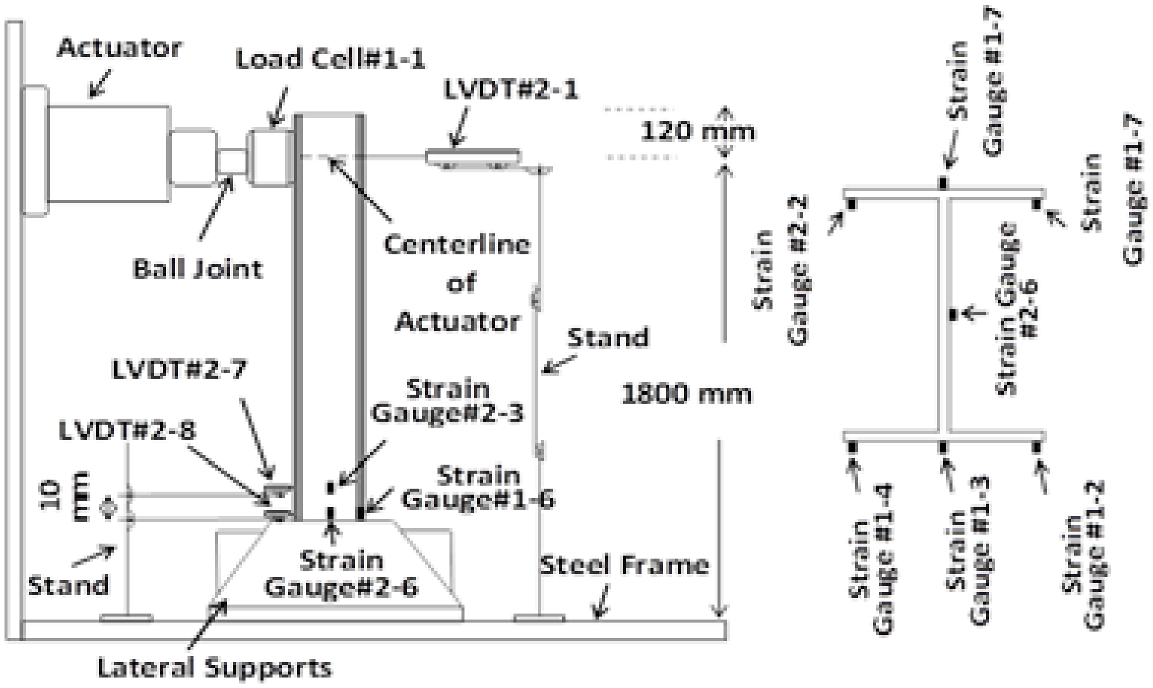
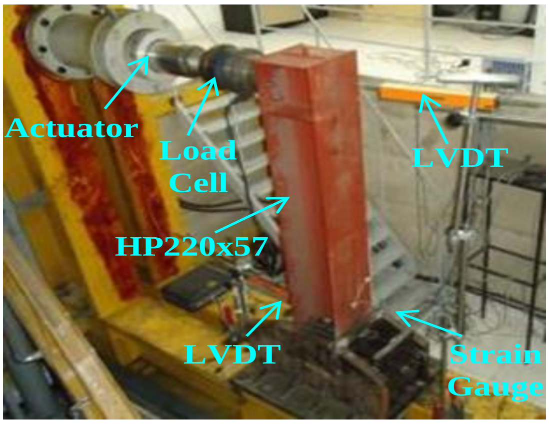
3. TEST SETUP

3.1 Instrumentation and Application of Displacement Controlled Cycles

Three types of measuring devices are used to instrument the steel H-piles as shown in Fig.6. These are, (i) electrical resistant strain gauges for measuring strains on the steel H–piles, (ii) Load cell for measuring the lateral load level and (iii) LVDT (displacement transducer) for measuring the lateral displacement. The pile is instrumented with twelve strain gauges and three displacement transducers. The plan view of the configuration of the strain gauges on the pile cross-section is shown in Fig.6-(a). Strain measurements are required to correlate fatigue life of HP steel section with the cyclic strain amplitudes. Therefore, strain measurement is performed at the critical locations where fatigue failure occurs. Displacements, strains and lateral loads are measured and recorded using a data-logger (TDG-Ai8b). Furthermore, in the test set up, a displacement controlled hydraulic actuator capable of applying ±500 kN lateral load and a stroke of ± 125 mm is used to impose lateral cyclic displacements. A second actuator with a 1000 kN load capacity and capable of keeping the applied load constant is used to exert axial load on the pile specimens (Fig. 6(b)-(c)).



(a)



(b)

(c)

Figure 6. (a) Schematic plot of the test set-up: depicting the location of the strain gauges and LVDT, Photograph of the test set up; (b) without axial load, (c) with axial load

3.2 Material Properties of the Piles Used in the Tests

The HP220x57 piles used in the tests are made of S 320 GP steel according to EN 10204. Standard tensile tests on steel coupons extracted from the HP220x57 section is performed according to American Standards for Testing Materials, (ASTM, 2005). Using the tensile test' results, the average value of the modulus of elasticity of the steel material is determined as 200,000 MPa. In addition, the yield and ultimate tensile strengths are determined as 306 MPa and 421 MPa respectively.

4. LOW CYCLE FATIGUE TESTS AND TEST RESULTS

In this study, three sets of steel HP220x57 pile specimens are tested. The first set of tests (Set #1) is a benchmark test where only large strain cycles with various amplitudes are applied to the pile specimens and the number of cycles to failure are counted. In this set of tests the effect of large strain amplitude on the low cycle fatigue life of steel H-piles is investigated. In the second set of tests (Set #2), consists of piles subjected to large strain cycles in the presence of a typical axial load. The results from this set of tests are compared with those from Set #1 to investigate the effect of axial load on the low cycle fatigue life of steel H-piles. The last set of tests (Set #3) is also performed to investigate the combined effects of large strain cycles, and axial load on the low cycle fatigue life of steel H-piles. In the tests, the amplitude of the large strain cycles is varied while the axial load and the amplitude of large strain cycles are kept constant. The number of cycles to failure are compared with those from, Set #1, Set #2 and Set #3. Detailed discussion of the experimental tests and test results are given in the following sections.

4.1 Set #1: Pile Specimens Subjected to Large Amplitude Strain Cycles

Set #1 tests employ pile specimens subjected to only large strain cycles. In Set #1-a, the piles are subjected to large flexural strain cycles such that a flexural strain equal to five times the yield strain ($\varepsilon_a=5\varepsilon_y$) is developed in the outermost fibers of the flanges in each cycle. This required the application of a cyclic lateral displacement of ±64 mm at the pile top. Fig.7 shows a typical HP220x57 pile specimen under such a cyclic lateral displacement. In Set #1-b however, the piles are subjected to cyclic flexural strains equal to ten times the yield strain ($\varepsilon_a=10\varepsilon_y$) in the outermost fibers of the flanges. This required the application of a cyclic lateral displacement of ±90 mm at the pile top. During the experimental testing of the piles under constant amplitude cyclic strains in Set #1-a and Set#1-b, the fatigue-induced cracks firstly developed in the intersection of the flanges and the web. The cracks then expanded towards the tips of the flanges under further cycling as shown in Fig.8. In the case of Set #1-a tests, the specimens fractured due to low cycle fatigue when the average number of cycles from the test reached 241. In the case of Set #1-b test however, the specimens fractured due to low cycle fatigue when the average number of cycles reached 154. In both set of tests, local buckling occurred in the flanges.

Figure 7. Application of a cyclic lateral displacement at the pile top (a) push, (b) pull direction.

Figure 8. Step-by-step spread of fracture throughout the pile flange.

4.2 Set #2: Pile Specimens Subjected to Large Amplitude Strain Cycles in the Presence of Axial Load

Set #2 tests employ pile specimens subjected to large amplitude strain cycles in the presence of a typical axial load of 170 kN equal to 7.5% of the yield axial strength ($P=0.075P_y$) of the pile specimen as shown in Fig.9. This series of tests consists of two subsets of pile specimens, Set #2-a and Set #2-b. In Set #2-a, the piles are subjected to large flexural strain cycles such that a flexural strain equal to five times the yield strain ($\varepsilon_a=5\varepsilon_y$) is developed in the outermost fibers of the flanges in each cycle.

This required the application of a cyclic lateral displacement of ±62 mm at the pile top. In Set #2-b however, the piles are subjected cyclic flexural strains equal to ten times the yield strain ($\varepsilon_a=10\varepsilon_y$) in the outermost fibers of the flanges. This required the application of a cyclic lateral displacement of ±91 mm at the pile top. The average number of cycles to failure from the pile specimens of Set #2-b are then compared with that from Set #2-a to determine the effect of the amplitude of large strain in the presence of axial load on the low cycle fatigue life of steel H-piles. In the case of Set #2-a tests, the specimens fractured due to low cycle fatigue when the average number of cycles reached 354. In the case of Set #2-b tests however, the specimens fractured due to low cycle fatigue when the average number of cycles reached 94 as shown in Fig.10.

Figure 9. Application of a cyclic lateral displacement at the pile top (a) pull, (b) push direction

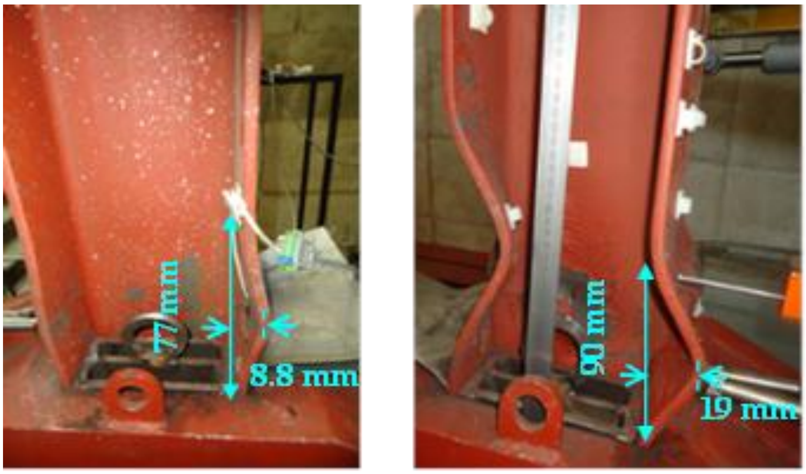


Figure 10. (a) Maximum Strain of $\varepsilon_a=\pm 5\varepsilon_y$, (b) Maximum Strain of $\varepsilon_a=\pm 10\varepsilon_y$.

5. CONCLUSIONS AND RECOMMENDATIONS

This research study provides a new insight into the behavior of integral bridge steel H-piles under seasonal large flexural strain cycles including the effect of axial load on the pile due to the self-weight of the structure. Accordingly, in this research study, individual and combined effects of largel flexural strain cycles and axial load on the low cycle fatigue life of uncompact steel H-piles at the abutments of integral bridges is investigated as a function of the amplitude of large strain cycles associated with seasonal temperature fluctuations. For this purpose, a series of parametric full scale experimental tests are conducted on HP220x57 steel H-pile specimens. It is observed that, as expected, number of cycles to failure is inversely proportional to the strain amplitude. Furthermore, the effect of axial load is observed to have a significant effect on the low cycle fatigue performance of steel H-piles in two ways: (i) when the pile is subjected to moderate strain amplitudes (five times the yield strain), the presence of axial load is observed to enhance the low cycle fatigue life of the pile. This mainly due to the fact that, the presence of axial load decreases the amplitude of the tensile strain that results in cracking of the material (it delays the initiation of the crack), (ii) when the pile is subjected to larger strain amplitudes (10 times the yield strain), the presence of axial load is observed to decrease the low cycle fatigue life of the pile. This is mainly due to local buckling of the flange under the effect of compressive stresses from the axial load and high compressive strains due to the effect of bending. Local buckling increases the local curvature and strains. This locally accelerates the cracking of the material.

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