| Rudarsko-geološko-naftni zbornik | Vol. 24 | str. 67-71 | Zagreb, 2012. |
|---|---|---|---|

UDC 624.19:539.377
UDK 624.19:539.377

Preliminary communication
*Prethodno priopćenje*

Language/*Jezik*: English/*Engleski*

# THE RESPONSE OF TUNNEL LINING ON THERMAL LOADING

# REAKCIJA TUNELSKE OBLOGE NA TERMALNO OPTEREĆENJE

MARKÉTA LEVOROVÁ, RADEK VAŠÍČEK

*Centre of Experimental Geotechnics, Faculty of Civil Engineering, Czech Technical University in Prague,*
*Thákurova 7, 166 29 Prague 6, Czech Republic*

**Abstract**

The long-term functionality, i.e. stability of the lining of disposal tunnels is a precondition for the safe removal and reprocessing of spent nuclear waste from deep underground repositories in the near or more distant future. The reason for removing containers with radioactive waste from such repositories lies in the potential development of presently unavailable "perfect" technology for its reprocessing. The stability problems of the tunnel lining exposed to the long-term thermal load generated by the waste in the disposal container was the subject of one task of the European TIMODAZ project (Thermal Impact on the Damaged Zone around a Radioactive Waste Disposal in Clay Host Rocks). Research was carried out by means of physical modeling. Although the project was terminated in September 2010, recorded data is being further analyzed. This paper describes the design, construction and results of an in-situ model which has been built at the Underground Research Centre Josef in the Czech Republic.

**Sažetak**

Dugotrajna funkcionalnost, odnosno stabilnost obloge tunela za oblaganje je preduvjet za sigurno uklanjanje i reprocesiranje nuklearnog otpada iz dubokih geoloških odlagališta u bližoj ili daljnjoj budućnosti. Razlog za uklanjanje spremnika s radioaktivnim otpadom iz odlagališta leži u potencijalnom razvoju trenutno ne raspoloživih „savršenih" tehnologija za njegovo reprocesiranje. Problem stabilnosti tunelske obloge izložene dugotrajnom termičkom opterećenju, koje nastaje djelovanjem otpada u spremniku, bili su jedan od zadataka projekta TIMODAZ (Thermal Impact on the Damaged Zone around a Radioactive Waste Disposal in Clay Host Rocks – Termičko opterećenje oštećene zone oko odlagališta radioaktivnog otpada u glinama). Istraživanje provelo metodom fizičkog modeliranja. Premda je projekt završen u rujnu 2010, zabilježeni podaci su i dalje analizirani. Ovaj članak opisuje dizajn, konstrukciju i rezultate in situ modela koji je izgrađen u podzemnom istraživačkom centru Josef u Češkoj.

## 1. Introduction

TIMODAZ (Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks) was an international research project one of the participants in which is the Centre for Experimental Geotechnics (CEG), Czech Technical University in Prague. 14 European universities and research institutions from 8 European countries cooperated on this project.

The project was focused on thermal impact on clayeous rock as a natural barrier of the deep repository. The laboratory investigation, in-situ testing as well as mathematical modeling of heat loading related phenomena took place during the project works. The stability of the concrete lining, which is fundamental part of the disposal tunnel in clayeous host rock, was investigated in frame of specialized task.

## 2. Research objective

The aim of research was to verify whether long-term thermal loading may induce such load (stress) within the concrete lining of the disposal tunnel that the strength characteristics of the concrete are exhausted thus negatively affecting its stability.

The in-situ physical model has been assembled in a rock continuum (hard tuffitic rocks) in the Josef underground facility (www.uef-josef.eu, Pacovský et. al., 2007). The space between the circular lining and the rock is backfilled with compacted concrete. This method of construction minimized the occurrence of lining deformation but maximizes the magnitude of various stresses arising within the lining and its vicinity due to thermal loading. The principal monitored parameters in this case include temperature and stress.

## 3. Construction of physical model

The model is made up of four rings. The width of individual segments is 500 mm, which makes the total length of the model 2000 mm. The thickness of the segments is 300mm, the inside diameter of the rings 1900 mm and the outside diameter 2500mm (Figure 1). The total weight of the ring amounts to 2540kg with a segment weight of 250 – 320 kg (ONDRAF/ NIRAS, 1998).

The site selected for the model was a short niche. This niche was driven into very hard tuffitic rocks with uniaxial compressive strength of 220 – 240MPa (Vašíček & Svoboda, 2011). The space between the rings and the rock was backfilled with concrete. The inside surface of the lining served for the installation of a heating system incorporating a plastic tube heating spiral with water as the circulating heating medium (Figure 2). This system allows the heating of the inside concrete lining surface to a final temperature of 90°C).

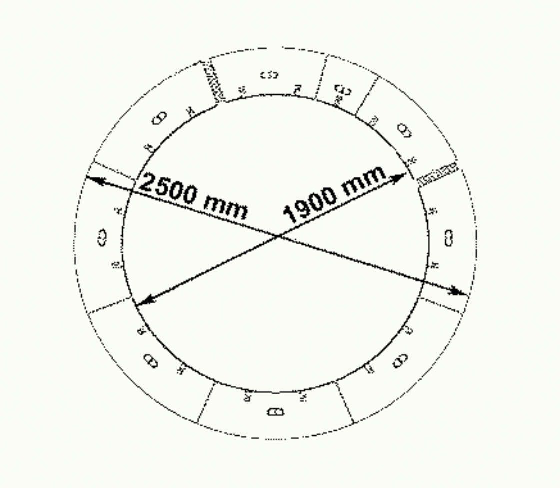

**Figure 1** The scheme of the lining.

***Slika 1.*** *Shema obloge*

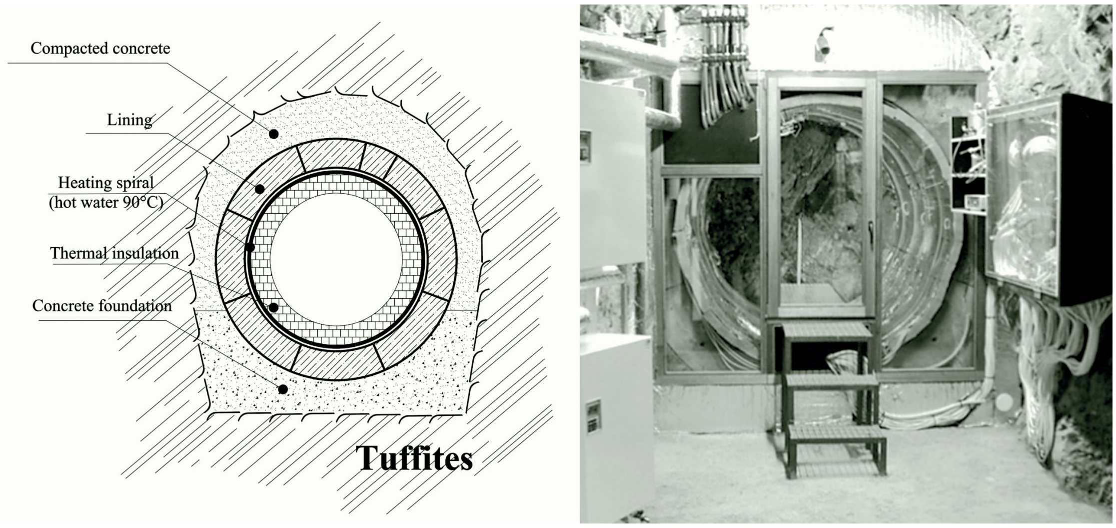

**Figure 2** In-situ model construction.

***Slika 2.*** *Konstrukcija in situ modela*

## 4. Instrumentation of physical model

Over 250 sensors measure the most significant parameters as temperature, stress and strain, moreover, the power consumption of heating system is also measured. Measurement is automated, the data being recorded once every 10 minutes.

Temperature is measured using standard, inexpensive semiconductor thermometers which have been installed in the surrounding rock continuum at contact points between the rock and the concrete filler, in the concrete filler between the rock and the lining, inside the concrete segments, on the inside lining surface and inside and outside the chamber. In addition, the temperature of the heating medium at the input and output points of the model is also measured.

Strain is measured within selected lining segments in which gauges were concreted during construction. Measurement is performed by means of vibrating wire strain gauges (Gauge Technique). 48 vibrating wire strain gauges were installed in total. Four hydraulic pressure cells were also installed between rock and compacted concrete.

## 5. Measurement procedures

The experiment has been started at the end of October 2008, when the heater system was switched on. The heater was switched off in June 2010. The cooling phase of the experiment is still in progress.

As for the in-situ experiment, the demand that the temperature difference between the inside and outside of the lining should not exceed 30°C had to be met. Exceeding the preset maximum gradient could cause the exhaustion of the strength of the lining concrete immediately after heating commenced.

Therefore, the in-situ model had to be thermally loaded on a step-by-step basis, in successive phases: 40°C (phase 1), 60°C (phase 2), 70°C (phase 3), 80°C (phase 4), 90°C (phase 5) and cooling phase (phase 6) (Vašíček, Svoboda, 2011). The final heating period (at 90°C) was maintained for approximately 6 months.

## 6. Results and discussions

The in-situ model was exposed to step-by-step loading so that the temperature difference between the inside and outside lining surfaces would never exceed 30oC. The time pattern of all loading phases and the development of the thermal gradient between the inside and outside lining surfaces in a selected profile are displayed in Figure 3. The time pattern shows that during the whole period of thermal loading there was two failures caused by heating medium pump breakage in September 2009, respectively in March 2010.

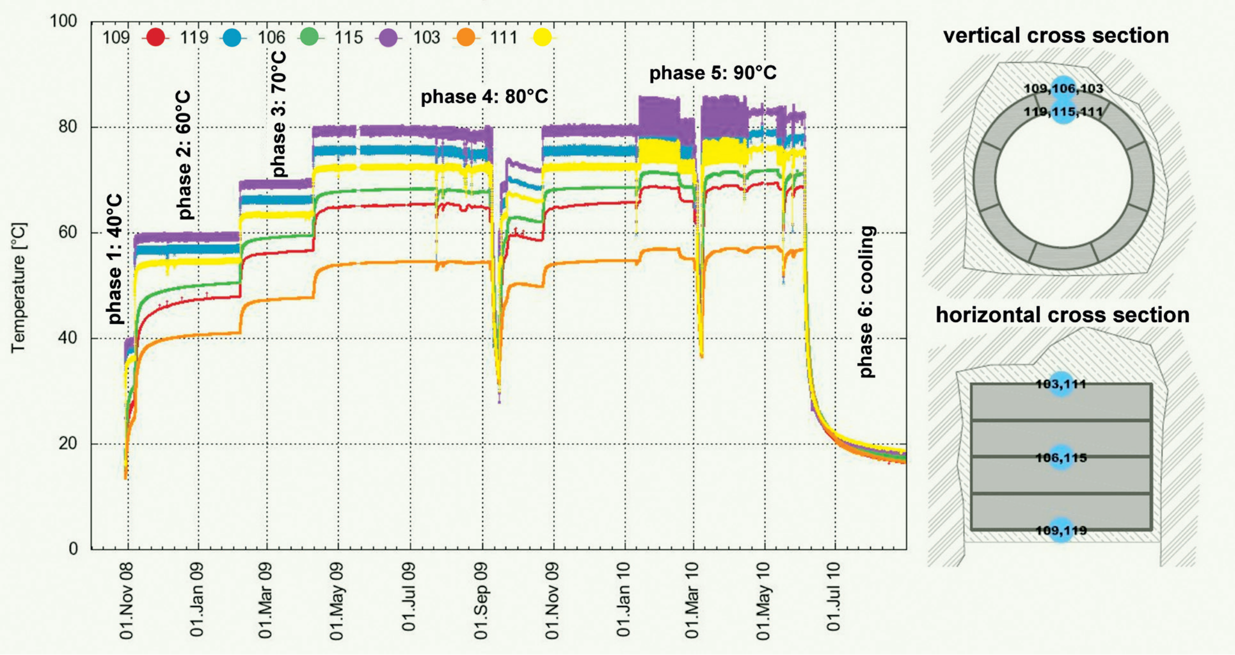

**Figure 3** Development of temperature on outside and inside surface of the lining during the course of the experiment.

***Slika 3.*** *Razvoj temperatura na vanjskoj i unutrašnjoj površini obloge tijekom pokusa*

The strain gauges installed in the segments quickly respond to changes in temperature (Figure 4). To convert relative deformation values into stress (Hook's law), Young's modulus of C80/85 segments (E = 35.9GPa) was applied. Obviously, increasing temperature induces increasing stress in the lining. The stress in the lining was in range of 0 - 25MPa. In one extreme case the stress value exceeded 30MPa.

During the phase 6 (cooling phase) the stress in the lining decreases with decreasing temperature, the stress range is 0 - 12MPa at temperature approx. 8°C.

Generally the stress in the lining slowly increased in every heating step although the temperature of the lining and surrounding environment was already in steady state (figure 4). That refers to long-term behavior of the concrete structure and surrounding rock.

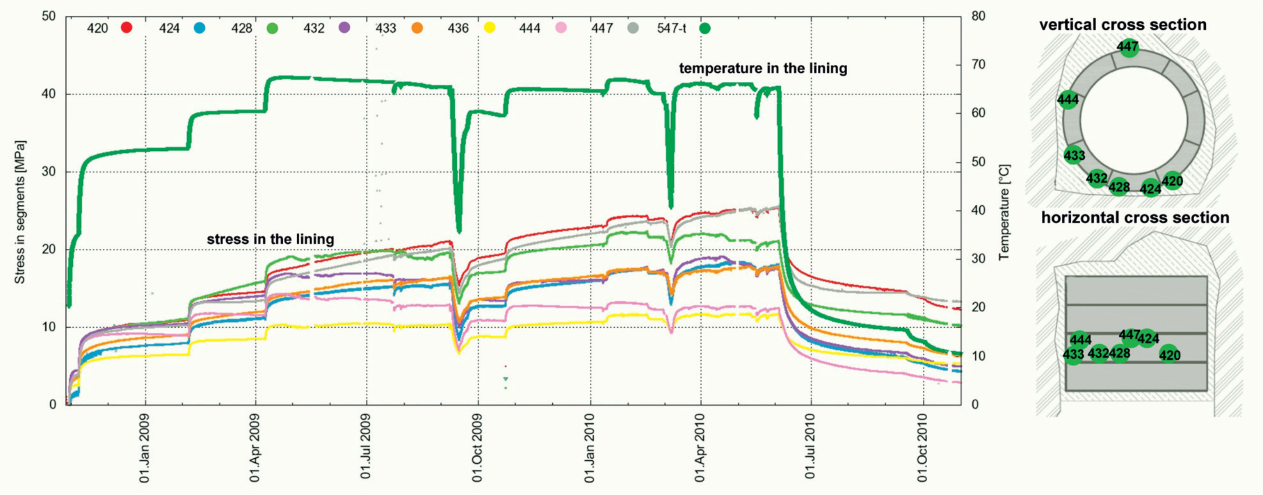

**Figure 4** Development of stress in the lining.

***Slika 4.*** *Razvoj naprezanja u oblozi*

## 7. Lesson learnt on instrumentation

During the course of the experiment 20 of 48 strain gauges installed inside concrete blocks failed. Only five of a total of 24 strain gauges positioned near the inside lining surface are still in operation. In addition, one strain gauge near the outside lining surface failed.

Figure 5 shows the development of the number of failed sensors (vibrating strain gauges), last (before failure) recorded stress measurement and the temperature on inside surface of lining. Most of the final measured values lie between 9 and 18MPa.

No clear relationship was detected between sensor failure and the stress recorded at the time of failure; indeed, figure 5 indicates that stress is probably not a key factor in their failure. Conversely figure 5 tends to suggest that time (duration of heat loading) and temperature changes may play a more important role in this regard.

In general, it can be concluded that the vibrating strain gauges used were unsuitable for this type of experiment. The hydraulic pressure cells installed between the rock and compacted concrete significantly helped to control the experiment development after vibrating strain gauges failures.

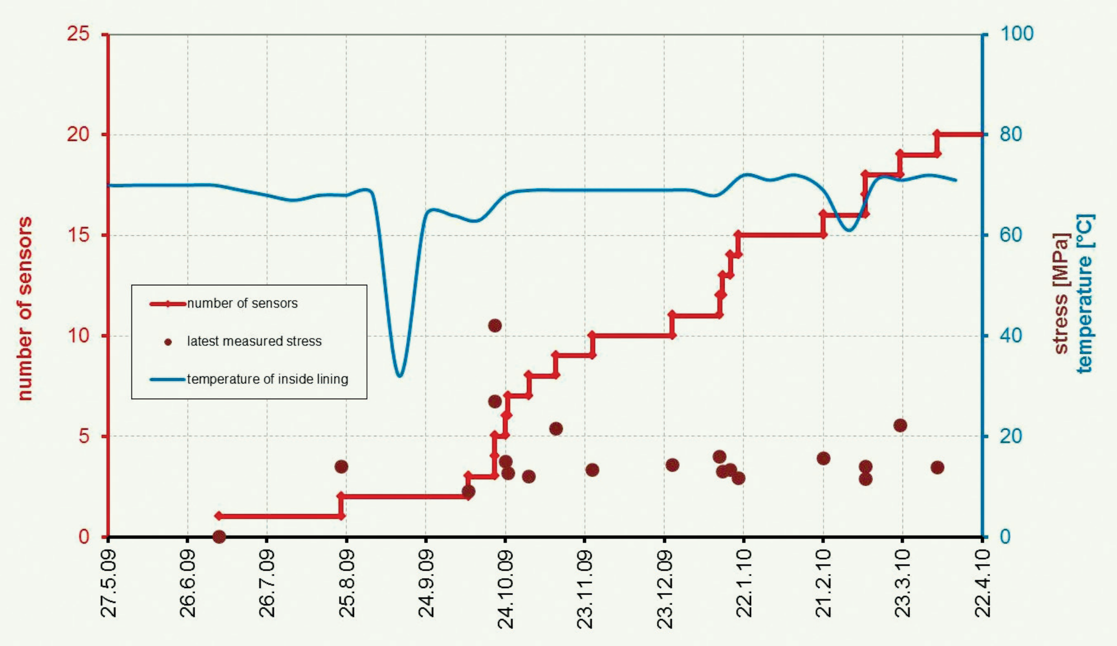

**Figure 5** Development of failed sensors, temperature on inside surface of the lining and latest measured stress.

***Slika 5.*** *Raspored uništenih osjetila i temperature na unutrašnjoj površini obloge i zadnja mjerenja naprezanja*

## 8. Conclusion

The aim of the in situ experiment was to model the least favourable loading state possible, i.e. a state in which the concrete lining is unable to deform into the surrounding rock thus creating high levels of stress.

Measured stress values of the concrete lining segments reached roughly 0 – 25MPa during the heating phases with temperature up to 85°C on lining. The thermal loading of the lining generated compressive stress within the concrete in one extreme case over 30MPa, which is about 35% of the compressive strength of C80/95 concrete. It shows the thermal effect on the lining stability is very significant and can be much more important than stress generated by loading of rock.

Greater attention must be devoted to instrumentation in long-term thermally loaded experiments. In terms of the long-term measurement of stress during heated tests the use of various principles of measurement (types of sensors) is very valuable, as was shown during reported experiment.

## Acknowledgements

Financial support was provided by “Institutional research plan MSM6840770031 - Complex System of Methods for Directed Design and Assessment of Functional Properties of Building Materials”.

## References

Pacovský, J. et. al. (2007): The Josef Underground Educational Facility Project. In Underground Space, 4 tf Dimension of Metropolises. vol. 1, p. 631-634. Leiden

ONDRAF/NIRAS (1998): «The PRACLAY project – Demonstration test on the Belgian disposal facility concept for high activity vitrified waste», CEC, Nuclear science and technology, EUR 18047 Brussels, Belgium (1998).

Vašíček, R.; Svoboda, J. (2011): Long-term lining performance - Civil engineering problem of potential retrieval of buried spent nuclear fuel. Nuclear Engineering and Design, 241, no. 4, p. 1233-1237.