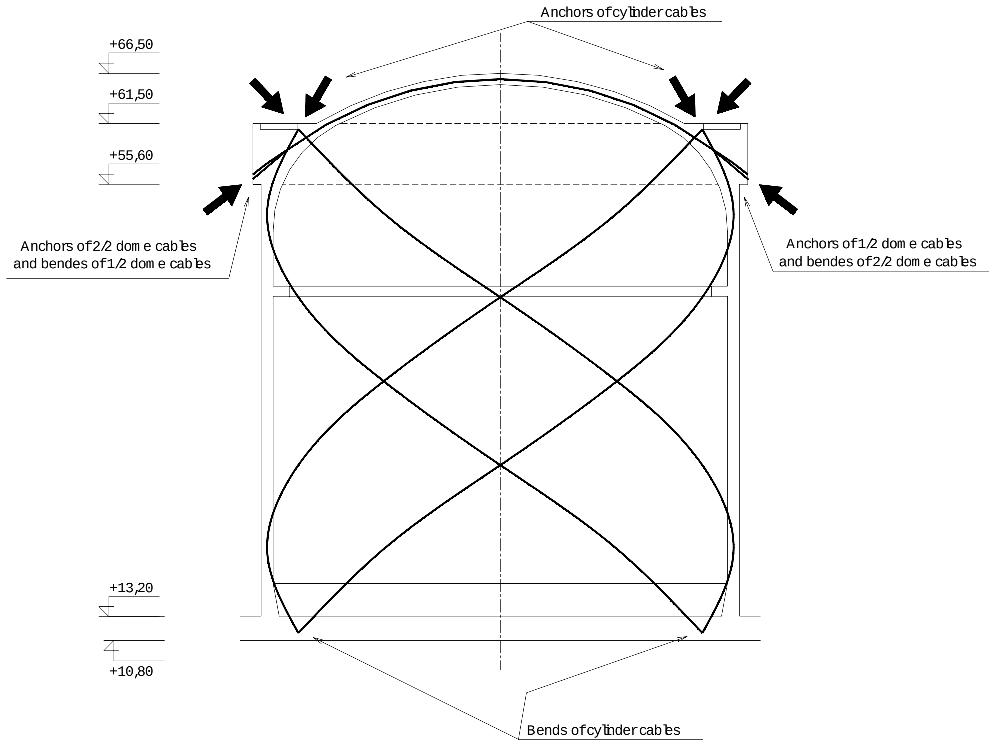

Fig. 1 Scheme of pre-stressing of containment

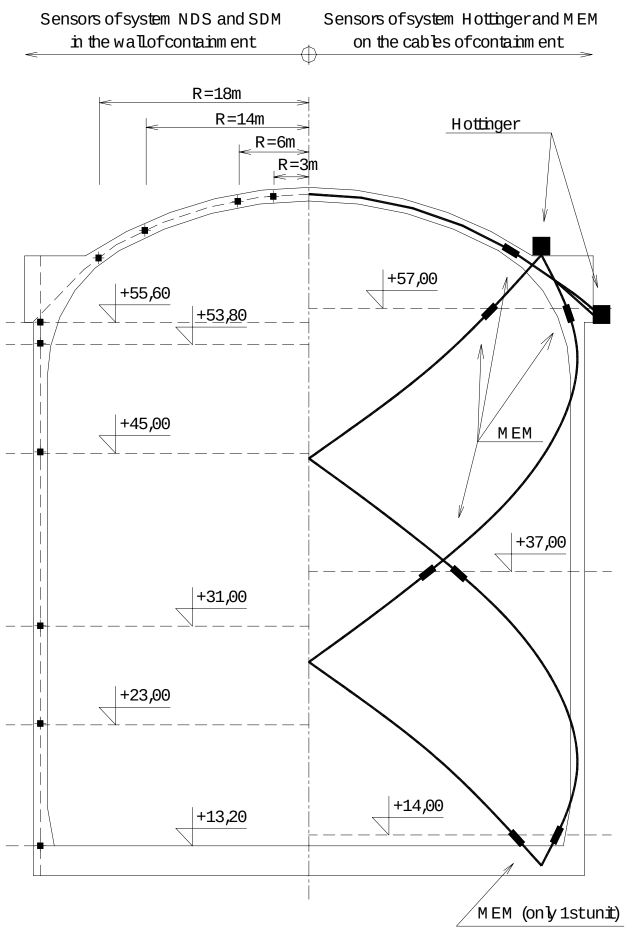

Fig. 2 Distribution of sensors on the containment structure

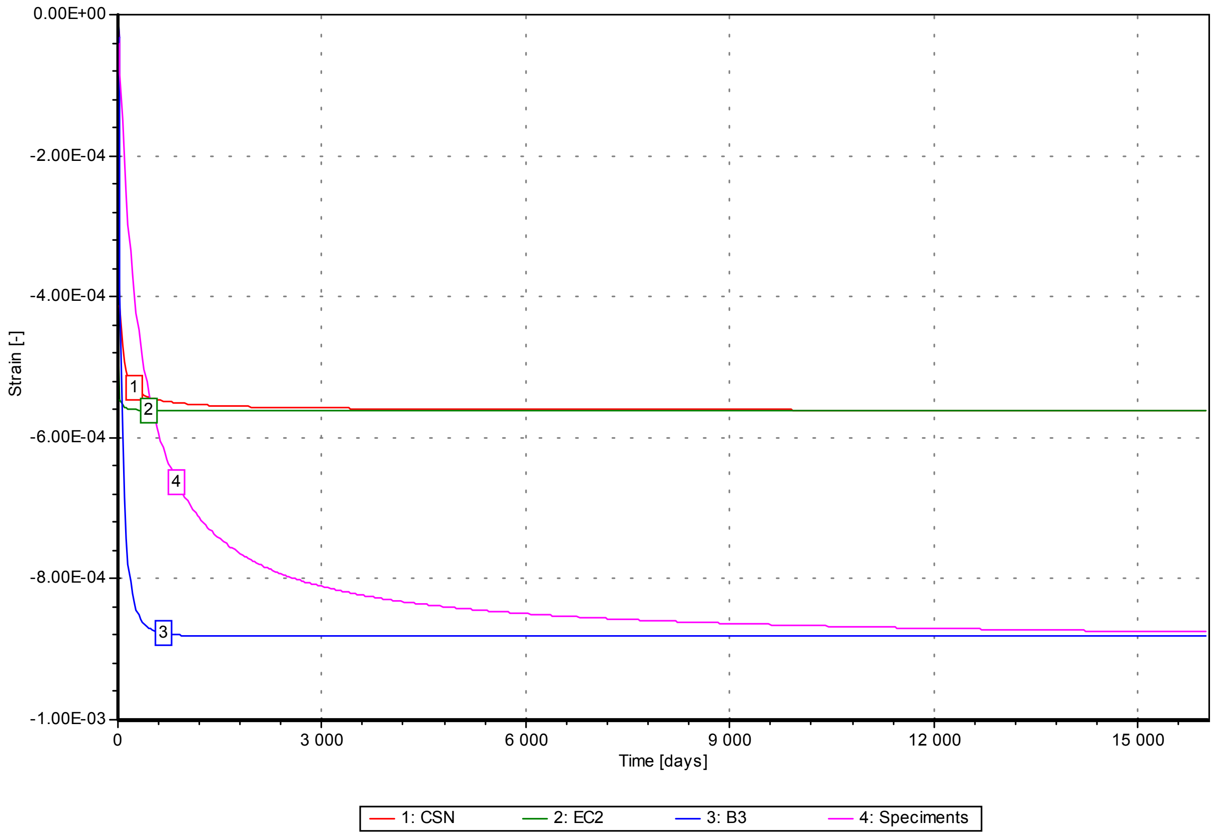

Fig 3. Shrinkage - size and environmental parameters of the speciments

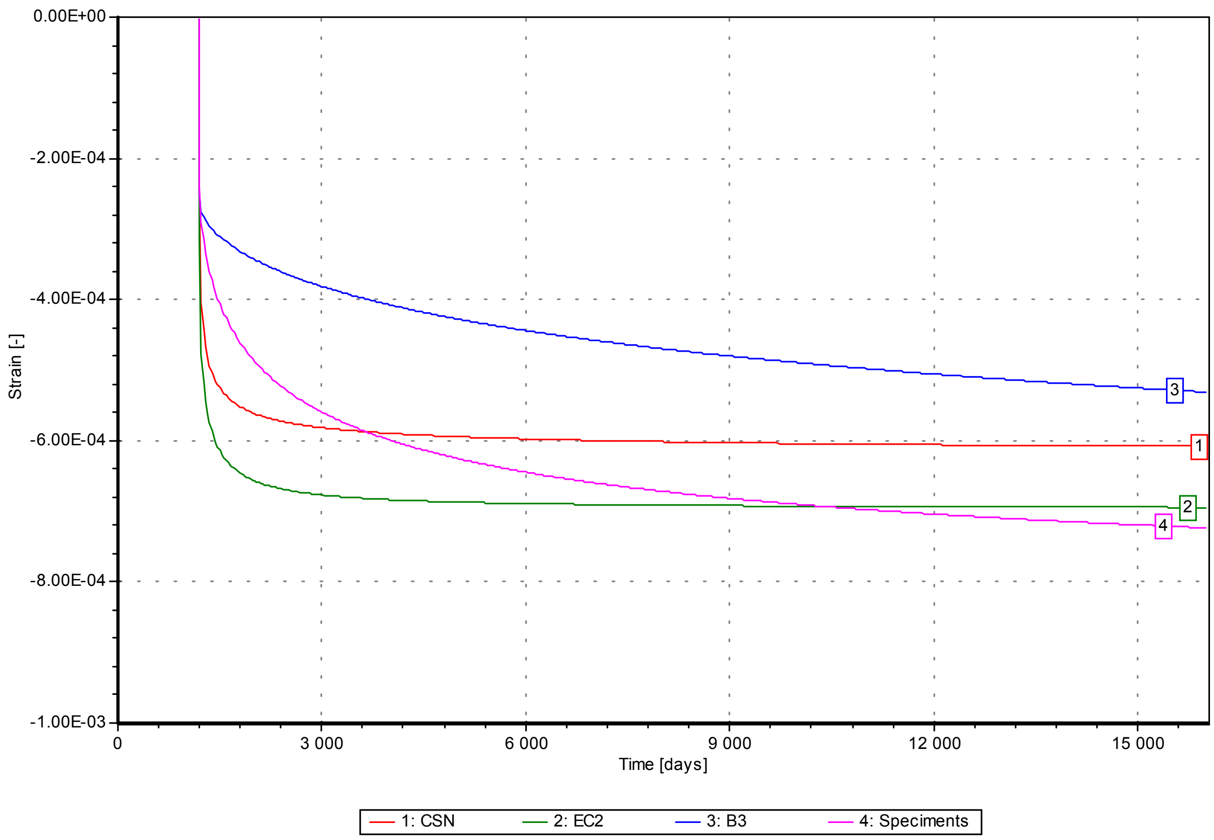

Fig 4. Creep – size and environmental parameters of the speciments

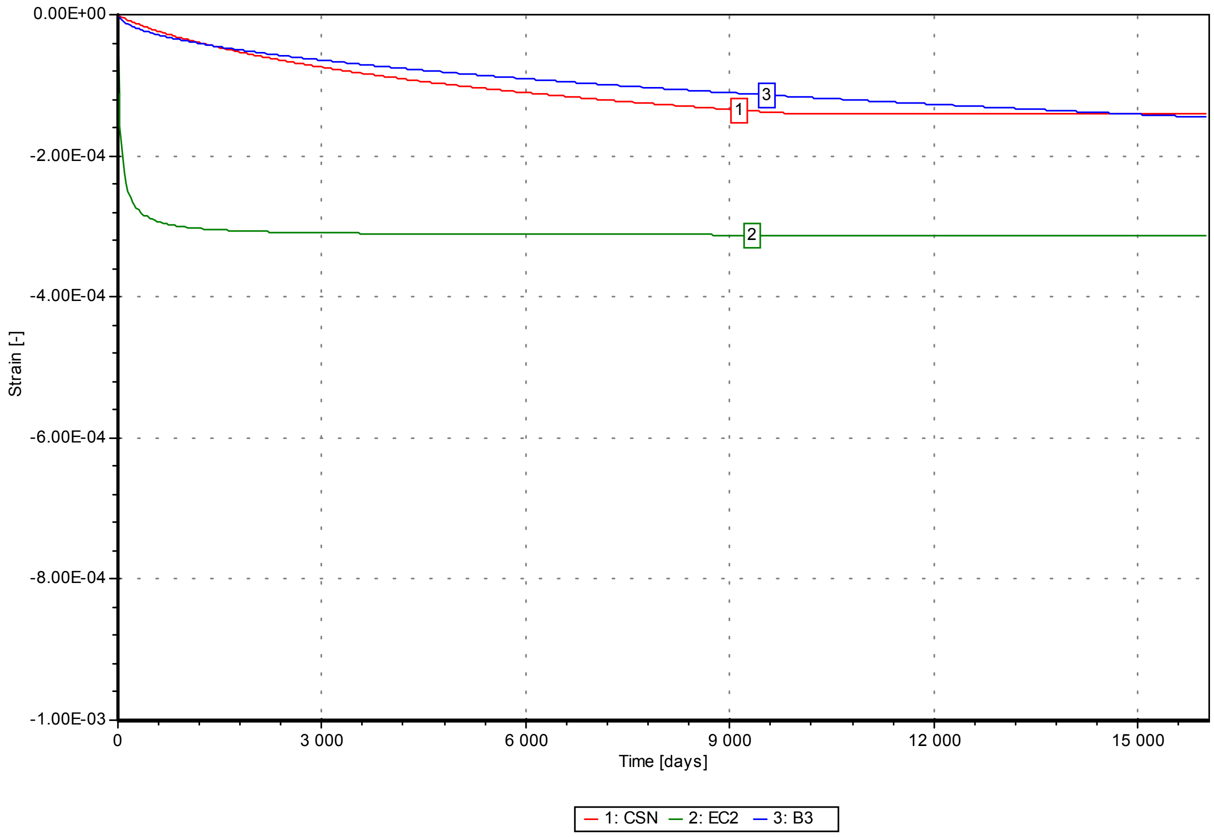

Fig 5. Shrinkage - size and environmental parameters of the actual structure

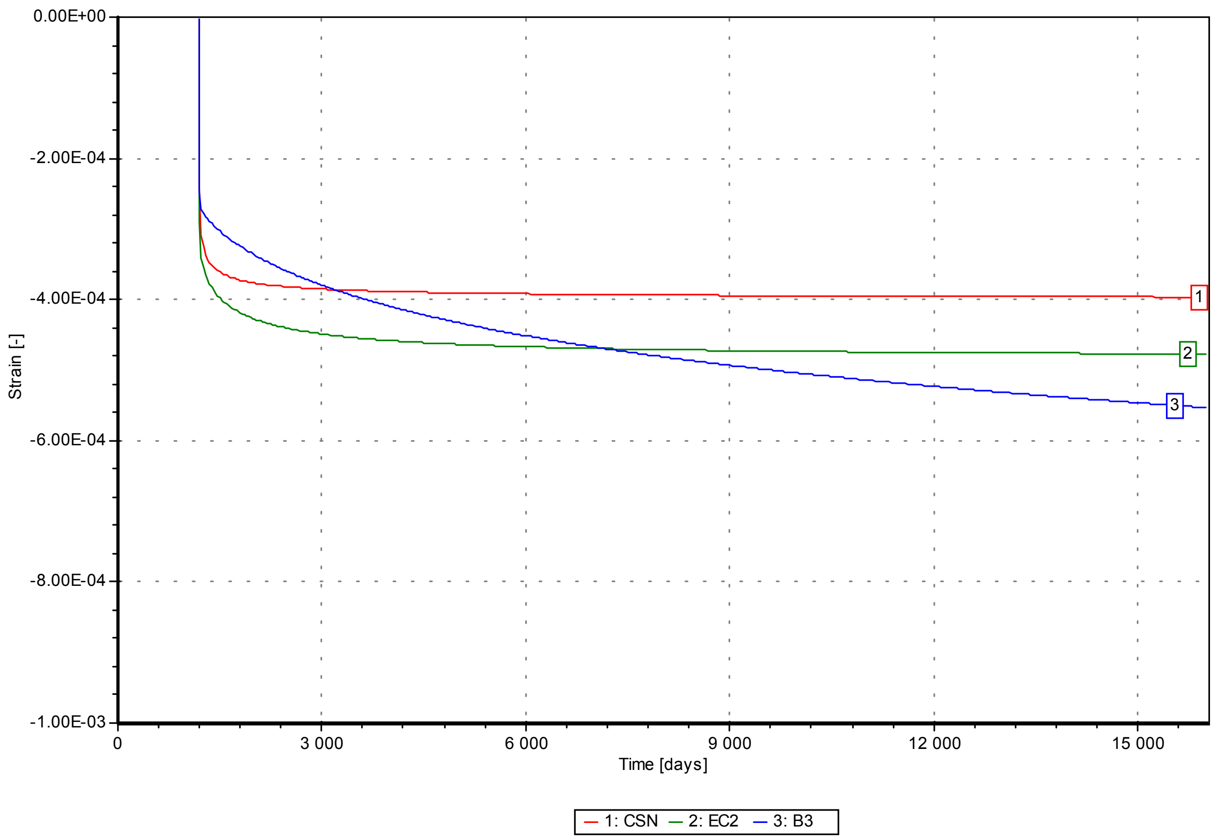

Fig 6. Creep - size and environmental parameters of the actual structure

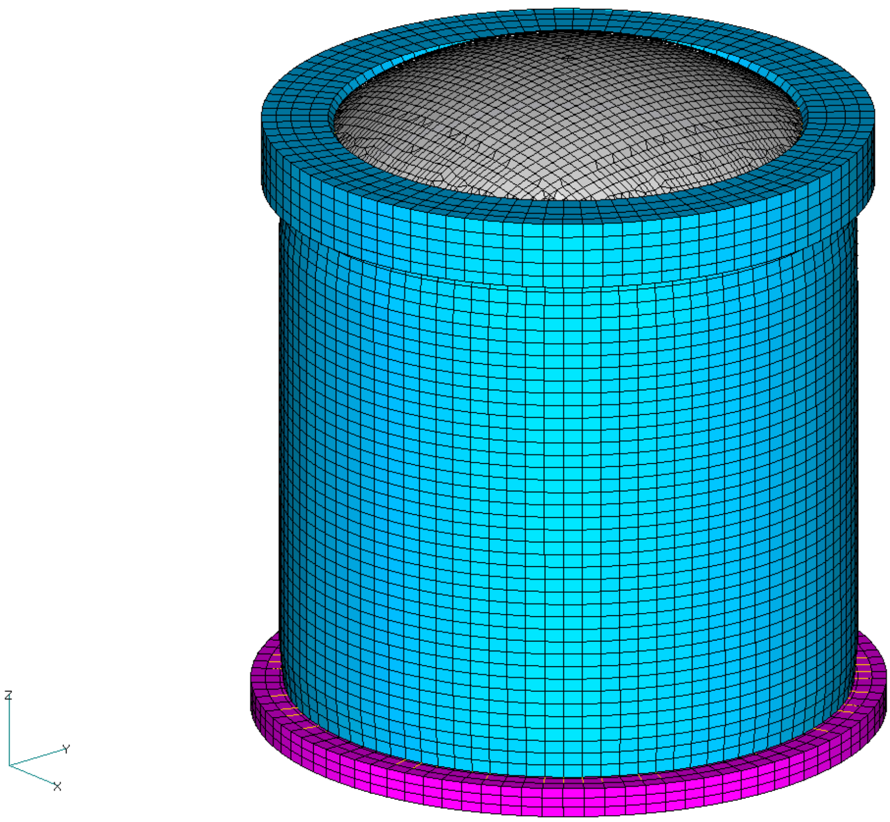

Fig. 7 FEM model of containment structure

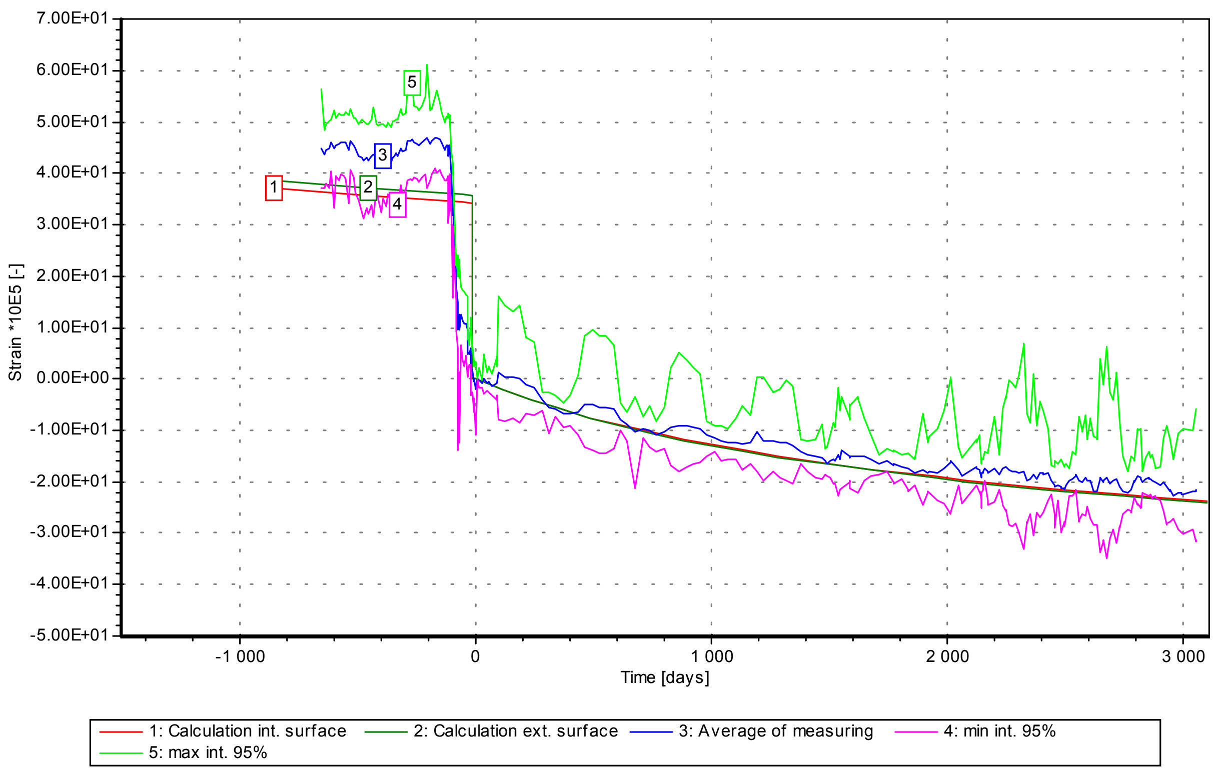

Fig. 8 Strain in the central part of the dome of the containment - circumferential direction

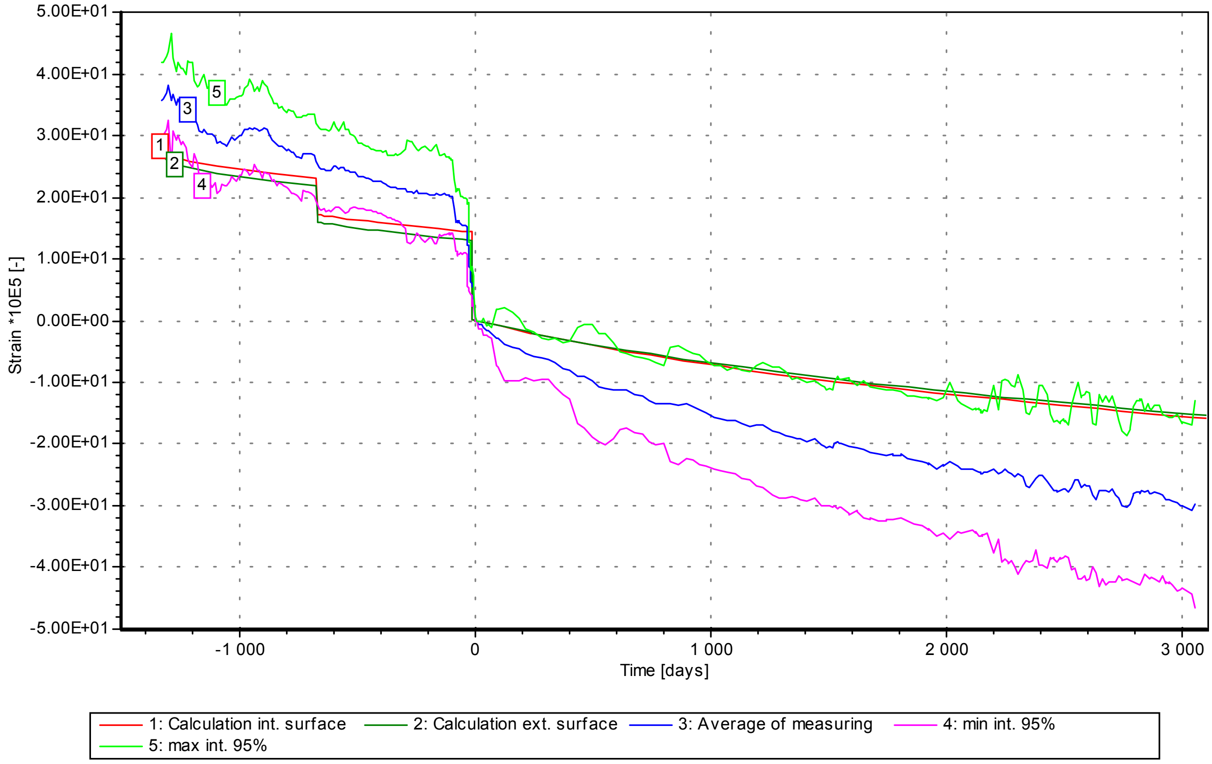

Fig. 8 Strain in the central part of the cylinder of the containment - meridian direction

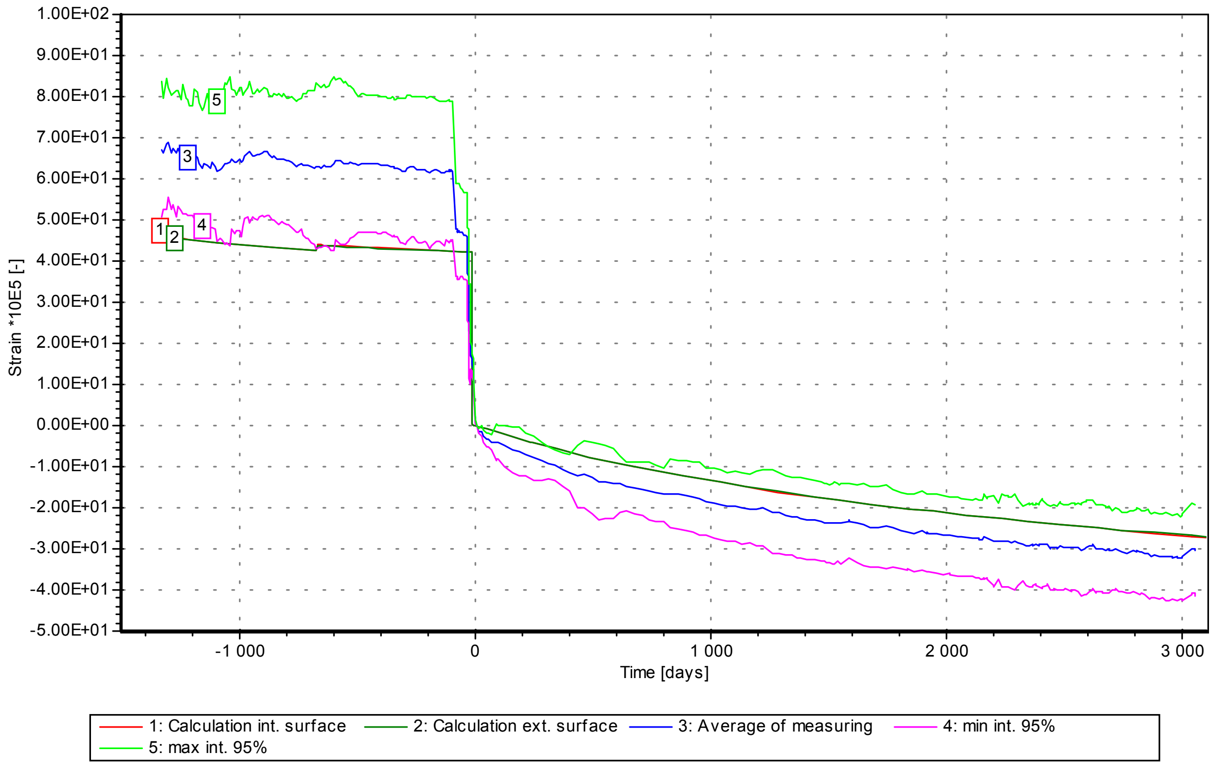

Fig. 8 Strain in the central part of the cylinder of the containment - circumferential direction