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Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **13 (1988)**

PDF erstellt am: **26.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-13177

Monitoring and Prediction of Strain in a Long-Span Segmental Bridge

Contrôle et prédiction des déformations dans un pont à voussoirs de grande portée

Kontrolle und Voraussage von Spannungen in einer Segmentbrücke grosser Spannweite

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1. INTRODUCTION

In recent years, segmental bridge construction has gained popularity in the UK as a method of construction for medium to long-span bridges. It has contributed to both the aesthetics of bridge design and economy of construction [1].

In segmental construction the bridge deck is divided longitudinally into short segments which are either precast or cast-in-situ and then prestressed together in stages to form the bridge superstructure. Because of the nature of this method of construction, creep and shrinkage of the concrete and relaxation of the prestressing steel have a significant influence on the vertical deflection. Loss of prestress and the development of stress in the bridge deck both during construction and after completion of the bridge are also affected. An objective study of the actual behaviour of this form of construction, accompanied by a rigorous analytical approach is essential for successful design of segmental bridges. To this end a comprehensive instrumentation programme has been carried out to monitor the time-dependent behaviour of the River Torridge Bridge in North Devon.

2. RIVER TORRIDGE BRIDGE

The River Torridge Bridge is a glued segmental bridge crossing the Torridge estuary at Bideford in North Devon. It carries two lanes of traffic over the tidal estuary at a height of 29 m above mean high water level. It consists of eight continuous spans up to to 90.00 m in length with a total length of 645 m.

The bridge deck is a single-cell non-prismatic box girder with a depth varying from 6.1 m at the supports to 3.1 m at midspan. It is formed from 251 precast concrete segments each approximately 2.5 m length. Segments were match-cast using the short-line method and erected by means of a launching girder using the balanced cantilever technique. Segment casting commenced in June 1985 and bridge construction was complete in May 1987. A detailed description of River Torridge Bridge, its design and construction, is presented in an earlier report [2].

3. INSTRUMENTATION

Four segments were instrumented within Cantilever 4 East of Span 5, which is one of the largest 90 m spans. Segments were designated P4/1E, P4/6E, P4/10E and P4/16E corresponding to their relative positions east of pier 4. Concrete strains were measured using vibrating wire gauges of 140 mm gauge length embedded within the concrete during construction. Both single gauge elements and delta-rosette arrangements were placed on the median line of the segment cross-sections in the plane of each wall . Single gauge elements provided longitudinal strains; the rosette gauges yielded information on both longitudinal and in-plane shear strains around the cross-section. Segments P4/10E and P4/16E contained single gauges only. A few additional gauges were also placed across the thickness of wall elements of segments P4/10E and P4/16E for assessment of shrinkage strains.

Temperature measurements were made using type K thermocouples, manufactured by fusing 17 swg copper and constanton wires together to form a junction. Segment P4/10E was instrumented fully for the measurement of temperature profiles across the concrete walls. Plastic rods were fixed across the thickness of each wall element with a number of single thermocouples attached at predetermined spacings. Distribution of temperature along the bridge was monitored by placing a single thermocouple at each gauge position within each of the instrumented segments.

4. MEASURED RESULTS

Field measurements of concrete strain and temperature from bridge segments were recorded initially at three hourly intervals, for the first day after stripping of formwork, and then daily for the first week. The interval between readings thereafter was gradually increased up to approximately one month. At each major event during construction such as segment placing, temporary prestress, final prestress and launching girder movements, strain and temperature readings were also recorded.

Despite the large number of gauge elements employed, all readings were taken manually without the use of data logging equipment. An estimated 8000 readings were recorded during the 15 months period from casting up to completion of the bridge. Some typical results from field and laboratory measurements were presented in earlier papers [3, 4].

5. MATERIAL PROPERTIES

Physical properties of concrete used in segments P4/1E and P4/10E were measured using a large number of prism and cube specimens. Short term physical properties measured included compressive strength, modulus of elasticity, Poisson's ratio and coefficient of thermal expansion, at four different ages of approximately 28, 90, 180 and 240 days after casting. Creep and shrinkage tests were conducted on specimens which were either fully sealed against moisture penetration, partially sealed (to take account of the surface area/volume ratio of the segment represented) or left unsealed. Shrinkage measurements were carried out on specimens stored indoors under a controlled environment and outdoors protected from direct rain or sunlight. Creep tests were conducted indoors at a constant temperature of 23^{o}C and 85% relative humidity, representing average climatic conditions in the British Isles. Basic and total creep tests were initiated at ages of approximately 28, 90, 180, and 240 days from casting, under a constant compressive stress of $14.4 N/mm^2$ representing approximately 25% of the 28 day characteristic cube strength.

6. COMPUTER-AIDED ANALYSIS

A computer program developed to perform non-linear time-dependent behaviour analysis for long-span segmental concrete bridges has been developed to calculate strains and deflections. It is based on a step-by-step procedure which accounts for most of the important parameters that influence the construction of segmental bridges. A procedure employing the method of superposition of specific creep curves has been used for estimating the creep of concrete subjected to a varying state of stress. Interaction between creep and shrinkage of concrete and induced prestress losses is considered. The analysis uses material properties and actual construction schedules to simulate time-dependent bridge behaviour. Material properties are used from results of laboratory and field tests or simulated from various design code recommendations. Also effects of actual loads applied on the River Torridge Bridge during each stage of construction are investigated.

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