AN INSTRUMENT FOR DETECTING DELAMINATION IN CONCRETE BRIDGE DECKS

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ABSTRACT

This report describes a research effort directed toward finding a means for detecting delamination, one of the more serious forms of deterioration found in concrete bridge decks. Its describes (a) [illegible]ne of the methods employed for delamination detection, (b) the development of the basic components required for automatic detection, and (c) the completed instrument resulting from the research. The detecting unit is in the form of a push cart, roughly the size and shape of a power lawn mower. Also included in the report is an evaluation of the device, acc[illegible]shed by measuring specially constructed test slabs and numerous in-service bridges. The evaluation tests indicate that the instrument provides a practical and effective means for the routine detection of bridge deck delamination by maintenance personnel. The instrument was found to be insensitive to deck texture, or to thin asphaltic surfacing layers. The operation of the detector is not impaired by rolling speeds of up to about ten miles per hour.

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1. INTRODUCTION

This is a progress report of Phase 1 of a research study entitled "A Study of Reinforced Concrete Bridge Deck Deterioration: Diagnosis, Treatment and Repair", being conducted by the Texas Transportation Institute and sponsored by the Texas Highway Department and the Bureau of Public Roads. The specific objective of this phase of the research is the development of methods to evaluate the extent of deterioration in bridge decks.

In the early part of this study it was decided jointly by representatives of the Texas Highway Department and the Texas Transportation Institute, that although many factors are required to characterize the extent of deterioration in a bridge deck, there are two defects that could be considered of paramount importance. They are (a) delamination (a separation of the original slab into two or more approximately horizontal layers) and (b) 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 is being written to describe the research efforts directed toward the former, the detection of delamination.

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 under the combined influence of weather and traffic may be expected to follow. Figure 1 illustrates a delaminated bridge deck in the last stages of deterioration.

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 will detect delamination in bridge decks and that its routine use is practical.

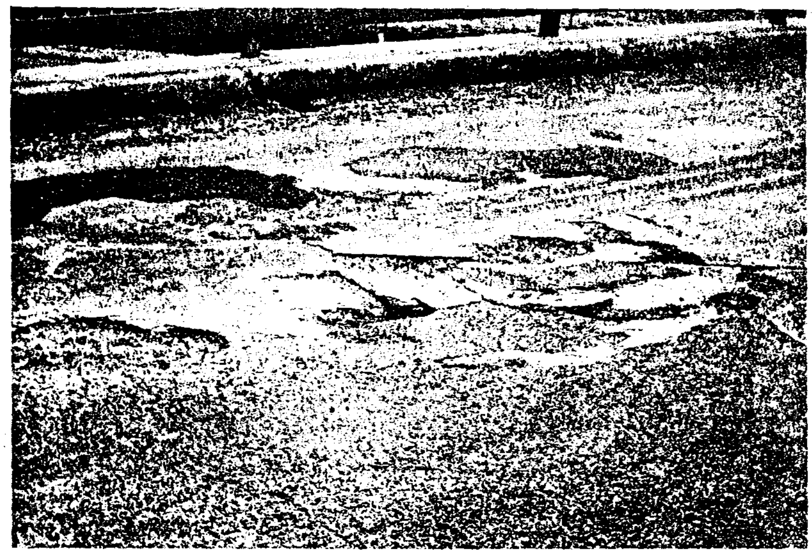

FIGURE 1: A typical delaminated area of a bridge deck in the last stages of deterioration.

2. EXISTING DETECTION TECHNIQUES

A literature search did not yield much information on delamination detection techniques. However, it has been learned that in actual practice, one principal technique is employed. This method uses the subjective judgement 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 sheet rock wall. The delaminated or non-bonded 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 judgement by testing personnel much more difficult. Thus, claw hammers, steel rods, etc. do not make good striking objects. The best type of striking object has been found to be a steel ball-like mass tied at the end of a soft rope. This device, which is shown in Figure 2, was developed by an inventive employee of the Texas Highway Department to facilitate bridge deck inspections. The steel mass, being essentially non-resonant, produces very little sound when hammered against a solid deck, but causes a delaminated area to give forth a loud distinctive hollow sound. Additionally, the mass may be dragged across 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 is also used for the same purpose by dragging it across the surface.

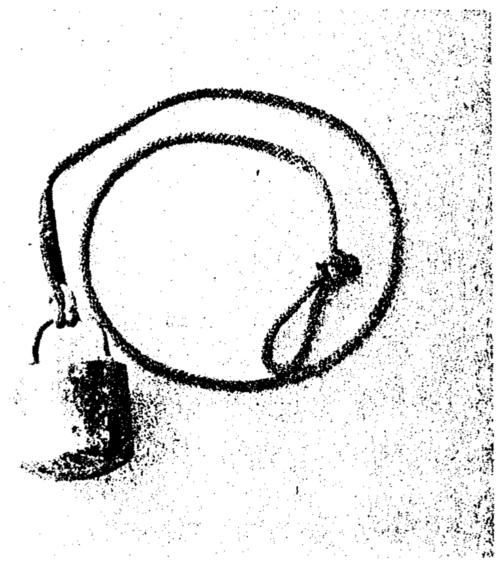

FIGURE 2: Tapping mass used for locating delaminated concrete in bridge decks. This simple but effective device was developed by an employee of the Texas Highway Department.

Another device, which was developed several years ago by the Research Department of the Kansas State Highway Commission to detect delamination in bridge decks, is shown in Figure 3. In operation this device strikes the deck at regular intervals with small wooden blocks, allowing the operator to make a subjective judgement as to the type of sound produced. It was described in some detail 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 judgement.

Another mechanism designed for the detection of delamination is illustrated 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.

FIGURE 3: Delamination detection device developed by the Research Department of the Kansas State Highway Commission.

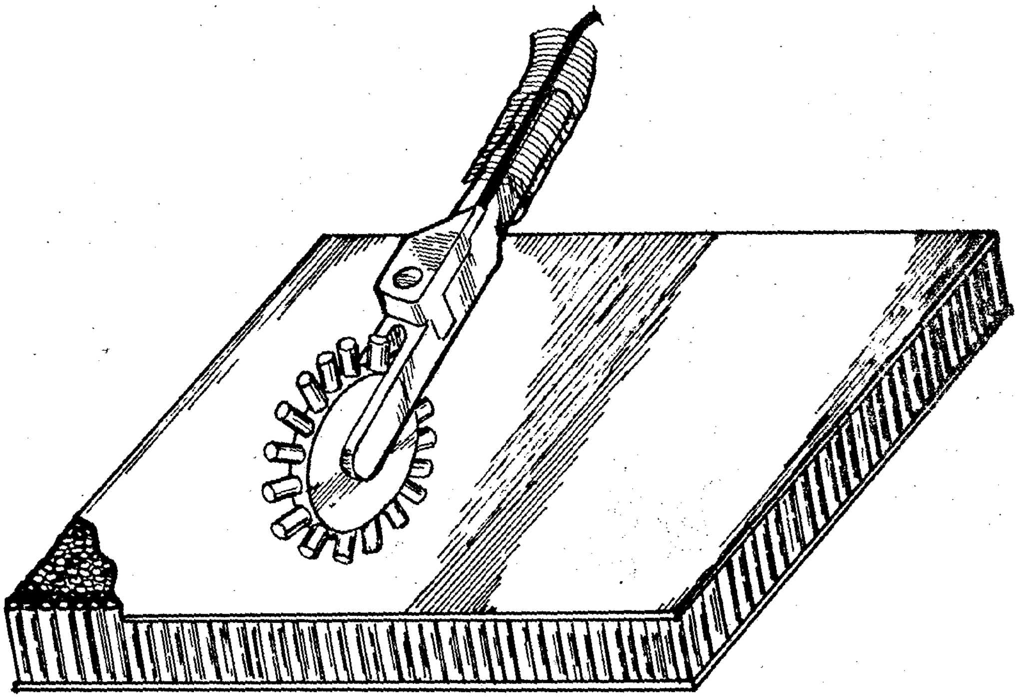

FIGURE 4: Hand operated sonic testing device invented by Nichols to detect delamination in honeycomb metal panels (2).

3. 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 judgement 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: (1) a tapping device, (2) an acoustic receiver (e.g. a microphone) and (3) a signal conditioner to distinguish and produce the desired output. Many variations have been tried. The most successful of the variations are described below and they have been incorporated into the delamination detector unit treated in Section 4.

Tapping Device

The tapping device that is used is shown in Figure 5. It consists of a plunger which 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 wheel to overcome gravity and break contact with the

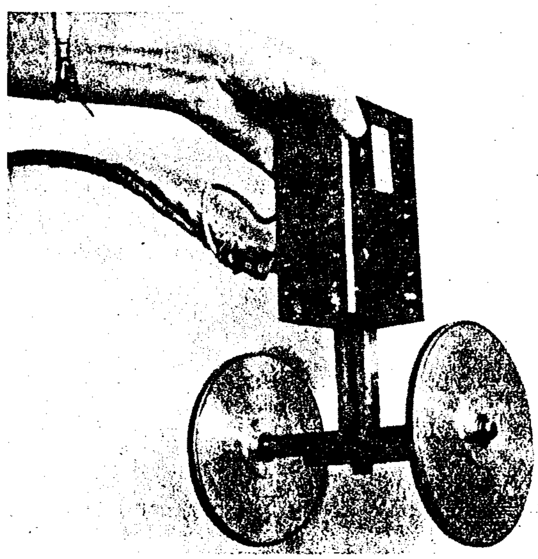

FIGURE 5: Tapping device for delamination detection. Oscillating solenoid strikes top and bottom of housing during each cycle, causing wheel to tap deck.

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 non-destructive 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, rolling, etc. were confused with the received signal and made it impossible to distinguish relibaly 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 desirable.

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

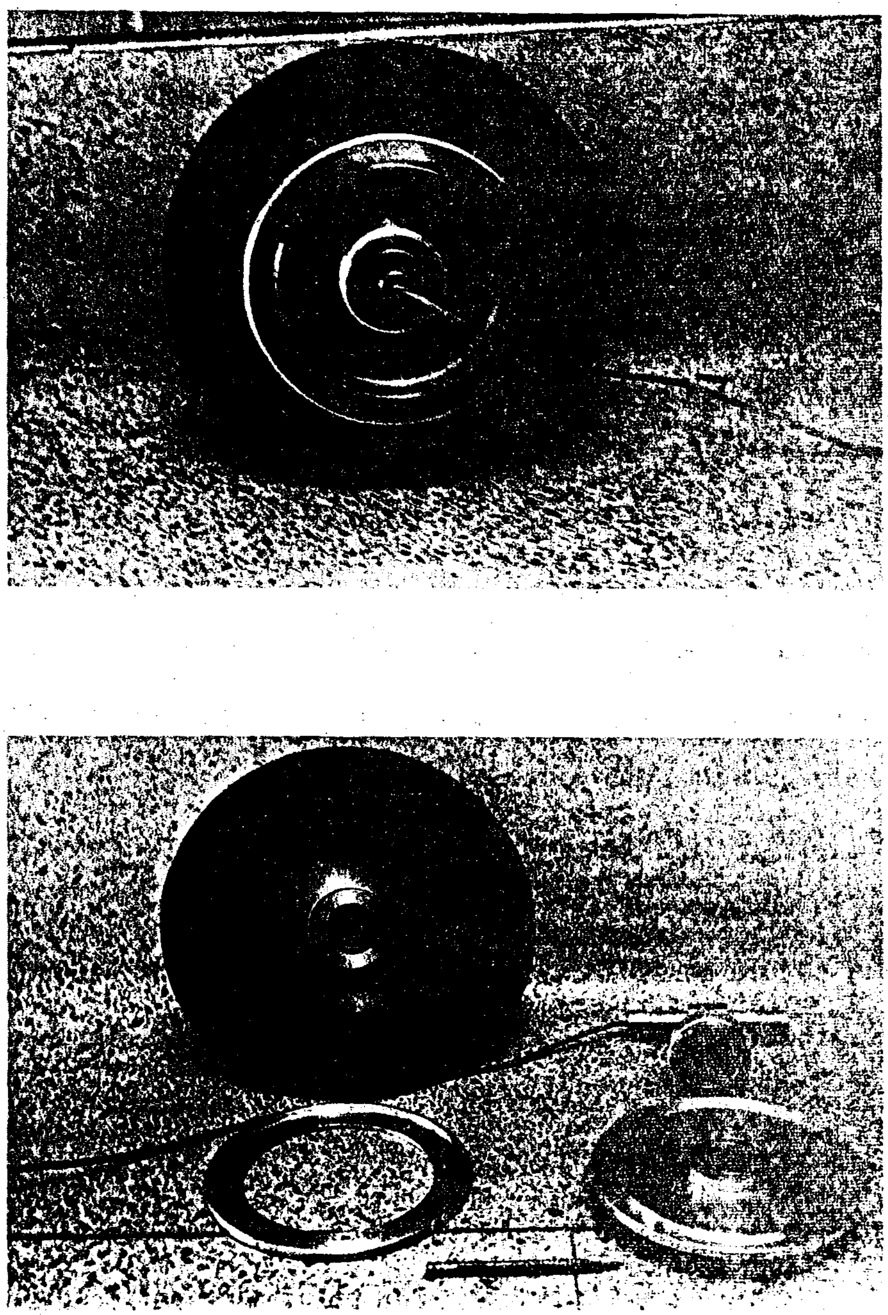

FIGURE 6: The rolling acoustic receiver developed for delamination detection contains a pressure sensitive crystal microphone inside the liquid-filled tire. The lower photograph shows the receiver partially disassembled.

or surface texture. It maintains excellent acoustic coupling while rolling, and it produces a relatively strong output signal.

Signal Conditioner

The signal conditioner which accepts the electrical signals produced by the rolling receiver and processes them for recording is diagrammed 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 non-delaminated zones is enhanced by selecting only those frequency components of the received sound which fall between 300 and 1200 Hz. Also, the distinction is further improved by accepting only that portion of the received signal which occurs during the first 3 milliseconds after a tap has been made. Taps, which are produced 60 times per second, occur at intervals of 16.7 milliseconds: 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 1/4 second. This provides a rapidly responding voltage suitable for display on a pen-recorder. Delaminated areas extending over one or two square feet ordinarily produce responses exceeding 1 volt. Smaller areas result in lesser responses which can be interpreted usefully down to about 0.05 volt. Unwanted responses, due to rolling over rough surfaces and to other disturbances are substantially below 0.05 volt.

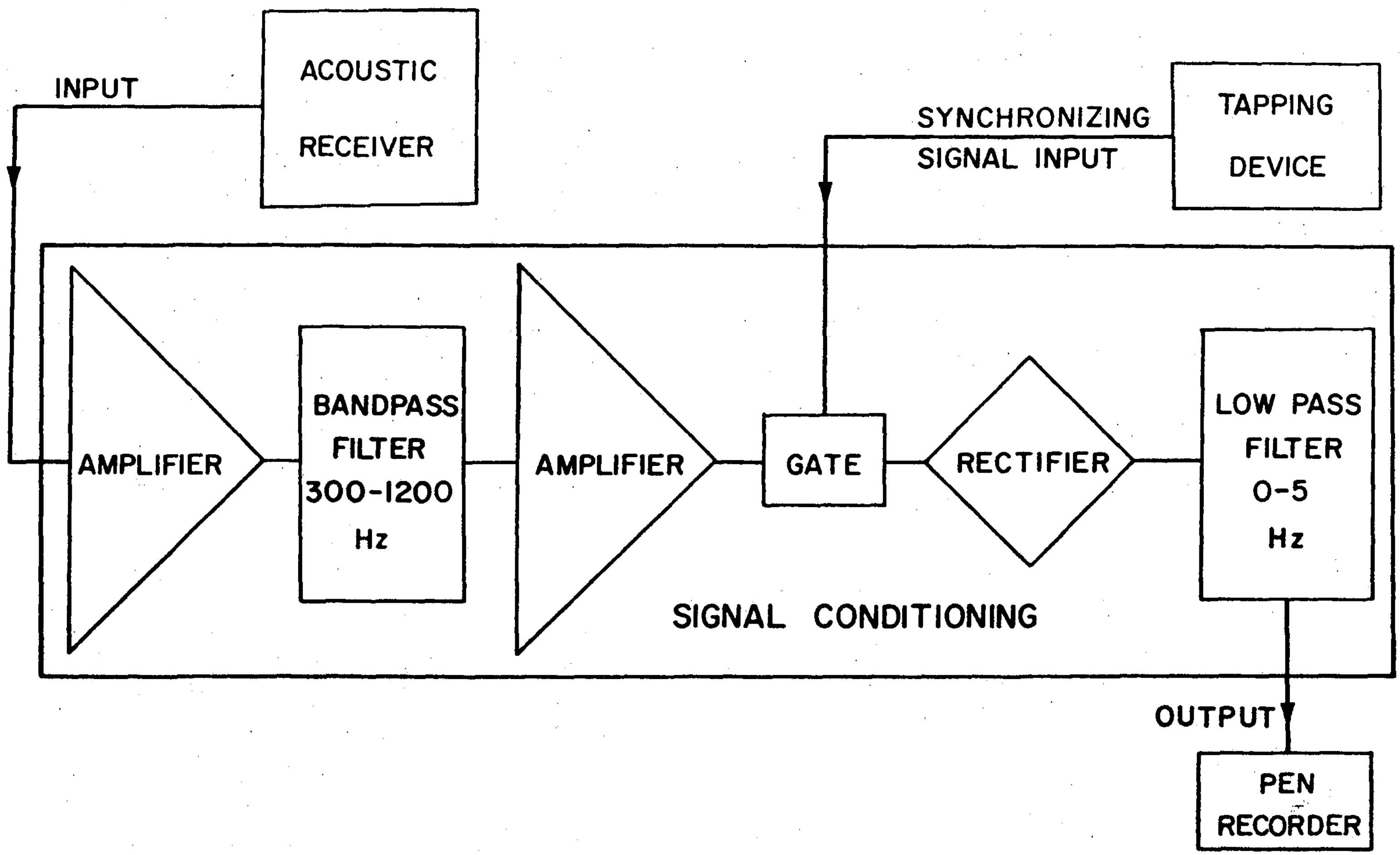

FIGURE 7: Block diagram of the signal conditioner which accepts the signal from the acoustic receiver and transmits to the pen recorder a voltage indicative of either solid or delaminated concrete.

4. DELAMINATION DETECTOR UNIT

The basic components developed in this study and described in the previous section have been incorporated into the delamination detector 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 twelve inches apart, and with two tapping wheels spaced six inches apart and centered between the receivers (Figure 9). Since the unit detects delamination only when a receiver and a tapping wheel are simultaneously over a delaminated area, the unit surveys two three-inch-wide parallel paths that are six inches 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 which houses the tapping device and rolling receivers, (b) a two channel pen recorder, (c) a control unit which contains two signal conditioning channels, and (d) a power pack which contains a small storage battery and an inverter for 120 volt AC. The disassembled unit is shown in Figure 10. Assembly or disassembly of the unit on site takes less than one minute.

The two-pen recorder uses four-inch-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 foot of traverse. On solid concrete the pens remain at a stable small value

FIGURE 8: Delamination detector in operation.

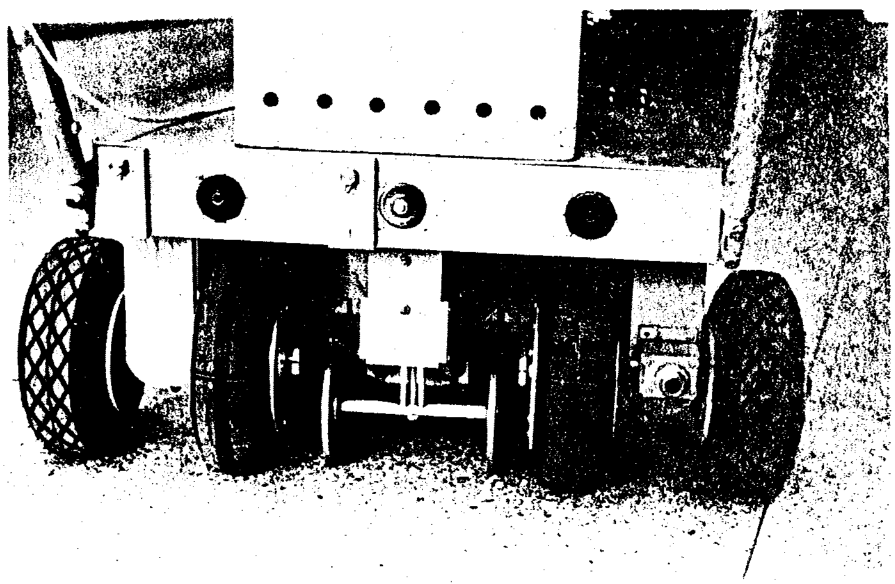

FIGURE 9: A rear view of the delamination detector. The acoustic receivers are spaced 12 inches apart and the tapping wheels, 6 inches apart. The outer wheels support the cart.

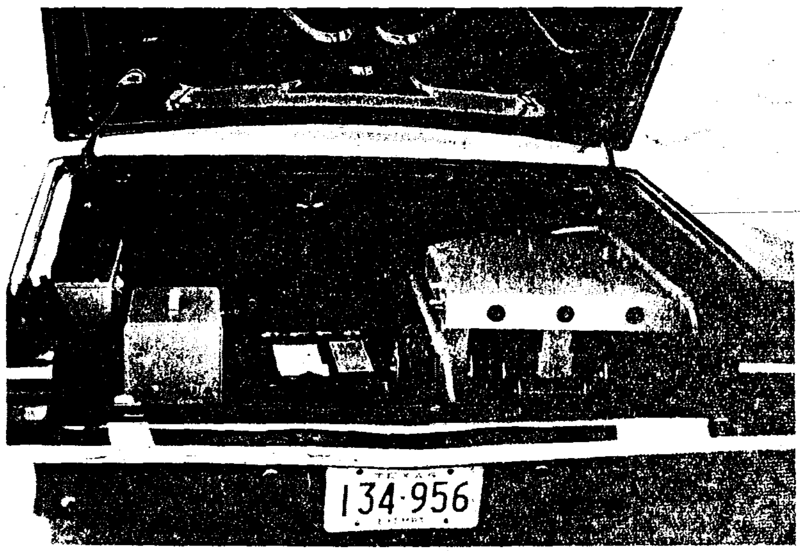

FIGURE 10: Delamination detector disassembled and stowed in an automobile trunk. From left to right: power pack, control unit, recorder and main frame.

(near zero on the transverse scale) and excursions larger than about 2 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, etc), it is normally not necessary to adjust any of them for operation.

The operation 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 power pack will provide sufficient power to operate the detector continuously for more than ten hours. For routine operations, it is charged each night for the next day's operation.

5. EVALUATION

In the early phase of the research, the two rectangular test slabs that are shown in Figure 11 were constructed to simulate bridge deck delamination. One of these slabs is about one-half inch thick and the other is slightly less than two inches 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 twenty-six bridge decks suspected of containing delaminations. Significant amounts of delaminated areas were found in about half of these bridges which were scattered over a wide area in Texas.

Results obtained from traverses about eighty feet long made on two typical bridges are illustrated in Figure 12. The upper record is from a bridge in which no delaminations could be detected and the lower record is from another bridge that contains many delaminations (any signal larger than two minor chart divisions is an indication of delamination). The lower record also illustrates that the two channels are independent. Delaminations were encountered in the left survey path at points where they

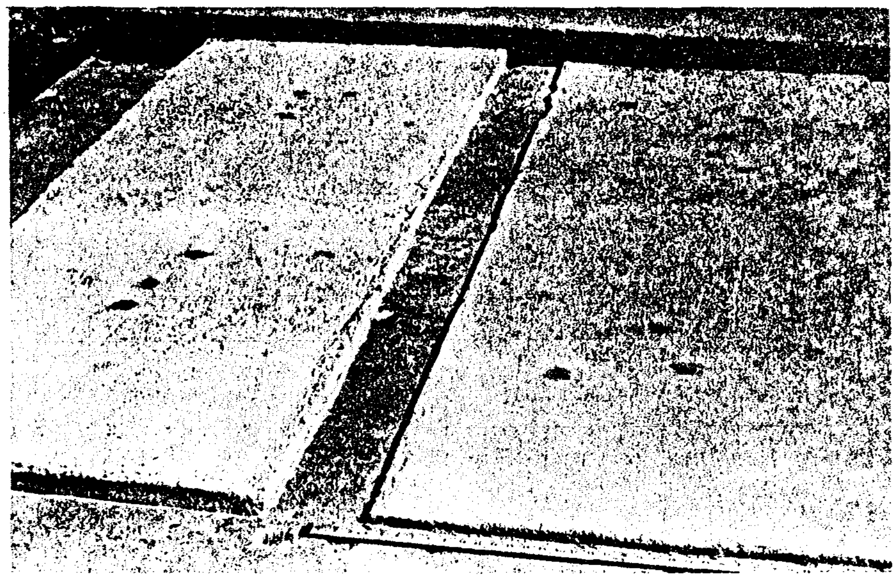

FIGURE 11: Test slabs used for development of delamination detector. The far halves of the slabs are delaminated and the near halves are bonded.

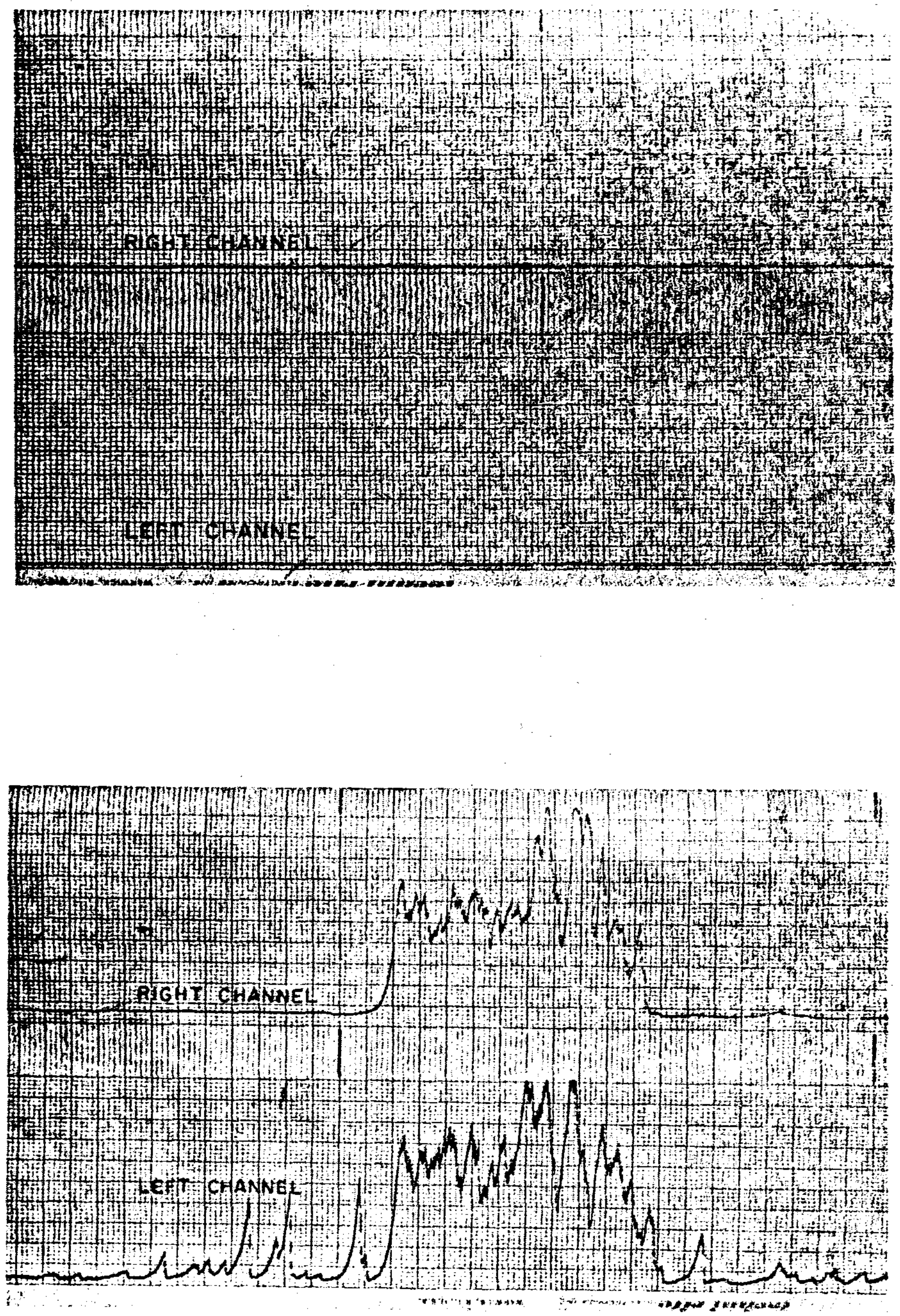

FIGURE 12: Typical records obtained with the delamination detector. The upper record was made on a solid deck and the lower record on a deck which contained many delaminations.

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. Typical multiple path records are illustrated in Figure 13.

The ability of the delamination detector to distinguish delaminated from solid concrete was verified by coring six different bridges. On each bridge one core was taken at a location where delamination was not indicated and another at a location where delamination was indicated. Agreement was perfect. No evidence of delamination or horizontal cracking could be found upon examination of the walls of the core holes at the six locations where delamination was not indicated. Delamination was obvious upon examination of each of the other six holes. Typical results are illustrated in Figure 14. The depth of the horizontal cracks at the six delaminated areas varied from one-half to three and one-half inches.

Several of the twenty-six 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. Two of the six decks cored had thin layers of asphaltic surfacing, one a seal coat and the other a half-inch asphaltic concrete overlay. Since the instrument performed well on these bridges it is concluded that the detector is insensitive to deck texture and to layers of asphaltic surfacing less than approximately one-half inch in thickness. The effect of thicker asphaltic

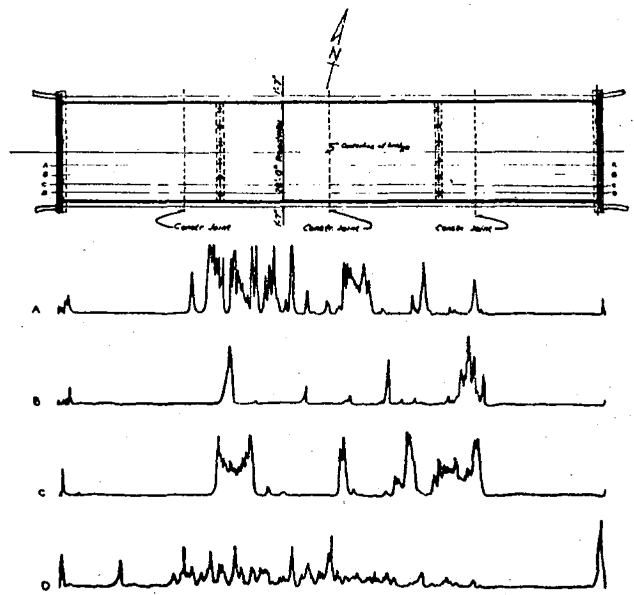

FIGURE 13: Multiple path records made on a bridge deck. Most of the delaminations found in this deck were in the middle two slabs.

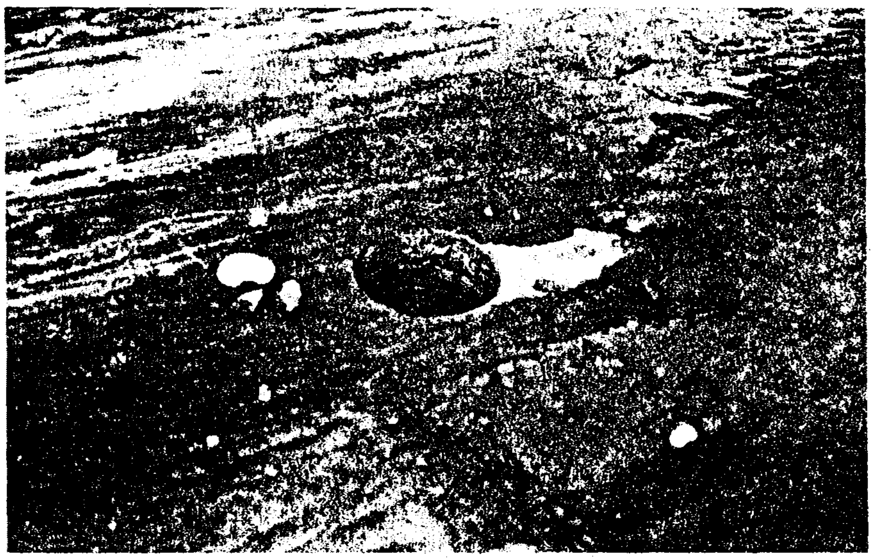

FIGURE 14: Typical results found by coring at a location where delamination was indicated by the unit.

6. 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.

2. The detector is easy to operate and practical for routine use.

3. The detector is insensitive to deck texture or thin asphaltic surfacing layers.

4. The operation of the instrument is not impaired at rolling speeds up to about ten miles per hour.

7. IMPLEMENTATION STATEMENT

The results reported here clearly indicate that multiple-path, automatic delamination detection is practical and possible. A detector can be designed and constructed that will survey a lane of a bridge at one time. Using modern data acquisition and reduction techniques, a map showing the delaminated areas of the deck can be automatically produced with such a detector.

The researchers believe that the present detector should be used in an extensive investigation to determine the growth pattern and uncover the causes of bridge deck delamination.

8. REFERENCES

1. Tallamy, Bertram, D. and Associates, "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures", National Cooperative Highway Research Program Report 1, Highway Research Board, National Academy of Sciences, National Research Council, Washington, D. C., 1964.

2. Nichols, D. R., "Sonic Testing Device", United States Patent No. 3,361,225, January 2, 1968.