Preparation of Asphalt Concrete Test Specimens Using Rolling Wheel Compaction

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Traditional techniques for preparation of asphalt concrete specimens for the purposes of mixture design, quality control, and research activities in the United States have, for the most part, utilized the Marshall hammer or the California kneading compactor. Recent research has shown that these techniques, particularly the Marshall method, do not simulate field compaction as well as either gyratory shear or rolling wheel compaction techniques. Because gyratory shear and rolling wheel compaction better simulate the field, researchers at Oregon State University (OSU) considered these two alternatives for the preparation of specimens to be used in the water sensitivity work as part of a Strategic Highway Research Program contract conducted at OSU and the University of California at Berkeley. Because of the necessity of fabricating large prismatic ("beam") specimens, the gyratory shear compactor was eliminated from consideration (this compactor can produce only cylindrical specimens). The procedure developed at OSU to produce asphalt concrete specimens utilizing rolling wheel compaction is described. The following were significant findings: (a) rolling wheel compaction is practical for the production of asphalt concrete test specimens in a research laboratory; (b) large numbers of specimens of various geometries can be produced on a daily basis; (c) slab width, length, and thickness are easily varied; and (d) the equipment and procedure can easily accommodate the fabrication of pavement layers such as overlays (e.g., open-graded mixture over a dense-graded mixture).

In the United States the laboratory methods most commonly used to prepare asphalt concrete specimens include the Marshall hammer and the Hveem kneading compactor. Developments from NCHRP (*1*) and the Strategic Highway Research Program (SHRP) (*2*) have indicated that the laboratory compaction methods that best duplicate the field include the gyratory and the rolling wheel compactor. As a result, SHRP will be recommending that the gyratory or rolling wheel compactor be utilized for mix design for heavy-duty highways. The rolling wheel would be used if beam fatigue tests were to be included in the mix design process.

This paper describes the rolling wheel compaction process used at Oregon State University (OSU) in conjunction with SHRP Project A-003A entitled "Performance Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures." In particular, it presents an overview of the facility and describes the mixing, compaction, and cutting or coring process. Finally, it outlines the costs of the equipment, time and personnel requirements, and perceived advantages and disadvantages of the method.

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FACILITY AND EQUIPMENT

The rolling wheel compaction process used at OSU resulted in prismatic and cylindrical samples that were evaluated as a part of the water sensitivity study for SHRP Project A-003A. The process requires the following equipment:

1. A modified portland cement concrete mixer, shown in Figure 1, included heating elements to maintain the required mixing temperatures for batch weights up to 136 kg (300 lb).
2. Figure 2 shows the ovens used for heating the asphalt, aggregate, and asphalt-aggregate mixtures. The small oven is used solely for the asphalt, whereas the larger oven is required to accommodate the approximately 136 kg (approximately 300 lb) of mixture.
3. Figure 3 shows a schematic of the mold used at OSU. Both the plan dimensions and the height can be easily adjusted to accommodate slabs of various sizes. Slab size is limited only by the mixer and oven capacity.
4. A tandem steel wheel compactor was used throughout. Other compaction devices such as that used at the University of California at Berkeley (UC-Berkeley), SWK-University of Nottingham (SWK/UN), and Exxon (New Jersey) can also be used. Figure 4 shows the roller used at OSU.

SPECIMEN PREPARATION PROCEDURE

Specimen preparation for this research effort was accomplished by means of rolling wheel compaction. Table 1 provides a brief description of the procedure. The procedure was developed at OSU to prepare specimens to be tested in the Environmental Conditioning System (ECS), the OSU wheel tracker (LCPC rutting tester), and the SWK/UN wheel tracker as part of the water sensitivity study.

Mixing

The mixing process is shown in Figure 5. The mixer consisted of a conventional concrete mixer modified to include infrared propane heaters (see Figure 1) to heat the mixer bowl before mixing as well as to reduce heat loss during the mixing process. The preheated and preweighed aggregate is added to the mixer followed by the asphalt. The mixture, typically 124.7 to 131.5 kg (275 to 290 lb), is mixed in a single batch. After mixing,

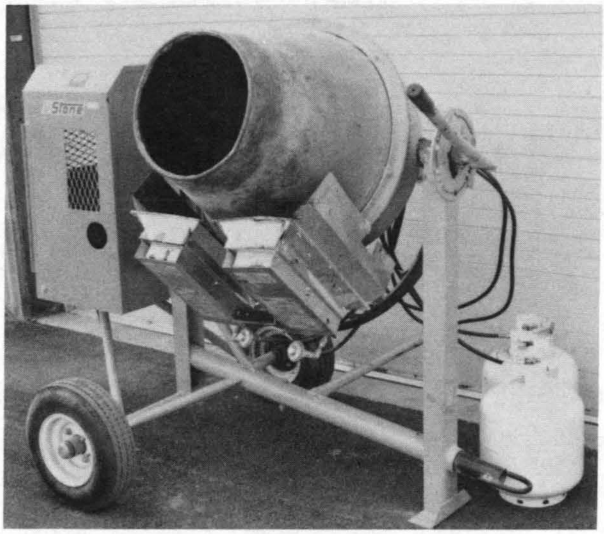


FIGURE 1 Asphalt-aggregate mixer used at OSU.

the asphalt-aggregate mixture is placed in a forced-draft oven set to 135°C (275°F) and "short-term aged" for 4 hr to simulate the amount of aging that occurs in a batch or drum dryer plant. The mixture is stirred once each hour to promote uniform aging.

Compaction

At the completion of the aging process, the mixture is placed in the mold and compacted to a predetermined density. The density is determined on a weight-to-volume basis for the specific mixture being compacted and for the specific air void level required. The compacted slab (Figure 6) is then allowed to cool overnight (approximately 24 hr), after which beam specimens are sawn and core specimens are drilled from the slab (Figure 7). The specimens are cut dry, without the use of water, to prevent errors in density and void analysis and initial air permeability tests. In addition, specimens prepared for water sensitivity tests such as the ECS should not be subjected to water before that test procedure.

Typical Void Data

As expected, a variation in density existed in the compacted slab. Slight variations in the air void levels (typically ± 0.6 percent) existed in the longitudinal and transverse directions, whereas larger variations (typically less than ± 1.5 percent) existed with depth. Figure 8 shows typical variations in air voids with depth: Figure 8 (*top*) indicates air voids calculated using bulk specific gravities determined by the saturated-surface-dried (SSD) method (ASTM D2726), whereas Figure 8 (*bottom*) indicates air voids calculated using bulk specific gravities measured with parafilm. In all but one case (RC aggregate, SSD method), the density is lower at the surface and bottom relative to that at middepth. The SSD method for determining bulk specific gravities resulted in the lowest density at the bottom of the slab; the parafilm method for determining bulk

FIGURE 2 Oven used in the specimen preparation process: (*top*) asphalt oven [0.065 m^3 (2.3 ft^3)]; (*bottom*) aggregate/mixture oven [0.71 m^3 (25 ft^3)].

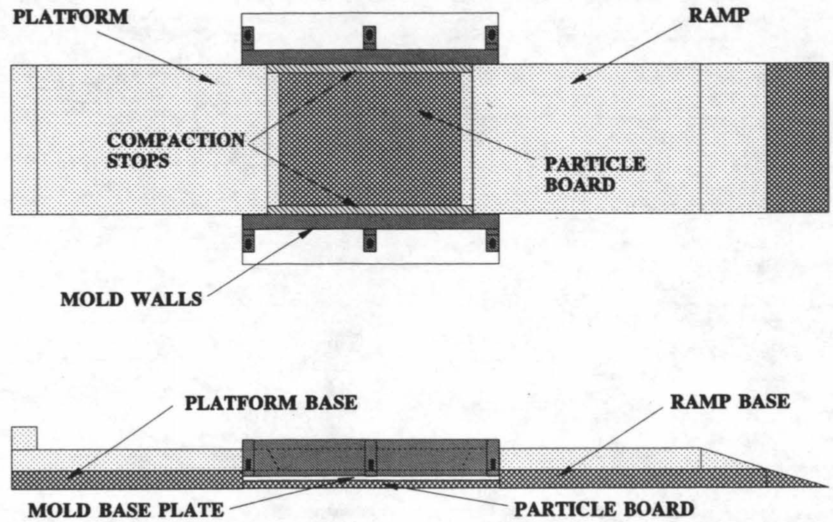


FIGURE 3 Compaction mold.

specific gravities generally resulted in nearly equal densities at the surface and bottom of the slab. This is not surprising because the SSD method for determining bulk specific gravities does not account for surface voids, as does the parafilm method. That is, in the SSD method, water drains out of the surface voids while measuring the SSD mass, thus neglecting the void spaces at the surface and bottom of the specimen. Harvey et al. (*3*) discuss the differences between the two methods for determining bulk specific gravities in more detail.

The density gradients in the slab can be attributed primarily to temperature gradients in the mixture during compaction. Invariably, the temperature at the top and bottom and around the perimeter of the slab was lower than that in the center and at middepth. The aggregate type (i.e., quarry rock versus gravels), aggregate gradation, and segregation of the mixture also contribute to density gradients in the compacted slab. Other laboratories (*3*; G. M. Rowe, unpublished data) have reported similar findings.

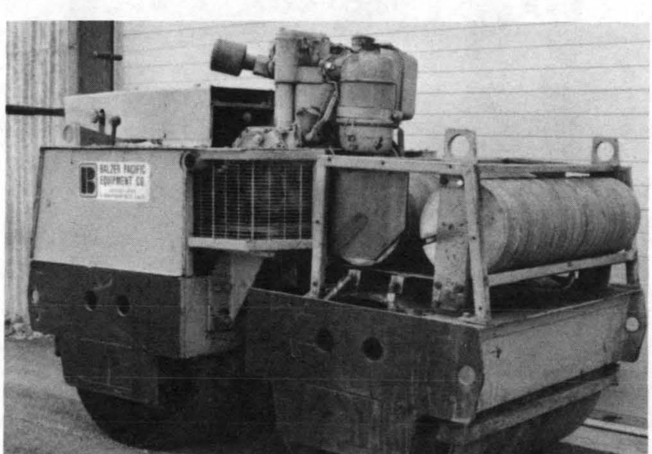


FIGURE 4 Rolling wheel compaction used at OSU.

It is the authors' opinion that a variation in density with depth is actually desirable because such variation simulates what actually occurs in the field. That is, the same conditions (temperature gradients, segregation, etc.) exist in both the laboratory and the field; therefore it can be surmised that a density gradient with depth also exists in the field.

ASSESSMENT OF PROCEDURE

In a research laboratory such as that at OSU, the procedure for the preparation of specimens by means of rolling wheel compaction has associated with it definite advantages over traditional techniques; at the same time, however, it is not without some disadvantages. This section discusses the perceived advantages and disadvantages of the rolling wheel compaction method compared with the Marshall and Hveem methods. Also discussed are comparisons of time, space, and personnel requirements as well as equipment costs.

Advantages

The following is a discussion of the perceived advantages of rolling wheel compaction relative to Marshall and Hveem compaction techniques.

Production of Varying Specimen Geometries

With rolling wheel compaction it is possible to produce specimens of widely varying geometries. Cylinders of various lengths and diameters, prismatic beams of various lengths, widths, and thicknesses, pyramidal specimens—all of these may be produced from one slab (i.e., one job mix formula). The dimensions of the parent slab, from which the test specimens are derived, can be easily varied to produce test specimens of virtually any practical size. At OSU the slab dimensions were typically 710 mm long by 710 mm wide by 102 mm thick

TABLE 1 Summary of Specimen Preparation Procedure for SHRP A-003A Task D.2.e.

Step	Description
1	Calculate the quantity of materials (asphalt and aggregate) needed based on the volume of the mold, the theoretical maximum (Rice) specific gravity of the mixture, and the desired percent air voids. Batch weights ranged between 124.7 to 131.5 kg (275 and 290 lbs) at an air void content of 8 ± 1%.
2	Prepare the asphalt and aggregate for mixing.
3	Heat the materials to the mixing temperature for the asphalt (170±20 cS). Mixing temperatures ranged between 137 and 160° C (279 and 320° F).
4	Mix the asphalt and aggregate for four (4) minutes in a conventional concrete mixer fitted with infrared propane burners and preheated to the mixing temperature for the asphalt.
5	Age the mixture at 135 ° C (275° F) in a forced-draft oven for four (4) hours stirring the mixture every hour to represent the amount of aging which occurs in the mixing plant.
6	Assemble and preheat the compaction mold using infrared heat lamps.
7	Place the mixture in the compaction mold and level it using a rake. Avoid segregation of the mixture.
8	Compact the mixture when it reaches the compaction temperature using a rolling wheel compactor until the desired density is obtained. This is determined by the thickness of the specimen (the only volumetric dimension that can be varied during compaction for a set width and length of slab). Steel channels with depth equal to the thickness of the slab prevent over-compaction of the mixture. Compaction temperatures (based on 630 ± 20 cS) ranged between 112 and 133 ° C (234 and 271° F).
9	Allow the compacted mixture to cool to room temperature (≈24 hours).
10	Disassemble the mold and remove the slab. Dry cut (saw) beams for the OSU and SWK/UN wheel trackers. Dry cut cores for the ECS.

(28 × 28 × 4 in.), from which the following were obtained: two beams 500 × 180 × 102 mm (20 × 7 × 4 in.); two beams 320 × 115 × 102 mm (12.5 × 4.5 × 4 in.); four cores 102 mm (4 in.) in diameter by 102 mm (4 in.) in height; and a Rice gravity specimen 2.5 kg (5.5 lb) (see Figure 7). At UC-Berkeley as many as 21 specimens consisting of cores 102 mm (4 in.) in diameter of varying lengths and prismatic beams 51 mm (2 in.) square by 200 to 380 mm (8 to 15 in.) in length were obtained from a single slab.

Obviously, this constitutes a distinct advantage over the Marshall method, which produces specimens either 102 or 152 mm (4 or 6 in.) in diameter by 64 mm (2.5 in.) in height. Similarly, the rolling wheel compaction method has an advantage over the Hveem method in that a greater number of beams of larger size can be produced by the rolling wheel.

Simulation of Field Construction Techniques

One obvious advantage of the rolling wheel compaction method is that it closely simulates techniques used in actual field construction. Use of a concrete mixer fitted with propane burner elements (Figure 1) simulates the drum dryer, and use of the rolling wheel simulates field compaction. In the laboratory, the mixture is compacted over a rigid base (as opposed to a flexible base in the field unless overlaying concrete or a hard asphalt pavement), and some lateral confinement occurs on the perimeter of the slab. However, as indicated in Figure 7, a portion of the slab [approximately 50 mm (2 in.) around its perimeter] is discarded to minimize the effects of lateral confinement.

It has been found that the rolling wheel as well as the kneading and gyratory compactors better simulate the field

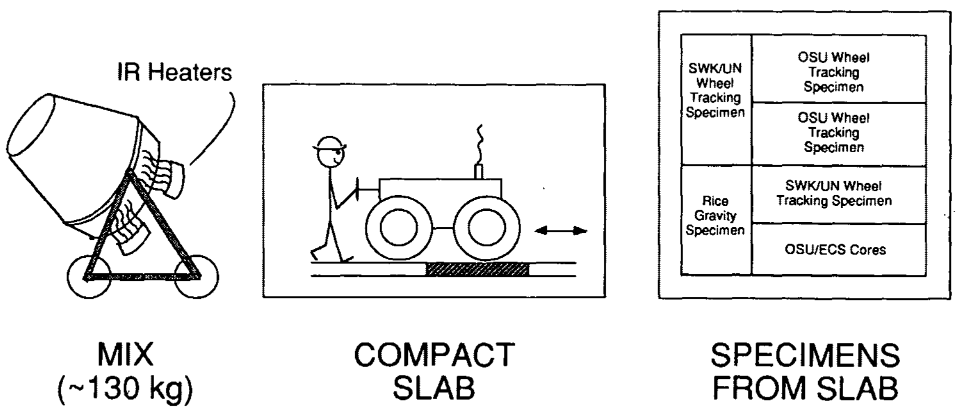


FIGURE 5 Mixing process.

FIGURE 6 Compacted slab.

than does the Marshall hammer, a procedure that has effectively been eliminated as a viable compaction method (*1*).

Although the Hveem method (kneading compactor) produces specimens with greater resistance to permanent deformation than does the rolling wheel and, in some respects, more sensitivity to mixture composition (namely, aggregate type and in particular angularity and surface texture), Sousa et al. (*2*) report that

> it may create a more stable aggregate matrix than is commonly developed by conventional construction practice, thereby failing to capture the critical role of the asphalt binder in properly performing pavements. Rolling-wheel compaction seems to be the preferred procedure for laboratory compaction. Among the methods investigated, it seems to best duplicate field-compacted mixtures.

Production of All Specimens for Mixture Design from One Batch

Another distinct advantage of the rolling wheel method, as opposed to all other methods, is that all specimens required for mixture design can be fabricated from a single batch. And, because it is likely that the proposed SHRP mix design and analysis system will require a large number of specimens, it appears that the rolling wheel method deserves serious consideration.

Disadvantages

The following are the perceived disadvantages of the rolling wheel compaction method.

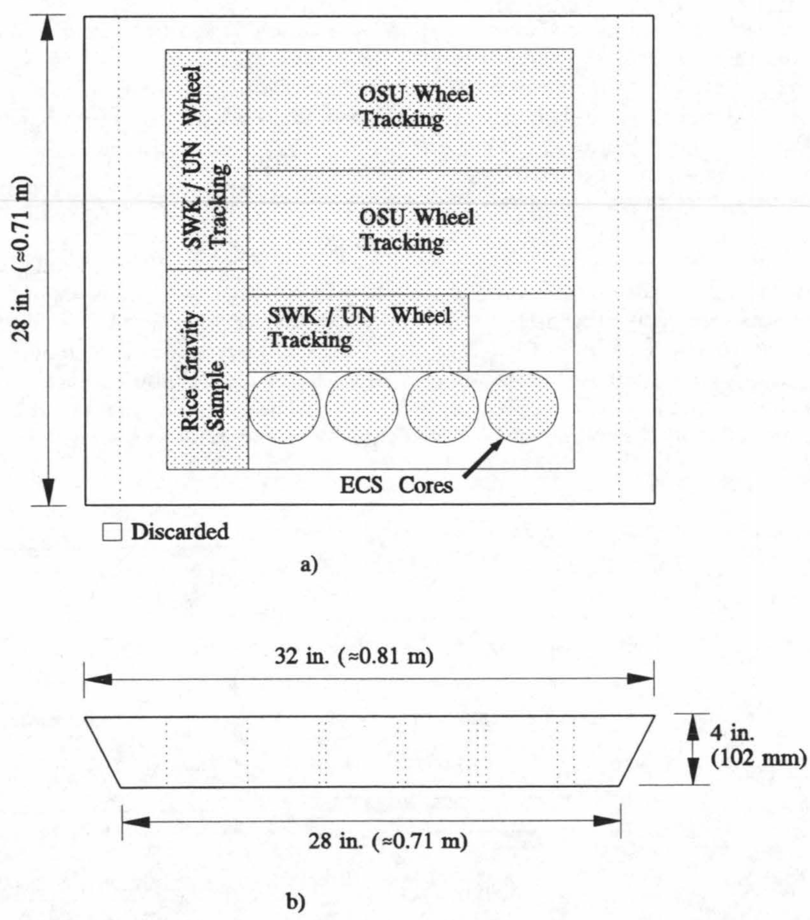


FIGURE 7 Layout of specimens cut from slab: (*a*) plan view, (*b*) elevation view.

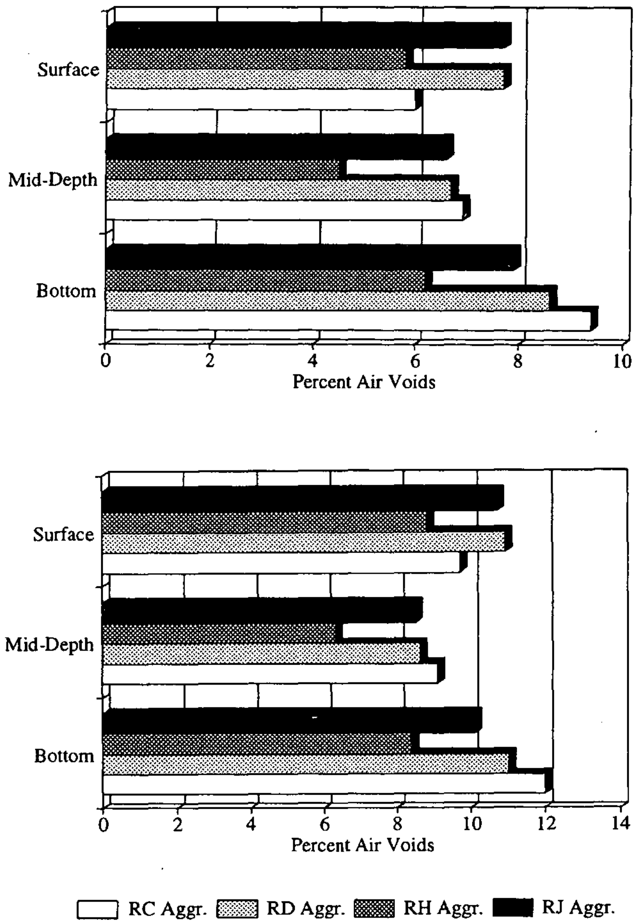


FIGURE 8 Typical variation in air voids with depth for roller compacted beam specimens: (*top*) air voids by SSD bulk specific gravity; (*bottom*) air voids by parafilm bulk specific gravity.

Space Requirements

Because of the necessity of using larger equipment to perform rolling wheel compaction, as performed at OSU and UC-Berkeley, a larger area is needed relative to other methods. At OSU the area required for rolling wheel compaction is roughly 2.5 to 3 times the area required for either kneading or Marshall hammer compaction. In addition, the area needs to be well ventilated because the compactor burns fuel.

Material Quantities

Another disadvantage of the rolling wheel method is that large quantities of materials need handling. Typical weights of the materials for a single slab produced at OSU ranged between 124.7 and 131.5 kg (275 and 290 lb). The quantity was not a problem during the mixing process because the materials were divided into several pans, each weighing at most 40.8 kg (90 lb). However, handling the compacted slab presented a more serious problem. The problem was overcome by removing the slab from the mold on the piece of plywood or particle board that makes up the bottom of the mold. The board and slab were moved by means of a pallet jack and were immediately prepared for cutting and coring of the specimens, thus minimizing the amount of time the entire slab was handled. The board supports the slab and was replaced if it was damaged during the cutting process.

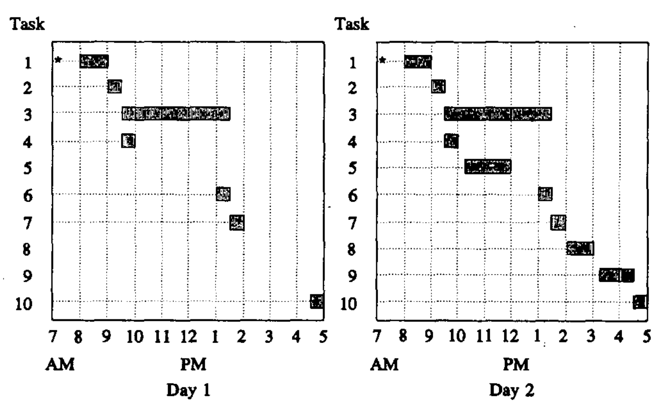
Time and Personnnel Requirements

The following is a discussion of the time and personnel requirements of rolling wheel compaction as performed at OSU. The requirements are compared with those of the Hveem and Marshall methods.

Time Requirements

The schedule for preparing specimens by means of rolling wheel compaction as performed at OSU is shown in Figure 9. As indicated, one slab can be produced per 8-hr shift, yielding 25 core specimens 102 mm (4 in.) in diameter and 102 mm (4 in.) in height. If only one slab is produced, the total time required to obtain all specimens from the slab is approximately 10 hr. However, if slabs are produced daily, all specimens can be obtained in an 8-hr shift, with the specimens from the last slab produced requiring an additional 2 hr to obtain.

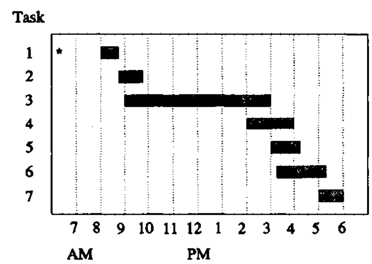
A typical schedule for preparing specimens 102 mm (4 in.) in diameter and 102 mm (4 in.) in height by means of Hveem compaction as performed at OSU is shown in Figure 10. The schedule for Marshall compaction would be similar but would stop at the end of Task 5 (i.e., nearly 2 hr shorter). The schedule excludes extrusion of the specimens from the molds, which was accomplished some time the next day. The schedule



Task

- * Timer-controlled asphalt oven begins heating asphalt at 6:30 or 7:00AM; rock is at the mixing temperature.
- 1 Pre-heat the mixer and prepare for mixing. If a slab was compacted the previous day, remove it from the mold.
- 2 Mix asphalt and aggregate.
- 3 Short-term oven age the mixture for 4 hr. @ 135°C.
- 4 Clean the mixer. If a slab was compacted the previous day, prepare to cut and core the slab.
- 5 Cut and core the slab compacted the previous day.
- 6 Pre-heat the compaction mold and prepare for compaction.
- 7 Compact the slab and clean-up.
- 8 Perform gravimetric measurements on specimens cut earlier in the day.
- 9 Batch aggregate and place asphalt in the timer-controlled oven for the next day.

FIGURE 9 Schedule for rolling wheel compaction as performed at OSU.



Task

* Timer-controlled asphalt oven begins heating asphalt at 6:00 to 6:30 AM; rock and mixing tools are at the mixing temperature.
1 Prepare for mixing.
2 Mix asphalt and aggregate.
3 Short-term oven age the mixture 4 hr. @ 135°C; samples are staggered in pairs.
4 Heat/cool the mixture to the compaction temperature.
5 Compact the mixture.
6 Cool the mixture in an oven set to 60°C.
7 Apply static compaction load.

FIGURE 10 Schedule for kneading compaction as performed at OSU.

shows the time requirements to produce six specimens, slightly less than one-fourth the number of cores of the same size that can be produced from a single-roller compacted slab (for comparison purposes, only cylindrical specimens are considered). As indicated, it takes roughly 4 times as long to produce the same number of specimens using either the Hveem or Marshall method as it does using the rolling wheel method.

Personnel Requirements

The rolling wheel compaction procedure performed at OSU requires two technicians. All work associated with the preparation of specimens from slabs can be accomplished in 8-hr shifts, as previously indicated. Thus, when slabs are prepared daily, each slab requires approximately 16 person-hr.

Preparation of specimens using either the Hveem or Marshall method requires only one technician. However, compared with rolling wheel compaction, the Hveem or Marshall method requires substantially more time (e.g., approximately 36 person-hr for Hveem compaction) to produce an equivalent number of specimens.

Equipment Costs

A summary of the costs of the primary equipment needed for the three methods of compaction being compared is given in Table 2. Also included are the projected costs for the new gyratory shear compaction equipment. The table gives capital costs (i.e., costs incurred in the procurement of new equipment). The costs are those for typical equipment as indicated in the table. Also, for comparison purposes, the costs given for the Hveem and Marshall methods include enough molds to produce the same number of specimens as were obtained from one slab compacted by the rolling wheel. As indicated,

TABLE 2 Comparison of Estimated Costs of Primary Equipment

Item	Marshall Compaction	Hveem Compaction	Rolling Wheel Compaction	Gyratory Shear Compactor
Ovens	Two small, one large: **$8,100**	Two small, one large: **$8,100**	One small, one large: **$7,000**	One small, one large: **$7,000**
Mixer	Two bowl mechanical mixer: **$3,950**	Two bowl mechanical mixer: **$3,950**	Modified concrete mixer: **$1,750**	Two bowl mechanical mixer: **$3,950**
Compaction Mold(s)	25 molds: **$1,675**	25 molds: **$3,000**	Custom mold: **$2,500**	25 molds: **$550**
Compactor	Mechanical hammer: **$2,740**	Kneading compactor[a]: **$18,950**	Small roller compactor: **$10,000-$12,000**	Small gyratory compactor[b]: **$15,000**
Extruder	**$360**	**$360**	N/A[c]	**$360**
Saw	N/A	N/A	Small walk-behind saw: **$1,000**	N/A
Core Drill	N/A	N/A	Core drill and core bit: **$1,000**	N/A
TOTAL	**$16,825**	**$34,360**	**$23,250-25,250**	**$26,860**

[a] Basic unit, excludes beam mold device
[b] After Leahy *(4)*
[c] Not applicable

equipment costs for rolling wheel compaction are greater than those for Marshall compaction but less than those for either Hveem or gyratory compaction.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Rolling wheel compaction as performed at OSU is an economical and practical means by which to obtain large numbers of test specimens daily (in 8-hr shifts).
2. Equipment costs for rolling compaction are lower than those for Hveem compaction but higher than those for Marshall compaction.
3. Test specimens of various geometries (i.e., cylindrical, prismatic, pyramidal, etc.) can be easily and readily produced from a single slab (job mix formula), thus potentially minimizing variations from specimen to specimen in terms of specific gravities (i.e., asphalt film thickness, bulk density, etc.) Rolling wheel compaction is particularly beneficial when both cores (cylinders) and beams (prismatic specimens) are needed from the same mixture design.
4. The mold size for rolling wheel compaction can be easily varied to produce slabs of various lengths, widths, and thicknesses.
5. The equipment and procedure for rolling wheel compaction can easily accommodate the fabrication of pavement layers such as overlays (e.g., open-graded mixture over a dense-graded mixture).
6. Although the personnel requirements for rolling wheel compaction are greater than those for either Hveem or Marshall compaction, the total number of person hours required to obtain a given number of specimens is less.
7. The primary disadvantages of the rolling wheel compaction method as performed at OSU include greater space requirements and the necessity to handle large quantities of materials. However, these disadvantages were not considered significant.

Recommendations for Implementation

1. Rolling wheel compaction is recommended when large numbers of specimens having differing geometries are needed from the same job mix formula.
2. Rolling wheel compaction is highly recommended for use in research and regional laboratories. In addition, because of the ease and practicality of the procedure used at OSU, it is entirely feasible that rolling wheel compaction can be used in a production laboratory such as that found at a state department of transportation.
3. Because the rolling wheel compaction method best simulates the field relative to traditional techniques as well as the gyratory shear compactor, rolling wheel compaction is recommended for use in regular mixture design and research activities.
4. Further research is needed to assess the relative merits of small (self-contained) rolling wheel compactors.

ACKNOWLEDGMENTS

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