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Experimental evaluation of longitudinal behavior of continuously reinforced concrete pavement depending on base type

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HIGHLIGHTS

- Longitudinal displacements of CRCP under temperature changes are measured in situ.
- Confining effect of base types on CRCP longitudinal displacements is investigated.
- Lean concrete base shows more effectiveness at confining CRCP expansion.
- Free-end expansion gradients of CRCP are developed.
- Optimum expansion joint widths for CRCP are proposed.

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ABSTRACT

The objective of this study is to understand the confining effect of two base types on the longitudinal displacements of the continuously reinforced concrete pavement (CRCP) subjected to short- and long-term temperature loadings. To this end, a series of full field experiments was carried out at two highway CRCP sections in Korea: one section with asphalt bond breaker beneath the concrete slab and the other with lean concrete beneath the concrete slab. Each section was instrumented with linear variable differential transformers and thermocouples to monitor the longitudinal displacements (expansions and contractions) of the concrete slab at different longitudinal locations as the temperature changed throughout the year. Results showed that the lean concrete base was more effective at confining the daily maximum expansions than the asphalt bond breaker especially in the region between the free end and 10 m away from the free end. In addition, the free-end expansion gradients (expansion per unit temperature change) were developed based on the test data to estimate the annual maximum expansions along with the daily maximum expansions of the terminals. Finally, the optimum expansion joint widths were proposed for CRCP with varying construction and design conditions, such as base type, slab length, and construction season.

1. Introduction

In the continuously reinforced concrete pavement (CRCP), longitudinal steel bars installed inside the concrete slab are primarily intended to restrain a significant volume change in the slab due to temperature variations. Although there are many visual transverse cracks developed in the CRCP slab, most of them end up being inactive cracks since the longitudinal steel bars prevent the transverse cracks from widening. In this regard, CRCP offers a longer service life than the conventional jointed concrete pavement (JCP) that experiences prevalent joint damages such as spalling and corner cracks [1–6].

CRCP is of wide extent and gains popularity in many countries for its high performance and low maintenance cost even under heavy traffic loadings and challenging environmental conditions. In the United States, State Highway Agencies (SHAs) in more than 35 states consider CRCP as one of viable concrete pavement design options. In Europe, CRCP is enjoying a renaissance especially in France and Belgium [7,8]. In Korea, CRCP was first introduced in the mid 1980s. Since then, its performance has been evaluated in relation to key design factors through various experimental studies [9–14].

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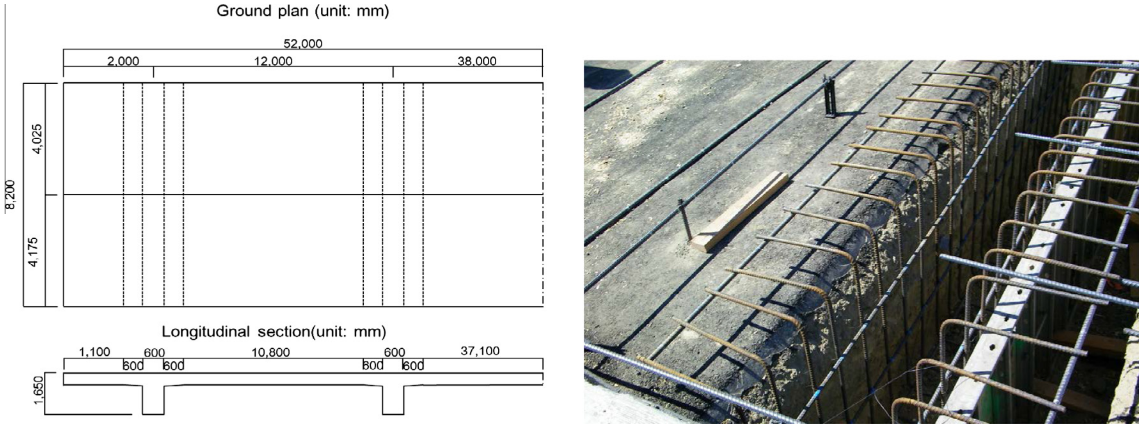

Fig. 1. Anchor lugs [17,18].

When designing CRCP, it is important to select an appropriate transition joint wherever CRCP terminates at a different pavement type or structure approach slab. Conventional transition joint types are expansion joints, wide flange beam terminal, and pavement end anchors (or anchor lugs). The main roles of transition joints are: (1) to isolate adjacent pavement of different types, (2) to anchor CRCP so that longitudinal movement does not occur, and (3) to accommodate longitudinal movement that would otherwise damage adjacent pavement segment or structures.

Many SHAs identify the criteria for where to use the various types of transition joints that best suit the site conditions, such as segment length and profile grades [15]. For instance, wide flange beam terminals have been used in relatively flat regions while anchor lugs are recommended to use for higher profile grades [16,17]. Interestingly, all CRCPs designed and constructed in Korea have anchor lugs regardless of the construction site conditions. Anchor lugs confine the longitudinal slab movements using a series of concrete lugs placed underneath the pavement that anchor to well-compacted subgrade as shown in Fig. 1 [17,18]. These anchors are often used in combination with expansion joints to further restrain CRCP movement at transitions with another type of concrete pavement or structure approach slab. Compared to other terminal types, the anchor lug is expensive as it requires more reinforcements and entails complex design and construction.

The general base types of CRCP include unbound aggregate, asphalt stabilized, cement treated, lean concrete, and combinations of them. The lean concrete base and the asphalt stabilized base, called asphalt bond breaker, on top of the lean concrete base are typical base types of CRCP in Korea. A recent study demonstrated that the asphalt bond breaker under the concrete slab alongside the expansion joints is effective in curbing excessive longitudinal movements at the ends of CRCP segment [19]. However, this effect has neither been fully understood over a wide range of temperature variations nor been compared against CRCP placed directly on lean concrete base. A current expansion joint width (20 mm) specified in the Road Design Standard for CRCP is, in fact, determined by experience mostly gained from JCP construction and maintenance works [20]. Therefore, this might not be appropriate for CRCP that reveals different longitudinal behaviors from JCP. Furthermore, the width of inserted expansion joints should be adjusted for various construction seasons, slab lengths, and base types because slab behaviors are closely dependent on these conditions.

The purpose of this study is to investigate the longitudinal behavior of the unanchored CRCP and to understand the effect of an asphalt bond breaker on restraining the longitudinal slab movements under temperature loadings compared to a conventional lean concrete base. To this end, both short- and long-term field tests are undertaken at two highway CRCP sections in Korea: one with asphalt bond breaker (referred to as A-CRCP herein) and the other without it (referred to as L-CRCP herein). Based on the findings from this comprehensive experimental attempt, the effect of base types on curbing longitudinal behaviors is investigated, and the optimum expansion joint widths are proposed for different base layer types, slab lengths, and even construction seasons that would assist pavement design and construction groups in saving costs and minimizing distresses in CRCP.

2. Test sections

2.1. A-CRCP section

A 390 m long A-CRCP section was constructed at the Korea Expressway Corporation Test Road (KECTR) in July 2002. This section consists of three layers placed over subgrade: concrete slab, asphalt bond breaker, and lean concrete. The thicknesses of concrete slab, asphalt bond breaker and lean concrete base are 300 mm, 50 mm and 150 mm, respectively. Since this section is placed in a relatively flat region (road grades less than 3%), anchor lugs are not necessary to be installed according to conventional practices in other countries. Nevertheless, the original KECTR construction design had forced the insertion of anchor lugs at both terminals (i.e., transition zones) with an intention of confining excessive slab expansions. This had caused not only construction cost increase but also KECTR site opening delay.

In summer of 2012, the concrete slab of the A-CRCP section was cut through the depth with a masonry saw at 43 m away from one of the terminal anchors to create an expansion joint as illustrated in Fig. 2. Since then, the A-CRCP section has been separated into two subsections: A-S (short subsection) and A-L (long subsection). This allows us to comparatively investigate the effect of base types under the same transition joint condition (i.e., expansion joint). The subsections were instrumented with a total of seven linear variable differential transformers (LVDTs) to measure the longitudinal movements at seven locations: 0 m, 10 m, 25 m, 50 m, 150 m, and 250 m from the free end of A-L, and the other free end of A-S. These measurement points were all positioned at the mid-depth of concrete slab (150 mm from the surface) to represent average slab movements and were selected based on the distribution pattern of transverse cracks such that crack opening/closing displacements were not picked up by LVDTs during the data collection. Fig. 3 shows a part of LVDT setups at A-CRCP section, in which all LVDTs are installed at the shoulder side of the CRCP slab. Along with air