Small-scale models and tests at the "Zentrum am Berg"

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Abstract:

During the master's program "Geotechnics and Tunneling" at the University of Leoben, several models of the Zentrum am Berg (ZaB) have been developed for the realization of small-scale tests. Using physical models of the ZaB, non-destructive small-scale tests will be carried out in the future. These experiments could be radiation and gas dispersion tests as well as blasting tests, which are performed on a small scale, while their effects can be proportionally converted to real cross-section dimensions.

Key Words: small-scale, 3D model, blasting, gas dispersion, radiation

1. Introduction

Up to now, it has not been possible to derive a proportionality factor from comparing the results of small-scale gas dispersion, radiation, or blasting tests with those of real-scale tests. Therefore, small-scale non-destructive tests are to be carried out on different physical models of the "Zentrum am Berg" (in short ZaB; see Figure 1). Thus, for example, the validity of the Reynolds number for fluidic conditions can be verified in gas propagation tests in tunnel tubes. In addition, these models can be used to investigate radiation propagation behavior in linear structures in more detail and to verify the validity of the inverse-square law. Two physical models have been developed for different purposes. The tunnel tube negative molds for model number one are manufactured by CNC milling. Next, concrete will be poured using a suitable concrete mix, which has yet to be developed. The second model will be made of Plexiglas for gas dispersion testing. In addition to measuring the gas dispersion (when "disco fog" is used), it will also be possible to observe it visually.

The project is divided into four major sections: the physical model, the digital model creation, blasting tests in the ZaB, and the influence of geology. The manufacturability of the "Presserstollen" and "Kerpelyflügel", both sections of the old tunnel system, is not in any reasonable relation to the benefit. Therefore, only the two road and railway tunnels including crosscuts were modeled in the final scale of 1:50.

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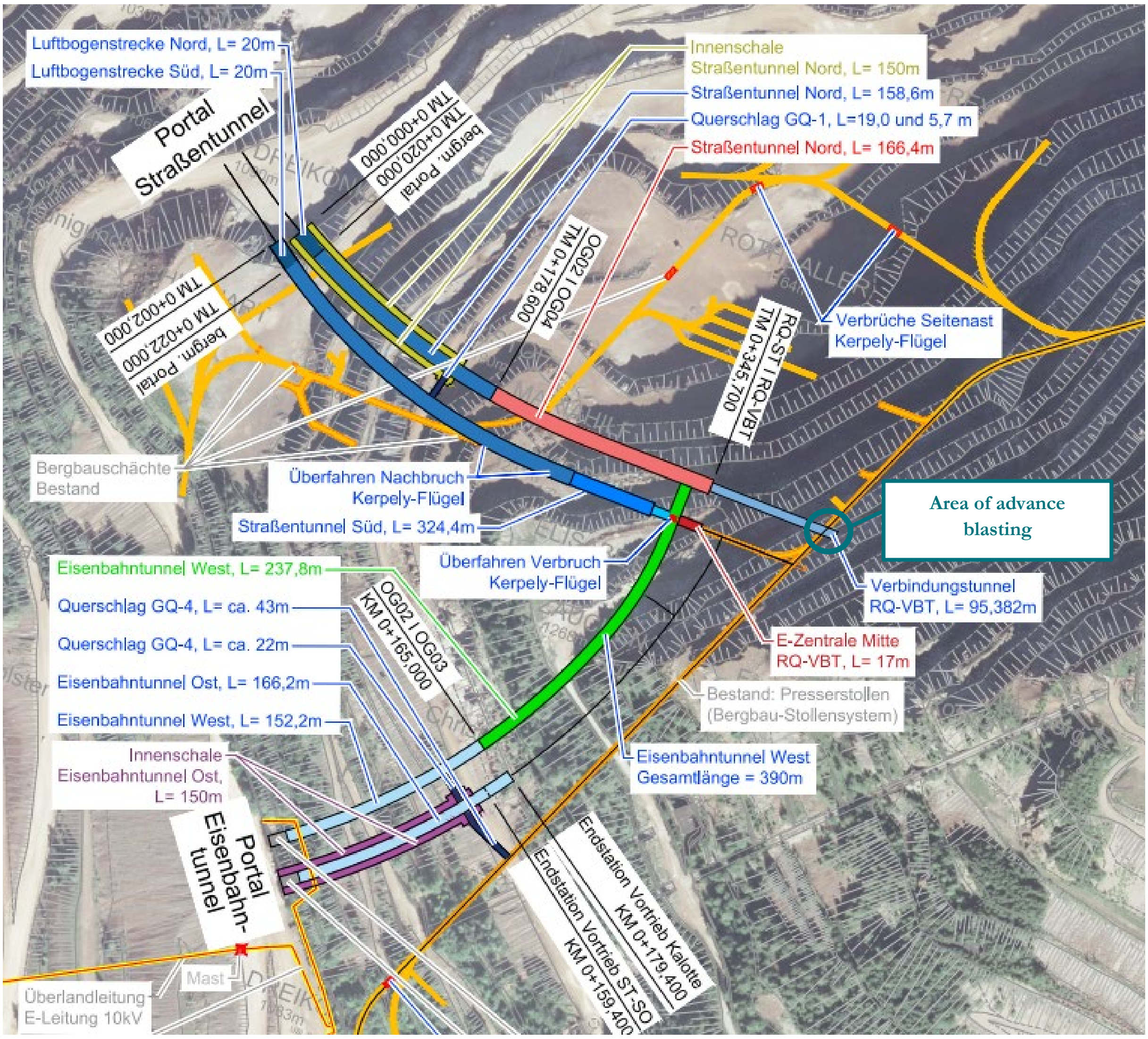

Figure 1: Overview of the ZaB; area of the advance blasting (turquoise) (IL – Ingenieurbüro Laabmayr & Partner ZT GesmbH 2017)

2. The physical model

As the project progressed, the initial ideas and requirements kept changing. Finally, two separate models were developed, one for radiation tests and possible blast tests, as well as another for gas dispersion tests.

a. Model for radiation tests and potential blasting tests

Throughout the creation process, various variants for the realization of the ZaB model were examined and planned in more detail. In the end, it transpired that CNC milling was the most technically and economically favorable method. A 3D solid is required to produce the milled tunnel tube negative molds.

The milled segments have a maximum length of 50 cm, which is limited by the size of the deep-drawing table. Furthermore, the tunnel tube cross-section of the negative mold must be cut in the horizontal symmetry axis.

In the course of this project, the milling materials EPS W30, as well as wood (MDF), have been examined more precisely. According to the cost estimation, the total price for milling and finishing (filling) for the production from EPS is approximately 2600 €. However, this negative mold can only be used once, as it cannot be removed from the concrete model without damage. Another disadvantage is the possible insufficient heat resistance of the EPS as a negative mold for the radiation propagation model. Wood is a suitable alternative. On the one hand, its heat resistance is sufficient, and it is, therefore, the ideal material for the thermoforming process. Furthermore, the mold can be reused. This in turn makes it possible to reproduce damaged concrete segments. Nevertheless, the costs for the production of the wooden negative mold amount to about 3700 €.

b. Model for gas dispersion tests

The model for conducting the gas dispersion tests was planned to be produced by thermoforming Plexiglas sheets. Thermoforming requires a negative mold (see 2.a), which is placed on a deep-drawing table. Above the table, there are radiant heaters that reach a temperature of about 260 °C and heat the Plexiglas sheets to 100 °C. At this temperature, the plastic is easily malleable and is sucked up to the negative mold by a vacuum attached to the table, whereby the Plexiglas plate takes on the shape of the negative mold. The milled tunnel tubes require a central horizontal division of the cross-section, since no overhanging shapes (as with a round cross-section) can be deep-drawn. Once the two tunnel tube halves have been deep-drawn, they must be glued to the flanges formed sideways during deep-drawing. This step is essential to achieve the tightness required for the gas dispersion tests. The joints between the individual segments are connected by gluing sealing tapes to the outside. Advantages are seen in the easy assembly as well as the non-destructive dismantling. This means that the entire model is not tied to a specific location but can be reassembled at a different location. Since the deep drawing table has a length of 50 cm, the length of the individual tunnel segments is limited to 50 cm, as mentioned in point 2.a. The costs of this variant are approximately 1600 €.[1]

3. Digital model design and development

As a result of the initial coordination discussions, the idea was developed to re-model the entire tunnel system of the Zentrum am Berg as well as the terrain surface above it on a scale of 1:100 using existing laser scans. These were opened and evaluated with the CloudCompare program. However, these laser scans contained fixtures such as roadway structure and track system and showed a too high point density for simple further adjustment. Therefore, an AutoCad Civil 3D visualisation model of the ZaB created by the engineering firm Laabmayr (IL – Ingenieurbüro Laabmayr & Partner ZT GesmbH.[2]) was used (Figure 2).

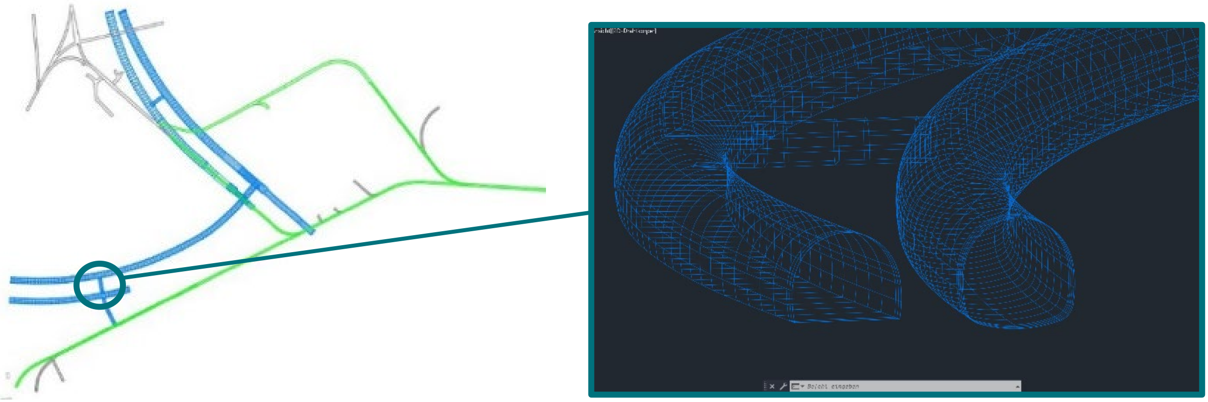

Figure 2: 3D solid of the entire tunnel and gallery system (left, top view) with zoom to the cross-section of the idealized railway tunnels (right)

Due to the size of the model, the concrete model was divided into a base plate and a cover plate. These two plates are additionally divided into blocks that can be lifted with the telescopic loader. Further, an additional attempt was made to find a plane lying diagonally in space, which is intersected by all tunnel and gallery systems. This plane should serve as the cutting plane of the blocks in the built model and be sealed with a

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[1] https://www.plexiglas.de/de/service/verarbeitung/plexiglas-biegen-und-formen

[2] https://www.laabmayr.at/

filler in the model for gas dispersion tests. The plane was retained until the final model, although it is also possible to switch to a stepped solution discussed later, which is certainly simpler to cast concrete.

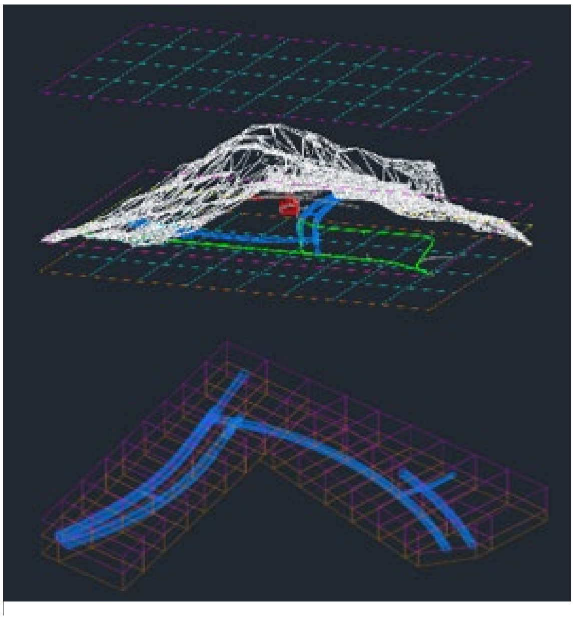

Figure 3: Model proposal with the topography of the Erzberg and geometry of the ZaB incl. the tunnel systems (top) as well as the block division of the model in a 3D view on a scale of 1:50 (bottom)

The scale for the final model was determined as 1:50. Furthermore, the feasibility of reproducing the terrain surface was questioned. This would have no or little influence on the test results but would require an enormous amount of concrete, as illustrated in the upper model in Figure 3. As a consequence, the modeling of the terrain surface was abandoned in the final solution. Nevertheless, to take the mass of the rock into account, an additional 25 cm (equivalent to 50 m) was modeled below the lowest point and above the highest point of the tunnel system. This is particularly necessary for the radiation tests taking place in the concrete model to avoid influencing the results to a large extent. The overburden or underburden was limited to 25 cm, as this dimension has a considerable influence on the weight of the blocks. The block division then resulted in 32 fields and thus 64 individual blocks to be concreted (Figure 3, bottom model). The entire model comprises a reinforced concrete volume of approx. 34.2 m^3 after deduction of the hollow tunnel geometry and the flat top and bottom faces of the blocks. When dividing the blocks, special care was taken to create geometries that can be concreted relatively easily and that have sufficient stability after stripping the formwork. In the case of transverse cuts, a crossing of 4 blocks had to be carried out to avoid the creation of thin, standing reinforced concrete cross-sections. An additional criterion for the cut was to ensure that the blocks could be reinforced as systematically as possible and that the agreed weight limit could be adhered to. In the course of the project, a weight limit of 2 tonnes for a standard block and 3 tonnes for exceptional blocks (edge blocks) was established.

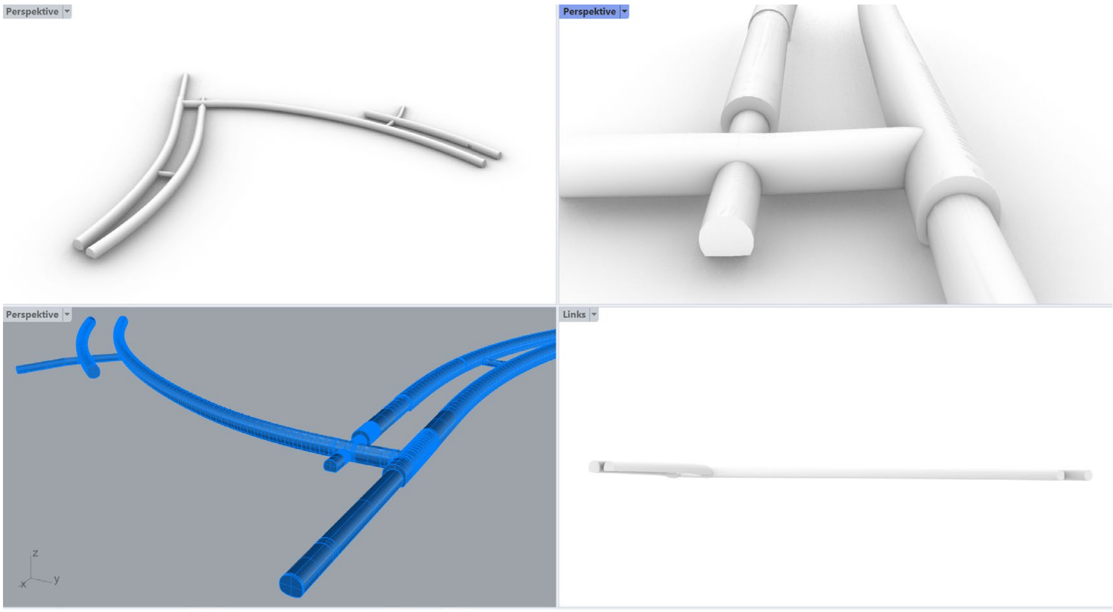

Figure 4: Final ready-to-mill model created in Rhino3D

To export the model to a STEP file format compatible with the CNC milling machine, the cross-sectional surfaces were drawn over splines in Rhino 3D. The final and ready-to-mill model can be seen in Figure 4. If the model or the 3D bodies are now actually milled, the geometry only has to be divided into 50 cm pieces for deep drawing and cut once in height. The Rhino 3D file or the finished STEP files can then be transferred to the milling machine.

4. Blasting tests in the Zentrum am Berg

Compared to the models for radiation and gas dispersion tests, respectively that only for gas dispersion tests, the development of a model for blasting tests in this sense was refrained from. However, it was determined that due to the limited experience with small-scale blasting, it would not be necessary to perform these in the models previously described. Instead, it was decided to conduct a series of advanced blasting tests, ranging from large ones to small ones, directly at the North Road Tunnel face at ZaB. These blastings aim is to derive a possible scale factor from the measured data (e.g., vibrations, blast vapor concentration as well as dispersion velocities), which does not exist up to now.

If blasting tests are planned in a model, it must be considered that only a small part of the surrounding rock can be represented. This means concerning vibration measurements, for example, that the reflection of the waves at the "outer boundaries" of the model must not be forgotten. In reality, these are diverted to the surrounding rock, but reflected at a bounded model and can thus falsify the measurement or the fracturing effect (compare small-scale open-cast blasting). This means that when blasting in a model, it should be tied to the surrounding rock to avoid reflections from behind the fracture wall.

a. Blasting cycle

The blasting test scales from large to small (Figure 5) are to be carried out according to the following blasting cycle:

1) Blasting at 6 m diameter, blasting requirements as per design

2) Production of a cross-section with a diameter of 4 m

3) Blasting at 4 m diameter, blasting material requirement according to design

4) Retraction of the remaining face from a diameter of 6 m to 4 m (dashed lines in Figure 5, right)

5) Blasting at 2 m diameter, blasting material requirements according to design, etc.

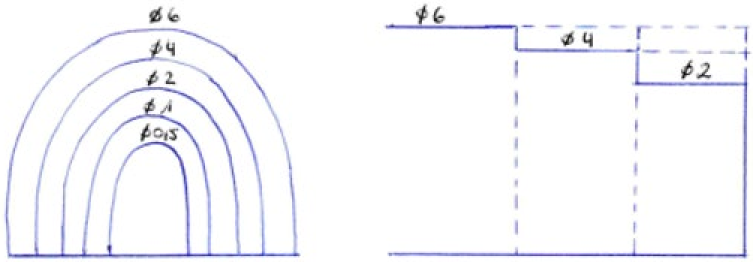

Figure 5: Concept blasting tests from the large to the small; view (left); section of the cut of the advance length (right)

The largest cross-section (ø 6 m) corresponds to the dimensions of the face of the advance blasting of the north road tunnel extension (see site plan Figure 1). Subsequently, the cross-sections are reduced blast section by blast section, for example, down to a cross-section diameter of 0.50 m. At this point, it should be mentioned that probably two to three cuttings in the next smaller profile are needed to restore the original situation at the face and to eliminate the influences of the disturbed rock of the previous heading blasting. One of the difficulties that will be encountered after two to three cuttings (reductions in cross-section) is that the minimum borehole diameter of 25 mm will be undercut. However, this is necessary to be able to install common blasting agents. To keep the disturbed rock area, caused by the preparation of the working face, as small as possible, a parallel collapse as a spiral collapse is intended.

b. Explosives

The same type of explosive should be used for all holes, regardless of type. Furthermore, for small-scale blasting, fuses should be sufficient as explosives. It should also be mentioned that the detonators, because of their small quantity of explosives (about 1 g), do not have to be dimensionally reduced or downsized as the cross-sections become smaller. Conventional explosives such as cartridge emulsion explosives or PETN explosives can be used for large-scale or real-scale blasting.

When calculating the explosive charge, it must be considered that each blast will affect the downstream rock (behind the face) to a depth of 15 to 20 meters. Therefore, the blast charge must be so lightly dimensioned that the compressive strength of the surrounding rock is exceeded, but not the tensile strength (corresponding to approx. 1/10 to 1/20 of the compressive strength), otherwise longitudinal cracks will occur in the direction of the rock behind the face.

c. Ignition system

The ignition of the boreholes should not be carried out by electric ignition systems. Therefore, a dual delay system (e.g., Austin Powder GmbH - Shock*Star Dual Delay detonator[3], Figure 6) is best suited for this project. This allows the ignition time sequence to be planned more precisely and the blasting to be better adapted to the local conditions. This detonator consists of a surface delay device that only initiates the detonation hose and a downhole detonator to ignite the explosive in the borehole. The advantage of the dual delay system (Figure 6) is that connections can be made more easily, and thus smaller amounts of hose are required. Consequently, it is also easier to control the connections at the blasting site.

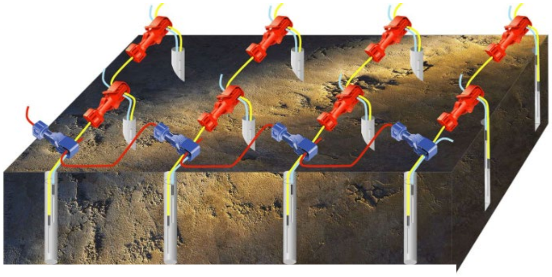

Figure 6: Dual Delay System – Austin Powder GmbH (Austin Powder GmbH 2018)

Since there must be no overlapping of measurement areas for a meaningful monitoring recording and evaluation, the boreholes may only be detonated one after the other. This means that all boreholes must be detonated one after the other using a surface retarder:

- 9 s delay in the borehole
- 100 ms delay from one borehole to the next (surface retarder)

The entire blasting design can be done with the help of the book "Applied explosives technology for construction and mining[4]" by Stig O. Olofsson.

5. Conclusion and outlook

The foundation for the realization of the small-scale tunnel research center has been created with this project. In the next step, experts must be involved to verify the results of the blast design and concrete formulation. Furthermore, such companies must also be recruited to support the implementation. Whether a proportionality factor or a formula is finally derived can only be established by numerous representative tests on the future models.

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