Österreichische Vereinigung für Beton- und Bautechnik

GUIDELINE

Inner Shell Concrete

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Österreichische Vereinigung
für Beton- und Bautechnik

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PREFACE

The Guideline on Inner Shell Concrete, first published in 1995, was revised by the ÖVBB Working Party on „Concrete in Tunnelling“ in 2003. The main purpose of the revision was to incorporate the new European standards in the field of concrete engineering, applicable also in Austria, and to consider the most recent findings of construction practice. At the same time, the Guideline was extended to include provisions regarding the construction of intermediate ceilings and partitions for ventilation ducts.

The Working Party comprises representatives of principals, contractors, university research and testing institutes, as well as concrete manufacturers and design engineers.

This Guideline contains a practice-oriented set of rules for reinforced and non-reinforced inner shells, covering planning, design, tendering, production and testing, with a special emphasis on the requirements of modern traffic tunnel construction.

The intended incorporation of the Guideline on Inner Shell Concrete into the binding set of rules of the Austrian Road and Transport Research Society in the near future is to contribute towards its uniform application and, thus, a further improvement of the quality of inner shells.

Vienna, August 2006 Baurat h.c. Dipl.-Ing. Dr. techn. Helmut Huber

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0 PRELIMINARY REMARKS

The provisions of RVS 1.0 apply in the countries of the EEA.

1. SCOPE

This Guideline applies to the production of inner shells from normal concrete, preferably for mined traffic tunnels, penstocks, shafts and cavities as well as arch-shaped structures built by the cut-and-cover method. Waterproof concrete structures built by the cut-and-cover method (see ÖVBB Guidelines on Waterproof Concrete Structures – White Tanking) are exempted from the scope of this Guideline.

As a matter of principle, the Austrian Standards and Guidelines specified under Item 11[1] apply in their current versions, in particular ÖNORM B 4710-1.

The composition of inner shell concrete (cement, additives, mineral aggregates, water, admixtures) is to be such as to guarantee achievement of the required concrete properties under the conditions to be expected at the construction site.

There are different types of inner shells:

- reinforced inner shells with and without sealing
- non-reinforced inner shells with and without sealing
- waterproof inner shells (WDI) for special requirements

The Guideline also applies to intermediate ceilings and partitions, but not to the production of safety barriers and concrete guardrails in traffic tunnels and to small structural components.

2. DEFINITIONS

Abutment (bench)

Foundation of the concrete arch.

Additive

Finely dispersed substance used in concrete, added to the concrete during mixing in order to improve certain properties (e.g. fly ash according to ÖNORM EN 450, prepared hydraulically active additives (AHWZ) according to ÖNORM B 3309 or silica dust according to ÖNORM EN 13263) or to obtain certain properties.

Arch

Upper part of the inner shell resting on a foundation (abutment).

Arch stripping time

The point in time when the formwork is removed from the arch and/or the inner shell (the structure being able assume the load of the deadweight of the inner shell and/or the arch).

Binder

Cement to which a hydraulically active additive can be added and which meets the requirements of the application concerned e.g. fly ash, silica dust, slag sand).

[1] Any deviation from an Austrian Standard (ÖNORM) is indicated in the text.

C_3A-free cement

Cement according to ÖNORM B 3327-1.

Fibre-reinforced concrete classes BB (increased fire resistance)

For arch concrete according to Annex 5: BB IG, BB 2 G)

Inner shell

Load-bearing, permanent concrete lining of an underground cavity, e.g. gallery, tunnel, underground chamber, shaft, etc. The inner shell can be formed and concreted either in one go (full-round formwork) or in two or several sections (inverted arch, abutment, floor, arch).

Joints

- Construction joints
  result from the interruption of concrete placing on a structural part forming a static unit.
- Movement joints
  are engineering joints in structures with interrupted reinforcement, serving to absorb movements in different directions. There are different types of movement joints - with or without joint fillers and with or without waterstops.
- Expansion joints
  are movement joints with joint fillers.
- Rigid joints
  are movement joints without joint fillers. They form the area of contact between two independent parts of a structure to be jointed through concreting.
- Dummy joints
  are joints with or without continuous reinforcement, separating the concrete cross section only partly. As a rule, dummy joints are placed as „planes of weakness“ in areas of high stress concentration through cutting after concrete placing. The transfer of forces is partly maintained.

Sealing (sheeting seal)

Covering of surfaces, mostly by means of waterproof plastic sheeting.

Section length

Length of a concreting section, usually the distance between movement joints.

Strip cycle time

Period of time between the completion of concrete placing and the removal of formwork.

Stripping strength

Compressive strength of concrete at the time of formwork removal.

Swell factor of swellable waterstops

Ratio of the effective ultimate cross section according to It. 5.2.3.3. to the effective initial cross section, with free expansion in the direction of action.

Tunnel cement

Cement for inner shell concrete according to ÖNORM EN 197-1 with additional properties according to ÖNORM B 3327-1 (e.g. WT38, WT42).

Water-binder ratio (W/B ratio)

Mass ratio of effective water content to cement content (eligible binder content) in fresh concrete.

Waterproof inner shell - WDI

Load-bearing, permanent concrete lining which also fulfils a sealing function.

3. CONCRETE

3.1 Principles of Concrete Composition, Requirements

A variety of partly conflicting requirements have to be met for the production of inner shell concrete. On the one hand, the development of a sufficiently high concrete temperature is considered necessary to ensure a rapid build-up of concrete strength and, thus, permit the removal of formwork at the earliest possible point in time; on the other hand, cracking is likely to occur under such circumstances. Special requirements in terms of exposure classes (e.g. XA or XF) may also result in high concrete temperatures, which in turn promote cracking. However, if the reactions occur too slowly, stripping is delayed.

To obtain the appropriate composition of concrete for inner shells, the constituent materials must be optimised in both qualitative and quantitative terms as a prerequisite for achievement of the desired results in terms of

- workability,
- stripping time and stripping strength,
- avoidance of cracking, and
- functional properties of finished structure.

The use of water-saving admixtures (BV, FM, LP, LPV) and small quantities of binder and water in inner shell concrete, to be produced in compliance with the requirements specified, helps to reduce temperature and shrinkage stress. The requirements of Table 3/2 and the indicative values of Table 3/3 apply. The indicative values shown in the Table refer to the usual strength classes and design arch thicknesses of up to 60 cm.

In general, testing for special concrete properties (e.g. exposure classes) is to be performed in hardened concrete (principle of equivalent concrete performance according to ÖNORM B 4710-1, It. 5.2.5.3).

To reduce thermal stresses, the use of CEM II type cement and/or a certain quantity of type II additives according to ÖNORM B 4710-1, e.g. fly ash, with the binder is recommended. The use of very fine additives may also result in improved workability of the fresh concrete and a denser concrete texture („filler effect“). As a rule, prepared hydraulically active additives (AHWZ according to ÖNORM B 3309) are to be used to obtain the desired properties.

The cement grades used in tunnel construction have to meet the requirements of ÖNORM B 3327-1.

Besides increased sulphate resistance, C_3A-free cement grades offer the advantage of very low heat development; they significantly reduce the risk of thermal stress cracking and are therefore particularly well-suited for waterproof inner shells (WDI) according to It. 4.2. Given the appropriate fresh-concrete temperature, the amount of cement and additives used must be such as to ensure the required stripping strength as well as compliance with the specified functional properties of the finished structure.

Besides the composition of the concrete, the fresh-concrete temperature has an influence on temperature development and the rate of setting of inner shell concrete, which in turn is essential for early removal of formwork; the rate of setting also has an impact on maximum concrete temperatures and, thus, the avoidance of cracking. Fresh-concrete temperatures of between 13°C and 18°C have been found to be particularly favourable. Fresh-concrete temperatures of below 10°C strongly delay the build-up of strength, while temperatures above 22°C promote crack formation. Fresh-concrete temperatures of more than 27°C are not permitted.

The temperature development in concrete depends on the fresh-concrete temperature, the heat build-up (hydration heat of cement and/or binder, cement/binder dosage), the thickness of the structural component, and external influences (e.g. ambient air temperature, rate of air flow). To avoid cracking as much as possible (separation cracks), the specified temperature values (fresh-concrete temperature, temperature rise in concrete) have to be complied with. If the expected maximum temperature of the structural component according to Table 3/2 is exceeded, additional measures according to Table 3/1 have to be provided for.

3.1.1 Workability

The usual consistency testing methods do not cover the entire range of fresh-concrete properties reflected in the overall notion of „workability“. However, the simple slump test adequately serves to assess the pumpability of concrete mixes.

The consistency of inner shell concrete must be adjusted to the conditions of concrete placing. As a rule, a consistency in the upper F 45 range is considered appropriate for non-reinforced arch concrete. For reinforced inner shells a consistency class (depending on the amount of reinforcement) of up to F 52 for the floor and up to F 59 for the arch is best suited. Note that working conditions are different for fibre-reinforced concrete. Particular attention is to be paid to consistency changes, especially if long hoses are used for pumping.

The type of mineral aggregate, the grain size distribution, and the grain shape have an influence on workability. Very fine additives, such as prepared hydraulically active additives, help to obtain easily movable, cohesive mix masses (filler effect).

Void-forming plasticisers with limited air entrainment (combinations of BV, FM, LP and/or LPV admixtures) not only make the concrete more durable and increase the ultimate strain of the hardened concrete, but also have a favourable effect on workability; the maximum range of variation of the air void content is between 2.5% and 5.0%.

Table 3/1 Favourable and unfavourable conditions for the avoidance of cracks

Favourable conditions	Unfavourable conditions
a) C_3A-free cement grades according to ÖNORM B 3327-1 and hydraulically active additives according to ÖNORM B 3309 b) Use of admixture combinations BV, FM, LP, LPV to reduce total amount of water (max. total water 170 l/m³) c) Low fresh-concrete temperature 13°C – 18°C (stripping strength must be guaranteed) d) Low temperatures of structural component e) Short section lengths, avoidance of constraint f) Use of heat-conducting formwork (e.g. steel formwork) g) Even excavation surfaces h) Formwork removal after more than 12 hours to reduce rate of cooling i) Separating layers for improved sliding j) Adequate curing, e.g. curing membrane, non-wovens (It. 7.2.1), curing wagon (It. 7.2.2 k) High air humidity	a) Fresh-concrete temperature > 22°C b) Formwork removal within less than 12 hours c) Stripping strength of more than 3.0 N/mm² d) Draught air (high rate of air flow) e) Large difference between concrete temperature and ambient temperature f) Movement of inner shell severely constrained (dowelling effect)

3,1.2 Timing of formwork removal, stripping strength

In order to avoid cracking, formwork should not be removed too early. To maintain the usual 24-hour cycle for one concreting section, arch formwork is removed 10 to 14 hours after placing, which is considered favourable from the viewpoint of concrete technology. If formwork is removed less than 10 hours after concrete placing, measures need to be taken to prevent excessive cooling and drying (according to It. 7.2).

Concrete strength at the time of formwork removal should not be too high, as this would be associated with a very high concrete temperature at the time of maximum sensitivity to cracking during formwork removal. In the case of arch concrete, the stripping strength values measured in the structure at the time of formwork removal usually range between 1.5 N/mm² and 3.0 N/mm² (according to It. 4.5).

To achieve the required stripping strength, the cement contents recommended in Table 3/3 are to be observed.

3.1.3 Avoidance of cracks

Cracking in arch concrete is usually caused by residual stresses and/or confining stresses due to the inability of the concrete to contract during cooling and to shrinkage. It is advisable to keep the maximum concrete temperature low and to ensure low rates of cooling and shrinkage (see Table 3/1) in all cases.

Therefore, the concrete temperatures specified in Table 3/2 should be observed.

Shrinkage can be reduced by keeping the total water quantity within the limits indicated in Table 3/2 and by applying an appropriate after-treatment. For watertight inner shells, concrete with reduced shrinkage (RS) according to ÖNORM B 3303, It. 7.13.1 and/or strongly reduced shrinkage (RRS) according to ÖNORM B 3303, It. 7.13.2 is to be used. If the total water content is ≤ 170 l/m³, testing for strongly reduced shrinkage is not required.

The measures taken have to be adjusted to local building site conditions; unfavourable conditions have to be offset by favourable measures (conditions) of equivalent impact to avoid cracking as much as possible.

3.1.4 Functional properties of the finished structure

The concrete grade (compressive strength class, including concrete age at evaluation, short designation according to Table 3/2, possibly additional requirements) is to be specified in the schedule of specifications (example see Annex 3). As a rule, testing for exposure classes is to be performed in hardened concrete.

If the structure is exposed to special physical and chemical attacks, e.g. expansive attack through sulphate (XAT), solvent attack (XAL), or frost attack (XF), and for waterproof inner shells (WDI), the concrete texture should be as dense as possible and largely crack-free. The requirements to be met by inner shell concrete for different applications are summarised in Table 3/2.

3.1.4.1 Compressive strength class

The compressive strength class is specified according to the requirements of the structure, usually either C 20/25 or C 25/30. To account for the post-hardening effect of additives of type II and/or according to ÖNORM B 3309, the compressive strength class is to be related to the oldest possible concrete (56, 90 days). If testing is performed after 56 or 90 days, the concrete age at the time of testing is to be indicated in brackets after the strength class, e.g. C25/30 (56).

3.1.4.2 Concrete with increased density of the concrete texture (XC3, XC4)

To ensure an adequate density of the concrete texture and the corresponding durability of the concrete, exposure classes XC3 or XC4, depending on the application in question, are required. Addition of a combination of BV + LP and/or LPV admixtures (according to ÖVBB Guideline) is obligatory. In the event of a chemical attack, the penetration of harmful liquids is slowed down in concrete of high density. Testing for exposure classes XC3 or XC4 is to be performed in hardened concrete (test according to ÖNORM B 3303). For concrete temporarily exposed to strong solvent attack and/or expansive attack by sulphate in concentrations of 400 to 1500 mg/l and for waterproof inner shells, the depth of penetration must not exceed 25 mm (XC4).

3.1.4.3 Frost attack without thawing agent (XF3)

In portal areas of tunnels (usually up to 1000 m in length) arch concrete must be frost-resistant (XF3) according to Table 3/2.

3.1.4.4 Concrete for applications subject to expansive chemical attack (XAT)

Given the fact that inner shell concrete cannot be protected against expansive attack from mountain water or repaired through subsequent measures, justifiable preventive measures must be taken even if only a slight attack of this type is to be suspected. This also applies to inner shell concrete with sealant sheeting.

As the sulphate concentration in mountain water may vary strongly, the risk of sulphate attack must be assessed in at least three samples taken at different points in time.

For applications subject to sulphate attack with an SO_4^{-2} concentration of between 200 and 400 mg/l, exposure class XC3 must be demonstrated in hardened inner shell concrete; the use of C_3A-free cement is recommended.

If the SO_4^{-2} concentration is between 400 and 1500 mg/l SO_4^{-2} , testing for exposure class XC4 and the use of C_3A-free cement is mandatory, although not provided for in the ÖNORM.

If the SO_4^{-2} concentration of the attacking medium exceeds 1500 mg/l, the provisions of ÖNORM B 4710-1 apply.

3.1.4.5 Concrete for applications exposed to solvent chemical attack (XAL)

For road and tunnelling applications exposure class XAL is usually required to protect the ground water against pollution by harmful liquids (e.g. high-density tunnel floor to prevent pollution through liquids escaping in the event of tanker accidents). Hence, the density of the concrete structure (XC4) and the avoidance of cracking are particularly important. Concrete grade IXAL according to Table 3/2 is to be used for applications exposed to slight solvent attack and short-term strong solvent attack. Short-term strong solvent attack is defined as the impact of highly solvent substances for a limited period of time as a result of accidents.

3.1.4.6 Frost attack with thawing agent (XF4)

Many years of experience with road tunnels in Austria have shown that frost-resistant arch concrete of exposure class XF3, combined with the usual light-enhancing tunnel paint coats according to the ÖVBB Information Sheet on Paint Coats for Inner Shells of Tunnels, is sufficiently durable.

If no protective measures (paint coats) are provided for, exposure class XF4 is required for areas exposed to splash water contaminated with thawing agents, e.g. in road tunnels. However, a higher risk of crack formation is to be expected under such circumstances. Therefore, arch concrete resistant to frost and thaw cycles should only be specified in exceptional cases (e.g. short road tunnels without paint coat).

As a matter of principle, the use of XF4 arch concrete in state-of-the-art traffic tunnel usually does not result in the desired increase of structural quality. Even if all standards of concrete production are complied with, exposure to frost and thaw cycles may result in weathering (higher water content and unfavourable distribution of voids due to steel formwork and consistency of pumped concrete).

Table 3/2 Requirements to be met by inner shell concrete – Testing in hardened concrete

	Arch concrete (standard)	Floor, inverted arch, abutment (standard)	Arch concrete and floor concrete with special properties				
			Frost attack without thawing agent and/or with tunnel paint coat (portal)	Frost attack with thawing agent without tunnel paint coat	Water-proof inner shell	Sulphate attack SO_4^{-2} 400-1500 mg/l	Solvent attack
Abbreviations of concrete grades [8)]	IG	IS	ISP/ IGP	IGT	WDI [5)]	IXAT	IXAL
Exposure classes [1)] according to ON B 4710-1 covered	XC3	XC3	XC3/XF3	XC4/XF4	XC4/XF3/ XA1T [2)]/ XA1L C_3A-free	XC4/XF3/ XA1T[2)]/ C_3A-free	XC4/XF3/ XA1L
Usual strength class	C20/25 (56) C25/30 (56)	C20/25 (56) C25/30 (56)	C25/30 (56) C20/25(56)	C20/25 (56) C25/30 (56)	C25/30 (56)	C25/30 (56)	C25/30 (56)
Max. permissible temp. increase in concrete according to ÖNORM B 3303 in K	15	15	15	17	13	13	17
Shrinkage [3) 6)]	RS	RS	RS	RS	RRS	RS	RRS
Cement according to ÖNORM B 3327-1	WT38, WT42	WT38, WT33 [7)]	WT38, WT42	WT38, WT38 C_3A-free	WT38 C_3A-free WT33 C_3A-free	WT38 C_3A-free, WT33 C_3A-free	WT38, WT42
Total water content (target value) l/m³ [4)]	max. 190	max. 190	max. 190	max. 170 [3)]	max. 170 [3)]	max. 170[3)]	max. 170[3)]
Mineral aggregates	F2, FNR	F2, FNR	F2	F1	F2	F2	F2
Grading line classes SK	SK2[12)]	SK2[12)]	SK2[12)]	SK1	SK1[12)]	SK1[12)]	SK1[12)]
Max. W/B value	0.65	0.65	0.65	0.52	0.60	0.60	0.60
Air content (GK22) %	2.5 – 5.0	2.5 – 5.0	2.5 – 5.0	4.0 – 7.0	2.5 – 5.0	2.5 – 5.0	2.5 – 5.0
Microprocessor control according to ÖNORM B 4710-1 required	yes	yes	yes	yes	yes	yes	yes
Fresh-concrete temperature °C	≤ 27	≤ 27	≤ 27	≤ 27	≤ 27	≤ 27	≤ 27
Max. expected temp. of structural component	40	45	40	45	40	40	45
Max. permissible temp. of structural component[11)]	45	50	45	50	45	45	50
Preconstruction test in hardened concrete [1)]	XC3	XC3	XC3, XF3, L300 [9)]	XC4, XF4, L300 AF[9)],	XC4, XF3 L300 [9) 10)],	XC4, XF3 L300 [9) 10)]	XC4, XF3 L300 [9) 10)]
Conformity, identity test in hardened concrete	XC3	XC3	XC3, L300 [9)]	XC4, L300 AF [9)]	XC4, L300 [10)]	XC4 L300 [10)]	XC4 L300 [10)]
Standard stripping time in h Min. stripping time in h with special measures acc. to It. 7.2.2	≥ 10 8	-	≥ 10 8	≥ 10 8	≥ 12 8	≥ 10 8	≥ 10 8

1) To keep heat build-up as low as possible, hardened concrete normally has to be tested for exposure classes to establish the optimum concrete composition. Testing in hardened concrete can be limited to the parameters specified.

2) No additional measures for arch and floor concrete required in case of sulphate concentrations of up to 400 mg/l (use of C_3A-free cement is recommended from 200 mg/l). In case of sulphate concentrations within the 400 – 1500 mg/l SO_4^{-2} range, testing for exposure class XC4 and the use of C_3A-free cement are required (exposure class XA1T C_3A-free). If the sulphate concentration exceeds 1500 mg/l SO_4^{-2} the requirements of ÖNORM B 4710-1 for XA2T apply.

3) RRS – strongly reduced shrinkage: in inner shell concrete with a total water content of max. 170 l/m³ (target value) strongly reduced shrinkage (RRS) is deemed to have been established. If the mix formulation does not permit compliance with this limit, strongly reduced shrinkage (RRS) has to be demonstrated according to ÖNORM B 3303, It. 7.13.2. The total water content established through conformity or identity testing must not deviate from the target value by more than the value permissible according to ÖNORM B 4710-1, Table 17.

4) Total water content according to ÖNORM B 4710-1, Sect. 3.1.29.

5) Corresponds to the requirements of W40 and BS1A of the Guideline on Waterproof Concrete Structures – White Tanking, except for the permissible placing temperature of < 27 °C. The higher permissible placing temperature is possible on account of the more favourable environmental conditions of inner shell concrete.

6) Shrinkage (RS, RRS) according to ÖNORM B 3303 It. 7 .13 is to be established during preconstruction testing and upon delivery at least once a year.

7) For thick floor slabs and abutments > 1.2 m WT 33 C_3A-free and AHWZ.

8) IG = Inner shell, arch, normal
IS = Inner shell, floor, normal
IGP = Inner shell, arch, portal
ISP = Inner shell, floor, portal
IGT = Inner shell, arch, exposure to thawing agent
WDI = Waterproof inner shell
IXAT = Inner shell (arch, floor) exposure to sulphate attack (400 – 1500 SO_4^{2-})
IXAL = Inner shell (arch, floor) exposure to short-term strong solvent attack

9) Requirements to be met by L 300 and AF according to ÖNORM B 4710-1, Table NAD 10

L 300:	for XF2 and XF3:	min. 1.0 %
	for XF4:	min. 1.8 %
AF:	for XF4:	max. 0.18 mm

10) Testing for XF3 and/or L300 only if necessary, e.g. portal area.

11) If the maximum permissible temperature of the structural component is exceeded, additional measures have to be taken to ensure compliance with the temperature requirement during continued concrete placing. The values specified in ÖNORM B 4710-1, Table 19, apply. However, if the temperature is exceeded, another measurement has to be performed in the subsequent concreting section. The tolerance of individual results of conformity testing (ÖNORM B 4710-1, Tale. 17) is 2K.

12) If 4 grain fractions are used, 2 mineral aggregates with a minimum grain size of less than 4 mm are permitted, one with a maximum grain size of 4 mm and the other with a maximum grain size of 16 mm. Except for concrete grade IGT, the use of 0/16 mm grain mixtures is permitted.

Table 3/3 Proposed composition (mix ratio) of inner shell concrete to be established through testing in hardened concrete

			Arch concrete and floor concrete with special properties				
	Arch concrete (standard)	Floor, inverted arch, abutment (standard)	Frost attack without thawing agent and/or with tunnel paint coat (portal)	Frost attack with thawing agent without tunnel paint coat	WDI	Sulphate attack SO_4^{-2} 400-1500 mg/l	Solvent attack
Abbreviations of concrete grades	C20/25(56) IG/ GK.. 3)	C20/25 (56) IS/ GK.. 3)	C20/25(56) ISP/IGP/ GK.. 3)	C25/30(56) IGT/ GK.. 3)	C25/30(56) WDI/ GK.. 3)	C25/30(56) IXAT/ GK.. 3)	C25/30(56) IXAL/ GK.. 3)
Recommended cement content 1) kg/m³	250-270	210-240	250-270	270-290	250-270	250-270	250-270
Prepared hydraulically active additives (AHWZ) kg/m³	70 - 50	80 - 60	70 – 50	80 - 60	70 - 50	70 - 50	70 - 50
Maximum water content l/m³	≤ 190	< 190	≤ 190	≤ 170	≤ 170	≤ 170	≤ 170
Maximum grain size of mineral aggregate	GK 16, GK 22, GK 32	GK 32, GK 45	GK 22, GK 32	GK 22, GK 32	GK 16, GK 22	GK 22, GK 32	GK 22, GK 32
Mineral aggregates	F2, FNR	F2, FNR	F2	F1	F2	F2	F2
Grading curve classes SK	SK2	SK2	SK2	SK1 2)	SK1 2)	SK2	SK2
Mineral aggregates Range 2/3 (A+B) – B if ϱ = 2700 kg/m³ g/m³	1850 - 1920	1870 - 1940	1850 - 1920	1750 - 1870	1850 - 1920	1850 - 1920	1850 - 1920
Admixtures BV, FM, LP, LPV	Dosage according to air-content and workability requirements						
Air content %	2.5 – 5.0	2.5 – 5.0	2.5 – 5.0	4.0 – 7.0	2.5 – 5.0	2.5 – 5.0	2.5 – 5.0
W/B value (target)	≤ 0.65	-	≤ 0.65	≤ 0.52	≤ 0.60	≤ 0.60	≤ 0.60
Cement grade acc. to ON B 3327-1	WT38, WT42	WT38, WT42 for thick floors >1.2m: WT33 C_3A-free	WT38, WT42	WT38 WT38 C_3A-free	WT33 C_3A-free WT38 C_3A-free for thick floors >1.2m: WT33 C_3A-free	WT38 C_3A-free WT42 C_3A-free	WT38 WT42

1) Cement content of > 250 kg/m³ required to comply with usual stripping cycle.
2) Standard maximum grain size for non-reinforced inner shells: GK 32; for reinforced inner shells: GK 22.

3.1.4.7. Concrete for waterproof inner shells without sealing (WDI)

In water-impermeable inner shells complete waterproofing is ensured by the inner shell concrete. Hence, inner shell concrete not only has to meet the requirements of exposure class XC4, which specifies the required textural density of the concrete, but must also be largely free of water-permeable cracks. Thus, exceptionally good workability, strict limitation of the fresh-concrete temperature, the maximum concrete temperature and the rate of cooling, and a low rate of shrinkage are essential for concrete for waterproof inner shells. In particular, the use of cement generating a low level of hydration heat according to ÖNORM B 3327-1 (e.g. WT 38

C3A-free), the addition of prepared hydraulically active additives, and use of the smallest quantity of water possible in combination with admixtures (BV+LP or LPV) is recommended (see Table 3/3). Except for the permissible fresh-concrete temperature of $\leq$ 27°C, the requirements for waterproof concrete listed in Table 3/2 correspond to the requirements of Concrete Standard BS 1A of the ÖVBB Guideline on Waterproof Concrete Structures – White Tanking.

The structural measures specified in It. 4 are to be observed.

For thick concrete tunnel floors (thicker than 1.2 m) special measures have to be taken to diminish the build-up of heat (e.g. use of WT 33 C_3A-free cement and prepared hydraulically active additives).

Curing measures are to be timed in such a way as to prevent rapid cooling during the first 3 days and rapid drying during the first 7 days after stripping (according to It. 7.2).

3.1.5 Increased fire resistance

In order to comply with the requirements of fire protection, measures may have to be taken to increase the fire resistance of concrete. Under the impact of fire, the temperature front penetrates into the arch concrete, which results in the built-up of thermal stresses and, possibly, modifications of the properties of concrete and steel.

A rapid temperature increase results in explosion-like spalling of the surface layers of the concrete, with deeper layers – possibly also the reinforcement – being exposed (the extent of spalling depends, among other things, on the concrete strength, the moisture of concrete in the structure, and the confining stress preventing deformation of the structure). Spalling can be reduced or prevented through the addition of fine polypropylene fibres (see It. 8.3 and/or ÖVBB Guideline on Fibre-Reinforced Concrete, ÖVBB Guideline on Increased Fire Resistance of Concrete for Underground Traffic Structures).

The addition of fibres modifies the properties of fresh concrete (lower consistency, higher quantity of admixtures required, different air content), makes placing more difficult (concrete distribution and embedding of reinforcement are more difficult, vibratory energy and/or vibrator distribution for reinforced arch concrete have to be optimised), and results in modified properties of the hardened concrete (e.g. frost resistance). These modifications have to be established through preliminary testing and taken into account through appropriate measures (see also It. 8.3 and/or ÖVBB Guideline on Fibre-Reinforced Concrete and ÖVBB Guideline on Increased Fire Resistance of Concrete for Underground Traffic Structures).

3.2 Constituent materials of concrete

The origin of the constituent materials of the concrete is to be indicated and their suitability must be demonstrated before concrete placing is begun.

3.2.1 Cement

Cement grades bearing a CE or ÜA mark and standard-compliant according to ÖNORM EN 197-1 and B 3327-1 and EN 197-1 are to be used.

Requirements to be met by cement (heat build-up, water segregation, fineness, C_3A content, cement temperature) in addition to those specified in EN 197-1 are laid down in ÖNORM B 3327-1 (see also Table 3/2).

3.2.2 Additives

The addition of type II additives according to ÖNORM B 4710-1 serves to improve the workability of the concrete, to diminish heat build-up and to achieve a dense concrete texture.

As a rule, additives according to ÖNORM B 3309 (prepared hydraulically active additives) are to be used for targeted air entrainment. These additives are counted to the water/binder value through application of a k-factor of 0.8.

The additives have to be metered as individual components on the basis of weight. The mixing time must be sufficient to ensure homogeneous mixing of cement, additives and the mineral aggregates.

3.2.3 Mineral aggregates

Mineral aggregates have to meet the requirements of ÖNORM B 3131. The use of mineral aggregates is subject to the requirements of ÖNORM B 4710-1, except for the fact that 2 mineral aggregates may contain grain fractions with a minimum grain size of less than 4 mm, if 4 grain size groups are used. The use of grain mixtures of up to 0/16 mm is permitted, except for concrete grade IGT.

For inner shell concrete meeting the requirements of at least frost class F2, mineral aggregates according to ÖNORM B 4710-1, supplied in separate grain fractions from an on-site preparation plant or a standard-compliant plant, are used. For XF4 concrete frost class F1 is required.

The aggregate grading curve is to be selected in such a way as to ensure the required workability while keeping water consumption as low as possible. For recommended grading curve ranges, see Fig. 3/1, Fig. 3/2 and Fig. 3/3. The maximum grain size, adjusted to the specific working conditions (e.g. thickness of structural component, position of reinforcement, etc.), is to be as large as possible, with the permissible fraction of oversized grains being fully utilised; subject to compliance with the workability requirement, the fraction of oversized grains may be exceeded by another 5%. Maximum grain size GK 45 is recommended for non-reinforced concrete and thick structural components.

The maximum permissible percentage of settleable solids (fraction < 0.063 mm) is subject to the provisions of ÖNORM B 4710-1. In crushed mineral aggregates with maximum grain sizes of 32 mm and 45 mm, this percentage may be increased to 5 wt.%, if the aggregate is purely carbonate and the fraction smaller than 0.02 mm (determined by sedimentation test) does not exceed 3.0 wt.%. The total water content must be in accordance with Table 3/2.

The grading curve ranges shown in Fig. 3/1 to 3/3 are based on many years of experience regarding pumpability, workability and surface structure to be obtained with the appropriate fine-grained content.

For grading curves GK32 and GK22, pumping tests must be performed prior to concrete placement in the inner shell, if the 4/8 fraction > 10% and the mineral aggregate consists mainly of angular grains.

No special measures are required if the standard ranges are exceeded as far as the B line, provided the above rule regarding the 4/8 fraction is observed.

In special cases, the use of mineral aggregates slightly exceeding the B line in the 1 mm to 4 mm fraction and/or remaining below the standard range is permitted, if the required concrete properties are achieved; however, workability (pumpability, placability and surface structure of the concrete) need to be demonstrated through testing.

The fine-grained content must not be lower than the value specified in Table 3 / 4.

Table 3/4 Fine-grained content (fraction ≤ 0.125)

Maximum grain size	Minimum fine-grained content
GK 16	390 kg/m³
GK 22	370 kg/m³
GK 32	350 kg/m³

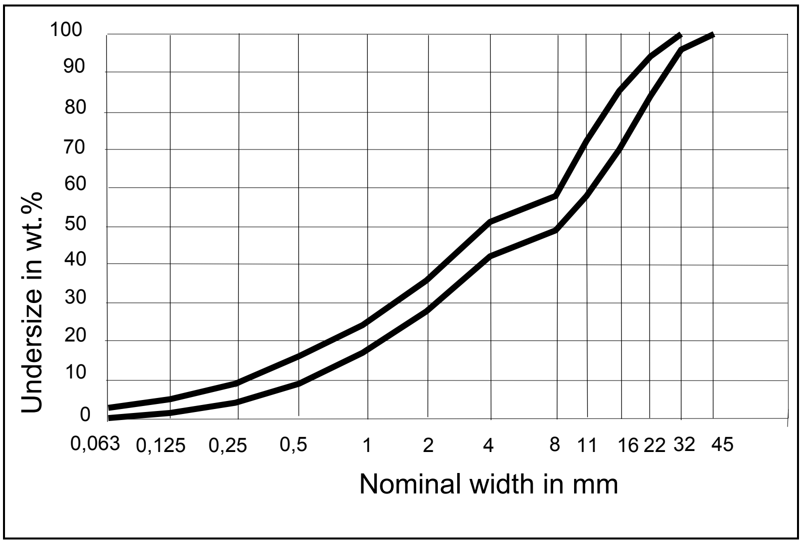

Fig. 3/1
Grading curve range for inner shell concrete
Maximum grain size 32 – standard range

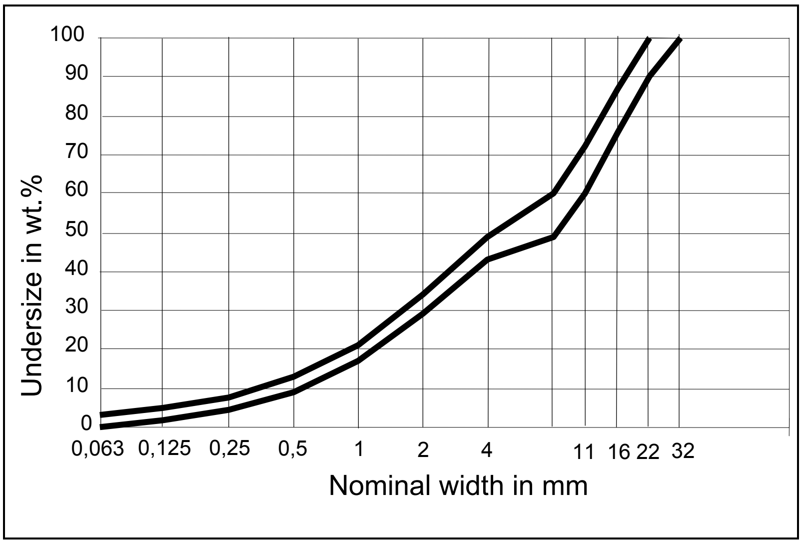

Fig. 3/2
Grading curve range for inner shell concrete
Maximum grain size 22 – standard range

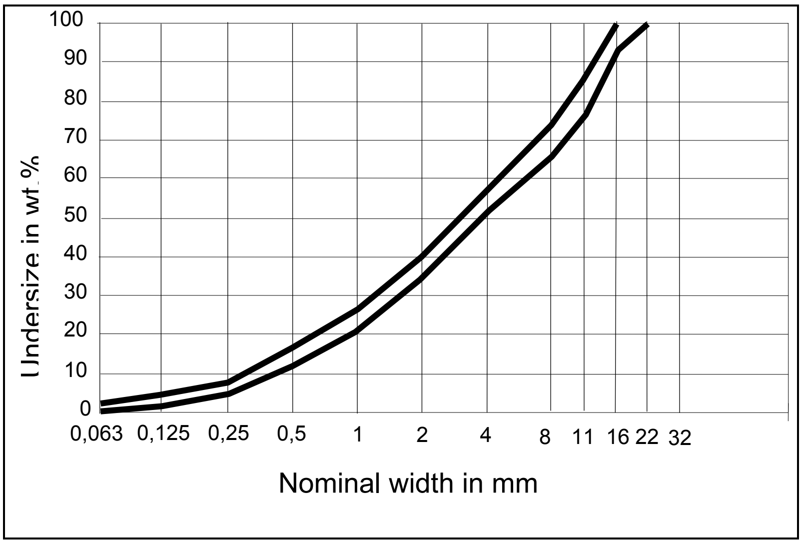

Fig. 3/3
Grading curve range for inner shell concrete
Maximum grain size 16 – standard range

3.2.4 Water

As regards the characteristics of mixing water, ÖNORM B 4710-1 applies.

3.2.5 Admixtures

All admixtures have to meet the requirements of ÖNORM B 4710-1 and ÖNORM EN 934-2; for LPV products the requirements of the ÖVBB Guideline on LPV Concrete apply.

For the admixtures used, approval documents, test reports and test certificates, as required in the technical regulations and not older than three years, must be available.

The effectiveness of concrete admixtures and their mutual compatibility (if several admixtures are used) has to be established through preconstruction testing and must also be assessed in the course of conformity testing (see ÖNORM B 3303, It. 7.16).

3.2.6 Fibres

Fibres have to meet the requirements of the ÖVBB Guideline on Fibre-Reinforced Concrete.

3.3 Preconstruction testing

Preconstruction testing serves to demonstrate that all requirements are met with the constituent materials used and the allowances according to ÖNORM B 4710-1. In specifying these requirements (e.g. consistency), account must be taken of differences in the conditions of execution (non-reinforced, sealed inner shell, length of pumping hose, stripping time, presence of aggressive mountain water, etc.). The percentages of the constituent materials in the concrete mix (cement, additives, admixtures, aggregates and water) are determined in the preconstruction test.

The preconstruction test is to be performed by an accredited inspection body. The properties of the hardened concrete must always be tested by an accredited testing body. The testing and inspection bodies concerned must be able to provide evidence of their experience in the construction of inner shells for mined tunnels.

Concrete grades (arch concrete, floor concrete, abutment concrete, hot-weather and cold-weather placing formulations) of similar composition may be treated as concrete families and subjected to a common preconstruction test under the following conditions:

- same constituent materials (if admixtures BV and/or FM are different, a single fresh-concrete test is sufficient)
- cement dose $\pm$ 15 kg/m³
- dose of prepared hydraulically active additives $\pm$ 10 kg/m³
- F45, F52
- maximum grain size of mineral aggregates: next higher or lower grain size classes (e.g. preconstruction test for GK 22 also applies to GK 16 and GK 32).

The scope of the preconstruction test depends on the requirements to be met by the structure (see Table 3/2). Tests to be performed over and above the standard test programme shown in Table 3/5 (special test programme) are to be specified in the tender documents.

Table 3/5 Standard test programme for preconstruction testing

	Arch concrete	**Floor concrete** **Abutment concrete**
Optimisation of concrete composition, (optimum grading curve of mineral aggregate, maximum grain size, cement grade, percentage of additives, mixing time)	x	x
Slump (a_{10}, a_{90}) Bulk density of fresh concrete Air content [5] (LP_{10},. LP_{90}) (with bulk density) Bleeding (BL) as informative value	x x x x	x x x
Testing of constituent materials [1]	x	x
Strength at intended stripping time, temperature-controlled	x	
Compressive strength 7 d, 28 d or 56 d [2]	x	x
Temperature increase according to ÖNORM B 3303 It. 7.17 (requirements according to Table 3/2)	x	x [4]
Shrinkage RS and/or RRS for (WDI)	x[3]	-
Testing for exposure classes depending on requirements according to Table 3/2 in hardened concrete	x	x

1) The results of in-plant inspections can also be used for cement and additives.
2) Depending on age at time of testing
3) Not obligatory if total water content < 170 l/m^3
4) To be demonstrated for thick concrete floors only (thickness $\geq$ 1.2 m): $\Delta T \leq 17$ K as tested according to ÖNORM B 3303, It. 7.17.2.
5) Air content in the middle of permissible range

- Special tests

The scope of special tests and the required concrete age at the time of testing are to be specified:

Examples:

- Modulus of elasticity (e.g. stripping strength of structures built by cut-and-cover method; after 3, 7, 28, 56 or 90 days),
- Tensile splitting strength
- Testing for reinforced-fibre concrete classes BB 1G and BB 2G in large-scale test specimen according to Annex 5.
- Stripping strength

If formwork is removed after less than 16 hours, the compressive strength of arch concrete is to be determined for the earliest intended stripping time in temperature-controlled test specimens (20 cm cubes) (see Table 3/6). The test method is to be calibrated upon performance of the test (pendulum hammer) (see It. 3.4.3).

Table 3/6 Storage temperature of the temperature-controlled test specimen

Fresh-concrete temperature		15 - 20 °C
Storage temperature of the specimens	0 - 4 hours	20 °C
	4 - 8 hours	25 °C
	more than 8 hours	30 °C

3.4 Conformity control

3.4.1 Conformity testing

The conformity test (Table 3/7) is carried out during execution of construction work to demonstrate that the composition of the inner shell concrete is such as to ensure achievement of the required properties at the age specified, provided adequate production, curing and storage.

As a rule, conformity testing of fresh concrete is performed at the site of placement (e.g. upstream of pump, conveyor belt, slide). The influence of transport and pumping (above all changes of the air content) is to be determined at the beginning and in the course of concreting and has to be taken into consideration both in the evaluation of the results and for the dosage of admixtures (allowance for air content, consistency and fresh-concrete temperature) to demonstrate continuity of placing conditions. The correlation of concrete properties upstream and downstream of the pump is to be established at the same truck mixer, preferably at the same filling level. The required fresh-concrete values apply to the site of placement (e.g. concreting hose downstream of the pump).

Except for concrete grades IGT and FaB (fibre-reinforced concrete), the conformity test may also be performed at the mixing plant and/or at the tunnel portal, if the time of transport between the site of testing and the site of placement (e.g. concreting hose downstream of the pump) does not exceed 30 minutes and if continuity of placing conditions (consistency, air content and fresh-concrete temperature) can be demonstrated.

- Proof of continuity of placing conditions

The following maximum changes of conditions between the test site and the placing site (absolute values without statistical evaluations) are permissible:

Consistency 30 mm, air content 2.0 %, fresh-concrete temperature 2°C

The minimum sample quantity to be obtained for testing, deviating from ÖNORM B 3303, is 15 l.

Table 3/7 Conformity testing (minimum frequency)

	I	II
Test measure	Beginning of concreting to 10th concreting section 2)	Continuous operation from 11th concreting section 2)
Cement, Additives 1)	1x month per cement and/or additive grade	
Mineral aggregate - grain size distribution 1) 0/4 other	 1 x weekly 1 x weekly	 1 x weekly 2 x monthly
Fresh-concrete temperature, air temperature	3 x per section	1 x per section
Continuity of placing conditions	every third section	every 20th section
Printout of statistical data of microprocessor control	for concreting period to be specified	for concreting period to be specified
Temperature increase according to ÖNORM B 3303	1 x arch concrete and floor concrete per concrete family 3)	for arch concrete and floor concrete per concrete family 3) every 20th section and/or every 6 months
Consistency	5 x per section, continuous visual inspection	2 x per section, continuous visual inspection
Air content (fresh concrete)	5 x per section	2 x per section
Water content of concrete 4)	every 3rd section	every 10th section
Compressive strength 7d	every 3rd section	-
Compressive strength 28d or 56d	every 3rd section	every 10th section
Shrinkage RS, RRS	1 / year	
Exposure classes according to Table 3/2 in hardened concrete (XC3, XC4, L300, AF)	for arch concrete, floor concrete, abutment concrete per concrete family 3) for WDI: every 20th section and/or every 6 months for other inner shell concrete: every 40th section and/or every 12 months	

1) The results of in-plant inspection may also be used to demonstrate the required properties.
2) A concreting section is defined as a section placed with the same concrete grade by the same mixing plant within 24 h under approximately the same climatic and placing conditions.
3) The following concrete grades may be grouped as a concrete family:
    - same constituent materials (if admixtures BV and/or FM are different, fresh-concrete testing is the only additional requirement to be met)
    - Cement dosage ± 15 kg/m^3
    - AHWZ dosage ± 10 kg/m^3
    - total binder dosage + 10 Kg/m^3 (cement + AHWZ)
    - W/B value max. + 0.02
    - F45, F52
    - Maximum grain size of mineral aggregates: next higher and lower grain size classes
4) Test according to ÖNORM B 3303, It. 6.4

3.4.2 Identity test

The identity test has to be performed by an accredited testing body or according to ÖNORM B 4710-1, Annex B, Section B2. It serves to determine the fresh-concrete properties and the compressive strength, and to produce test specimens for further tests in hardened concrete, which may also be performed by a construction-site laboratory, provided the latter is supervised by a duly qualified representative of the principal, who verifies and confirms the test results.

The identity test, to be initiated by the principal, is performed at the site of concrete placing (e.g. upstream of the pump, conveyor belt or slide) and serves to verify that the concrete placed corresponds to the concrete grade evaluated by the manufacturer through conformity testing. To verify the identity of the concrete, the following properties have to be tested (Table 3/8).

Table 3/8 Identity test

Test measure	Minimum frequency
Consistency	every 20th concreting section
Air content	
Continuity of placing conditions	
Water content	
Compressive strength 28 d or 56d	
Exposure classes according to Table 3/2	for WDI concrete: every 20th concreting section for other inner shell concrete: every 40th concreting section

Compressive strength testing may be performed by an accredited testing body or at the construction-site laboratory. Testing of hardened concrete for exposure classes is also performed by an accredited testing body.

- Compressive-strength testing at the construction-site laboratory

The compressive strength is established through a test performed on a calibrated concrete compression tester in the presence of a representative of the principal, who confirms the readings obtained. Parallel samples have to be tested by an accredited testing body at intervals to be agreed upon (at least every 3 months).

Moreover, identity testing also serves to assess the proof of conformity established by the manufacturer for all concrete grades used in the contract section on the basis of the conformity tests performed by the manufacturer (ready-mix plant) since the last identity test (on-site mixing plant) and/or since the last external inspection.

3.4.3 Structural testing

The structural tests are to be performed and documented by the user.

- Stripping strength:

  The stripping strength is to be verified in each concreting section prior to the removal of formwork. The compressive strength of the arch of a mined tunnel at the time of formwork removal (max. 24 h) is to be determined at the structure, e.g. by means of the pendulum hammer according to the PT model by E. Schmidt. For structures built by the cut-and-cover method, the compressive strength at the time of formwork removal is established by means of the P model or the rebound hammer. The stripping strength is to be tested at the face of the roof and on the concrete surface of the wall area (concreting window). The pendulum hammer is to be calibrated within the framework of preconstruction testing of the concrete.

- Temperature development in the structure:

  The temperature development of arch concrete and ambient air is to be established in every 40th concreting section (every 20th concreting section in the case of WDI). The test is to be performed before the temperature starts to decline (as a rule within

36 hours). Two measuring points each in the roof and wall area, centrally located in the structural component, are to be provided for.

- Concrete cover of steel reinforcement (in reinforced inner shells):

  To avoid system errors, the required concrete cover of the steel reinforcement (minimum size) is to be verified for the first five concreting sections, and subsequently for every 40th concreting section, by means of a suitable concrete cover measuring device (e.g. Profometer by Hilti) according to RVS 9.35, It. 5 and It. 6 (also applies to intermediate ceilings and partitions).

- Verification of the thickness of the inner shell in hardened concrete (to be specified as a separate item in the tender documents in the case of reinforced inner shells):

  Compliance with the nominal thickness of the inner shell is an essential quality feature of double-shell structures. To avoid reductions in thickness in the roof area and, if applicable, in the abutment, wall and floor-arch transition areas, and to prevent direct damage to the sealing, the inner shell has to be tested by non-destructive methods. As a rule, the roof area and the areas along block joints are to be inspected. As regards the use of non-destructive testing methods, please refer to the corresponding Guideline [8].

3.4.4 Control samples

Table 3/9 Sampling for control purposes

Sample	Quantity	Frequency	Duration of storage from date of sampling
Cement	10 kg	once in 2 weeks	2 months
Additive	5 kg	once in 2 weeks	2 months
Admixture	1 l	once in 2 weeks	2 months

The samples have to be taken upon delivery of the concrete and stored under appropriate conditions. The duration of storage is counted as of the sampling date.

4. STRUCTURAL MEASURES

4.1 General remarks

Depending on their function, inner shells are designed as structures

- without reinforcement or
- with reinforcement

A sealing layer can be applied to both types of structures.

As a matter of principle, a tunnel can be designed either as a watertight tube or as a drained structure. The design decision depends on the following considerations:

- the possibility of free, pressure-reduced or pumped drainage of ground or mountain water into a receiving body of water,
- the expected volume of water,
- the expected water pressure,
- the impact on the hydrological environment,
- the construction costs,
- and the operating and maintenance costs.

As a rule, inner shells of drained tunnels are made from non-reinforced concrete.

Reinforced inner shells are usually required for watertight traffic tunnels and tunnels in urban areas; for watertight tunnels, preference is given to waterproof inner shells (WDI).

4.2 Waterproof inner shell (WDI)

A waterproof inner shell (WDI) is a structural element impervious to water without application of a sealing. The concrete used has to meet the requirements of XC3 according to ÖNORM B 4710-1; moreover, special concrete properties (Table 2/3) as well as special structural measures (Table 4/1) and appropriate working methods (e.g. separating layers) have to be specified in order to avoid crack formation and water leakages as much as possible.

Inner shells qualify as waterproof if no more than a few traces of moisture are visible on the inner side (e.g. wet patches, local discolourings and shades of dampness not extending beyond 20 cm). Waterproof inner shells (WDI) must meet the requirements of class A1 of the ÖVBB Guideline on Waterproof Concrete Structures – White Tanking.

More substantial water leakages, which do not show signs of incrustation after a period of observation to be specified, have to be repaired through grouting.

According to the tunnel design, a grid-shaped reinforcement is to be provided for on both the air side and the rock side of the concrete cross section. If possible, reinforcing bar diameters of more than 20 mm are to be avoided. To ensure proper concrete placing, the mesh width of the reinforcement must be at least 100 mm.

RSV 9.35 applies to the concrete cover of the reinforcement. If a concrete cover of more than 10 cm on the rock-side reinforcement cannot be avoided in an underground cavity, one of the following measures has to be taken:

- Additional skin reinforcement (min. CQS5) is to be provided for in areas with a thicker concrete cover.
- The design reinforcement is to be adjusted to the cross section and the alignment of the structure.
- Advance filling of the over-excavated cross section with concrete.

The formwork surface as well as stiffenings and stabilisers of formwork must be adjusted to local requirements in terms of permissible stresses and strains.

Slippage in the hinges of formwork elements, service girders and formwork wagons is to be minimised.

For continuous anchor holes (e.g. in cut-and-cover method) sheet-metal sleeves and sealing systems are to be used to exclude the passage of water and to ensure permanent waterproofing of the structure.

The number of construction joints is to be minimised. For excavated cross sections of up to 50 m², use of a full-round formwork wagon is recommended.

Construction joints have to be sealed by means of waterstops.

Between concreting sections, movement joints with expandable waterstops, at least 30 cm wide, have to be provided for. The joint itself may be designed as a rigid joint or with a compressible joint insert.

Compressible joint inserts are to be placed at the interface of structures with different deformation behaviour.

4.3 Minimum structural requirements to be met by the floor and the abutment

In all types of floors the joints must be aligned with those of the arch concrete. Additional longitudinal joints in the floor are possible. Additional separations of the arch are also permitted.

Floor slabs must be at least 30 cm thick.

As regards the minimum reinforcement and the concrete cover of floor slabs, ÖNORM B 4700 and/or RVS 9.35 and/or RVS 9.32 apply.

If the inner shell is designed as a waterproof structure (WDI), the floor has to meet the same requirements as the arch.

If drained tunnels (tunnels with sealing layers) are to be equipped with water-impermeable floor slabs and waterproof concrete abutments, standard section lengths of up to 12.50 m – deviating from the values specified in Table 4/1 – are permitted.

4.4 Timing of concrete placement

The timing of concrete placement depends on the rate of deformation of the outer shell after installation of the support and on the toughness of the inner shell.

Based on empirical values, placing of the inner shell is possible without additional measures up to a rate of deformation of the outer shell of 4 mm per month.

Other considerations apply to tunnels in swelling rock. Any of the following additional measures may have to be taken:

- increase of the support resistance (higher concrete strength)
- placing of bubble film or non-wovens, installation of deformation elements
- structural measures (ductile reinforcement, uniform elongation > 5%o according to ÖN B 4753, fibres).

4.5 Stripping strength in mined tunnels

Statically speaking, the compressive strength of the concrete at the time of formwork removal depends on the size of the cavity, the geometry of the inner shell, and the thickness of the inner shell.

Based on empirical values, a minimum stripping strength of 2.0 N/mm² in the crown area is required for design cross sections with radii of ≤ 6.00 m. For such cross sections with wall thicknesses of > 25 cm, this level of strength offers a sufficient degree of safety during construction also for sections over-excavated by a value corresponding to the wall thickness.

Additional proof of structural strength (e.g. beam on elastic foundation, with due consideration of overbreak) or a higher level of stripping strength are required in the case of:

- special cross sections (e.g. niches),
- larger curvature radii,
- irregular thickness of the lining, e.g. due to large overbreak,
- unilateral load concentration and/or chimney-type rock failure in the roof area, overbreak of longer sections.

Compressive strength tests are performed according to 3.4.3, e.g. by means of the pendulum hammer.

4.6 Stripping strength in tunnels built by the cut-and-cover method

The compressive strength of the concrete required for structural reasons at the time of formwork removal is to be demonstrated on a case-by-case basis.

To obtain the rate of deformation, the modulus of elasticity has to be established through testing (preconstruction testing).

Table 4/1 Minimum structural requirements to be met by inner shells (arch)

<table>
<tr><th rowspan="2">Criterion</th><th colspan="5">Arch</th></tr>
<tr><th colspan="2">without reinforcement</th><th colspan="2">with reinforcement</th><th rowspan="2">WDI "Waterproof inner shell"</th></tr>
<tr><th>Sealing</th><th>without</th><th>with</th><th>without</th><th>with</th></tr>
<tr><td>Min. thickness in cm</td><td>20[1)]</td><td>25[1)]</td><td>30[1)]</td><td>30[1)]</td><td>40[2)]</td></tr>
<tr><td>Standard section length[3)] in m</td><td>12.5[4,5)]</td><td>12.5[5)]</td><td>12.5[5)]</td><td>12.5[5)]</td><td>10[6)]</td></tr>
<tr><td>Min. stripping cycle [7)]</td><td>8 h</td><td>8 h</td><td>8 h</td><td>8 h</td><td>8 h[8)]</td></tr>
<tr><td>Standard stripping cycle</td><td>10 h</td><td>10 h</td><td>10 h</td><td>10 h</td><td>12 h</td></tr>
<tr><td>Measures to minimise cracking
a) Separation layers</td><td>recom-mended</td><td>present through sealing</td><td>recom-mended</td><td>present through sealing</td><td>required</td></tr>
<tr><td>b)Reinforcement</td><td>-</td><td>-</td><td>according to RVS 9.32</td><td>according to RVS 9.32</td><td>according to RVS 9.32</td></tr>
<tr><td>Joint design</td><td>Rigid joint</td><td>Rigid joint</td><td>Rigid joint</td><td>Rigid joint</td><td>Waterstops required for construction and block joints[9)]</td></tr>
<tr><td>Evenness of substrate</td><td>-</td><td>acc. to Annex 4</td><td>sufficient to apply separation layer</td><td>acc. to Annex 4</td><td>Special measures[9)]</td></tr>
<tr><td>Min. design thickness of concrete cover</td><td>-</td><td>-</td><td colspan="3">RVS 9.35</td></tr>
</table>

1) Rock tips and anchor heads must not penetrate into the cross section of the inner shell by more than 5 cm. The required minimum design thickness of the concrete cover must be guaranteed (e.g. exchange of reinforcement).
2) In special cases with external waterstop 30 cm
3) Limitation of section length to avoid cracking and improve concrete quality.
4) Exceptions e.g. for penstocks (longer sections permitted).
5) Near portals and in sections with strong temperature fluctuations (e.g. shafts), cutting of dummy joints to reduce section length by half is recommended (see It. 5.2.2).
6) Shorter connecting sections are to be provided for at the transition to structures with substantially different deformation behaviour.
7) See It. 3.1.3 and special measures according to It. 7.2.2.
8) Applicable only if C_3A-free cement is used (for hydration heat, not for sulphate resistance)
9) see detailed explanations in It 5.1.2.

5. PREPARATIONS FOR CONCRETE PLACING

5.1 Preparing the substrate

5.1.1 Ingress of water

Running water and water dripping from surfaces must be drained prior to concreting in order to prevent fines and binder being washed out and to avoid the build-up of water pressure during concrete placing.

The following measures can be taken:

5.1.1.1 Floor

- Placing of drainage strips, drainage bodies, drainage layers and drainage lines, e.g. gravel with a low fines content, pervious concrete, and the like.
- Water to be drained via longitudinal drainage lines and construction drainage systems or through pumping.

5.1.1.2 Crown and wall areas

- Adequately sized hoses connected to drainage systems (centre split pipes are to be used in exceptional cases only)
- Surface drainage systems (bubble film, non-wovens, foils, etc.)
- Complete sealing.

Sealing of the structure also offers the necessary protection of young concrete against the ingress of water.

5.1.2 Evenness of the concrete substrate

Prior to concrete placing, the substrate must be prepared appropriately both in the arch and floor areas.

In the case of umbrella sealings and/or watertight sheet sealing systems (with or without reinforcement), the evenness of the substrate must be ensured through the measures specified in Annex 4. In the case of saw-tooth excavation lines (grout curtain), the block joints should be aligned with the offset of the saw-tooth profile.

For waterproof inner shells, the air-side surface of the substrate (e.g. sliding film on sprayed concrete) should be such as to minimise interlocking between the waterproof inner shell and the sprayed concrete shell. In inner shells designed to take constraining forces, favourable conditions are deemed to exist if the depth from a measuring rod is less than 10 cm. A straight, 4 m measuring rod is to be used in the longitudinal direction of the tunnel; radially, a curved measuring rod is to be used, its curvature corresponding to the design radius and its length corresponding to an angle of 45°. The flank inclination of an unevenness must not exceed 1 : 10 relative to the measuring rod. If these requirements are not met, cracks must not be wider than 0.2 mm.

Anchor heads have to be grouted; compliance with the above surface criteria of the concrete substrate is required.

5.1.3 Preparation of the concrete substrate

Dirt and loose particles must be removed from the concrete substrate (e.g. sprayed concrete or rock, segmental lining).

Precautions must be taken to prevent cement slurries from penetrating into drainage systems and filter bodies.

If the floor is based on a rock foundation, loose material must be removed from the rock surface; if necessary, the rock surface is to be cleaned by means of compressed air or, conditions permitting, an air-water mixture.

In case if a loose soil foundation, the floor must be true to cross section; if necessary, the floor surface has to be drained through pumping and soaked areas have to be exchanged and compacted. If reinforcement is required, a granular sub-base must be installed.

5.2 Concrete joints

5.2.1 Construction joints

Construction joints are joints with or without friction locking resulting from the sequence of construction operations. If possible, construction joints in reinforced inner shells should be either vertical or horizontal. Generally speaking, all construction joints are to be cleaned (air, water or air-water mixture) before concrete is placed in the adjacent section.

As a rule, the transition to the contiguous concrete section must be „smooth“ as defined in ÖNORM B 4700, Section 3.4.4.5. Additional requirements have to be specified in the design documents.

Waterstops are required for construction joint (e.g. joint between floor and arch) in waterproof inner shells.

Under difficult conditions, the possibility of grouting of the contact surface is to be provided for.

5.2.2 Movement joints

Movement joints are structural joints with (expansion joint) or without (rigid joint) joint fillers. For rigid joints in inner shells, see Fig. 5.1. Rigid joints without waterstops can be used in the arch area of sealed tunnels. Compliance with the joint width specified in ÖNORM B 3800-4, It. 3.1, is not mandatory.

If movement joints are executed as dummy joints, the cross section of the structural component concerned is reduced by at least one third of its design thickness. Dummy joints must be cut early enough to avoid cracking due to constraining forces as much as possible. Moreover, the concrete must be sufficiently set to obtain clean cutting surfaces.

Shuttered movement joints have to be cleaned, if necessary. If joint inserts (foam panels, soft-fibre panels, stone wool panels) are used, these must be placed over the entire surface without spaces in between (bonding). The project-related fire protection requirements have to be observed.

In reinforced inner shells the profile of the inserted fillet must be such as to guarantee the required overlap of the reinforcement (e.g. triangular fillet).

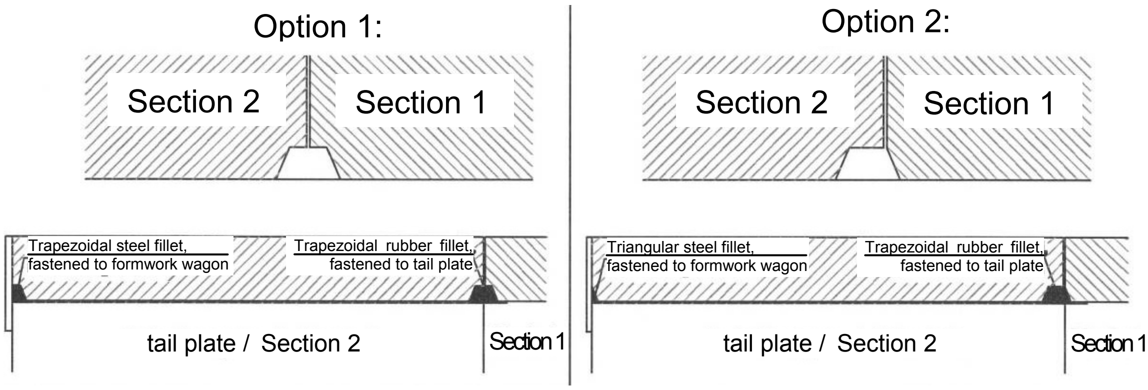

fig. 5/1 Examples of joints in inner shells of traffic tunnels

5.2.3 Joint sealing

The choice of material depends on the specific requirements as regards ease of working, fastening to sealing sheet webs, expandability, resistance to chemicals, and ageing.

All waterstops have to be transported, stored and placed according to the manufacturer's instructions.

The width of the waterstop must be at least 30 cm and not more than 35 cm; a minimum thickness of 5 mm in the expansion area is required. The position of the waterstops must be indicated in the design drawings.

Except for the waterstop width, the requirements of It. 4.6 of the ÖVBB Guideline on Waterproof Structures – White Tanking have to be complied with for waterproof inner shells. Other than provided for in the Guideline, a minimum waterstop width of 30 cm – 35 cm is required for all water pressure classes.

Careful and watertight jointing of all waterstops to each other (expansion waterstop with external waterstop, expansion waterstop with swellable waterstop, etc.) is essential. All waterstops in contact with the sealing material must be compatible with the latter.

Waterstops have to be fastened in the desired position to prevent displacement in the course of concrete placing. To fasten the waterstops, the fastening devices provided by the manufacturer have to be used and/or the special placing requirements are to be observed. Waterstops have to be cleaned prior to placing of the concrete for the subsequent section

Halves of waterstops projecting from a concrete section must be cleaned thoroughly before concrete is placed in the contiguous section. If concrete placing in the neighbouring section does not follow immediately, the waterstops must be protected by appropriate means. Forms and formwork overlaps must be as tight as possible in the area around the waterstops to prevent leakage of cement slurry and fines.

In reinforced inner shells, the necessary overlap of the reinforcement must be ensured over the entire joint area.

In waterproof inner shells, grouting hoses are to be placed with all waterstops. Grouting with suitable substances may be necessary.

5.2.3.1 External waterstops

External waterstops must rest solidly on the formwork, the improved subgrade, the sealing, the sprayed concrete surfaces or other surfaces, the area of contact being clean and as plane as possible. In the floor area, special care must be taken to keep the web plates of the waterstops clean. To ensure that external waterstops in the roof area are fully functional, grouting hoses are to be provided for in the design.

As a rule, internal waterstops are to be used. However, if external waterstops are required (welding of sections with sealant sheeting – bulkheads), the possibility of subsequent grouting of cavities is to be provided for (e.g. waterstop with grouting hose).

5.2.3.2 *Internal waterstops*

In non-reinforced concrete (e.g. floor) the waterstop is to be secured in place by means of an ancillary device. Placing of additional grouting hoses is recommended, as they permit subsequent sealing of leakages through grouting. The use of swellable waterstops may be appropriate, since fastening in non-reinforced concrete requires additional measures.

5.2.3.3. *Swellable waterstops*

Swellable waterstops prevent water leakages, as they swell when in contact with water.

The swelling of waterstop materials must be sufficiently reversible (swell factor of the effective sealing material min. 200%); moreover, an appropriate swelling time and sufficient stability under higher water pressure or under the impact of major joint movements are essential.

Swelling must be reversible and independent of the chemical composition of the contact water. For joints exposed to substances other than water, the manufacturer has to demonstrate the sealing effect and the chemical resistance of the product. The component reacting with water must not be washed out or release deleterious substances into ambient water. It is important to bear in mind that swelling takes some time, which means that the sealing effect is not produced immediately.

The concrete surfaces on which swellable waterstops are to be placed should be as even as possible and free of pockets. The manufacturer's instructions are to be followed carefully. Preferably, waterstops are to be placed in grooves to keep them in the desired position.

- Swellable waterstops are to be placed in such a way as to protect them from uplift in fresh concrete.
- The structure of the substrate must not be disturbed by the swellable waterstop being fastened.
- The waterstop must be fastened on the substrate so as to prevent seepage also when not swollen. On a rough substrate, this can be achieved through the use of swellable putty, one-component PU putty or two-component bonding putty based on epoxy resin.
- Early swelling of waterstops prior to concrete pouring is to be prevented.
- As a rule, swellable waterstops are to be placed centrally in the concrete cross section; if this is not possible, a distance of at least 10 cm must be maintained on each side.

In traffic tunnels exposed to the risk of accidents involving hydrocarbon-containing liquids, swellable waterstops for the floor area must be resistant to hydrocarbon.

5.2.3.4 *Grouting hoses*

- Grouting hoses have to be placed in such a way as to protect them from uplift in fresh concrete.
- The grouting hoses (e.g. diameter, length) are to be adjusted to the grouting material to be used.

5.2.3.5 Repair of joints and waterstops

If construction joints or expansion joints become pervious to water and/or waterstops are damaged, the following repair and/or maintenance measures have to be taken:

a) Water-permeable construction joints

If self-healing does not occur in water-permeable construction joints, grouting is necessary. It. 7.5 (repair or waterproof concrete) applies by analogy.

b) Water-permeable expansion joints

As regards the repair of expansion joints, the measures to be taken depend on whether the problem is due to leakage at the legs of the waterstop or a defect in the expansion area.

Leakages can be eliminated through

- grouting in the area of the legs of the waterstop
- grouting directly above the waterstop

If a leakage occurs at the legs of the waterstop, grouting of the defective spot by means of a bore packer is advisable. Epoxides, polyurethanes or acrylates can be used for this purpose. The choice of material depends of the requirements of the specific case.

Grouting can also be performed directly above the expansion joint. To this end, the expansion joint must be closed with a plastic hose over its entire length. Epoxide mortar has to be applied to prevent displacement of the hose under grouting pressure. Expansion joint grouting is performed via the plastic hose or by means of a bore packer via the joint flanks.

If the waterstop itself is damaged, it can be repaired according to c), provided the waterstop can be exposed. If these methods do not produce the desired success, a second sealing layer must be installed on the air side, with the expansion joint kept free from water through temporary measures (provisional sealing). This can be achieved through either flanging or bonding. To this end, flexible plastic strips are friction-locked to the concrete body at the flanks in waterproof fashion or bonded by means of epoxy resin.

c) Damaged waterstops

To repair a waterstop, the damaged area first needs to be exposed. After successful repair, the exposed areas of the waterstop have to be reprofiled by means of waterproof mortar (e.g. epoxy-resin mortar) to achieve friction-locking. Minor damage to PVC and PVC/NBR waterstops can be repaired with „patches“ welded onto the damaged part by means of hot-air blowers. Waterstops made of elastomers can be repaired through vulcanisation. If larger parts of the waterstop are damaged, these are to be bonded with a suitable piece of overlapping waterstop through thermal welding or application of an adhesive (polyurethane). If the damaged area of the waterstop is too large to permit overlapping and bonding, the damaged waterstop must be removed and replaced through flanging. If swellable waterstops are damaged, they must be replaced in all cases.

5.3 Intermediate layers between the substrate and the concrete

Intermediate layers between the substrate and the concrete include separation layers, sheet drainage systems and sealing layers.

5.3.1 Laying and fastening

The individual webs of the intermediate layers have to overlap in such a way as to allow free drainage of mountain water behind the webs without contact with fresh concrete. In the case of a stronger ingress of water, hose drainage is to be provided for in order to avoid the formation of water pockets behind the intermediate layer. The edges of the individual webs must be either bonded or overlapped to prevent the penetration of concrete into the space between the intermediate layer and the rock and/or the sprayed concrete shell.

The intermediate layer must be fastened so as to prevent it from being displaced by the rising concrete or torn off the fastenings. As a rule, special nails are used for fastening.

As regards sealing, the specifications of RVS 8T, and additionally Issue 365 of Straßenforschung [1], apply.

5.3.2 Separation layers

Separation layers serve to diminish the adhesion and interlocking between the cavity lining and the rock and/or the sprayed concrete lining. They are used mainly in combination with non-sealed inner shells. They serve to diminish the build-up of restraint stresses in the cavity lining in the course of the setting process and the resulting crack formation. As a rule, mesh-reinforced, thin plastic sheeting, film-covered non-wovens or bubble film according to [1] are used.

5.3.3 Sheet drainage systems

Sheet drainage systems permit low-resistance drainage of mountain water to be collected in drainage lines (see ÖVBB Guideline on Tunnel Drainage Systems). As a rule, structured plastic panels (bubble film), special non-wovens or drain elements are used for this purpose.

5.3.4 Sealing layers

The installation of sealant sheeting permanently prevents the ingress of water into the cavity.

As regards the execution and testing of sealing layers, RVS 8T, and additionally [1], apply.

5.4 Formwork

Given the straight ground plan of most formwork elements, curves take a polygonal course. Permissible geometrical tolerances are to be observed.

In formwork design, care must be taken to ensure that dynamic strain through formwork vibrators, hydrostatic fresh-concrete pressure (e.g. uplift) and hydraulic pump pressure upon closure of the roof via the pump flanges does not result in unacceptable deformations of the formwork skin and the roof formwork.

All formwork must be set up according to the design as a stable and waterproof system. Formwork vibrators require a particularly stiff formwork and rigid fastening for the vibrations to be transferred to the concrete. Special care must be taken when executing formwork for facing concrete. Formwork edges are to be executed with great care (e.g. through insertion of triangular fillets).

Prior to its use, formwork must be cleaned thoroughly and treated with a suitable release agent to ensure that residues of the outer concrete skin do not stick to the formwork. The release agent applied to the formwork must not cause any physical or chemical damage to the concrete surface (e.g. dust formation). Wooden formwork is to be wetted or impregnated before the concrete is poured.

Elements used to lock formwork across concrete parts are to be laid in pipes to permit easy removal. The remaining openings are to be waterproofed (e.g. through grouting) and carefully sealed. For waterproof concrete components, watertight formwork anchoring systems are to be used.

5.4.1 In-place formwork

If the use of travelling formwork is not economically justifiable on account of the small number of standard concreting sections or the changing shape of the cross section, in-place formwork is used.

This type of formwork is assembled from prefabricated elements. Pre-bent or polygonally assembled steel girders or wooden structures are used as service girders. To move the formwork, the components are lowered via wedges and/or spindles; parts of the formwork may have to be dismantled by means of rope winches or hoists.

5.4.2 Travelling formwork

For longer standard sections the use of travelling formwork, which can be moved either mechanically or hydraulically, is used to save time and keep costs down.

Travelling formwork can be designed as full-round wagons or split formwork wagons. Arch formwork is placed on structural components concreted in advance. The wagons used for smaller cross sections (up to approx. $20m^2$) take up, place and remove the self-supporting formwork skin elements block by block. For larger cross sections, the formwork wagon is often assembled with the complete formwork skin for the entire length of the concreting section and serves both as a transport wagon and a stiffening structure during concrete pouring.

5.5 Release agents

As a matter of principle, release agents must be environmentally safe and compatible with the formwork material used. Preference is to be given to chemically/physically active release agents. Wax solutions and pastes may form a particularly resistant release film of great adhesive strength, which is essential if the formwork remains in place for a long time and is exposed to heavy stress and strain while the reinforcement is laid. Release agents must be applied to the thoroughly cleaned steel formwork in thin layers. Moreover, release agents must contain anti-corrosive additives (inhibitors).

The release agent used is to be compatible with paint coats and other coatings which may be subsequently applied.

Release agents must bear clear and indelible labels indicating the group of substances used. If dilution is permitted, the dilutant to be used and the degree of dilution are to be indicated. The following information should be specified on the label:

- instructions for use
- average quantity to be applied
- effect of overdosage
- instructions for the removal of residues of the release agent from the concrete surface
- fire hazard (hazard class), shelf life and storage conditions.

Moreover, the presence of hazardous substances is to be specified on the label.

For each delivery, the following information is to be specified on the container:

- batch number,
- year and month of production,
- shelf life.

5.6 Reinforcement

In the case of self-supporting reinforcement, care must be taken to ensure adequate stability of the load-bearing structure.

The position of the reinforcement, as indicated in the design drawings, is to be secured through adequate measures, while keeping impairments to concrete placing to a minimum (exchange of reinforcement at the openings for pouring and vibrating is necessary). Overlaps of reinforcement mats should not be placed near concreting flanges and/or observation windows. The spacing between the reinforcement layers is to be maintained through basket supports or similar devices.

Overlaps of reinforcing mats must be arranged in such a way as to avoid the superposition of four mat layers (impairment of concrete placing).

RSV 9.35 applies to the concrete cover and its inspection.

The air-side concrete cover is to be ensured through the use of suitable spacers according to RVS 9.35 (e.g. triangular concrete fillets, min. 1/m²). The concrete spacers used must be long enough to extend over at least two neighbouring reinforcement bars which do not cross each other. The quality of the spacers must correspond, at least, to that of the inner shell concrete. Reinforcement overlaps must be positioned in such a way (moveable) as to prevent destruction of the spacers through formwork pressure.

5.6.1 Sealed inner shells

As a rule, reinforcement is not provided for in sealed inner shells. If reinforcement is required for structural reasons, the following design variants, depending on the conditions of the cavity in question and the sequence of construction operations, are possible:

- self-supporting reinforcement
- reinforcement fastened by means of a disk in offset position on the sealing (plane of weakness between disk and sealing is required)
- reinforcement laid on formwork; reinforcement with erection head and through-sealing (special case)

Care must be taken to ensure proper fastening of the reinforcement in front of the sealing layer in order to prevent damage to the sealing through displaced or bent reinforcement rods during concrete placing.

5.6.2 Inner shells without sealing

In inner shells without sealing, reinforcement is usually installed via assembly hooks drilled from the outside and longitudinal reinforcing rod spacers.

5.7 Construction tolerances

The actual geometry of the soffit (air-side) after completion of the lining may deviate from the design geometry to a certain extent (tolerance). This is due to unavoidable inaccuracies in site surveying and formwork erection. Moreover, the formwork wagon, the geometry of which is dimensionally inaccurate, experiences a certain amount of deformation during concrete placing. In tunnel curves the ideal ground-plan geometry is reproduced through a polygonal arrangement of the concreting sections. Except for the area of block joints, this results in a calculable lateral narrowing of the design cross section. (In the case of narrow curve radii, the geometry of the block sections is to be taken into account already during tunnel excavation.)

In bored traffic tunnels (with TBM), the provisions of the relevant Guidelines [5,6,7] are to be observed.

Given the unavoidable inaccuracies in construction practice, tolerances are to be calculated according to the following models:

5.7.1 Surveying tolerances

Given the unavoidable formwork surveying inaccuracies, tolerances must be taken into account.

Tolerances depend on:

- surveying possibilities (closed or open traverse)
- length of the tunnel

In view of the above, the tolerances required for construction practice are classified as shown in Table 5/1:

Tolerance class A1	Closed traverse: Surveying of a traverse with a starting point and an end point is possible (tunnel already cut through, with pilot gallery)
Tolerance class A2	Open traverse: Surveying of an open traverse only (e.g. placing of inner-shell concrete in a tunnel not yet cut through) Calculation of the break-through error is required. The accuracy depends on the tunnel length (TL). TL is defined as the sub-length until closure of the traverse.

5.7.2 Formwork tolerances

Tolerances must be taken into account during formwork erection due to dimensional inaccuracies and construction tolerances. These inaccuracies depend on the size of the formwork and are classified as follows:

B1 Inaccuracies in formwork production

B2 Inaccuracies in formwork erection

B3 Deformation of formwork during concrete placing

5.7.3 Geometrical tolerance

For tunnel cross sections in curves, the tolerances resulting from lateral narrowing due to the block polygon of the formwork wagon must be taken into account. These tolerances depend on the block length (L), the design width of the clearance (B) and the curve radius (R) of the tunnel axis; they are calculated according to the following equation (dimension in mm):

$$C = R + \frac{B}{2} - \sqrt{2,(R+\frac{B}{2})^2 - (\frac{L}{2})^2}$$

5.7.4 Total tolerance

The projected geometry of the soffit of the tunnel lining must exceed the required minimum geometry by the sum total of the individual tolerance values listed in Table 5/1 (see example in Annex 2). The formwork and, if applicable, the reinforcement have to be designed accordingly. The tolerances taken into account are to be specified in the design drawings. Any other tolerances required are to be taken into account in the course of project execution.

Upon acceptance of the work, the minimum geometry required is to be demonstrated.

The geometrical tolerance is calculated by summing up the individual tolerances. Surveying tolerance A1 or A2 is to be selected, as applicable. The corresponding formwork tolerance B1, B2 or B3 and the geometrical tolerance C are to be added up and, together with the corresponding value for A1 or A2, represent the total tolerance.

Beyond the tolerance values, the soffit of the finished lining should not deviate from its design position by more than 10 cm at any point, measured in radial direction. For galleries, structures of minor importance and structures not under load from equipment mounted in the roof area, larger deviations are permitted, provided they do not occur abruptly.

The minimum thickness and/or design thickness of the lining must be complied with throughout the structure. Values below the required minimum (according to Table 4/1) are permitted in isolated spots (e.g. around anchor heads). In view of a possible deviation of the lining from the design geometry, corresponding allowances are to be provided for in the outer shell and/or the excavated rock surfaces.

An accuracy of ± 2.5 cm is required for prefabricated parts, cable ducts, installations and niche sizes. Niches must be positioned to an accuracy of ± 10 cm.

After completion of the inner shell, a new reference axis can be defined to optimise further support work.

Table 5/1 Tolerances for inner shells

Surveying tolerances				**Formwork tolerances**							**geometr. tolerances**
	A1	**A2**		**B1**		**B2**			**B3**		**C**
		TL[1)] ≤ 1000 m	TL[1)] > 1000 m	F[2, 5)] ≤ 50 m²	F[2, 5)] > 50 m²	Arch	Floor Type 1[3)]	Floor Type 2[4)]	F[2, 5)] ≤ 50 m²	F[2, 5)] > 50 m²	[± mm]
Position	±10 mm	±20 mm	±10 mm additional per 1000 m TL[1)]			±20 mm	±20 mm	±50 mm	±10 mm	±20 mm	Equation acc. to It. 5.8.3
Height	±10 mm	±10 mm				±20 mm	±20 mm	±50 mm	±10 mm	±20 mm	
Radial				±10 mm	±15 mm						

1) TL Tunnel length until closure of traverse
2) F Cross section of clearance
3) The floor is not part of the outer shell.
4) The floor is part of the outer shell and is concreted in the course of tunnel driving.
5) To be taken into account for the floor only if full-round formwork wagon is used.

6. PRODUCTION AND PLACING OF CONCRETE

6.1 Mixing plant

Preconstruction testing of the mixing plant and on-site production testing are to be performed by an accredited inspection body or a qualified representative of the principal.

The mixing plant must be equipped with a microprocessor control system according to ÖNORM B 4710-1, It. 9.6.2.3.

- Storage and printout of mix formula
- Logging of all dosages of constituent materials for a batch or filling, including deviations from target weights.
- Measurement of the water content of at least 90% of the grain fraction under 4 mm by means of measuring probes with a tolerance range of ± 0.5% by weight and automatic correction of water added. The average water content of the remaining grain fractions is to be considered separately.
- Checking of actual and target values of all concrete components of each batch or filling, including deviations from target weights. The tolerances of Table NAD 12 b of ÖNORM B 4710-1 apply.
- Batch protocol: protocol number, delivery note number, date, time of day (beginning of mixing), formula number, batch size (quantity), mixing time, fresh-concrete temperature, actual and target weights of all concrete components, moisture, set tolerance, deviation of actual value from target, total water content, W/B value, residual water.
- Concreting protocol: the following data must be recorded, stored and printed out clearly upon request for the period of time and/or construction section selected:
  total number of batches, batches with dosage deviations from target weights or manual switching, mean value, maximum and minimum, standard deviation of weight of all concrete components (cement, additives, admixtures, total water, mineral aggregates) compared with target quantity, construction site, structural part, concrete grade, formula number, concreting time, mixing time, fresh-concrete temperature (for model protocol see Annex 1).
- A comparison of the batches with deviations from target weights and manual switching with the total number of batches provides an indication of the performance of the mixing plant. The statistical records of the weights of constituent materials used serve to demonstrate compliance with the required concrete composition for the section concerned and constitute a verifiable system of quality control. Actual weight errors are permitted in a maximum of 10% of the total number of batches, provided the dosing accuracy for the filling of the mixing plant is observed.
- If possible, the fresh-concrete temperature in the mixer is to be kept within a range of 13°C and 18°C to obtain concrete of good quality. In periods of hot weather, simple cooling measures, e.g. covering the sand to protect it from solar irradiation and/or spraying of coarse-grained aggregates, may have to be applied. Concrete with a fresh-concrete temperature of less than +5°C (at outside temperatures < 3°C) or more than +27°C (measured at the construction site, e.g. before pumping) must not be placed. If the fresh-concrete temperature is higher than 22°C, all other conditions should be as favourable as possible (see Table 3/1). For arch concrete a minimum fresh-concrete temperature of +10°C is required.

During the hot season, cooling of fresh concrete (e.g. nitrogen cooling, large-scale storage sites of mineral aggregates) may be necessary to comply with the maximum fresh-concrete temperature requirement (to be indicated in the tender documents).

If concrete is placed in winter, the water or the mineral aggregates have to be heated to a sufficient temperature. The mineral aggregates have to be mixed with water which has been pre-heated to a temperature of over 60°C.

The minimum mixing time in the mixer is 30 seconds.
The aggregate bin of the mixer must be covered to protect it from rain and snow.

6.1.1 Stand-by mixer

Stand-by mixers are to be used only in the event of failure of the main mixer. The type of stand-by mixer is to be indicated prior to the beginning of concrete placing.

Stand-by mixer type 1: only permitted for completion of the structural component under construction (mixer and concrete grade according to ÖNORM B 4710-1). The concrete formula to be used is to be specified before concrete placing is begun.

Stand-by mixer type 2: mixers for short-term use (maximum of 3 concreting days) in the event of failure of the main mixer. These mixers have to meet the requirements of ÖNORM B 4710-1. Preconstruction testing of the concrete according to It. 3.3 of this Guideline is required. The frequency of conformity testing must be twice as high as the testing frequency specified in Table 3/7.

Stand-by mixer type 3: mixers meeting the same requirements as the main mixer in terms of mixer design and concrete grade.

6.2 Transport

Fresh concrete is to be protected from climatic influences during transport. Concrete of consistency classes > F38 must not be transported by means other than truck mixers.

Depending on the cement grade used, the concrete temperature and the air temperature, ready-mix concrete usually has to be placed after 105 minutes, at the latest. If this period is exceeded, evidence of prolonged workability (VV) must be produced. If concrete placing is interrupted for more than 3 hours (e.g. failure of a concrete mixer), timely vibration of the surface and execution of a construction joint are required.

6.3 Conveying, placing, compacting

6.3.1 Conveying

As a rule, arch concrete is conveyed by means of pumps; if suitable relay pumps are available, it can be pumped over a distance of up to 1500 m. If long pump hoses and relay pumps are used, a sufficient allowance for the required placing consistency and compliance with the required void content of the concrete are necessary.

In case of non-compliant consistency (loss of water, stiffening), correction is possible through the addition of a suitable plasticiser (to be kept in store if long pump hoses are used).

6.3.2 Placing

Arch concrete can be placed by means of a through-type concrete distributor, distributor pumps or manual handling via filling flanges.

The rate of concreting and the difference in concrete levels depend on the structural design of the formwork wagon. As a rule, the maximum rate of vertical rise is 2.0 m/h, with the maximum difference in concrete levels being approx. 1.0 m.

As a rule, the horizontal distance between the concreting window and the filling flange is 3.0 m.

Maximum head (distance of the pouring outlet of the concrete conveyor from the concrete level) 2.0 m.

The height of the individual concrete layers in the wall area must not exceed 0.5 m.

In case of manual handling of the concreting hose, the concrete stream is to be directed at the fresh concrete.

Flush closure of the roof is to be aimed at.

To check the quality of concrete placement in the roof area, inspection tubes are to be installed in longitudinal direction every 3.0 m to 4.0 m, the top of which must not be more than 2 cm from the highest point of the outer arch.

In the event of scheduled interruptions of concrete placement in the inverted arch, evidence according to ÖNORM B 4710-1, It. 4.2.7, is to be produced in respect of the maximum duration of the intended interruption.

6.3.3 Compaction

Concrete compaction is to be performed by means of high-performance internal or external vibrators. Depending on the formwork wagon design, formwork vibrators are to be positioned as regularly as possible, with one vibrator for approx. 3 m^3 to 4 m^3 of formwork skin.

The capacity of the vibrators is to be such as to ensure proper compaction of the arch concrete to its design thickness. Experience has shown that the effective depth of vibration is 40 cm to 50 cm. Only the formwork vibrators positioned at or around the concrete level and, at most, those immediately below are to be operated at the same time.

If necessary, the density of formwork vibrators is to be increased in the construction joint between the floor and the arch and/or in formwork areas where the formwork comes to rest on parts of the structure already completed.

Specific compaction schedules are to be elaborated for arch concrete, fibre-reinforced concrete for non-reinforced and reinforced inner shells, sealed reinforced inner shells, and waterproof inner shells.

7. REQUIREMENTS AND MEASURES AFTER CONCRETE PLACING

7.1 Stripping

The provisions of It. 3.1.2 and 4.6 are to be observed. The stripping time refers to the internal formwork of the arch concrete. As a rule, formwork on the face of the arch is removed after 4 – 5 hours so that the development of compressive strength can be observed.

After the removal of the internal formwork, forms usually remain in place for a longer period of time in niches and similar construction features, depending on their shape and size.

To prevent damage to edges, ring joint profiles, unless firmly attached to the steel formwork, also remain on the concrete for a longer period of time.

7.2 Concrete curing

7.2.1 Standard curing

As a rule, liquid curing agents according to RVS 11.064, Part II, are used for curing of inner shell concrete. The curing agents are to be applied in sufficient quantities over the entire surface as early as possible, preferably by spraying. Care should be taken not to impair the bonding of paint coats or other coatings to be applied at a later point in time. To prevent excessive cooling and drying, measures have to be taken to diminish strong air flows (e.g. covering a tunnel portal). Curing is not necessary, if air humidity is relatively high (> 90%) and the rate of air flow is low ($\leq$ 1 m/s).

7.2.2 Special measures

If the formwork is removed prior to the standard stripping time, evidence must be provided of equivalent curing measures to protect the concrete immediately after stripping against rapid cooling for at least 3 days and against drying for at least 7 days in order to ensure sufficient hardening of near-surface areas under construction-site conditions and to avoid crack formation.

A multi-chamber curing wagon [2] with heat insulation and water-vapour spraying can be used for curing. The design of the control system (temperature- or time-dependent) must be such as to permit cooling of the concrete to ambient temperature within 3 days after stripping in approximately equal increments.

7.3. Concrete surfaces

7.3.1 Requirements

Concrete surfaces of inner shells have to meet the requirements of ÖNORM DIN 18202 in terms of dimensional, geometrical and positional tolerances. The requirements for facing concrete S, P and F according to ÖNORM B 2211 do not have to be met.

In wall areas, under inclined forms, voids of up to a void diameter of 2 cm cannot be avoided in practice and have no deleterious effect. In the case of reinforced inner shells, the depth of the voids must not exceed 1 cm. If the concrete surface has to meet special requirements, e.g. architectural design or resistance to frost-thaw cycles, additional measures have to be taken (e.g. non-wovens for drainage, paint coats).

7.3.2 Repair measures

Minor defects, which do not adversely affect the fitness of the finished structure for its intended use, do not need to be repaired. If repair measures have to be performed, it is important to bear in mind that the removal of a thin surface layer of concrete, e.g. by grinding, is always preferable to the application of a thin layer of mortar. This holds, in particular, for larger, shallow defective areas (see ÖVBB Guideline on Formed Concrete Surfaces).

When repairing defects (e.g. concreting pockets, voids deeper than 1.0 cm or deeper than 1.5 cm in non-reinforced inner shell concrete), the provisions of the ÖVBB Guideline on the Maintenance and Repair of Plain and Reinforced Concrete Structures regarding the preparation of the substrate and the materials to be used for repair (coatings, reprofiling mortar) have to be observed.

Large areas with defects to a depth of $\geq$ 2 cm have to be repaired by spraying them with suitable reprofiling mortars, e.g. to obtain the necessary concrete cover.

Continuous cracks > 0.3 mm in reinforced inner shells have to be friction-locked through grouting (e.g. fine cement, to be applied according to ZTV-RISS).

In non-reinforced inner shells grouting is not obligatory, if evidence of the safety of the structure is produced.

In traffic tunnels, unavoidable offsets of individual concrete sections of the inner shell against each other are usually concealed through joints (see It. 5.2.2). Defects in joints are to be repaired and levelled through grinding.

For filler openings (filling flanges) deviations from the design inner surface of up to 1/5 of the concrete cover and/or a maximum of 5 cm are permitted. This also applies to reinforced inner shells, as the reinforcement is cut out and exchanged. The required thickness of the inner shell must, however, be observed in waterproof inner shells.

7.3.3 Surface protection

For additional protection of the concrete surfaces of inner shells, impregnating layers, sealings, paint coats or other types of coatings can be applied. Protective measures are particularly recommended in road tunnels for the lower part of the cross section (walls) and the portal areas to improve resistance to frost and thaw cycles (see ÖVBB Information Sheet on Coatings for Inner Shells of Tunnels).

The Information Sheet contains recommendations regarding the selection, assessment and application of such products as well as the preparation of the concrete surface (exposure of the granular skeleton through sand blasting or by means of water jets).

7.4 Grouting of the roof cavity and other arch areas

Once the arch concrete has sufficiently set, the cavities in the roof area are grouted at low pressure (ca. 1 – 2 bar) with stable binder slurry via the grouting holes. Grouting is considered to be complete when slurry starts to exit from the nearest tubes.

A stable binder slurry has to meet the requirements of Table 7/1. The parameters have to be established before grouting is begun.

Table 7/1 Requirements to be met by stable binder slurry

Requirements	**Test**
Water-binder value /W/B value) max. 0.80	Reduction roasting
Water segregation max. 10% after 2 h	1000 ml column
Viscosity (Marsh funnel) min. 30 sec	Marsh funnel
Compressive strength min. 15 N/mm² after 28 days [1)]	Cylinder d= 100 mm /d:h = 1

1) Testing for compressive strength is only required if the water-binder value of 0.80 is exceeded.

As an alternative for sealed tunnel sections, backfilling of the roof cavity by means of a hose produced and installed in the roof especially for this purpose, with a connecting flange at the end of the section, is possible.

In reinforced and sealed inner shells, care must be taken to ensure sufficient grouting of cavities between the sealing and the reinforced arch component. Grouting must be performed before the temporarily lowered mountain water is again raised to its normal level. Systematic grouting of abutments, walls and floor/arch transition areas may be necessary, in addition to grouting of the roof cavity. This measure serves to prevent damage to the sealing by exposed reinforcement.

7.5 Repair measures in waterproof concrete

If water-permeable cracks and/or unacceptable patches of moisture occur in structural components made of waterproof concrete (floor and abutments), the following maintenance and repair measures have to be taken:

If the rate of water flow is low and the crack flanks do not move to any significant extent, it is advisable first, if possible, to wait and see if the crack closes through self-healing. If not, grouting of defects has to be performed in due time. The materials best suited for grouting are epoxides, polyurethanes or acrylates. The choice of substance depends on the specific requirements and must be approved by the principal. Grouting is performed via grouting anchors fastened through bonding along the crack or drilled laterally at an angle of 45°. To prevent grout from escaping, the crack is closed with a filling compound between the packers. Grouting is performed from bottom to top until grout starts to escape from the next higher packer. After grouting, the filling compound and the packers are removed and drill holes, if any, are closed.

8. SPECIAL PROCEDURES

8.1 Sprayed concrete inner shells

Sprayed concrete for inner shells is to be produced and placed according to the ÖVBB Guideline on Sprayed Concrete. Moreover, the following supplementary provisions apply:

Fibres:
Steel fibres, also used in combination with steel reinforcement, primarily serve to improve the post-cracking behaviour of the concrete (testing for load-bearing capacity or functional properties of the finished structure according to the ÖVBB Guideline on Fibre-Reinforced Concrete). Glass and plastic fibres may serve to diminish early shrinkage cracking. Plastic fibres increase the fire resistance of concrete by reducing spalling.

Wet mix:
The water-binder value must not be higher than 0.50.

Design:
Sprayed concrete for tunnels with a single-pass lining ("monocoque design") has to meet the following requirements:

Sprayed concrete for the outer shell:
at least SpC 20/25(56)III/XC4/J_1 or J_2.

Sprayed concrete for the inner shell:
at least SpC 20/25/III/XC4, XF3 if necessary.

The frequency of conformity testing corresponds to Class III according to the ÖVBB Guideline on Sprayed Concrete.

If the outer shell is required to form a composite structure with the inner shell, the adhesive strength has to be at least 1.0 N/mm² according to the ÖVBB Guideline on Sprayed Concrete.

The bonding action (adhesive strength of the substrate and tensile adhesive strength of the sprayed concrete) is tested according to ÖNORM B 3303.

8.2 Concrete segmental linings

As a rule, segmental linings made of prefabricated concrete [4] are put in place in the course of tunnel excavation by means of a circular full-face tunnel boring machine. They are mainly used in tunnels with a uniform cross section.

The inner shell consists of prefabricated segmental linings, which are assembled on site to form a closed inner ring. Depending on the design, the prefabricated parts are jointed longitudinally and in transverse direction by suitable means; if necessary, the structure is made waterproof through appropriate joints and joint seals. The annular ring between the rock and the shell made of segmental linings, unavoidable for engineering reasons, is grouted continuously immediately after installation of the segmental linings.

Segmental linings offer the advantage of continuous and systematic tunnel support. A load-bearing shell is in place just behind the full-face TBM. In the case of very substantial rock deformation, the segmental linings must be designed to absorb such deformation (e.g. deformable intermediate layer, yielding segmental lining).

In addition to ÖNORM B 3308 and ÖNORM B 4705, the requirements of this Guideline apply by analogy to the production and testing of segmental linings. Sufficient curing is to be ensured.

If a waterproof system is required, the segmental linings must be dimensionally accurate. Depending on the requirements, the tolerances have to be agreed on a case-by-case basis for the project and system in question. The tolerances for the finished inner shell must correspond to It. 5.7.

The first linings produced are assembled without joint tapes to establish their dimensional accuracy and their geometry.

Neoprene sections and/or swellable waterstops are used as joint tapes.

8.3. Fibre-reinforced concrete

Fibre-reinforced concrete, as defined in the ÖVBB Guideline on Fibre-Reinforced Concrete, is a composite material consisting of a concrete matrix to which fibres are added in the course of production. On the one hand, the special properties of fibre-reinforced concrete, as specified in the Guideline, can be used to improve the load-bearing behaviour of inner shell concrete (e.g. arch concrete in areas subject to long-term deformations of the outer shell, large tunnel niches, portal sections), i.e. through fibre-reinforced concrete classes T (usually T3 or T4). On the other hand, the fire resistance of traffic tunnels can be increased, i.e. through fire-resistant concrete class BB 2G. For floor slabs in tunnels built by the cut-and-cover method, fibre-reinforced concrete class FS 1 or FS 2 may help to reduce the risk of early shrinkage cracking (addition of PP fibres).

According to the results of recent research projects ([9], ([10]), fibre-reinforced concrete class BB 2G, which largely prevents spalling of near-surface concrete layers in the event of a fire, is achieved through the addition of fine mono-filament polypropylene fibres (e.g. 1.5 – 2.0 kg/m³ PP fibres, 6 mm long, diameter < 20 micrometers). To demonstrate achievement of reinforced-fibre concrete class BB 2G, the fibre may have to be tested for its basic suitability once prior to its use in arch concrete for tunnel inner shells according to Annex 5. Annex 5 will only remain in force until publication of the ÖVBB Guideline on the Increased Fire Resistance of Concrete for Underground Traffic Structures, which contains the final provisions governing fibre-reinforced concrete classes BB 1G and BB 2G.

As regards the constituent materials and the composition, production, placing and testing of the concrete, the provisions of this Guideline as well as those contained in the ÖVBB Guidelines on Fibre-Reinforced Concrete and Increased Fire Resistance of Concrete for Underground Traffic Structures apply.

The material quality, length and geometrical shape of the fibres, both longitudinally and across, as well as their surface have an influence on the workability, strength, deformation behaviour and other properties of the concrete.

As a rule, fibre-reinforced concrete can be produced in pug-mill mixers without special precautions and is easily pumpable. The fibres must be added to and mixed with the concrete so as to ensure a homogeneous distribution. A documented procedures, based on previous tests, must be available, specifying the type, timing and rate of fibre addition as well as the required mixing time after addition of the fibres to ensure their uniform distribution, the required consistency and the specified void content.

The addition of fibres results in a stiffer, sticky consistency, which normally can be compensated for through the addition of plasticising admixtures. If the maximum permissible water content according to Table 3/2 is exceeded, reduced shrinkage (RS or RRS) must be demonstrated according to ÖNORM B 3303. Care must be taken to ensure that the required stripping times can be observed, even if the plasticiser dosage is increased. Before concrete placing is begun, a concreting trial is to be performed to establish if the concrete can be properly placed by means of the placing and compaction equipment available on site.

It is important to note that the distribution of fibre-reinforced arch concrete behind the formwork and its compaction between the outer shell and the steel reinforcement are more difficult and therefore demand a special placing and compaction procedure (e.g. more frequent repositioning of the pumping line, adjusted vibration energy, frequency).

As regards the section length of inner shells made of fibre-reinforced concrete, Table 4/1 applies. In the case of tensile force transfer, construction joints need to be secured additionally through reinforcement. For block joints to be sealed by means of expansion joint tapes, fastening of the joint tape in the correct position by means of a supporting structure (e.g. latticed bend) is essential.

9. INTERMEDIATE CEILING AND PARTITION FOR VENTILATION DUCTS IN TRAFFIC TUNNELS

9.1 Intermediate ceiling

9.1.1 Concrete for intermediate ceilings

9.1.1.1 Principles of concrete composition

The composition of concrete for intermediate ceilings has to be determined, above all, with a view to workability, avoidance of early shrinkage cracking, stripping strength and the functional properties of the finished structure.

- For reasons of workability, the concrete must be pumpable and has to permit easy levelling of the intermediate ceiling surface after placing and compaction (usually consistency F45).
- To avoid early shrinkage cracking, the total water content should be $\leq$ 190 l/m³. Curing is to be performed immediately after levelling (spraying with a curing agent suited for fresh concrete).
- In practice, the use of several formwork elements and formwork removal after $\geq$ 36 hours has proved successful. The stripping strength must be demonstrated through testing. As a rule, a stripping strength of $\geq$ 20 N/mm² is required. Heating of the intermediate ceiling concrete is not permitted. The modulus of elasticity must be determined to establish the rate of deformation at the time of formwork removal.
- To ensure compliance with the required functional properties of the finished structure, concrete grade C25/30/XC3/XF3/RS (abbreviated: C25/30/B3/RS) is recommended.
- Increased fire protection requirements must be taken into consideration according to It. 3.1.5.
- To obtain the required concrete properties, the following concrete composition has proved appropriate (Table 9/1):

Table 9/1 Proposed concrete composition for intermediate ceilings

Mineral aggregates GK 16, GK 11 Range 2/3 (A+B) - B at ς =2.700 kg/m³	1830 – 1900 kg/m³
Cement WT 38, WT 42	260 – 280 kg/m³
Additives according to ÖN B 3309 (AHWZ)	0 – 40 kg/m³
Total water content	≤ 190 l/m³
Air content	2.5 – 5.0 %
Consistency	F 45
Admixtures BV, FM, LP, LPV	To obtain the required consistency with permissible water content

9.1.1.2 Quality control

- Preconstruction testing is to be performed by an accredited inspection body. The following parameters have to be tested and demonstrated:
  Optimisation of concrete composition with regard to early stripping, fresh concrete properties, stripping strength and modulus of elasticity upon formwork removal at a storage temperature of + 15°C, 28 d compressive strength, water penetration depth according to ÖNORM B 3303 (XC3), XF3, calibration of the rebound hammer, porosity.

- Conformity checks and identity testing are to be performed, by analogy, according to the requirements of Tables 3/7 and 3/8.

- Testing of the structure (to be performed by the user).
  Use of the rebound hammer is recommended for stripping strength testing in each concreting section. The concrete cover of the steel bars is to be tested according to It. 3.4.3.
  To check proper concrete placement and curing, porosity tests are to be performed in three drilled cores from the first three ceiling elements and repeated at intervals of 30 ceiling elements. The results are evaluated by comparison with the porosity established in the preconstruction test.

9.1.2 Design measures

The provisions of RVS – Structural Fire Protection for Road Traffic Structures - apply.

- Deformation under different load conditions (e.g. partition formwork load) and vibration behaviour have to be demonstrated
- Recommended thickness of structural component: 20 cm
- Minimum cover of steel reinforcement: minimum structural dimension 35 mm, minimum design dimension 45 mm (according to Information Sheet RVS 9.35)
- Section length to be adjusted to block division of the arch.

The design assumption for intermediate ceilings is a passenger car on fire, which means that ÖNORM B 3800-4 applies. For security installations, such as air fans, etc., special provisions apply (e.g. proof of deformation under fire load).

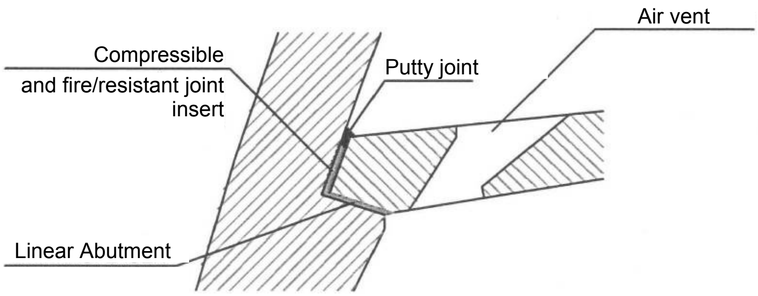

Fig. 9.1 Example of abutment for intermediate ceiling

9.1.3 Concrete production, placing, curing

The provisions of It. 6.1 of this Guideline apply to concrete production. A curing agent suited for use on fresh concrete is to be applied to the finished part of the intermediate ceiling immediately after production (to be sprayed twice).

9.2 Partition

9.2.1 Concrete for partitions

9.2.1.1 Principles of concrete composition

The composition of concrete for partitions is to be optimised with a view to workability, stripping strength, shrinkage and the functional properties of the finished structure.

For reasons of workability, the concrete must be pumpable over short distances and well suited for easy placement in the reinforced, thin (12 – 15 cm) partition without compaction (F 66).

- As a rule, a stripping time of ≥ 12 hours at a stripping strength of ≥ 1 N/mm² is considered state of the art. As a thin structural component, the partition is extremely sensitive to cooling under the influence of cold air.
- A tight joint between the partition and the arch concrete of the roof is to be provided for (air flows between the fresh-air duct and the waste-air duct are to be avoided). Therefore, low bleeding (BL) and low shrinkage (RS) are essential properties (RS also to avoid crack formation).
- To ensure compliance with the required functional properties of the finished structure, concrete grade C25/30/XC3/XF1/BL/RS/GK16(A) is recommended for partition concrete (XF3 for portal areas).
- Increased fire protection requirements must be taken into consideration according to It. 3.1.5.
- To obtain the required concrete properties, the following concrete composition has proved appropriate (Table 9/2):

Table 9/2 Proposed concrete composition for partitions

Mineral aggregates GK 16, GK 11 Range 2/3 (A+B) – B at ς =2.700 kg/m³	1830 – 1900 kg/m³
Cement WT 38, WT 42	260 – 280 kg/m³
Additive according to ÖN B 3309 (AHWZ)	120 – 100 kg/m³
Total water content	≤ 190 l/m³
Air content [1)]	2.5 – 5.0 %
Consistency	F 66
Admixtures BV, FM, LP, LPV	According to required consistency and LP content

[1)] Recommended for XF1, mandatory for XF3

9.2.1.2 *Constituent materials*

For the constituent materials, compliance with the requirements of ÖNORM B 4710-1 for the required concrete grade is to be demonstrated.

To obtain the required properties in terms of low bleeding and stripping strength, use of cement grades WT 38 or WT 42 according to ÖNORM B 3327-1 is appropriate.

9.2.1.3. *Quality control*

- Preconstruction testing is to be performed by an accredited inspection body (inspection report). The following parameters have to be tested and demonstrated in accordance with the tender specifications and/or this Guideline:
  Optimisation of concrete composition, fresh concrete properties, low bleeding, stripping strength > 1 N/mm² at the time of formwork removal and at a storage temperature of + 15°C (average ambient air temperature in the tunnel), 28 d compressive strength (possibly 56 d), water penetration depth according to ÖNORM B 3303 (XC3), XF3 (if required), reduced shrinkage.

- Conformity checks and identity testing are to be performed, by analogy, according to the requirements of Tables 3/7 and 3/8. As regards testing for reduced shrinkage, the frequency is the same as for exposure classes.
  Use of the pendulum hammer, e.g. Schmidt PT, is recommended for stripping strength testing (at the beginning of concreting and at low temperatures). The equipment used is to be calibrated in the course of preconstruction testing.
  The concrete cover of the steel bars is to be verified according to It. 3.4.3.

9.2.2 Design measures

- Thickness of structural component 12 – 15 cm (= diameter of partition suspension plus reinforcement and minimum cover on both sides)
- Minimum concrete cover: design dimension 45 mm, minimum structural dimension 35 mm
- Section length: to be adjusted to block division of the arch
- Design of abutments (recess in arch concrete)
- Joint design: to diminish air resistance, broken edges are not permitted for block joints in the ventilation duct area (no triangular fillet inserts). Deficiencies of up to

10% of the corresponding joint length, unavoidable for practical reasons, are to be tolerated.

Special corrosion protection for the suspension system of the intermediate ceiling (suspension rods) is required in the joint between the arch and the partition. Given the dynamic strain acting on the suspension rod., a non-bonded section is to be provided for in the joint area.

9.2.3 Concrete production, placing, curing, concrete surface

- Concrete production has to be in accordance with It. 6.1 of this Guideline.
- As a rule, the stripping cycle is $\geq$ 12 hours. If ambient air temperature is low, the required stripping strength of 1 N/mm² can only be reached through removal of formwork, heating of the section concerned, or insulation of the formwork.
- As a rule, steel formwork is used to obtain as smooth a concrete surface as possible. Class GB 2 according to the ÖVBB Guideline on Formed Concrete Surfaces is required for the concrete surface.
- Immediately after formwork removal, a thixotropic curing agent, according to RVS 11.064, Part II, is to be applied in at least two spraying operations, the total weight corresponding to the value established through qualification testing.
- Horizontal concrete flow must not exceed 7m.
- Given the soft concrete consistency, the increased formwork pressure and the closing pressure upon termination of concreting must be taken into consideration. Joint grouting may be necessary.

9.3 Sealing of ventilation ducts against intermediate ceilings and partitions

Section joints intermediate ceiling	- sealing tape
Section joint partition	- sealing tape facing fresh air duct
Jointing intermediate ceiling – partition	- design according to Fig. 9.2, detail C
Jointing arch – intermediate ceiling	- putty joint facing fresh-air duct (Fig. 9.2, detail B)
Jointing arch – partition	- trapezoidal fillet and putty joint facing fresh-air duct or sealing tape (Fig. 9.2, detail A)
Intersection block joint	- intermediate continuous putty joint topped by sealing tape ceiling

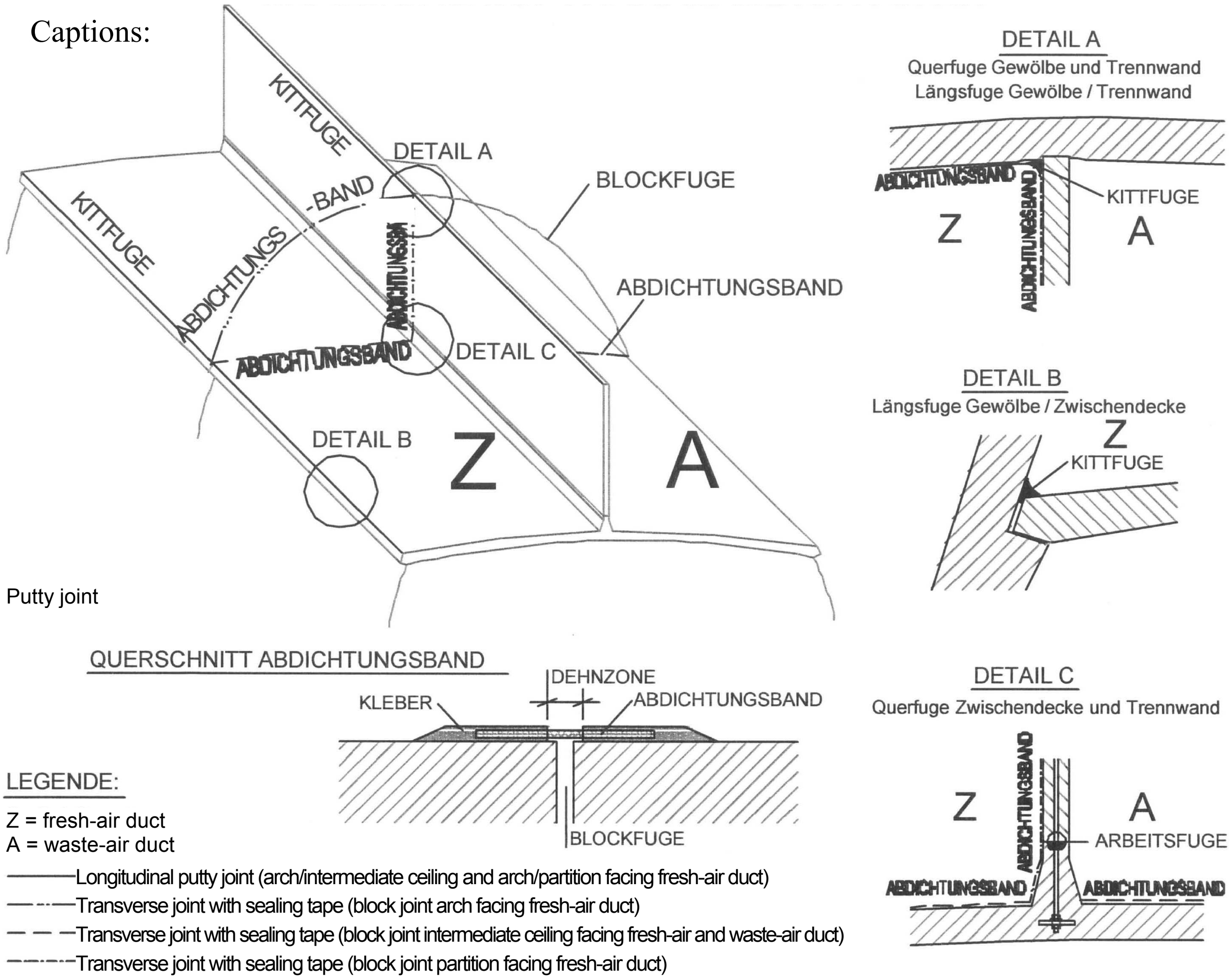

Fig. 9.2 Example of air-duct sealing systems

The durability of the sealing tape and a minimum tensile adhesive strength of 1.5 N/mm² are to be demonstrated.

10. RECOMMENDATIONS FOR TENDERING

Recommendations for tendering are contained in ÖNORM B 2203-1, RVS 7T Performance Specifications for Tunnelling, and RVS 8T Technical Contract Terms for Tunnelling. Examples of concrete grades are specified in Annex 3 of this Guideline.

11. NORMEN, RICHTLINIEN, VORSCHRIFTEN UND LITERATUR

11.1 Angeführte Normen

ÖNORM B 2203-1	Untertagebauarbeiten-Werkvertragsnorm, Teil 1: Zyklischer Vortrieb; Ausgabe 12/01.
ÖNORM B 2211	Beton-, Stahlbeton- und Spannbetonarbeiten-Werkvertragsnorm; Ausgabe 04/98.
ÖNORM B 3303	Betonprüfung; Ausgabe 09/02.
ÖNORM B 3308	Güteüberwachung der werksmäßigen Herstellung von Fertigteilen aus Beton, Stahlbeton und Spannbeton; Ausgabe 08/80
ÖNORM B 3309	Aufbereitet hydraulisch wirksame Zusatzstoffe für die Betonherstellung; Ausgabe 09/99.
ÖNORM B 3131	Gesteinskörnung für Beton – Regeln zur Umsetzung von EN 12620; Ausgabe 06/03.
ÖNORM B 3327-1	Zemente gemäß ÖNORM EN 197-1 für besondere Verwendungen, Teil 1: Zusätzliche Anforderungen; Ausgabe 01/02.
ÖNORM B 3800-4	Brandverhalten von Baustoffen und Bauteilen; Baustoffe: Einreihung in die Brandwiderstandsklassen; Ausgabe 05/00.
ÖNORM B 4700	Stahlbetontragwerke - EUROCODE-nahe Berechnung, Bemessung und konstruktive Durchbildung; Ausgabe 06/01.
ÖNORM B 4705	Fertigteile aus Beton, Stahlbeton und Spannbeton und daraus hergestellte Tragwerke für vorwiegend ruhende Belastung; Ausgabe 11/02.
ÖNORM B 4710-1	Beton, Teil 1: Festlegung, Herstellung, Verwendung und Konformitätsnachweis (Regeln zur Umsetzung der ÖNORM EN 206-1); Ausgabe 01/02.
ÖNORM B 4753	Spannbeton – Eisenbahnbrücke; EUROCODE – nahe Berechnung, Bemessung und konstruktive Durchbildung; Ausgabe 06/03
ÖNORM EN 197-1	Zement, Teil 1: Zusammensetzung, Anforderungen und Konformitätskriterien von Normalzement; Ausgabe 12/00.
ÖNORM EN 450	Flugasche für Betondefinitionen, Anforderungen an Güteüberwachung; Ausgabe 09/95
ÖNORM EN 934-2	Zusatzmittel für Beton, Mörtel und Einpressmörtel, Teil 2: Betonzusatzmittel - Definitionen und Anforderungen; Ausgabe 02/02
ÖNORM EN 1363-1	Feuerwiderstandsprüfungen, Teil 1: Allgemeine Anforderungen; Ausgabe 01/00
ÖNORM EN 1363-2	Feuerwiderstandsprüfungen, Teil 2: Alternative und ergänzende Verfahren; Ausgabe 01/00.
ÖNORM EN 13263	Silikastaub für Beton –Definitionen, Anforderungen und Konformitätslenkung; Ausgabe 08/98.
ÖNORM DIN 18202	Toleranzen im Hochbau – Bauwerke; Ausgabe 02/98.

11.2 Richtlinien und Vorschriften

RVS 7T	Leistungsbeschreibung für Tunnelbau, Ausgabe xx/03.
RVS 8T	Technische Vertragsbedingungen für Tunnelbau, Ausgabe xx/03.
RVS 9.32	Tunnel; Geschlossene Bauweise im Lockergestein unter Bebauung; Ausgabe 01/93 (Neuauflage in Vorbereitung).
RVS …..	Baulicher Brandschutz für Straßenverkehrsbauwerke (in Vorbereitung)
RVS 9.35 Merkblatt	Tunnel; Statisch–konstruktive Richtlinie; Betondeckung der Stahleinlagen; Ausgabe 06/02.
RVS 11.064; Blatt II	Grundlagen – Prüfverfahren; Beton; Nachbehandlungsmittel Beton; Ausgabe 12/85.
ÖVBB – Richtlinie	„Erhaltung und Instandsetzung von Bauten aus Beton und Stahlbeton“ Anwendung und Prüfverfahren; (Neuauflage in Vorbereitung).
ÖVBB – Richtlinie	„Spritzbeton“; Ausgabe 10/98; (Neuauflage in Vorbereitung).
ÖVBB – Richtlinie	„LPV-Beton“; Ausgabe 09/99.
ÖVBB – Richtlinie	„Faserbeton“; Ausgabe 03/02.
ÖVBB – Richtlinie	„Geschalte Betonflächen“; Ausgabe 06/02.
ÖVBB – Richtlinie	„Wasserundurchlässige Betonbauwerke – Weiße Wannen“; Ausgabe 12/02.
ÖVBB – Richtlinie	„Ausbildung von Tunnelentwässerungen“; Ausgabe 06/03.
ÖVBB – Merkblatt	„Anstriche für Tunnelinnenschalen“; Ausgabe xx/03.
ÖVBB – Merkblatt	„Erhöhte Brandbeständigkeit von Beton für unterirdische Verkehrsbauwerke“ (in Vorbereitung).
ZTV-RISS 00	Zusätzliche Technische Vertragsbedingungen und Richtlinien für das Füllen von Rissen in Betonbauteilen; Ausgabe 07/00.

11.3 Zusätzlich zu beachtende Normen, Richtlinien

ÖNORM B 2221	Bauspenglerarbeiten; Werkvertragsnorm; Ausgabe 01/01.
ÖNORM B 4701	Betontragwerke; EUROCODE–nahe Berechnung, Bemessung und konstruktive Durchbildung; Ausgabe 11/02.
ÖNORM EN 1008	Zugabewasser für Beton-Anforderungen und Prüfung; Ausgabe 10/02.
ÖNORM C 2358	Beschichtungsstoffe - Fassadenbeschichtungen – Mindestanforderungen und Prüfungen; Ausgabe 07/01.
RVS 12.241	Bauprodukte und Bauleistungen; Beton; Qualitätssicherung gemäß ÖNORM B 4710-1; Merkblatt, Ausgabe 12/01.
RVS 13.61	Instandsetzung von Kunstbauten; Anwendung; Ausgabe 07/95.
RVS 13.62	Instandsetzung von Kunstbauten; Prüfverfahren; Ausgabe 07/95.
ÖVBB – Richtlinie	„Frost–Tausalz–beständiger Beton“; Ausgabe 03/89.
ZTV-SIB	Technische Vorschriften und Richtlinien für Schutz und Instandsetzung von Betonbauteilen. (Neuauflage in Vorbereitung).

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[7] Projektierungsrichtlinie RVS 9.2xx „Kontinuierlicher Vortrieb von Straßentunnel mit Tunnelvortriebsmaschinen" - Stand Dezember 2002.

[8] Richtlinie für die Anwendung der zerstörungsfreien Prüfung von Tunnelinnenschalen - RI-ZEP-TU der deutschen Bundesanstalt für Straßenwesen, Ausgabe 2001.

[9] Brandbeständigkeit von Faser-, Stahl- und Spannbeton; Straßenforschung Heft 53 – 2003

[10] Praxisverhalten von erhöht brandbeständigem (Innenschalen-)Beton (EBB); FFF-Projekt Nr.: 806201; Forschungsinstitut der Vereinigung der Österreichischen Zementindustrie – 2003

ANNEX 1

Concreting PROTOCOL
(Model form)

Date: 11.11.02	Time: 17:37			
Plant	1			
Construction site	A			
Structural member	Floor			
Concrete grade	4/ 4/1425008			
Concreting date	11.11.02 8:43 a.m.	to	11.11.02	17:37 p.m.
Number of mixes				
Total	120			
Errors detected	6			
Manual switching	0			
Mixing time	60 s			

Designation	Target	Actual			
		Min.	Max.	Mean	Standard deviation
MINERAL AGGREGATE 1) GK 4-16	547 kg	545 kg	549 kg	547 kg	
GK 0-16	533 kg	529 kg	535 kg	532 kg	
GK 0-4	392 kg	387 kg	395 kg	392 kg	
GK 16-32	487 kg	483 kg	491 kg	488 kg	
CEM II/A 42.5 R/WT38	230 kg	229 kg	232 kg	230 kg	
FLUAL	45 kg	45 kg	46 kg	45 kg	
LPV	0.91 kg	0.91 kg	0.92 kg	0.91 kg	
TOTAL WATER CONTENT 2)					
Concrete temperature		18° C	23° C	20° C	

1) Dosages of mineral aggregates are to be indicated in dry weight.
2) Total water content according to ÖNORM B 4710-1, It. 3.1.29.

ANNEX 2

EXAMPLE FOR it. 5.7: ESTABLISHMENT OF DIMENSIONAL TOLERANCES FOR TOLERANCE CLASS A2

Assumptions:

- Tunnel length (irrelevant for tolerance calculation): l = 7000 m
- Selected tunnel length to breakthrough: TL = 2500 m
- Clear cross section: 90 m²
- Invert concreted in the course of tunnel driving
- Length of concreting section (L) 12 m
- Clear width (B) 10 m
- Radius of tunnel axis in ground plan (R) 1500 m

Tolerances for the arch:

Tolerance classes	Individual tolerances	
	Position (± mm)	Height (± mm)
Basis A2	20	10
Additional per 1000 m	15	
B 1	15	15
B 2	20	20
B 3	20	20
C	12	
Sum total	**102**	**65**

$$C = 1500 + \frac{10}{2} - \sqrt{(1500 + \frac{10}{2})^2 - (\frac{12}{2})^2} = 12\text{mm}$$

Tolerances for the floor:

Tolerance classes	Individual tolerances	
	Position (± mm)	Height (± mm)
Basis A2	20	10
Additional per 1000 m	15	
B 1	15	15
B 2	50	50
B 3	20	20
C	12	
Sum total	**132**	**95**

ANNEX 3

EXAMPLES OF CONCRETE GRADES*

	Structure / Structural member	Example of concrete grades indicated in technical specifications
1	Arch concrete for road tunnel, sealed, coated, portal area	C20/25(56)/IGP/GK32
2	Arch concrete for railway tunnel, sealed	C20/25(56)/IG/GK32
3	Arch concrete for road tunnel, reinforced portal sections	C20/25(56)/IGP/GK16
4	Arch concrete for road tunnel, sealed, coated, mountain water containing SO_4^{2-} = 400-1500 mg/l	C20/25(56)/IXAT/GK32
5	Inner shell concrete, e.g. for underground railway, without sealing, ground water containing SO_4^{2-} = 400-1500 mg/l	C25/30(56)/WDI/GK22
6	Floor concrete (invert) for railway tunnel, non-reinforced	C25/30(56)/IXAL/GK45
7	Concrete for floor plates and invert for cut-and-cover railway tunnel, with sealed arch	C25/30(56)/WDI/GK22
8	Floor concrete for road tunnels, with pavement above floor	C20/25(56)/ISP/GK32
9	Inner shell concrete (full round) for bored penstock (d = 15 cm)	C25/30(56)/IGP/GK22
10	Arch concrete for urban location, increased fire resistance requirement	C25/30(56)/WDI/GK16/FaB-BB2 G
11	Arch concrete for cut-and-cover tunnel	C25/30(56)/IGP/GK22
12	Intermediate ceilings	C25/30/B3/RS/GK22
13	Partitions	C25/30/B3/BL/RS/GK16

* The strength classes specified in the Table are examples only and need to be adjusted to specific conditions.

Minimum strength class: C 20/25.

ANNEX 4

EVENNESS CRITERIA TO BE MET BY THE SUBSTRATE (SPRAYED CONCRETE) FOR THE USE OF SEALING FILM

The surface characteristics and the compressive strength of the substrate must be such as to meet the requirements of the sealing system. In terms of surface geometry, the requirements depend on the specific conditions of the construction site:

1) Tunnel cross section:

As a rule, plastic sealing webs can be placed in tunnel cross sections without any special measures, provided the substrate meets the following conditions:

a) drained tunnel (drained film sealing system, „umbrella sealing") (see Fig. A4/1):
- Adequate dimensional stability and strength.
- Maximum grain size GK 11.
- Inclination of substrate to target position maximum 45°, if flexible sealing webs, up to 2.5 mm thick, are used to compensate for excavation-related unevenness; for thicker webs, the angle is to be reduced to 30°.
- Curvature radius r of the surface not smaller than 20 cm.

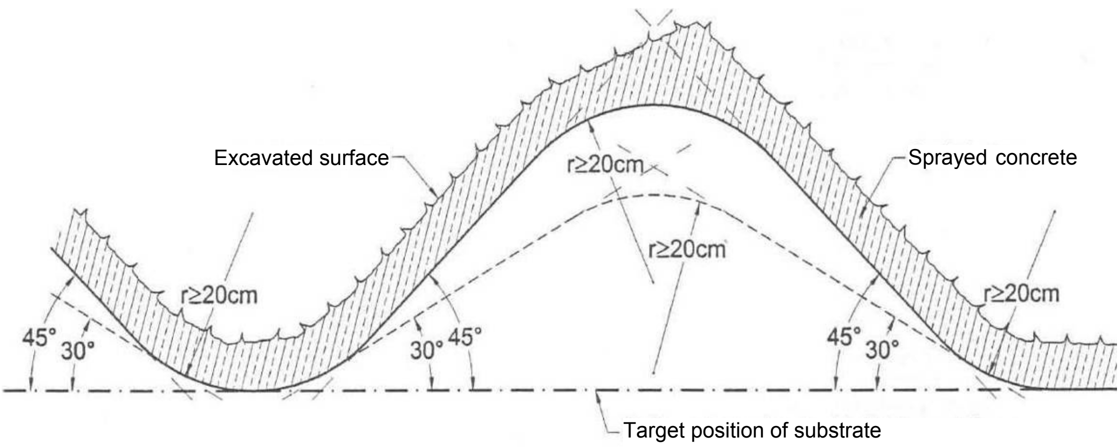
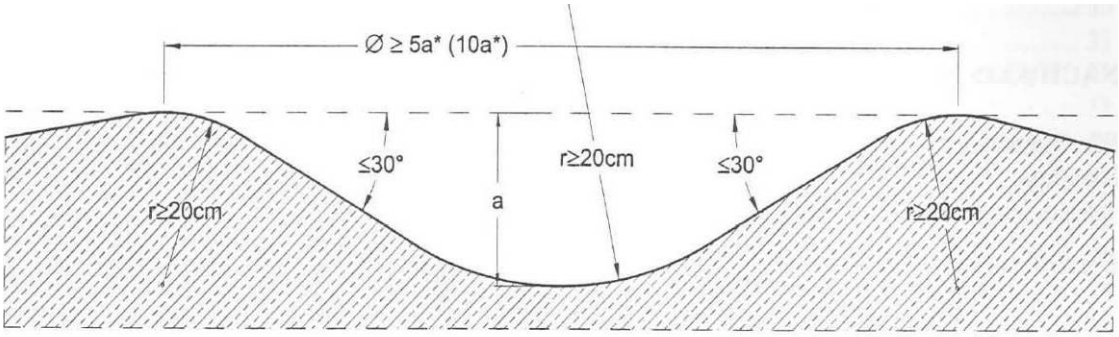


Fig. A4/1: Maximum permissible excavation geometry with rounding radii, depending on angle

b) watertight tunnel (waterproof film sealing system, „submarine") (see Fig. A4/2)
- Adequate dimensional stability and strength.
- Maximum grain size GK 11.
- Ratio of diameter to height of local excavation-related unevenness in substrate: for flexible sealing webs up to 2 mm thick at least 5:1, for non-flexible webs or webs thicker than 2 mm at least 10:1.
- Inclination of substrate to target position maximum 30°.
- Curvature radius r of surface not smaller than 20 cm.

Basically, these criteria apply regardless of scale. The most stringent criterion has to be observed.



*) 5a for flexible sealing webs (e.g. soft PVC or ECB) up to 2 mm thick; 10a for non-flexible sealing webs or webs thicker than 2 mm (e.g. PE).

Fig. A4/2: Permissible unevenness of substrate

2) Niches and changes in cross section

Routine laying of plastic sealing webs to offset the unevenness of the substrate is not permitted in these areas. The plastic sealing web has to be cut, fastened and welded to adjust it accurately to the unevenness of the substrate and fix it in its final position.

The criteria listed under 1), applicable to geometrical imperfections of the substrate, need not be observed on a large scale, if edges and grooves are due to niches and changes in cross section provided for in the design.

Edges and grooves of the substrate have to be smoothed as carefully as possible. The radius must not be less than 20 cm. (see Fig. A4/3).

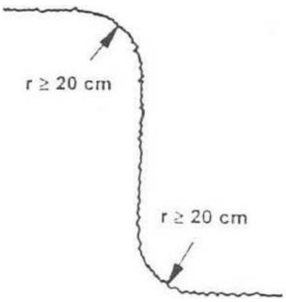


Fig. A4/3: Minimum radii in niches and sections with changes in cross section

Generally speaking, the following applies:

The material properties of the substrate and the method of fastening the plastic sealing web must be adjusted to each other. The fastening elements must not come off the substrate before completion of the inner shell. Nailing must not result in spalling of the substrate.

If the substrate is too wet to permit proper sealing, suitable measures must be taken to capture and drain the ingress of water.

ANNEX 5

ESTABLISHMENT OF FIBRE-REINFORCED CONCRETE CLASSES BB1G AND BB2G IN LARGE-SCALE TEST SPECIMENS

For inner tunnel shells and tunnels built by the cut-and-cover method, the tests required to establish the fibre-reinforced concrete classes specified in the ÖVBB Guideline on Fibre-Reinforced Concrete have to be performed by a testing body accredited for fire tests on large-scale test specimens according to the following procedure:

The test is performed on two test specimens measuring 180 x 140 x 50 cm (l x w x h).

Formwork:

The lost formwork consists of 4 mm steel plates mounted at the sides, which extend 30 cm into the lower face of the test specimen. For concreting and curing, the test specimen is to be placed flat on the forms (Fig. A5/1 – formwork).

Reinforcement:

The test specimen is reinforced with a steel grid made of BSt 550 steel rods, 14 mm in diameter, 10 cm spacing, with 4 cm concrete cover according to Fig. 5A/2. Spacers (made of fibre cement) are to be positioned outside the area exposed to fire.

Temperature sensor:

Prior to concreting, temperature sensors (iron constantane) are to be attached laterally to the reinforcement rods of the first 2 layers at the centre of the plate and at a corner on every fifth rod. Another sensor is to be positioned at a distance of about 25 cm from the fire compartment, if possible at the centre of the test specimen (for position of temperature sensors see Fig. A5/2).

Constrained thermal expansion:

Not earlier than one day before the fire test, a centric compressive stress of 0.5 MPa and/or 1.16 MPa is to be applied through 2 tendons in longitudinal direction and 4 tendons in transverse direction. Transverse prestressing can also be achieved through a tensioning frame.

Concrete:

The concrete used is either waterproof inner shell concrete according to this Guideline or concrete grade BS 1A according to the ÖVBB Guideline on Waterproof Concrete Structures – White Tanking and/or earlier issues of these Guidelines.

Addition of fibres in the appropriate dosage. The fibres, which have to meet the requirements of the Guideline on Fibre-Reinforced Concrete, are subject to self-inspection and external inspection. Slump is to be maintained, at least, at consistency class F 45 through the addition of a plasticising agent.

Production of reference concrete without fibres is not required. (Comparative value of spalling depth 25 cm, according to *Straßenforschung* 3.269).

Fresh concrete testing and compressive strength testing at the age of 28 days are to be performed. The loss of slump due to the addition of fibres is to be indicated.

Internal vibrators are to be used for compaction.

Storage:

The test specimens are to remain in the formwork for 14 days. They are to be stored at a temperature of 20±5° C. Water is to be applied to the face of the test specimen exposed to fire in the fire test during the period between production of the test specimen and performance of the test. The fire test has to be performed between the 28th and the 56th day after production.

Fire test:

The fire chamber, internal size 120 x 80 cm, 57 cm high, is to be heated by means of an oil burner from the short side. A flue gas pipe, 21 cm in diameter, is to be fitted on the opposite side. Two temperature sensors (platinum-rhodium-platinum) are to be positioned in the fire chamber approx. 13 cm underneath a horizontal plate to control the temperature in the fire chamber. Ceramic wool is to be used for insulation.

The fire chamber temperature is controlled according to the RWS fire curve (see Guideline on Fibre-Reinforced Concrete) and the tolerances of the hydrocarbon curve according to ÖNORM EN 1363-2. The test is to be performed in analogy to ÖNORM EN 1363-1.

Evaluation:

The test specimen is to be removed from the fire chamber 15 minutes after the end of the fire test for immediate inspection and evaluation of the spalling depth. The mean value of the 2 plates is to be used as a basis for concrete classification (fire classes BB). Given a spalling depth of 25 cm in reference concrete, the mean spalling depth for

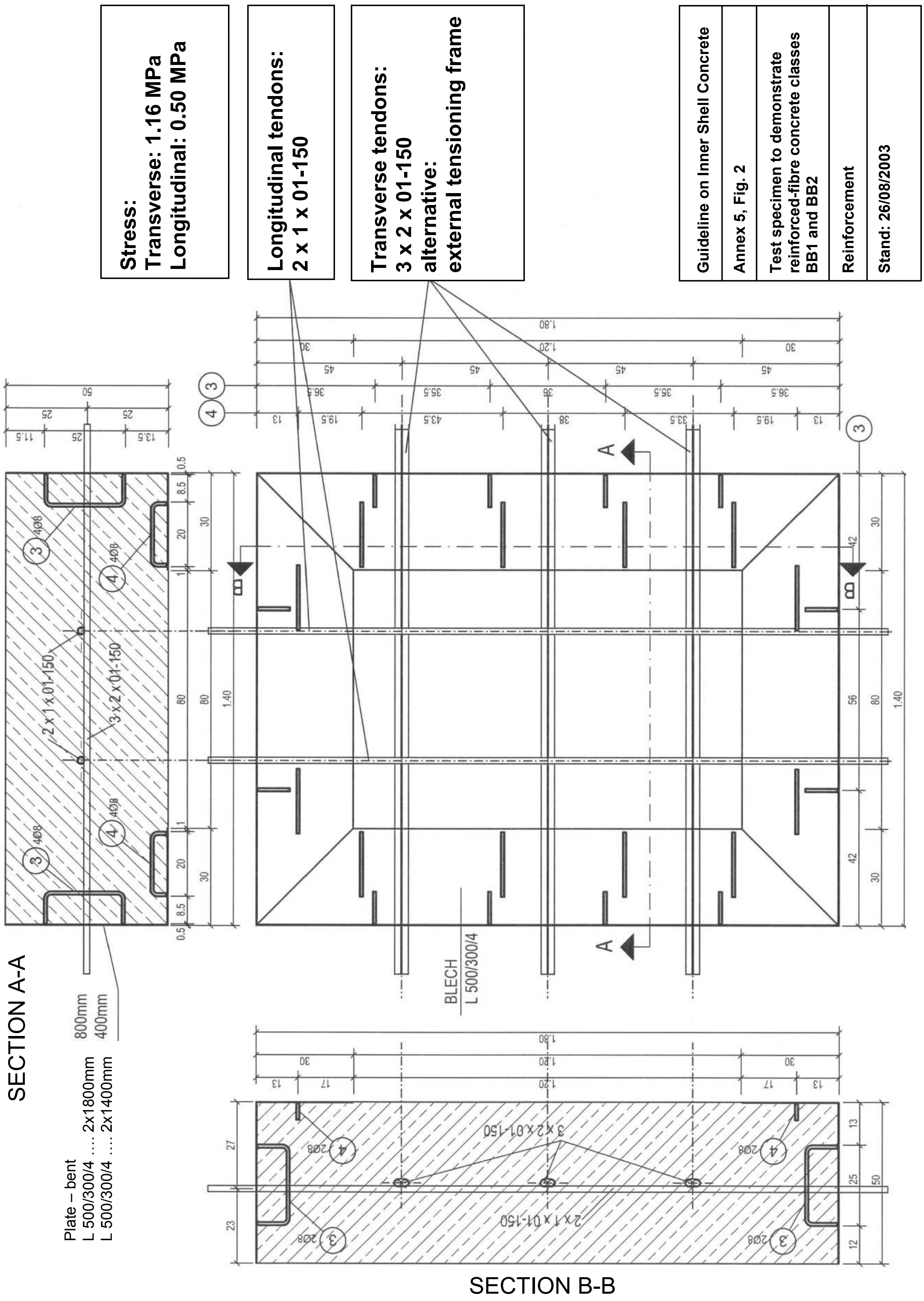
BB 2 must be less than 1 cm (nowhere as far as the reinforcement),

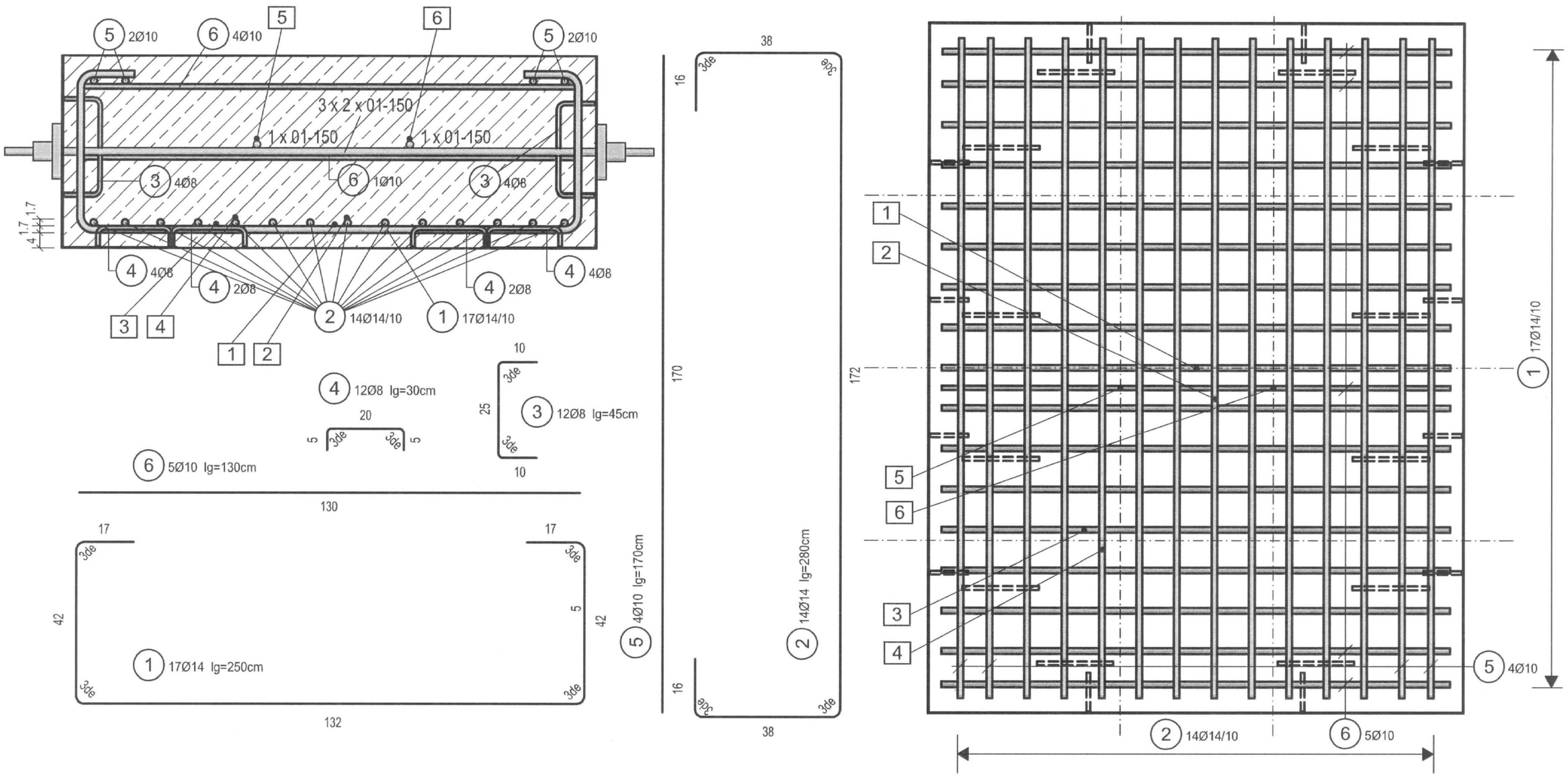
BB 1 must be less than 7.5 cm (2nd reinforcement layer just visible, deep local spalling must not exceed twice the limit value).

Report:

The test report has to contain the following:

- Reference to this Guideline and to the ÖVBB Guideline on Fibre-Reinforced Concrete
- Concrete used and preconstruction testing data
- Fibres used, dosage and fibre properties according to ÖVBB Guideline on Fibre-Reinforced Concrete
- Fresh-concrete test (w/b value, slump, air, temperature), incl. loss of slump
- 28 d compressive strength
- Production data and storage conditions
- Prestressing protocol
- Total mass of test specimens before and after the test
- Date of fire test and all test observations
- Fire chamber temperature and sensor temperatures
- Spalling depths after the fire
- Concrete classification (classes BB 1 and BB 2)


Stress:
Transverse: 1.16 MPa
Longitudinal: 0.50 MPa
Longitudinal tendons:
2 x 1 x 01-150
Transverse tendons:
3 x 2 x 01-150
alternative:
external tensioning frame
Guideline on Inner Shell Concrete
Annex 5, Fig. 2
Test specimen to demonstrate reinforced-fibre concrete classes BB1 and BB2
Reinforcement
Stand: 26/08/2003
SECTION A-A
Plate – bent
L 500/300/4 .... 2x1800mm 800mm
L 500/300/4 .... 2x1400mm 400mm
BLECH
L 500/300/4
2 x 1 x 01-150
3 x 2 x 01-150
SECTION B-B



Guideline on Inner Shell Concrete
Annex 5, Fig. 2
Test specimen to demonstrate reinforced-fibre concrete classes BB1 and BB2
Reinforcement, Position of temperature sensors
Stand: 26/08/2003

Concrete cover:
4.0 cm (minimum design size)

Positioning of temperature sensors (assembly of probes on the upper side of the reinforcement rods)

Probe	Position	Probe	Position
[1]	1st reinforcement layer (c = 5.5 cm), centre	[4]	2nd reinforcement layer (c = 7.0 cm), edge
[2]	2nd reinforcement layer (c = 7.0 cm), centre	[5]	tensioning steel (c = 25.0 cm)
[3]	1st reinforcement layer (c = 5.5 cm), edge	[6]	tensioning steel (c = 25.0 cm)

VERÖFFENTLICHUNGEN DER ÖSTERREICHISCHEN VEREINIGUNG FÜR BETON- UND BAUTECHNIK

Richtlinien

Richtlinie “Konstruktive Stahleinbauteile in Beton und Stahlbeton” (Ausgabe 2006)

Merkblatt “Schutzschichten für den erhöhten Brandschutz für unterirdische Verkehrsbauwerke” (Ausgabe 2006)

Merkblatt “Kreisverkehre mit Betonfahrbahndecken” (Ausgabe 2006)

Sachstandsbericht “Tübbinge” (Ausgabe 2005)

Richtlinie “Erhöhter Brandschutz mit Beton für unterirdische Verkehrsbauwerke” (Ausgabe 2005)

Merkblatt “Unterwasserbetonsohlen (UWBS)” (Ausgabe 2005)

Richtlinie “Fugenausbildungen im Tunnel und Konstruktionsprinzipien am Übergang offene/geschlossene Bauweise” (Ausgabe 2005)

Richtlinie “Bohrpfähle” (Ausgabe 2005)

Richtlinie “Qualitätssicherung für Instandsetzungsfachbetriebe und Instandsetzungsprodukte” (Ausgabe 2004)

Merkblatt “Anstriche für Tunnelinnenschalen” (Ausgabe 2004)

Richtlinie “Spritzbeton” (Ausgabe 2004)

Richtlinie “Erhaltung und Instandsetzung von Bauten aus Beton und Stahlbeton” (Ausgabe 2003)

Richtlinie “Kathodischer Korrosionsschutz von Stahlbetonbauteilen” (Ausgabe 2003)

Richtlinie “Innenschalenbeton” (Ausgabe 2003)

Richtlinie "Ausbildung von Tunnelentwässerungen“ (Ausgabe 2003)

Richtlinie "Nachträgliche Verstärkung von Betonbauwerken mit geklebter Bewehrung" (Ausgabe 2002)

Merkblatt "Selbstverdichtender Beton“ (SCC) (Ausgabe 2002)

Merkblatt "Beton für Kläranlagen“ (Ausgabe 2002)

Richtlinie "Wasserundurchlässige Betonbauwerke – Weiße Wannen" (Ausgabe 2002)

Richtlinie „Geschalte Betonflächen (‚Sichtbeton’)“ (Ausgabe 2002)

Richtlinie "Faserbeton" (Ausgabe 2002)

Richtlinie "Schmalwände" (Ausgabe 2002)

Richtlinie "Dichte Schlitzwände" (Ausgabe 2002)

Richtlinie "Bewehrungszeichnungen" (Ausgabe 2001)

Richtlinie "LPV-Beton"(Ausgabe 1999)

Merkblatt "Hochleistungsbeton" (Ausgabe 1999)

Richtlinie "Dichtwandmaterialien"(entspricht der ÖNORM B 4452 "Erd- und Grundbau, Dichtwände im Untergrund")

Richtlinie "BETON - Herstellung, Transport, Einbau, Gütenachweis" (Ausgabe 1999)

Sachstandsbericht "Hochfester Beton" (Ausgabe 1993)

Richtlinie "Frost-Tausalz-beständiger Beton" (Ausgabe 1989)

Richtlinie für die Herstellung von Betonfahrbahndecken (Ausgabe 1986)

Richtlinie für Herstellung und Verarbeitung von Fließbeton (Ausgabe 1977)

Richtlinien für Leichtbeton, Teil 1-4 (Ausgabe 1974 - 1978) (Teile 1 und 4a sind durch ÖNORM B 4200-11 ersetzt)

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