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The effect of prestress force magnitude and eccentricity on the natural bending frequencies of uncracked prestressed concrete beams

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ABSTRACT

This paper describes the outcome of static 3-point bending testing and output-only experimental modal analysis on 9 post-tensioned concrete beams. Static 3-point bending testing and dynamic impact testing were conducted on each of the 9 beams at different levels of post-tensioning force. The Fast Fourier Transform (FFT) was implemented on the dynamic accelerometer impact data, and the fundamental frequencies of the simply supported post-tensioned concrete beams were determined by a peak-picking algorithm at each post-tensioning load level. The tests were repeated 10 times at each impact location to ensure repeatability of the experiment. There were 3 impact locations per post-tensioning load level, and there were 11 post-tensioning load levels at which the beams were tested. A first-order linear regression model was then applied to the measured fundamental bending frequencies with increasing post-tensioning load. Statistical significance tests were subsequently conducted on the recorded data to determine if any statistically significant changes in fundamental bending frequency with increasing post-tensioning load was observed, for both static and dynamic results. The results obtained for the static 3-point bending tests were then compared and contrasted with the results obtained from dynamic testing. No statistically significant relationship between natural frequency and post-tensioning load level was found for these uncracked concrete beams.

1. Introduction

The prediction of the change in natural vibration frequencies with varying prestress force magnitude for prestressed concrete (PSC) structures is a particularly important problem. It has implications in the field of PSC bridge girders and for post-tensioned concrete wind turbine towers, both of which are structures that are susceptible to extreme dynamic excitation. The effect of applied prestressing force on the dynamic behaviour of pre- and post- tensioned structures is a widely debated topic [1]. Some authors argue that the natural vibration frequencies of PSC structures tend to decrease as the magnitude of the pre-stressing force is increased. This is known as the *"compression-softening"* effect and is based on Euler–Bernoulli beam theory of an externally axially loaded homogeneous beam [2–8]. Others [8–10] suggest that the natural

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frequencies of PSC structures are unaffected by pre-stress force magnitude. This argument has been taken to the fore by Hamed & Frostig [11], who present a nonlinear kinematic model and conclude that the final equation of motion for the vibrating beam system is independent of the prestress force magnitude. Finally, there is also the argument that the NFs of PSC structures tend to increase as the magnitude of the pre-stressing force is increased. This was found to be the case in numerous empirical studies, conducted [12–14]. A satisfactory mathematical model predicting the increase in NFs with increasing pre-stressing force has yet to be formulated, despite some attempts [14,15]. A short review of these models and studies has been outlined in previous works [16]. Prestress force decreases over time due to concrete creep, steel relaxation, anchorage pull-in and other factors. Structural engineers should thus be able to monitor or estimate changes in the natural bending frequency of PSC structures over the course of their design life to ensure their safety and serviceability. As a result, prediction of change in natural frequency of PSC structures over time is of great importance.

The aim of this paper is to report on results of both static and dynamic testing on post-tensioned concrete beams. The purpose of the research is to determine the relationship between post-tensioning force magnitude and fundamental bending frequency for post-tensioned concrete beams.

The novelty of this paper lies in the statistical significance testing of the results. Previous papers report the results for one concrete beam only [17], and others present frequency results for all 9 beams [18], however, this paper presents the results for all 9 concrete beams, including the result of static three-point bending tests, comparison of the static results with dynamic results outlined previously [18], draws conclusions based on the comparisons between the static and dynamic results. This paper also calculates changes in damping ratio with increasing post-tensioning force, and conducts a statistical analysis on the data to determine significance. Lastly, an analysis of the combined effect of post-tensioning force magnitude and eccentricity is also conducted. Numerous other papers have been presented reporting correlation between natural frequency and post-tensioning load magnitude [3,5,12,13,15], but none have reported on the statistical significance of their results. Furthermore, this paper reports on the results of 9 beams, each with a different straight-profiled post-tensioning strand eccentricity, and as such the effect of post-tensioning strand eccentricity on natural bending frequencies of post-tensioned concrete beams is also determined. Finally, the post-tensioned concrete beams tested were verified as uncracked sections, unlike the specimens tested in previous studies [12].

This paper is organised as follows: Section 2 describes the set-up of two experiments in the laboratory. The first experiment is a static 3-point bending tests conducted on 9 post-tensioned concrete beams at different levels of post-tensioning force magnitude. The second experiment is a dynamic impact test, conducted on the same 9 beams, at the same post-tensioning load levels. Section 3 outlines the analysis of the results from both static and dynamic test regimes. Also, it outlines the prediction of the fundamental bending frequency of the beam sections, and describes the extensive signal-processing regime that was designed and implemented for the dynamic signals obtained. Section 4 describes the results of the static and dynamic experiments conducted, and compares the outcomes of both sets of experiments. Section 5 summarises the paper, drawing some significant conclusions and describes future work to be conducted. Appendix A outlines the detailed statistical parameters determining the statistical significance of the data collected and presented in Section 4.

2. Experimental set-up

2.1. Static 3-point bending tests

Three point static bending tests were conducted on post-tensioned concrete beams in the laboratory, as shown in the schematic in Fig. 1. Nine post-tensioned concrete beams were tested statically through three point bending. The 9 beams each had a different straight-profiled post-tensioning strand eccentricity, as outlined in Fig. 4. The beams were placed

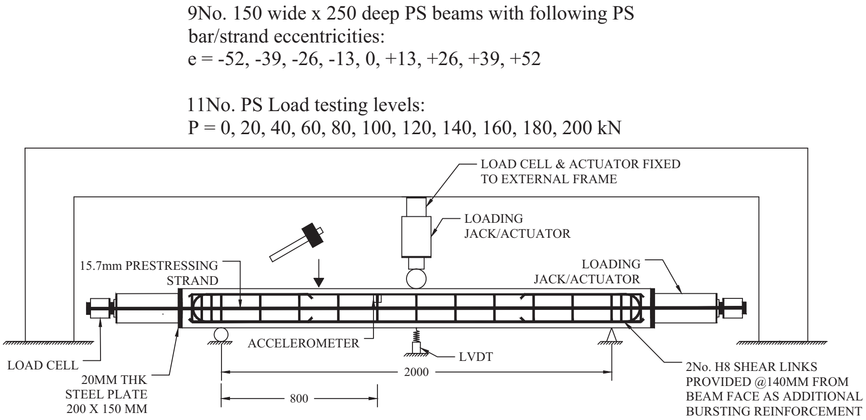

Fig. 1. Experimental set-up.