

# 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 ought to 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 cutting.

**Key words:** bond, strengthening, concrete, structures

## 1. INTRODUCTION

The aim of the study was to investigate the bond strength of glued steel plates with laboratory loading tests both under statical and cyclic loading. The plates were glued on the tensile side of the beams. Both concrete and steel beams were used in the tests. 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 beams. However, the bond strength is very essential and must be studied for all materials, which are used.

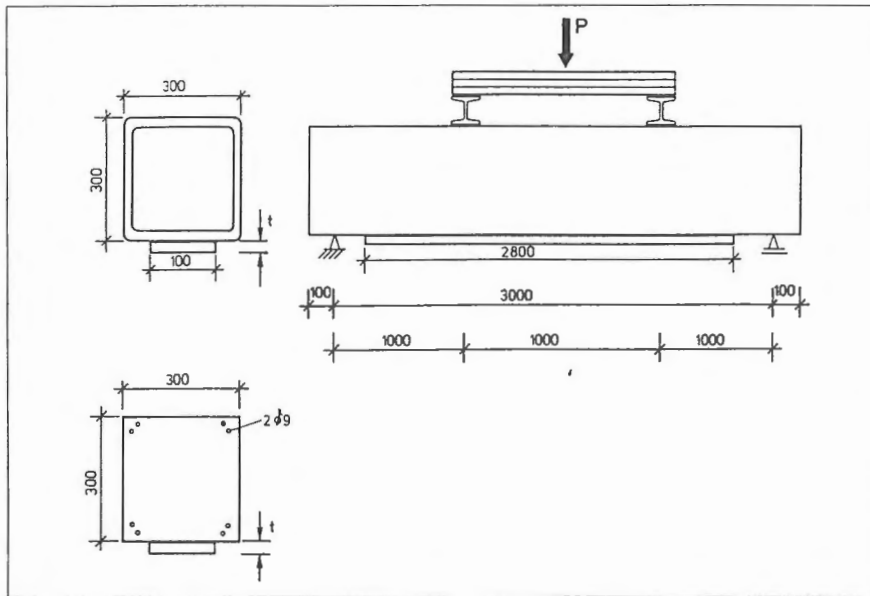
## 2. SPECIMENS AND TEST ARRANGEMENTS

In the tests there were used both concrete (cross section 300x300 mm<sup>2</sup>) and steel beams (cross section 300x300 mm<sup>2</sup>, 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, what must be ratio for the width and thickness, so that the bond of the plate is adequate to ensure the beam to reach the yield limit of the plate in loading tests. The thicknesses of the plates, which were glued on concrete beams, were 2, 5 and 10 mm. The plates, which were glued on steel plates, were 5 and 10 mm thick. The width of the plates was 100 mm in every case. The length of the beams was 3200 mm and the length of the bonded plate 2800 mm. The bonding work was done so, that both surfaces were first layed with the glue layer and after that the plate was put on the beam surface. The thickness of the glue layer after hardening was about 1 mm.

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

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The span length of the beams in loading tests was 3000 mm and the loading consisted of two point loads. The load arrangements are presented in Fig. 1.



**Figure 1. Test specimen structures and test arrangements**

The manufacturing details of the beams are presented in Table 1.

**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

<b>Table 1. continues</b>				
2 x concrete beam	2.0	100	1	cyclic.+static.
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 so, that in the first phase (= I loading phase in Table 2.) the beams were loaded with cyclic loading ja after this test the beams were loaded 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 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.

### 3. TEST RESULTS

The ultimate loadings of the concrete beams are presented in Table 2. The calculated stresses of the steel plates in the ultimate state are also presented. For comparison there are also presented elastically calculated stresses on the basis of the measured steel plate strains. Naturally the stresses are not real (always) because in most cases the plate has yielded.

**Table 2. Ultimate loadings of concrete beams and calculated stresses in steel plates calculated 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.	I loading phase 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

Table 2. continues						
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	-
24	-	-	-	79.3	(602)xx	-

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 so these stresses are not real, because they have been calculated with elasticity theory).

Comparisons between the measured and calculated stresses are presented in Tables 3 and 4 for steel beams. The steel beams had only service state loading and they were not loaded to the ultimate state.

**Table 3. 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 n	Loading steps in service state loading (kN) after cyclic loading	Stress calculated from the strain (MPa)	Stress calculated from the moment (MPa)
Before cyclic loading	10	7	5
	40	21	20
	70	36	36
P between 10 and 70 kN n=80000	10	6	5
	40	21	20
	70	36	36
	100	51	51
P between 40 and 100 kN n=100000	10	6	5
	100	51	51
	130	66	66
	160	81	82

<b>Table 3. continues</b>			
P between 70 and 130 kN n=100000	10	10	5
	100	57	51
	160	84	82
P between 100 and 160 kN n=100000	10	12	5
	100	61	51
	140	80	71
	170	94	88
	200	106	102
P between 140 and 200 kN	100	64	51
	170	98	88
	240	129	122

**Table 4. Comparison between the measured and calculated stresses in the steel beams when the glued steel plate was 10 mm thick.**

<b>Cyclic loading P; and cycle number n</b>	<b>Loading steps in service state loading (kN) after cyclic loading</b>	<b>Sress calculated from the strain (MPa)</b>	<b>Stress calculated from the moment (MPa)</b>
Before cyclic loadind	10	6	5
	100	53	47
	170	88	80
	240	123	113
P between 170 and 240 kN n=50000	170	90	80
	240	123	113
P between 170 and 240 kN n=77462	100	50	47
	240	116	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

In Table 5 there are presented the strength and strain properties of the bonded steel plates.

**Table 5. 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

#### 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 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 for 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 /2/ there has been presented that one method to increase the  $b/t$  ratio is to taper the plate 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 concrete 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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