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Beams Strengthened by Epoxy Bonded Steel Plates

Poutres en béton armé renforcées par des plaques en acier collées à l'époxy

Verstärkung von Stahlbetonbalken mit epoxygeklebten Stahllamellen

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SUMMARY

This paper describes the initial stages of a long-term investigation of the durability of reinforced concrete beams strengthened by epoxy bonded steel plates. Details of accelerated test programmes, using freeze-thaw and salt spray environments, and long term exposure tests are given. Some initial results are presented.

RÉSUMÉ

Cet article décrit les premières étapes d'une recherche à long terme sur la durabilité de poutres en béton armé renforcées par des plaques en acier collées à l'époxy. Le détail des programmes des essais accélérés utilisant les méthodes de gel-dégel et de vaporisation salée, et des essais d'exposition des poutres aux conditions atmosphériques à long terme sont présentés. Des résultats préliminaires sont donnés.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt das Anfangsstadium einer langfristigen Untersuchung über die Widerstandsfähigkeit armierter Betonbalken, die mit epoxygeklebten Stahlplatten verstärkt sind. Die Einzelheiten der beschleunigten Testprogramme, mit Gefrier- und Auftauzyklen und Salzspray-Umgebung, sind dargelegt. Die Langzeit-Bewitterungsversuche an Balken unter atmosphärischen Bedingungen sind ebenfalls gegeben. Erste Resultate werden vorgestellt.

1. INTRODUCTION

1.1 Background

The use of externally bonded steel plates is now established as a useful and economical method of stiffening and strengthening existing concrete structures. The plates are normally bonded to the concrete members by means of an epoxy resin adhesive. A range of applications of the technique to buildings and bridges has been summarised by Mays [1]. A considerable amount of research has been carried out in order to investigate the behaviour of plated beams under short term loading and to establish design criteria. The anchorage zone at the ends of the plates has been shown to play a critical role in determining the failure load. This has been investigated by Swamy and Jones et al [2, 3].

1.2 Durability Considerations

Only a relatively small amount of research work has been directed at determining the long term behaviour of strengthened beams. An on-going programme of long term exposure tests on beams of various sizes has been described by Calder [4]. It was reported that there was evidence of corrosion and some loss of bond area after ten years of exposure in an industrial environment but the load capacity of the beams was not significantly affected. This may be because the design of the specimens and their loading arrangement is such that the plate anchorage zones are restrained by the beam supports.

The long term performance and durability of epoxy bonded plated beams may be investigated at three levels:-

(i) the material level
(ii) the composite joint level
(iii) the engineering level i.e. considering the full composite structural system.

Mays, Vardy and Hutchinson [1, 5] have considered the requirements for adhesives in civil engineering applications and have devised tests at level (i). The investigation described herein is concerned with levels (ii) and (iii). Bridges and other exposed structures may be subjected to freeze-thaw cycles and the action of salt spray. The investigation therefore includes accelerated durability testing using small specimens in a freeze-thaw cabinet and a salt spray cabinet. In addition a programme of long term exposure tests on both small and large specimens is being carried out to assess the creep behaviour under long term loading and the effects of natural weathering. This paper describes the test arrangements and presents some initial results from the programme, which is still in progress.

2. TEST SPECIMENS

2.1 External Exposure Tests

Two sizes of beams are being used, as shown in Figure 1(a) and (b). The beams have been designed so that anchorage zone failure, rather than yielding of the steel plate, is likely to be critical. Two different epoxy resins have been used to bond the plates. Most of the beams were plated in the unloaded condition but two pairs of the 2500mm long and two pairs of the 1000mm long beams were plated whilst they were under a sustained load equal to 50% of the load capacity of the unplated beams. This meant that the concrete in the tension zones of these beams was cracked when the plates were applied. Unplated beams of each size are being used to provide a basis for comparison.

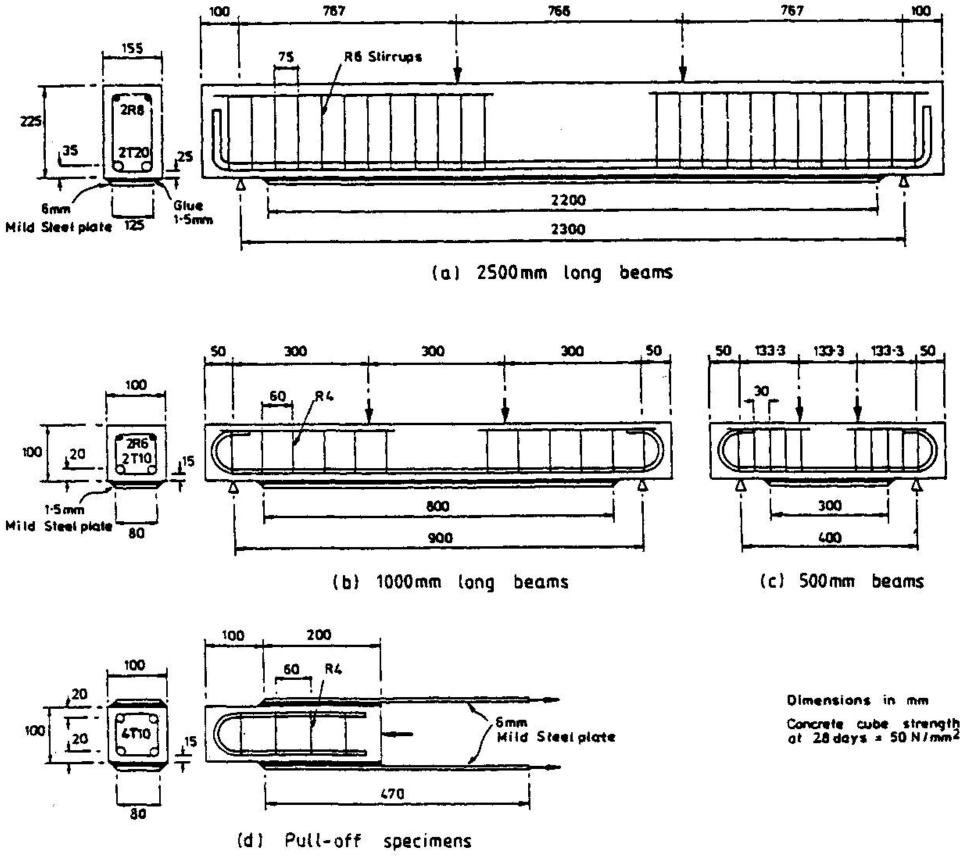

Fig. 1 Details of Test Specimens

2.2 Accelerated Tests

Smaller beams are being used for these tests so that they can be accommodated in the freeze-thaw and salt spray cabinets. These are shown in Figure 1(c). In addition, the pull-off specimens shown in Figure 1(d) have been designed to simulate the conditions in the anchorage zones of the plated beams. The same two epoxy resins have been used in these specimens as were used in the larger beams in the external exposure programme. In addition, the influence of different forms of preparation of the steel plates is being investigated by including specimens in which the plates were primed before the resin was applied and in which zinc grit blasting was used as an alternative to the normal grit blasting surface preparation.

3. TEST PROGRAMMES

3.1 External Exposure Tests

These beam tests are summarised in Table 1. Duplicate sets of long term beams are being used so that the effects of two exposure periods may be investigated. It is initially planned to use periods of 5 years and 10 years, but these may be revised as data is accumulated. One set of beams will be returned to the laboratory and load tested at the end of each period. The long term control beams are being permanently stored in the laboratory.

BEAM TYPE		LONG TERM EXTERNAL EXPOSURE				LONG TERM CONTROL		SHORT TERM CONTROL	
		LOADED		UNLOADED		LOADED	UNLOADED		
		2500mm	1000mm	2500mm	1000mm	1000mm	1000mm	2500mm	1000mm
Plated	Resin 1	2 No.	2 No.	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
	Resin 2	2 No.	2 No.	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
Cracked and Plated	Resin 1	2 No.	2 No.	-	-	-	-	1 No.	1 No.
	Resin 2	2 No.	2 No.	-	-	-	-	1 No.	1 No.
Unplated		2 No.	2 No.	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.

Table 1 External Exposure Test Programme

The loaded beams are supported in pairs in purpose designed loading rigs and the unloaded beams are stored on racks. The overall layout of the exposure site is shown in Figure 2. The loaded beams were loaded to 50% of the load capacity of an unplated beam, as determined from the short term control tests. Strains at the midspan cross-sections of all beams are monitored at intervals using demountable mechanical gauges. The ambient temperature at which readings are taken is also recorded. At approximately 8 to 9 months after the initial loading the loads on the beams were checked, and were found to have reduced by 15% to 20%. The rigs were re-loaded to their original loads and this checking and re-loading procedure will be repeated at intervals throughout the test programme.

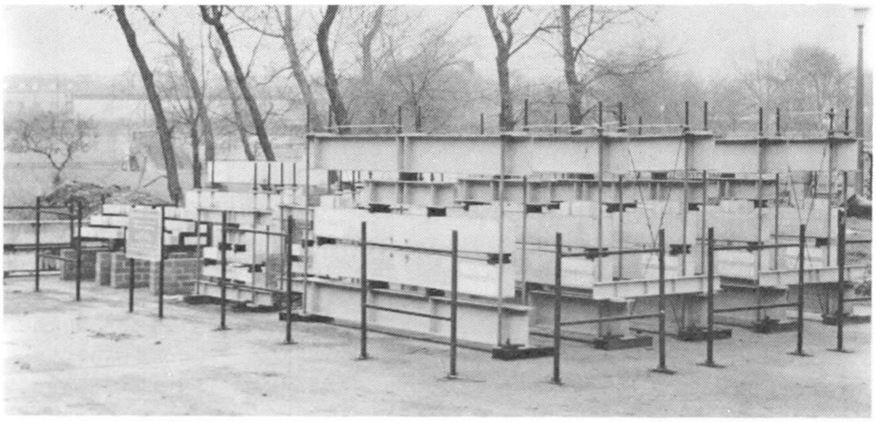

Fig. 2 External Exposure Site

3.2 Accelerated Tests

The numbers of specimens used in this test programme are shown in Table 2. Again, duplicate sets of specimens have been constructed to enable two exposure durations to be used for each type of test. The salt spray specimens will be subjected to 500 and 1000 cycles and the freeze-thaw specimens to 100 and 200 cycles.

Demountable mechanical gauges are used to monitor permanent changes in strain and relative movement between the plates and the concrete in the freeze-thaw specimens. Additional dummy specimens with thermocouples embedded at various

BEAM TYPE		ACCELERATED EXPOSURE				SHORT TERM CONTROL	
		FREEZE/THAW		SALT SPRAY			
		500mm	P.O.S.	500mm	P.O.S.	500mm	P.O.S.
Plated	Resin 1	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
	Resin 2	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
	Resin 2 + ZINC grit	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
	Resin 2 + primer	2 No.	2 No.	2 No.	2 No.	1 No.	1 No.
Unplated		2 No.	-	2 No.	-	1 No.	-

P.O.S. = Pull-off specimen

Table 2 Accelerated Test Programme

depths below the surface are being used to monitor the time-temperature relations and the temperature gradients within the concrete. At the end of each accelerated exposure period, the specimens will be removed from the cabinets, visually examined and load tested. Short term control specimens are used to give a basis for assessing the effect of the exposure type and period on the structural performance of the specimens.

4. RESULTS TO DATE

4.1 External Exposure Tests

Typical strain data for the compression face of a loaded plated beam are presented in Figure 3. The readings taken on the companion unloaded beam are used to determine the strain due to shrinkage and moisture movement. All the data is corrected to a standard temperature of 15°C. This calculated thermal strain and the corrected shrinkage and moisture movement strain are plotted in the figure.

A comparison between the strain data for an unplated beam, a beam that was plated in its unloaded condition and a beam that was plated in the loaded, pre-cracked condition is shown in Figure 4. The data will be corrected to allow

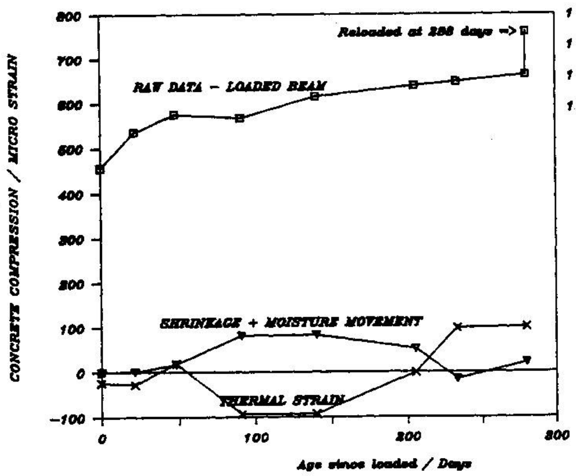

Fig. 3 Strain Data for Plated Beam

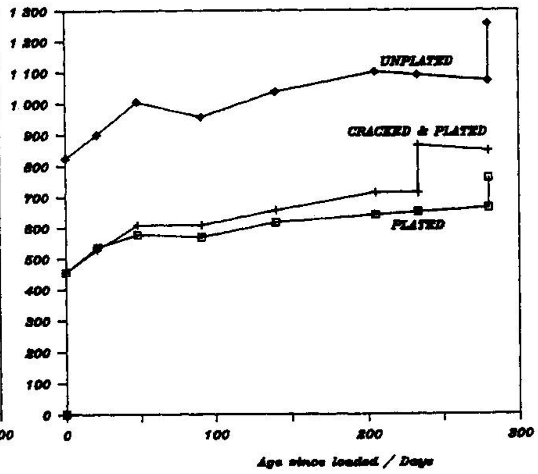

Fig. 4 Comparison of Three Beams

for the loss in load with time once long term strains after further re-loading to the original load level are available. The lower initial elastic strains on loading of the plated beams reflect their increased stiffness when compared with the unplated beam. The additional creep strains are, however, similar up to this stage.

4.2 Accelerated Tests

The initial periods of testing in the salt spray and freeze-thaw environments have yet to be completed, so no load test data is yet available. Visual inspection of the salt-spray specimens after 450 cycles revealed some evidence of surface deterioration of the steel plates, producing rust staining of the concrete. Strains in the freeze thaw specimens after 75 cycles indicate a net expansion of less than 50 microstrain. There is no measurable differential movement between the plates and the concrete.

5. CONCLUSIONS

These initial results indicate that the creep behaviour of plated beams is similar to that of unplated beams. This tentative conclusion remains to be confirmed as longer term data is obtained. The accelerated test programmes indicate that plated beams are able to survive 450 cycles of salt spray and 75 cycles of freeze-thaw action without serious apparent deterioration. The actual effect on anchorage bond strength remains to be established.

6. ACKNOWLEDGEMENTS

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