OVERLAP SPLICES FOR RIBBED BARS FOR FREE USE IN A CONCRETE STRUCTURE

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ABSTRACT

The object of the investigation is to develop a simple splice construction with confinement, which can anchor at least the yield stress of the reinforcing steel under static load and which has a fatigue strength exceeding that of unspliced tensile reinforcement.

Beam tests with lapped tensile reinforcement have been performed under static and dynamic load. Every lap is confined by a spiral. Parameters as bar diameter, concrete strength, lap length and confinement have been varied. Analytical bond theory for laps has been used to calculate the resistance of the laps under monotonic load and also under repeated loading, resulting in fatigue.

Based on the investigation three types of spiral confined laps are proposed for use anywhere in a structure, where there is enough space for the splice construction.

KEYWORDS: Concrete
Reinforcement
Splices
Confinement

1. INTRODUCTION

In case there is a failure of a reinforced concrete structure, it should always be ductile. This means that the concrete members are designed in such a way that they will fail in a flexural failure after a certain moment redistribution has taken place. For the reason of ductility, it is preferable that the members are underreinforced, so the yielding ductility of the tensile reinforcement can be utilized. The brittle shear and bond failures should be avoided by increasing these strengths in comparison with the moment resistance of the concrete members.

In the codes the strength of overlapped tensile reinforcement splices is ensured by certain restrictions. Thus the numbers of spliced bars are limited, the placing of the splices is prescribed, and confinement is required.

It would be convenient in certain situations, that there were a simple overlap splice construction, which can be placed everywhere and which can transfer at least the yield strength of the reinforcing bar. In case of fatigue loads, the resistance of the splice should exceed that of the spliced reinforcing bar.

2. OBJECT OF INVESTIGATION

The object of this investigation is to develop a simple splice construction with confinement, which is capable of anchoring at least the yield stress of the steel under static load, and which has a fatigue strength exceeding that of unspliced tensile reinforcement. The splice construction should be simple to produce and safe in operation.

3. INVESTIGATED SPLICE CONSTRUCTION

Overlap splices without confining reinforcement show a brittle failure. Confinement increases the strength and toughness of the splices and also reduces the scatter in ultimate resistance.

The present investigation analyses the strength of tensile reinforcement splices surrounded by spiral reinforcement in such a way that every overlap has a separate spiral, in accordance with FIG. 1.

The tested spliced reinforcements are Swedish Ks 400, Ks 420 and Ks 600 high bond bars with yield strength fsy = 400, 420 and 600 MPa, respectively. The confinement is made of plain reinforcement spirals with fsy =260 MPa. Ks 420 has ribs inclined to the bar axis and the Ks 400 and Ks 600 have transverse ribs.

The splices were tested in concrete beams. The beams were isostatic and loaded with two symmetrical point loads, FIG. 2. The tensile reinforcement splices investigated were situated between the point loads and were therefore loaded by almost constant bending moment. All tensile reinforcing bars were spliced at the same cross section.

The concrete compressive strength fcc is refered to cubes with side length 150 mm.

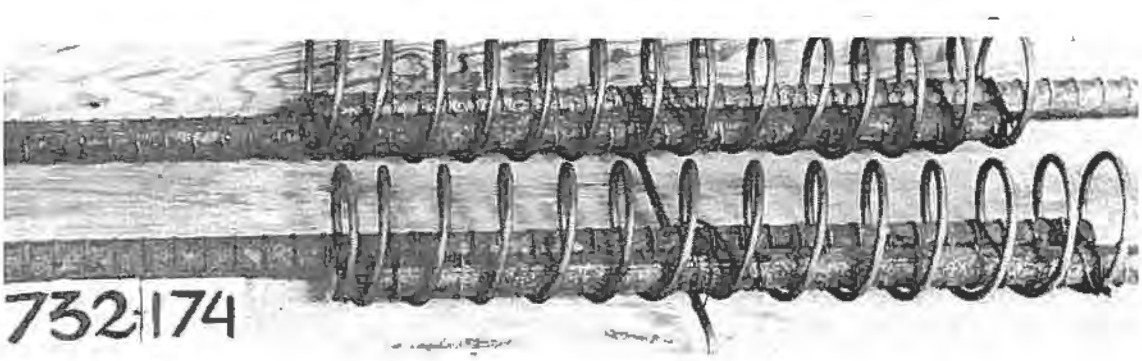

FIG. 1. Tensile reinforcement splices confined by spirals.

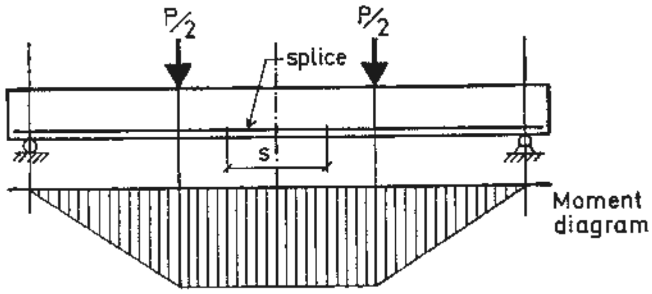

FIG. 2. The loading of test beams.

4. TEST RESULTS

4.1 Influence of concrete strength and spiral confinement.

Tensile overlap splices have been tested with and without spiral confinement using different concrete strengths. The beneficial effect of confining spiral reinforcement becomes evident in FIG. 3, when the curves for splices without confinement are compared with curves for splices surrounded by spirals. The comparison must be made for splices of the same steel quality. Ks 600 reinforcement with specific rib area 0.4 · Ø gives a better anchorage effect than Ks 400 and Ks 420 reinforcement with specific rib area 0.2·Ø. The spiral has bar diameter Øst = 6 mm, inner diameter D = 50 mm and pitch a = 50 mm.

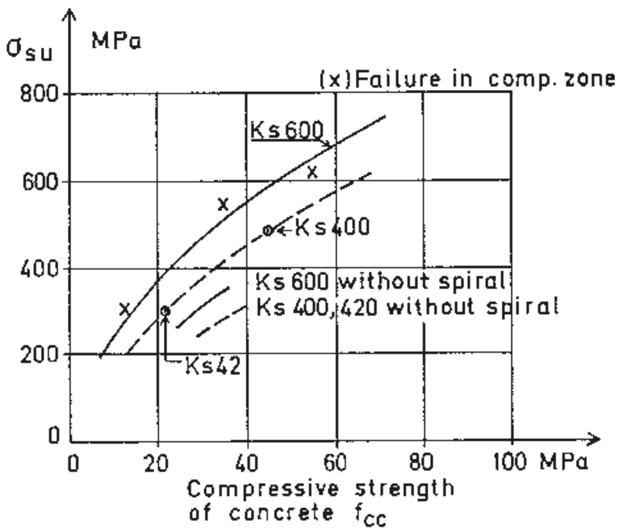

FIG. 3. The splice strength represented by the stress σ_{su} in the tensile reinforcement just outside the spliced section at failure as a function of the compressive strength f_{cc} of the concrete for laps of Ks 400 and Ks 600 confined by spirals. The splice length is 320 mm and the diameter of the lapped bars is Ø = 16 mm.

4.2 The influence of splice length

The influence of splice length on the strength of splices confined by spiral reinforcement is investigated in FIG. 4. The figure shows that it is possible to exceed the yield stress of the spliced tensile reinforcement, when the splices are confined by spirals, without splice failure occuring. The splice lengths required are fairly short, but they are naturally dependent on the concrete strength. For instance with the spirals used here and concrete with compressive strength fcc = 30 MPa, a splice length of s = 500 mm is sufficient to fulfil the yield criteria for Ø 16 Ks 600. The spiral as under 4.1.

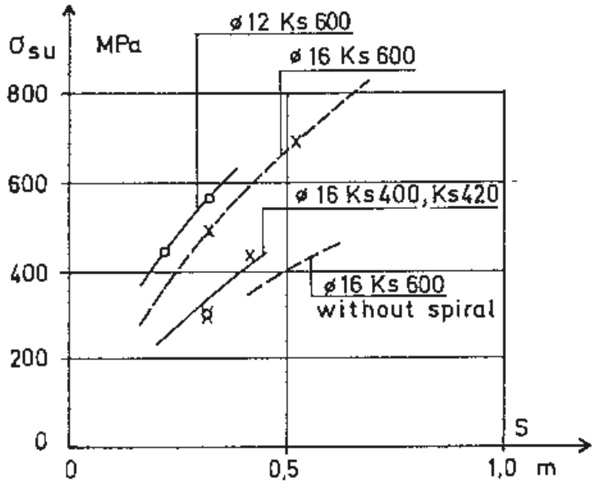

FIG. 4. The splice strength represented by the stress σsu in the tensile reinforcement just outside the spliced section at failure as a function of the length of the splice s for laps of Ks 600, Ks 400 and Ks 420 reinforcement confined by spirals. fcc = 25 MPa. For reasons of comparison the curve for Ø 16 Ks 600 without spiral confinement is also plotted.

4.3 The influence of spiral bar diameter on confinement

The effect of the spiral bar diameter Øst on the strength of the overlap splice is investigated in FIG. 5. It is obvious that the

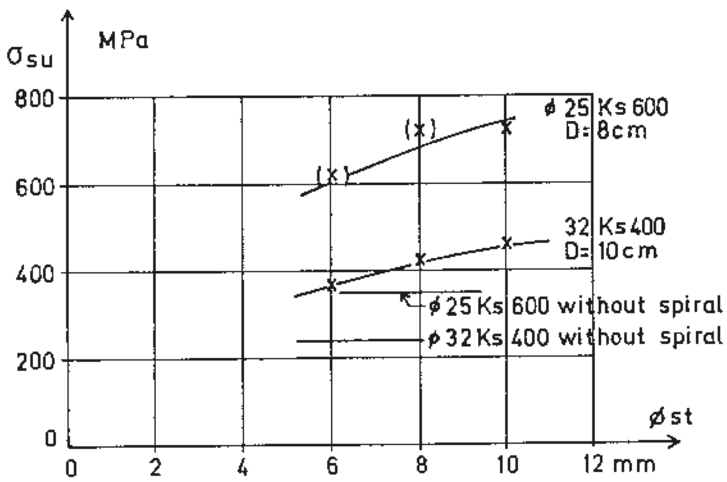

FIG. 5. The splice strength represented by the stress σsu in the tensile reinforcement just outside the spliced section at failure as a function of the diameter Øst of the confining spiral. fcc =34 MPa. Splice length s = 520 mm. Pitch of spiral a = 50 mm.

splice strength increases with the spiral bar diameter, i.e. with the amount of confining reinforcement.

4.4 The calculated splice strength

It is possible to calculate the strength of the overlaps surrounded by spirals using the methods presented in [1], [2] and [3].

In the course of analysis, bond failure must be regarded as a concrete splitting phenomenon, and calculation of the ultimate load may in a simplified procedure be based on the tensile strength of the concrete. The bond forces radiating outwards from the anchored bars, FIG. 6, are counterbalanced by the tensile strength of the concrete in the ultimate crack pattern in question and the confining reinforcement. On the basis of observations made in the splicing tests, six different types of failure pattern have been examined, FIG. 7. The ultimate strength of splices can be estimated with the assistance of the six types of failure. In view of the distribution of the bond stress along the anchorage length, three different modes of failure, A, B and C may be distinguished, FIG. 8.

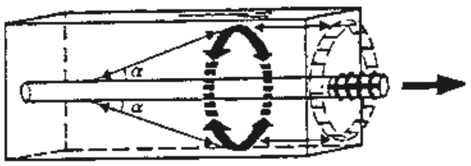

FIG. 6. Schematic representation of how the radial bond forces are counterbalanced by hoop forces in the anchorage zone in the concrete.

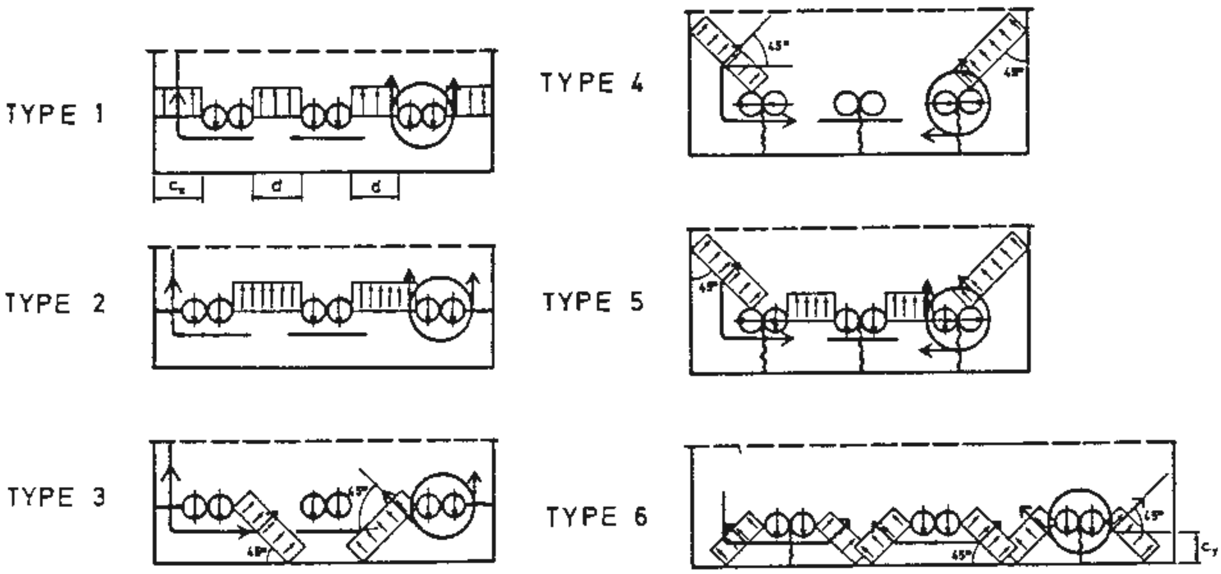

FIG. 7. Ultimate splitting failure patterns with confining reinforcement and stress diagrams. The uniformly distributed stress in the ultimate failure patterns of the concrete is the tensile strength of concrete fct. The radial bond forces have the magnitude $\tau_u \cdot tg\alpha \cdot \emptyset$. Angle α (see FIG. 6) is assumed to be 45°.

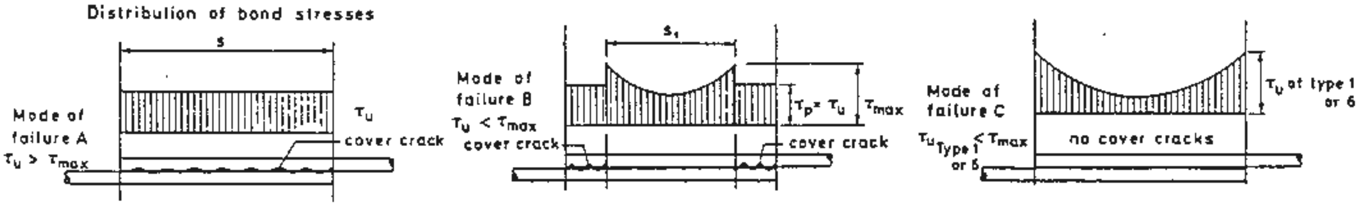

FIG.8. Distribution of bond stresses along spliced bars for modes of failure A, B and C. τu = smallest ultimate bond stress of the appropriate type to be used. τ max = bond stress which initiates the cover crack. s = splice length. s1 = part of splice length without longitudinal crack in the concrete cover.

Using the briefly presented theory, the resistances of the tested spiral confined overlaps are calculated. In FIG. 9, the measured ultimate forces transferred by the laps are compared with the calculated ones. From the figure it can be concluded that the theory is applicable for determination of the ultimate load.

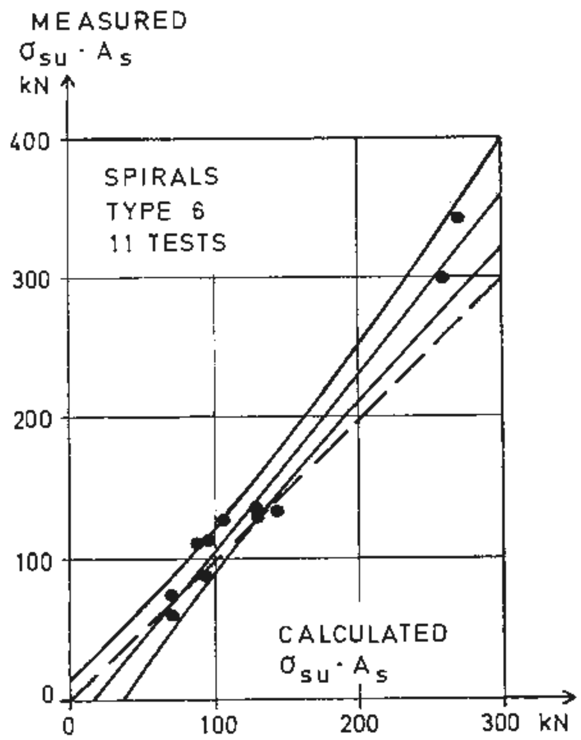

FIG. 9. Analysis of overlaps with confining spirals. Vertical axis represents the measured anchored force in the lapped reinforcement at splice failure and the horizontal the calculated one. The dotted line represents the coincidence of measured and calculated values. A straight regression line for the 11 test results is plotted with 95% confidence band.

4.5 Fatigue resistance of the spiral confined lap splices

Four beams with spiral confined tensile lap splices and concrete strengths according to FIG.10 and 11, were tested. The tensile reinforcement stress was pulsated sinuately between σ max/fsy = 0.465 and σ min/fsy = 0.069 with σ max = 240 MPa. The pulsating stress level increased in the remaining reinforcement when the bars started to fail one by one. The tensile reinforcement sustained between 1 and 2 million load cycles. All tensile reinforcement fatigue failures were located just outside the spliced cross section and are marked in FIG. 11. The laps were not affected, FIG. 12. Thus the fatigue tests show that the fatigue resistances of the splices are higher than the fatigue strengths of the tension bars.

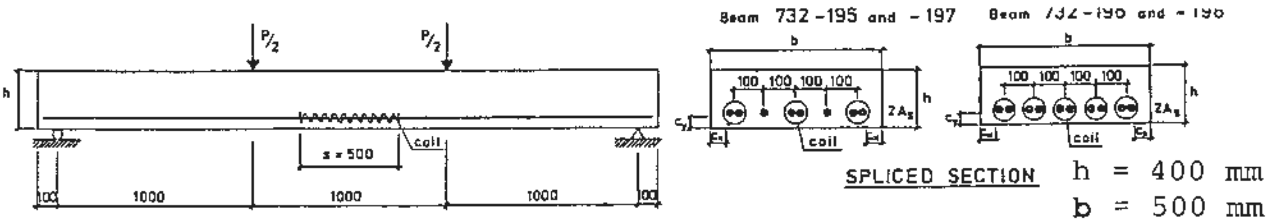

FIG. 10. The design of the beams tested in fatigue.

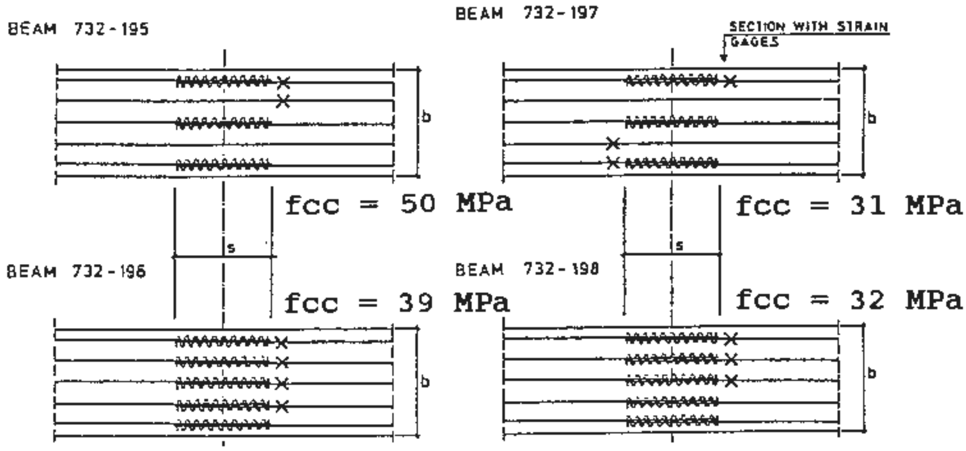

FIG. 11. The location of fatigue failures for the tensile bars are marked with x.

FIG. 12. Tensile face of beam 732-198 after fatigue failure of tensile reinforcement outside the unaffected central lapped section.

5. TESTS ON BEAMS WITH CONTINUOUSLY SPLICED REINFORCEMENT

The splice tests described above were situated in a part of the beam where the flexural moment was constant, and they were thus loaded uniformly along their entire length. It is of interest to know the behaviour of the splice construction in every part of the beam, i.e. also in parts of the beam subjected to shear. Beams 732-173 and 732-174 were designed for combined pulsating and static load test and for pulsating load test, respectively. The beams had two tensile reinforcing bars, one of which was continuously spliced along the beam and the other one continuously spliced along half the beam length only. The design of the beams is shown in FIGS. 13 and 14. The beam 732-173 had concrete strength fcc = 30 MPa (in joint fcc = 27 MPa) and the beam 732-174 fcc = 36 MPa. The reinforcement, the construction of the beams and the appearence of the beams after failure are presented in FIGS. 15 to 19.

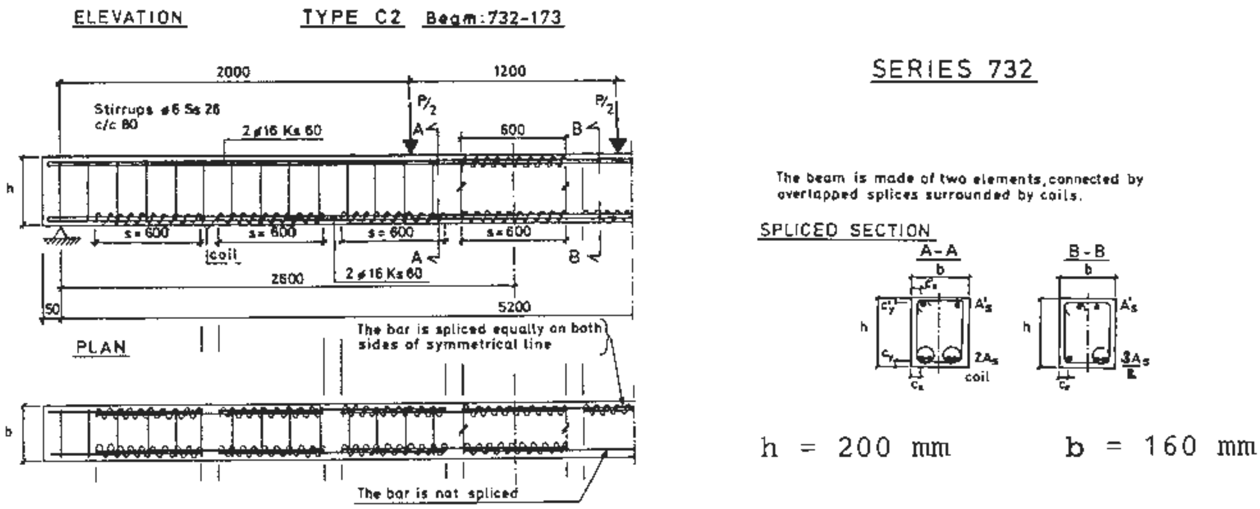

FIG. 13. Design of beam 732-173.

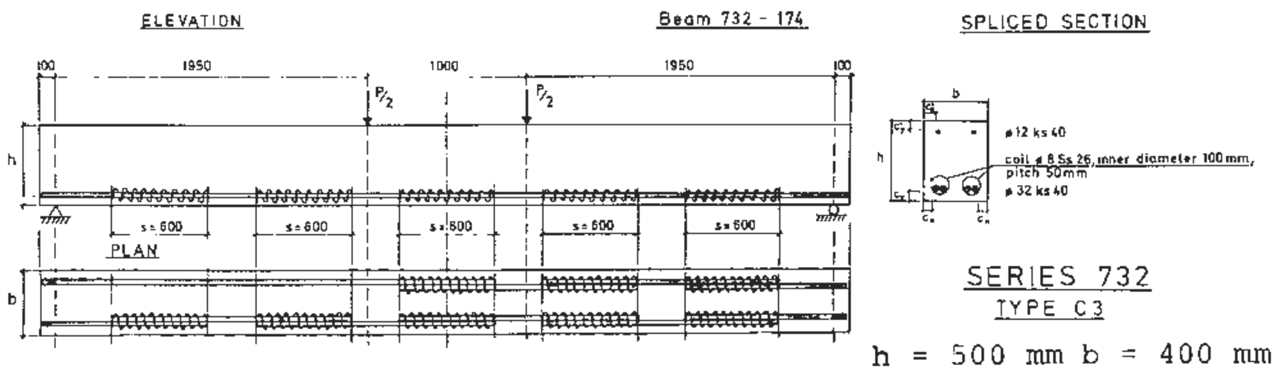

FIG. 14 Design of beam 732-174.

FIG. 15. Tensile reinforcement in the two beam elements in beam 732-173.

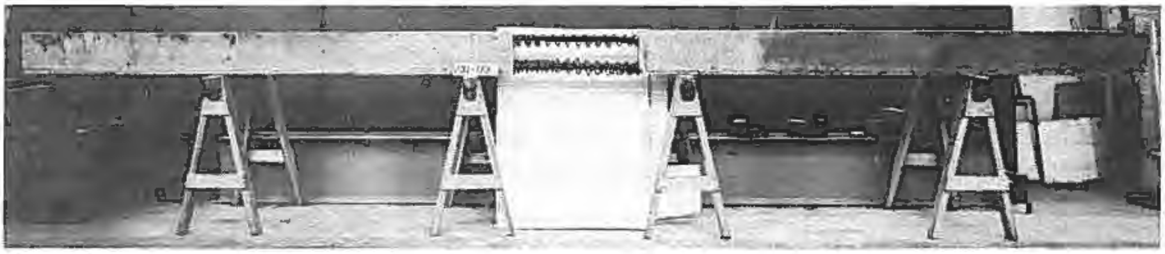

FIG. 16. Beam 732-173. The two elements before casting of the joint in the middle of the beam.

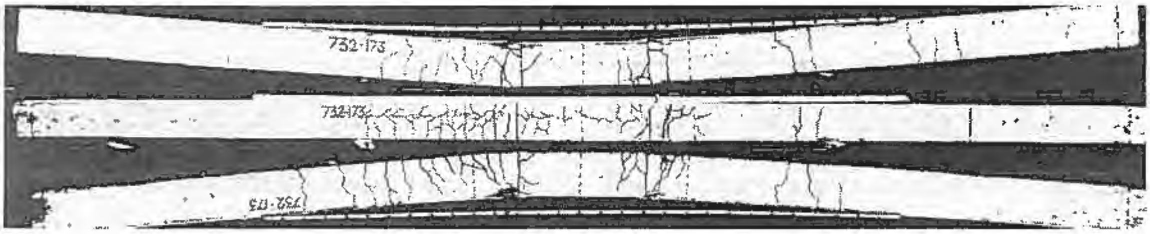

FIG. 17. The beam 732-173 after yielding of the tensile reinforcement and failure in the compressive zone close to the middle of the beam. The tension face of the beam is shown in the middle.

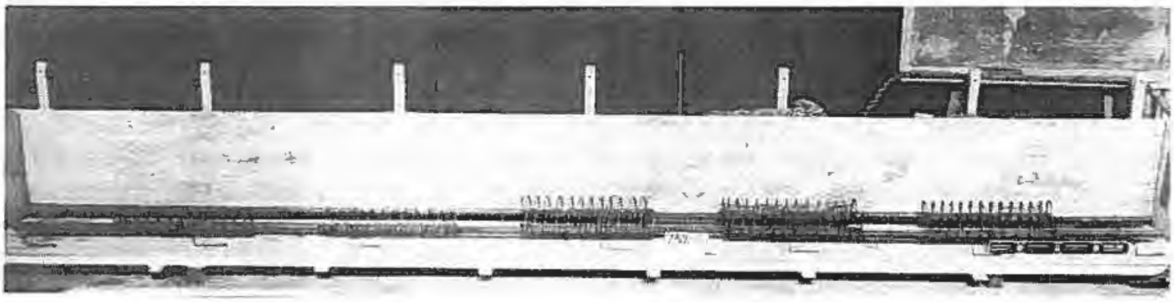

FIG. 18. Tensile reinforcement in beam 732-174.

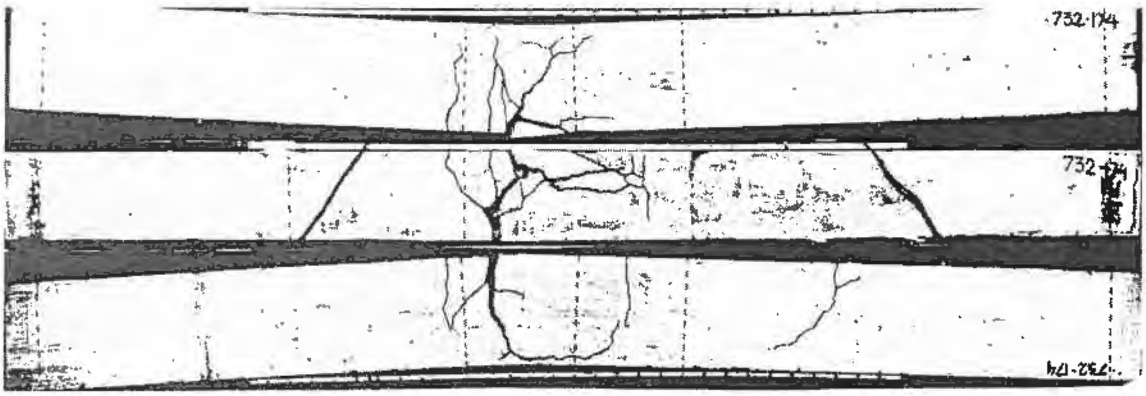

FIG. 19. Beam 732-174 after fatigue failure of one bar of the tensile reinforcement. The middle splice of the second bar is destroyed after yielding of this bar by the pulsating load after the failure of the first bar. The tension face of the beam is shown in the middle.

The splices at the middle sections of the beams where the flexural load is constant were earlier analysed according to the theory in [1] and satisfied the expectations, which were yielding of the tensile reinforcement without failure of the splice for beam 732-173 and fatigue of the tensile reinforcement prior to failure of the splice for beam 732-174.

The beam 732-173 was loaded by pulsating load 50.669 load cycles without failure occuring. The tensile reinforcement maximum stress was 332 MPa and minimum stress 49 MPa. Then the beam was loaded by monotonic load to failure. In beam 732-173 the maximum anchored tensile stress in the spliced reinforcement was as high as 727 MPa, higher than the yield stress fsy = 692 MPa, without failure of the splices. Failure of the beam was due to a secondary failure in the compressive zone.

The beam 732-174 was loaded by pulsating load. The tensile reinforcement maximum stress was 221 MPa, minimum stress 47 MPa and the yield stress fsy = 420 MPa. The beam sustained 1.326.570 load cycles. The cause of failure was fatigue of tensile reinforcement just outside the spliced section.

According to the theoretical analysis for pulsating loads, [1], for both beams the two splices had a higher fatigue strength than the tensile reinforcement.

The other tensile reinforcement splices in parts of the beams which were subjected to shear functioned completely satisfactorily and showed no damage at any stage of the tests. Only in beam 732-173, when the yielding of the tensile reinforcement had spread out from the middle of the beam, did the neighbouring splices show very pronounced cover cracking, FIG. 17. It is obvious that the splice tests and analysis of the splices at the mid sections of the beams loaded by constant moment represent the most serious loading case. Splices subjected to a changing flexural load along their length can be analysed on the basis of the highest moment, with the associated tensile stress in the spliced reinforcement, at one end of the splice, this moment being assumed to act along the entire length of the splice. This way of analysis will then compensate for the additional bond stresses in parts of the beam subjected to shear.

6. CONCLUSIONS

The object of the investigation was to suggest a simple splice design which is capable to anchor at least the yield stress of the steel under static load and which has a higher fatigue strength than that of the tensile reinforcement. Such spiral confined splices can be designed using the theory presented in [1].

Based upon this investigation spiral confined splices with the following parameters are suggested for use anywhere where it is necessary to splice a tensile reinforcing bar in a concrete structure:

Concrete compressive strength $f_{cc} = 20$ MPa
Splice length $s = 600$ mm
Concrete cover $c = 1,5 \cdot Ø$
Spiral pitch $a = 50$ mm
Inner diameter of spiral D and bar diameter $Ø_{st}$:
- for spliced bars $12 < Ø < 16$ mm, D = 50 mm, $Ø_{st} = 6$ mm.
- for spliced bars $16 < Ø < 25$ mm, D = 80 mm, $Ø_{st} = 8$ mm.
- for spliced bars $25 < Ø < 32$ mm, D = 100 mm, $Ø_{st} = 8$ mm.

These splice constructions can be used for both Swedish standard grades of reinforcing steel Ks 400 and Ks 600, although the dimension $Ø = 32$ mm only for the grade Ks 400. The length of the spiral will determine the splice length. When bars have to be spliced, the only thing to do is to thread the lapped bars through the spiral. These splices can be placed on the building site at any point in a structure where this is necessary. One factor which limits the use of this splice construction is lack of space for the spirals and difficulties in casting the concrete when the reinforcement becomes dense. Another factor is that the spliced section becomes stronger due to increased amount of tensile reinforcement, which might change the moment redistribution in comparison with that obtained in design with the theory of plasticity without a lap splice. The shear resistance of the member might then become the load capacity limiting factor.

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