Severe Cracking of Viaduct Piers and Pilecaps due to Delayed Ettringite Formation

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Summary

Damage due to Delayed Ettringite Formation (DEF) can be severe, and can compromise the structural adequacy of an existing structure. This paper illustrates the severity of problems that can occur, outlines the diagnosis of DEF and the assessment of structures affected by DEF, and discusses some issues related to potential remedial works schemes.

Keywords: Ettringite; DEF; insitu; concrete; cracking; diagnosis; monitoring; assessment; remedial.

1. Introduction

Severe cracking was found to be developing in a Malaysian viaduct within two years of the viaduct being built and opened to traffic. The viaduct concerned carries a dual carriageway on two post-tensioned box girders, which are typically supported on T shaped piers - as shown in Figure 1.

The features of the viaduct that are considered to have led to the occurrence of DEF include the use of high cement contents, large structural sections and unrestricted curing temperatures, in a hot wet environment.

2. Structural Monitoring

As part of the investigations into the causes of cracking, Halcrow instigated monitoring of crack widths and reinforcement strains on several of the most severely cracked crossheads. The results provided clear evidence that the crossheads were expanding, with crack opening occurring at rates of up to 2.5mm/year, and with reinforcement exhibiting clear signs of yielding, associated with local strain rates of up to 12,000 microstrain/year or 1.2%/year, as shown in Figure 2.

Fig. 1: Viaduct in Kuala Lumpur, Malaysia

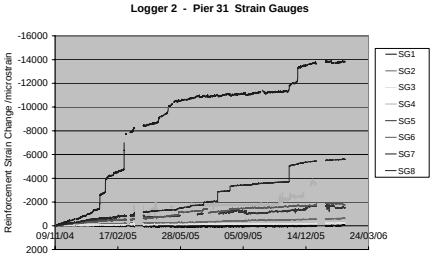

Fig. 2: Reinforcement strain change results

https://doi.org/10.2749/222137908796292489

3. Delayed Ettringite Formation (DEF)

Delayed Ettringite Formation involves the formation of ettringite crystals within the hardened concrete matrix, after the initial curing period.

As ettringite crystals are formed by an expansive reaction, when this reaction occurs after the concrete has hardened, it will tend to lead to expansion and cracking of the concrete.

4. Modelling and Assessment of the Effects of DEF

The nature of DEF expansion is unusual since the centre of a concrete section is trying to expand relative to the outer regions and the reinforcement. As a result it was found that this situation could not be analysed using existing proprietary section analysis software. For this reason the section behaviour was modelled from first principles using a series of linked spreadsheets.

In addition to modelling the effects of DEF from first principles, the effects of DEF were also modelled using 3D non-linear finite element analysis, which was undertaken under the direction of Professor Bicanic of Glasgow University. This analysis reproduced the pattern of cracking that had been observed in the crossheads, and also confirmed that extensive reinforcement yielding would occur with ongoing DEF expansion - as shown in Figure 3.

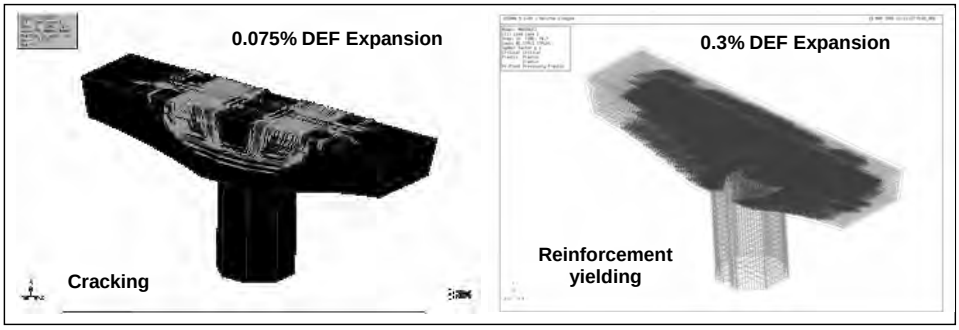

Fig. 3: Results from the non-linear finite element analysis

5. Remedial Works Design

As DEF can cause large expansions in a concrete element, a remedial strengthening scheme should be sufficiently ductile to allow for any ongoing expansion that may occur.

In addition to carrying out any necessary strengthening, if the DEF expansion is to be slowed or stopped, then it is vital to exclude water from the affected elements. The exclusion of water is particularly important as ettringite formation cannot continue without water.

6. Concluding Remarks

DEF has probably been under reported, and could be present in thick elements where the curing temperatures were not controlled, and where those elements are subsequently in a damp environment. Such elements include buried pilecaps, where cracking could go undetected for many years.

DEF induced expansion can cause severe cracking in affected structures, and there could be a risk of sudden collapse occurring if the cause of the cracking is not identified, assessed and managed correctly.

In order to reduce the risk of DEF occurring in new construction, particular attention should be paid to controlling the peak curing temperature of thick elements.