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Transverse fatigue behaviour of lightly reinforced concrete bridge decks

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ABSTRACT

The transverse fatigue behaviour of the top slab of box-girder bridges is dealt with in this paper. The cantilevers and central span of the top slab usually require a small reinforcement ratio and significant slenderness to fulfil the static design requirements. Nevertheless, the application of a high number of load cycles due to traffic or train passages may lead to fatigue damage accumulation. An experimental program on half-scale specimens reproducing the bridge slab was carried out. The fatigue failure was due to brittle fracture of the reinforcement, which could be predicted safely by available S–N curves. Furthermore, the experimental results showed the cycle-dependent reduction of tension stiffening, which was very significant due to the large tension stiffening capacity of lightly reinforced members. Special attention was paid to the development of negative tension stiffening contribution at unloading stages. This effect indicates that permanent and residual cracks and deflections are larger than those calculated with the fully cracked member. The experimental results showed that negative tension stiffening in members manufactured with self-compacting concrete can be larger than those with normally vibrated concrete.

1. Introduction

Many concrete bridges are subjected to a high number of load cycles over the service life. Verifications regarding fatigue safety may be relevant, for example, in railway bridges where repeated dynamic loading leads to fatigue damage accumulation. The fatigue failure mode of reinforced concrete is usually controlled by fatigue of the steel reinforcement, which can be studied by the S–N curves. Even in over-reinforced concrete elements, the different fatigue damage experienced by the concrete along the member depth leads to a process of redistribution of stresses within cross-sections that avoids fatigue failure of concrete and results in fatigue of the reinforcement [1]. The S–N curves for the reinforcement provide the maximum bearable number of cycles of the steel bars as a function of the stress oscillation [2]. Such curves are defined in logarithmic scale and some authors have shown the relevant effect of many parameters (including the appropriate selection of the S–N curve) on the resulting fatigue life of structures such as short-span concrete railway bridges [3] or motorway bridge deck slabs [4]. Adequate fatigue safety of new structures can be achieved by choosing the appropriate S–N curve and performing a detailed stress analysis, but this does not provide information about the influence of repeated loads on the in-service condition of reinforced concrete.

For medium- and long-span bridges, where box or voided slab cross-sections with longitudinal prestressing are generally employed, the attention regarding fatigue safety should focus on the transverse behaviour, rather than that in the longitudinal performance. The top slab of the cross-section usually presents a small reinforcement ratio and significant slenderness of the lateral cantilevers and the central span. In general, such dimensions are enough to fulfil the design requirements, taking into account that train loads are usually applied on the webs (see Fig. 1(a)) and they lead to small transverse forces. Nevertheless, small eccentricities of the traffic load (e.g. due to geometric demands, and considering that train loads are distributed through the ballast under a 45° angle) would result in significant stress oscillations, and therefore fatigue, under the aforementioned conditions (dynamic amplification, low reinforcement ratio and a high number of cycles). Other factors able to produce larger transverse forces are the change of the railway gauge (relevant in countries like Spain) or the substitution of the ballast by slab track and vice versa.

Besides the fatigue failure itself, repeated loading may significantly affect the serviceability of reinforced concrete elements, leading to excessive cracking and deformations. It is well known that lightly reinforced concrete members present a high tension stiffening contribution [5], which means that the relationship between the uncracked and the cracked stiffness is very high. Since tension stiffening is reduced under repeated loading [6–8], it seems interesting to study this effect on the increase of cracks and deflections. In addition, recent studies on the cyclic behaviour of the reinforced concrete tension chord have shown that negative bond stresses develop at the steel–concrete interface between adjacent cracks during the unloading stages, leading to deformations larger

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