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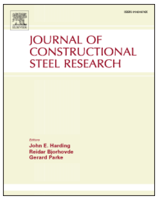

Fatigue in jointless bridge H-piles under axial load and thermal movements

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ABSTRACT

The seasonal and short-term temperature variations produce cyclic horizontal displacements in the continuous superstructure of jointless bridges and hence in the abutment piles. Thorough study of the available field measurement data for jointless bridges showed that the thermal-induced cyclic flexural strains in steel H-piles (SHPs) at the abutments are composed of large, primary small and secondary small flexural strain cycles. While the SHPs at the abutments of jointless bridges laterally deform and experience these cyclic flexural strains due to thermal effects, they also carry axial loads transferred from the superstructure through the abutments. Review of the literature revealed that there is no specific study on the combined effects of axial load and thermal-induced/flexural strain cycles with various amplitudes on the low cycle fatigue (LCF) performance of jointless bridge SHPs. For this purpose, parametric experimental studies on full scale SHP specimens are conducted to simulate the cyclic behavior of SHPs under thermal effects in jointless bridges by considering the effect of axial load combined with large and small flexural strain cycles with various amplitudes. It is observed that at large flexural strain amplitudes, local buckling of the pile due to the effect of axial load adversely affects the LCF life of SHPs at the abutments of jointless bridges. Furthermore, it is observed that the effect of small flexural strain cycles on the LCF life of uncompact SHPs depends on the amplitude of large flexural strains and the amplitude ratio of the small and large flexural strains.

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1. Introduction

Jointless bridges are single or multi-span structures with flexible foundations in which the girders are made monolithic with the abutments. The simplest form of a jointless bridge is a frame structure, but there are also several quite different forms of jointless bridges as well. There is also a design variant called the semi-integral abutment bridge, which is a combination of conventional and jointless bridge. The semi-integral abutment is similar to fully integral abutment, except for a lateral joint forming a rotational hinge above the top of the piles. The most commonly used type of jointless bridge is the one where the abutments are supported by a single row of steel H-Piles (SHPs). SHPs with strong axis or weak axis are widely used to support the abutments of such jointless bridges [1,2]. Although some researchers proposed a pin connection between the abutment and SHPs to reduce the pile moments and provide more flexibility, fixed connection is more commonly used [3]. A typical jointless bridge and pile abutment connection detail is shown in Fig. 1. The seasonal and short term temperature variations at the bridge site produce cyclic horizontal displacements in the continuous superstructure of jointless bridges and hence, in the SHPs at the abutments.

For longer jointless bridges, the temperature-induced bridge elongation or contraction and associated lateral cyclic deformations of the SHPs at the abutments become larger as well. This may produce cyclic yield deformations of the SHPs and associated decrease in the service life of the bridge due to low cycle fatigue (LCF) in the piles. The number of cyclic flexural strains in SHPs produced by temperature variations and their amplitude are key factors that affect the LCF life of the piles. Available field measurement data [4] for jointless bridges indicated that the measured cyclic flexural strains in SHPs at the abutments due to temperature fluctuations at the bridge site consist of large, primary small and secondary small flexural strain cycles.

A number of research studies on the LCF effects in the SHPs of jointless bridges are available in the literature [4–14]. In an earlier research study, Dicleli and Albahisi [4] have formulated the LCF life of SHPs based on a fatigue damage model developed for compact SHP sections and pile strain measurement data available in the literature [5,6,9]. In the aforementioned research study, the effect of axial load was neglected and local buckling of the flanges was not considered as the developed fatigue damage model was intended only for compact

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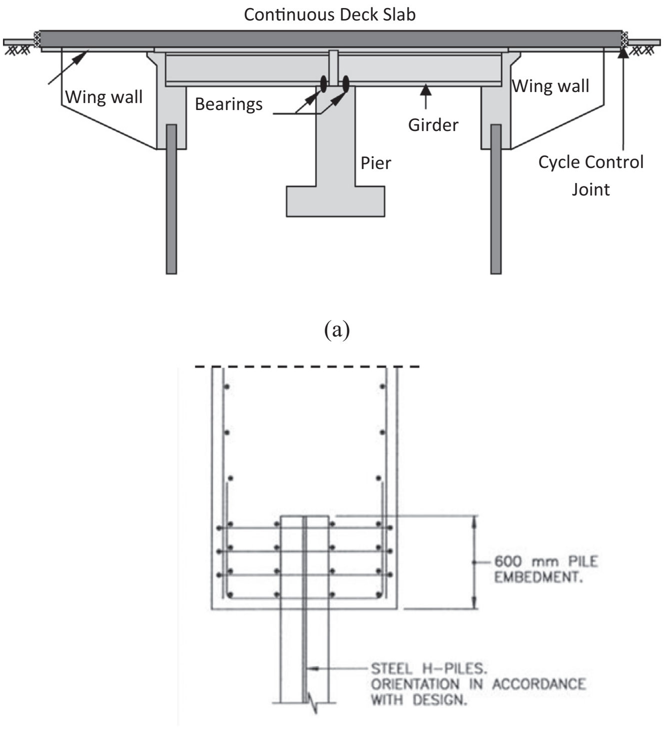
Nomenclature

LCF	low cycle fatigue
SHP	steel H-pile
L_B	length of bridge
L_b	length of the flange-buckling wave
M	fatigue ductility coefficient in Coffin-Manson strain formulation
m	fatigue ductility exponent in Coffin-Manson strain formulation
N_{fL}	number of large amplitude strain cycles to failure
N_{fS}	number of small amplitude strain cycles to failure
n_L	number of large amplitude strain cycles
n_{S1}	number of the primary small amplitude strain cycles
n_{S2}	number of the secondary small amplitude strain cycles
t_f	thickness of the pile flange
α	the coefficient of thermal expansion
β	ratio of small strain amplitude to large strain amplitude
Δ	bridge displacement (expansion or contraction)
Δ_b	amplitude of the flange-buckling wave
ΔT	the temperature difference
ε_a	plastic strain amplitude
ε_{aL}	large amplitude flexural strain
ε_{aS}	small amplitude flexural strain
ε_{LT}	total strain amplitude
Φ	curvature

SHP sections. Thus, the LCF life of uncompact SHPs subjected to axial load may not be predicted using the fatigue damage model presented by Dicleli and Albahisi [4]. Arsoy et al. [7] experimentally investigated the LCF behavior of three pile types (steel H, steel pipe and reinforced concrete) subjected to cyclic thermal induced displacement reversals. The research study revealed that SHPs are more appropriate for jointless bridge construction due their flexibility and ductility capacity. However, the effect of axial load combined with local buckling of flanges of SHPs was not studied in the research of Arsoy et al. [7]. In a recent research study, Karalar and Dicleli [14] have developed a cycle counting method for the thermal induced strain cycles in jointless bridges. From their research study, it was found that the thermal induced flexural strain cycles in the SHPs of jointless bridges are composed of large, primary small and secondary small amplitude strain cycles. The effect of primary small and secondary small flexural strain cycles on the LCF life of SHPs at the abutments of jointless bridges were then investigated and found to be negligible. Other research studies on the SHPs of jointless bridges available in the literature are generally related to the field measurement of the cyclic response of such piles under seasonal thermal fluctuations [5,6,9].

None of these research studies mentioned above provide information on the combined effects of pile axial load together with flexural strain cycles with various amplitudes on the LCF life of SHPs at the abutments of jointless bridges. Accordingly, the main objective of this research study is to investigate the individual and combined effects of axial load, large and primary small flexural strain cycles as a function of the flexural strain amplitude on the LCF life of SHPs at the abutments of jointless bridges. For this purpose, a series of parametric full scale experimental tests are conducted on HP220x57 SHP specimens, where the pile specimens are subjected to; (i) only large flexural strain cycles with various amplitudes, (ii) large flexural strain cycles combined with primary small flexural strain cycles with various amplitudes, (iii) only large flexural strain cycles with various amplitudes in the presence of a typical axial load, (iv) large and primary small flexural strain cycles with various amplitudes in the presence of a typical axial load. In addition, a fracture mechanics approach is used to predict the test results. Furthermore, a detailed nonlinear finite element model of one of the tested pile specimens together with the test set-up is developed. A realistic fatigue damage model suitable for the material of the tested pile is employed in the finite element analyses. The finite element model is used in this study as a verification and prediction tool for the experimental data. A reasonably good agreement was found between the experimental and finite element analyses results. As an outcome of this research study, the effect of various important parameters on the LCF life of SHPs is introduced. Furthermore, experimental data is provided for the assessment of the adequacy of the current design methods in relation to the LCF life of SHPs at the abutments of jointless bridges. Consequently, this research study may form a background for the development of guidelines for the design of SHPs to endure LCF effects throughout the service life of jointless bridges.



(b)

Fig. 1. (a) Typical jointless bridge, (b) pile-abutment connection detail.

2. Effect of temperature variations on steel h-piles at jointless bridge abutments

Construction materials such as steel or concrete are affected by temperature variations causing a structural member made of such materials to change its length. This particular feature of such construction materials is responsible for the elongation and shortening of jointless bridges. The elongation and shortening of the bridge is a cyclic phenomenon that repeats over time due to seasonal and short term temperature variations. The maximum elongation of the bridge superstructure takes place during summer days and the maximum shortening occurs during winter nights. Accordingly, the abutments together with the piles are pushed towards the backfill in the summer season and pulled away in the winter season producing cyclic displacements in the abutment piles in the longitudinal direction of the bridge as shown in Fig. 2. The elongation and shortening of the jointless bridge superstructure produces one large cyclic lateral displacement of SHPs at the abutments each year due to seasonal temperature variations and several smaller cyclic lateral displacements due to short term

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