A FIELD INVESTIGATION OF CONCRETE PAVEMENT IN TEXAS

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This investigation involved an examination of current technology on concrete consolidation, current continuously reinforced concrete pavement consolidation practices in Texas, and selected current concrete pavement problems through field examination and laboratory investigation. Principal conclusions reached are as follows: (a) Although the vast majority of concrete pavements are in excellent condition, inadequate concrete consolidation has been found in many areas of Texas, the most prevalent locations occurring adjacent to transverse construction joints in CRCP; and (b) with proper construction control, rigorously enforced, these isolated consolidation problems can be minimized. Based on these conclusions, recommendations are made that involve the introduction of more effective construction controls and the introduction of selected changes in current practices.

In recent years continuously reinforced concrete pavement (CRCP) has come into extensive use. Performance studies have shown that cracking patterns in CRCP are related to the uniformity of the concrete and the degree to which it is uniformly consolidated (1). The purpose of this study was to examine the vibration techniques and practices used to consolidate the concrete and determine if the current practices might be improved. The study involved 3 phases: (a) an examination of current technology in the field of concrete consolidation, (b) an examination of current CRCP consolidation practices in the Texas Highway Department, and (c) an evaluation of current concrete pavement problems existing on selected Texas pavements.

DESCRIPTION OF THE PROBLEM

In Texas today there are many miles of excellent CRCP in service. However, on some projects problems have occurred. Some of these problems have been the result of improper consolidation of the concrete.

One location that has been particularly troublesome for CRCP is the area adjacent to construction joints, or headers as they are sometimes termed. As shown in Figure 1, the concrete adjacent to the joint is badly cracked and the bottom is honeycombed, as seen on the core turned upside down to show the honeycombing. Such areas that appear to indicate this type of distress are rather prevalent in the older paving projects throughout the state.

In addition to construction joints, problems resulting from improper consolidation have occurred randomly in isolated, small locations on many projects. Although such

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problems are not nearly so prevalent as observed distress adjacent to construction joints, they do occur frequently enough to be of concern to the highway engineer. Invariably, the question arises: How may such areas of distress be prevented?

Figure 1. Areas of distress adjacent to a construction joint in CRCP (core upside down to show honeycombing).

CURRENT TECHNOLOGY

Although literature in the field of concrete consolidation is extensive, most of it deals with consolidation of concrete used in such structures as beams, columns, floor slabs, and dams. Reports in the areas of concrete pavement consolidation are somewhat limited in number. The major findings from the literature survey were as follows:

1. Vibration of fresh concrete is not new. Significant reports have been published for more than 35 years (2, 3, 4). Such reports indicate that vibration cannot overcome the lack of proper spreading (3).

2. In well-proportioned concrete of proper consistency (not over 1½-in. slump for concrete pavement), it is very difficult to overvibrate (5, 6). Even vibration placed directly on the reinforcement actually improved bond strength (7).

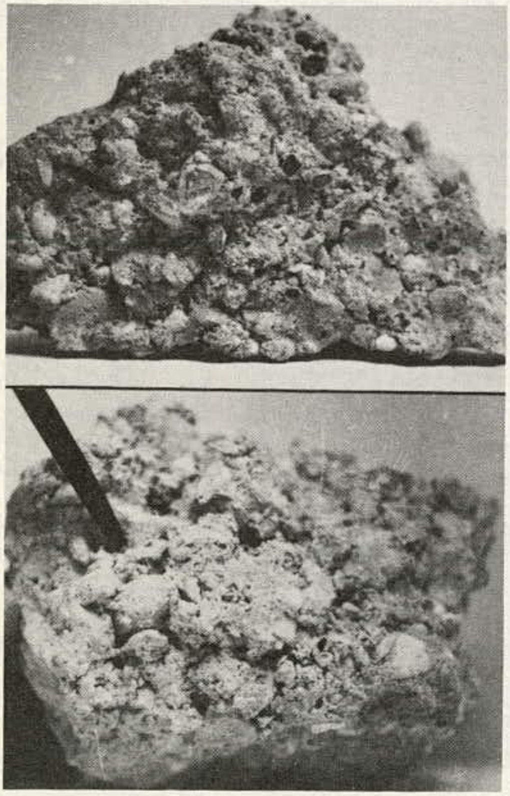

Figure 2. Honeycombed concrete taken from bottom side of continuously reinforced concrete pavement.

3. Surface vibration gives adequate consolidation of reinforced concrete pavements, provided that sufficient amplitude and time of vibration are supplied by the surface unit (8). Surface vibrators should have frequencies in excess of 3,500 vpm (5).

4. Internal vibrators should have frequencies in excess of 7,000 vpm (5).

POSSIBLE PROBLEM CAUSES

Unconsolidated or honeycombed concrete usually develops when concrete is dumped on the grade without spreading and flash set occurs, or when the concrete is spread out and either is allowed to segregate or is inadequately vibrated or not vibrated at all. In Texas, CRCP is constructed with the reinforcing steel at the mid-depth of the slab. Through this obstruction the relatively dense mass of low-slump concrete must flow. Thus, it is sometimes difficult for the desirable mix to be adequately consolidated. As the concrete passes through the spacings between the reinforcing bars, it needs to be vibrated by mechanical means, such as either the conventional pan type of surface vibrator or the conventional spud type of internal vibrator. Both have been used to satisfactorily consolidate pavement. However, as stated earlier, there have been projects in which the concrete was vibrated and where areas of distress have occurred because of improperly consolidated concrete (Fig. 2). It is hypothesized that, in a concrete matrix such as this, very little tensile strength could be expected from the concrete.

As mentioned in the previous section, pavement distress has also occurred where improper consolidation was not found. The probable causes for this distress may include factors such as loss of subgrade support, improper curing, weak concrete, concrete that achieves its strength too fast, or a combination of these.

CURRENT CONSOLIDATION PRACTICES

When Texas first began using CRCP, the specifications did not include mechanical vibration of the plastic concrete; however, it was optional with the contractor. This soon proved to be unwise, and vibration became a required item. About 1960 the Texas Highway Department began specifying mechanical vibration of paving concrete with both surface and internal methods allowed on paving projects. The first specification concerning vibration was rather "loose" as it did nothing more than specify vibration, and to this date for the spud type of internal vibrator the specifications still do not include any requirement concerning amplitudes or frequencies. For the pan type of vibrator, a frequency range is recommended, but neither frequency nor amplitudes are specified.

Special coring operations on problem pavements throughout the state have shown that no single vibration method is the lone culprit causing the unconsolidated or honeycombed areas that contribute to distress. Because areas adjacent to transverse construction joints are not accessible with machine vibrators on the paver itself, they usually have to be vibrated by hand-operated mechanical vibrators. This is usually not an easy task and areas can be missed. Large areas are not necessary to cause failure in CRCP because the slab thickness is, in most pavements, 8 in. thick. The current special provision on mechanical vibratory equipment used by the Texas Highway Department is as follows:

> All concrete placed for pavement shall be consolidated by approved mechanical vibrators operated ahead of the transverse finishing machine and designed to vibrate the concrete internally and/or from the surface. Unless otherwise shown on the plans, vibrators of the surface-pan type will be used for two-lift placement of concrete and the internal type will be used for full-depth placement. Vibratory members shall extend across the pavement practically to, but shall not come in contact with the side forms. Mechanically-operated vibrators shall be mounted in such manner, as not to come in contact with the forms or reinforcement and not to interfere with the transverse or longitudinal joints.
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> The internal-type vibrators shall be equipped with synchronized vibratory units. Separate vibratory units shall be spaced at sufficiently close intervals to provide uniform vibration and consolidation to the entire width of the pavement. The frequency of the internal type vibratory units and the method of operation shall be as determined by the engineer. The Contractor shall have a satisfactory tachometer available for checking the vibratory elements.
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> The pan-type vibratory units shall apply the vibrating impulses directly to the surface of the concrete. The operating frequency shall be not less than 3500 cycles nor more than 4200 cycles per minute. The Contractor shall have a satisfactory tachometer available for checking the speed of the vibratory elements.
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> The pavement vibrators shall not be used to level or spread the concrete, but shall be used only for the purposes of consolidating. The vibrators will not be operated where the surface of the concrete, as spread, is below the elevation of the finished surface of the pavement and the vibrators shall not be operated for more than 15 seconds while the machine upon which they are installed is standing still.
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> Approved hand manipulated mechanical vibrators shall be furnished in the number required for provision of proper consolidation of the concrete along forms, at joints and in areas not covered by mechanically controlled vibrators. These vibrators shall be sufficiently rigid to insure control of the operating position of the vibration head.

In addition to this special provision, one or more of the following practices have also been followed: (a) use of a mechanical spreader; (b) reduction of maximum size of coarse aggregate from 2½ to 1½ in.; (c) use of a coarse aggregate factor in the range of 78 to 82; and (d) a more rigid restriction of grading on the fine aggregate.

FIELD INVESTIGATIONS OF CONCRETE PAVEMENT PROBLEM AREAS

Sections of CRCP were initially selected from 3 areas of the state. These sections were examined for pavement problem areas, and from certain areas cores 4 in. in diameter were taken for evaluation. The evaluation of each core included dynamic modulus of rigidity (9), density of the top and bottom portions, and splitting tensile strengths of the top and bottom portions (10). In every area an attempt was made to obtain a sound core, that is, one that did not contain a crack or reinforcing steel. Although this was not always achieved, the majority of the cores were sound. From suspected problem sites, a total of 50 cores was taken. The data were analyzed statistically by using normal distribution functions and, for each parameter, the average, median, standard deviation, variance, and coefficient of variation were determined.

The average and standard deviations for splitting tensile strength and bulk density were compared for each area and are shown in Figure 3. The comparisons are in terms of top of core, bottom of core, and overall values. Figure 3 shows some interesting findings. First, considered as a group in each area, the concretes are of excellent quality as indicated by the high densities and high splitting tensile strengths. Second, the concretes sampled are uniformly consolidated as indicated by the very low standard deviations in density values. Third, although at first glance the standard deviations for splitting tensile strengths appear to be rather high (122 psi in one instance), this can be

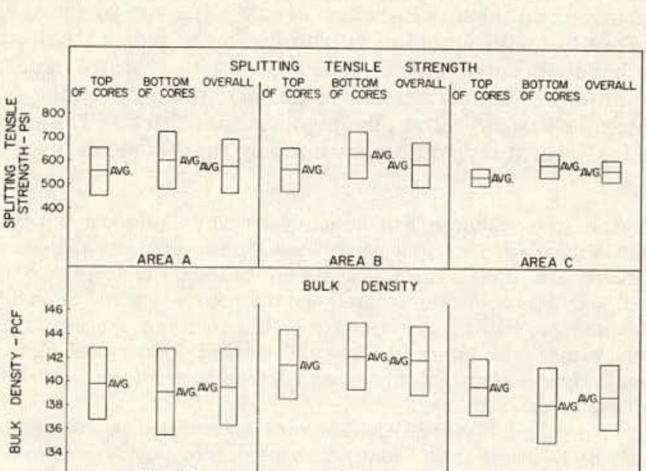

Figure 3. Comparison of splitting tensile strength and bulk density values of cores from 3 areas.

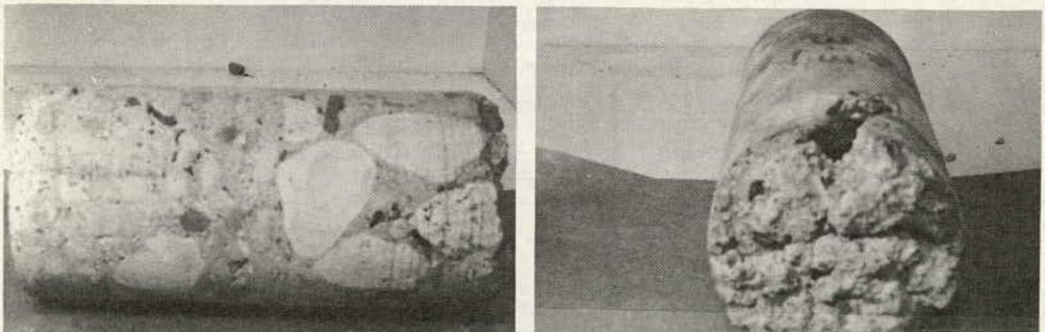

Figure 4. Core 3-3 from area B.

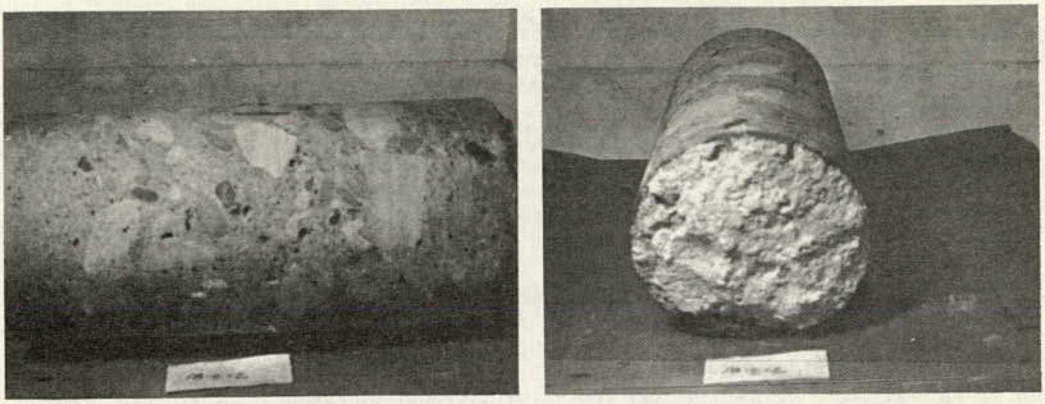

Figure 5. Core 2-2 from area B.

easily explained by the few cores exhibiting low strength or honeycombing. The remainder of the strengths are uniformly high. Fourth, improper consolidation was found in only 6 of the 24 sites investigated. Thus, although improper consolidation was found in these 3 areas, it does not appear to be too widespread a cause for localized pavement distress, with the exception of distressed areas at construction joints on some of the older projects.

Pictures of selected cores are shown in Figures 4 and 5. Figure 4 depicts a suspected honeycombed area in the bottom of the core resulting from improper consolidation, and Figure 5 shows concrete segregation with the top 2 in. devoid of any coarse aggregate. A fourth area of the state (area D) contained a CRCP project in which extensive honeycombing occurred. Although this area was investigated and reported in another investigation (11, 12), the data concerning the evaluation of the cores are included here.

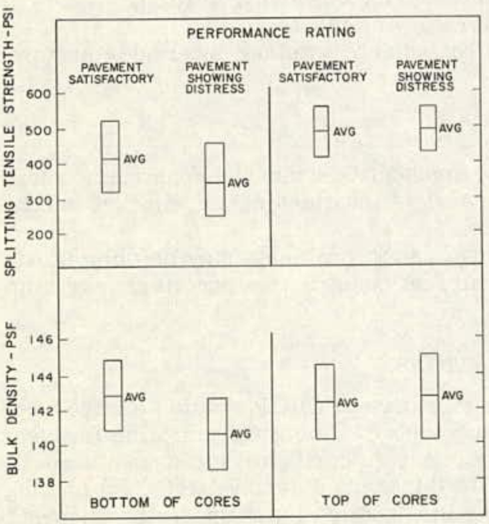

Figure 6. Comparison of tensile strength and bulk densities for top and bottom of concrete cores from good and poor performing pavement sections in area D.

A total of 40 cores were obtained, two at each location. One core was selected from a section of the pavement showing distress and another from an adjacent section that appeared to be performing satisfactorily. These data were analyzed statistically, and the results are shown in Figure 6. In the distressed sections, the average density of the bottom halves of the cores was 140.8 pcf, while the average density of the top halves of the cores was 142.6 pcf. Even though the density values were scattered, there is a difference in densities, indicating that the bottoms may have been poorly consolidated. This conclusion is verified by the splitting tensile strengths, also shown in Figure 6. Here the strengths of the bottom halves of the cores were significantly lower than the corresponding strengths of the top halves. One other point should be made. When the splitting tensile strengths of all the bottom halves of the cores in area D were compared, the average value was 382 psi, with a standard deviation of 100 psi and a coefficient of variation (C_V) of 26 percent. The average strengths of the bottom halves of the cores in the other 3 areas were 605, 619, and 576 psi. These are significantly higher than the strengths reported for area D. It is dangerous to draw any firm conclusions from these data because of the variations in mix design and aggregate types, but it does appear that area D contained some weak concrete, which may have contributed to the many failures that occurred. This is more fully discussed in another report (12).

NEED FOR STATISTICAL CONTROL OF CONSOLIDATION

In present Texas construction practices there is no quantitative measurement of the degree of consolidation being obtained. Experiences in the field certainly do indicate that some type of control measure would be desirable. As indicated in the current special provision for surface vibratory equipment by the Texas Highway Department, checks on the frequency are required. There are measurements such as this check to make sure that the equipment used is operational and operating properly; but because no requirements presently exist concerning frequency on the spud type of vibrator, there is not much control that can be exercised over the equipment. Thus, it becomes necessary to check the product being produced, in this case the pavement. Cores are drilled for thickness determination and payment. It would appear to be sensible to use these same cores, or a larger population of cores, for checks on consolidation as well as on thickness. Acceptance for consolidation would be desirable on a statistical basis, although research in this area would certainly be needed before establishing the statistical limits.

SYNTHESIS OF PRESENT PRACTICES

The survey of present practices now being used in Texas for constructing CRCP indicates that several items now being required in isolated areas of the state should be made part of the standard specifications for general use throughout the state. The following items should be made part of the standard specifications:

1. Require the use of a mechanical spreader;
2. Reduce the maximum size of the coarse aggregate from 2½ to 1½ in.;
3. Use coring operations as a check on consolidation as well as on thickness;
4. Assign a trained inspector the sole job of ensuring uniform vibration;
5. Make a tachometer available to check vibratory elements; and
6. Require visual indication on equipment to indicate whether internal vibrators are operating.

CONCLUSIONS

1. Distress that appears to be attributed to inadequate concrete construction has been found in many areas of Texas; the most prevalent locations occur adjacent to transverse construction joints in CRCP.
2. With improved construction control, consolidation problems may be minimized
3. The introduction of selected changes in current construction practices may minimize consolidation problems.

RECOMMENDATIONS

1. More effective construction control over vibration of CRCP should be introduced and could be accomplished by (a) requiring a tachometer to measure vibration frequency at regular intervals on all projects; (b) utilizing concrete coring or some nondestructive technique to inspect consolidation in addition to thickness determinations; (c) making inspectors more aware of the potential problems in consolidation, especially adjacent to transverse construction joints; and (d) requiring a visual indication on equipment to indicate whether internal vibrators are operating.

2. Selected changes in current practices should be introduced to include (a) standardizing present practices, as much as possible, throughout the state; (b) requiring a mechanical spreader on all projects; (c) reducing the maximum size of the coarse

gregate from 2½ to 1½ in. on all projects; and (d) requiring a minimum frequency, in air, of 7,000 vpm for internal vibrators.

If these recommendations are implemented, there is reasonable confidence that distressed areas in concrete pavement attributable to improper consolidation may be minimized.

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