Anchorage of Multilayered Reinforcement at Supports

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Abstract

It is well known that the load carrying capacity of anchorages of reinforcement at a support is larger than if the anchorage zone is placed where there is no pressure on the surface of the concrete.

In the literature, test results with anchorage of reinforcing bars in one layer at a beam support are described, while more than one layer of reinforcement has not been treated experimentally, as far as is known.

This paper deals with a pilot test series with anchorage of ribbed reinforcing bars in more than one layer at a beam support. The specimens, the materials, the test set-up, the measuring instruments and the test results are described.

Key words:
Anchorage, support, multilayered reinforcement, tests

1 Introduction

The transfer of stresses between a reinforcing bar and the surrounding concrete is a very complex problem. In designing reinforced concrete structures it is very important to know how the transfer from the reinforcement to the concrete takes place. Therefore many tests have been carried out to investigate this problem. Because the stress transfer depends on many parameters, there are still many problems which are not satisfactorily covered by tests. Moreover only a few attempts to create a rational theory have been made, and the theories cover only special cases. Hence many anchorage problems are still solved by using empirical rules based on experiments and experience. Often these rules are rather conservative, but sometimes they result in unsafe solutions, wherefore they must be used with caution.

It is obvious that one must distinguish between anchorage of smooth and deformed bars. A smooth bar without a hook or an anchor plate can easily be pulled out of a concrete body, as a result of the elastic contraction of the bar. Therefore smooth bars should always be anchored by mechanical means.

Anchorage of deformed or ribbed bars involves failure in the surrounding concrete; therefore a mechanism of pure slip is not possible. The longitudinal displacement of the bar is accompanied by radial deformations of the concrete. Hence, if the bar is close to the concrete surface, splitting action will lead to spalling of the concrete.

In Andreasen /4/ a theory for anchorage of deformed reinforcing bars is expounded. The formulation is based on the theory of plasticity, where the concrete strengths are modified to effective plastic strengths. The theory is compared to test results in the case of splices and anchorage at supports, and the theory was found to agree satisfactorily with the test results.

Unfortunately test results in literature covering anchorage in more than one layer are found only in a few cases for splices, see e.g. Tepfers /1/. In the case of anchorage at supports, no test results are found.

Here a pilot test series on anchorage of multilayered reinforcement at supports is reported. For more information than given here reference is make to Andreasen /5/.

The principle in the test method used here is the same as used by Jensen /1/ and /2/ investigating anchorage at beam supports of one layer of reinforcement. An element representing the support zone in a beam is used as test specimen. This test method reflects well the conditions in a real beam support, and it is possible to control the force in the reinforcement, independent of the reaction force at the support.

2 Test Plan

The specimens used in the tests are shown in figure 1. As can be seen from the figure, there are two different types of specimens. Type 1 with four bars in 2 layers, and type 2 with six bars in 3 layers. The bars are placed in the corners of the specimens, and the vertical distance between the bars is the same in all the tests. In figure 2 the type 2 specimen is illustrated.

The reinforcing bars in front of the specimens are long to ensure that only longitudinal forces are carried by the reinforcement. None of the test specimens had stirrups.
The total number of tests, carried out in the test program are 8; 4 tests with specimens of type 1 and 4 tests with specimens of type 2. The tests were divided into two series; test series 1 and 2. Each test series consists of 2 specimens of type 1 and 2 specimens of type 2.

The 4 specimens in one series were cast together with 19 $100/200mm$ cylinders cast from one batch of concrete at the same time. The reinforcement used in all tests was Swedish Kam Steel, with 10 mm in diameter.

One test consists of one test specimen and 4 or 5 cylinders. The specimen was in principle tested as shown in figure 4. The forces R and T in figure 4 were active, while the reaction forces R_H and R_V were passive. In every test of a specimen the force R, the total force in the reinforcement T, and the force in every reinforcing bar were measured. Moreover the free end slip of the reinforcement (slip at the unloaded end) and the displacements of the specimen were measured.

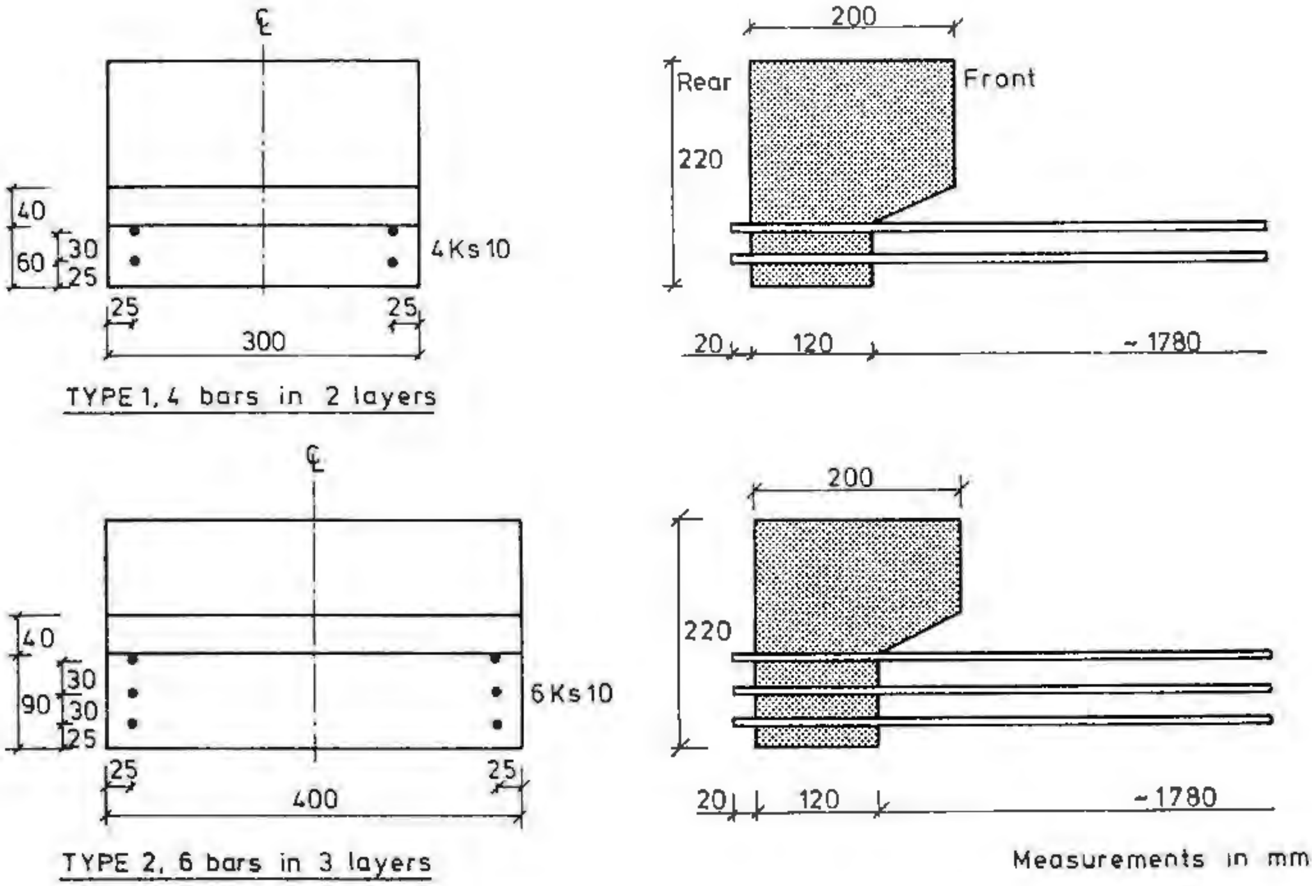

Figure 1: *Geometry of the two types of specimens.*

Figure 2: *Type 2 speciman with 6 bars in 3 layers.*

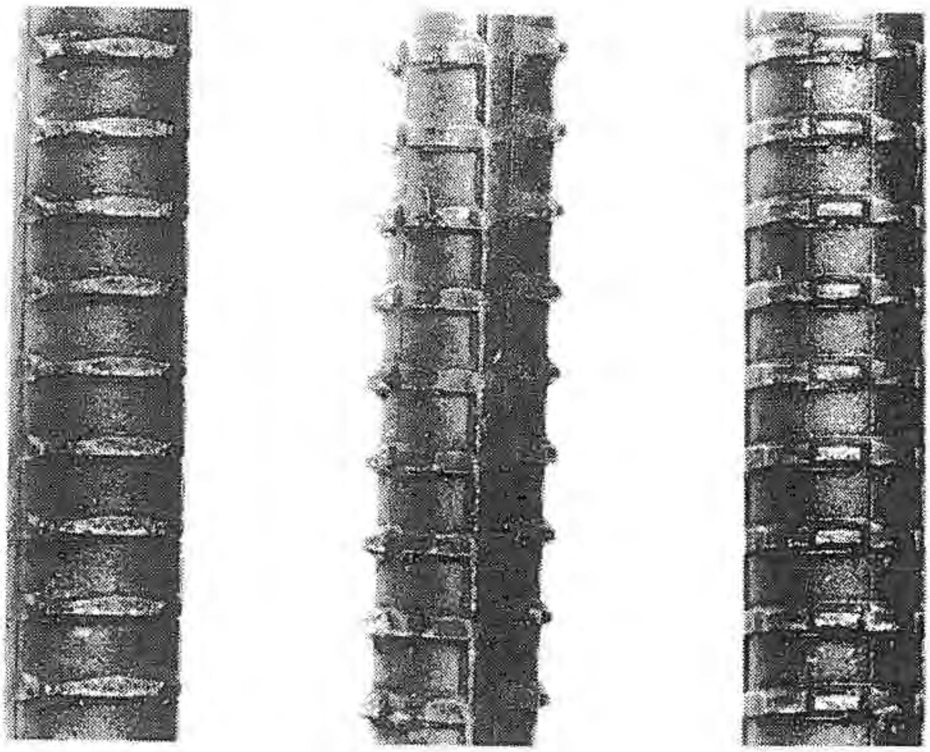

Figure 3: *The reinforcement used in the tests: Swedish Kam Steel with diameter equal to 10 mm (Ks 10).*

3 Materials

3.1 Reinforcement

In all tests Swedish Kam Steel with a diameter of 10 mm (here denoted as Ks 10), with a nominal yield stress on 550 MPa was used. In figure 3 a photo of the reinforcement is shown.

The reinforcement of one test specimen was taken mainly from the same length of reinforcing bar. However, the difference between the various lengths of reinforcement was minimal. In table 1 the geometrical properties of the 8 different lengths of reinforcement used, are listed. As can be seen from the table, the geometrical properties of the different lengths are almost identical.

For every length of reinforcement the yield force, the ultimate force and the force-strain relationship were obtained by tension tests. From the tests the mean values for the ratio between T and ϵ (strain), $E' = T/\epsilon = 15467$kN, the yield force $T_y = 47.5$kN and the ultimate force $T_u = 57.5$kN was found.

3.2 Concrete

The specimens in one series, consisting of 2 type 1 specimen and 2 type 2 specimen were cast together with 19 cylinders from one batch of concrete simultaneously. The specimens and the cylinders were vibrated on a vibrating table. After casting, the specimens were covered by plastic. After about 24 hours the formwork was removed, and the specimens were then covered by wet sacks and plastic. The sacks were kept wet during the next 24–48

No.	1	2	3	4	5	6	7	8	Mean
d [mm]	9.65	9.55	9.50	9.65	9.50	9.50	9.65	9.70	9.59
a [mm]	3.33	3.22	3.24	3.20	3.21	3.21	3.21	3.21	3.23
h_d[mm]	0.60	0.65	0.70	0.50	0.65	0.65	0.65	0.60	0.63
u [mm]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

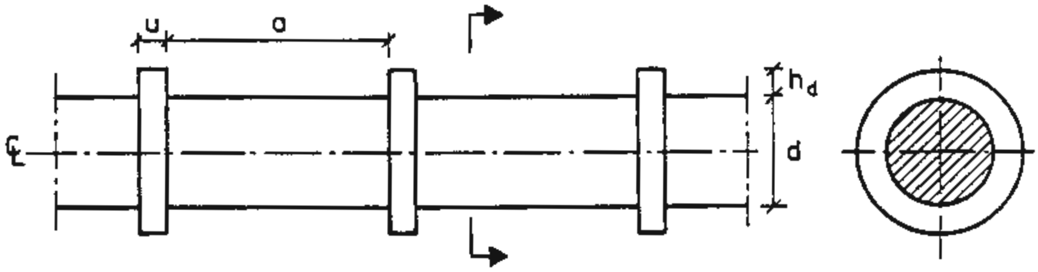

Table 1: *Geometrical properties of the different lengths of reinforcement.*

Serie	1				2			
Test No.	1-1.1	1-1.2	1-2.1	1-2.2	2-1.1	2-1.2	2-2.1	2-2.2
Ages,days	32	34	42	43	25	29	36	38
1	35.4	33.3	32.9	36.0	31.8	33.6	36.5	34.1
2	32.9	37.5	33.0	35.8	33.4	35.5	36.5	37.8
3	36.1	35.1	35.1	35.4	30.2	31.7	34.6	33.5
4	33.2	35.6	35.8	33.3	33.2	34.6	37.5	27.6
5	-	34.4	31.7	31.6	-	33.0	33.1	32.0
Mean value	34.4	35.2	33.7	34.4	32.2	33.7	35.6	33.0
Standard deviation	1.59	1.60	1.70	1.91	1.50	1.46	1.77	3.70
Mean&standard dev.	34.4 ± 1.65				33.7 ± 2.51			
Mean&standard dev.	34.1 ± 2.12							

Table 2: *Uniaxial concrete compression strength,f_c, in MPa measured on 100/200 mm cylinders.*

hours. The specimens were then placed in a water basin in about one week. Hereafter the specimens were stored in a store room for one week (18–19^oC, 55–60% relative humidity). After this the specimens were placed in the testing hall (21 ^oC, 45% relative humidity) until they were tested. The concrete was made of Portland Rapid cement, gravel (0–4 mm) and sea pebbles (4–16 mm).

On the day a specimen was tested, 4 or 5 concrete cylinders were tested. The cylinders were tested up to failure and loaded with about 12 MPa per minute. In table 2 the results of the compression strength tests on the cylinders are shown. As can be seen from the table, the strengths measured in the different tests are almost identical. Hence an analysis was carried out to check if it could be assumed that the concrete strength was the same in all the tests. By means of a statistical analysis it was found that the concrete compression strength can be assumed to be independent of the age of the concrete, when the age is within the above interval.

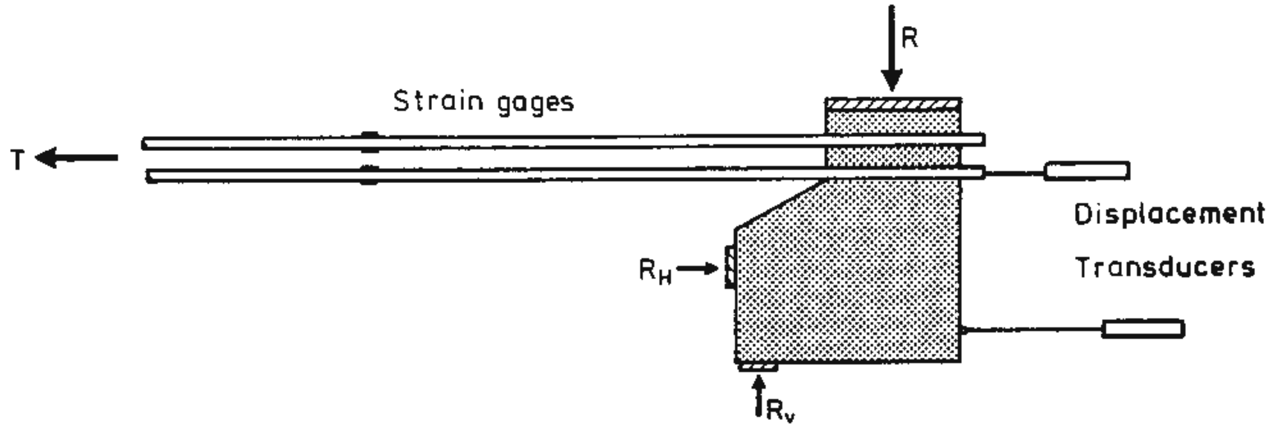

Figure 4: *Main principle in the test set-up.*

4 Test Set-Up and Test Procedure

4.1 Test Set Up

The main principle in the testing of the test specimens is shown in figure 4. The specimens were tested upside down, and loaded by a force through the reinforcement, T, and a force on the concrete surface, R, perpendicular to the reinforcement, evenly distributed over the anchorage length. The force R acts as the reaction force on a beam support. The specimens are supported by the horizontal and vertical forces R_H and R_V, respectively. These supports were designed and positioned in such a way that only forces perpendicular to the concrete surface were carried. During the test the positions of the support forces R_H and R_V are fixed, wherefore the ratio between R and T must be constant. In figure 5 the test set-up is also illustrated.

The test specimen is in figure 5 white colered and it is located at the bottom to the right (near the floor). The load was obtained by two 50 Mp one way hydraulic oil pressure jacks, type Amsler EPZg50. The ratio between R and T was kept constant by means of an Instron Servo-Controller, using a load-box. The horizontal force, the total force in the reinforcement, T, was controlled by a spring-manometer, type Amsler, and the vertical force, R, was forced, through the servo-controller, to follow T in such a way that the ratio between them was kept constant. The force delivered by the vertical jack is distributed to the specimen through a strengthened I-profile. To obtain a uniform stress distribution on the concrete surface a 10 mm weak wood fibre board was placed between the I-profile and the specimen. The horizontal force was transferred from the jack through a load yoke to another load yoke where the reinforcing bars were fixed. The load yoke was placed on roller bearings in horizontal direction. The reinforcing bars were fixed to the load yoke by a special end anchorage arrangement, see figure 6. The end anchorage ensures that the yield force (and the ultimate force) can be carried by the bars.

The horizontal and vertical forces R_H and R_V were supported by 9 mm birch plywood plates, shown in figure 2. To ensure that only small horizontal forces were obtained at the vertical support, a teflon bearing was placed under the plywood plate.

4.2 Test Procedure

On account of the way in which the horizontal force is transferred from the load yoke to the reinforcing bars, a special tensioning arrangement must be used. The reinforcing bars pass

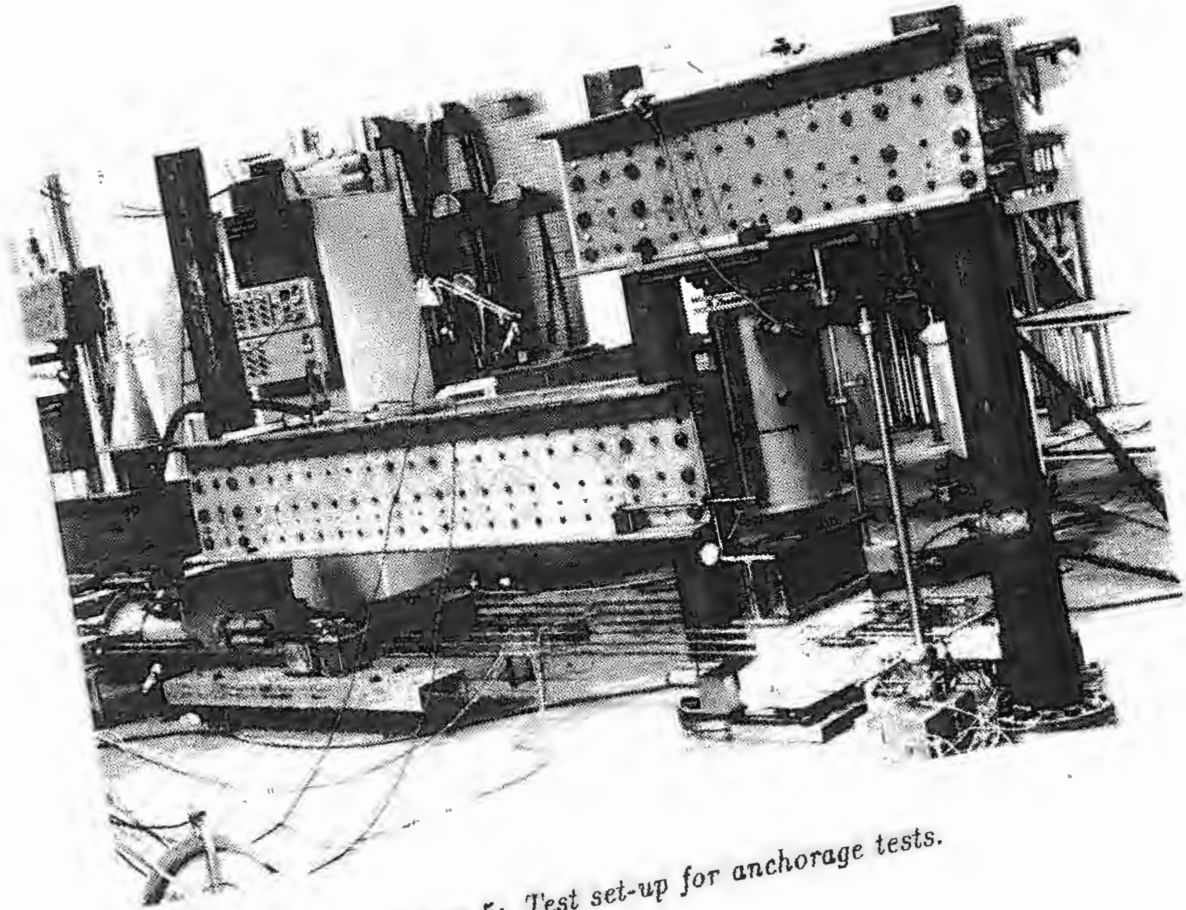

Figure 5: *Test set-up for anchorage tests.*

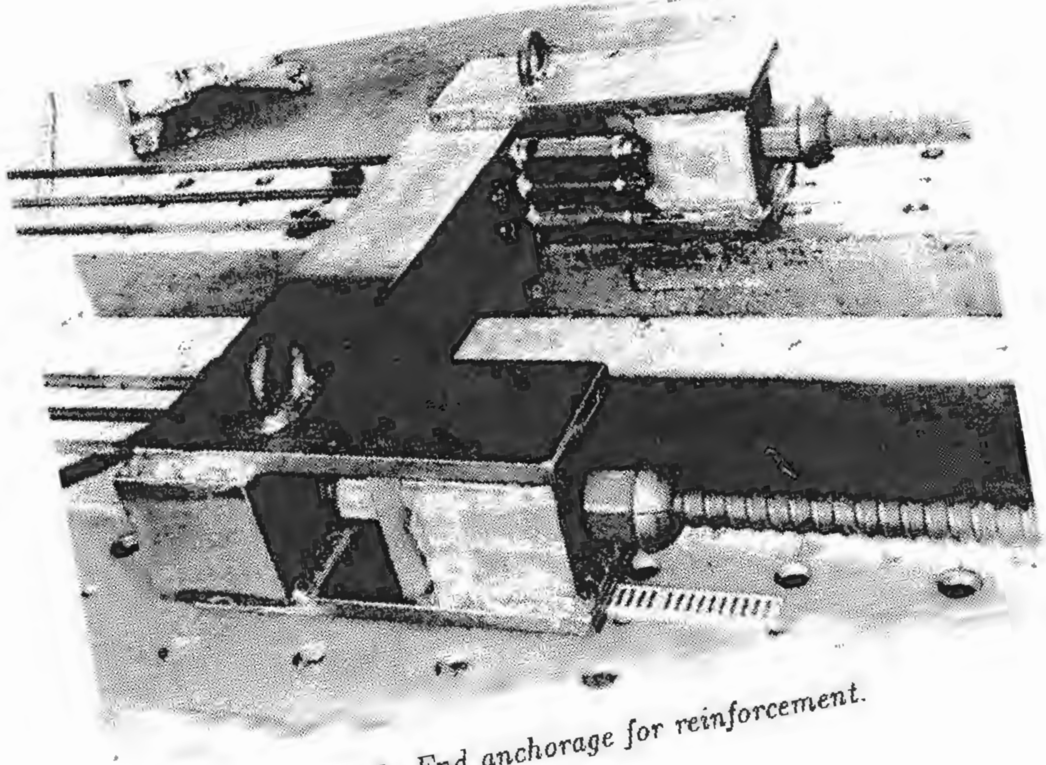

Figure 6: *End anchorage for reinforcement.*

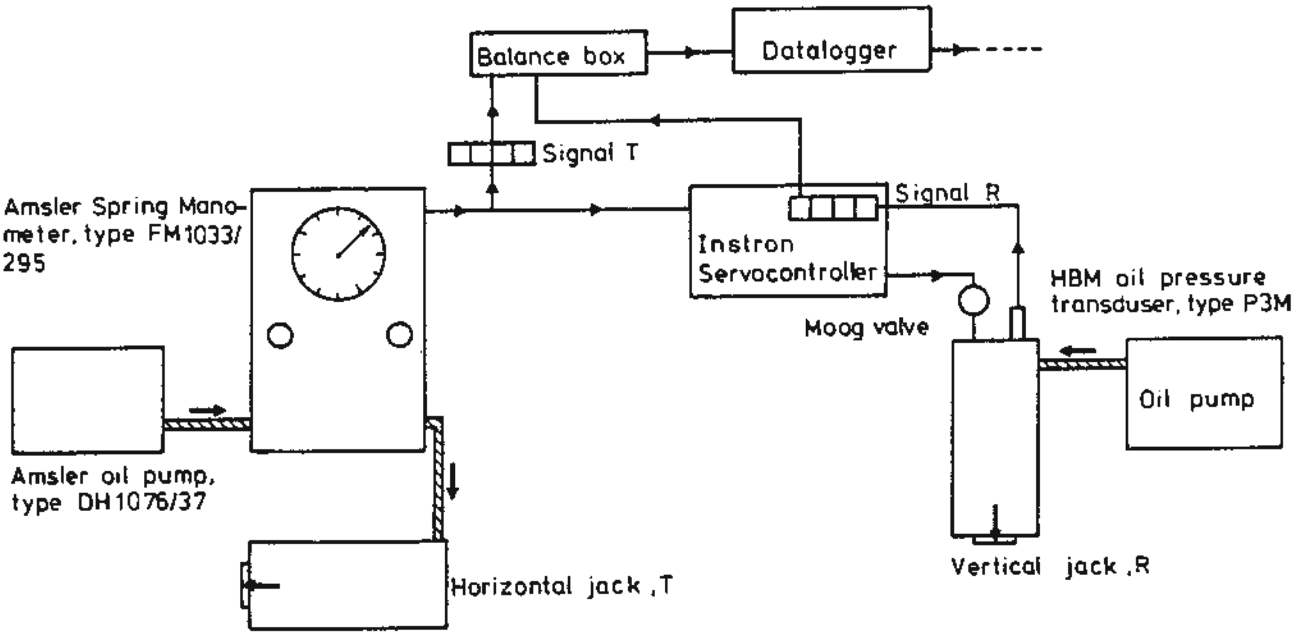

Figure 7: ***Diagram showing recording of signals from the vertical and horizontal forces, and control of the ratio between these two forces.***

through the load yoke, resting on the yoke by means of a special end anchorage and ball bearing pad on the other side, see figure 6. This joint is statically indeterminate; therefore the distance from the specimen to the end anchorage must be equal in all the bars. This was obtained by a special fixing procedure where it was encured that the forces in all bars were equal. The forces in the bars were measured by strain gages on every bar, in front of the specimen.

The test was started with zero force in the reinforcement. The load was applied gradually, step by step. At every step the load was kept constant for some minutes, before increasing it. The load was increased until the specimen failed. During the tests the crack formations and deformations were observed. After failure the failure type were noticed and the specimen was photographed.

5 Measurements

In every test the total horizontal and vertical forces and the force in every bar were measured. Furthermore strains in the reinforcement were measured; the slip between the reinforcement and the concrete at the free end of some of the bars and the displacements of the test specimen were measured.

As mentioned in the preceding section the ratio between the vertical and the horizontal force, R/T, was kept constant during the test. The ratio was controlled by an servocontroller. A schematic diagram showing the registration of the signals from the vertical and horizontal forces and the control of the ratio between the forces is shown in figure 7.

On every reinforcing bar two strain gages, were placed between the test specimen and the load yoke. Using these strain gages, it was possible to measure the force in every reinforcing bar.

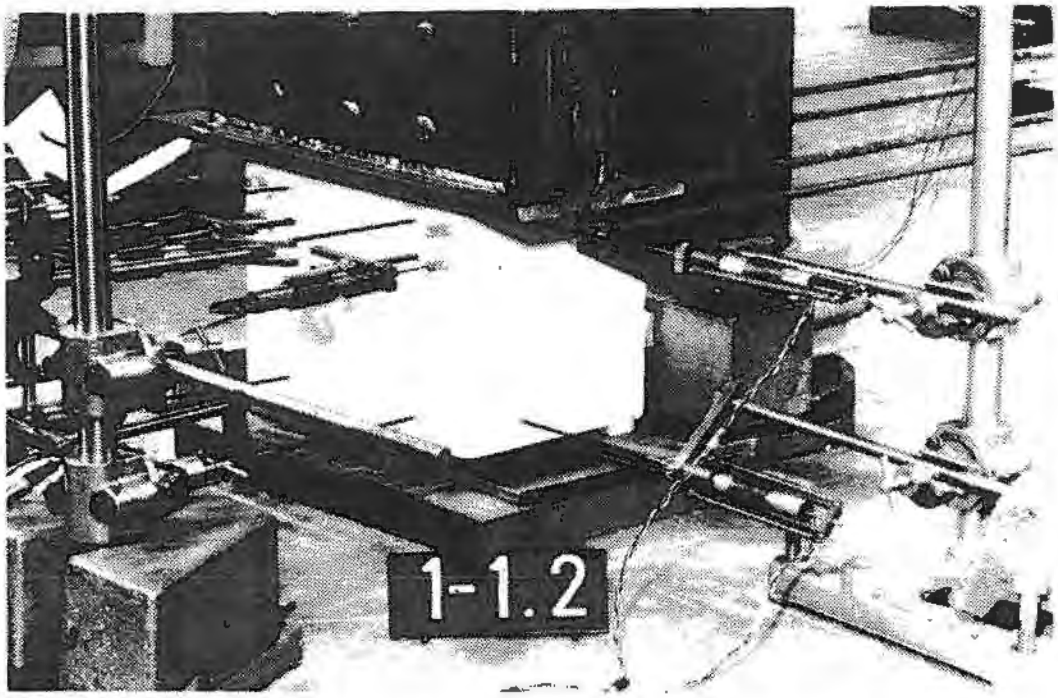

Figure 8: *Displacement transducers placed on a specimen.*

The slip between the reinforcement and the concrete was recorded at the free end, the unloaded end, by displacement transducers. The transducers were fixed to the specimen by means of metal gadgets. In all the tests slip measurements were taken on two bars, as illustrated in figure 9.

The displacements of the specimen were also registered and the transducers were placed on the specimen as indicated in figure 9. This figure applies to specimens with both 4 and 6 bars. Using this displacement measurement, it is possible to calculate the translation and rotation of the specimen during the test. In figure 8 the displacement transducers on a specimen are shown.

6 Test Results

The main results of the tests are given in table 3. In table 3 different values for the total horizontal and vertical forces T and R, respectively, are given. T_e and R_e is the maximum force recorded by electrical means, i.e. strain gages, datalogger etc. The maximum force obtained by the spring manometer is indicated by an s. The vertical force R_s is determined from T_s multiplied by the actual ratio R/T. The small inconsistancy between the values with indices e and s comes as a result of the reading inaccuracy by the spring manometer. In some cases the e values are less than the s values. This is because the electrical scan was taken at intervals of 60 seconds. Therefore the load could have been increased and the specimen failed without a scan being taken.
Various diagrams for test No. 1-2.1 are given in the figures below. Diagrams and photos for all the specimens similar to those shown here are given in Andreasen /5/. The relationship between the total horizontal force T and time is given, in figure 10. Correspondingly the relationship between the actual ratio R/T, divided by the desired ratio (the given ratio) and the time is given, in figure 11. The forces in the reinforcing bars obtained by strain

Test No.	No. of bars	f_c [MPa]	Ratio R/T	Max forces T_e [kN]	R_e [kN]	T_s [kN]	R_s [kN]	Max slip left [mm]	right [mm]
1-1.1	4	34.4	0.895	121.2	108.6	121.5	108.8	0.475	0.078
1-1.2	4	35.2	0.895	118.3	105.9	118.0	105.6	0.074	0.204
1-2.1	6	33.7	0.796	154.4	122.9	153.6	122.3	0.001	0.121
1-2.2	6	34.4	0.796	82.2	66.2	96.6	76.9	0.015	0.013
2-1.1	4	32.2	1.462	154.1	224.9	153.6	224.6	0.335	0.048
2-1.2	4	33.7	1.462	181.8	264.9	185.5	271.1	0.153	0.127
2-2.1	6	35.6	1.299	109.1	142.7	109.7	142.6	0.015	0.060
2-2.2	6	33.0	1.299	121.2	156.9	125.7	163.2	0.027	0.048

Table 3: *Main results of the tests.*

gages, $T_{straingages}$, are shown as a function of the total horizontal force, T, in figure 12. In a similar manner, the sum of the forces in the reinforcing bars, $Sum\ T_{straingages}$, are shown as a function of the total horizontal force, in figure 13.

The deformations of the specimen and the slip af the reinforcement as a function of the total horizontal force, using the symbols shown in figure 9, are given in figure 14 and figure 15.

The dotted line in the figures indicates the failure load recorded by the spring manometer, see T_s in table 3.

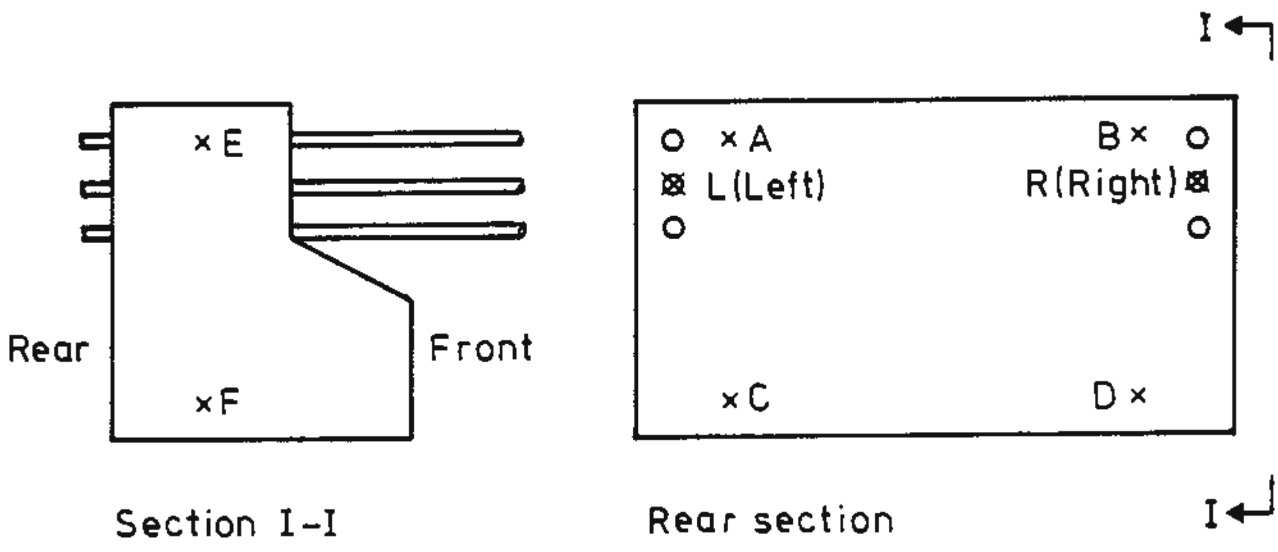

Figure 9: *Symbols for the various measurement points.*

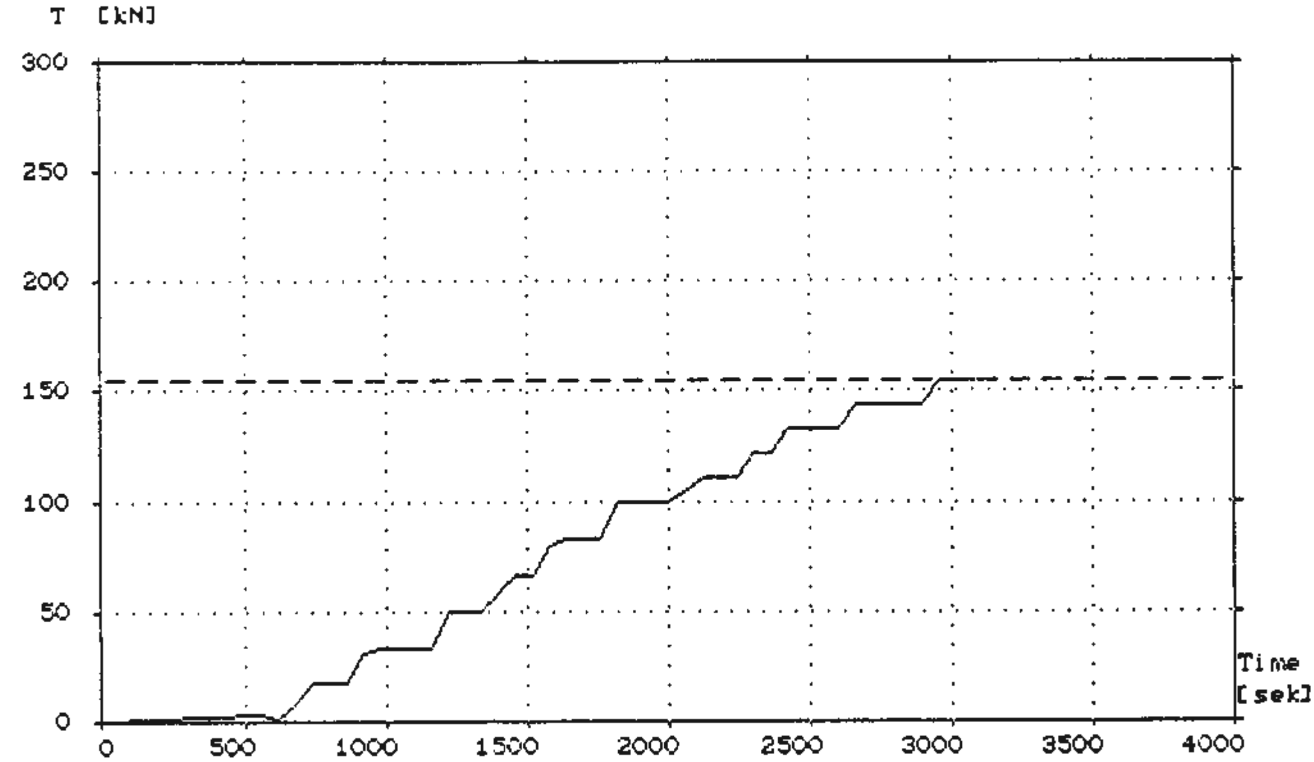

Figure 10: *The total horizontal force T as a function of time for test No. 1-2.1.*

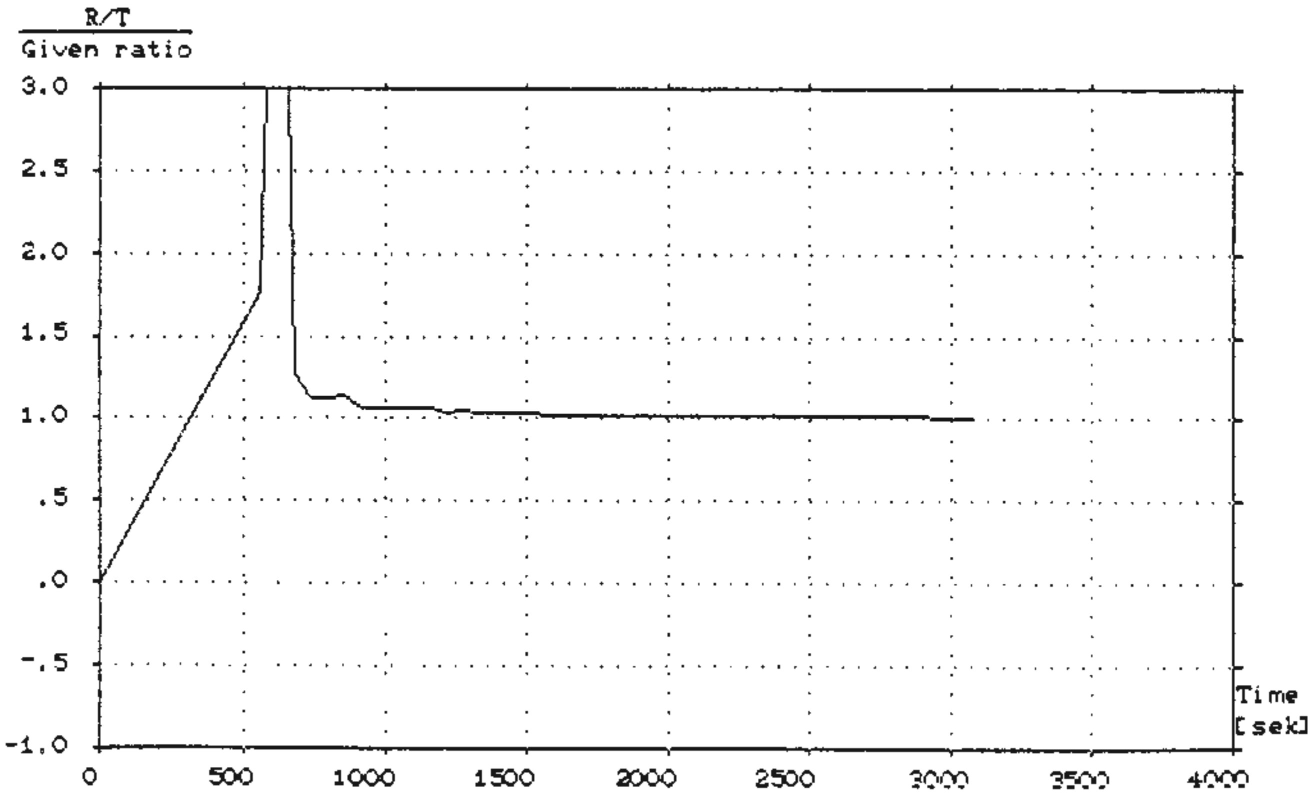

Figure 11: *The actual ratio R/T divided by the given ratio of R/T as a function of time for test No. 1-2.1.*

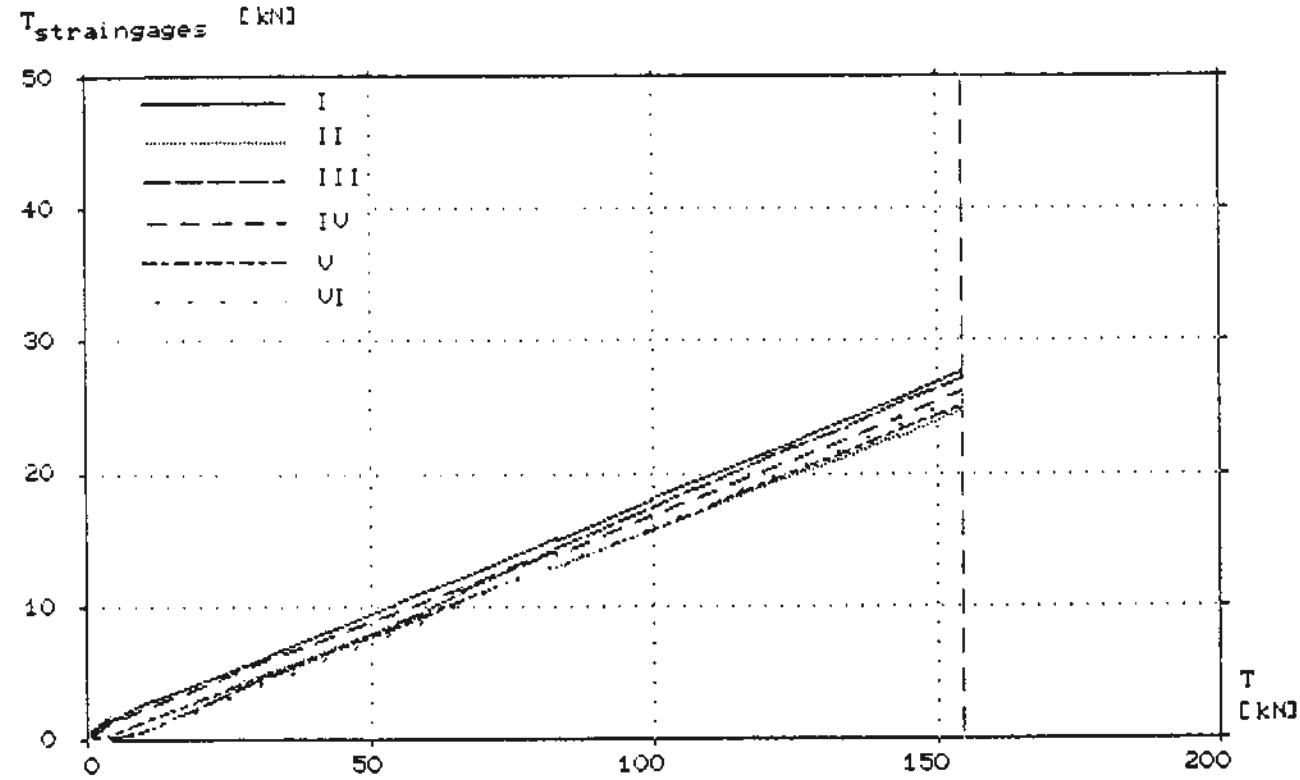

Figure 12: *The force in the reinforcing bars $T_{straingages}$ as a function of the total horizontal force T for test No. 1-2.1.*

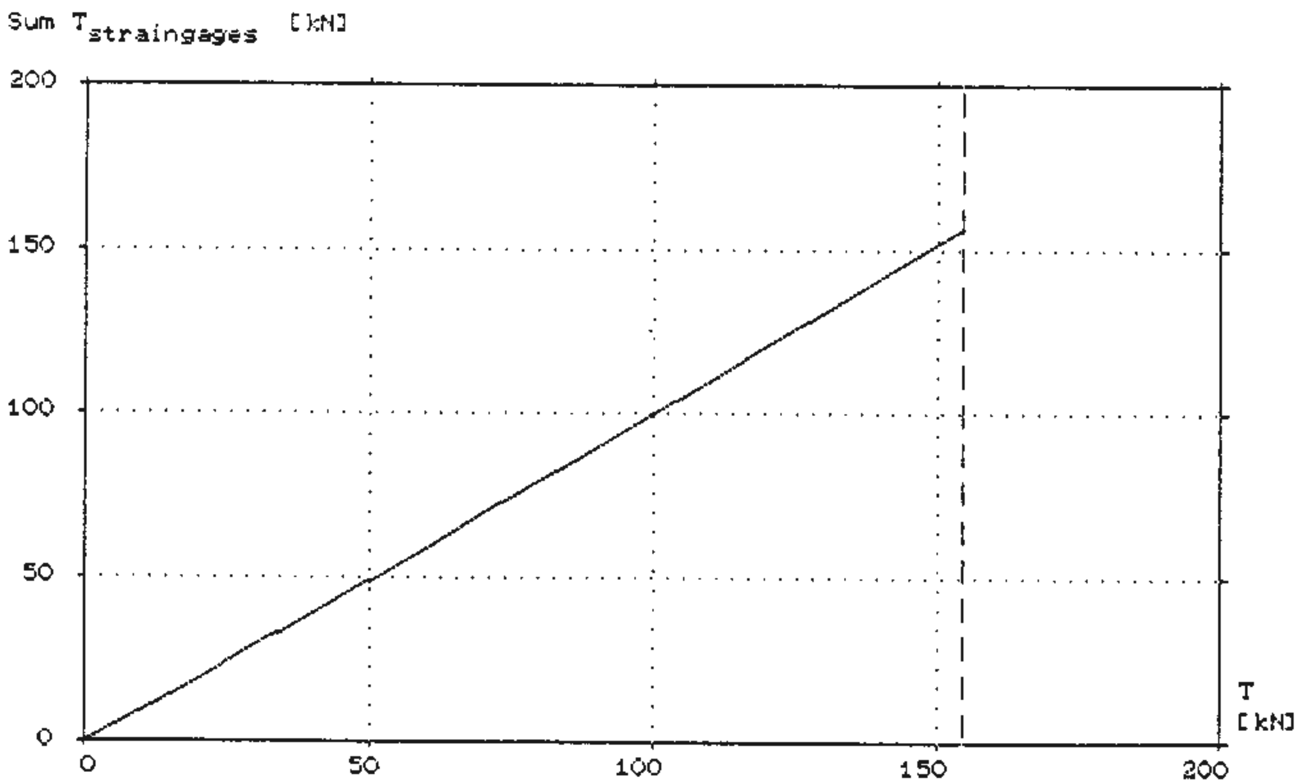

Figure 13: *The sum of the forces in the reinforcing bars $Sum T_{straingages}$ as a function of the total horizontal force T for test No. 1-2.1.*

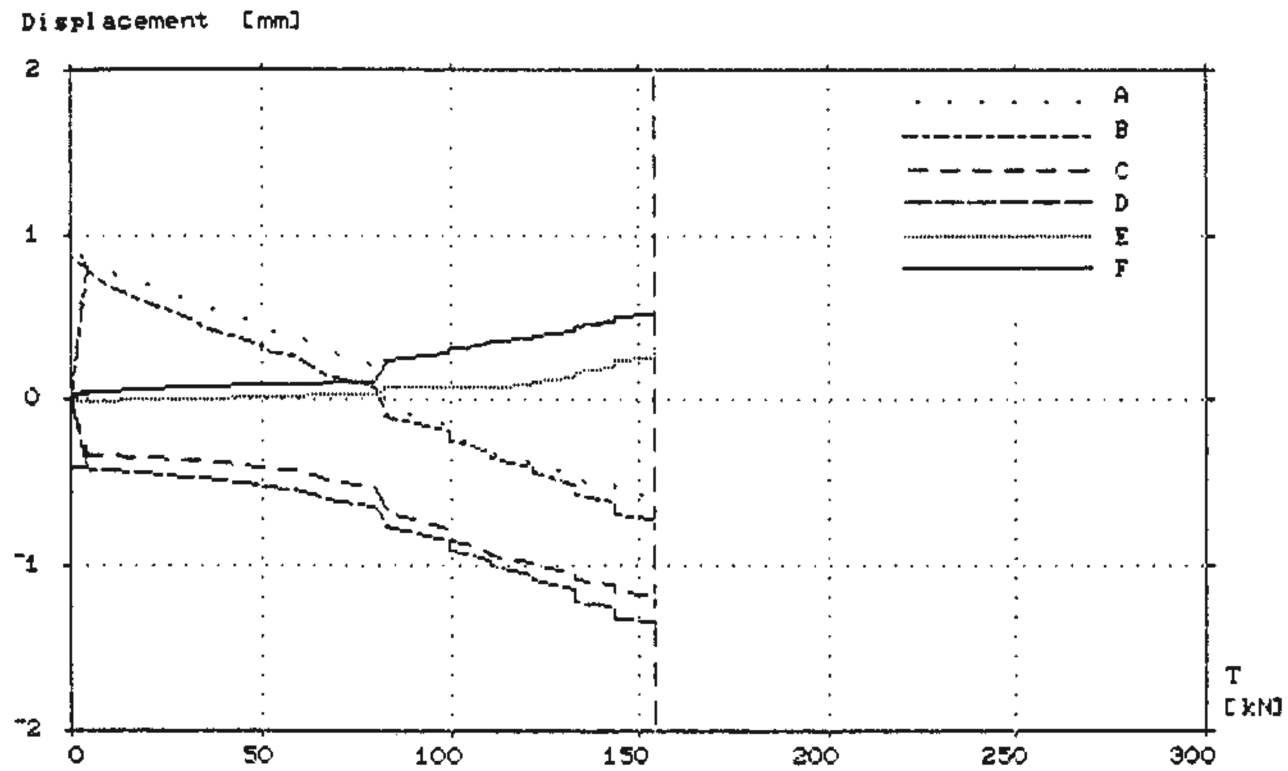

Figure 14: *Displacements as a function of the total horizontal force T for specimen No. 1-2.1.*

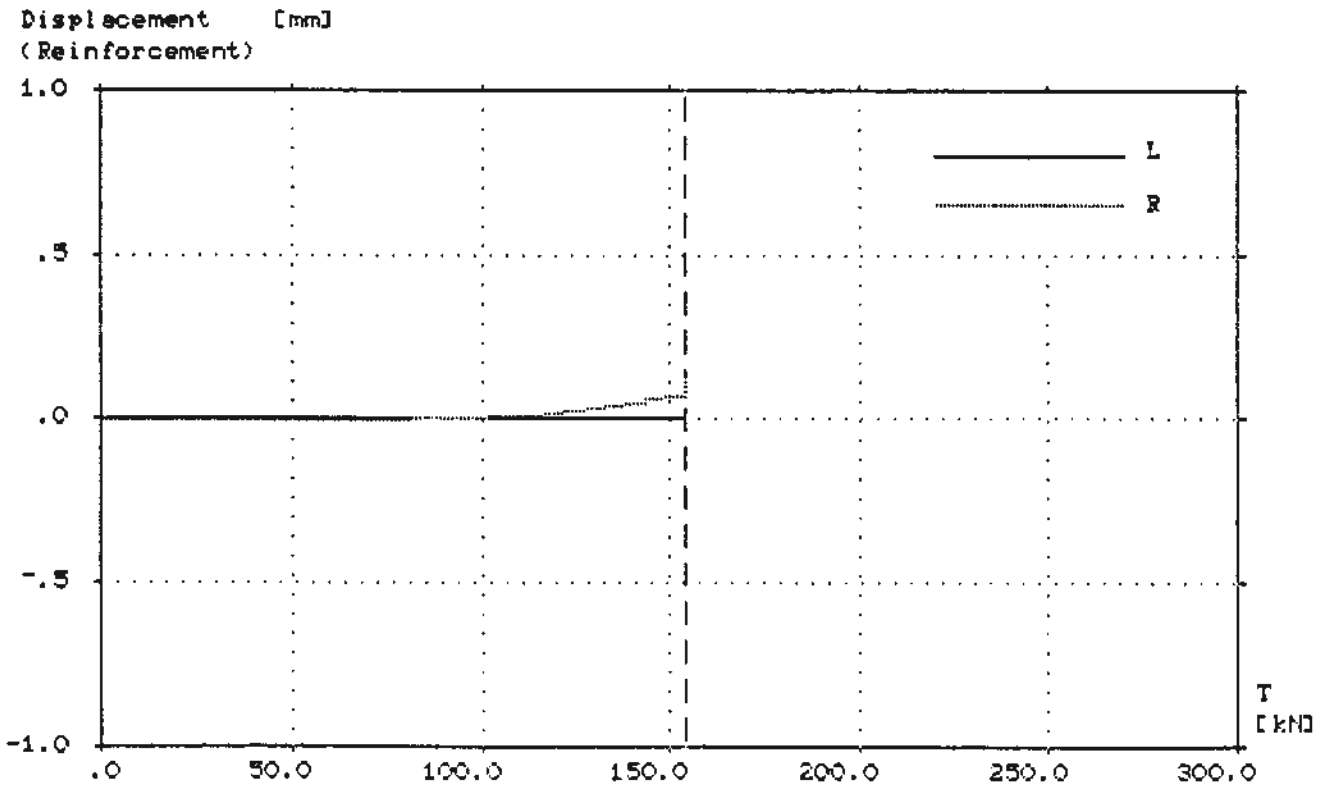

Figure 15: *Free end slips as a function of the total horizontal force T in specimen No. 1-2.1.*

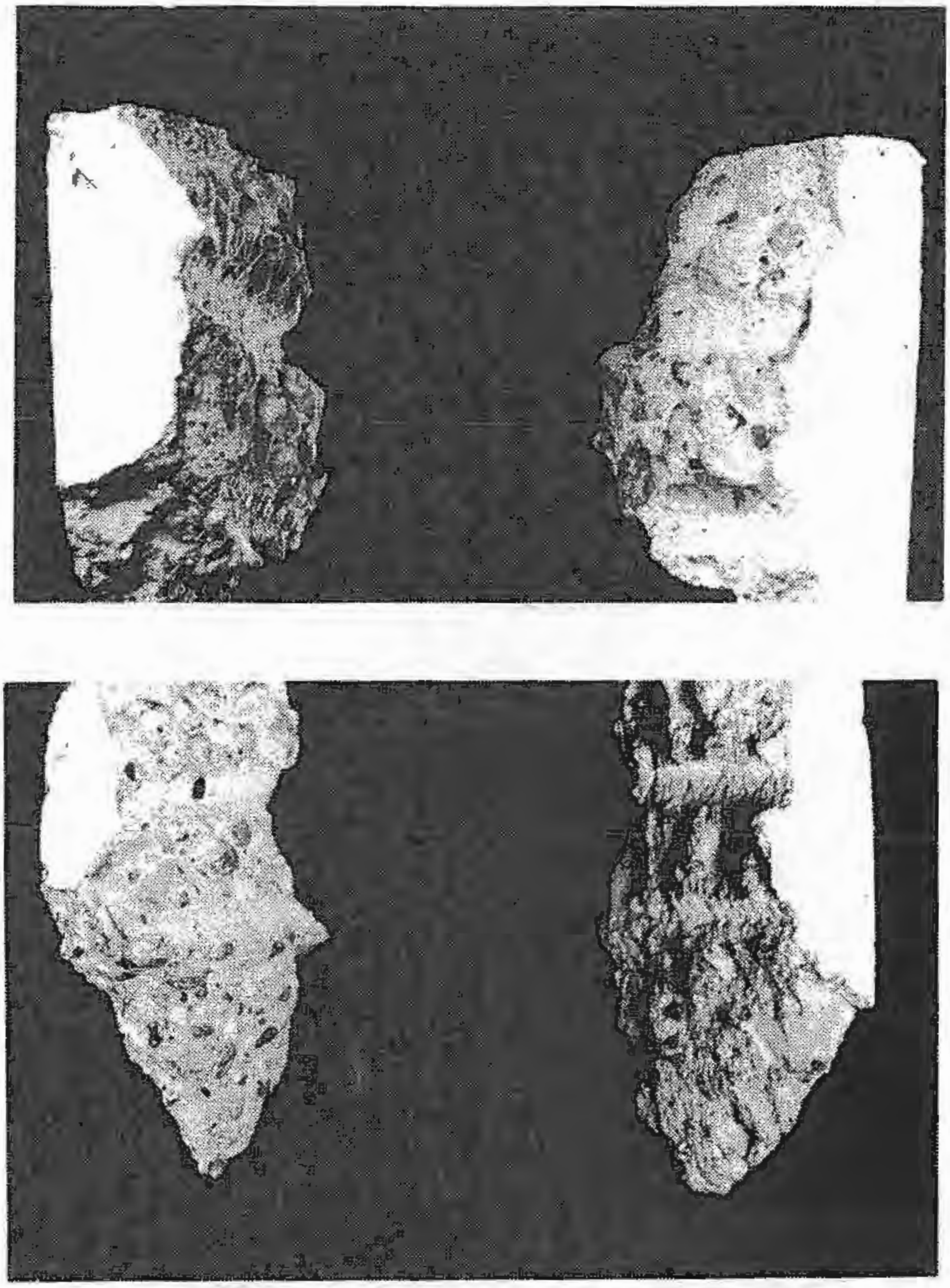

Figure 16: *Broken off concrete corners.*

After failure the specimen was photographed from different positions, see figure 17 . For the other tests reference are made to Andreasen /5/.

In figure 16 the concrete corners broken off at failure in some of the tests are shown.

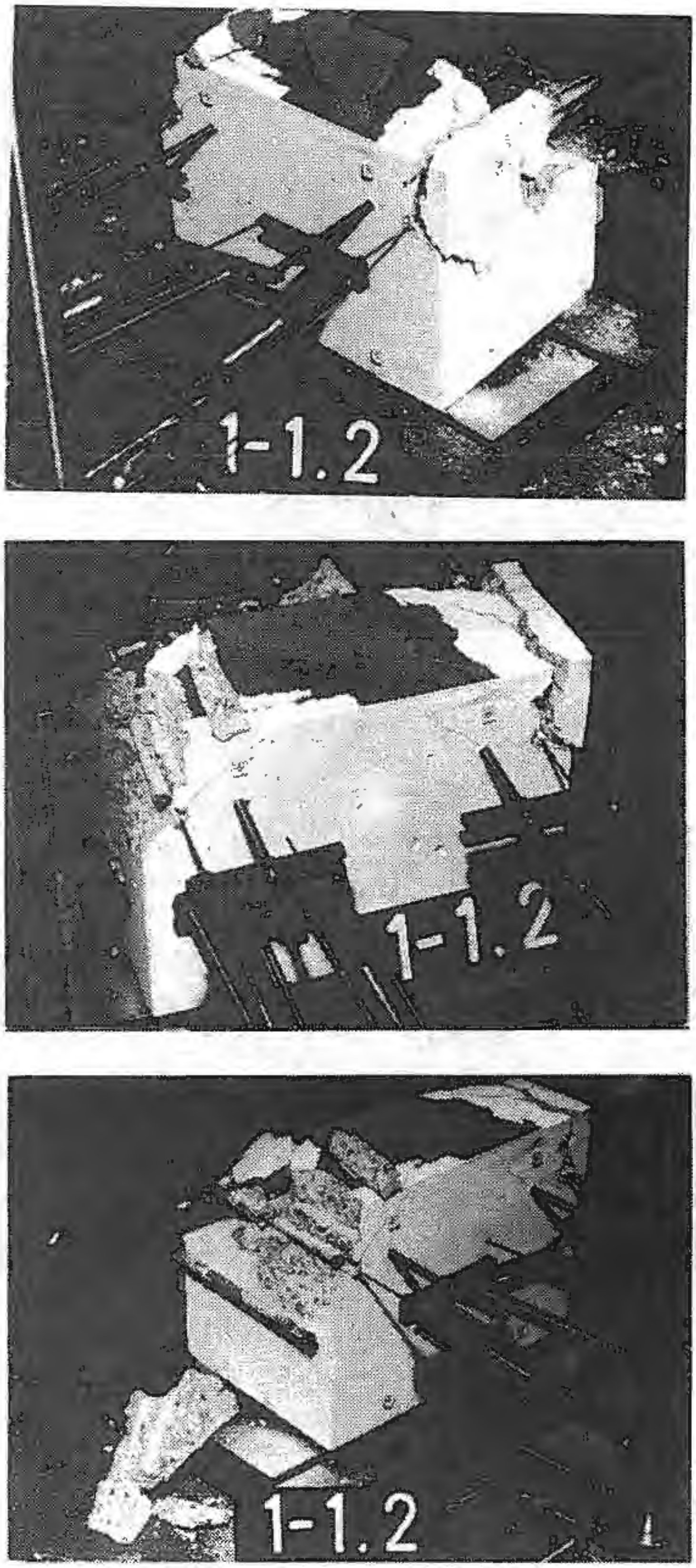

Figure 17: *Photos of test No. 1-1.2.*

6.1 Observations

As indicated in figure 11, showing the actual ratio R/T divided by the given ratio R/T as a function of time, there are inconsistencies between the actual and the given ratios at the start of the tests, when the loads are small. When the loads increase, the correspondence between the actual and the given ratios is good. The difference in general was less than 5 and 1.3 % for small loads and for loads near the failure load, respectively. The inconsistency is certainly caused by the fact that the vertical jack (producing R), which was controlled by the servosystem, was a one way jack. However, it must be concluded that the control system acts acceptably.

The curves for the forces in the different reinforcing bars, $T_{straingages}$, show that there is fairly good correspondence between the force of different bars, figure 12. This in spite of the fact that the way in which the total horizontal force is transferred to the reinforcement is rather simple. Comparing the total force in the reinforcement, $Sum\ T_{straingages}$, with the total horizontal force from the jack, T, figure 12, it can be seen that they agree satisfactorily; the two forces are almost identical. The transfer of the force from the jack to the reinforcement may therefore be considered to be without loss of force, i.e. the friction in the roller bearings and the other connections is minimal.

The displacements of the test specimens are shown in figure 14 and 15. As can be seen in figure 14 there were some problems at the start of the tests, when the loads were small, which was a general problem. This corresponds to the discrepancy between the actual and the given ratios of R/T. When the load is increased the displacements in the different tests are in general similar. The displacements at the rear of the specimen, indicated by A, B, C and D, see figure 9, start at zero and increase linearily, and the inclination of the curves for the four points are identical, other things being equal. The problems at the beginning of the tests are probably caused by the previously mentioned discrepancy between the actual and the given ratios of R/T, and because the specimen settles down when the load begins to act on it. The displacements observed when the load is increased are, very likely, due to the compression of the plywood support plates. Perhaps a more stiff material should have been used, but after all, the displacements are small and apparently they cause no problems.

It seems that the measurement of the free end slip is acceptable in spite of the relatively simple method which is used (see section 5).

In general the final failure came violently and suddenly without warning. In some cases not even a visible crack had appeared on the concrete surface before failure. In other cases a few cracks developed just before failure. In the case of anchorage failure, the concrete corners along the anchorage length broke off at failure.

It seems as test No. 1-1.1 was an anchorage failure.The observations made during the test. the photographs and the slip measurements indicate that this is the case. Only a few cracks around the bars at both the unloaded and the loaded end appeared just before failure. In tests No. 1-1.2, 2-1.1 and 2-1.2 no cracks appeared before failure and the failure in all cases came without any warning. In tests No. 2-1.1 and 2-1.2 it is not entirely certain whether it was the anchorage which caused the failure or not. It was not possible at the time of failure to observe if it was a shear type failure or if it was an anchorage failure, but the slip curves for these two tests indicate that it was an anchorage failure (compared to the slip curves for test No. 1-1.1 and 1-1.2). An analysis of the shear failure indicates that it was not a shear failure, see Andreasen /5/.

The test specimen with 6 bars, tests No. 1-2.1, 1-2.2, 2-2.1, and 2-2.2, failed in a more complex manner. It is not possible with certainty to say what type of failure caused the final failure or if it was a combination of different failure types. In test No. 1-2.1 a vertical crack appeared at the rear of the specimen at about 2/3 of the failure load. The crack developed with increasing load until failure. There were no shear cracks before failure, and the anchorage failed only on one side. The failure in test No. 1-2.2 came without any warning at all, and occured at a load a great deal less than the load obtained in test No. 1-2.1. The specimen failed only on one side, while the other side and the specimen in general were without any visible sign of damage. After failure a piece of concrete on the damaged side, having the same length as the anchorage length and a dimension of 2 to 3 times the diameter of the bar in the direction perpendicular to the bar axis, was still fixed to the reinforcement. The failure was probably caused by a local weakness in the corner which failed.

At the front and the rear of the specimen, vertical cracks appeared in the middle in test No. 2-2.1 at a load of about 2/3 of the failure load. The cracks developed with increasing load. It appears that three types of failure occured: anchorage, "bending" and shear failure. Regarding the bending failure, see Andreasen /5/. It is not possible to say what type of failure was decisive. However, the calculations indicates that it was probably not a shear failure. Considering the slip curves, it is possible that the failure was not an anchorage failure. This is also confirmed by the photos. A piece of concrete is still fixed to the three reinforcing bars on the damaged side.

Test No. 2-2.2 was similar to 2-2.1 but the support plates were placed a little differently. However, the two tests were carried out with the same ratio R/T. A vertical crack appeared in the middle at the rear of the specimen at about 2/3 of the failure load. Just before failure a similar crack developed at the front. The final failure seems to be an anchorage failure considering the photographs, but the slip measurements do not support this.

The few tests which were carried out, do not of course clarify all problems concerning anchorage of bars in more than one layer at a beam support. However some informations appeared from the tests. The failure seems to be violent and comes without warning. The tests with the 6 bar specimens can probably not be used as more than a guidance of how new tests should be carried out.

7 Summarized Comments

The system of controlling the ratio between the total horizontal and vertical forces in the test set-up seems to achieve its purpose. However, if the vertical jack which was controlled by the servo controller, had been a doubly active jack, instead of a one way jack, the actual ratio would certainly have been even better. Because the vertical jack was only one-way active, it vibrated when the load was increased. This could have caused failure in the specimens for a load less than if there had been no vibrations.

The tensioning and injection procedure of the end anchorage of the reinforcement made to ensure that the same force was transferred through every bar, seems to act acceptably. The force in every bar was not the same but the difference between them was small, especially when the specimen was close to failure.

The principle used to test the anchorage strength here is sensitive to inaccuracy in the placing of the specimens in the test set-up. For small loads the inaccuracy may influence the result, but when the load increases, the influence of the deviation from the correct position will more or less disappear.

The advantage of the test principle used is that the specimens are simple, and that it is clear what is being measured, and what results are obtained. Beyond this it is possible to vary arbitrarily the ratio between vertical and horizontal forces.

The disadvantage is that the specimen not necessarily represents a beam support. However, many things indicate that the conditions in the specimen are similar to those in a real beam support.

The conclusion is that the method reported here to test the load carrying capacity of anchorage of reinforcement in more than one layer at a beam support can be employed. Some small changes with regard to what has been done here should probably be made but the main ideas of the test specimen, the test set up and the test procedure can be used.

In Andreasen /4/ anchorage problems are threated by use of the theory of plasticity, and the theory developed is, among other, used to analyse anchorage of multilayered reinforcement at supports. The results from the tests reported here and in Andreasen /5/ has been used. For a more detailed description the reader is refered to Andreasen /4/.

8 Notation

a	Distance between ribs on the reinforcement.
b	Width of beam or specimen.
d	Diameter of reinforcing bar.
f_c	Uniaxial cylinder compressive strength of concrete.
h_d	Depth of ribs or deformations.
u	Dimension of ribs in the direction of the bar axis.
M	Moment.
R	Vertical force on the specimen, reaction force.
R_e	Maximum vertical force R recorded by electrical means.
R_H	Horizontal support force (horizontal reaction force).
R_s	Maximum vertical force R recorded by the spring manometer.
R_V	Vertical support force (vertical reaction force).
T	Horizontal force on the specimen.
T_e	Maximum horizontal force T recorded by electrical means.
T_s	Maximum horizontal force T recorded by the spring manometer.
T_u	Ultimate force in one reinforcement bar.
T_y	Yield force in one reinforcement bar.

9 References

/1/ Tepfers, R.: *A Theory of Bond Applied to Overlapped Tensile Reinforcement Splices for Deformed Bars.* Göteborg, Chalmers Tekniske Högskola, Division of Concrete Structures, Publ.73.2, 1973.

/2/ Jensen, J.H.: *Forkammmede armeringsstængers forankring specielt ved vederlag (Anchorage of Deformed Reinforcing Bars at Supports). Part 1.* Department of Structural Engineering, Technical University of Denmark, Lyngby, Serie R, No. 155, 1982.

/3/ Jensen, J.H.: *Forkammmede armeringsstængers forankring specielt ved vederlag (Anchorage of Deformed Reinforcing Bars at Supports). Part 2 - Appendix A-F.* Department of Structural Engineering, Technical University of Denmark, Lyngby, Serie R, No. 156, 1982.

/4/ Andreasen, B.S.: *Anchorage of Ribbed Reinforcing Bars.* Department of Structural Engineering, Technical University of Denmark, Lyngby, Serie R, No. 238, 1989.

/5/ Andreasen, B.S.: *Anchorage Tests with Ribbed Reinforcing Bars in more than One Layer at a Beam Support.* Department of Structural Engineering, Technical University of Denmark, Lyngby, Serie R, No. 239, 1989.