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Low water-binder ratio concrete for bridges: Experience from full scale construction

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Sammendrag

Siden 1988 har standard-spesifikasjonen for norsk brubetong inkludert en begrensning på masseforholdet $V/(c + 2 \cdot s) \leq 0{,}40$. Silikainnholdet (s) er spesifisert 2-5 % av portland sementmengden.

Produksjon av dette betongmaterialet med lokale tilslag og bygging av bruer året rundt under alle slags klimatiske betingelser har vist seg å være en utfordring og en læreprosess, hvor mange av de gamle sannheter har måttet revideres.

Hovedproblemet har vært å oppnå passende støpelighet, og beholde støpeligheten tilstrekkelig lenge. Stavvibratorer har mindre effekt på grunn av betongens kohesivitet og tiksotrope karakter.

Et problem som ennå ikke er løst, er tendensen betongen har til oppsprekking mens den ennå er i den plastiske fasen.

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Statens vegvesen, Vegdirektoratet

Veglaboratoriet
Postboks 8142 Dep, 0033 OSLO
Telefon: 22 63 99 00 Telefax: 22 46 74 21

LOW WATER-BINDER RATIO CONCRETE FOR BRIDGES: EXPERIENCE FROM FULL SCALE CONSTRUCTION

Reidar Kompen
Norwegian Road Research Laboratory, Norway

SUMMARY

Since 1988 the standard specification for Norwegian bridge concrete has included a limit on the water- binder ratio W/(C + 2 x S) less or equal to 0.40. The silica fume content (S) is specified 2 - 5 % by weight of Portland cement.

Production of the concrete material with local aggregates and casting of structures year around in all types of climatic conditons has shown to be a challenge, and a learning process where several of the "old truths" have had to be revised.

The main problem is to obtain proper workability, and retain workability for a sufficiently long period of time. Internal vibrators have less efficiency due to the cohesive and tixotropic character of the concrete.

An annoying problem which is not yet solved, is the tendency for cracking while the concrete is still in the plastic stage.

THE CONCRETE SPECIFICATION

Durability concerns and developments in concrete technology have both called for higher quality requirements for bridges. From 1988 onward, the Norwegian standard specification for bridges (1) has included

- strength class C45
- durability class "very aggressive", i.e. water to binder ratio W/(C + 2 x S) less or equal to 0.40
- silica fume content (S) 2 - 5 % by weight of Portland cement
- air content 5 ±1.5 % measured in fresh concrete
- consistency max. 12 cm slump for superstructures, max. 16 cm slump for other structural members.

Since 1988 strength classes C55 and C65 have been specified in numerous projects. According to experience gained the slump limits are no longer adhered to. Slump is typically 18 - 20 cm, and the air content is kept around 4.0 - 4.5%.

GENERAL EXPERIENCE

Early experience showed that production according to the new specification was borderline to a great number of ready mix producers. Contractors could no longer trust old experience in how to handle and cast concrete. Through new experience, however, most problems have been reduced to an acceptable level.

The main problems were:

1. To obtain proper workability

2. To retain workability for å reasonable period of time

3. Trowelling of concrete surfaces

4. Cracking of free concrete surfaces while the concrete was still plastic

Additional problems showed up as to the reliability and reproducibility of concrete testing, which will not be decribed further.

WORKABILITY

Compared to "ordinary concretes" low W/b-ratio concretes are always very cohesive and sticky. To obtain workable concrete with low W/b-ratio, the use of water-reducing admixtures at rather high dosages is a necessity. Workability made by superplasticizers is quite different from workability made by water.

Because of the cohesiveness the concrete sticks to reinforcement, formwork and tools. More important, however, is that poker vibrators have less efficiency. Because the fresh concrete looks wet and plastic, experienced concrete workers misinterpret the need for compaction. It has been experienced that many construction crews were not currently equipped with poker vibrators able to compact low W/b-concrete adequately.

New generations of superplasticizers and re-proportioning with less admixtures have improved workability.
Retarders have also showed to improve the compactability, even though retardation is not necessary nor desired.
For Norwegian conditions guidance (2) how to produce and handle low W/b-concrete has been worked out.

Nevertheless the need for compaction should not be underestimated where low W/b-ratio concretes are used. The slump test does not tell anything about the concrete, except the slump value.

RAPID LOSS OF WORKABILITY

The rapid loss of workability often experienced with low W/b-concretes is a major constraint for achieving well cast concrete structures.

Loss of workability occurs in two different ways:

1. Ordinary slump loss as with "ordinary concrete".

2. Some kind of coagulation occuring when the concrete moves slowly or stands still, due to its tixotrophic character.

When these two effects multiply, the result can be rather dramatic.

Conventional means of reducing rapid loss of workability are of some help, but may not solve the problem. Superplasticizers having a long duration time are also helpful and should be used. The loss of workability is mainly connected to the degree of cohesiveness and tixotrophy of the mix.

It has been experienced that if workability is to be retained, the water content (or the binder paste volume if one prefers), has to be above a critical limit, which is dependant on the aggregate source and the mixing procedure.

The limit is quite sharp, 2-3 liters of water may decide if the workability is retained or is completely lost in 10 minutes. If the water content is below this limit, the consumption of superplasticizer will increase enormously.

In practical construction work the following rules should be applied:

- during transport the automixer drum should rotate at a very low speed

- upon arrival at the site the concrete should be mixed vigorously at full speed of the automixer drum. Retempering with superplasticizer should be regarded the normal case

- placing of concrete should start and continue without delays or hesitation

- the concrete should be compacted as soon as and at the same rate as it is placed in the form

- the time lap between succeeding concrete layers should not be very long

Temporary casting fronts left to loose workability are risky, as they often create some type of surface defects. Dark coloured lines are the most common and innocent ones. Generally low W/b-concretes therefore require larger concreting rates, and probably also stronger formwork.

TROWELLING OF SURFACES

Trowelling to produce a large and nice, homogeneous surface is very difficult with low W/b-concrete because:

1. The concrete sticks to almost every tool material.

2. The time from initial set to final set is very short, there is very little time available for trowelling.

3. Setting occurs often very irregularly, even within the same truck load. Neighbouring spots are too wet or too stiff for trowelling.

The difficulty of achieving a nice, homogeneously trowelled surface increases immensely with the area of the surface.

CRACKING OF PLASTIC CONCRETE

The most annoying phenomenon with the low W/b-ratio concrete has been (and still is) the susceptibility to early cracking, i.e. from 15 minutes to 5 - 6 hours after placing. We still do not know the reason for this cracking, but have experienced a lot of how to reduce it.

The reason behind the cracking is believed to be a combination of one or more of the following effects:

A) Conventional cracking mechanisms; i.e.

- plastic shrinkage
- thermal gradients
- lateral movement on inclined surfaces
- plastic settlement
- deformations and vibrations in the scaffolding

and a "new" phenomenon

B) Early volume contraction of the binder paste

Well accepted conventional curing procedures have shown not to solve the early cracking problem. It has been experienced that the quicker the workability is lost, whatever is the reason, the more cracking occurs. Very early cracking gives very wide cracks of 1 - 3 mm, whereas later cracking will give a great number of haircracks.

Both proportioning practice and construction procedures can be altered to reduce, but not eliminate cracking:

- higher binder paste volume and less superplasticizer reduce cracking

- increasing the top layer thickness to 25 - 30 cm from the conventional "good workmanship" of max. 10 - 15 cm also reduces cracking

Curing procedures must of course also be carried out very conscientiously.

CONCLUSIONS

It has been shown through practice that concrete with a W/b-ratio of 0.40 can generally be used. However, the skill and experience to produce and handle such concrete is not gained overnight.

Extended use of water-reducing admixtures is a necessity for producing workable low W/b-ratio concrete. Experience shows, however, that plasticizer dosages should be kept in the medium range, say below 8 liters per m^3, to avoid compaction problems in full scale construction.

The main remaining problem with low W/b-ratio concrete is its tendency for cracking in the plastic stage.

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