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ИЗМЕРЕНИЕ И РАСЧЕТ ХАРАКТЕРИСТИК СЖИМАЕМЫХ ЭЛЕМЕНТОВ ДЛЯ КРЕПЕЙ ГОРНЫХ ВЫРАБОТОК

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Аннотация.
При проходке тоннелей с использованием щитовых агрегатов или открытых тоннельных буровых станков для крепления горных пород используются разные технологии. Тюбинговые опоры обычно состоят из нескольких бетонных сегментов. В случае высоких значений конвергенций пород крепь должна позволять выдерживать большую нагрузку. Это может быть реализовано с помощью соответствующих элементов, таких как WABE с его характерной «сотовой» структурой. Для многих из этих решений характеристики сжимаемых элементов были проверены в тестах на сжатие. Задача заключалась в разработке инструмента для высококачественного прогнозирования поведения сжимаемых элементов. Была разработана расчетная модель для расчета характеристик силовых отклонений по различным параметрам. Характеристики могут быть рассчитаны в диапазоне от прямой трубы (без прогиба) до максимального отклонения (сплющенная труба). Представленный инструмент дает новые возможности для применения сжимаемых элементов для тюбинговых систем и систем арочной крепи. Характеристики могут быть спланированы точно в соответствии с требованиями, касающимися конвергенции и крепления пород.

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Ключевые слова: тюбинговые опоры, горная крепь, сотовая структура, конвергенция пород.

MEASUREMENT AND CALCULATION OF THE CHARACTERISTICS OF COMPRESSION ELEMENTS FOR MINING SUPPORTS

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Abstract.
During tunneling using closed shield machines or open tunnel boring machines, different technologies are used for rock support. Tubbing supports typically consist of several concrete segments. In case of high convergences supports must be able, to avoid too high load effects on themselves. This may be realized by compliance elements like WABE with its characteristic “honey comb” structure. For a lot of these solutions the characteristics of the compression elements were verified in compression tests. The challenge was to develop a tool for the high quality forecast of compression element behavior. A calculation model was developed in order to calculate the force-deflection-characteristics regarding various parameters. The characteristics can be calculated from no deflection of the pipe until maximum deflection (flat pipe). The introduced tool gives new opportunities for the application of compression elements for tubbing systems and arch support systems. The characteristics can be planned exactly according to the requirements regarding rock structure convergence and support system.

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Mining Supports

During tunneling using closed shield machines or open tunnel boring machines different technologies are used for rock support. Tubbing supports typically consist of several concrete segments. The segments are assembled to a closed ring, which is finalized by a so called key segment. Tubbing supports are more or less rigid. Concrete quality and reinforcement are suitable to bear rock pressure. If rock pressure exceed limit states tubbing failure can be expected. The same behavior may be expected in usage of grid girder rigid supports (Fig 1, Fig. 2).

Fig. 1: Grid girder rigid support with compression elements [Bochumer Eisenhütte GmbH & Co. KG]

Fig. 2: Grid girder rigid support with compression elements [Bochumer Eisenhütte GmbH & Co. KG]

Compliance elements for mining supports

In case of dynamic, high pressures, fault zones in rock respectively high convergences supports must be able, to avoid too high load effects on themselves. This may be realized by compliance elements (Fig. 3). They must be designed to absorb the rock convergence without overloading the rigid support, which is not able to deform significantly.

The resistance of the compression elements has to be somewhat lower than that of the support structure. During absorption the support circumference has to be reduced. Result of this process is a new state of equilibrium. This especially applies for concepts, where the rock structure supports itself after convergence instead of taking full forces by the implemented support. During this process considerable deformations may occur during several months.

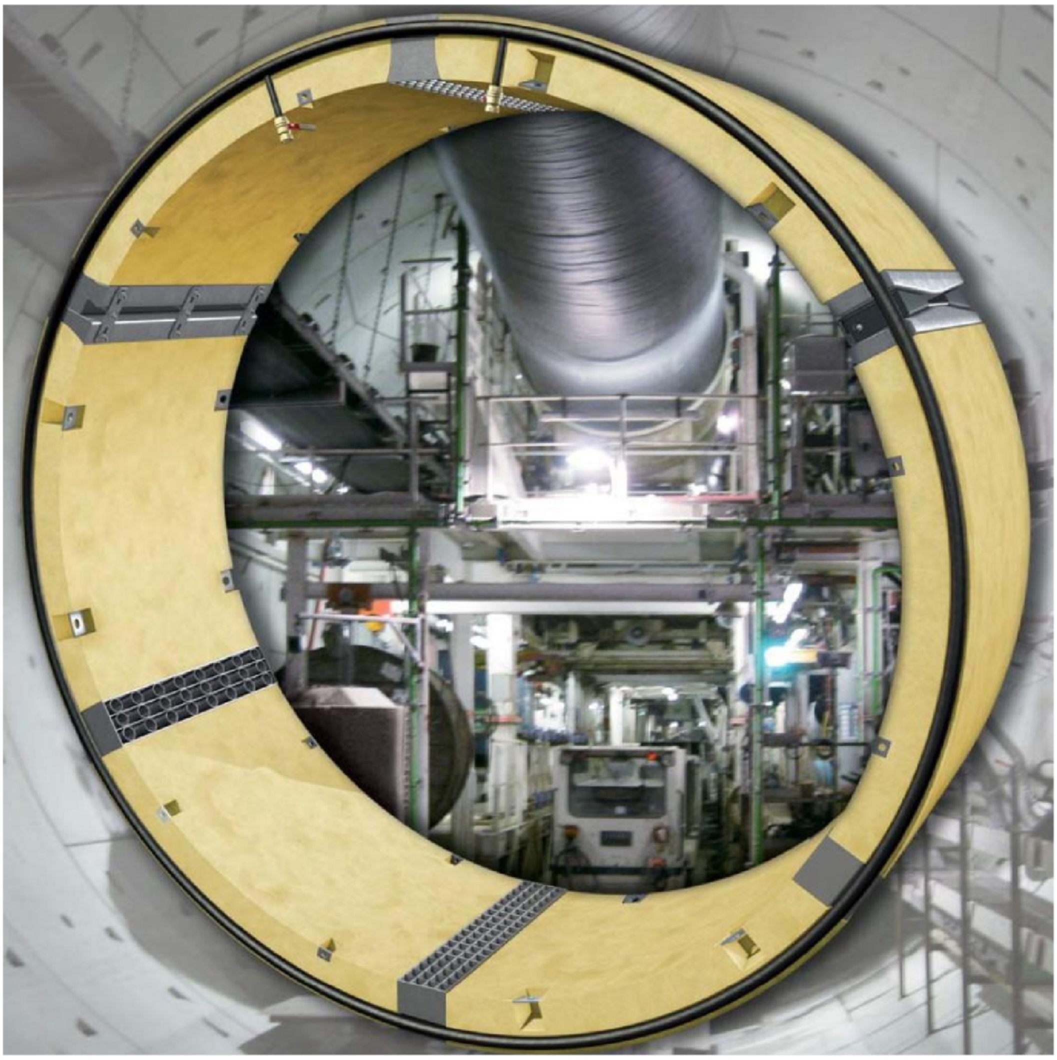

Fig. 3: Compression elements of different types [Bochumer Eisenhütte GmbH & Co. KG]

Compression elements type WABE

One solution to ensure deformability of the rigid support are compression elements type WABE with "honey comb" structure of Bochumer Eisenhütte GmbH & Co. KG (Fig. 4). The compression elements consist of circular hollow sections, which are divided respectively linked by intermediate sheets. The upper and lower sheets include mounting elements for installation at support as well as reinforcement elements for concrete interconnection. Deformability is achieved by complete com-

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pressibility of the gaps in comb wise structure. Therefore approximately total height of stress controlling compression elements is used as yield way. Advantages of this solution are:

- Selectable, additional deformation resistance by application of variable intermediate supports.
- Prearranged adjustable resistance.
- Selectable deformation distance.
- Possibility to use different types and materials of intermediate elements.
- Easy handling by module design options.
- Continuous interconnection element by spraying with porous concrete for higher acceptance of transverse and bending forces.
- Customizable shaping.

The elements type WABE allow force absorption in tangential (normal forces), radial (lateral forces) and axial (Longitudinal force in the direction of advance) direction.

The chosen characteristics of the compression element is controllable and depends on diverse parameters as pipe diameter, pipe wall thickness, pipe length and pipe material and quality.

Various parameter combinations and different pipe combinations allow the adjustment of required characteristics. Additionally the characteristics can be adjusted during use by implementation of additional pipes inside the original pipes. So the compression element can be adjusted to the strength of hardening concrete.

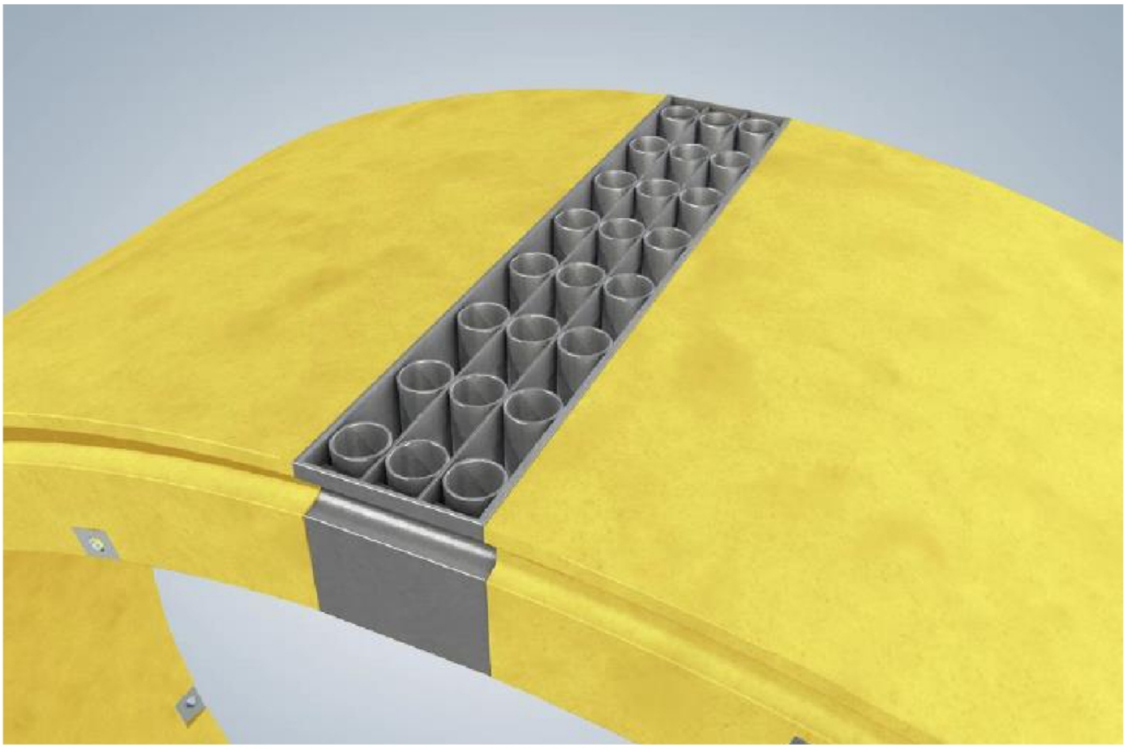

Fig. 4: Compression element of type WABE [Bochumer Eisenhütte GmbH & Co. KG]

Measurement of Characteristics

In the meantime a lot of compression elements were designed, built and implemented already. For most of these solutions the characteristics of the compression elements were verified in compression tests (Fig. 5, Fig. 6). Result of these tests are force-deflection-characteristics (Fig. 7). They separate in three phases. In phase one the force is rising within a small deflection. This happens just according to the setting of the whole mechanical setup. In phase two the force is increasing slightly over about 70% of the maximum theoretic compression. In phase three, occurring after exceeding about 70% of the maximum theoretic compression, the force is increasing with higher gradients. As to be expected forces are higher with higher yield strength of the pipe material (Fig. 7).

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Fig. 5: Compression test, initial condition [Bochumer Eisenhütte GmbH & Co. KG]

Fig. 6: Compression test, compressed condition [Bochumer Eisenhütte GmbH & Co. KG]

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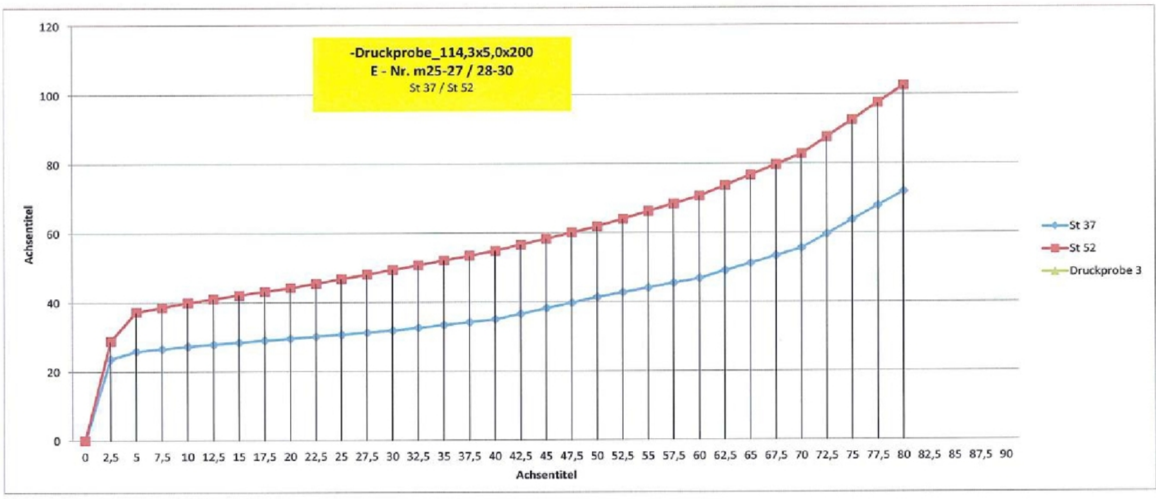

Fig. 7: Measured compression element characteristics [Bochumer Eisenhütte GmbH & Co. KG]

On basis of these test results a database and expert system was built up and developed, in order to have a base for planning of upcoming projects. This database is an excellent base for forecasting compression element behavior, if system parameters are not differing too much from cases covered by the database. In combination with verification of every built element this is a profound planning base.

Calculation of Characteristics

The challenge was to develop some tool for the high quality forecast of compression element behavior. Especially this tool should be able to deal with elements of very new parameter sets. To realize this target a new mechanical model considering plasticity was developed. Aspects of this model are:

- Modeling as four joint.
- Corners of four joint fully plasticized at every moment.
- End of pipe circular at every point of time.
- Radius of circular end decreasing according to element deformation.
- Rest tube shell length laid out flat.
- According radius reduction size of four joint is reduced.

With this model it is able, to calculate the force-deflection-characteristics regarding following parameters: Outer pipe diameter, pipe wall thickness, pipe length, pipe material parameters, number of columns of pipe arrangement, number of rows of pipe arrangement. The characteristics is calculated from no deflection of the pipe until maximum deflection (flat pipe). The characteristics of the pipe considered looks as follows (Fig. 8).

Accuracy

In order to estimate the quality of the model a bundle of realized projects was analyzed. The diagram (Fig. 9) shows the medium deviation of measured data from the calculated data, depending on the convergence of the element. At smaller convergences a maximum medium deviation of about 9% is occurring. This value is not of high importance. It just indicates, that the surrounding construction has to bear somewhat higher forces at smaller convergences. At higher convergences a maximum medium deviation of about -4% is occurring. In this situation the surrounding construction has to bear somewhat lower forces at higher convergences. This can be interpreted as some additional protection to the surrounding construction.

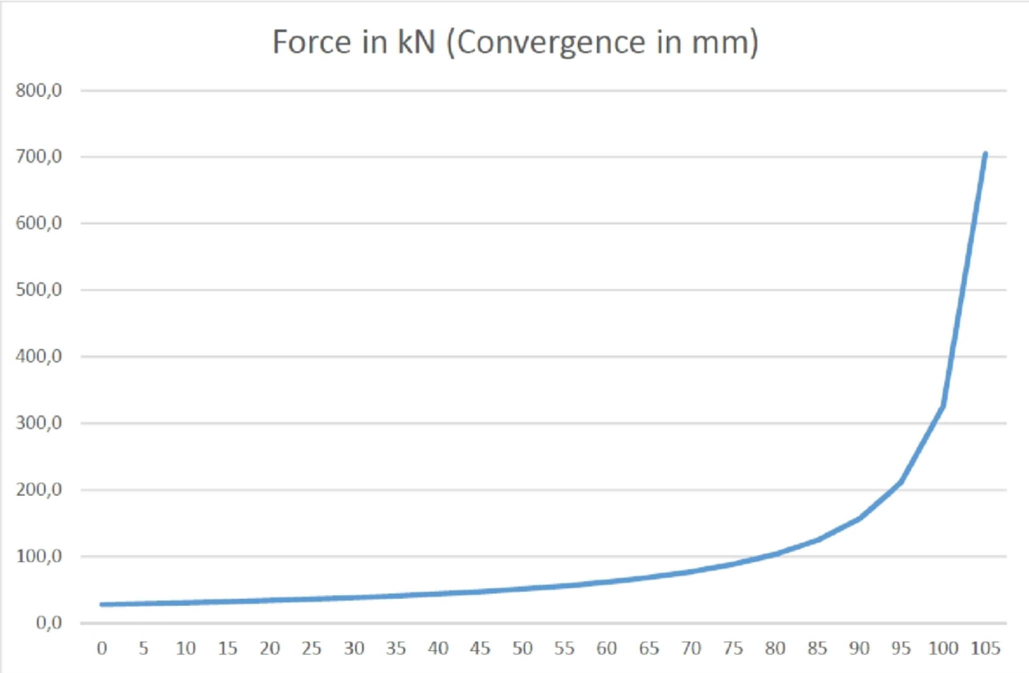

Fig. 8: Calculated compression element characteristics [AppliedDesign]

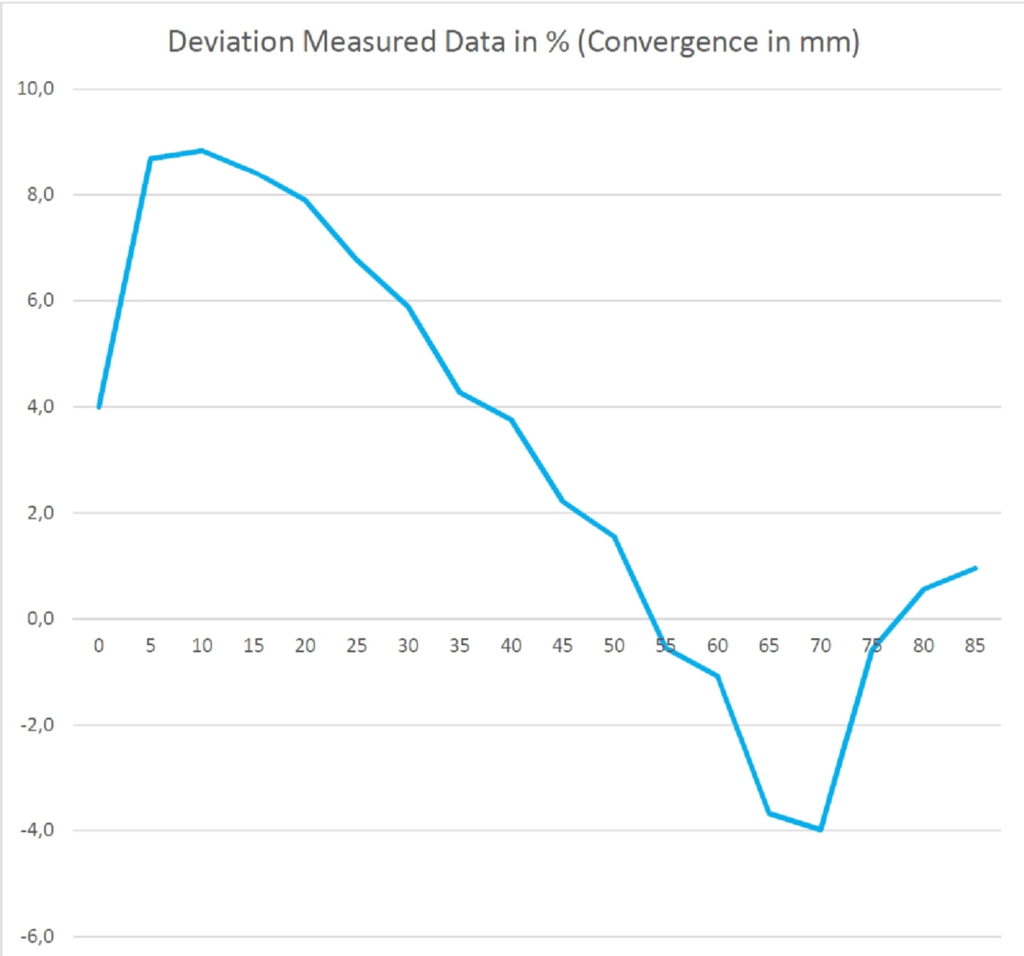

Fig. 9: Medium deviation of calculated data against measured data [AppliedDesign]

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Conclusions

The introduced calculation of the force-deformation-characteristics gives new opportunities for the application of compression elements for tubbing systems and arch support systems. The characteristics can be planned exactly according to the requirements regarding rock structure convergence and support system. Diverse parameters of the compression element offer diverse degrees of freedom to find a suitable design. These means of planning prevent non-suitable designs, which are not realized not until the built parts are tested. So product development is accelerated and more focused on the target.

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