AN INSTRUMENT FOR DETECTING DELAMINATION IN CONCRETE BRIDGE DECKS

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Although many factors are required to characterize the extent of deterioration in a bridge deck, there are two factors that can be considered of paramount importance: delamination (a separation of the original slab into two or more approximately horizontal layers) and poor quality concrete. These two factors were singled out because it was felt that most structural damage to deteriorating bridge decks resulted from one or the other or both of these defects. Other considerations in the selection of these factors are that damage to structures caused by them is often not visible until significant deterioration is present and, also, that the known techniques for their detection are slow and tedious. Thus, the major emphasis of this research has been directed toward methods for detecting delamination and also detecting poor quality concrete. This report describes an instrument that has been developed specifically to detect delamination. It also includes an evaluation of the device, accomplished by measuring specially constructed test slabs and numerous in-service bridges. All evaluation tests that have been conducted indicate that the instrument satisfactorily detects delamination in bridge decks and that it provides a rapid and practical tool for routine use in bridge condition surveys.

•DELAMINATION is sometimes referred to as horizontal cracking. It occurs frequently at the elevation of the reinforcing steel and most often at the upper level of reinforcing steel. Delaminated areas may range in size from a few square inches to several square yards. After initial delamination occurs, additional rapid deterioration of the deck may be expected to follow, under the combined influences of weather and traffic. Figure 1 shows a delaminated bridge deck in the last stages of deterioration.

A literature search yielded relatively little information on delamination detection techniques. However, it was learned that, in actual practice, one principal technique is employed. This method relies on the subjective judgment of testing personnel regarding the sound produced by striking the bridge deck with a hammer or other solid object. This is basically the same technique employed by carpenters to locate a stud behind a rock wall. The delaminated or nonbonded area produces a distinctive "hollow" sound when it is struck.

The sound produced when the hammer strikes the concrete depends on the vibrational characteristics of the hammer itself as well as the concrete. If the hammer is highly resonant, its sound is confused with the sound from the slab. This makes the judgment by testing personnel much more difficult. Thus, claw hammers, steel rods, and the like do not make good striking objects. The best type of striking object has been found to be a steel mass tied at the end of a soft rope. This device, which is shown in Figure 2, was developed by an employee of the Texas Highway Department to facilitate bridge deck inspections. The steel mass, being essentially nonresonant, produces very little sound when hammered against a solid deck, but it causes a delaminated area to give forth a loud, distinctive hollow sound. Additionally, the mass may be dragged across

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the surface, and, unless the surface is unusually smooth, its irregularities produce a high-speed tapping effect. This dragging also produces the distinctive hollow sound on a delaminated area. A steel chain has also been used for the same purpose by dragging it across the surface.

Another device, which was developed several years ago by the research department of the State Highway Commission of Kansas to detect delamination in bridge decks, is shown in Figure 3. This device strikes the deck at regular intervals with small wooden blocks, allowing the operator to make a subjective judgment as to the type of sound produced. It was described in some detail in a report by Bertram D. Tallamy Associates (1). Although this device is capable of surveying large areas rather quickly, the wooden blocks are somewhat resonant, which in turn impairs the operator's judgment.

Another mechanism designed for the detection of delamination is shown in Figure 4. This device, invented by Nichols (2), was designed to detect the lack of bond in honeycomb metal panels. Basically, the instrument consists of a metal pegged wheel with an acoustical pickup on the handle. As the device is rolled across a metal panel, the lack of bond between the honeycomb and the metal panel is said to be indicated by the output signal from the acoustical pickup.

DEVELOPMENT OF BASIC COMPONENTS

After one considers the existing techniques for delamination detection, the device invented by Nichols appears to offer one substantial advantage—it does not require the subjective judgment of testing personnel. Thus, an instrument of this general type was tried. The attempt was not successful. The mechanism generated a large amount of signal when operated on a solid deck and, hence, gave a poor contrast between solid and delaminated areas. Nevertheless, after investigating and trying several other alternatives, the researchers concluded that the acoustic response to a tapping-type stimulus had substantial advantages over the other possible approaches.

The basic concept of an automatic device using the acoustic response to a tapping-type stimulus leads to requirements for the following three basic components: (a) a tapping device, (b) an acoustic receiver (e.g., a microphone), and (c) a signal conditioner to distinguish and produce the desired output. Many variations were tried. The most successful of the variations are described in the following subsections. They have been incorporated in the delamination detector unit discussed in the next section.

Tapping Device

The tapping device that is used is shown in Figure 5. It consists of a plunger that is oscillated vertically by a pair of solenoids. The plunger strikes a sharp blow at each end of its stroke. At one end, the blow is sufficiently violent to cause the tapping mechanism, with its rigid steel-rimmed wheels, to overcome gravity and break contact with the concrete surface. Thus, the tapping assembly chatters against the bridge deck surface and excites the characteristic vibration of any delaminated area with which it comes in contact. The magnitude of the tapping is kept to a nondestructive level. However, the wheel of the tapper leaves a visible white track consisting of fine-powdered material along the traverse. This minor crushing of surface grains is similar to that which would result from dragging the tip of a steel bar along the deck.

Acoustic Receiver

The development of a suitable acoustic receiver was unquestionably the most difficult task. Early in the research, it was found that receiving the signal through air with a conventional microphone presented a hopeless case. Ambient noises due to traffic and rolling were confused with the received signal, which made it impossible to distinguish reliably between solid and delaminated concrete.

The first successful receiver consisted of a piezoelectric crystal receiver mounted on the axle of a solid aluminum wheel. A rubber tread was glued to the aluminum wheel to minimize the noise-producing effect of deck texture. Although this receiver was able to distinguish between solid and delaminated concrete while rolling across the deck, the distinction was not as clear as desired.

Figure 1. Delaminated area of a bridge deck in the last stages of deterioration.

Figure 2. Tapping mass used for locating delaminated concrete in bridge decks.

Figure 3. Delamination detection device.

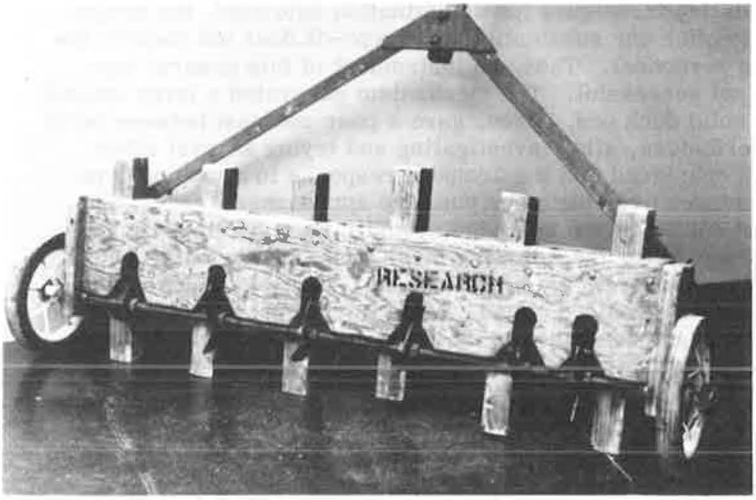


Figure 4. Hand-operated sonic testing device.

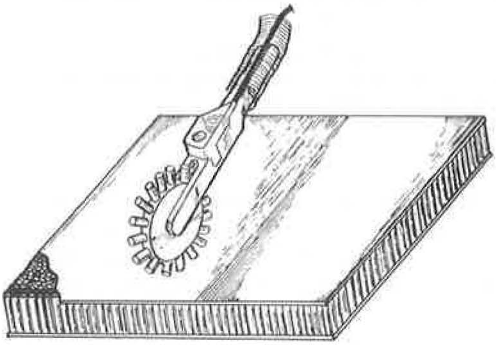
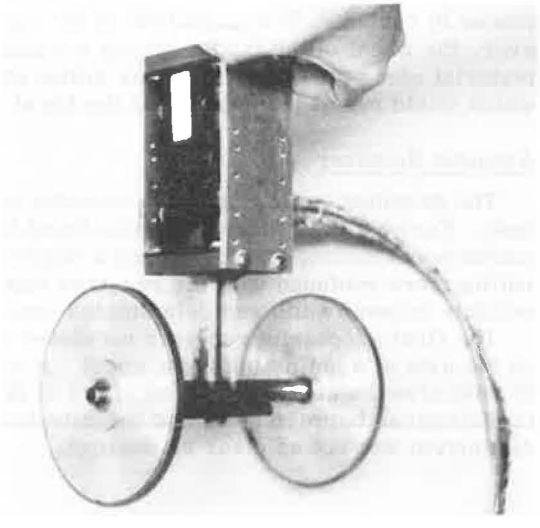


Figure 5. Tapping device for delamination detection.



The most satisfactory of the various designs tried is shown in Figure 6. It consists of an immersion-proof microphone (pressure transducer) mounted internally near the bottom of a soft rubber tire. Acoustic coupling is obtained by filling the tire with a mixture of water and ethylene-glycol. This receiver has almost no sensitivity to ambient noises or surface texture. It maintains excellent acoustic coupling while rolling, and it produces a relatively strong output signal.

Signal Conditioner

The signal conditioner that accepts the electrical signals produced by the rolling receiver and processes them for recording is shown in Figure 7. The distinction between delaminated and solid concrete is enhanced by filtering and by time-interval gating. Specifically, the distinction between delaminated and nondelaminated zones is enhanced by selecting only those frequency components of the received sound that fall between 300 and 1,200 Hz. Also, the distinction is further improved by accepting only that portion of the received signal that occurs during the first 3 msec after a tap has been made. Taps, which are produced 60 times per second, occur at intervals of 16.7 msec; thus, there is a relatively short interval during which the recording system is allowed to accept signals from the rolling receivers.

The final signal conditioning is accomplished by rectifying and integrating the signal over a period of approximately ¼ sec. This provides a rapidly responding voltage suitable for display on a pen recorder. Delaminated areas extending over 1 ft^2 or 2 ft^2 ordinarily produce responses exceeding 1 V. Smaller areas result in lesser responses that can be interpreted usefully down to about 0.05 V. Unwanted responses, resulting from rolling over rough surfaces and other disturbances, are substantially less than 0.05 V.

DELAMINATION DETECTOR UNIT

The basic components developed in this study and described in the previous section have been incorporated into the delamination detector unit shown in Figure 8. This unit, in the form of a mobile cart, is roughly the size and shape of a push-type power lawn mower. It is equipped with two rolling acoustic receivers spaced 12 in. apart and with two tapping wheels spaced 6 in. apart, centered between the receivers (Fig. 9). Because the unit detects delamination only when a receiver and a tapping wheel are simultaneously over a delaminated area, the unit surveys two 3-in. wide parallel paths that are 6 in. apart.

The unit consists of several separable components, each of suitable size and weight for one-man lifting and stowage in an automobile trunk. They are (a) a main frame that houses the tapping device and rolling receivers, (b) a two-channel pen recorder, (c) a control unit that contains two signal conditioning channels and an inverter for obtaining 120 Vac, and (d) a box that contains a 12-V storage battery. The disassembled unit is shown in Figure 10. Assembly or disassembly of the unit on site takes less than 1 min.

The two-pen recorder uses 4-in. wide chart paper divided for two-pen records. The drive for the chart paper is geared directly to one of the cart support wheels; thus, the lengthwise chart scale represents forward distance traversed. One minor chart division represents 0.5 ft of traverse. On solid concrete the pens remain at a stable small value (near zero on the transverse scale), and excursions larger than about two minor chart divisions from this low value are indicative of delamination. Although there are several control knobs on the recorder (gain, pen intensity, zero adjustment, and so forth), it is normally not necessary to adjust any of them for operation.

The operating controls consist of two on-off switches on the control unit. One is the main power switch, and the other is the tapper switch.

After charging, the storage battery will provide sufficient power to operate the detector continuously for more than 10 hours. For routine operations, it is charged each night for the next day's operation.

Figure 6. Rolling acoustic receiver.

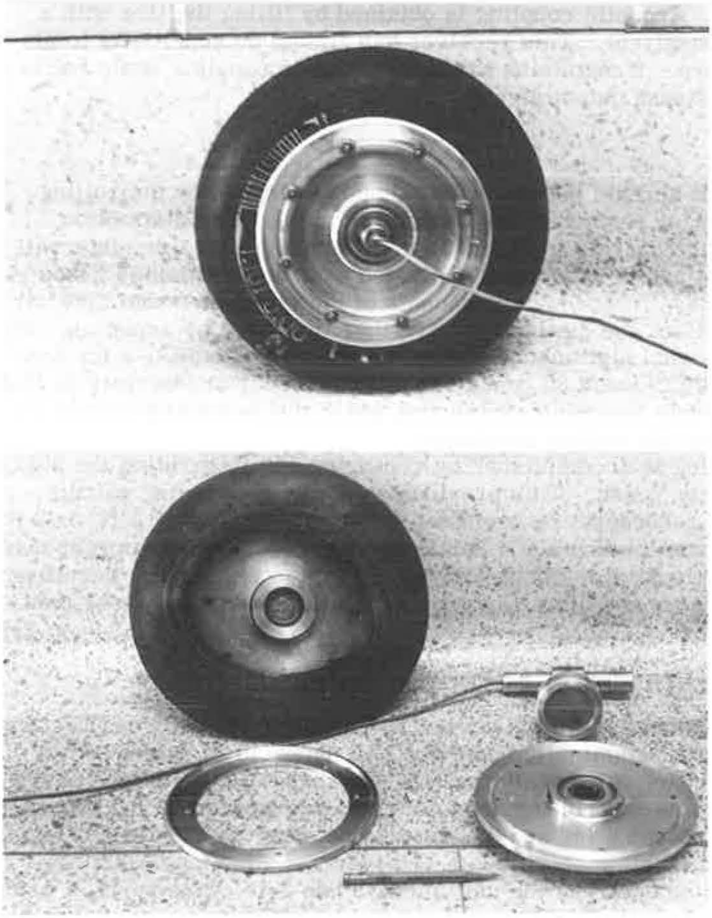


Figure 7. Block diagram of the signal conditioner.

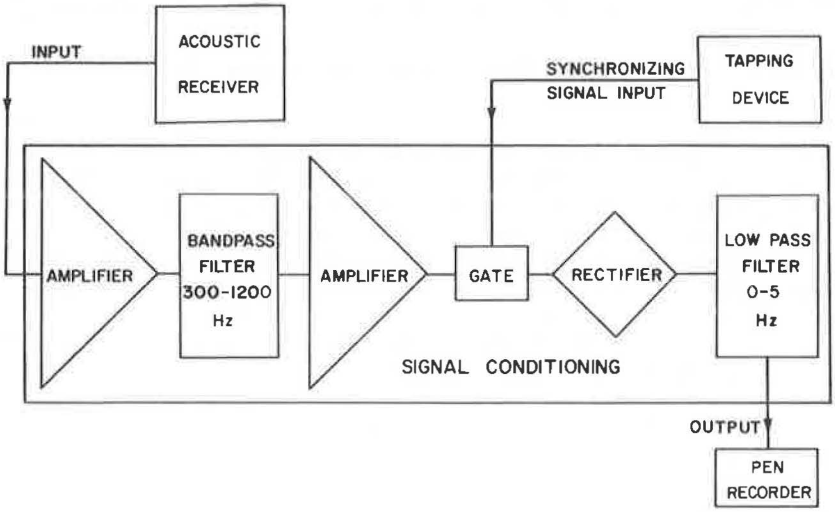


Figure 8. Delamination detector in operation.

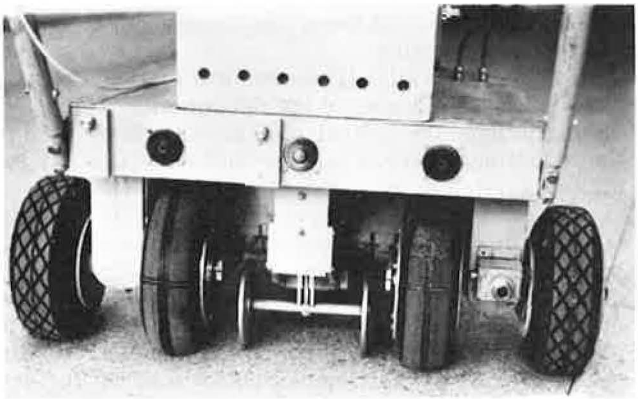


Figure 9. Rear view of delamination detector.

Figure 10. Delamination detector disassembled and stowed in an automobile trunk.

EVALUATION

In the early phase of the research, two rectangular test slabs (Fig. 11) were constructed to simulate bridge deck delamination. One of these slabs is about $\frac{1}{2}$ in. thick, and the other is slightly less than 2 in. thick. Prior to placing these slabs, the foundation concrete was prepared to cause bonding to occur on half of each slab and delamination on the other half. This was accomplished by carefully cleaning the foundation concrete and allowing it to dry. Then, immediately prior to placing the fresh concrete, a neat cement paste was applied to the foundation for the bonded halves, and a fine layer of kaolinite dust was applied for the delaminated halves. The desired results of delamination and bonding were achieved, and these test slabs were used for the primary instrumentation development work.

After the delamination detector was completed, a field evaluation was initiated, consisting of surveying 30 bridge decks suspected of containing delaminations. Significant amounts of delamination were found in about half of these bridges, which were scattered over a wide area in Texas.

Results obtained from traverses about 80 ft long made on two typical bridges are shown in Figure 12. Figure 12a shows a record from a bridge in which no delaminations could be detected, and Figure 12b shows a record from another bridge that contains many delaminations (any signal larger than two minor chart divisions is an indication of delamination). Figure 12a also shows that the two channels are independent. Delaminations were encountered in the left survey path at points where they were absent in the right path. At these points, the right edge of the delaminations must lie between the two survey paths.

If several parallel traverses are made on a deck, the detector recordings can be used to prepare a map of the delaminated areas. Upon transferring the locations where delaminations are indicated on each traverse to a properly scaled plan view of the deck, the delaminated areas may be outlined. Closely spaced traverses permit drawing a highly detailed map.

The ability of the detector to distinguish delaminated from solid concrete has been verified by specially constructed test slabs (both delaminated and solid) as well as by coring 10 different bridges. On each bridge, one core was taken at a location where delamination was not indicated, and another at an apparently identical location where delamination was indicated. Agreement has been perfect. No evidence of delamination or horizontal cracking could be found on examination of the walls of the core holes at the 10 locations where delamination was not indicated. Delamination was obvious on examination of each of the other 10 holes. Six of the ten bridges had asphaltic surfacing layers that varied in thickness from $\frac{1}{4}$ to $3\frac{1}{2}$ in. The delaminations found in these six bridges varied in depth from 1 to $4\frac{1}{2}$ in. In one instance, the delamination was 3 in. below a $1\frac{1}{2}$-in. asphaltic concrete overlay. In another it was 1 in. below a $3\frac{1}{2}$-in. asphaltic concrete overlay. The delaminations found in the four unsurfaced bridges varied in depth from $\frac{1}{2}$ to $2\frac{1}{2}$ in. It is doubtful that conventional sounding techniques could have been used to locate the delaminated areas in most of the 10 bridges cored.

Several of the 30 bridge decks surveyed were badly spalled and, therefore, had a very rough surface texture. The instrument's operation was not impaired by the rough texture. Because the instrument performed well on these bridges and on those with overlays, it is concluded that the detector is insensitive to deck texture and to layers of asphaltic surfacing up to approximately 4 in. in thickness.

Another limited experiment was conducted during the field evaluation to determine the effect of rolling noise. Several paths on bridge decks, some on very rough textured decks, were traversed several times at various speeds. No significant differences could be detected among the records made at speeds varying from a slow walk to a fast run.

CONCLUSIONS

From the results of this study the following conclusions appear warranted:

1. The delamination detector developed in this phase of the research study provides an effective means for determining the extent of delamination in concrete bridge decks,

Figure 11. Test slabs used for development of delamination detector.

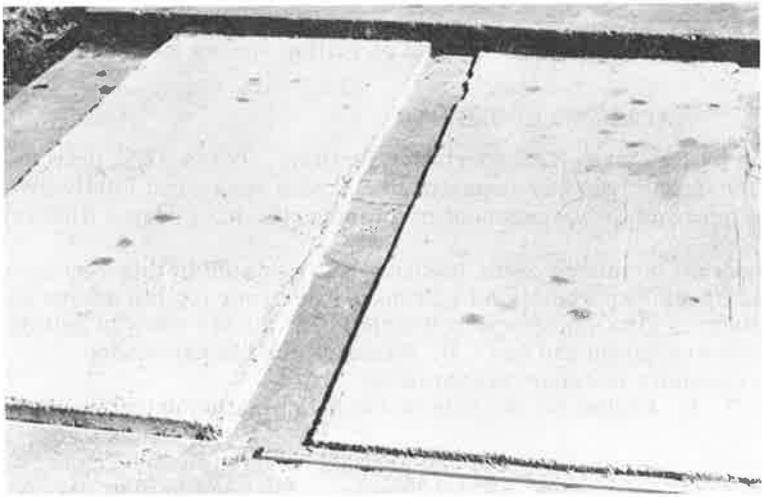
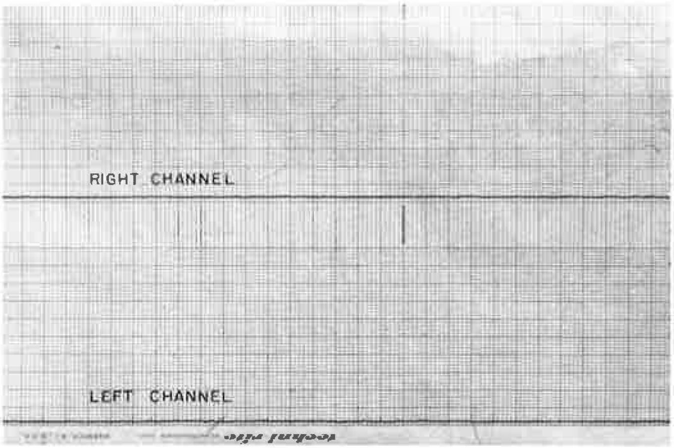
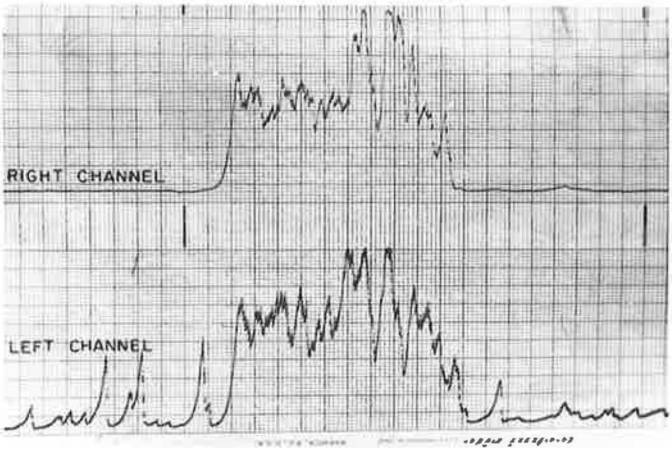


Figure 12. Typical records obtained with the delamination detector.



(a) SOLID DECK



(b) DECK CONTAINING DELAMINATIONS

2. The detector is easy to operate and practical for routine use,
3. The detector is insensitive to deck texture or to asphaltic surfacing layers up to at least 3½ in. thick, and
4. The operation of the instrument is not impaired at rolling speeds up to about 10 mph.

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. The report does not constitute a standard, specification, or regulation.

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