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Implications of Exposure of Main Steel during Patch Repairs

Sollicitations d'une armature principale mise à nu lors de réparations locales

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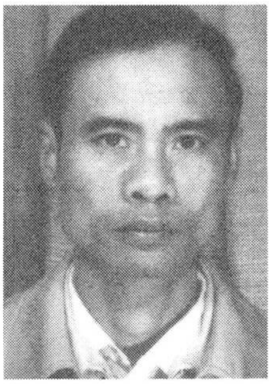

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SUMMARY

Results are reported for an extensive series of experimental works on 132 reinforced concrete beams in which loss of cover and exposure of the reinforcement in the course of the patch repair process has been simulated by forming recesses in the concrete elements. Both small and large scale beams with various extents of exposed reinforcement have been tested covering a range of structural parameters including percentage of tensile reinforcement, extent of removal of steel/concrete bond, distance of damage from the support, load position(s) relative to the support, depth of concrete removal, proportion of nominal top steel (in beams unreinforced in shear), effect of including shear reinforcement in the form of stirrups, and loading arrangement.

RÉSUMÉ

L'article rapporte les résultats d'une vaste série d'essais sur 132 poutres en béton armé. Une perte d'enrobage et une mise à nu des armatures pouvant se produire lors de réparations locales ont été simulées par formation de niches dans les éléments en béton. Des poutres à petite et grande échelles et avec des niches de différentes tailles ont été testées. Les paramètres structuraux comme le pourcentage d'armature passive, l'importance de la perte d'adhérence acier/béton, la distance du dommage aux appuis, la position de la charge par rapport aux mêmes appuis, la profondeur des niches, la proportion nominale d'armature supérieure (poutres sans armature d'effort tranchant), l'effet d'un renforcement de la résistance à l'effort tranchant par ajout d'étriers et la distribution de la charge ont également été variés.

1. INTRODUCTION

The previous limited literature as regards the loss of strength in reinforced concrete beams due to removal of concrete/steel bond for patch repairs was reviewed elsewhere [1]; it was concluded that there was a need for a systematic series of tests which covered a much wider range of parameters than those previously examined with particular emphasis on cases when the exposed steel area is located near the supports where loss of strength can be more critical.

Very briefly, although there is currently extensive literature on the causes of chemical attack and their effects on concrete and steel reinforcement on a material level and also on the means of reducing or eliminating such decays, there is very little available literature on the structural implications of, for example, removal of concrete/steel bond during the patch repair process. The aim of the present paper is to report details of an extensive series of tests (covering a wide range of design parameters) on, both, small and large scale reinforced concrete beams in which the main steel reinforcement is exposed by varying extents.

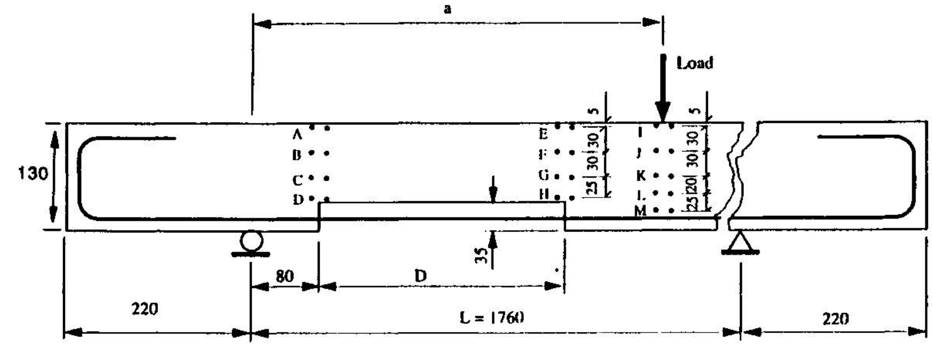

Fig. 1
Details of the small scale beams

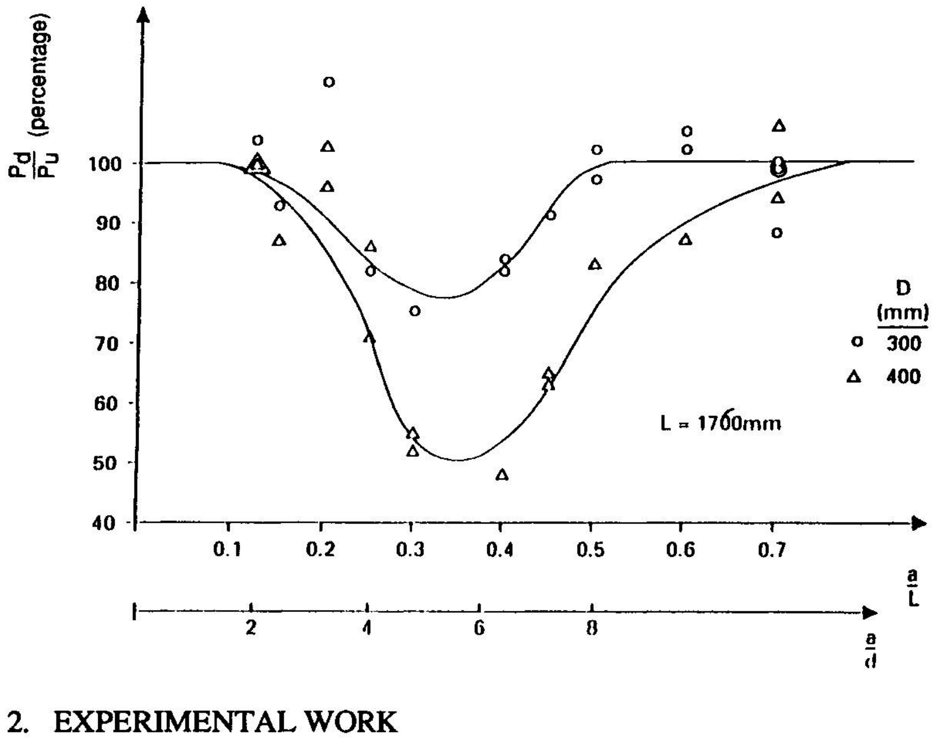

Fig. 2
Variation of the loss of strength with changes in the position of the single point load for two values of D = 300 and 400mm - small scale tests.

2. EXPERIMENTAL WORK

2.1 Small Scale Tests with No Shear Reinforcement

In these series of tests forty-four simply supported beams were tested in eleven sets of four. Each set consisted of one undamaged (i.e. control) beam and three beams in which the cover was omitted and the reinforcement exposed over a variable length near one end. Fig. 1 gives the beam details and the loading arrangement: all the beams were simply reinforced for bending and unreinforced in shear.

Fig. 2 presents plots of the loss of strength, P_d/P_u, where P_d = ultimate strength of damaged beam, and P_u = ultimate strength of undamaged beam in the same batch, against the parameters a/L and a/d (representing the load position), where d = effective depth, for two lengths of imposed damage, D = 300 and 400mm. It is concluded that as the extent of damage is enlarged, the loss of strength increases. The loss of strength, however, is also controlled by the load position: the latter appears to have a greater effect than the extent of damage, on the loss of strength. It is rather alarming that the percentage decrease in strength in Fig. 2, rises to values as large as 20 and 50 percent for extents of removal of concrete/steel bond D = 300 and 400mm, respectively. Space limitations do not permit a full description of the results (and indeed a full discussion): these are fully covered elsewhere [1].

2.2 Large Scale Tests with No Shear Reinforcement

In the next phase of the experimental programme, a total number of eighty-eight large scale beams were tested following a similar testing procedure to that adopted for the small scale beams, but covering a much wider number of potentially important parameters: these included variations in the loading position, a/L, percentage of tensile steel reinforcements, A_s/bd, extent of loss of cover and bond, D, relative position of the damaged section from the support, x, depth of removal of concrete, h, effect of including nominal top steel (in the absence of stirrups), loading arrangement, and finally the effects of including shear reinforcement in the form of stirrups. The large scale beams had overall dimensions of 150 x 300mm with an overall length of 3500mm. They were all tested as simply supported beams with a clear span of 3000mm under single (or two) point loading whose position(s) varied from beam to beam. In most cases, each batch of large scale beams consisted of one undamaged (control) beam and three beams in which the cover and bond to main steel reinforcement was removed over a variable length, D. Three levels of D, namely, 300, 600 and 900mm were investigated.

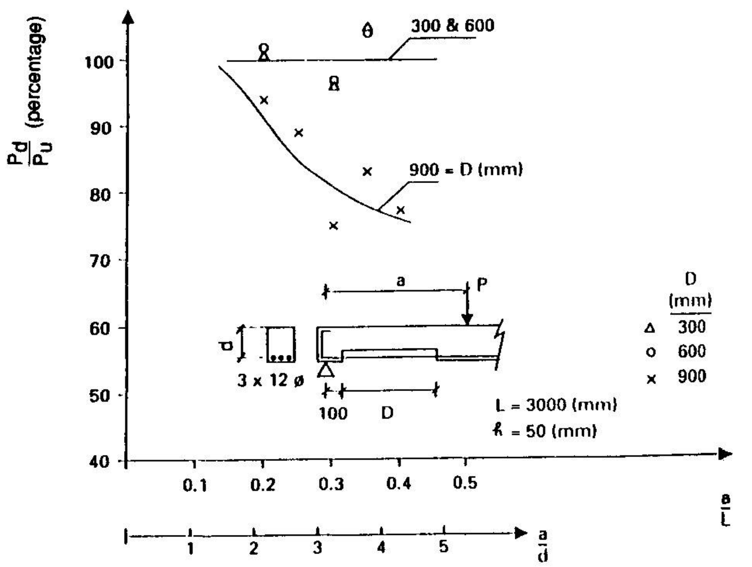

Fig. 3
Variation of the loss of strength with changes in the position of the single point load for three values of D = 300, 600 and 900mm - large scale tests.

Fig. 3 shows plots of residual strength, P_d/P_u, against the parameter, a/d (or a/L) (defining position of the load), for a number of beams under single point loading with three different extents of removal of concrete cover and bond, D. The other parameters were kept nominally constant. The beams had no shear and/or top reinforcement. The plots in Fig. 3 show no loss of strength for values of D = 300 and 600mm, over the wide range of 2 < a/d < 4. Only for D = 900mm some loss of strength with a value of 23% at a/d = 3.23 is found. The question then arises as to what has caused such a drastic change of behaviour between small and large scale beams with the results for the small beams, Fig. 2, giving much higher levels of loss of strength. Test data presented in Fig. 4 provide the necessary clue and support the suggestion that rather significant reductions in the magnitude of the residual strength, P_d/P_u, can occur with increasing levels of the percentage of tensile steel. Here, values of measured P_d/P_u are plotted against the percentage of steel in the range 0.75% < A_s/bd < 1.2% with the other parameters kept nominally constant. Test data in Fig. 4 suggest that increases in the percentage of tensile reinforcement can lead to substantial increases in the percentage loss of strength. Noting that the percentage of tensile reinforcement in small-scale beams of Fig. 2, and large scale beams of Fig. 3, were A_s/bd = 1.61% and 0.75%, respectively, it is concluded that the much larger values of loss of strength in small scale beams (c.f. larger ones) has been mainly due to their significantly higher percentage of tensile reinforcement, with the relative values of h = 35 and 50mm in small and large scale beams, respectively, playing a role.

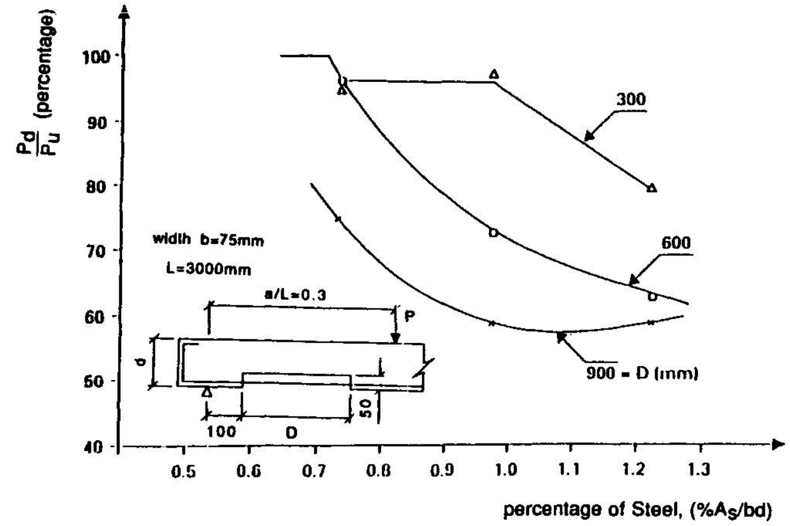

Fig. 4
Variation of the loss of strength with changes in the percentage of tensile steel for D = 300, 600 and 900mm - large scale tests.

The effect of varying the depth of removal of concrete cover, h, on the percentage loss of strength, P_d/P_u, is shown in Fig. 5. All the data in Fig. 5 were obtained for beams with x = 100mm, a/d = 3.23 (or a/L = 0.3) and A_s/bd = 1%. From data in Fig. 5 it is concluded that for the beams tested, the parameter P_d/P_u is only mildly sensitive to changes of h below 40mm. Values of h greater than 40mm are found to lead to sudden reductions in the measured values of residual strength with the reductions being more severe for increasing levels of the extent of damage, D. As mentioned previously, from plots in Fig. 5, there appears to be a threshold value of h above which (depending on concrete strength) substantial reductions in strength can occur. The value of h = 28mm in Fig. 5 corresponds to a nominal 1mm gap between the steel and concrete simulating total loss of bond. In, for example, spalling conditions, it appears that even in extreme cases of total loss of bond there may be no significant adverse effect on ultimate strength. This observation may prove of value to those interested in the assessment of corrosion damaged structures where partial bond may still exist.

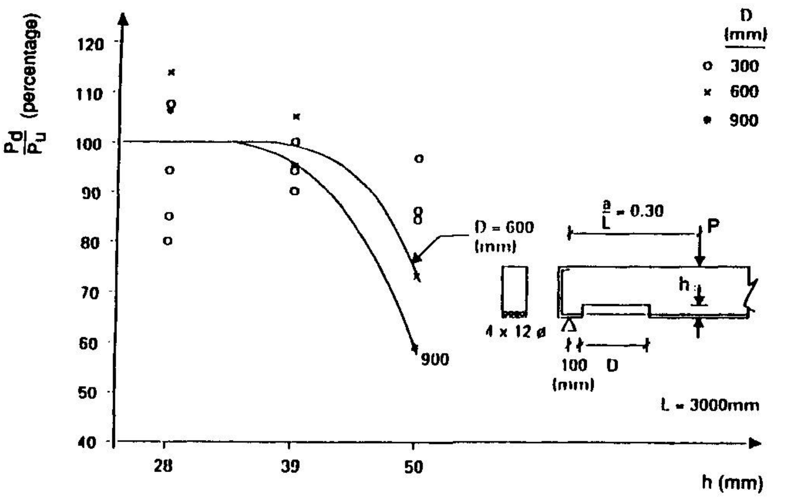

Fig. 5
Effect of varying the depth of removal of concrete cover, h, on the percentage loss of strength in large scale tests for D = 300, 600 and 900mm.

Fig. 6 shows the variation of P_d/P_u with the parameter, x, which defines the location of the region of exposed reinforcement (recess) from the simply supported end. Results in Fig. 6 suggest that, keeping other parameters constant, the closer the region of exposed reinforcement is to the support, the higher will be the magnitude of the loss of strength.

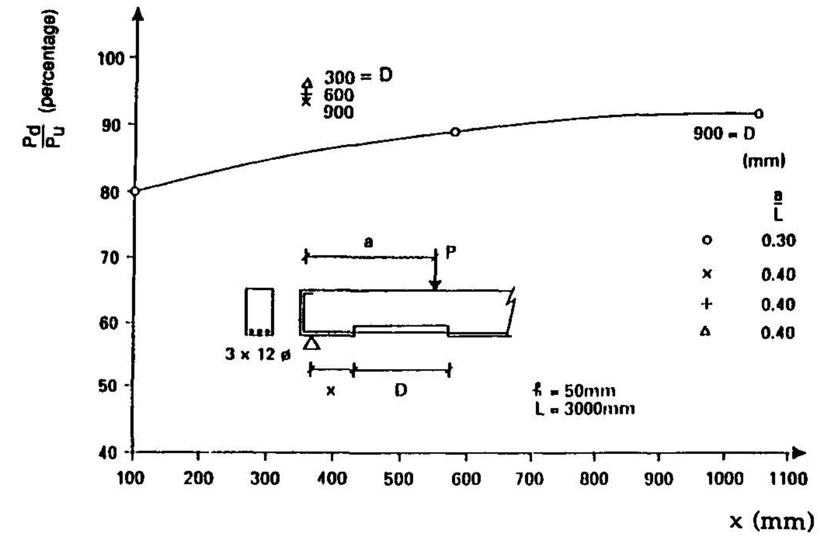

Fig. 6
Variation of the percentage loss of strength with the location of the simulated damage area (recess) with respect to the simply supported end, x, for D = 900mm - large scale tests.

2.3 Large Scale Tests with No Shear Reinforcement but with Nominal Top Steel

The measured patterns of direct strains over the depth of both the small and large scale beams whose results are presented in Figs. 2-6, suggested that the concrete at certain locations along the beams is in tension above the so-called Neutral Surface and in compression below it over, for example, section A-B-C-D in Fig. 1. Furthermore, a number of beams exhibited a tensile crack running vertically downwards from the top surface which was located in the vicinity of section A-B-C-D in Fig. 1.

A series of tests were carried out with nominal top steel placed in the beams. All the beams had h = 50mm, x = 100mm with four 12mm diameter main reinforcing bars. Only the extent of exposed main reinforcement, D, and diameter of top nominal steel was changed from test to test. In all cases, the number of nominal top steel bars was two with their diameter changing from 6-10mm in equal increments of 2mm. Such small diameter bars are similar to those used in practice for holding stirrups in place with their contribution to the structural behaviour of beams with no exposed reinforcement invariably ignored in design. The beams were all tested under single point loading with a load position a = 900mm (or a/d = 3.23). It is most interesting that in all cases the measured residual strength was found to be raised very substantially with certain beams giving P_d/P_u = 143% or 137% (once top steel was included). Reinforcing the top surface of beams with exposed main reinforcement was, therefore, found to be beneficial (in terms of raising the ultimate strength of damaged beams by some substantial margins). Variations of the diameters of the top steel bars within the range 6-10mm was not found to make any significant difference in terms of the measured P_d/P_u ratios. It must be noted that although inclusion of nominal top steel was found to virtually remove any loss of strength due to loss of concrete cover and bond (at least under single point loading), certain beams with exposed main steel exhibited brittle failure with others failing in a ductile fashion.

The discussions in the preceding sections have solely addressed the case of single point loading on simply supported beams. Fig. 7 shows a plot of the residual strength, P_d/P_u , versus load position for the case of simply supported beams (with no top steel and/or shear reinforcement) experiencing two-point loading. Full details of the corresponding test results are given in Ref. [1] where residual strengths as low as 52% were recorded with all the damaged beams failing in a brittle fashion.

A further series of two-point loading tests were carried out (with a/d = 4.30) on beams with D = 900mm, h = 50mm, x = 100mm and four 12mm diameter main tensile bars. Top steel was included in beams whose corresponding residual strength in the absence of top steel was $P_d/P_u \approx 53\%$: full set of test data is given in Ref. [1]. Out of the four beams tested one had no nominal top steel with the other three beams each having two nominal top bars with diameters of 6, 8 and 10mm. It was most interesting to note the increases in strength of 177%, 185% and 149% (c.f. to the beam with no top steel) for the three beams which had nominal top steel. It should, however, be noted that none of the beams exhibited a ductile mode of failure.

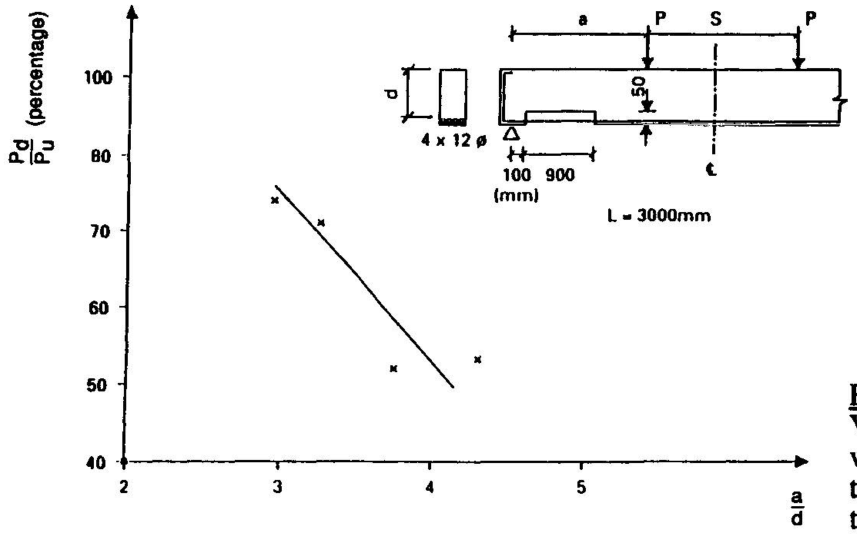

Fig. 7
Variation of the loss of strength with changes in the position of two-point loadings - large scale tests.

2.4 Large Scale Tests with Shear Reinforcement

Ref.[1] also presents a full set of test results for 8 simply supported beams with nominal top steel and also stirrups, tested under two-point loading. Four loading positions S = 200, 600, 900 and 1200mm, (where S is defined in Fig. 7), were chosen and for each load position, one control beam and one beam with exposed main reinforcement over a distance of 900mm was tested, with h = 50mm, x = 100mm, and four 12mm diameter tensile bars. No significant loss of strength (due to removal of concrete cover and bond) was found in all cases. The observed failure mode in all cases was ductile. A detailed examination of the test results suggested that in terms of reducing the strength loss, the nominal top steel (such as those which are invariably used for holding stirrups in place) has the major influence as compared to the stirrups themselves. Over the range of test parameters used, the loss of strength for all beams containing both nominal top steel and stirrups was minimal. The presence of stirrups was, however, found to ensure occurrence of ductile failure as opposed to certain cases of brittle failures in connection with beams which had nominal top steel and no stirrups.

3. CONCLUSIONS

Results from a number of small and large scale tests on reinforced concrete beams are reported which cover a wide range of potentially important parameters in terms of the structural performance of an RC member weakened by removal of concrete and steel/concrete bond.

Increasing the percentage of tensile steel (in the absence of stirrups and nominal top steel) has been found to increase the observed percentage losses of strength. Moreover, the ultimate loads of beams with exposed reinforcement were found to change dramatically by using nominal top steel, the introduction of which was found to reduce the strength loss. Tests showed that, in terms of ultimate strength, the nominal top steel (such as those which are invariably used for holding stirrups in place) was having the major influence as compared to stirrups. However, presence of stirrups was found to cause a ductile failure in beams which even in the presence of nominal top steel exhibited a brittle failure. Over the range of test parameters used, the loss of strength for all beams containing both nominal top steel and stirrups was minimal.

REFERENCES

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