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EXPERIMENTAL MODELLING METHODS OF STRESS ANALYSIS FOR DETERMINATION OF UNDERGROUND STRUCTURE STABILITY

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ABSTRACT. Verification possibility of experimental [illegible] of their results for numerical solutions in geotechnics [illegible] physical models have been constructed. [illegible] front of the tunnel heading and around the robbed space were studied. The results of experiments were each other compared. On the basis of these results the input parameters for mathematical models were determined.

KEYWORDS: physical modelling, underground opening, stability, coupled modelling

1. INTRODUCTION

The requirements [illegible] all demands for the continually increasing population [illegible] enforcing underground spaces utilization. [illegible] works stability and their operability assessment is not the question of mining mineral deposits any more, but first of all it [illegible] structures (deposits [illegible] garages etc.). Following up different types of structural activities the requirements for solution of underground structure stability and determining the changes in the initial stress state [illegible] these [illegible] viewpoints of construction, economy and environment protection.

The construction of any underground structures is the reason of both qualitative and quantitative [illegible] first [illegible] state [illegible] changes in the [illegible] responses of the rock mass can be observed directly in situ or predicted on the base of numerical or experimental model solutions. Modelling in geotechnics enables to observe the [illegible] their effects in various processes of the underground work construction, but also in simulated operational [illegible] a model which must fulfil all determinant properties of real natural environment.

The success of the modelling methods first of all depends on the accuracy of input parameters.

simulation of the process that is taking place in the rock mass. The formulation of border conditions is based upon the principles of physical and geometrical similarity (Kožešník, 1983; Kohoutek et al., 1977). On the other hand the advantage of numerical solutions consists in the operativeness by means of which it is possible to change the input parameters and in the rapidity by means of which it is possible to achieve the results. The most objective results are achieved b

both of these methods, i.e. by the method of coupled modelling.

The aim of this work was to verify the capability of physical models to record the changes of the stress in the model in consequence of underground work structure simulation and to identify the reliability of transducing and registration of measured stresses.

for mathematical modelling.

2. DESCRIPTION OF THE EXPERIMENT

A horizontally tunnelled underground work of circular section (diameter 100 mm) was modelled for experimental purposes. The models

elling stand with the dimensions of 480 × 1460 × 1200 mm (width × length × height). The tunnel was driven horizontally, excentrically from the side part of the modelling stand in t

nal loading of the model. In the models the behaviour of the underground structure heading and its immediate surrounding during the excavation was observed. The stress state changes in different distances in front and behind of proceeding heading, stress distribution and the rise of unloading

dicular to the longitudinal axis of the underground structure were determined. the model the rock mass was simulated by model material. Three types of models were tested.

a) Model (9318) where the rock mass was c

In this case the used model material consisted of the mixture of bentonite 30 %, sand 67% and fat 3 %.

b) Model (9503) where the rock mass was considered horizontally bedded, formed by two kinds of model material. For the model construction two mixtures were used. First mixture — the same as in point a), the

prepared from sand

c) Model (9602) where the rock mass was bedded, the gradient of the layers was led under the angle of 22.5° with regard to the longitudinal axis of the tunnel. The used model materials were

The properties of model material were indicated by means of laboratory methods which are usual in soil mechanics with the following results:

bentonite 30 % + sand 67 % + fat 3 %	
volume weight τ	1.53 g/cm^3
uniaxial compression st	0.007 MPa

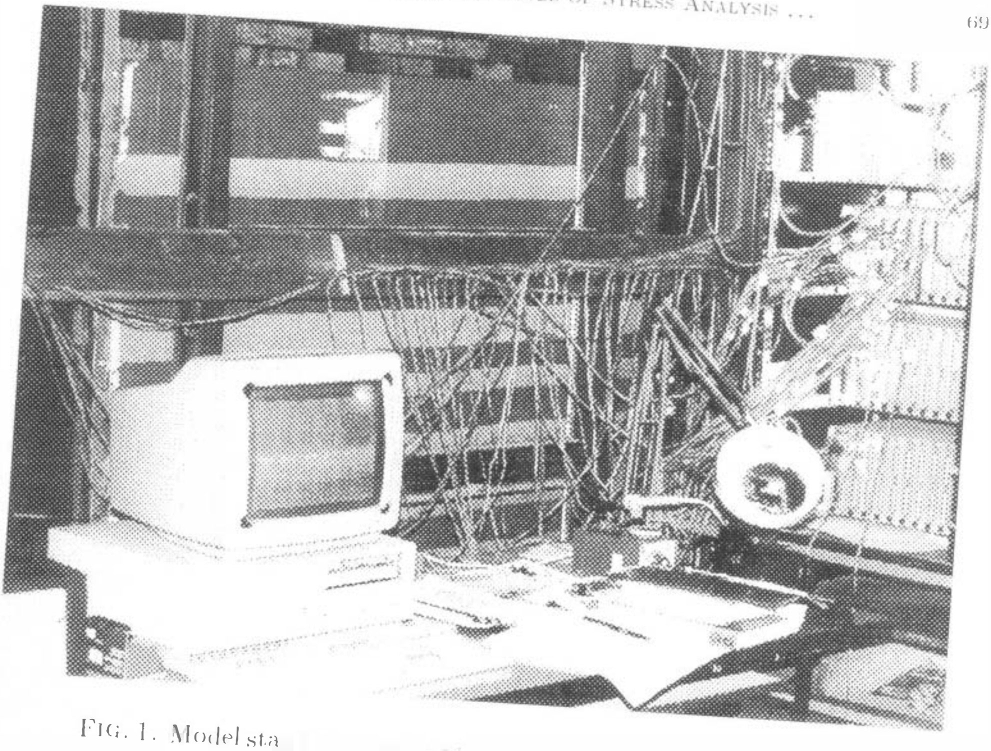

FIG. 1. Model sta
experiment

elasticity modulus E	4.5 MPa
Poisson ratio	0.284
cohesion c_p	0.014 MPa
angle of internal fri	31.0°

sand 98.6 % + paraffine 1.4 %

volume weight τ	1.45 g/cm^3
uniaxial compression strength σ_t	0.02 MPa
elasticity modulus E	13.0 MPa
Poisson rat	0.300
cohesion c_p	0.011 M a
angle of inte	38.5°

Monitoring of
miconductor transducers of
which measure the stress applied perpendicularly on their bearing surface. During the model construction the transducers were located in the vertical plane passing
t hrou
the tu
to r eg
that only vertical st

UNILOG 2500 was utilized

The model stand
shown in Figure 1.

The models were testing
After deliberation that the model scale was 1 : 100, the models could represent the
tunnel with
in the rock mass formed by medium–rigid sandstones
find e.g. in the area of the Kladno coal basin (Živor et al., 1995; Vydra, 1995).

The model tests
the model construction
carried out
derivation
pla
of the
before the
recorded on the
side of the
for evaluation
of 30 cm, 20 cm, 10 cm, 5 cm (namely 40 cm, 30 cm, 20 cm, 10 cm and 5 cm for the
9318 model) ahead of the transducer plane, approximately on the plane of the
transducers, and 5 cm, 15 cm, 25 cm (and also 35 cm for the 9602 model) after the
plane of the transducers.
gradual tunnelling wa
sufficient for finishing the
tensometric data

3. RESULTS OF THE MODEL TESTS

The measured tens
set of programmes of TN1, TN2 for calibration of transducers in the model and for
the
locat
ratio of the calculated stresses age of the tunnelling with
regard to the initia
complete illustration of the rise of an increased stress area in front and behind of
the proceeding tunnel heading and a complete illustration of increased (decreased)
stress state zones formation after the
which the transducers had been located, were obtained.

The ratio of the initial stress state to the stress state measured for each tunnelling
stage
material
20 cm ahead the transducer plane, t
changes due to tunnelling. In stages 5, a
in the distance
area of increased stresses, a

9318

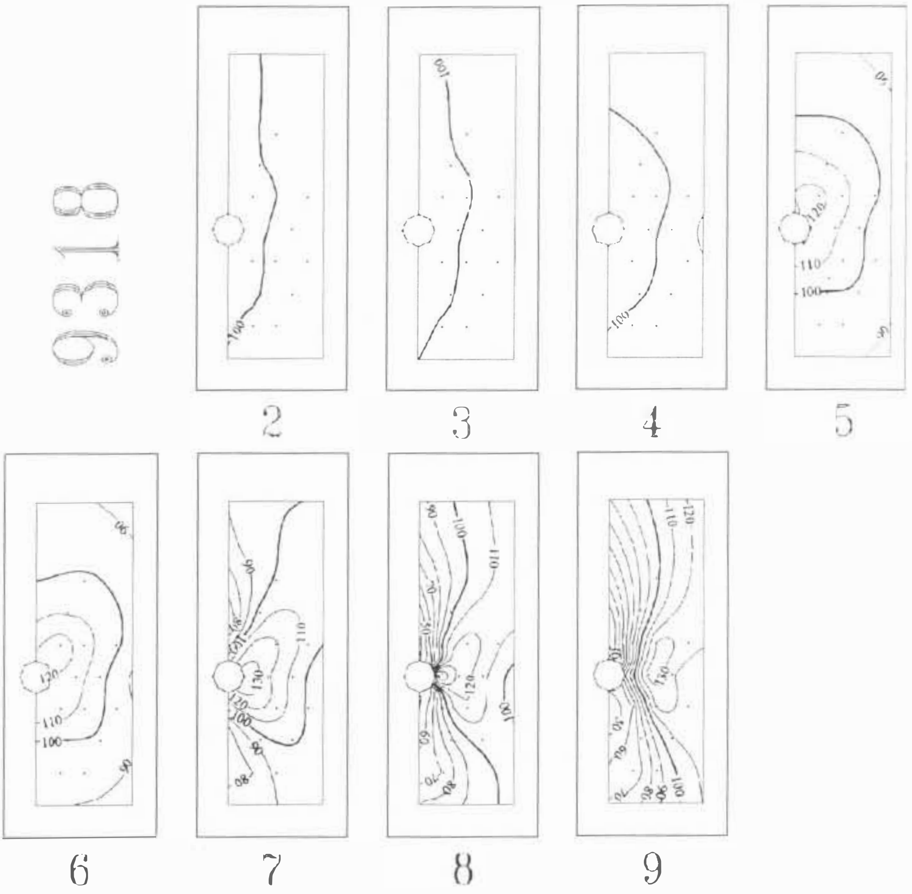

FIG. 2. Isolines of stress ratios
tensometric
regard to the initial stress state: — with-
out layers
Stages 2 – 9: heading distances 40 cm, 30 cm, 20 cm, 10 cm, 5 cm ahead of the transducer plane, approximately on transducer plane and 5 cm, 15 cm behind transducer plane

was formed in front
after transducer plane was crossed by tunnel heading the stress on the tun
increased and under and above the tunnel decrease of stress appeared. With the
longer distance of the tunnel heading behind the transdu
longer time distance from the moment
the transducer plane it was possible to observe the development of the areas with
maximum vertical stresses on the sides of the tunnel. Not only tl
maximum
the motion of maximum stresses in the direction into the mass was found. This is

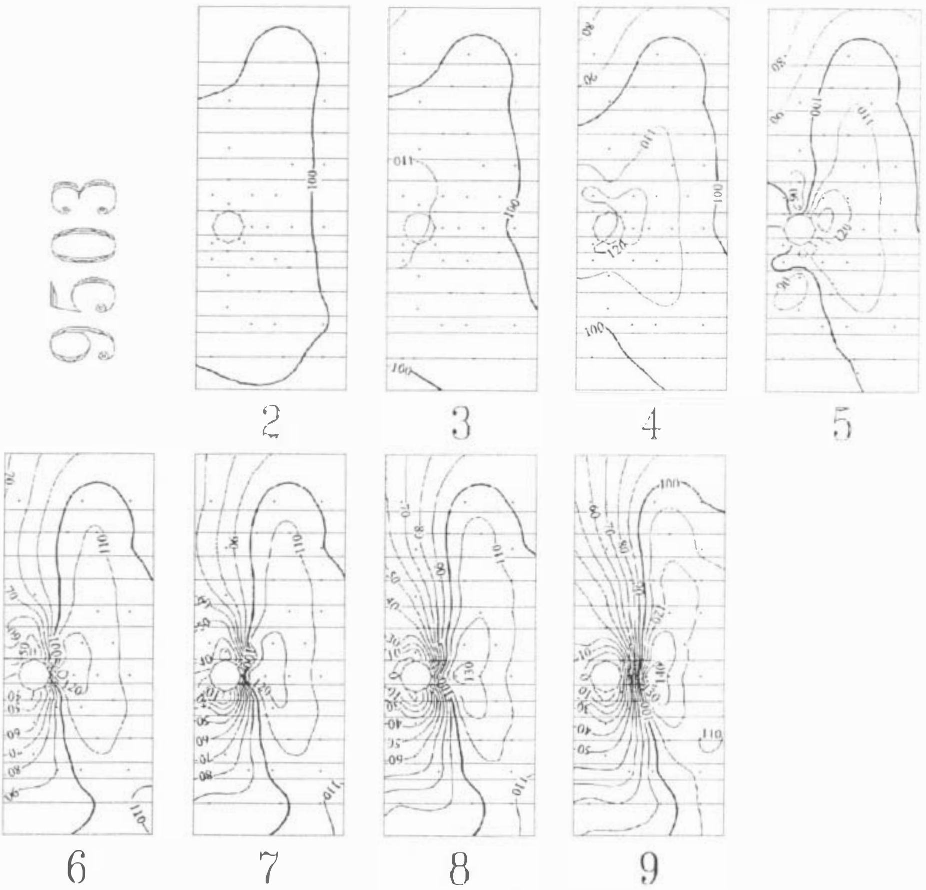

FIG. 3. Isolines of stress ratios (in %) determined on the base of tensometric measurements for stage of driving with regard to the initial stress state: the 9503 model — horizontal layers

Stages 2 – 9: heading distances 30 cm, 20 cm, 10 cm, 5 cm ahead of the transducer plane, approximately on transducer plane and 5 cm, 15 cm, 25 cm behind transducer plane

caused by the reducing of strength of the rock mass equivalent and by the rise of disturbed areas around the tunnel. This process, which is known from construction of subsurface works, is very hardly modellable in mathematical models.

Similar processes were illustrated in Figs. 3. and 4. in which the isolines of the stress state changes in the models with horizontal (model 9503) and declined (model 9602) layers were drawn. The influence of bedding on the shape of the isolines is very evident in this pictures.

The differences between the initial stress state of the model and its stress state shortly (5 cm) after the tunnel heading crossed the transducer plane for each model

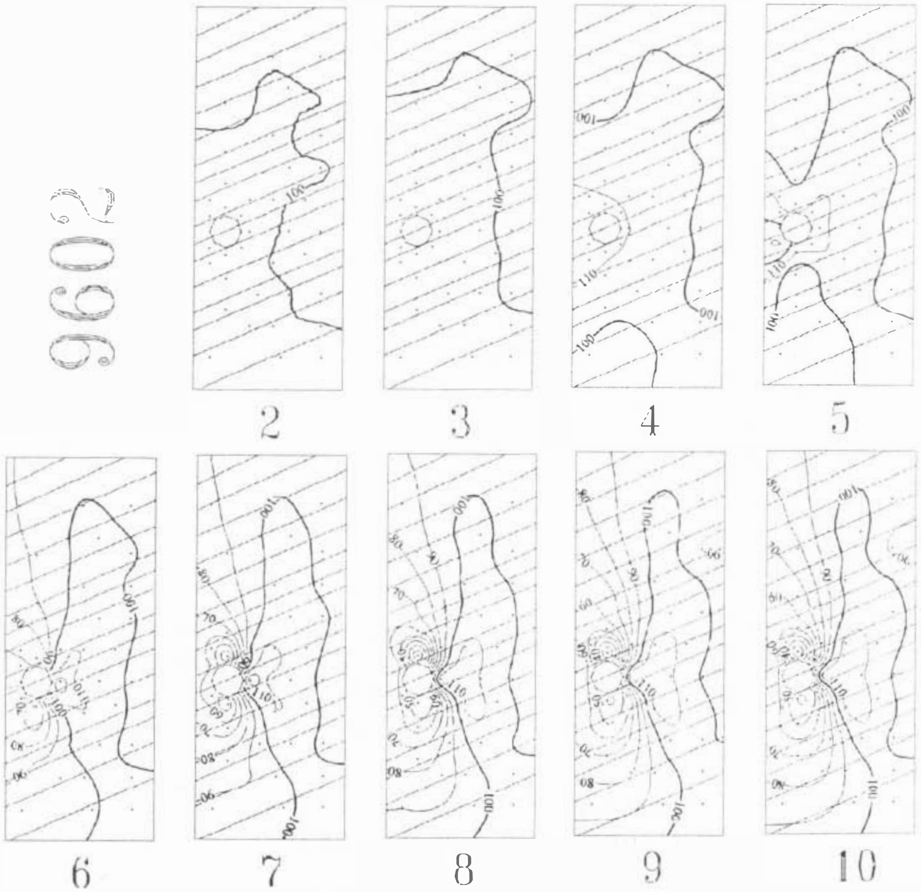

FIG. 4. Isolines of stress ratios (in %) determined on the base of tensometric regard to the initial stress state: the 9602 model — layers with 22.5° gradient

Stages 2 – 10: heading distances 30 cm, 20 cm, 10 cm, 5 cm ahead of the transducer plane, approximately on transducer plane and 5 cm, 15 cm, 25 cm, 35 cm behind transducer plane

type (with no–layers, with horizontal layers and with the layer under the angle of 22.5°) were illustrated in Fig. 5. The initial stress state in the tunnel axis was 18.75 kPa in the no–layers model, respectively 18.53 kPa and 18.68 kPa in other model types.

For the same phase of the model experiments, the isolines of stress between model 9318 and model 9503, respectively between model 9318 and 9602, were illust

Even though the determined values of the stress on each particular transducer were affected with errors which were caused by the not always perfect contact of

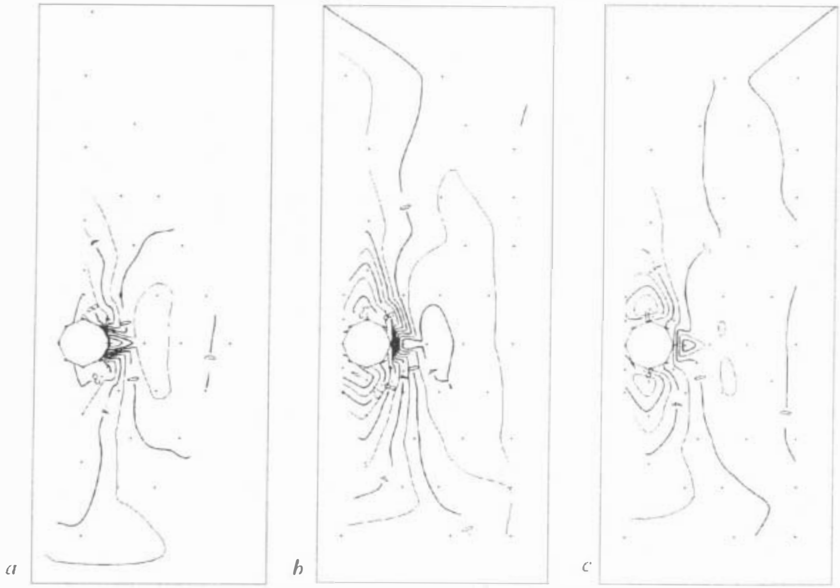

FIG. 5. Isolines of the differences between the initial stress state
of the
ducers for the state when the tunnel heading was
distance
metric transducers
a) — no–layers model
b) — horizontal layers model
c) — inclined layers model

the surrounding material with the transducer and also by
locate the transducers into
provided sufficiently significant informat
in the model during tunnelling.

4. UTILIZATION OF THE EXPERIMENT RESULT FOR MATHEMATICAL MODELLING

The results of tensometric measurements in physical models can be utilized for determination of input parameters for mathematical models (Procházka, Skořepová, 1996).

For the same mechanical and deformational properties of the medium, which were
used for construction
model, a mathematical
were based on generalized Mohr–Coulomb's Law and Drucker–Prager's Hypothesis
(Procházka,

In the mathematical
1. .

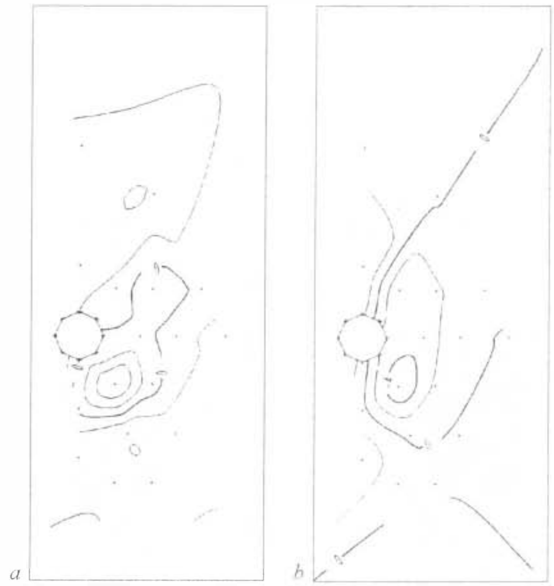

FIG. 6. Isolines of stress difference for the state when the tunnel heading was in the distance of 5 cm behind the plane of the transducers (kPa):
a) no–layers model minus horizontal layers model
b) no–layers model minus 22.5° gradient layers model

rock mass. The discrete values of vertical stresses σ_i^m, $(i = 1, \ldots, n)$, which were measured by tensometrical transducers in the A_i points of the physical models in the plane perpendicular to the tunnel axis when certain length of the tunnel was driven, were confronted with the stress values calculated by the method of mathematical modelling for corresponding points. The aim was to minimize the variance between both the computed and the determined from the experiment values at the comparative points A_i by the change of some parameters p_α. It is necessary to know them for the mathematical solution (Procházka, 1997). The other parameters, which are determined in situ measurements or laboratory tests, remained correspondent with the experiment. The input data processed in this way and characterizing the rock mass in the mathematical model are suitable for further utilization to realize a series of alternative parametrical numerical solutions for the given rock mass without the necessity to carry out further experiments.

The isolines of the differences between the stress values determined from the experiment and calculated partly for linear (a), partly for the fifth iteration (b) of the mathematical solution were given on the Fig. 7. In this case the tunnel heading did not passed through the plane where the transducers were situated in the physical model. In the next figure (Fig. 8.) there were the same case, but for the situation when the tunnel heading passed through the transducer plane. Both pictures proved obvious approximation of the results of both methods after carrying

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Experimentální modelovací metody analýzy napětí pro posouzení stability podzemní konstrukce

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Výstavba jakéhokoliv podzemního díla je příčinou kvalitativních i kvantitativních změn horninového prostředí v jeho okolí. Deformačně–napěťové odezvy horninového masivu mohou být sledovány přímo in situ, nebo předem prognózovány na základě numerických nebo experimentálních modelových řešení.

Cílem práce bylo ověřit schopnost fyzikálních modelů reagovat na změny napjatosti v tělese modelu následkem simulace konstrukce podzemního díla a zjistit spolehlivost snímání a registrace naměřených napětí. V konečné fázi pak výsledky experimentu využít jako vstupní data pro matematické modelování.

Pro účely experimentu bylo modelováno vodorovně ražené podzemní dílo kruhového průřezu. Na modelech bylo sledováno chování čelby podzemního díla a jeho bezprostředního okolí během ražby. Byly určovány změny původní napjatosti v různé vzdálenosti před i za postupující čelbou a rozložení napětí a vznik oblastí odlehčení a přitížení v rovině kolmé k podélné ose podzemního díla.

Konfrontace hodnot změn napjatosti, které byly určeny na základě měření na jednotlivých typech fyzikálních modelů během ražby tunelu, prokázala schopnost zaregistrovat i malé změny napjatosti dané namodelováním rozdílné geologické stavby prostředí (vrstevnatost) při jinak stejných podmínkách. Naměřené hodnoty odpovídají teoretickým předpokladům o chování horninového prostředí kolem otvírky kruhového průřezu. Na modelech se podařilo postihnout reologické chování horninového materiálu, kdy dochází k přenosu maximálních napětí od boku otvírky dále do masivu a k rozšiřování oblastí ovlivněné ražbou tunelu.

Tyto výsledky daly možnost využít experimentálního modelování při formulování vstupních parametrů pro matematické modelování.

Pro stejné mechanické a přetvárné vlastnosti prostředí, které byly použity pro konstrukci fyzikálního modelu a stejnou geometrii jako fyzikální model bylo realizováno matematické řešení na základě lineárního výpočtu metodou konečných prvků s rovinným lineárním rozdělením posunů a alternativně se zahrnutím zobecněného Mohr–Coulombova zákona a Drucker–Pragerovy hypotézy (Procházka, 1997). Diskrétní hodnoty vertikálních napětí $\sigma_i^{\text{měř}}$, $(i = 1, \ldots, n)$, které byly naměřeny pomocí tenzometrických snímačů v A_i bodech fyzikálního modelu v rovině kolmé k ose tunelu po vyrubání jeho určité délky, byly konfrontovány s hodnotami napětí vypočtenými metodou matematického modelování pro odpovídající body. Cílem bylo iteračním postupem minimalizovat rozdíly mezi z experimentu určenými a numerickým postupem vypočtenými hodnotami napětí ve srovnávacích bodech A_i změnou některých parametrů p_α. Ostatní parametry, určené z měření in situ nebo laboratorních zkoušek, zůstaly shodné s experimentem. Takto ověřená vstupní data charakterizující horninové prostředí v matematickém modelu je možno dále využívat pro realizaci řady alternativních parametrických numerických řešení pro dané horninové prostředí bez nutnosti provádět další experimenty.

Kombinací obou metod s využitím jejich předností se podstatně zlepší reálnost výsledků modelování.