CRC JointCast

CRC JointCast is a fibre reinforced high performance concrete, used for on-site casting of joints between precast members in conventional concrete or in CRC. CRC JointCast always has a steel fibre content of 6 % by volume corresponding to approximately 460 kg of steel fibres per m^3 of JointCast, and is sold as a dry-mortar so that only water has to be added on site.

CRC has a very high compressive strength (typically 140 N/mm^2), and this – combined with a large content of micro silica and steel fibres – provide excellent bond properties. Typical lap lengths in a jointing detail are 6-10 times the diameter of the reinforcing bar.

CRC JointCast is a special version of CRC concrete. CRC is short for Compact Reinforced Composite, a type of concrete developed by the Danish cement producer Aalborg Portland in 1986. In the years since then a number of research projects have been carried out to document the properties of CRC and CRC is currently used for precast components such as staircases, balcony slabs, beams and columns. Several of the research projects mentioned included bond tests or joint tests and the results achieved here led to the development of CRC JointCast. CRC JointCast was first used commercially in 1995 at Aalborg University, where a column/flat slab building system was used for a new building on campus. In this project CRC JointCast was used for joints between the slabs. A few years later as another building was added at the university, the system was developed further so that the columns were fixed in the slabs above with the CRC JointCast, thus making a fully moment resisting connection not only between slabs, but also between the slabs and the columns /1/.

Design

Joints using CRC JointCast are typically designed with straight reinforcing bars lapping, and using transverse reinforcing bars. For an estimate of the lap length required, a formula developed by Carl Bro as, Denmark is used. The formula was developed from results achieved in the international Brite/EuRam project MINISTRUCT.

$$\frac{\tau_u}{\sqrt{f_c}} = 0.5 + 17\phi_t + 0.7\frac{c}{d}\sqrt{\frac{d}{L}}$$

where τ_u = maximum bond stress (N/mm^2)
f_c = compressive strength of CRC (N/mm^2)
c = cover to reinforcement (mm)
d = diameter of reinforcement (mm)
L = embedment length or lap length of reinforcement (mm)

$$\phi_t = \frac{nA_{st}}{dL}, < 0.1$$

A_{st} = cross section of transverse reinforcing bar (mm^2)
n = number of transverse reinforcing bars

A more detailed description of the background for the development of the formula is given in /2/ and /3/. The formula was developed as a curve fit for results from pullout tests carried out with deformed reinforcing bars with diameters of ø8, ø12 and ø16 mm. The ratio of embedment length to rebar diameter varied between 1.25 and 5.7, the cover to the pull-out bar varied between 10 and 70 mm and the transverse reinforcing index ϕ_t varied from 0 to 0.17. An example of how the formula is used is given in /4/.

It is to be expected that more precise estimates will result from use of the formula in cases where the jointing details fall within the range of values that the curve fit is based on. In cases where details differ substantially from this – e.g. reinforcing bars with a diameter larger than 30 mm, cover layers less than 10 mm or very short lap lengths – it may be necessary to perform supplementary tests. However, a substantial number of tests have already been carried out with CRC JointCast, and it is thus often possible to find test results with a bearing on a specific jointing detail. As an example, Shimizu Corporation, Japan has carried out tests on reinforcing bars with a diameter up to 51 mm. The range of rebar diameters where the most information is available is on ø8, ø12, ø16 and ø25 mm bars.

An example of a CRC JointCast connection compared to a more traditional joint is shown in fig. 1.

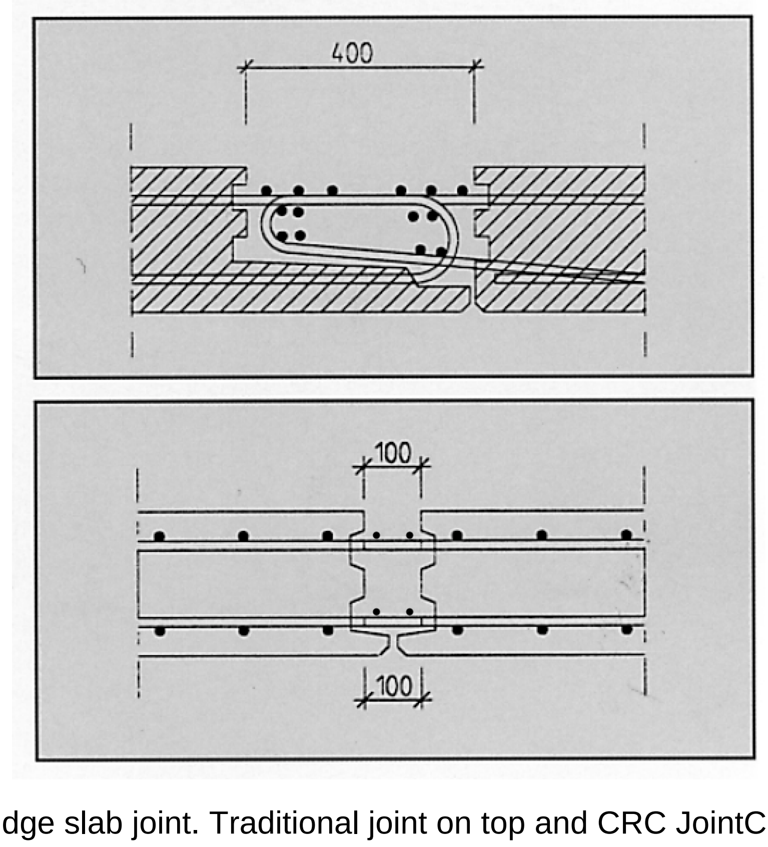

Figure 1 Bridge slab joint. Traditional joint on top and CRC JointCast connection below. The joint was developed in cooperation with Strängbetong, Sweden and tested at Chalmers Technical University, Sweden. Straight ø16 mm diameter rebars are used in the joint.

In the top of fig. 1 is shown a traditional joint for bridge slabs that has been used in Sweden. This type of joint has a number of disadvantages, e.g. the need for looped bars and a large number of transverse reinforcing bars. Additionally, the joint requires placing a relatively large volume of concrete on site, and even so the strength of the joint will be inferior to that achieved in a monolithic structure. The CRC JointCast connection is considerably smaller, only straight bars are used as well as a limited number of transverse reinforcing bars and the strength of the joint is above that of the slabs being joined. A failure load is thus determined by the strength of the slabs, not by the strength of the joint. A more detailed description of design and testing is available in /5/.

Another example of a typical joint detail is shown in fig. 2, in this case a beam joint. The beam-ends have straight ø12 mm bars protruding. The joint has a width of 100 mm and the lap length is 80 mm. As shown in the picture the beam-ends are rough to ensure better concrete bond. The roughness has in this case been achieved using a retarder on the forms and then using a high-pressure water spray to expose the aggregates.

Figure 2 Beam ends with ø12 mm rebars before the joint is cast with CRC JointCast.

Fig. 3 shows a picture from the testing of the joint. The beam was tested in 3-pont bending with the load point placed directly on the joint, but as can be seen the failure occurred as a bending failure in the parent concrete rather than as a failure of the joint. Testing was carried out approximately 7 days after the joint was cast. In corresponding pullout tests with ø12 mm bars where the embedment length of the reinforcing bar was 80 mm, the bars were actually pulled out prior to failure. The rebar stress at pullout was 715 N/mm^2. The pullout tests were carried out at 3 days, and it appears that the added maturity for the beam tests as well as a more beneficial mode of failure in bending was sufficient to achieve full moment capacity for the beam joint.

Figure 3 The joint shown in fig. 2 under 3-point bending.

A typical CRC JointCast detail is designed so that the reinforcement will fail before it is pulled out, which means that the load capacity of a structure is not influenced by the joint.

Durability

The low water/binder ratio of 0.16 and the large micro silica content in CRC JointCast ensures a durability that is considerably better than what can be achieved with conventional concretes. Intrusion of chloride ions – and the subsequent risk of rebar corrosion – takes place at very reduced rates, and even in cases where chlorides are already present at the reinforcement – e.g. where salt water has been used for mixing – there has been no corrosion observed /6/. The results of tests carried out in Denmark and Spain has provided the documentation for using CRC drain covers in the Great Belt Link in Denmark, in a chloride environment with only 10 mm of cover to the reinforcement and with a design life of more than 100 years. CRC JointCast is also fully frost resistant.

With the large content of steel fibres, there is a risk of fibre corrosion. This is, however, purely aesthetic, as the fibres will only corrode to the depth of carbonation. Even after several years carbonation will only have occurred to depths of a few fractions of an mm.

In the boundary zone between CRC JointCast and the parent concrete there will be a limited bond if the surface of the parent concrete is smooth, and this may provide easier access to reinforcing bars for water and chlorides. In a number of cases – for structures in a passive environment – this is not significant, but for structures in an aggressive environment the surface of the parent concrete should be rough to provide a strong bond. One way of achieving this could be by spraying a retarder onto the formwork, and then spraying the surface with water at high pressure at striking to expose the aggregates. If done properly, the bond in this zone will be as strong as the parent concrete.

Fire resistance

CRC elements that have a low moisture content – achieved either through drying of the concrete or simply by maturing naturally over a few months – demonstrate better performance in a fire and a higher residual strength than conventional concrete /7/. This improved behaviour is in part due to the added tensile strength of the matrix achieved with the incorporation of steel fibres and in part due to the negligible content of calcium hydroxide in CRC. This has been demonstrated in several international research projects. Most of these tests have, however, been on CRC elements or specimens such as columns, beams or small cylinders.

In connection with the first commercial application of CRC JointCast for slab/slab joints at Aalborg University fire tests were also carried out, demonstrating that the elements – and the joint – satisfied the requirement of 1 hour of resistance to a standard fire under service load. During a longer test – in this case 97 minutes – the beam failed away from the joint, while there were no adverse effects of the joint. However, an anchorage failure can occur if a joint has been exposed to a standard fire for 60 minutes, and is then loaded to failure in bending after cooling. For this reason CRC JointCast connections should be assessed before reuse after a fire – as should conventional concrete structures.

Referencer

1. **Hansen**, L.P. & **Jensen**, B.C. ”A new building system using joints of ultra high-strength fibre reinforced concrete”. Innovation in Concrete Structures: Design and Construction, 1999, pp. 543-552, Dundee.

2. **Nielsen**, C.V. & **Olesen**, J.F. & **Aarup**, B., ”Effect of fibres on the bond strength of high strength concrete”. BHP96 Fourth International Symposium on Utilization of High-Strength/High-Performance Concrete, 29-31 May, 1996, Paris, France.

3. **Aarup**, Bendt & **Jensen**, Bjarne Chr., ”Bond Properties of High Strength Fiber Reinforced Concrete”. Bond and Development of Reinforcement, ACI Publication SP-180, 1998, pp. 459-472.

4. **Aarup,** Bendt, “Practical use of anchorage length fomula”, note from CRC Technology, January 2002.

5. **Aarup**, Bendt & **Lindström**, Gösta, ”High strength joints for precast bridge slabs”, note from CRC Technology, June 2001.

6. **Andrade**, C. & **Frias**, M. & **Aarup**, B, “Durability of Ultra High Strength Concrete: Compact Reinforced Composite (CRC)”. BHP96 4th International Symposium on Utilization of High-Strength/High-Performance Concrete, 29-31 May, 1996, Paris, France.

7. **Jensen**, B.C. & **Aarup**, B., “Fire Resistance of Fibre Reinforced Silica Fume Based Concrete”. BHP96 4th International Symposium on Utilization of High-Strength/High-Performance Concrete, 29-31 May, 1996, Paris, France.