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Effect of vehicle-induced vibrations on early-age concrete during bridge widening

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HIGHLIGHTS

- This study focused on the effect of vehicle-induced vibrations on fresh concrete.
- A laboratory program including field test was performed.
- 120 concrete specimens were used to assess the attainable compressive and bond strengths.
- Two test variables were considered: the peak particle velocity and vibration duration.
- Some recommendations suggested based on the results of this study.

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ABSTRACT

The purpose of this study was to conduct laboratory experiments that considered the effect of vehicle-induced vibrations on fresh concrete to determine the attainable concrete strength for bridge widening. A laboratory experimental program was carried out, where 120 concrete specimens were used in total to measure the compressive and bond strengths. The experiment results showed that vehicle-induced vibration does not need to be considered a serious risk to the concrete strength if the vibration duration is 6 h or less and the peak particle velocity is 0.3 cm/s or less.

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1. Introduction

In Korea, road traffic congestion is expected to become worse each year with the growing population and increasing number of vehicles, and much of the existing infrastructure cannot handle the increasing demand under present conditions. The average daily number of vehicles that cross bridges is increasing every year, and the bridges continue to age. Therefore, to accommodate the rapidly increasing road traffic volume, existing bridges must be widened or reconstructed at some point.

As the construction of new bridges not only takes time but also is expensive, most bridge operators prefer to widen existing bridges [1,2]. In bridge widening projects, the vibrations induced by the vehicles on adjacent lanes and old bridge decks affect the newly placed concrete [3]. In particular, when concrete is subjected to vibration as it is setting, its compressive strength may decrease. The bond strength between steel and concrete may also decrease [4]. A decrease in the concrete strength caused by vibrations from vehicles crossing a bridge negatively affects the rigidity of the repaired area of the bridge, the bond performance between the concrete and steel reinforcement, the crack width, and the longitudinal expansion joints between the widened and existing bridge segments [5–11].

Over the years, researchers have attempted to understand the effect of early-age vibration on concrete strength. Previous studies mostly considered the vehicle load [12–14], pile driving [15–17], and blasting [18–20] as vibration sources. Vehicle-induced vibration probably has the greatest effect on bridge widening projects. Understanding the effect of vehicle-induced vibration on newly placed concrete for the widening of a concrete bridge or deck is important.

Many past studies focused on predicting the vibration magnitude that will not damage concrete or that can be expected or recommended [21–23]. They would then determine the effects of such a vibration magnitude on the concrete strength. Most

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of these studies concluded that vibrations did not actually increase or have any effect on the compressive strength [2,24,25]. Furthermore, some researchers demonstrated that vibrations had insignificant or non-critical effects on the bond strength [3,12,13,26]. However, the studies in the existing literature failed to strictly simulate an environment where new concrete is exposed to vibrations. In particular, they did not expose concrete to vibration at an early age [2]. In other words, in most of the past laboratory experiments, the concrete was subjected to the first vibration sometime after it was mixed and poured into a mold. This is quite different from an environment where concrete is subjected to vibration during bridge widening works. Bridge builders do not control the vehicles because of the construction schedule and for economic reasons, and most concrete sections are subjected to vehicle-induced vibrations as soon as they are placed.

Furthermore, there are various parameters at an actual bridge widening site that can affect vehicle-induced vibrations. In particular, the type and current condition of a bridge can have the greatest effect among the various parameters. It is wrong for researchers to attempt to understand the strength characteristics of concrete using the generally expected vibration without considering the aforementioned parameters. Only a few studies actually placed concrete specimens at an actual bridge widening site, applied the same vibrations that an actual bridge receives [2,27], and then evaluated the strength characteristics of the concrete. Moreover, even these studies did not report the types, cycles, sizes, etc. of the vehicle-induced vibrations that the concrete received. Instead, they stated that more tests were needed in a better-controlled environment.

The purpose of this study was to experimentally investigate the parameters with the greatest effects on the concrete strength during vehicle-induced vibrations. A field experiment was conducted to evaluate the characteristics of vibrations that occurred on a bridge that was actually being widened. The experimental variables to be considered in the laboratory experiment program were determined based on the field experiment results. One experimental parameter was the peak particle velocity (PPV), for which values of 0.3, 0.45, 0.6, and 1.0 cm/s were considered. Another parameter was the vibration duration, for which values of 3, 6, 12, and 24 h were considered. The age of the concrete when vibrated was excluded because concrete is subjected to vehicle-induced vibrations as soon as it is placed in an actual bridge. The laboratory experiment results were used to determine whether vehicle-induced vibrations at an early age pose a risk to the attainable compressive and bond strengths of concrete. Appropriate PPV and vibration duration values were proposed that can be used as guidelines by bridge constructors.

2. Vibration of concrete

Concrete must be unconditionally protected until it develops sufficient resistance against the external environment. This is required to guarantee the formation of internal structures as well as the strength and durability of concrete. However, in most bridge widening projects, concrete is inevitably exposed to a harmful environment produced by vehicles [28]. Therefore, the effects of vehicle-induced vibrations on newly placed concrete must be accurately determined. Moreover, attachments for expressing the strength of concrete are formed at an early age inside the hardened cement paste [29], and vibrations may damage these attachments or reduce their achievable strength. Therefore, the harmful effects of vehicle-induced vibrations on concrete during the hardening process need to be determined.

3. Previous studies

Results on the effect of vibrations or vehicle movements during the placement of fresh concrete for bridge widening have been mixed. Some studies have reported that such vibrations have insignificant or non-critical effects on the concrete strength.

Manning [14] investigated bridge widening projects in four U.S. states and reported that vehicle-induced vibrations were found to be potentially harmful to the concrete and bond strengths in only one of these projects. In his report, he concluded that there was insufficient evidence for vehicle-induced vibrations reducing the bond performance of concrete as long as good-quality concrete was used for bridge widening.

Furr and Fouad [3] completed a massive study on vehicle-induced vibrations in already-completed or ongoing bridge widening projects. Their results did not provide any clear evidence that vehicle-induced vibrations are harmful to the bond strength between concrete and steel during the concrete setting period. In a follow-up study, Furr and Fouad [12] concluded that vehicle-induced vibrations have no negative effect on the bond strength between steel and concrete.

Deaver [2] performed field experiments on two actual bridges that were being widened. Two specimens were placed on the tops of the bridges to allow them to be subjected to the same movements as the bridges. To generate traffic vibrations, both reference trucks that had been weighed and general vehicles were allowed to pass over the bridges; the characteristics of the vibrations (e.g., size, period, type) were not reported. In conclusion, the traffic vibrations were not found to be harmful to the bond strength, but the author called for more tests under better-controlled conditions.

Harsh and Darwin [13] reported that vehicle-induced vibrations have no harmful effects on the bond strength as long as good-quality low-slump concrete is used. However, they found that slumps of 10.2–12.7 mm could be harmful to the bond strength and noted that the bond strength could considerably decrease if concrete with slumps of 17.8–20.3 mm or higher was exposed to vehicle-induced vibrations.

Cusson and Repette [30] investigated the effects of vehicle-induced vibrations on fresh concrete during the renovation of reinforced concrete barriers on highway bridges. They reported that many transverse cracks were generated in the few days after concrete placement and concluded that these cracks were caused by a combination of the temperature gradient, differential shrinkage, and traffic.

Issa [31] examined the causes of cracks on concrete bridge decks through a literature survey and tests to assess the changes in the elastic coefficient of concrete due to vibrations. The author concluded that the vibrations in the bridge decks caused by the adjacent traffic were not the cause of the strength reduction in the well-balanced and well-packed low-slump concrete.

Fernandes et al. [25] evaluated the early-age behavior of high-strength concrete exposed to an environment with vibrations. Their results showed that high-strength concrete specimens subjected to vibrations at an early age experienced tensile strength and elastic coefficient losses. Furthermore, they pointed out that special care must be taken with regard to the tensile strength of concrete because its reduction can have a negative effect on the usability of a concrete structure and can result in a greater deflection.

In most of the previous studies, the vehicle-induced vibrations were found to have no harmful effects on general concrete. Furthermore, the vehicle-induced vibrations considered in these studies were experiential or recommended in the specifications. The characteristics of vibrations generated by a vehicle load can vary by bridge type. If a target bridge that needs to be widened was

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