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O'FLAHERTY, Fin and MANGAT, Pal

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Performance of High Stiffness Concrete Repairs over a Five Year Period

F.J. O'FLAHERTY
Senior Lecturer
Sheffield Hallam University
Sheffield, England
f.j.oflaherty@shu.ac.uk

His main research interests are in the field of maintenance and repair of reinforced concrete infrastructure. He has numerous publications to date on this topic. He is a Chartered Engineer and a member of the Institution of Engineers of Ireland.

P.S. MANGAT
Professor
Sheffield Hallam University
Sheffield, England
p.s.mangat@shu.ac.uk

He has published extensively in the fields of fibre reinforced concrete, performance of reinforced concrete repair and marine durability of reinforced concrete. He is member of ACI and RILEM (as chairman) technical committees. He is a Chartered Engineer and member of the ICE and IStructE.

Summary

The paper presents results of field monitoring of repair patches in a reinforced concrete highway structure over a period of five years. The repair patches were applied by spraying (guniting) repair materials to unpropped compression members. The strains in the repair patches were monitored with vibrating wire strain gauges. The performance of three different repair materials was investigated whose elastic modulus was greater than that of the substrate concrete ($E_{rm} > E_{sub}$).

The results show that efficient repairs are achieved with $E_{rm} > E_{sub}$ with the optimum ratio approximately 1.3. This allows the repair material to shed a significant portion of shrinkage strain to the substrate concrete (0-11 weeks after application) and subsequently attract external load from the parent concrete (25-47 weeks) with virtually negligible redistribution thereafter. Thus, if the repair patch remains crack free within the critical shrinkage period (0-11 weeks), the repair material will perform satisfactorily in the longer term. Conversely, a cracked repair material presents further problems to the bridge engineer. Emphasis must therefore be placed on producing durable load-sharing repairs through the specification process prior to repair.

Keywords: concrete repair materials, elastic modulus, shrinkage, creep, long term performance.

1 Introduction

Over the past number of years, the interaction between spray applied patch repairs and the substrate concrete from unpropped compression members (abutments and piers) has received considerable attention from the authors [1, 2, 3]. Publications to date have concentrated on the distribution of strain within the repair patch throughout the first year after application of repair and provides recommendations for optimal repair based on these findings. The aim of this paper is to present data obtained over a five year period to determine if the recommendations based on short term performance also lead to satisfactory performance in the longer term.

Lawns Lane Bridge (carrying part of the M1 motorway in West Yorkshire, UK) was repaired with three spray applied repair materials, labelled L4, L3 and L2 and with $E_{rm} > E_{sub}$, Table 1. The distribution of strain was monitored using vibrating wire strain gauges. One gauge was attached to the cut-back substrate concrete (labelled 'subs'), one welded to the steel reinforcement ('steel') and one embedded in the repair material ('emb') as shown in the section through repair in Fig. 1. Detailed information on the repair materials, technique and monitoring equipment can be found elsewhere [1, 2].

Table 1 Basic properties of repair materials and substrate concrete

Material	Elastic Modulus (kN/mm^2)	100 day free shrinkage^{a,b} (µstrain)	70 day compressive creep^{b,c} (µstrain)	Compressive strength, f_{cu} (N/mm^2)
L4	29.1	238	510	60.0
L3	27.4	210	748	35.0
L2	30.3	136	774	60.0
substrate	23.8	-	-	34.1

[a] correction factors have been applied to relate laboratory shrinkage to field shrinkage
[b] stored at 20ºC, 55%RH
[c] 30% stress/strength

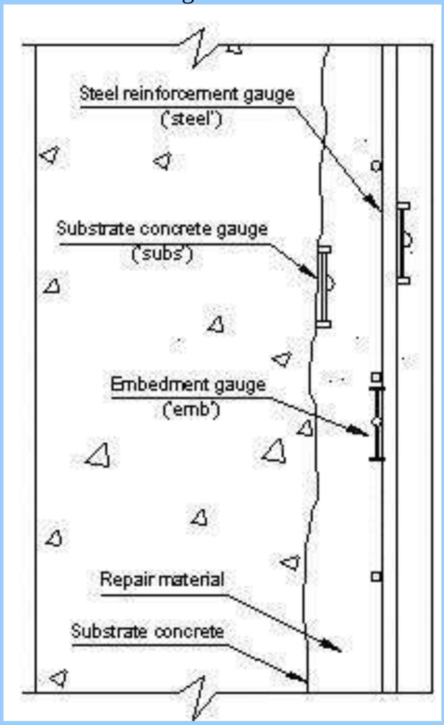

Fig. 1 Section through repair

2 Results and Discussion

2.1 One year strain data (period 0 to 60 weeks)

Fig. 2 shows the strains from the gauges between weeks 0 to 60 for material L4 [1]. Datum readings were taken 24 hours after the application of repair (week 0 on the graph). Referring to Fig. 2, the strain in the substrate concrete ('subs') increases rapidly during approximately the first 11 weeks after application of the repair material. The substrate concrete strain then remains relatively constant between approximately week 11 and week 25. After 25 weeks, an increase in strain is again observed in the substrate concrete until approximately week 47 (see Fig. 2). From approximately week 47 onwards, the strain in the substrate concrete remains relatively constant until the end of the monitoring period (week 60, Fig. 2). The strain in the steel reinforcement ('steel') and repair material ('emb') are also presented within this period (week 0 to week 60, Fig. 2) and shows a fairly similar pattern to the strain in the substrate concrete (Fig. 2). However, the magnitude of strain is lower. The redistribution of strain throughout the first 60 weeks after application was similar for the other repair materials (L2 and L3) and is presented in more detail elsewhere [1].

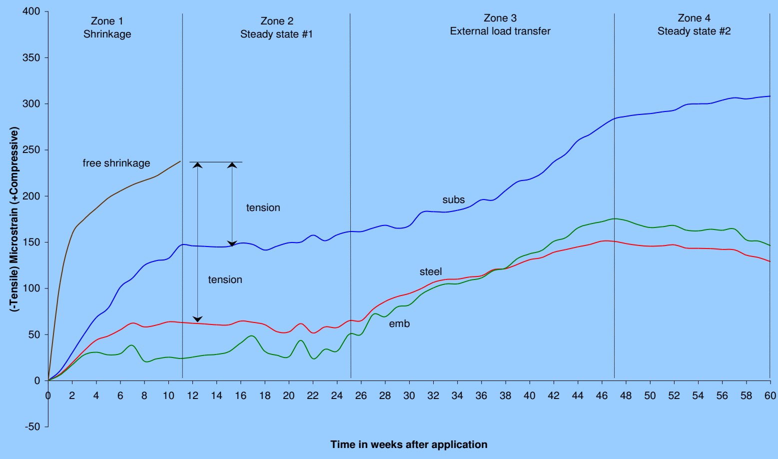

Fig. 2 Strain data from repair material L4 over a 60 week period

2.2 Period 0 - 25 weeks

The spray applied materials have elastic modulii which are greater than the elastic modulii of the substrate concrete (Table 1). When the stiffer repair materials exhibit shortening due to shrinkage (Table 1), compressive strain is transferred into the less stiff substrate, which results in the high compressive strain in the substrate concrete, see Fig. 2, weeks 0 to 11. This occurs after the repair material has hardened and attained its full elastic modulus (i.e. the repair material becomes stiffer than the substrate concrete). It was reported elsewhere [4] that on average, 96% of the 28 day elastic modulus of a repair material is achieved at 21 days. The measured strains between weeks 1-3 in Fig. 2 are linearly interpolated since the automatic logging device was not installed until approximately 4 weeks after the application of the repair patch. Compressive strain is also transferred to the steel reinforcement during this period, but is less than the strain transferred to the substrate concrete due to a higher stiffness. There will be a virtual tensile strain in the repair material which is caused by the restraint to shrinkage provided by the substrate concrete and the steel reinforcement. This tension will be equivalent to the free shrinkage strain of the repair material (see free shrinkage curve, Fig. 2) minus the compressive strain measured by the interfacial strain gauge ('subs') and the steel reinforcement gauge ('steel') respectively, Fig. 2. The virtual tensile strain is greater at the steel reinforcement/repair material interface due to the greater shrinkage restraint provided by the relatively much stiffer reinforcement. In the case of the substrate concrete/repair material interface, the elastic modulus of the substrate concrete is marginally lower than that of the repair material (Table 1). The large surface area of contact, however, assists with the strain transfer from repair material to substrate concrete. The rate of the substrate strain increase in the first 11 weeks (zone 1, Fig. 2) is steep after which it reaches a stable state when shrinkage in the repair material has reached negligible levels. This stable period lasts from approximately week 11 to week 25 (zone 2, Fig. 2).

2.3 Period 25 - 60 weeks

The next stage of redistribution of strain occurs from approximately week 25 to week 47 (zone 3, Fig. 2). The compressive strain increases in the repair material (‘emb’ gauge) and consequently, due to strain compatibility, in the steel reinforcement (‘steel’ gauge) as externally applied load is attracted into the relatively stiffer repair material from the substrate concrete. The transfer of external load from the substrate concrete to the repair patch does not decrease the strain in the substrate concrete but in fact increases the compressive strain, see Fig. 2, weeks 25 to 47, zone 3. This is due to the restraint provided by the interfacial bond between the substrate concrete and stiffer repair material which helps to maintain strain compatibility. The transfer of the external compression from the substrate concrete may ultimately neutralise the tensile stress in the repair material caused by the restraint to shrinkage (which is reduced to some extent by stress relaxation due to tensile creep). Thereafter, the strain from weeks 47 to 60 (zone 4, Fig. 2) remains relatively constant as the transfer of external load from the substrate concrete has ceased.

Consequently, the distribution of strain can be idealised into distinct zones as shown in Fig. 2 for materials with $E_{rm} > E_{sub}$, namely, Zone 1, shrinkage; Zone 2, steady state #1, Zone 3, external load transfer, Zone 4, steady state #2 [1].

3 Five year strain data (period 1-5 years)

Figs. 3 to 5 show the distribution of strain in the repair patches of material L4, L3 and L2 over an extended monitoring period of 5 years. The distribution of strain as influenced by the repair material/substrate concrete properties for the first year after application has already been discussed in Sections 2.2 and 2.3. Referring to Figs. 3 to 5, the strain in the steel reinforcement ('steel') and repair material ('emb') exhibit a smooth sinusoidal appearance from year 1 onwards but do not show a significant increase in the strain within this period. The strain profile in the substrate concrete in the same figures again exhibit a smooth sinusoidal appearance but the strain is seen to increase slightly. Referring to Fig. 3, years 1 to 5, the time between the peaks (or troughs) in the strain profiles (substrate concrete, steel reinforcement and repair material) is approximately one year. Variations along the strain profile within this period (1-5 years) is therefore due to external influences and is not influenced by material properties - the peak in the strain profiles at week 100 in Fig. 3 coincides with a summer temperature whereas the trough at week 126 (6 months later) coincides with a winter temperature. A peak in the strain profiles is again observed at week 152 (a further 6 months). However, the slight net increase in strain in the substrate concrete between years 1 to 5 in Figs. 3 to 5 is approximately 60 microstrain compared with a strain of up to 300 microstrain being developed in the first year after application. Consequently, it confirms that most of the redistribution of strain as influenced by material properties occurs within the first year after application of repair and the longer term strains largely remains unaffected.

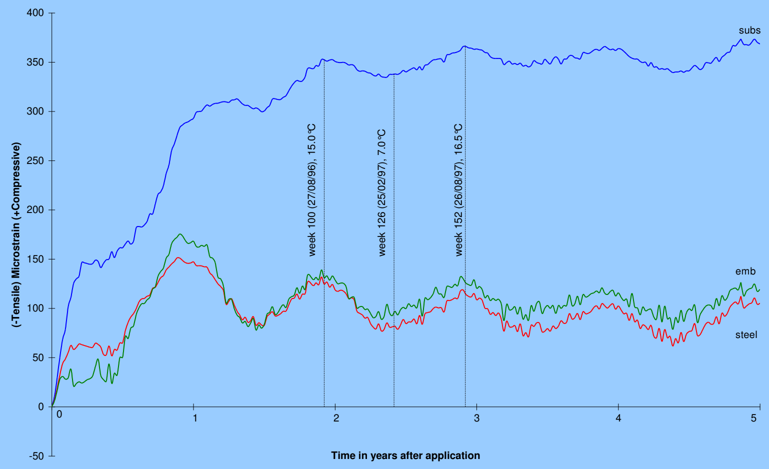

Fig. 3 Five year strain data from repair material L4

Fig. 4 Five year strain data from repair material L3

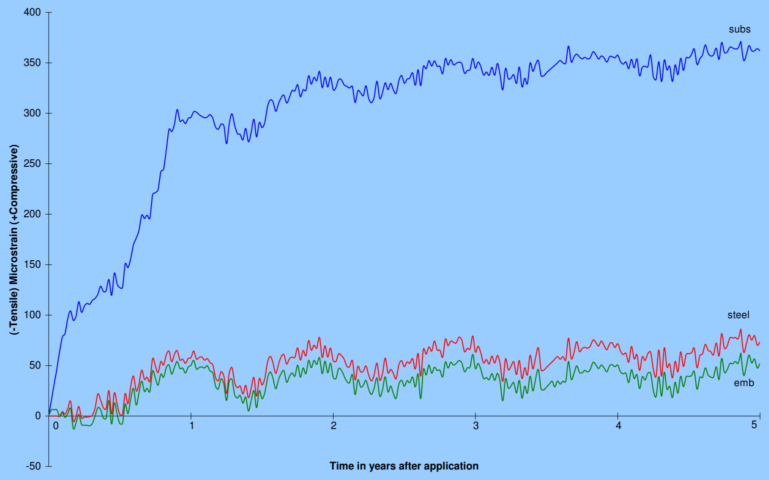

Fig. 5 Five year strain data from repair material L2

4 Serviceability performance of repair

The repair materials represented in Figs. 3 to 5 performed well under service conditions in the initial (1 year) monitoring period despite the fact that they did not comply with the Highways Agency repair standard [5] at the time of application. Compliance with the standard included criteria such as limitations to the maximum aggregate size and type of fibre to be included in the mixture. The characteristic strength of the repair material is also specified (e.g. 40 N/mm^2 for sprayed concrete). However, the primary properties considered when selecting repair materials L4, L3 and L2 were the elastic modulus, shrinkage and creep. Referring to Table 1, the elastic modulus and compressive strength is given for repair materials L4, L3 and L2. The stiffer repair materials in Figs. 3 to 5 were able to transfer a portion of the shrinkage to the substrate concrete which reduced the risk of cracking and also attracted external stress into the repair patch to reduce/neutralise the residual tensile stress in the repair patch. On the other hand, the compressive strength of material L3 is 35 N/mm^2, which is less than the requirement of 40 N/mm^2 as specified in the repair standard [5]. Nevertheless, this material performed well under service conditions. The fact that the three non-standard materials performed satisfactorily indicates that the key properties required for satisfactory long term performance are the elastic modulus, shrinkage and creep of the repair material. These properties should, therefore, be the most important criteria for design of patch repair. The authors have recommended acceptance values for these properties elsewhere [6] for inclusion in the European Standard for concrete repair [7]. Further information on the design process for concrete patch repairs can be found elsewhere [8].

5 Conclusions

The following conclusions are based on the results of the 5 years in-service monitoring carried out on repairs which were applied to Lawns Lane Bridge:

- Four stages (or zones) of distribution of strain are evident in spray applied repairs to unpropped compression members:
  - (i) shrinkage stage (zone 1, weeks 0 to 11)
  - (ii) steady state #1 (zone 2, weeks 11 to 25)
  - (ii) external load transfer (zone 3, weeks 25 to 47)
  - (iv) steady state #2 (zone 4, week 47 onwards)
- Most of the strain redistribution takes place in the first year after repair application (zone 1, shrinkage strain transfer and zone 3, external load transfer)
- Satisfactory long term (5 year) performance is dependant upon the repair material remaining crack-free within zone 1, the shrinkage transfer stage
- Fluctuations in the strain profiles in the repair patch (years 1 to 5) are influenced by seasonal (climatic) variations and not by basic repair material properties

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7 References

[1] Mangat, P.S. and O’Flaherty, F.J., "Long-term performance of high stiffness repairs in highway structures", Magazine of Concrete Research, 1999, 51, No. 5, October, pp. 325-339.

[2] Mangat, P.S. and O’Flaherty, F.J., "Influence of elastic modulus on stress redistribution and cracking in repair patches", Cement and Concrete Research, 30 (2000), pp. 125-136.

[3] Mangat, P.S. and O'Flaherty, F.J., Keynote paper, "Long-term performance criteria for concrete repair materials", Proc. International Congress, Creating with Concrete, Concrete Durability and Repair Technology, University of Dundee, 6-10 September, 1999, Thomas Telford, London, pp.381-393.

[4] Pinelle, D.J., "Curing stresses in polymer modified repair mortars", Cement, Concrete and Aggregates, CCAGDP, Vol. 17, No. 2, Dec. 1995, pp. 195-200.

[5] Department of Transport, "Materials for the repair of concrete highway structures", BD 27/86.

[6] O'Flaherty, F.J. and Mangat, P.S., "Recommendations for the European Prestandard for concrete repair", Proc. RILEM 2nd International Workshop on Life Prediction and Aging Management of Concrete Structures, 5-6 May 2003, Paris, France, RILEM Publications S.A.R.L., ISBN 2-912143-36-5, pp. 237-245.

[7] British Standard Institution, Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation and conformity, DD ENV 1504-1997.

[8] Mangat, P.S. and O’Flaherty, F.J., "Analysis of interfacial shrinkage stresses in patch repairs" accepted for publication in the Magazine of Concrete Research, May 2003