Development of Rolling Compaction Machine for Preparation of Asphalt Beam Samples

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A rolling compaction machine developed for fabricating asphalt beam samples is described. The machine was developed as a part of a research program for evaluating the rutting resistance of asphalt mixes using the loaded wheel tester. The uniqueness of this machine is that the asphalt beam sample is compacted by a rolling compaction action that simulates the compaction of asphalt mixes in the field. The machine is capable of fabricating beam samples up to 375 mm long by 175 mm wide by 125 mm thick. The overall dimensions of the machine are 1.2 m long by 0.45 m deep by 1.3 m high. The machine is portable and easy to operate. The experience of the Georgia Department of Transportation through one year of extensive use of this machine has shown that it can improve quality and productivity of fabricating asphalt beam samples. Results of the bulk densities of the asphalt beam samples fabricated by this compaction machine as well as by the static compaction procedure using a universal testing machine are presented. Three types of asphalt mixes—a surface mix, a base mix, and a stone mastic asphalt mix—were used for preparing the beam samples by the different compaction methods. To evaluate the density variation in each beam sample, the density of the whole beam was first measured, the sample was then sawed in sections (sometimes as many as 12), and densities of all sections were measured. Results from three studies presented indicated that the maximum variation of density for beam samples compacted by the rolling compaction procedure was under 1.5 percent. Visual observations of all asphalt beam samples made by the three compaction methods showed that samples prepared by rolling compaction have the least amount of crushed aggregates.

A rolling compaction machine developed exclusively for fabricating asphalt concrete beam samples is described. This machine was developed as a part of the research program for evaluating the rutting resistance of asphalt mixes using the loaded wheel tester (LWT). In this testing method, asphalt beam samples conditioned at elevated temperatures (40°C) are subjected to a repeated wheel loading of controllable wheel load (450 N) and contact pressure (0.69 MPa). Rut depths developed on asphalt beam samples at the end of 8,000 cycles of load repetitions are measured and used to assess rutting characteristics of asphalt mixes. The LWT procedure was developed by Lai (*1–3*) in collaboration with the Georgia Department of Transportation (GaDOT). This procedure has been incorporated into GaDOT Standard Test Procedure GDT-115 "Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester" as a supplement to the Marshall mix design method for the design of asphalt mixes. This procedure has also been used by other highway agencies to evaluate rutting characteristics of asphalt mixes (*4*).

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Preparation of asphalt beam samples to required compaction densities is an integral part of the LWT procedure. Unlike the dedicated Marshall compaction apparatus for preparing Marshall samples, no standard procedure or dedicated asphalt beam sample compaction apparatus is available for preparing asphalt beam samples for LWT. Several compaction procedures, including the kneading compaction method, and different static compression procedures for preparing the asphalt beam samples were developed and tested with varying degrees of success in the course of conducting LWT studies (*1,3*). The consensus from the users of LWT, including those participating in a round robin test program of LWT (*5*), was that a dedicated compaction apparatus for preparing asphalt beam samples could significantly ease sample preparation and improve the quality of asphalt beam samples and thus the accuracy of LWT results.

The rolling compaction machine described in this paper was developed to meet this need. The machine is capable of fabricating beam samples up to 375 mm long by 175 mm wide and up to 125 mm thick, although at the present time the beam sample dimensions are set at 300 mm long by 125 mm wide by 75 cm thick. The uniqueness of this compaction machine is that the asphalt beam sample is compacted by a rolling compaction action, which is intended to simulate the compaction of asphalt mixes in the field. The machine can also compact the asphalt mix when it is in the kneading compaction mode.

REVIEW OF PREVIOUS ASPHALT BEAM SAMPLE COMPACTION PROCEDURES

Kneading Compaction Procedure

Initially the asphalt beam samples used in the LWT test were fabricated by a California kneading compactor. The loose asphalt mix was placed in the heated beam mold, and the rectangular-shaped loading foot of the kneading compactor was activated to apply controllable compressive forces on the asphalt mix in the mold. The beam mold was moved manually on the sliding track during the compaction operation to effect the uniform compaction of the beam sample. The beam was compacted in two or three lifts. After the top layer was compacted to approximately the required height, a heated thick steel plate was placed on top of the beam and high pressure was applied to compress the mix in the mold to the final required height. This sample preparation method was used for preparing the beam samples in the early studies by Lai (*1,2*) for evaluating the rutting characteristics of asphalt mixes using the LWT. This procedure has also been used to prepare asphalt beam samples for evaluating fatigue properties.

Use of the kneading compaction method to fabricate beam samples was quite time consuming. A significant amount of aggregate crushing was observed on the compacted beam samples caused by the high contact pressure of the steel kneading foot. Another drawback of this method was that a special kneading compaction machine was required that was not readily available in most of the testing laboratories.

A different type of kneading compactor called the HasDek SLAB-PAC linear kneading compactor was developed by R/H Specialty & Machine (Terre Haute, Ind.). In this compaction procedure a beam sample mold is filled with a weighed amount of asphalt mix; the mix was calculated on the basis of the desired final density and the volume of the mold. A series of 125-mm thick steel compacting plates are placed on top of the loose asphalt mix. A roller is then lowered against the steel plates to force them to press into the loose asphalt mix while the asphalt mix and the beam mold move back and forth on a sliding table (see Figure 3). By controlling the downward movements of the roller, the asphalt mix in the beam mold can be compacted to the prescribed thickness.

Static Compaction Procedure

A simplified procedure to fabricate the beam samples by static compression was developed by Lai (*3*). This procedure utilizes a compression machine to press the weighed amount of asphalt mix in a sturdy steel beam mold to the required density. This procedure is simple to perform and is readily implementable since most testing laboratories are usually equipped with some type of compression machine suitable for this procedure.

The static compaction procedure has produced satisfactory density requirements (*5*), although the procedure is viewed to be cumbersome. The other concern was that the properties of the beam samples fabricated by the static compaction procedure, such as the orientation and interlocking of aggregate particles in the beam sample, may be different from the asphalt mixtures compacted in the field. The round robin test program showed that the variability was quite high for bulk densities of beam samples fabricated by different laboratories using different static compaction machines but the same compaction procedure (*5*). However, the single-laboratory variability of beam sample densities from each participating laboratory was quite low. Results of the round robin tests and the comments from the other users strongly suggested that development of equipment with dedicated rolling type beam sample compaction is highly desirable.

French Sample Compaction Method

The French compaction machine was developed by the Laboratory Central des Ponts et Chaussées (LCPC) to prepare asphalt beam samples for wheel tracking testing to evaluate rutting of asphalt mixtures (*7*). The machine used a 415-mm diameter by 109-mm wide wheel with smooth-tread tire that can move longitudinally and laterally against the beam sample mold filled with loose asphalt mixes. The maximum size of the beam sample that can be fabricated by this machine is 600 mm long by 400 mm wide by 150 mm thick. According to the report (*7*), different compaction procedures can be used to achieve different degrees of compaction. The advantages of this compaction procedure are that (*a*) relatively large samples can be fabricated and (*b*) the resulting aggregate orientation pattern and level of void content in the asphalt beam samples will be closer to those obtained in actual pavements. The main disadvantage is probably the high cost of the equipment, which is in the neighborhood of $100,000.

ROLLING COMPACTION MACHINE DEVELOPMENT

The important considerations in the development of this compaction machine were the ability to simulate the rolling compaction action of asphalt mixes in the field, ease of beam sample fabrication, ability to fabricate asphalt beam samples with uniform and controllable densities, and the cost of the machine. The rolling compaction machine (Figures 1 and 2) has overall dimensions of 0.45 m wide by 1.20 m long by 1.30 m high. The machine is portable and can be easily moved near the asphalt batching facility.

The machine consists of the following four basic components:

- Sliding motion assembly,
- Rolling compactor assembly,
- Beam sample mold, and
- Hydraulic system and operational control.

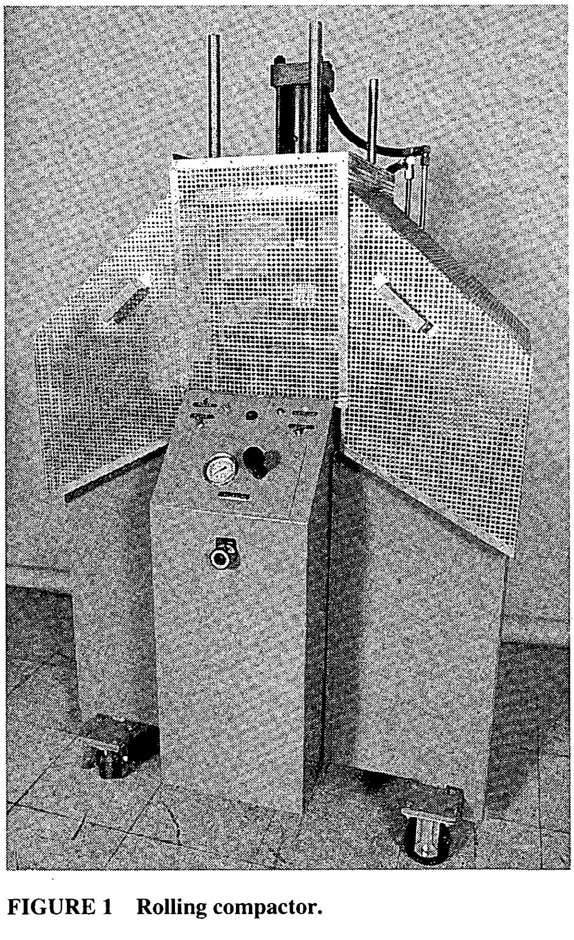

FIGURE 1 Rolling compactor.

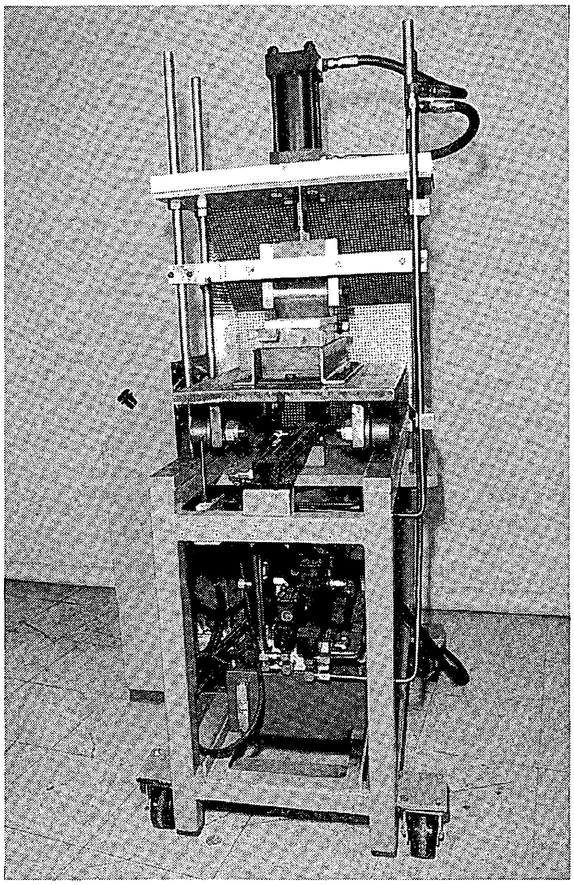

FIGURE 2 Rolling compactor (side view).

Sliding Motion Assembly

The sliding plate assembly, shown in Figure 2, consists of a 25-mm-thick steel plate 450 mm wide and 600 mm in length having four heavy-duty roller bearings attached to the bottom of the plate. The bearings are aligned longitudinally and ride on two rails. The bottom of the plate is connected to a horizontally aligned double action hydraulic cylinder. The extension and retraction action of the piston rod generates the reciprocating sliding motion of the plate. The beam sample mold restraints are on the top of the sliding plate. These removable restraints are used to secure the beam mold.

Rolling Compactor Assembly

The rolling compactor assembly generates the force for compacting the beam samples. The assembly, shown in Figures 2 and 3, consists of a load frame, a double-action hydraulic cylinder, and a compaction roller. The system is capable of applying 54 kN of force to the beam sample. Two horizontal restraining bars, one on each side of the roller clevis, are installed to restrain the horizontal movements of the roller caused by the shear force developed between the beam sample and the roller. Installation of the restraining bars is needed to minimize the wear of the cylinder bearings. During beam sample compaction, the roller exerts an adjustable vertical pressure through a nylon pad placed on top of the loose asphalt mixture in the beam mold. When the compaction roller presses against the semistiff nylon pad, it deforms and creates a curvature comparable with the curvature of a compaction roller used in the field (see Figure 4). The combined actions of the horizontal reciprocating motion of the beam mold, adjusted to approximately 3 rpm, the curvature on the nylon pad, and the vertical force from the compacting roller cause the asphalt mix confined in the beam mold to be compacted in a rolling action similar to the compaction of asphalt mixes in the field.

A kneading-type compaction similar to that of the HasDek linear kneading compactor (R/H Specialty + Machine, Terre Haute, Ind.) can easily be adapted to this compaction machine by replacing the nylon pad with a loading pad consisting of a series of loosely connected steel plates (see Figure 4).

Beam Sample Mold

Beam sample mold assembly is shown schematically in Figure 5. It includes a split mold made of a 5-mm steel plate, a loosely fitted bottom plate, and the restraints made of steel angle sections. The restraints are bolted down to the sliding plate to confine the lightweight split beam mold during compaction. Only one restraint section needs to be removed to free the beam mold. The light weight of the beam mold and ease of removing the compacted beam sample from the split beam mold make beam sample fabrication much easier than the static compaction procedure described previously.

Hydraulic System and Operational Control

A schematic diagram of the hydraulic system controlling compaction operation is shown in Figure 6. The horizontal reciprocating motion of the sliding plate is controlled by a horizontal actuator activated by an On-Off toggle switch, and the speed of the horizontal motion is adjustable by a flow control valve. When activated by the solenoid, the actuator pushes (or pulls) the sliding plate at a constant speed in one direction until it contacts the limiting switch positioned at the extreme end. When the limiting switch is activated on contact, it causes the solenoid to reverse the direction of motion of the actuator and the sliding plate to move in the opposite direction until it contacts another limiting switch positioned at the other extreme end. Thus, the sliding plate automatically slides back and forth horizontally at a constant speed within the travel length set by the limiting switches.

The movement of the compaction roller is controlled by Up and Down switches on the control panel. When the Down switch is activated, the solenoid causes the cylinder rod of the vertical actuator to extend and applies a vertical force through the roller on the nylon pad. The magnitude of the vertical force is manually controlled by a pressure regulator.

To prevent overcompaction on the asphalt beam sample, the machine is also equipped with a vertical limiting switch that controls the maximum downward movement of the compacting roller. The position of this limiting switch can be adjusted so that when the beam is compacted to the desired depth, the switch is activated and causes the vertical actuator to retract, thus preventing possible over-

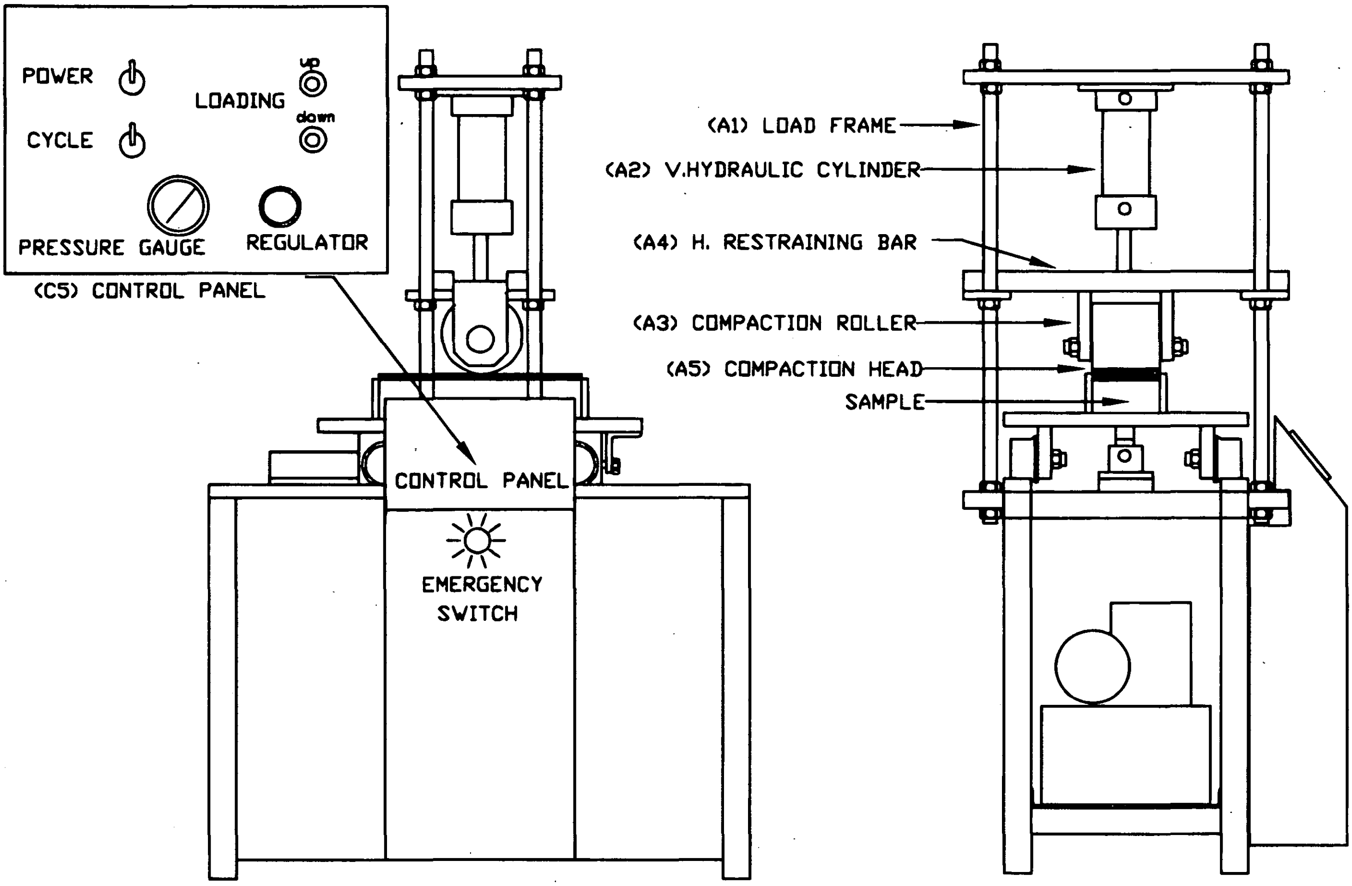

FIGURE 3 Schematic of rolling compactor.

compaction of the beam sample. Additional compaction, if needed, can be done by manually depressing and holding the Down button to cause the actuator to extend and apply the compressive force on the sample. A horizontal line inscribed on the side of the nylon pad can be used as the reference to detect uneven compaction of the beam sample. This reference line can also be used to determine the level of compaction of the beam sample. When the reference line is level with the top edge of the beam mold, the asphalt beam sample in the beam mold has been compacted to the predetermined 75-mm height. The vertical actuator can only be activated when the horizontal sliding movement of the plate is already in action. Whenever the horizontal cycle switch is turned to the Off position to stop the sliding action, the vertical actuator will automatically retract, preventing any application of compaction on the beam sample when the horizontal motion is accidentally stopped.

BEAM SAMPLE COMPACTION PROCEDURE

The procedure for using this machine to fabricate asphalt beam samples is as follows:

1. Pour the hot asphalt mix into the mold, spade the loose mixture thoroughly, and spread the mix evenly in the mold. Place the nylon pad (for rolling compaction) or the steel kneading pad (for kneading compaction) on top of the asphalt mix.
2. Secure the beam mold on the sliding plate with the restraining brackets.
3. Turn on the power, and activate the "Cycle" switch. The sliding plate will begin to make horizontal cyclic motions. Activate the "DOWN" switch to initiate the compaction, using a small force initially and gradually increasing the force to a predetermined maximum. Allow the beam sample to be compacted under the reciprocating rolling or kneading actions until the predetermined density requirement has been reached.
4. When the required compaction has been achieved, deactivate the Cycle switch, which causes the roller to retract and the sliding plate to stop at the far end. While it is still warm, remove the beam mold from the machine and extract the split beam mold (except the bottom plate) from the compacted sample.

Since the procedures for rolling compaction with the nylon pad and kneading compaction with the steel kneading pad (HasDek SLAB-PAC linear kneading compactor) are essentially the same, a comparison of these two compaction procedures was also made. The following summarizes the differences in the operational characteristics of these compaction procedures. Use of rolling compaction can occasionally develop an unevenly compacted beam sample if

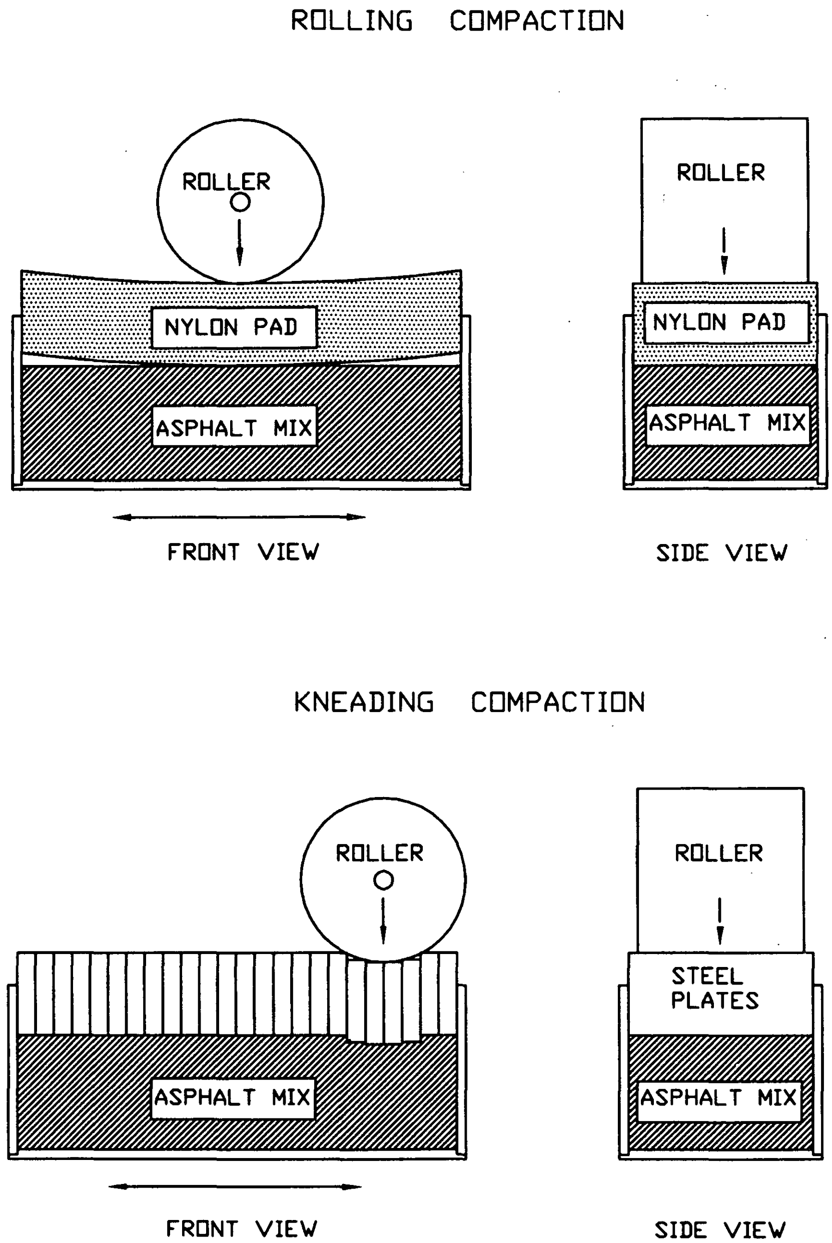

FIGURE 4 Schematics of rolling compaction and kneading compaction.

the initial compaction force applied on the loose mix is too high or if some tender asphalt mixes have low stability. The control system has the capability to allow for manual adjustment via the control switches to correct this problem. The kneading compaction procedure using the steel kneading pad minimizes this problem to a certain extent. Kneading compaction is somewhat easier to use and the compaction force can be applied faster, thus reducing the time required to compact the beam sample. These are the advantages of the kneading compaction procedure over the rolling compaction procedure. On the other hand, kneading compaction tends to cause a higher percentage of aggregates crushed in the beam sample. Also, kneading compaction does not seem to simulate field compaction of asphalt mixes as the rolling compaction procedure does. A typical time required to fabricate a beam sample, excluding the batching of asphalt mix, is about 15 and 10 min, respectively, for rolling and kneading compactions. Results of the beam densities obtained from the asphalt beam samples fabricated by these two procedures are presented in the next section.

RESULTS

The purpose of the studies presented here is to evaluate the variabilities of the beam densities within each beam sample fabricated by different compaction methods. The difference between the averaged beam densities of beam samples fabricated by different compaction methods has no significance because the level of compaction can be changed by altering the magnitude of the maximum

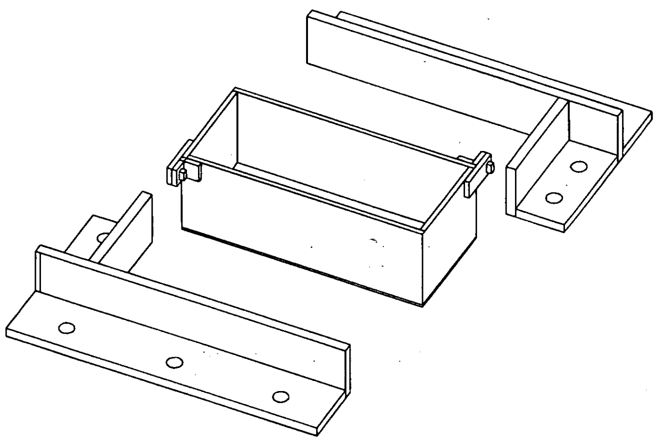

FIGURE 5 Schematic of beam mold assembly.

compaction force as well as the duration of such force applied in each compaction method.

Rolling Compaction Versus Static Compaction

Beam samples from two different mixes, a base mix (B-mix) and a stone-mastic asphalt mix (SMA-mix), were prepared by the rolling compaction procedure using the machine described in this paper and by the static compaction procedure. Two beam samples from each mix were fabricated, one by rolling compaction and one by static compaction. The following density measurements were made for each sample.

1. Determining the density of the whole beam sample;
2. Sawing the beam sample longitudinally in two halves and measuring the density of each half; and
3. Sawing half of the beam transversely in three parts identified as A, B, and C and measuring the density of each part.

Results of the density values are shown in Figure 7. The maximum density variations in the beam samples made by rolling compaction are 0.3 and 1.1 percent for the B-mix and the SMA-mix, respectively, and the maximum deviations are 1.6 and 0.9 percent for the B-mix and the SMA mix, respectively, for the beam samples made by the static compaction method. The corresponding air voids are also shown in Figure 7. For rolling compaction, a maximum force of 36 kN (8,000 lb) and 45 kN (10,000 lb) was applied for compaction of the B-mix and the SMA-mix, respectively. For static compaction, a 540-kN (120,000-lb) force was applied for both the B-mix and the SMA-mix. The significant difference in the compaction forces required between rolling compaction and static compaction indicates that in rolling compaction the contact width between the nylon pad and the asphalt mix has to be quite narrow to develop a sufficient contact pressure generated by the 36- to 45-kN

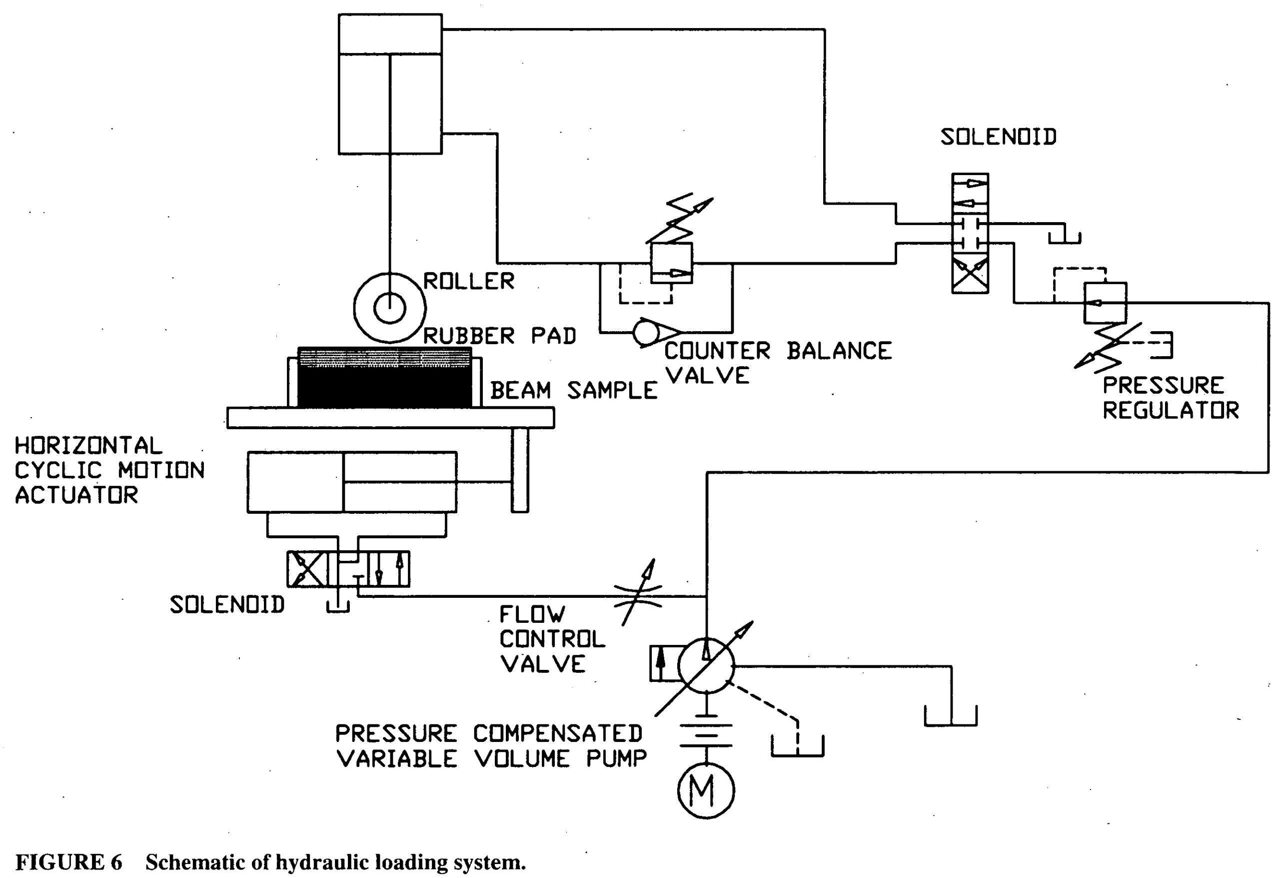

FIGURE 6 Schematic of hydraulic loading system.

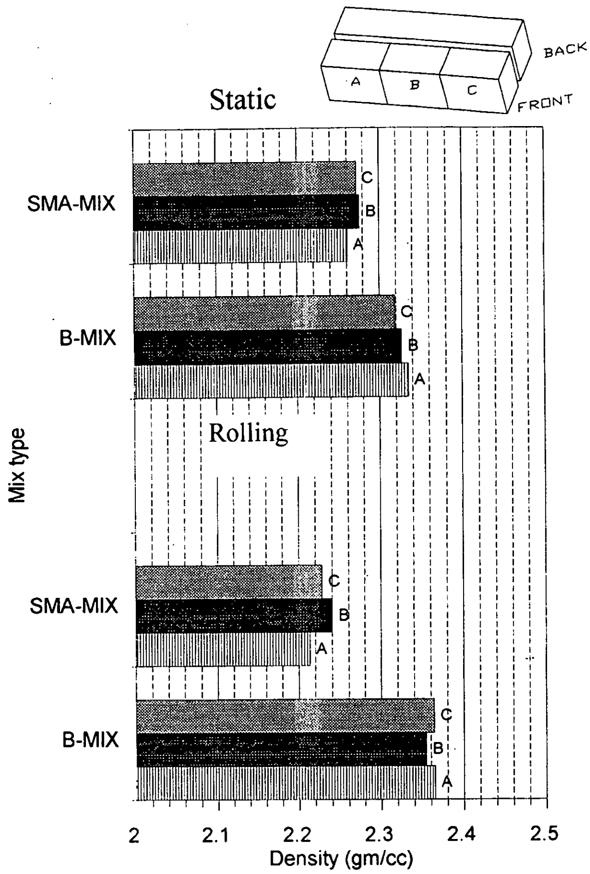

FIGURE 7 Results of rolling compaction versus static compaction.

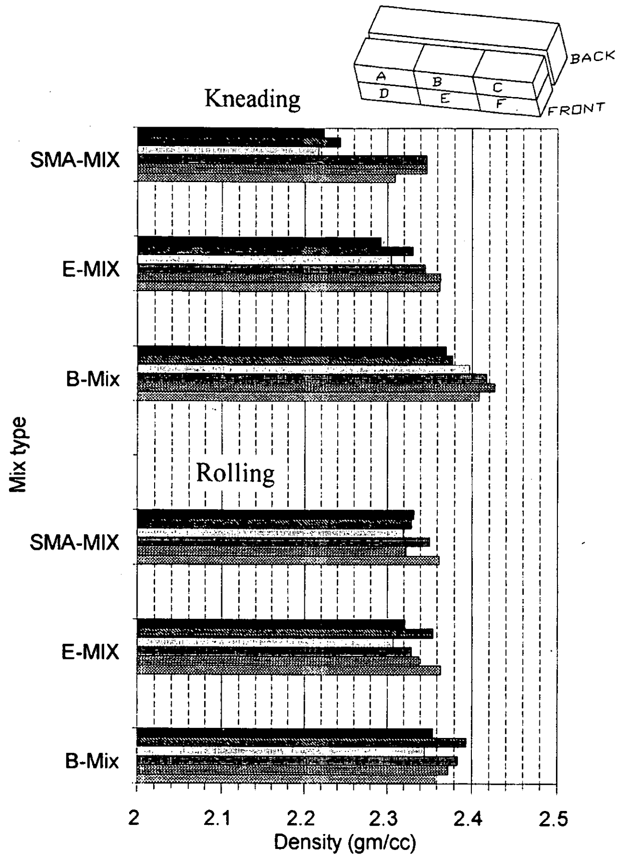

FIGURE 8 Results of rolling compaction versus kneading compaction.

force to compact the loose asphalt to the required densities. A noticeable amount of crushed aggregate particles was seen on the surfaces of the beam samples made by the static compaction method.

Rolling Compaction Versus Kneading Compaction

Three different asphalt mixes were selected in this study, a B-mix, an E-mix (surface mix), and an SMA-mix. Six beam samples were fabricated, two for each mix, with one fabricated by using the rolling compaction method and the other by using the kneading compaction method. The following density measurements were made for each beam sample.

1. The density of the entire beam sample was determined;
2. The beam samples were sawed longitudinally in two halves and the density of each half was measured; and
3. One half of the beam was sawed horizontally at mid-height and transversely into three approximately equal widths, and the bulk densities of all six sections were measured.

The results of the density measurements are shown in Figure 8. Among the beam samples fabricated by the rolling compaction method, the maximum variation of beam densities within each beam is 1.5 percent of the averaged value. There are no consistent trends of variation of the densities within beam samples. Among beam samples fabricated by the kneading compaction method, the top portions of all three beam samples have higher densities than those of the bottom portions. The difference is most noticeable for the SMA-mix where there is an average difference of 3.5 percent between the top and bottom half of the beam sample. From the visual inspection of the exposed sample surfaces, the aggregate concentration and the particle orientation were somewhat different between the upper and lower halves of the beam. Bleeding of asphalt was visible also near the bottom of the lower half of the beam samples. It was observed that many more aggregates were fractured among the beam samples fabricated by the kneading compaction method. This is not surprising as the steel plates exerted higher concentrated loads on the aggregates during the course of compaction. This type of aggregate crushing was also observed previously in the asphalt beam samples fabricated by the kneading method using the California kneading machine.

Additional asphalt beam samples were fabricated by both compaction methods, and the beam densities were measured. In this additional series of studies, each beam sample was sawed horizontally at mid-height and transversely into six approximately equal widths. Results of the density measurements of the 12 portions for each beam sample are shown in Figures 9 and 10. The densities in the beam samples fabricated by the kneading compaction method are much more consistent with the maximum deviation being 1.25 percent throughout the whole beam sample while that from the rolling compaction method exhibited more variation.

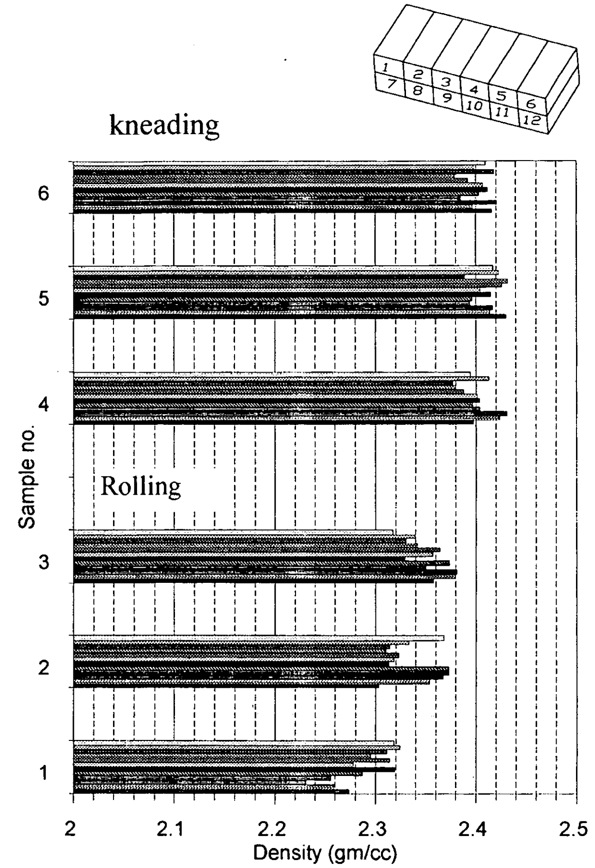

FIGURE 9 Results of rolling compaction versus kneading compaction, B-mix second testing series.

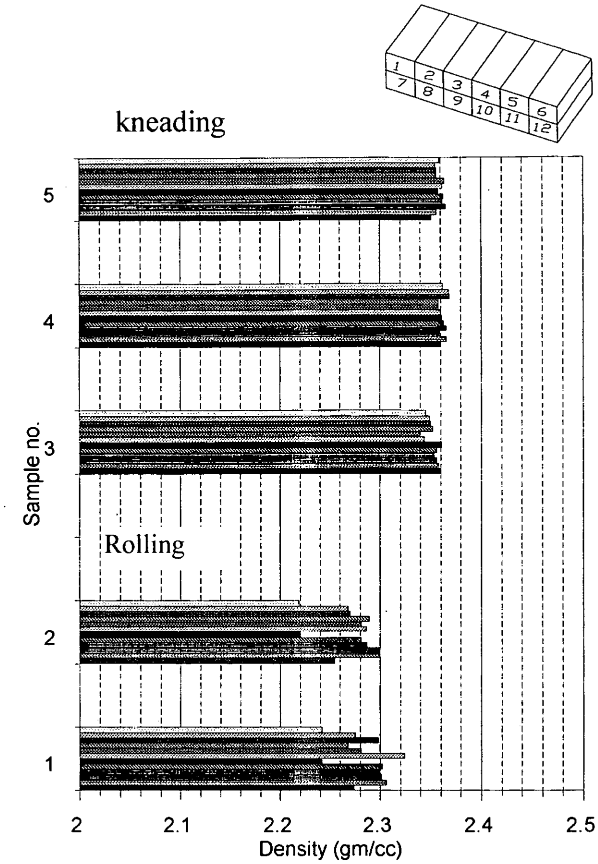

FIGURE 10 Results of rolling compaction versus kneading compaction, E-mix, second testing series.

CONCLUSIONS

The rolling compaction machine has been used extensively to fabricate asphalt beam samples for evaluating rutting characteristics of asphalt mixes since September 1993 by the Office of Materials and Research of the Georgia DOT. The experience of the Georgia DOT has shown that this machine is easier to use than the static compaction procedure, can fabricate asphalt beam samples with uniform and controllable densities, and can significantly improve the productivity of fabricating asphalt beam samples. Since the rolling compaction and the kneading compaction methods each offer certain advantages over the other, additional evaluations will be made in the future round robin evaluation program before deciding which method should be adopted as the standard procedure for fabricating asphalt beam samples.

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