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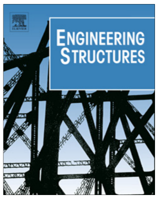

Research of long-term behaviour of non-prestressed precast concrete beams made continuous

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ABSTRACT

Despite the extensive analytical and numerical research carried out in the last two decades on the long-term behaviour of continuous concrete beams composed of precast units, only limited number of experimental data is currently available in the literature. This paper presents an experimental study of the time-dependent behaviour of continuous concrete beams that has been carried out at the University of Belgrade. Two beams were made of precast reinforced elements with cast in situ upper part and continuity joint at middle support. Two cast in place continuous beams of same span and load were also tested. All beams were subjected to equal sustained load for a period over 4 years and deflections, strains and reactions were measured. Experimental program is described and the results are presented. The experiment was also analytically simulated. Analysis of this type of structure should incorporate effects of creep, shrinkage and cracking of concrete.

Simplified procedure that involves the AAEM method and the bilinear approach is proposed for calculation of the restraint moment. Calculated values obtained using measured concrete properties are close to the experimental values. Experimental results presented in the paper offer data for calibration of more complex theoretical procedures.

1. Introduction

Since late 1950s concrete bridges were often built using precast prestressed beams with cast in situ deck slab. The gaps between adjacent spans were provided with the expansion joints that often exhibited functional difficulties. To avoid joints, various techniques for establishing continuous action were developed. At the beginning, the continuity was established using postensioning, since the precast beams were usually prestressed [1]. Various solutions have been developed in the past to provide partial or full continuity, following progress in construction techniques and building equipment. Except for postensioning of end diaphragms, deck slabs or even whole spans after erection, the continuity is often provided using the deck slab reinforcement to resist the negative live load moment. Rods, bolts or dowels may also be embedded into precast beams of the adjoining spans and connected to resist positive moments [2]. This type of bridges, known as ‘continuous for live load’ bridges, is efficient for small to medium spans.

Segmental construction process often includes changes of the cross section and/or support restraints. Redistribution of the internal forces takes place in course of time due to creep, shrinkage and the additional restraints. Calculation of a restraint moment at the continuity joint is essential for the design of continuous for live load bridges. Over the past 50 years a significant number of research studies have been carried out to improve prediction of time-dependent restraint moment, particularly in the North America: [3–10]. PCA method, suitable for hand calculation, was proposed in 1969 [4]. It is based on the experimental research from early 1960s [3]. Forty years after this research had been published, Hastak et al. [11] reported that PCA method was in use in approximately 70% designs in the North America. In late 1980s CTL method [5] was introduced. It was followed by computer program BRIDGERM, and later by RMCalc [9], using the same algorithm. In NHCRP 519 [10] new analytical procedures have been implemented in the computer program RESTRAINT. Results of parametric studies were summarized in several recommendations [10].

Numerous methods for the time-dependent analysis of concrete structures have been proposed in the literature. The AAEM method is frequently used as a simplified method. Simulation of the construction process using AAEM method was investigated by Dilger [12], Ghali et al. [13], Gilbert and Ranzi [14]. Some authors [15–18] advocated modification of the AAEM method using the redistribution function, to account for multiple changes of statical scheme due to construction process. Progress in computational tools has enabled

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non-linear and time-dependent analysis of the reinforced concrete structures. In general, all these methods are based on the selected concrete creep law and the step-by-step integration in time. Such methods use incremental-iterative procedures to predict structural response throughout the elastic, cracked and ultimate load levels. Their implementations are reported by many authors [19–26]. Extended list of papers is provided by Mari et al. [27].

Generally, experimental researches on long-term behaviour were reported far less frequently than analytical studies. Most of the long-term experiments on reinforced concrete beams under sustained load have been performed on simply supported beams [28]. Experiments related to the beams cast in phases or with change of the structural system are rare. Some of them relate to simple span composite (precast–cast in place) beams [12], [29,30].

Experiments on long-term behaviour of continuous beams made by assembling precast elements are reported by Mattock (beams were observed over a period of approximately 2 years) [3], Favre et al. (300 days) [31], Peterman and Ramirez (50 days) [6], Mari and Valdés (500 days) [32], Miller et al. (120 days) [10], Halvonik et al. (330 days) [33]. Gilbert and Bradford reported experimental research of long term (340 days) behaviour of two span continuous steel–concrete composite beams [34]. Time dependant redistribution of the bending moment due to concrete creep and shrinkage has been reported in all these experiments.

Most of the available experiments that involved change of the structural system were on precast–prestressed beams that remained uncracked under the permanent load. Whenever deck slab reinforcement is used for continuity, the continuity region is subjected to cracking. For bridges of small spans, if there is no interest to avoid span cracks, non-prestressed precast beams may be used. In that case, cracking of the precast elements under self weight and weight of cast-in situ slab or construction load may occur. The contractors often use the precast concrete beams to resist these loads in order to accelerate construction works or to fulfil particular demands during execution. Experimental research, presented in this paper, has been carried out at the Faculty of Civil Engineering in Belgrade [35], in order to establish design recommendations concerning long-term behaviour of cracked precast beams.

The major objectives of the experimental program were to obtain laboratory-controlled data for evaluation of an analytical method for treatment of the non-prestressed composite beams that change structural system due to phase construction. Analytical method involves the AAEM method based long-term analysis of composite sections and CEB [36] model for the mean curvatures of cracked regions. A simplified method for prediction of the restraint moment, based on extended application of the bilinear method [36], is also proposed. The results obtained both by the numerical integration of long-term curvatures and the simplified method showed compliance with the experimental data.

2. Experimental program

Total of four continuous beams were tested to evaluate effects of creep and shrinkage on the structural behaviour. Two continuous beams made from precast elements and two control monolithically built continuous beams were monitored for more than 4 years. Precast reinforced elements had been permanently loaded above the cracking level before casting of the top part of a beam and continuity joint. Continuous monolithic beams stayed uncracked under the equal permanent load.

2.1. Test beams, construction process and instrumentation

Two beams, A1 and A2 (set A), were constructed in phases. Two beams, B1 and B2 (set B), were precast monolithic beams. Test beams and companion prisms for measuring creep and shrinkage were kept under controlled temperature and humidity conditions ($T = 20\,^{\circ}\mathrm{C}$ and relative humidity [RH] = 70%). Experiment commenced on November 2007.

Beams used in this experiment had rectangle cross section cast in one (set B) or two steps (set A). There was no intention to use the shape of a cross section of a real structure, since scaling already significantly affects model behaviour in long-term tests. Scaled models have larger surface-area-to-volume ratio and both creep and shrinkage strains are increased in comparison to full size elements. Also, shrinkage of concrete is more affected by the scale factor than creep is, and effects of the differential shrinkage (difference between the shrinkage of cast in place concrete and the remaining shrinkage of precast concrete) are expected to be additionally enlarged in scaled models. On the other hand, long-term properties of the concrete in real structures also significantly vary depending on concrete mixture, environment and construction schedule. Scaled models under controlled environmental and load conditions are convenient for testing of the analytical procedures. Similar size of the cross section of test beams and test specimens provided reliable values of the long term concrete properties in the experiment.

Continuity joint (set A) was cast in the second step, together with upper part of the beam. Concrete CI was used for set B and precast part of set A (phase I, Fig. 1). Concrete CII was used for phase II (top part of set A and continuity joints). Concrete was wet cured for a period of 3 days.

Two pairs of the precast beams (set A) were set on columns with spans of 3.0 m, with their adjacent end faces 10 cm apart at the middle support. Total length of a single precast beam was 3.12 m (phase I). Total length of the beams A1 and A2, after casting of joints and upper part of the beams, was 6.34 m (phase II), as it was for the beams B1 and B2. Elevation of the beams and the load arrangement for long-term observation is shown in Fig. 2, together with cross sections of the beams A1 and A2.

Beams B1 and B2 (Fig. 3) were also positioned on double supports (spacing 22 cm) in the middle to achieve identical spans as for the set A. Size of the cross section was 12 × 25 cm, same as the total size (phase II) of A1 and A2.

Weight of the precast beams is a large part of the permanent load on concrete bridge structure. Self weight of the precast model beam is relatively small to produce stress level that is corresponding to real structures. To produce similar stress level as in a real structure, additional permanent load is applied at two points of each span (2.2 kN at each point spaced 1.0 m), Fig. 2. Total permanent load was designed so that cracks due to the bending moments appeared in the precast part of beams A1 and A2. It simulated effects of the self weight of precast beam and cast-in situ part of

Fig. 1. Beams A (phase I).