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Case Study

The effect of concrete vertical construction joints on the modulus of rupture☆

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ABSTRACT

The purpose of this study is to experimentally correlate the compressive strength (f'_c) of concrete to the modulus of rupture (f_r) for plain concrete beams with a vertical construction joint placed at their center. The ACI code provides a formula for the correlation of f_r to f'_c, but with the provision that the concrete specimen is monolithic (no joints). It is well known that no concrete structure is built without the use of construction joints, whether planned or un-planned, an engineer would definitely benefit from an equation that could relate the modulus of rupture of concrete as a function of its compressive strength. A better understanding of the effects of construction joints on the modulus of rupture will assist engineers in making rational decisions on how to deal with vertical construction joints, which in turn will lead to ultimate cost savings on large-scale projects.

In this study, seven different concrete mix designs were used. From each concrete mix, six plain concrete beams were poured, half of which were monolithic and the other half with a vertical construction joint at the beam center. Four cylinders per design mix were casted for the purpose of obtaining the mix compressive strength. The experimental results indicate that for monolithic beams, the ACI Code always underestimates the modulus of rupture, whereas in the presence of a vertical construction joint, the conducted experiments yield a significant loss in the modulus of rupture of concrete that varies between 24% and 83%. Thus, there is a clear justification for providing dowels at construction joints in order to assure continuity in strength over joints in plain concrete.

1. Introduction

It is often not possible to complete a job at one go, for example because of the size or complexity of the structure or because of limited materials or manpower. When work resumes it will be necessary to place fresh concrete on or against the previous pour that will have already hardened. The resultant contact surface is known as a construction joint or day work joint (Waters, 1968; Critchell, 1968) (Fig. 1). Waters (McCormac and Nelson, 2006) was a pioneer in addressing the issue of concrete tensile strength across construction joints and had mainly investigated the topic of bonding surfaces.

The flexural strength of concrete beams, which is also known as the modulus of rupture, has been experimentally studied on many different levels for the past century. Lane (1998) had developed correlations among flexural, split tensile, and

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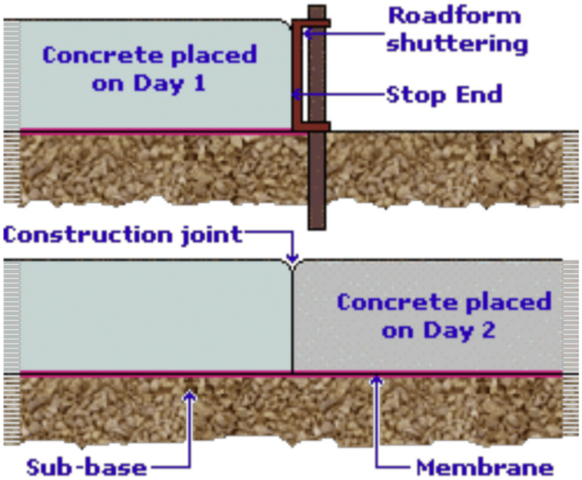

Fig. 1. Typical schematic of a construction joint in pavement construction.

compressive strengths and ultrasonic pulse velocity from laboratory testing using materials and mix designs proposed for use in a paving project. By definition, flexural strength is a measure of an unreinforced concrete beam or slab to resist failure (McCormac and Nelson, 2006). Another important factor that affects the beam or slab ability to resist failure is the compressive strength of concrete (f'_c). This experimental study was based on the ASTM C78 Standard (ASTM Standard, 2002a) test method for flexural strength of concrete. In ASTM C78 Standard, the modulus of rupture of concrete is obtained by breaking simple beams (760 mm × 150 mm × 150 mm) using third-point loading. In the standard, the beam is monolithic (no joints within the beam).

In the ACI Code, equation (9–10) in section 9.5.2.3 of the ACI manual (ACI Committee, 2008) provides the following equation relating between f'_c and the modulus of rupture (f_r) for normal weight monolithic beams:

$$f_r = 0.62\sqrt{f'_c} \quad (1)$$

In this study, the proposed equation for the modulus of rupture that would be used is as follows:

$$f_r = k\sqrt{f'_c} \quad (2)$$

where f_r is the modulus of rupture, MPa; k is the a factor that would be determined experimentally; f'_c is the compressive strength of concrete, MPa.

The purpose of this study is to experimentally derive an equation that relates the compressive strength of concrete to the modulus of rupture for a beam that contains a construction joint (CJ). ACI defines a construction joint as: 'the surface where two successive placements of concrete meet, across which it may be desirable to achieve bond and through which reinforcement may be continuous.' (ACI Committee, 2000). Most construction projects (if not all) will run into construction joints, whether they are planned or un-planned. Having an equation that accounts for construction joints in determining the flexural strength of concrete is beneficial, since that will allow the structural engineer to determine a more accurate result in the calculation of flexural strength for a location that contains a construction joint, hence reducing the tendency of overdesigning these joints.

2. Overview of experimental study

In order to achieve a reasonable set of data points with a wide range of concrete compressive strengths (f'_c) and flexural strengths (f_r), seven different mix designs were utilized (Table 1). The identification of each concrete mix design are designated in the following manner: Mix A, Mix B, Mix C, Mix D, Mix E, Mix F and Mix G. For each mix design, a total of six plain concrete beams were poured: three were monolithic and the other three had a construction joint at the center of the beam (Fig. 2). In addition, four test cylinders were poured for each set of beams. In total, 42 beams and 28 cylinders were poured for this experimental study. The average compressive strengths of each mix design were obtained by crushing the corresponding four test cylinders. The standards used for concrete pouring, compressive strength cylinder testing, and cylinder capping are ASTM C192 (ASTM Standard, 2002b), ASTM C39 (ASTM Standard, 2005), and ASTM C617 (ASTM Standard, 2002c), respectively.

Modulus of rupture is usually obtained from direct tension tests, but direct tension tests of concrete are seldom carried out because it is very difficult to control. Also, perfect alignment is difficult to ensure and the specimen holding devices introduce secondary stress that cannot be ignored. In practice, it is common to carry out the splitting tensile test or flexural