Austrian Society for Geomechanics

The Austrian Practice of NATM Tunnelling Contracts

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1 PRELIMINARY REMARKS

1.1 General

Tunnelling stands out among the various engineering disciplines for its large measure of unpredictability. It is in particular the uncertainties of the ground which call for an approach that differs from many of the other engineering disciplines.

Its special feature is the need for intensive feedback between assumptions and reality. Information needs to be gathered constantly on actual ground conditions, characteristics, actual ground behaviour and the interaction between the ground and the selected tunnelling methods (supports and construction processes). This information will form the central basis for adjusting the design directly at the tunnel site. This in turn will enable optimum decision-making only where information of this kind is provided in "real time", that is, as tunnelling proceeds.

For optimum decision-making at the tunnel site, it is necessary to provide for the following conditions during the tendering phase preceding NATM (New Austrian Tunnelling Method) tunnelling:

- Adequate preparatory investigation and description of the ground,
- Interpretation of the forecast in terms of tunnel engineering and geomechanics,
- A design that covers the expected range of ground behaviours,
- Formulation of criteria and targets that should govern the selection of the various tunnelling methods.

If a tunnelling method is to be safe and economical, it needs adequate adjustment to changing ground conditions by use of flexible construction methods.

Construction contracts must thus answer the requirement of flexibility in order to enable the strengths of the NATM, which lie primarily in its adaptability, to be used to best advantage. **Austrian Standard ÖNORM B 2203-1"Underground works-Works contract" Part 1** Cyclic driving, which forms the basis for contracts in tunnel construction, addresses these requirements.

The construction contract needs to be drawn up in a manner that will serve as the best possible aid for optimal decision-making. The "flexible" construction contract in conformity with B 2203-1 thus meets the following principles:

- The ground-related risk, that is, the risk of differing ground properties and ground behaviour, is borne by the owner (risk allocation instead of risk sharing);
- The construction contract provides unit prices for all tunnelling items expected to be needed on the basis of the tender design;
- Payment is made for actual tunnelling work, rather than work items provided for in the design;
- The items of the bill of quantities and the payment models are formulated so that in the event of changes in the tunnelling process payment is adjusted largely without the necessity of a variation order;

- The construction contract provides for decision-making at the tunnel face, with a mutual agreement between owner and contractor. These decisions are based mainly on results of on-site inspection, geological and hydrogeological routine documentation, geotechnical measurements and the constant evaluation and interpretation of such information.
- In case agreement cannot be reached, the authoritative decision of an official tunnelling expert can be resorted to; this person is a mediator appointed by contract whose advice is sought in the case of difference of opinion in technical matters between owner and contractor.

1.2 Risks and responsibilities

Although Austrian Standard B2203-1 provides for no explicit allocation of risk, the following principle of risk sharing between owner and contractor is applied:

- **The risks and responsibilities of the owner include:**

  All information provided by the owner (such as preliminary work, tender documents, detailed construction documents) and the **ground**.

Thus, the ground is clearly the responsibility of the owner. Austrian Standard B2203-1 mentions "characterisation of ground (rock mass)" instead of a description. This should be prepared in conformity with the Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation issued by the Austrian Geomechanics Society (ÖGG). This guideline states that such characterisation should be made not only for the properties of the ground (rock mass), but also – and in particular so – for its behaviour. This clear allocation (also) of ground behaviour to the owner's sphere of risk is a special feature of the B2203-1, which goes beyond the international contractual practice laid down in the FIDIC Red Book of 1999. The B2203-1 stipulates the preparation of a Geotechnical Interpretative Report, which falls within the responsibility of the owner.

Note for the sake of comparison: Paragraph 4.10 "Site Data" of the FIDIC Red Book mentions "subsurface and hydrological conditions" and provides for the contractor to be responsible for their interpretation.

The following thus remains within the sphere of the contractor:

- **The risks and responsibilities of the contractor include:**

  All assumptions made by the contractor on the basis of the tender documents for price calculation and construction; all arrangements made by the contractor and by the suppliers and sub-contractors selected by him.

1.3 Fundamental structure of a bill of quantities

Unit price contracts usually provide two item categories:

- One-off pay items (flat-rate items such as site facilities, site clearance etc.) and

- Quantity-dependent pay items (items for payment according to pay quantities such as tunnel excavation, support elements etc.)
    - labour costs
    - material costs
    - costs of equipment operation and wear.

The intended flexible construction contract provides an additional item for

- Time-dependent pay items

  These are items that are only indirectly dependent on the quantities to be provided, while being directly dependent on the construction time.

    - costs for the site manager, engineers, surveyor, quantity surveyor etc. and for auxiliary site personnel (such as cleaning staff),
    - cost of site equipment, such as for implicit depreciation and interest as well as maintenance (repair) of equipment other than listed among the costs of individual pieces of equipment within a quantity-dependent item,
    - cost of operating special equipment (such as a workshop, warehouse, accommodation, canteens),
    - cost of operating site vehicles,
    - other continuing site overheads (such as rents, leases, communication, heating, lighting).

Payment for such items must be made even when due to unforeseen events either no or reduced quantity-dependent items are executed. The time-dependent pay items and consequently the time-dependent costs normally remain unchanged during such a phase.The time-dependent item category is thus also intended to ensure the realistic management of payment for the normal work which continues to be needed during such unforeseen phases.

In the case of a ground-related event or other unexpected incident (within the owner's sphere of risk and responsibility) affecting the normal tunnelling operations, the time-dependent items are paid for on the basis of the time elapsing until tunnelling is resumed. In addition, the contractor receives payment for all quantity-dependent and/or potential one-off items implemented during such a period.

The idea of time-dependent pay items is, among other things, to avoid the arising of any advantages or disadvantages for the contractor as the result of unexpected tunnelling scenarios. During such phases, the contractor receives payment for the greater part of the work to be performed by way of the regular settlement procedure (monthly progress payment). This minimises conflicts of interests, while supporting the desired optimal decision-making process.

2 TENDERING AND COSTING

2.1 Time-dependent costs (B2203-1: 4.3.1)

2.1.1 Tendering procedure

Tender documents should provide special pay items for time-dependent costs. For underground work of major longitudinal extent, these items should be subdivided into phases in conformity with the sequence of works as shown below:

a. Commencement of the construction works to commencement of tunnelling (fixed time),
b. Tunnelling (variable time),
c. Extra charge on tunnelling for simultaneous installation of final lining (variable time),
d. Installation of final lining after the contractual end of tunnelling (variable or fixed time),
e. Work following the installation of the final lining (fixed time)

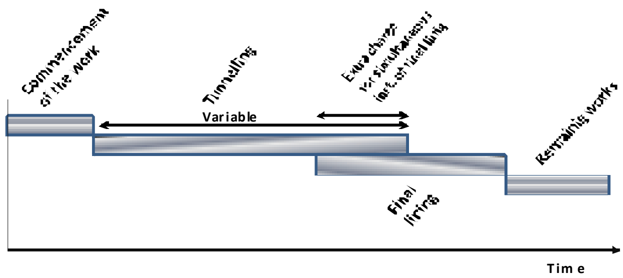

Figure: Simple work sequences for time - dependent cost

In the case of complex work sequences, in particular where several headings and above-ground work are implemented simultaneously, an allowance should be included for overlaps, mutual dependencies and the potential complications involved. The work sequence underlying the costing sheet should always be based on the critical path as follows from a construction schedule provided by the owner.

Whereas phases a., d. and e. are considered independent of the ground conditions actually encountered, phases b. and c. are directly dependent on the tunnelling conditions, such as ground behaviour, tunnelling classes (TC), supplementary measures and special measures.

It is thus necessary to agree by contract on advance rates for each predicted tunnelling class and also for potential supplementary and special measures as well as complications. These advance rates should be included in the offer submitted by the bidder.

2.1.2 Costing guidelines

Advance rates are calculated by the bidder. These are primarily based on:

- typical cross sections,
- tunnelling classes (TC) and their lengths, including typical support-element drawings,
- excavation method,
- multiple-drift tunnelling and criteria for longitudinal spacing of drifts, ring closure distance
- ground characterisation (rock mass behaviour, geotechnical longitudinal section).

A cycle period for one excavation round is calculated referring to all other tender information, in particular information on geology and rock-mass behaviour, as well as for the boundary conditions of the project, and serves as a basis for calculating an advance rate for each tunnelling class. The length of an excavation round is assumed as being the upper limit of the round-length range.

Example: Cycle diagram for tunnelling class 5/2.21 (see Annex 1):

Drilling, charging	90min
Blasting, ventilation	20min
Mucking	120min
Wire mesh and steel arch installation	40min
Shotcrete Spraying	90min
Anchor installation	40min
Other	10min
Total	410min / 60min/h = 6.8h per cycle

For a length of 1.7m per excavation round and a daily working time of 24h/d, the resulting advance rate is

24h/d / 6.8h/cycle x 1.7m/cycle = 6.0m/d

This method is applied for determining advance rates for all tendered tunnelling classes (TC), and for entering them in a construction-time calculation table. The predicted tunnelling time is calculated from the tendered tunnelling class lengths and the advance rates offered.

The pay items for time-dependent costs are tendered and offered as lump sums in order to permit cost comparison during bid evaluation.

Example: Conversion of time-dependent cost lump sum into pay units (see Annex):

The following example shows the method of converting one lump sum (1LS) related to the predicted tunnelling time into pay units (PU) at contract award to permit payment during the construction period.

Pay item in the offer:

Item xxx Time-dependent tunnelling cost 1 LS € 996,265.-

This lump sum relates to a predicted tunnelling time, calculated from the offered advance rates and predicted tunnelling-class lengths of 104.65 work days (WD).(see Annex, Page 23)

Item in the contract:

Item xxx Time-dependent tunnelling cost

104.65 PU of € 9,519.97 each WD = € 996,265.-

2.2 Tunnelling Classes (TC) (B2203-1 : 4.3.2)

2.2.1 Tender documents

The geotechnical design of underground structures is based on the Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation issued by the Austrian Geomechanics Society (ÖGG), which describes the individual design phases.

In the tender design phase, the final step in geotechnical design for typical support-element combinations and work sequences is determining tunnelling classes in conformity with B 2203-1. Tunnelling classes are best defined in the form of a matrix (tunnelling class matrix) considering the excavation methods required for technical reasons (such as blasting or mechanical excavation), subdivisions of the specified excavation cross section and the longitudinal development of the sequence of tunnelling activities. These boundary conditions should remain unchanged for each line in the matrix, or else a different matrix should be provided.

The matrix provides a separate box for each tunnelling class, defined by first and second organising numbers. The first organising number for top heading and bench or full face (no division into top heading and bench) results from the splitting of the tunnelling activities into round-length ranges, while the excavation of the invert is split up according to opening-length ranges.

Each typical support-element design (characteristic support-element combination) is based on the sum total of quantities of support elements and supplementary measures multiplied by the rating factors provided in B2203-1, Table 3. This sum is then divided by the corresponding "rating area". This gives the support number as the second organising number.

The rating factors for the individual support elements are dimensionless and mutually balanced factors that represent a relative measure for the time required for installing the support elements. The implementation of a rating area considers the more efficient installation of support elements in larger cross sections. The support on the tunnel shape increases linear with tunnel diameter, while rating area increases exponentially with the power of two.

No support number is determined for the invert. The second organising number results from the type of primary support, that is, open floor, invert slab, invert arch with or without longitudinal division.

The scope of application of the second organising number (the "width of the matrix box") is a function of the round length as shown in Standard ÖNORM B2203-1, Table 4.

The tender documents should provide an excavation pay item for each tunnelling class in m³.

2.2.2 Costing guidelines

- **Labour costs**

Computation of the advance rates for the individual tunnelling classes should include the entire tunnelling cycle, (i.e both the principle excavation work and the installation of support elements, should be weighted together). It is natural, therefore, that the overall labour costs calculated for the tunnelling crew should be considered in the excavation item so as to avoid burdening the support items with labour costs.

Minor changes in support quantities arising as tunnelling proceeds will not affect the advance rate in any appreciable degree. Should major changes in support quantities occur, however, the application of the rating factors will result in a new support number and, hence, a new second organising number. Then a different tunnelling class will apply in the matrix system and this will be based on a different contractual advance rate and thus involve different labour costs.

Within the area of a matrix-box there is no difference of advance rates and excavation item price. It is the contractor’s risk where inside this area his calculation lies.

B2203-1 does not, however, provide for the entire tunnelling wages to be included in the excavation pay item. It is also permissible to allocate wages to individual support elements.

Where the matrix model is applied, the labour costs in the excavation items will normally be computed as follows:

- Workforce x working time (h/WD)* / advance rate (m/WD) **=**
  man hours / m (MH/m)

- MH/m / cross-sectional area (m²) **= man hours / m³ (MH/m³)**

*WD = work day.

For the purposes of the above calculations, the cross-sectional area is understood to be the specified excavated face area, as this is the quantity for which payment will be made.

- **Other excavation costs**

The other costs of the excavation item include

- auxiliary materials such as explosives and blasting accessories (kg/m³),
- secondary materials (€/m³),
- working consumables such as power (kWh/m³) and
- diesel (lt/m³) and wear parts ((€/m³) for equipment.

These are derived from empirical values obtained from back analysis of costing for previous projects and adjusted to meet the requirements or boundary conditions of the current project. The working consumables power and diesel can each be categorised as a work-related part (such as tunnelling equipment) and a time-related part (such as lighting, ventilation, pumps etc.). These must be designated as such in the cost calculation to enable the contractor to realise these costs adequately. In order to ensure fair payment, time-dependent other costs should be shown in the items for time-dependent costs, where they are paid per day or payment unit even through periods of tunnelling interruption.

2.3 Difficulties due to water ingress (B2203-1: 4.3.6.1 and 5.5.2.6.1)

2.3.1 Tender documents

The Standard B2203-1 distinguishes on principle between dewatering (pump sumps, pumps, piping etc.) and water complications incurred during the implementation of the tunnelling works. Dewatering and water complications form separate pay items.

Dewatering measures include works required for removing the water from the drive. Water complications are understood to be those complications which affect and thus delay tunnelling due to inrush of underground water in the face- working area. Payment for this delay is made through additional labour cost, time-dependent costs and additional construction time.

In the preparation of the tender, the owner estimates the number of days on which water complications are expected to occur, using the geological predictions, and specifies the following:

- contractual critical flows,
- predicted flows,
- up gradient or down gradient tunnelling,
- impact of water on the rock mass,
- partial drift in which the water complications occur (crown, bench, invert),
- location of water ingress within the partial drift (may be omitted where appropriate).

Allowance for difficulties is made by the owner in the construction-time calculation tables of the tender documents by specifying expected work days in a matrix on the basis of up to 6 different yield ranges for water inflow and in up to 4 different complication classes.

2.3.2 Costing guidelines

The bidder should list reduction factors for advance rates within certain limits for each water range and each complication class (from favourable to very unfavourable). If the yield of underground water is larger than the critical flow within the specified tunnelling face-working area, this reduction factor is applied to increase the corresponding contractual time (without water complication) by an additional tunnelling time (to allow for water difficulties).Pumps, pump sumps, pipes e.g. are paid with separate items.

2.4 Over-excavation and excess concrete (B2203-1 : 4.3.5 and Fig. 2 and Fig. 3)

Any excavation outside the specified excavation profile is termed over-excavation in B 2203. This is a generic term that includes deformation allowance ($ü_m$) and over-profile ($ü_p$).

2.4.1 Tender documents

- **Deformation allowance "$ü_m$"**

Deformation of the rock mass following excavation reduces the excavated underground space. In order to arrive at the specified tunnel size it is necessary to enlarge the excavation volume by an adequate allowance, the deformation allowance ("$ü_m$"). This enlargement is considered in computing excavation volumes and support quantities. Adjustment of the deformation allowance as the work proceeds is possible. This is the responsibility of the owner.

The actual deformation of the rock mass (v) is determined by measurement.

It is rarely possible to estimate in advance exactly what the deformation will be. The difference between the deformation allowance and the actual deformation volume ($ü_m$-v) must, therefore, be filled up with inner-lining concrete. This concrete quantity is paid for by the owner and the computation method to be used is specified in the tender documents.

- **Over-profile ($ü_p$)**

As a result of the natural properties of the rock mass and the excavation method used, the actual excavation contour will lie on the outer side of the specified excavation line.

The magnitude of the difference depends both on the working skill of the contractor and the properties of the rock mass, which are the responsibility of the owner. Accurate contractual separation of the spheres of responsibilities between owner and contractor is not possible.

The spheres of responsibility of owner and contractor are, therefore, defined by fixing a limit for the excavation work. This dimension is termed over-profile ($ü_p$). The excavation line displaced by the dimension $ü_p$ is termed boundary surface A. The dimension $ü_p$ is specified by the owner for each round-length range in the tender documents. By experience this will be between 0.2 and 0.4m, dependent on the magnitude of the cross-sectional area. It is well known that longer round lengths cause more over-profile.

No extra payment is made for over-excavation inside boundary surface A. This should be allowed for by the contractor when pricing the tunnelling classes specified in the tender documents. Over-excavation outside boundary surface A, unless caused by improper work, is paid for under separate items independent of tunnelling classes.

Separate pay items are provided for filling up over-excavation volumes with shotcrete or concrete. Boundary surface A moves into the cavity as a result of the actual deformations, so as to form a new boundary surface B. Payment for filling up accepted over-excavation volumes on the outer side of boundary surface B is based on cubic metres. Payment for over-excavation on the inner side of boundary surface B is per square metre of excavated surface, with filling of inner-lining.

2.4.2 Costing guidelines

Since no separate payment is made for over-excavation on the inner side of boundary surface A, the contractor needs to make a price allowance for such extra volumes. This not only concerns the excavation perimeter, because wire mesh, lattice girders / steel arches will also need to be installed later along a larger radius and a substantial proportion of this over-excavation volume will be filled up with shotcrete to comply with the specified excavation line.

Costing must naturally allow for these excess-quantity factors.

Example: It is accepted practice to assume, for a specified risk limit $ü_p$ of 0.3m, an extra shotcrete thickness of some 0.15m for the primary lining in order to meet the level-surface criteria for the subsequent installation of waterproofing and final lining.

Assuming a theoretical nominal thickness of 0.2m and a rebound of 15%, this would give a shotcrete excess consumption factor of (20+15)/20*1.15 = 2.0, for which allowance must be made in costing.

Filling-up of the remaining 0.15m – or possibly more or less as estimated by the contractor – with final-lining concrete should be tendered per square metre in a separate item. This pay item on a square-metre basis enables the contractor to allow in his costing for expected thickness increases or reductions on the basis of the limit $ü_p$. No payment is made for filling up gaps caused by attested improper work.

2.5 Support elements (B2203-1 : 4.3.7 and 5.3.3.3)

2.5.1 Tender documents

Adequate pay items should be provided for the individual support elements. The quantities should be calculated on the basis of the predicted distribution of tunnelling classes as seen from the tunnelling drawings. The computed quantities (for unforeseen events, supply of subsequent support elements etc.) should not be increased by more than 5-10% in the tender documents. Reserve quantities of more than 10% may have undesirable impacts on pricing and make bid comparison difficult.

2.5.2 Costing guidelines

The pay items for support elements should allow for the costs of support materials including excess consumption (overlap of wire mesh, overlap of steel arches, excess shotcrete consumption from over-excavation and rebound) in addition to the required operating costs and costs of auxiliary materials and wear. The wages for the corresponding installation works are normally (see 2.2.2 above) included in the labour cost for the entire tunnelling crew in the excavation item.

3 CONSTRUCTION AND PAYMENT

3.1 Time-dependent costs (B2203-1 : 5.5.2.1)

Payment for time-dependent tunnelling works is made on the basis of contractual tunnelling time rather than on actual tunnelling time.

Below is an example showing the method of determining contractual tunnelling time from tunnelling classes (TC).

Tunnelling Class	**Predicted tunnel length**	**Actual tunnel length**	**Contractual rate of advance**	**Predicted tunnelling time**	**Contractual tunnelling time**	**Actual tunnelling time**
1	2	3	4	5	6	7
TC 5/2.21	53,2	94.0m	6.00m/WD	8.9 WD	15.7 WD	18.0 WD
TC 5/3.53	80.0m	78.0m	5.20m/WD	15.4 WD	15.0 WD	12.0 WD
TC 5/4.93	66.8m	28.0m	4.00m/WD	16.7 WD	7.0 WD	9.0 WD
Tunnelling interruption				0.0 WD	1.0 WD	1.0 WD
Total	200.0m	200.0m		41.0 WD	38.7 WD	40.0 WD

In the example above for a tunnel length of 200m the predicted length of each tunnelling class is shown in column 2. The contractor gave contractual rates of advance (e.g. 6.00m/WD for TC 5/2.21 in column 4). The predicted tunnelling time, computed from predicted tunnel lengths and contractual rates of advance, is shown in column 5.

The tunnelling class lengths actually encountered during the works are shown in column 3. The contractual tunnelling time, shown in column 6, was calculated from the actual tunnel lengths and the contractual advance rates.

Column 7 reveals that the contractor took longer to do the TC 5/2.21 and 5/4.93 sections and less time for the TC 5/3.53 section (compare column 7 with column 6). With a tunnelling time of 40.0 WD, the contractor was slower by a total of 1.3 WD than stated in the contract.

Payment for this time-dependent cost item is not based on the actual tunnelling time of 40.0 WD, but on the contractual tunnelling time of 38.7 WD. This comes from the fact that the increased tunnelling time of 1.3 WD falls within the sphere of the contractor. This model thus commits the contractor to make up for excess tunnelling time in another tunnel section. At the same time, this model provides an incentive for the contractor to speed up the work and thus to acquire some advance over the contractual tunnelling time, which he may use as a cushion for the works ahead. (An additional example is given in the Annex)

The following demonstrates the separation of risk and responsibility:

The change in TC distribution, which in this case has caused the tunnelling time to be reduced from 41.0 WD to 38.7 WD, falls within the owner's sphere of risk and responsibility. This reduction "belongs" to the owner since it is a result of the ground conditions.

The contractor's risk and responsibility is the non-realisation of the contractual advance rates in TC 5/2.21 and 5/4.93, a delay which was not entirely made up for by the increased advance rate in TC 5/3.53. The excess tunnelling time of 40.0 – 38.7 = 1.3 WD must be made up for the works ahead. If this involves extra expenses, these are borne by the contractor.

3.2 Tunnelling interruptions

In case the sequence of works (tunnelling, concrete pouring etc.) is interrupted for reasons not within the contractor's responsibility, payment for the time-dependent costs occurring during this period is continued on the basis of the relevant items of the bill of quantities. The labour cost for the crews must also be reimbursed unless these cannot perform other works at the site for which proceeds may be generated. Such reimbursement usually calls for an amendment to the contract to be agreed on.

3.3 Selection of supporting measures and classifying tunnelling (B2203-1 : 5.5.2.3)

The information obtained from the geotechnical measurements, the geological documentation and visual inspection of the tunnel and the ground forms the basis for deciding, by mutual agreement between owner and contractor, on the action to be taken for the tunnelling work ahead. The results are documented in primary-support stipulations. This kind of on-site decision-making takes place on a daily basis. The primary-support stipulation has the status of a working drawing.

Where no agreement is reached on site between owner and contractor, advice is sought from a independent tunnel expert so as to avoid tunnelling interruptions due to contractual disputes.

The primary-support stipulation can omit specification of quantities for the individual support elements or can specify ranges. The works actually implemented are documented in an excavation-round report jointly by owner and contractor. The support number or 2nd organising number is determined, for each round, from the quantities of support elements installed, on the example of the tender documents. The round is thus assigned a certain tunnelling class.

3.4 Over-excavation (B2203-1 : 5.5.2.4)

3.4.1 Over-excavation on the inner side of boundary surface A

This volume does not need to be measured during implementation of the work as this is allowed for in the excavation unit price.

3.4.2 Over-excavation outside of boundary surface A

In case over-excavation occurs outside of boundary surface A despite proper work, this should be measured jointly by owner and contractor prior to shotcreting. Payment for excavations of this kind includes the loading, hauling and disposal of the material.

3.4.3 Over-excavation to provide for the deformation allowance ($ü_m$)

In determining excavation volume, this over-excavation should be understood to be excavation as designed.

3.5 Excess concrete

3.5.1 Excess concrete on the inside of boundary surface B ($ü_p$)

The additional concrete requirements are not measured. The excess concrete for "$ü_p$" item in m² is calculated according to round-length range along pay line "1b".

3.5.2 Excess concrete on the outside of boundary surface B ($ü_p$)

Concrete or shotcrete, according to expediency, for filling up over-excavation (m³) as jointly measured by owner and contractor is paid for up to the boundary surface.

3.5.3 Excess concrete for non-occurrence of the deformations (v)

When the deformations (v) have ceased, "$ü_m$-v" is measured and the volume is determined using the computation model stated in the bill of quantities.

4 FINAL REMARKS

A great help in optimising decision-making for on-site design adjustments is the fact that the price structure of a flexible construction contract holds little potential for a conflict of interests.

The goal is to arrive at a situation where the contractor will face neither advantages nor disadvantages from whatever changes arise from the project. Any profit or loss should mainly result from the contractor's performance within his own range of risk and responsibility. This goal can be attained provided the bill of quantities, payment models and pricing conform to the principles defined in **Austrian Standard ÖNORM B2203-1**. This avoids contradicting interests and motivation conflicts.

ÖNORM B 2203-1 provides incentives for adequate pricing through:

- quality requirements for tender design and tender documentation,
- realistic values for the bill of quantities,
- clear and well-defined separation of spheres of risk,
- detailed description of payment models,
- comprehensible final invoice.

The NATM views the tunnelling process as a complex system of interaction between man and nature, or in other terms, between tunnelling measures and the ground. Systems of such complexity are impossible to control by previously defined "if – then" solutions. The control of a NATM tunnelling project thus calls for a continual feedback system. The main feedback processes are:

- implementation of geotechnical measurements and interpretation of the results,
- ongoing documentation and updating of predictions of ground conditions,
- inspections at the tunnel face,
- tunnel stability considerations and back analyses where required,
- holistic interpretation of all information gathered.

"Real-time" use of all this cumulative information gathered requires for a high level of competence mainly for the following staff:

- tunnelling crews at the tunnel face,
- tunnelling design staff,
- geologists on site,
- geotechnical engineers on site,
- contractor's site management,
- local site supervision,
- project management.

Competence in this context is understood as meaning experience, teamwork capacity, critical faculty (in respect to the selected tunnelling measures), and creativity and communication skills.

A flexible construction contract combined with staff competence combines forms a firm basis for successful NATM tunnelling.