NEW GERMAN GUIDELINE FOR DESIGN OF CONCRETE STRUCTURES FOR THE CONTAINMENT OF HAZARDOUS MATERIALS

NEUE DEUTSCHE RICHTLINIE FÜR DEN ENTWURF VON BETONBAUTEN ZUR RÜCKHALTUNG VON WASSERGEFÄHRDENDEN STOFFEN

NOUVELLE DIRECTIVE ALLEMANDE SUR LA CONCEPTION D'OUVRAGES EN BETON POUR LA RETENTION DE PRODUITS DANGEREUX POUR L'EAU

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SUMMARY

The paper deals with the main issues of the German guideline on „Concrete structure in contact with water-contaminating liquids“. The guideline can be used for the design and construction of concrete structures for containment of hazardous materials such as filling stations, catching basins, industrial floors, storage facilities. The guideline focuses mainly on the fluid tightness of uncracked concrete structures but supplies also some suggestions how to treat cracked structures. The guideline gives recommendations for the construction materials of new structures and explains strategies for the maintenance and repair of containment installations.

ZUSAMMENFASSUNG

Der Beitrag behandelt die wesentlichen Punkte der deutschen Richtlinie „Betonbau beim Umgang mit wassergefährdenden Stoffen“. Die Richtlinie kann verwendet werden für Entwurf und Ausführung von Betonkonstruktionen, die zum Schutz des Grundwassers und Bodens vor Kontamination dienen, also z. B. für Tankstellen, Auffangwannen, Industrieböden und Lageranlagen. Die Richtlinie behandelt hauptsächlich die Flüssigkeitsdichtheit von ungerissenem Beton, gibt aber auch Hinweise auf die Behandlung von gerissenem Beton. Die Richtlinie gibt Empfehlungen für Neubauten und erklärt die Vorgehensweise bei Unterhaltung und Instandsetzung von bestehenden Anlagen.

RESUME

Cet article traite les points essentiels de la nouvelle directive allemande "Ouvrages en béton en contact avec des substances polluantes pour l'eau". Cette directive peut être utilisée pour la conception et la réalisation d'ouvrages en béton visant à protéger les sols et l'eau contre la pollution, par exemple pour des stations service, bassins de rétention, sols industriels et entrepôts. La directive traite essentiellement l'étanchéité des bétons non fissurés, mais fournit également des suggestions quant au traitement du béton fissuré. Elle contient des recommandations pour les ouvrages neufs et décrit la façon de procéder pour l'entretien et la réparation d'ouvrages existants.

KEYWORDS: Concrete, containment, hazardous materials, contaminants, liquids, permeability, penetration, cracking

1 BACKGROUND

When the new German law for the protection of groundwater was released in 1986 many structures had to be reconsidered [1]. The new law stated that the groundwater may not be polluted in a very broad and strict sense. Production, storage and handling of water contaminating fluids have to take place in a very careful way. For safety reasons the containments of such fluids have to have a secondary containment in case the primary containment gets a leak of breaks. One of the possible materials which can be used for the secondary containments is concrete.

In the beginning, there was a great concern about the capabilities of concrete knowing that concrete is a porous and brittle material. Depending on the water-cement ratio of concrete (i.e. the mass of water to the mass of cement in concrete) the porosity of concrete amounts between 8 and 20% by volume. The less water is used for the mixing of concrete and the longer the cement can hydrate (i.e. harden) the denser the concrete will become. But irrespective of the best composition and curing of the concrete some pores will remain. However, there are different pores. The ones which can function as fluid conductor are the capillary pores and the ones which are too small for fluid transport are the gel pores. With a lower water-cement ratio than 0.36 all capillary pores can be suppressed [2].

There was a second concern about the use of concrete, i.e. cracking. If concrete is loaded in tension the strain to failure is only 10^{-4}. This means that the strain must be limited to a very low level in order not to risk a crack. A crack is much more permeable than bulk concrete [3, 4]. As conclusion from the said above are two aspects for the use of concrete as secondary containment material: the concrete as such has to have a low water cement ratio and the design of a structure has to be such that tensile stresses are almost avoided. The first aspect can easily be fulfilled while tensile stresses cannot be completely excluded. Nevertheless, concrete can be used as material as will be shown in the following. There are many structures which are concerned: catching basis in chemical plants; slabs on ground of filling stations; structural floor slabs in production plants; industrial floors in storage facilities; floors and slabs in machine shops; sumps and ditches in industrial plants. Many more examples could be mentioned when water contaminating fluids are handled and stored.

2 STRUCTURE OF THE GUIDELINE

The guideline „Concrete construction in contact with water-contaminating liquids“ [5] contains 3 parts and 2 appendices. The first part concerns „Basics, design and construction of uncoated concrete structures“, the second deals with „Construction materials and action of water-contaminating liquids“, and the third treats „Repair and strenthening“. The appendices contain „Test methods“ and „Explanations“. The new guideline is the second edition after a thorough review process of the first guideline which appeared in 1992 and was revised in 1996. The first guideline has been widely used in practice. The guideline is more or less analogous to the ACI Report „Concrete Structures for Containment of Hazardous Materials“ [6].

3 DESIGN OF UNCOATED CONCRETE CONTAINMENT STRUCTURES

The philosophy of the guideline is that uncoated reinforced or prestressed concrete can be used as impervious barrier material for a certain time. Because it is well understood that liquids penetrate into concrete one can not be sure that the liquid will not permeate through the concrete. Therefore an inspection interval of the installation and a maximum duration of contact of a liquid with concrete are assumed. Table 1 shows the four scenarios for a single contact, Table 2 shows the situation for intermittant contacts of a liquid. For such contacts, an equivalent contact duration is defined.

Table 1. Single contact of contaminating liquid

Inspection interval	Maximum contact duration	Example of structure
Permanent observation	8 hours	Industrial floor
≤ 12 hours	24 hours	Industrial floor
≤ 48 hours	72 hours	Secondary containment
3 months	2200 hours	Secondary containment

Table 2. Intermittant contact of contaminating liquid

Use	Contact cycle	Equivalent contact duration	Installation example
Daily	5 hours per day on 28 days	144 hours	Public filling station
Weekly	5 hours per day during 14 weeks	48 hours	Filling station in industrial plant

From theory and experiment [4] follows that the penetration of a liquid into concrete occurs according to a square-root-of-time relation

$$\frac{e}{e_1} = \left(\frac{t}{t_1}\right)^{1/2} \tag{1}$$

When the penetration depth is e_1 for time duration t_1 then it has the value e at another time t.

Safety factors for the penetration depth, the structural behaviour of concrete, and for crack width are defined according to Table 3. These factors are taken into account in the analysis.

Table 3. Safety factors

Penetration depth	$\gamma_e = 1.50$
Structural behaviour	$\gamma_c = 1.25$
Crack width	$\gamma_r = 1.50$

For the action side, there are also coefficients defined which are valid for combination of actions [5].

Since many structures are built out-door a significant loading case is temperature. The guideline defines temperature regimes for structures exposed to the sun, structures in the shade, for winter and summer time. The regimes determine the most severe temperature action which has to be taken into account in the structural analysis.

Three limit states with respect to the tightness of a structure are defined

a) uncoated concrete

b) cracked concrete in bending

c) cracked concrete in tension.

In the uncracked state the thickness of the structural element h must fulfill the condition

$$h \geq \gamma_e \, e_{tk} \tag{2}$$

with γ_e the safety factor for penetration and e_{tk} the characteristic value of the penetration depth after time t which is defined in Tables 1 and 2. Eq. (2) may be applied to those parts of a structure where the normal tensile stress due to mechanical loading and temperature

$$\sigma_{cN} \leq f_{ctk} / \gamma_c \tag{3}$$

with f_{ctk} the characteristic tensile strength of concrete and γ_c the safety factor for structural behaviour. f_{ctk} follows from the German design code for concrete DIN 1045-1 [7] as function of the concrete grade.

When cracks occur in a bending member there is still a tight compression zone if the following condition is met

$$x \geq \gamma_e \, e_{tk} \tag{4}$$

with x compression zone height and γ_e and e_{tk} as in Eq. (2). This means that the same approach is used as for uncracked concrete, but limited to the compressive zone. This zone has to be at least 30 mm high and twice the diameter of the maximum grain of the concrete used. There are special rules in the case of alternate moments.

If imposed deformations occur it may happen that a through-crack develops. This is the worst case because these cracks are normally very permeable, except for very viscous fluids. The design rule reads

$$w_{cal} \leq w_{crit} / \gamma_r \tag{5}$$

with w_{cal} the calculated expected crack width which depends mainly on the reinforcement ratio and which is ≤ 0.2 mm, w_{crit} the critical crack width for a certain fluid, and γ_r the safety factor acc. to Table 3. The fluids are characterized according to its viscosity from 0.3 mPa s to 3.00 mPa s.

The guideline contains a chapter on minimum reinforcement ratio as function of the length of the structural elements and the occurring tensile stress. Slabs till a length of 2.5 m can be made of plain concrete, larger slabs have to be reinforced.

4 STRUCTURAL DETAILS AND CONSTRUCTION

Great attention is given to structural details because they are responsible for the integrity of a structure. The detailing of joints, the detailing of reinforcement, the seal of pipe penetrations, the friction between structure and soil are treated. The reader is referred to the original publication [5] for accurate understanding and comprehensive reading.

Recommendations are given for the construction of a barrier structure. It is stated that the structure should be poured at once in order to avoid cold joints. Moist curing is essential for a reliable hydration process of the cement and for minimizing shrinkage. Spacers have to be resistant against the penetrating fluid. Good documentation have to be saved for later check of the installation. A supervision of the installation should take place on regular intervals, at least once in five years.

5 SPECIFICATION OF CONSTRUCTION MATERIALS

Part 2 of the guideline deals with the materials for barrier structures. The main material is concrete. A so-called liquid-tight concrete (FD-concrete) is specified with a water-cement ratio ≤ 0.50 and a strength class ≥ C30/37 acc. to the European standard EN 206-1 [8]. Cements acc. to EN 197-1 [9] may be used, i.e. portland cement CEM I, portland composite cements CEM II, and ground granulated blastfurnace slag cements CEM III. The aggregates should be well graded with a maximum grain size between 16 and 32 mm. Flyash and silica fume may be used as additions and air-entraining agents may be added for frost resistant concrete. In order to minimize shrinkage the volume content of cement + water (cement paste) may not be greater than 290 litres per m^3 fresh concrete. For the FD-concrete, the penetration of a liquid can be predicted by

$$e_{72} = 10 + 3.33(\sigma / \eta)^{1/2} \quad (6)$$

where e_{72} is the mean penetration depth after 72 hours in mm, σ is the surface tension of the liquid in N/m and η is the dynamic viscosity in Pa s. The term σ/η has then the unit m/s. The fluid properties can be taken from a table in the guideline for some liquids or from chemistry handbooks. The guideline contains a table for alkanes with $(\sigma/\eta)^{0.5}$ = 5.80 to 8.53 $(m/s)^{0.5}$, for ethers with values between 4.75 and 8.09 $(m/s)^{0.5}$, and for alcohols with 1.47 to 6.30 $(m/s)^{0.5}$. Di-chloromethane has a value of 7.97 $(m/s)^{0.5}$. If one has calculated the mean penetration depth acc. to Eq. (6) one can extrapolate to other penetration times with Eq. (1). The characteristic value which is needed in the design is

$$e_{tk} = 1.35\, e_t \quad (7)$$

If the fluid properties are not known tests have to be performed.

A few rules are given for how to treat cracked concrete. One has to distinguish between through-cracks and bending cracks. The designer has to select solutions such that through-cracks do not appear because the proof of tightness is seldom successful. In the case of bending cracks the remaining uncracked compression zone is taken as solid concrete and treated acc. to Eq. (4).

Other materials are also dealt with. These are steel and polymer fibers, sealants for joints, coatings, reinforcing steel and prestressing ducts. The main property in this context is the chemical resistance against the hazardous materials. Other properties follow from usual standards.

6 REPAIR AND STRENGTHENING

When a barrier structure shows damages it should be repaired with the means as explained in part 3 of the guideline. These means concern the inspection, the maintenance, the repair, and the stengthening. Another aspect is the decontamination after an accident. Self-decontamination is possible for volatilizable liquids after a certain time which is specified in the guideline. If this is not possible the contaminated layer of concrete has to be removed and replaced by new concrete or repair material.

A main concern are cracks. Therefore a great deal of part 3 of the guideline is devoted to the filling of cracks. Various materials can be used such as epoxy resin, polyurethane, micro-cement, and, for larger cracks, normal cement paste.

Attention should be given to the moisture content of the crack in order to secure adhesion of the filling material with the concrete.

Strengthening methods are the replacement of concrete, additional prestressing, and the application of coatings or liners.

7 APPLICATION

The previous guideline has extensively been used for the design of concrete barrier structures. Publications appeared on the usefulness of the guideline [4, 10, 11]. Many examples are treated in detail. These concern public and industrial filling stations, barrel warehouses, oil storage tanks, catching basins, industrial floors etc. The structures are made of normal concrete or steel fiber reinforced concrete. A repair solution with Slurry Infiltrated Concrete (SIFCON) is also described. In all these cases the guideline has proven successful.

8 CONCLUSION

The German guideline on „Concrete construction in contact with water-contaminating liquids“ shows that uncoated concrete can be used as construction material for containments which protect the environment against contaminating liquids. Some scenarios are described which differ mainly in the contact time of a liquid with the concrete. Rules are stated on the design of containment structures, on the materials, and on repair and strengthening. The first edition of the guideline of 1992 has proven successful, the new one of 2005 will also serve the practitioner.

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