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FRACTURE BEHAVIOUR OF NORMAL AND HIGH STRENGTH CONCRETE IN ANCHOR PULL-OUT

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Abstract
A new test setup is used to perform pull-out tests with anchors under displacement control, in order to evaluate differences in the fracture behaviour between normal (NSC) and high strength concrete (HSC). Besides, an empirical equation is proposed to determine fracture loads in pull-out tests both for NSC and HSC.

1 Introduction

Generally, pull-out tests with anchors are carried out under load control. Thereby, the external load is increased continuously, the test is terminated by a sudden failure at maximum load forming a typical fracture cone in case of concrete failure. This test method does not allow to control the experiment beyond peak load. A different possibility of controlling pull-out tests is displacement control. In opposition to load control, it is not the external force but a specific displacement, which is increased continuously. Using this method, it is possible to follow „softening“ branches in pull-out tests.

2 Pull-out tests under displacement control

2.1 Test setup

The used setup can be seen in Fig. 1 (Wörner and Zeitler, 1994/1995). The slab with the anchor is turned upside down and lies on a circular bearing to ensure an axisymmetrical state of stress. Due to the form of the undercut anchor, three LVDTs can be placed nearby, measuring against a hardened steel ring, which decreases the high local pressures. By a specially manufactured hardened steel punch, the (compression) force is introduced into the anchor. A ball centres the load and minimizes any effect of restraint.

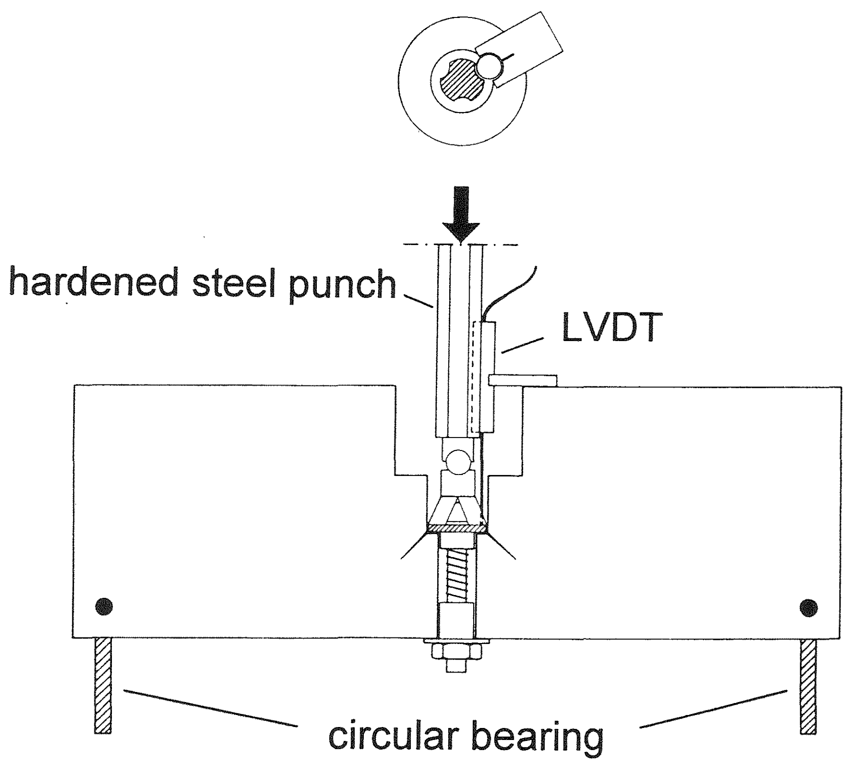

Fig. 1. Test setup for pull-out tests under displacement control

During the experiment, a constant deformation velocity in the range of 0,1 to 0,4 μm/s is prescribed. The vertical displacement results from the beginning crack growth, which is governed by the extension of a circumferential crack. In opposition to pull-out tests under load control, where failure is accompanied by the sudden eruption of a fracture cone, here the small deformation velocity enables slow (quasi-static) crack growth, the typical concrete cone is formed in a slow continuous process.

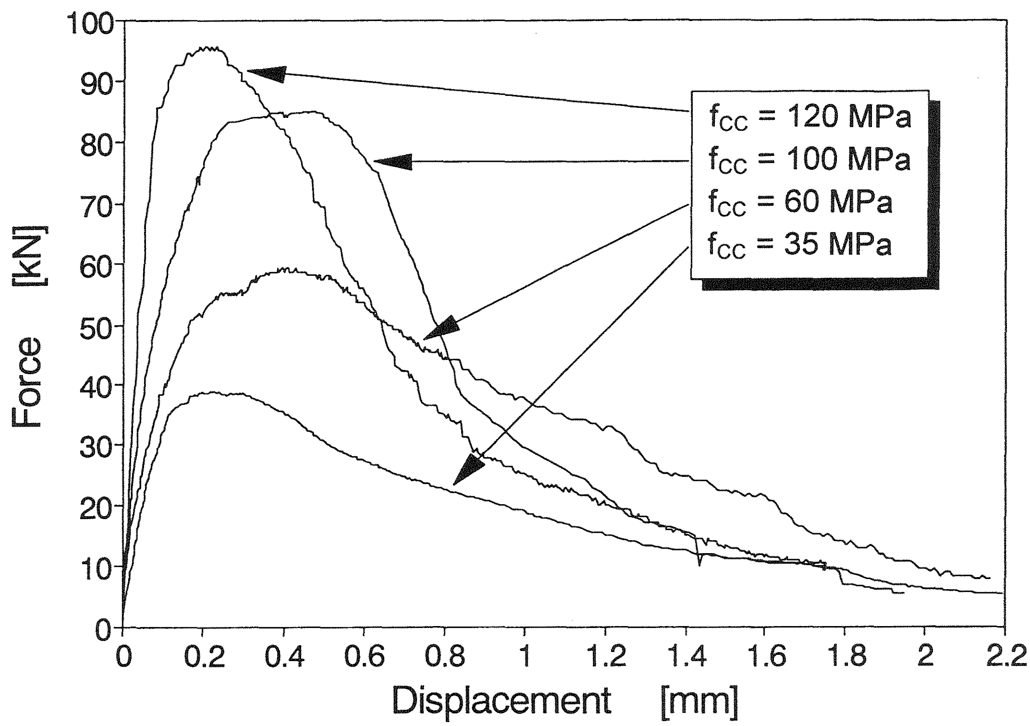

Fig. 2. Typical load-displacement curves for NSC and HSC

Fig. 2 shows typical load-displacement curves for similar anchorage depths, but different compressive strengths. It becomes obvious that failure after peak load does not occur abruptly as under load control. Indeed, the fracture behaviour seems to be quite „ductile", also for higher compressive strengths. The typical brittleness of HSC manifests itself in the steeper decay after maximum load compared to NSC. Crack growth starts at a low load level; at maximum load, however, the fracture cone is not completely formed. In the „softening" phase of the load-displacement curve the crack slowly proceeds towards the slab surface to complete the entire fracture cone.

2.2 Measured work and fracture energy in pull-out tests

The area under the load-displacement curve equals the work of the external load. In Fig. 3, the measured works for different compressive strengths can be seen. Obviously, the delivered work increases with increasing anchorage depth, but it seems to be independent of the concrete strength.

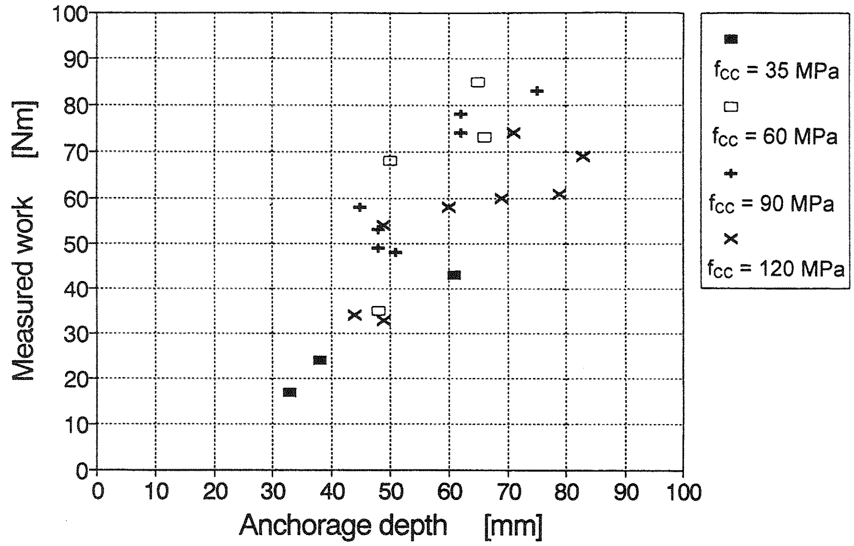

Fig. 3. Measured works for different depths of anchorage

If the measured work is related to the size of the fracture zone (= ligament area A_{lig}), which corresponds to the surface of the fracture cone, it is possible to determine a specific „fracture energy": $G_f = \int F(v)dv/A_{lig}$ (Wörner and Zeitler, 1994). In opposition to the definition of G_f, assuming a state of pure mode I, hereby other influences like crack branching, transmission of shear or friction stresses seem to play an important role, for they increase the fracture energy enormously compared to pure tension (mode I: $G_f \leq 200$ N/m), s. Fig. 4.

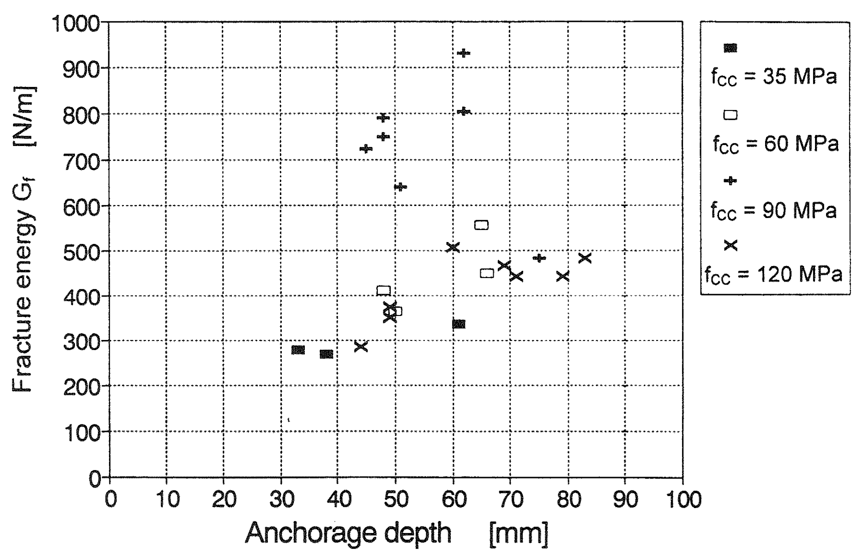

Fig. 4. Fracture energies from pull-out tests

3 Fracture loads in pull-out tests

In order to derive an empirical formula for the calculative determination of pull-out loads at any compressive strength, about 100 pull-out tests, both under load and displacement control, were carried out. In all tests the same undercut anchor (Liebig „ultraplus") has been used. The following equation is a good approximation for pull-out loads (Zeitler and Wörner, 1995):

$$F_u = 7{,}8 \cdot f_{CC150}^{2/3} \cdot h_v^{3/2} \qquad [N] \qquad (1)$$

with: f_{CC150} = concrete compressive strength in [MPa], measured on 150 mm-cubes
h_v = anchorage depth in [mm]

In Fig. 5, the measured fracture loads are related to equation 1. Additionally, the standard empirical formula (Eligehausen et al., 1987) for the calculative determination of pull-out loads with post-installed steel anchors is shown:

$$F_u = 13{,}5 \cdot f_{CC200}^{1/2} \cdot h_v^{3/2} \qquad [N] \qquad (2)$$

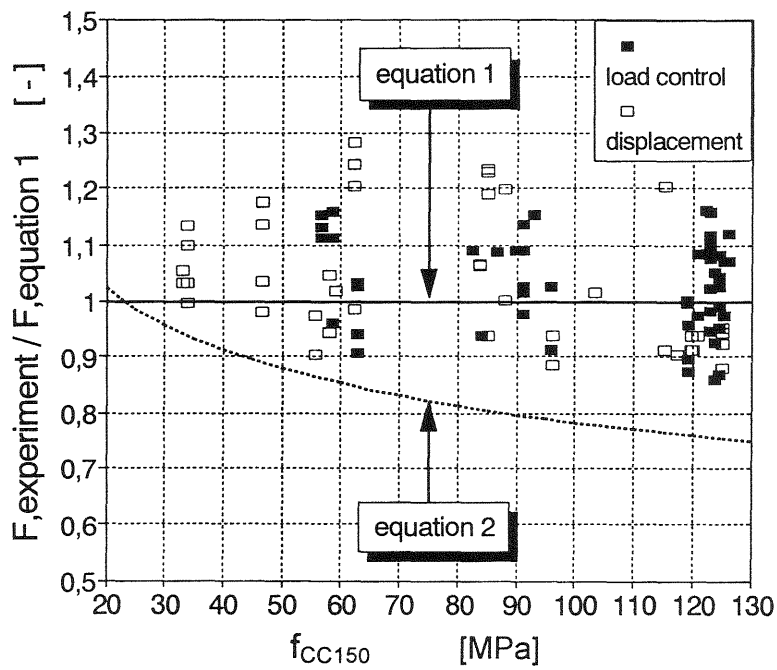

Fig. 5. Measured fracture loads related to equation 1

It becomes obvious that formula 2 clearly underestimates the concrete bearing capacity for higher compressive strengths. If formula 1 can be validated with different types of anchors, it can be regarded as a general proposal for the determination of fracture loads in case of concrete failure.

4 Conclusions

- With the presented test setup, pull-out tests can be performed under displacement control for any compressive strength.
- The typical fracture cone in case of concrete failure is completed in the descending branch of the load-displacement curve.
- With increasing concrete strength, failure after peak load becomes more brittle.
- The fracture energy in pull-out tests (= mixed mode) is much larger compared to pure mode I.
- The fracture loads for the used undercut anchor can be determined with sufficient accuracy both for NSC and HSC using equation 1.

5 References

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