IMPROVED DURABILITY OF CONCRETE STRUCTURES BY TESTING DURING CONSTRUCTION

ERHÖHUNG DER DAUERHAFTIGKEIT VON BETONKONSTRUKTIONEN DURCH PRÜFUNGEN WÄHREND DER BAUAUSFÜHRUNG

AMELIORATION DE LA DURABILITEE DE STRUCTURES EN BETON PAR DES ESSAIS REALISES PENDANT LA CONSTRUCTION

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SUMMARY

While the constituents of concrete are quality controlled and fresh concrete is tested there is no test required with respect to cover, compaction, and curing of concrete. The 28 days strength of concrete specimens cured under water give an estimate of the potential durability, but do not reflect the real state of a structure. It is suggested to measure some properties during construction which will improve the quality of a structure. The testing methods are presented and discussed.

ZUSAMMENFASSUNG

Während die Betonausgangsstoffe qualitätsüberwacht sind und Frischbeton geprüft wird, gibt es keine vorgeschriebenen Prüfungen für die Betondeckung, die Verdichtung und Nachbehandlung des Betons. Die 28-Tage-Festigkeit von wassergelagerten Betonproben ergibt einen Schätzwert für die mögliche Dauerhaftigkeit, spiegelt jedoch nicht den wirklichen Zustand der Konstruktion wieder. Es wird vorgeschlagen, einige Eigenschaften während der Bauausführung zu messen, was zur Verbesserung der Qualität einer Konstruktion führen wird. Meßverfahren werden vorgeschlagen und erörtert.

Résumé

Pendant que les composants du béton soient soumis au contròle de qualité et le béton frais soit testé, aucun essai est demandé pur l'enrobage en béton, le compactage et la conservation du béton. La résistance d'éprouvettes de béton après 28 jours de conservation à l'eau donne une valeur estimée de la durabilité possible mais ne reflète pas l'ètat réel d'une structure. Il est donc proposé de mesurer quelques qualités pendant la réalisation de la construction ce qui pourrait améliorer la qualité d'une structure. Des procédés de mesure sont proposés et discutés.

Key-words: durability of concrete, quality control, concrete cover, compaction.

1 MOTIVE AND SCOPE

Many concrete structures need repair and refurbishment after only ten to twenty years in use although they were expected to be maintenance free for a much longer period of time. Especially those structures which are exposed to rain and frost and those exposed to deicing salts and marine climate suffer from deterioration. If design related causes are not considered like improper water drainage and unsufficient consideration of imposed thermal and shrinkage deformation, there are mainly two causes of most durability problems: cover to the reinforcement and permeability of the concrete. Special problems are related to chemical attack, alkali silicate reaction, aggregate impurities, and high temperature exposure which will not discussed here. In prestressed concrete structures, the reliable grouting of ducts may also be a concern.

In the following, some ideas will be presented and discussed how the durability of concrete structures could be improved if the construction industry made use of testing equipment which is available on the market or which is being developed in laboratories.

2 QUALITY CONTROL

The construction process of concrete structures contains two periods of testing and quality control: one before concreting and one after concreting. In the first period, the constitutents of concrete are controlled and certified that they fulfil all requirements which are stated by standards, recommendations etc. The constituents are cement, water, aggregate, reinforcing and prestressing steel, admixtures and additives. The first period comprises also the composition of the concrete, at least as the production is concerned, i.e. equipment and measuring devices of the mixing plant are controlled and calibrated. Furtheron, air content, density, and workability of the fresh concrete are tested after delivery.

During the second phase which is 28 days after concreting, the compressive strength of specimens is determined (and in special cases also other mechanical properties like flexural strength and Young's modulus). The quality of concrete is judged by this measurement which is not suitable to assess the real properties of contents in the structure and which does not allow corrections in the construction process in due time.

The result of these kinds of testing is an estimate of the potential durability of the concrete, i.e. if all other measures were correctly taken the structure may have adequate durability for long time. Whether this will be true depends on other factors.

3 LACKING CONTROL

As long as the reinforcing and prestressing steel does not corrode in a concrete structure there is almost no durability problem (exept the cases mentioned in Chapter 1). This means that the relevant parameters have to be defined and controlled. The main parameter is the cover to the reinforcement, i.e. the size of the cover and the physical and chemical properties of the concrete. Size and properties are specified in building codes and depend on exposure conditions.

What should be measured is the realized depth of the cover and the permeability of the cover concrete. The permeability depends on the concrete mix, for instance on water/cement ratio, type of cement, admixtures and additives, but also on compaction and curing. Compaction is influenced by workability at the time of concreting and curing depends on temperature and moisture.

To assess the durability in an early state the following quantities should be controlled: the end of workability of the mix in order to ensure proper compaction, the depth of the cover, and the permeability of the cover concrete. In prestressed concrete structures, the grouting of the ducts needs an additional check.

One remark should be made: it is not intended to ask for all these tests on all parts of a structure. For instance, if corrosion of reinforcement is not promoted, i.e. in structures with indoor climate, there is no need for such tests.

4 TEST METHODS

4.1 General requirements

Tests which are to be performed on a structure should be non-destructive or only very little destructive, easy to perform, quick and not expensive. Since the pressure for faster construction increases the results of the tests should enable the contractor to react on problems and deficiencies in due time.

4.2 End of workability

Especially for slipforming, it is important to know the setting time of concrete and the end of workability. Since there is no clear relation between the measurements on cement (by the Vicat needle apparatus) and the workability time of a concrete mix the relevant quantities have to be measured on the construction site.

There are various procedures such as a qualitative visual inspection of a hole made by an internal vibrator. If the penetration hole does not flow together any more the end of workability is said to be reached.

A better method has been proposed by Nicolay. A cube mold with polystyrene walls is filled with concrete 30 minutes after mixing. A thermo-couple is placed in the center of the cube and the mold is covered by a sheet of polystyrene. The temperature of the concrete is recorded automatically while similar cubes were stored at 10 and 20°C ambient temperature. It turned out that the end of workability was reached when the temperature in the cube has risen by one centrigade. This temperature increase applies to Portland cement as well as to blended cement.

A more direct measurement of end of workability should reflect the increasing immobility of the particles in the fresh concrete. One physical property which depends on the stiffness of the material is the velocity of sound. This is the reason why several researchers have investigated the setting behaviour of concrete by ultrasonic pulses. A thorough study on numerous mixes has been performed by Van der Winden who has shown the influence of water-cement ratio, type of cement, admixtures and temperature on the pulse velocity during the first 24 hours after mixing. Although a final proof is still missing it is obvious from the test results that a pulse velocity of about 1000 m/s indicates the end of workability for concrete mixes.

4.3 Cover of reinforcement

Whether corrosion of reinforcing steel is due to carbonation or chloride is not the question; the question is how to prevent the steel from corrosion. It has been demonstrated theoretically and has been proven by practical experience that the thickness and impermeability of the concrete cover are the essential parameters involved [4]. If a certain depth of cover is reliably achieved which depends on the depth of moisture fluctuation, there should not be a corrosion risk [5].

Daily practice is that spacers and chairs are used with such a size that the prescribed concrete cover should be realized. However, not all those devices are reliable and strong enough and not always these devices are placed correctly and in sufficient number [6]. The consequence may be an improper cover of reinforcement.

To improve durability, i.e. to ensure correct cover, the cover depth should be measured before concreting or just after stripping of the formwork. Although it is rather simple to measure the cover before concreting this is not practized on the building site.

Nondestructive measurement of cover can be performed by standard procedures which are based on electromagnetic or magnetic properties of the embedded steel. Electromagnetic reflection techniques allow to distinguish between various layers of reinforcement and to penetrate deeper in the concrete [7].

4.4 Curing and compaction

The quality of the cover concrete is the second most important parameter of durability. This quality cannot measured by cubes which are being cured under water at room temperature. It can only be assessed by in-situ measurements or, as an alternative, by measurements on companion specimens which are stored and cured in the same way as the cover concrete or, as an indirect approach, by a maturity function which takes account of the real temperature and moisture conditions.

It is aggreed that the transport properties of the cover concrete should be measured (like permeability, capillary suction, coefficient of diffusion) in order to estimate durability. Those measurements can be performed in the laboratory under well defined conditions [8]. However, what makes the measuring principle difficult to apply to in-situ concrete is the great dependence of the test results on the moisture content of concrete [9]. If, for instance, the moisture state is changed from 60 to 95% r.h. the diffusion coefficient of oxygen drops by three orders of magnitude [10].

Research is going on on the preconditioning of a concrete surface before measuring the permeability of the concrete in-situ. The results will show whether physical testing of the cover concrete is meaningful with respect to durability.

Indirect methods are proposed and partially applied to concrete surfaces. One is to follow the moisture evaporation during a certain time [11], a second is to perform abrasion tests [12], and finally the pull-out strength of a small disc embedded 25 mm deep in concrete (Lok-test [13]). Moisture evaporation is of course linked to permeability but also to the relative moisture state in the concrete.

Abrasion resistance depends on strength of concrete, aggregate type and maximum aggregate size. Since it has been shown [12] that a strong correlation exists between abrasion depth and permeability an in-situ abrasion measuring device may lead to durability predictions which are less moisture sensitive than the direct permeability measurement.

The pull-out force of a small disc embedded in concrete is a standard method used in Skandinavian countries to assess the hardening state of concrete. Because strength is closely related to permeability the results reflect also the cumulative effect of curing.

To reach the goal reliably, i.e. a high durability, the measurements should be performed in a time when measures can still be taken to improve the quality of the structure. This is during the construction phase when improper results can cause the responsible engineer to try all means for improving the quality in the following construction steps.

5 CONCLUSIONS

The durability of concrete structures can be improved by testing during construction. Today, testing and quality control takes place before construction, i.e. the constituents of concrete are tested and some properties of fresh concrete as well. Then, after 28 days after concreting the quality of concrete is checked on specimens which are cured under water. All results give an estimate of the potential durability but not of the actual durability which is mainly determined by compaction, cover, and curing. (Together with "constituents", these are the foor UK Cs acc. to Pomeroy).

The last three properties should be checked and measured during the construction phase. Testing methods are available which are easy to perform. Poor results in the beginning of a job will lead to better results in the following steps of construction if engineer, contractor, and owner are quality conscious.

The extra cost for this type of quality concrete is part of the contract and has to be paid. It is a low amount compared to the repair costs after a few years. Furtheron there is another argument, an ecological one. If a structure has a good durability, material and energy are optimally used.

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