ACTION OF GLUED STEEL PLATES IN STRENGTHENING OF STRUCTURES

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ABSTRACT

The strengthening of reinforced concrete and steel beams with steel plate bonding was studied with laboratory loading tests. The steel plate was bonded on the tensile side of the beam. The thickness of the plate varied from 2 to 10 mm. The width of the plate was 100 mm. The test results showed that the ratio between the width and thickness of the bonded plate should be greater than 20. The bonding work must also be performed with care, as well as, the cleaning of the surfaces of the beam and plate. Suitable cleaning methods are for instance sand-blasting or mechanical cuttering.

Key words: bond, strengthening, concrete, structures

1. INTRODUCTION

Bonded steel plates have been used for a few years to strengthen old reinforced concrete structures, for instance, bridges. The plate bonding is a very simple, economical and fast method to increase the load carrying capacity of beams, slabs and columns. The plates can be used to increase both the bending and shear capacity of the beams. However, the bond strength is very essential and must be studied for all materials, which are used.The method of strengthening concrete structures by epoxy bonded steel plates was first introduced by R. l'Hermite (1967). The method has been studied mostly with laboratory tests. Especially the bonding agents, the glues, have been studied with bond and shear tests. There have been done also some theoretical research on this field. For instance B.Tälsten (1994) from Luleå University of Technology has dealed the bonding problem in his doctoral thesis both on the theoretical and empirical point of view. He has performed also full scale tests with strengthened bridges. Also CEN/TC104/SC8/WG3 on structural bonding has worked with the bonding problems, such as failure criterions and test methods.

The aim of this study was to investigate the bond strength of glued steel plates for three types of glues in strengthening of beams. The study was performed by using laboratory loading tests, both statical and cyclic loadings. The plates were glued on the tensile side of of the beams. Both concrete and steel beams were used in the tests.

2. SPECIMENS AND TEST ARRANGEMENTS

In the tests there were used both concrete (concrete piles, cross section 300x300 mm^2 with 8 reinforcing steels of 9mm diameter) and steel beams (cross section 300x300 mm^2, steel thickness 8 mm). The steel plates were bonded on the tensile side of the beams. The width-thickness ratio of the plates was varied. Also the ratio between the normal and shear (bond-) stresses of the plate was varied. One of the aims was to find the width - thickness ratio, when the bond of the plate is adequate to ensure the beam to reach the yield limit of the plate. The thicknesses of the plates, which were glued on concrete beams, were 2, 5 and 10 mm. The plates, which were glued on steel beams, were 5 and 10 mm thick. The width of the plates was always 100 mm. The length of the beams was 3200 mm and the length of the bonded plate 2800 mm. The plate bonding work was performed by laying first the both surfaces on with the glue and by compressing the surfaces together. The thickness of the glue layer after hardening was about 1 mm.

Two glue types were used for the concrete beams; **Epoxy BI-R** (glue nr 1.) and **Concressive 1380** (glue nr. 2.). For the steel beams the glue was **Araldite AV 129 HV 997** (glue nr.3.).

The span length of the beams L in the loading tests was 3000 mm. The loading consisted of two point loadings P/2.The loading arrangements are presented in Fig. 1 and the manufacturing details of the beams in Table 1.

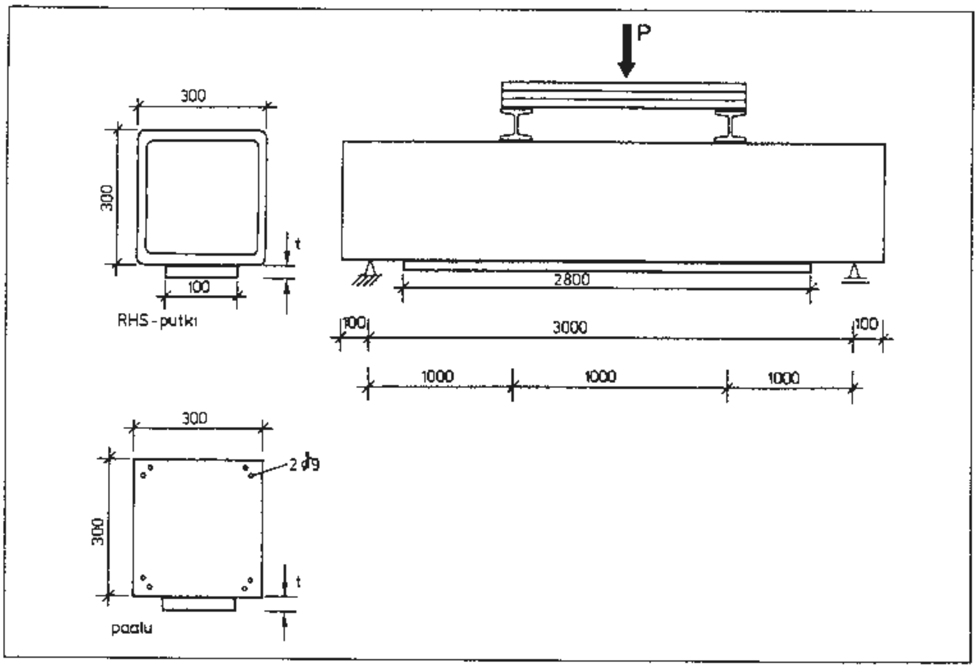

Figure 1. Test specimen structures and test arrangements

Table 1. Manufacturing details of specimen

Specimen no.	Steel plate thickness (mm)	Width of steel plate (mm)	Glue no.	Testing type
2 x concrete beam	without plates	-	-	statical
2	2.0	100	1	statical
2	2.0	100	2	statical
2	5.0	100	1	statical
2	5.0	100	2	statical
2	10.0	100	1	statical
2	10.0	100	2	statical
2 x concrete beam	2.0	100	1	
2	2.0	100	2	cyclic.+static.
2	5.0	100	1	cyclic.+static.
2	5.0	100	2	cyclic.+static.
2	10.0	100	1	cyclic.+static.
1 x steel beam	5.0	100	3	cyclic.+static.
1 x steel beam	10.0	100	3	cyclic.+static.

Some of the beams were loaded first with cyclic loading (= I loading phase in Table 2.) and then to ultimate state with statical loading. Some of the beams were loaded only with statical loading to the ultimate state (see Table 1.)

The cyclic loading consisted of 100000 loading cycles for concrete beams and of 50000-100000 loading cycles for steel beams on every loading level.

In statical tests the service load was repeated four times before the loading was increased to the ultimate state. The service loadings were determined during the tests so, that the measured steel stress in the steel plate was 200 MPa.

In Table 2 there are presented the strength and strain properties of the bonded steel plates.

Table 2. Strength and strain properties of the steel plates.

Plate thickness (mm)	Yield limit (MPa)	Ultimate strength (MPa)	Max. elongation (%)
2	179	338	46.0
2	173	331	43.3
5	213	370	41.0
5	225	386	41.7
10	346	411	39.0
10	341	412	38.8

3. TEST RESULTS

The ultimate loadings of the concrete beams are presented in Table 3. The calculated stresses of the steel plates in the ultimate state are also presented. For comparison there are also presented calculated elastic stresses on the basis of the measured steel plate strains. Naturally, these stresses are not real (always) because the plate has yielded in most cases.

Table 3. Ultimate loadings of concrete beams and calculated stresses in steel plates. The calculations both on the basis of the bending moment and on the basis of the measured steel plate strains (calculated with elasticity theory)

Beam no.	Plate (mm)	Glue no.	Type of loading before ultimate loading	Ultimate loading (kN)	Stress calculated from moment (MPa)	Stress calculated from strain (MPa)
1	-	-	cyclic	77.0	(585)xx)	-
2	-	-	cyclic	77.6	(590) xx)	-
3	2	1	-	101.3	396	(3250)xxx)
4	2	1	-	103.6	407	(3200)xxx)
5	2	2	-	96.6	378	(2250)xxx)
6	2	2	-	94.6	371	(1650)xxx)
7	5	1	-	146.6	346	(4300)xxx)
8	5	1	-	144.6	342	(3150)xxx)
9	5	2	-	101.5	240	210
10	5	2	-	138.5	327	(430)xxx)
11	10	1	-	167.7	244	270
12	10	1	-	47.7	x)	-
13	10	2	-	159.8	233	270
14	10	2	-	114.0	166	159
15	2	1	cyclic	100.1	392	-
16	2	1	cyclic	99.8	391	-
17	2	2	cyclic	76.8	301	-
18	2	2	cyclic	83.7	328	-
19	5	1	cyclic	143.1	338	-
20	5	1	cyclic	142.7	333	-
21	5	2	cyclic	123.1	291	-
22	5	2	cyclic	141.1	334	-
23	-	-	-	69.0	(504)xx)x)	-
24	-	-	-	79.3	(602)xx)x)	-

x) The plate removed in the cyclic test,
xx) The stress has been calculated in reinforcing steels,
xxx) The stress has been calculated on the basis of the measured strain (the strains are over the

yield limit and consequently not real, because they have been calculated with elasticity theory).

Comparisons between the measured and calculated stresses are presented in Tables 4 and 5 for the steel beams. The steel beams had only service state loading and they were not loaded to the ultimate state.

Table 4. Comparison between the measured and calculated stresses in the steel beams when the glued steel plate was 5 mm thick.

Cyclic loading P; and cycle number u	Loading steps in service state loading (kN) after cyclic loading	Sress calculated from the strain (MPa)	Stress calculated from the moment (MPa)
Before the cyclic loadings	10 40 70	7 21 36	5 20 36
P between 10 and 70 kN n=80000	10 40 70 100	6 21 36 51	5 20 36 51
P between 40 and 100 kN n=100000	10 100 130 160	6 51 66 81	5 51 66 82
P between 70 and 130 kN n=100000	10 100 160	10 57 84	5 51 82
P between 100 and 160 kN n=100000	10 100 140 170 200	12 61 80 94 106	5 51 71 88 102
P between 140 and 200 kN	100 170 240	64 98 129	51 88 122

Table 5. Comparison between the measured and calculated stresses in the steel beams when the glued steel plate was 10 mm thick.

Cyclic loading P; and cycle number n	Loading steps in service state loading (kN) after cyclic loading	Stress calculated from the strain (MPa)	Stress calculated from the moment (MPa)
Before the cyclic loadings	10	6	5
	100	53	47
	170	88	80
	240	123	113
P between 170 and 240 kN n=50000	170 240	90 123	80 113
P between 170 and 240 kN n=77462	100 240	50 116	47 113
P between 170 and 240 kN n=100000	100	51	47
	170	87	80
	240	121	113
	170	88	80
	100	52	47
	317	159	149
	0	3	0

4. CONCLUSIONS

On the basis of the test results it can be concluded as follows:

-the steel plates of the concrete beams yielded in all beams (except beam no. 9), when the plate thickness was 2 or 5 mm, but in beams with 10 mm plate the plates loosened before the yield phase,

-the steel plates in the steel beams were fixed very well during and after the loading tests, the maximum measured tensile stress was 129 MPa, when the steel plate thickness was 5mm, and 159 MPa, when when the steel thickness was 10 mm.

"**Bonded steel plates**" is a very effective and economical method to strengthen concrete beams and slabs. It can also be used for steel beams. It must be placed, however, some restrictions on the use of the glued steel plates. The test results showed, that the ratio between the width **b** and thickness **t** of the bonded steel plate ought to be greater than **b/t= 20**. The ratio is, of course, dependent on the type of the glue. Only in this case the bond capacity of the glued plate has a sufficient shear strength in comparison with the tensile strength of the plate. The bonding work must also be performed with care, as well as the cleaning of the surfaces of the beam and plate. Suitable cleaning

methods are for instance sandblasting and mechanical cuttering.
In Ref. /2/ there has been presented that one method to increase the b/t ratio is to taper the plate thickness towards its ends. In that study there was used the ratio b/t=62.5. The tapered plate ought, however, in practise to manufacture of several plates, which have different thicknesses and which will be welded together.

The glued steel plates can also be used to decrease the deflection and crack width in reinforced concrere structures.

Anchor bolts can also be used to avoid plate separation at the ends of the plates. The bolts have, however, no effect on the load bearing capacity before the concrete above the plate has begun to crack. Sudden failure by plate separation can, however, be prevented by bolts /2/.
The longterm durability of the glue was not considered in the study.

5. REFERENCES

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