H06/4

STUDY ON THE INFLUENCE OF STEEL FIBRE REINFORCED CONCRETE ON THE BEHAVIOUR OF ANCHORAGE FOR STEEL LINERS

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1 GENERAL

Prestressed Concrete Pressure Vessels (PCPVs) usually are provided with a steel liner on the interior wall in the case of high requirements concerning the leak-tightness. The steel liner is attached by flexural anchors like headed studs or cooling pipes designed for shear and tensile forces caused by constraining effects of the rigid vessel. The carrying capacity of the anchors is defined as an integral load displacement curve usually nonlinear shaped. Such curves are directly used as input for the design of liner anchor systems, see /1/.

Until now used curves have been derived on simple ways regarding not enough the liner specific loading behaviour, as there are bending effects of thin liner plates, distances of the anchors, combined behaviour of different types of anchors, etc., at least influences of elevated temperature. In an extensive test program at the Universities of Bochum and Kaiserslautern the main parameters have been investigated. The results are reported in /2/ to /5/. They are a good basis for future designing liner anchor systems.

In the first part of this paper some results of the test program will be shown concerning the tests with headed studs and cooling pipes anchored in normal concrete and in steel fibre reinforced concrete. In the second part some results of theoretical investigations will be discussed comparing the consequences of these two different types of curves on the carrying behaviour of liner anchor systems.

2 ANCHOR TEST PROGRAM

2.1 Test parameters and experimental set-up

The test program has been worked out mainly to investigate the maximum shear forces and shear displacements of the anchors, furthermore the tightness of the cooling pipes.

The main test parameters have been:

- temperatures 20, 70, 120 and 250 °C;
- short-time tests: loading increasing monotonously, pulsating and changing;
- long-time tests: loading increasing monotonously, duration until two weeks;
- prestressing: without and with 20 N/mm².

The test specimens consisted of square shaped concrete blocks 280 x 280 x 360 mm of concrete quality B55 and an outside attached liner plate of 12 mm thickness of close grained steel TSstE 285. The cooling pipes 25 x 25 x 3 mm were made of steel St 37-2, the headed studs of type Nelson have been 150 mm long and 16 mm in diameter. The steel fibre reinforced concrete was made of 1,0 % by volume steel fibres type Dramix 30/50.

The normal concrete was not reinforced. Prestressing the test pieces four HV-screws M30 and M36 were used.

2.2 Test results

In the following it will be mainly reported on the cooling pipe tests. All these tests have shown the well-known disadvantageous properties of the concrete: its low tensile strength and low ductile deformation capability. The cooling pipes showed greater plastic deformations nevertheless they remained tight. Most of the cooling pipe tests failed by compression strain of the concrete, some of them showed widely gaped cracks with a shear plane sloped under 45° . All tests ended abruptly.

The shear displacements of the cooling pipes embedded in normal concrete resulted from 0,8 to 1,3 mm, see Fig. 1. The corresponding shear forces reached nearly 1,1 kN/mm. The elevated temperature has no significant influence on the maximum of anchor forces and displacements. That means that the strength of concrete and steel has not decreased even at a temperature of 250°C . However the curves show very clearly a lower gradient.

The corresponding tests of steel fibre reinforced concrete result in ultimate displacements of the cooling pipes within nearly the same magnitude of 0,8 to 1,6 mm. That means failure by compression strain, too, as before using normal concrete. The compressive strengths of both materials do hardly differ from each other. Distinct tensile failure could not be observed in any case. Only the anchor forces have increased to about 1,2 kN/mm, that means an average rate of 15 %. Comparing both groups of curves the steel fibre reinforced concrete curves are placed more together.

On principle the test results of headed studs embedded in normal concrete and steel fibre reinforced concrete show the same increasing tendency of nearly 15 % of the anchor forces whereas the ultimate displacements scatter in the same magnitude of 6 to 11 mm, see /3/ and /5/.

2.3 Comparative assessment and evaluation of the test results

With regard to the low sampling size for each parameter only the minimum anchor displacements are plotted in Figures 1 and 2. Fig. 1 shows the influence of temperature on the displacements of cooling pipes embedded in prestressed normal concrete with regard to different stiffened supporting elements of the liner plate simulating the stud anchors.

The band width of the curves is large. Only the test results on the temperature tests are placed more close together and further they show a lower gradient. Compared with the results of steel fibre reinforced concrete in Fig. 2 as it is already said the band width of these curves is very small and in spite of the low sampling size quite sufficient. The shape of these curves is very similar to that curves of normal concrete.

Evaluating the test results load displacement relationships shall be derived for designing liner anchor systems. Characteristics of those relationships are ultimate displacements and corresponding forces as well as the gradient of the curve.

Aim of the evaluation is to get limit curves which regard the influence of the parameters in a sufficient manner dependent on the loading conditions of the plant. Figures 3 and 4 show the design curves of cooling pipes and headed studs embedded in normal respectively in steel fibre reinforced concrete. These are representative curves for designing liner anchor systems. Using steel fibre reinforced concrete an advantage can be expected analysing such systems.

3 THEORETICAL INVESTIGATIONS

Analysing a composite liner, nonlinearities of the mechanical behaviour of the liner material as well as of embedded anchors have to be taken into account. Satisfying results are gained by analysing the liner anchor system on the basis of an uncoupled two-dimensional model which is

not directly interacting with the concrete structure, as shown formerly by the author in /1/ and /6/. Two different design criteria concerning the assumed imperfections are used here as developed in /1/. A great flexibility results if the anchor arrangement allows a "wave-like" increasing of deformation of initially deformed liner plate panels (see Fig. 6). A more rigid construction is given if there only the increasing of deformation of a "honeycomb" like pattern of initially deformed liner plate panels is possible (see Fig. 7).

Figures 5 to 7 show some results of theoretical investigations having been worked on in /7/. Fig. 5 shows the distribution of the anchor displacements assuming a "wave-like" deformation pattern of the liner plate panels. The parameters are indicated in the figure. They are representative of given plants. The concrete strains of the interior wall are assumed in a conservative magnitude. The warming-up of the liner plate represents two working states of the plant: the normal load category and the extreme environmental load category. Fig. 5 shows clearly the in every case smaller displacements when using steel fibre reinforced concrete. The area necessary for the distribution of the constraining forces does not increase if the liner is loaded by elevated temperature. The reason for this behaviour is given by the plasticity of the liner plate material and the greater flexibility of the "wave-like" deformation pattern of the liner plate which compensates the constraining forces. A further result of this is the higher gradient of the curve.

On principle this is valid, too, in the case of a given "honeycombed" pattern of deformed liner plate panels shown in Fig. 6. Comparing the results of Fig. 5 and 6 the stiffening effect of the more rigid behaviour of the liner anchor system in the case of "honeycombed" pattern becomes evident very clearly. While all the displacements of Fig. 5 are greater than 0,5 mm under the same loading conditions in Fig. 6 they even do not reach 0,5 mm.

Fig. 7 only shows the maximum anchor displacements dependent on temperature and concrete strains. Further parameters are type of concrete and type of initial deformation pattern of the liner plate. With regard to the fact that the distances of the cooling pipes are relatively great with $l_p = 300$ mm and that further the assumed flexibility of the initially deformed liner panels is great, too, even then anchor displacements result not greater than about 1,0 mm under worst loading condition of 100 K warming-up.

These results are very important, because they show very clearly the effect of the studs as tie back studs combined with cooling pipes as main shear anchors. The mechanical toughness of these two anchor-types is used in an optimal way. Greater shear deformations can be avoided if the concrete should crack under worst loading conditions. More realistic results are shown in the case of an assumed "honeycombed" pattern of deformed liner panels because the distances of the cooling pipes agree fully with the until now used. Main result is that the embedding area of the cooling pipes in any case remains undisturbed, and this means a great advantage concerning the safety related aspect.

4 SUMMARY AND CONCLUSION

A series of experimental tests was carried out to investigate the behaviour of liner anchor systems consisting of headed studs, cooling pipes and liner plate embedded in steel fibre reinforced concrete especially with regard to high temperatures. The results are load displacement curves which are compared with those obtained from former tests with normal concrete as embedding material. A further object was the investigation of the influence of these different shaped load displacement curves on the design of liner anchor systems of concrete vessels which must be sealed on the inner surface by a steel liner. In the case of reinforced concrete containments the steel liner is anchored only by headed studs, in the case of prestressed concrete pressure vessels usually the steel liner is anchored by headed studs and cooling pipes. Summarizing it can be concluded that using a combined anchor concept of continuous and discontinuous anchor elements like cooling pipes and studs under realistic boundary conditions the displacements will not be greater

than here shown as about 1,0 mm. Comparing the results of normal concrete and of steel fibre reinforced concrete on average the displacements can be reduced by about 30 % using steel fibre reinforced concrete.

5 REFERENCES

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Fig. 1 Influence of temperature on the displacements of cooling pipes embedded in prestressed normal concrete

Fig. 2 Influence of temperature on the displacements of cooling pipes embedded in prestressed steel fibre reinforced concrete

Fig. 3 Load displacement curves for cooling pipes (70 °C)

Fig. 4 Load displacement curves for headed studs (70 °C)

Fig. 5 Distribution of anchor displacements assuming a "wave-like" deformation pattern of the liner plate

Fig. 6 Distribution of anchor displacements assuming a "honeycomb-like" deformation pattern of the liner plate

Fig. 7 Maximum anchor displacements for headed studs and cooling pipes