A.—Traffic Analysis

5.05 TRAFFIC ESTIMATES.—The traffic expected on the asphalt pavement structure should be estimated as closely as possible and allowances made for probable future traffic increases. Because of the inherent difficulties in accurately forecasting the volume and axle-loading conditions of expected traffic, it is recommended that the analysis be made on the following basis:

(1) Estimate the daily volume per lane of passenger cars and of light trucks having single axle loads of 6,000 lbs or less.

(2) Estimate the daily volume per lane of commercial trucks and buses having a single-axle load in excess of 6,000 lbs.

(3) Establish the maximum single-axle load of commercial trucks and buses expected on the pavement.

5.06 TANDEM AXLES.—It should be noted that the above data are based on anticipated single axle loadings. It is recognized that greater loadings may be carried on tandem axles. Legislation in the individual states, however, generally prescribes allowable loading conditions for tandem axles with respect to those permitted on single axles. The design engineer, therefore, should determine this equivalency for the state in which the pavement structure is to be built. Single axle load thickness designs determined by procedures outlined in this chapter are generally satisfactory for tandem axle loading conditions allowed by the various state highway departments.

5.07 MULTIPLE LANES.—Where the pavement structure is being designed for two or more lanes of traffic in each direction, it should be recognized that commercial truck and bus traffic is normally concentrated in the outside lane.

5.08 CLASSIFICATION OF TRAFFIC.—On the basis of the data established above, the traffic should be classified in accordance with the information contained in Table V-1.

5.09 BUS STOP AREAS.—For bus stop areas, the pavement structure should be designed for the “Heavy” traffic classification where the normal design is for “Light” or “Medium” traffic and for “Very Heavy” traffic where the normal design is for “Heavy” or “Very Heavy” traffic.

5.10 PARKING LOTS.—For parking lots, the pavement structure should be designed for “Heavy” traffic, except that when only passenger cars and light trucks of 6,000-lb axle load or less are expected to use the parking facility, the minimum required thickness of base and pavement may be reduced as noted in Article 5.35.

5.11 SUMMARY.—Thus, the first step in the design of an asphalt pavement structure is to determine by procedures outlined above:

(1) Traffic classification
(2) Maximum single axle load

B.—Evaluation of Subgrade, Subbase and Base Course Materials

5.12 GENERAL.—Several methods for evaluating the strength characteristics of various courses in an asphalt pavement structure are in common use throughout the United States and elsewhere. They range from the purely visual evaluation of the material to those requiring laboratory tests. All of the methods now in use are generally considered to
be of an empirical nature and no one method can be precisely correlated with another. Properly used, however, each method included in this chapter has been found to be satisfactory by several agencies.

5.13 EVALUATION METHODS.—In evaluating materials it should be recognized that the distribution of wheel loads through the depth of the structure allows the design engineer to use a great variety of materials. The selection of various materials for the successive strata of improved subgrade, subbase and base courses above the naturally occurring soils is dependent upon the quality of each material as defined by some evaluation method. Most popular methods include:

(1) Resistance Value—(R)
(2) California Bearing Ratio (CBR)
(3) Bearing Value, psi, 12-in. Plate, 0.2 in. Deflection, 10 Repetitions
(4) AASHO Classification
(5) Unified Soil Classification

For “Heavy” and “Very Heavy” categories of traffic, the Asphalt Institute recommends direct mechanical methods for evaluating soil bearing capacity. The three most widely used methods are (1), (2), and (3) above.

The AASHO Classification System has been widely used in connection with the engineering design of roads, streets and highways. The Unified Soil Classification also has been used in connection with the engineering design of airfields, as well as roads, streets and highways.

This manual provides a choice of methods for evaluating soil and granular materials to be used in the asphalt pavement structure. The method selected may be one which is familiar to the engineer or for which testing equipment is locally available. It must be recognized, however, that local variations in test methods and in the interpretation of test results often lead to inconsistent design data by agencies reportedly using the same evaluation method. In order to eliminate these inconsistencies,sofar as possible, procedural outlines for each method, as referenced in Appendix A, should be followed.

5.14 TWO CATEGORIES OF TEST METHODS FOR SOILS.—Soils are evaluated and selected by classification tests which imply strength values, by direct mechanical strength tests, or by both procedures. Classification tests are often faster and less expensive, but closer correlation has been established between direct strength measurements and actual service conditions. Thus, since thickness of the pavement structure for any traffic classification is dependent upon evaluation of soil strength, direct strength tests are recommended.

The use of both methods provides a means of maintaining and improving the correlation shown in Figure V-3. The frequency of testing can then be reduced in a given area as a history and classification of local soils is built up; or identification tests can be used more frequently as soils become classified by direct testing.

5.15 SELECTION OF MATERIALS.—On the basis of evaluation by one of the procedures noted, the subbase and base aggregates may be selected from locally available native deposits or from nearby commercial sources. Native sands, sand and gravel mixtures, or sand-silt mixtures for the AASHO Soil Classification types A-1, A-2, or A-3 will often be satisfactory for subbase aggregates.

Base aggregates will usually be composed of high quality crushed stone, crushed slag, crushed or uncrushed gravel and sand, or a suitable combination of these materials. These aggregates will be carefully prepared in crushing and screening plants to meet specified requirements.

5.16 ASPHALT TREATMENT OF BASE MATERIALS.—Asphalt treatment of base materials usually will result in an improvement of quality and will permit a reduction in the required thickness of base and in the required total thickness of asphalt pavement structure, as described in Article 5.34.

5.17 MOISTURE AND FROST EFFECTS.—In the evaluation of materials to be used in the asphalt pavement structure, the engineer must give due consideration to anticipated moisture and frost conditions (see Article 5.44) where such factors may affect the load supporting characteristics of the material. A study of the evaluation method chosen for use in designing the pavement will indicate the extent, if any, to which these factors have been taken into
5.18 SUMMARY.—In summary, the second step in the thickness design of an asphalt pavement structure is the evaluation, by one of the methods noted above, of all subgrade, improved subgrade, subbase and base materials which may be considered for use in the structure. A suggested form for the summary of these data is shown in Figure V-1.

C.—Design Procedures

5.19 PAVEMENT COURSES.—The courses of the asphalt pavement structure may include the following:

(1) The surface course
(2) The binder course
(3) The leveling course (when overlaying an old pavement)
(4) The base course or courses
(5) The subbase course or courses
(6) The improved subgrade course or courses.

The design of a given course in the asphalt pavement structure is affected both by the strength properties of the course itself, and also by the strength of its supporting course. Typical sections are shown in Figure V-2.

5.20 ALTERNATE DESIGNS.—Alternate designs of asphalt pavement structures are usually possible and economies may often be realized through their preparation and by economic analysis of each design. Alternate designs should therefore be prepared for all but the smallest jobs.

Alternate designs may differ in type and thickness of the asphalt pavement surface and in type and thickness of the various elements of base, subbase and improved subgrade materials composing the structure beneath the asphalt pavement surface. The designer must give full consideration to the various combinations of pavement and supporting materials which are likely to provide a suitable standard of performance at a minimum of cost.

5.21 DESIGN CONSIDERATIONS.—In the following discussion of thickness considerations, it is assumed that the data discussed in Sections A and B of this chapter have been

<table>
<thead>
<tr>
<th>Element</th>
<th>Material Identification</th>
<th>Bearing Value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sta. to Sta.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sta. to Sta.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sta. to Sta.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Subgrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Enter here the name of the system used in evaluating the characteristics and bearing values of the various materials (e.g., AASHO Soil Classification, Resistance Value—R, etc.).

** By evaluation system indicated in heading of data sheet.
Figure V-2—Typical Asphalt Pavement Sections

established. Alternate designs may then be made by proper consideration of the following factors:

1. Total thickness of asphalt pavement structure.
2. Type and thickness of asphalt surface and binder course.
3. Quality and thickness requirements for bases.
4. Quality and thickness requirements for subbase and improved subgrades.
5. Miscellaneous design details.

These factors are discussed in detail in the remainder of this Chapter.

Total Thickness of Asphalt Pavement Structure

5.22 GENERAL.—The total thickness of an asphalt pavement depends primarily on the load-supporting characteristics of the native soil over which the structure is
to be built and also on the materials making up the pavement structure. The native soil is usually designated as the “subgrade” although some prefer to use the term “basement soil” or “foundation soil.” In some instances the subgrade soils may be relatively uniform throughout the limits of the project while considerable variations may be encountered in other instances. Economics may often be realized by varying the design thickness where major variations in the supporting characteristics of the subgrade soil are encountered over reasonable lengths of the highway structure. For practical construction purposes, however, frequent changes in thickness design should be avoided.

5.23 DETERMINATION OF TOTAL THICKNESS.

The first step in the design of alternate sections should be a review of the test data for the subgrade soils, discussed in Sect. B of this chapter. The decision must then be made whether to use a single bearing value for the subgrade throughout the project or to vary this value within certain limits of the project. When the subgrade bearing value (or values) has been selected, the designer may then refer to Figure V-3 to determine the required total thickness of the asphalt pavement structure. This chart is used by first locating the scale of bearing values for the test method used in evaluating the subgrade soil (e.g., Unified Soil Classification, Resistance Value—R, California Bearing Ratio—CBR, etc.). Next, the subgrade bearing value as determined by the particular evaluation method being used is located on the proper scale. Then, a line is drawn vertically to intersect the proper single axle load design curve. A line is then drawn horizontally to an intersection with the vertical axis on the left side of the chart. From this intersection, a straight line is drawn through the point on the “Traffic Classification” scale for the traffic classification selected as noted in Sect. A of this chapter, and continued to an intersection with the right-hand vertical axis labelled “Total Thickness of Asphalt Pavement Structure in Inches.”

By arrows on the chart, an example of its use is illustrated. The following assumptions are made:

<table>
<thead>
<tr>
<th>Traffic Classification</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Single Axle Load</td>
<td>18,000 lbs.</td>
</tr>
<tr>
<td>CBR Value for Subgrade</td>
<td>4%</td>
</tr>
</tbody>
</table>

It will be noted that the total thickness of asphalt pavement structure required for these assumed conditions is 12 inches. In a similar manner, the total thickness of asphalt
pavement structure for other conditions of subgrade support, maximum axle load and traffic classification may be determined.

![Table]

5.24 STAGE CONSTRUCTION.—In many areas substantial future increase of traffic may be anticipated, calling for heavier pavement structure at a later date than may be justified immediately or financially practicable at the time of construction. For this condition, “stage construction” is often desirable. A relatively heavy base and subbase are topped by asphalt surfacing of comparatively light type, to be covered later with heavier pavement or strengthened with increased base thickness and/or heavier pavement as the need arises. It is not necessary to scrap any portion of the pre-existing structure as it all continues to function in the over-all load carrying capacity. Stage construction is especially desirable where there is considerable uncertainty in the traffic future or a local record of unpredictable behavior available materials.

5.25 MISCELLANEOUS.—It should be noted at this point, however, that the total thickness thus determined may be decreased when certain types of asphaltic bases are used. This is discussed in Article 5.36.

Reference to Figure V-3 will indicate that a 42,000-lb. single axle load curve is the maximum included on the chart. This is not to imply that a 42,000-lb. single axle load is the maximum for which an asphalt pavement structure may be designed; it is simply the maximum loading currently anticipated for normal highway design. In actual practice, asphalt pavement structures have been designed for military planes having gross loads of as high as 500,000 pounds. For pavement designs for single axle loads above 42,000 pounds, consult the nearest office of The Asphalt Institute.

---

Type and Thickness of Asphalt Surface and Binder Courses

5.26 GENERAL.—The versatility of asphalt pavement construction is such that different types of surface and binder courses are often suitable for certain traffic and climatic conditions. State highway engineers and Asphalt Institute engineers are well acquainted with the types and thicknesses of these courses which have been proven by experience to be satisfactory for local conditions of traffic and climate. They should be consulted by designers who are unfamiliar with local conditions.

It will often be found that old roads in a given vicinity, especially on high-clay types of soils, are satisfactorily carrying traffic with lesser thickness than engineering design methods call for. This should not be a reason for reducing the design thickness for new roads for the reason that certain clays have work-hardening characteristics which cause them to build up strength under gradually increasing traffic over the years. Sometimes an old road will carry traffic with half the thickness required for a new one. Consequently, if an old road structure which seems to show this property is to underlie new construction, the soil under it may be given a higher valuation.

5.27 CHARACTERISTICS AND FUNCTIONS OF SURFACE COURSE.—The surface course of an asphalt pavement structure must have the following characteristics and perform the following functions:

1. Provide a smooth, quiet surface for traffic
2. Be resistant to the wear of traffic
3. Be highly stable to resist rutting, shoving or other surface deformations
4. Have a high coefficient of friction to resist skidding and to provide proper traction
5. Be of sufficiently impermeable density to be waterproof, to retard weathering, and to prevent damage from freezing and thawing cycles.

5.28 PAVING MIXTURE REQUIREMENTS.—Stability, voids and other characteristics are important in the design of hot asphalt paving mixtures. Detailed information on the design of such mixtures is contained in Mix Design Methods for Hot-Mix Asphalt Paving, Manual Series No. 2, published by The Asphalt Institute. Other Institute publi-
cations contain information on the construction of such asphalt pavements, as follows:

5. Asphalt Macadam, Asphalt Institute Specifications MP-1, MP-2, SS-1, B-7 or A-1.
6. Asphalt Plant Mixes, Asphalt Institute Specifications SS-1, A-6, CL-2, CL-3 or CL-4.
8. Asphalt Surface Treatment, Asphalt Institute Specifications S-2, S-3, S-5 or combination thereof.

5.29 SELECTION OF SURFACE TYPE AND THICKNESS.—As a general guide in the selection of the asphalt surface type and thickness, Tables V-2 and V-3 may be used. Table V-2 provides, in a general manner, information as to the expected service life, relative quality and relative cost of asphalt pavement surfaces normally used for different densities of traffic. Table V-3 contains suggested pavement thicknesses and references to appropriate Asphalt Institute specifications for these various types of asphalt pavements.

Suggested thicknesses of the asphalt surface and binder courses may be varied where local experience provides a suitable basis for such modification. Generally, where high-quality base materials are to be used immediately beneath these courses, the pavement thickness recommended in Table V-3 are adequate. For extremely heavy axle loads, however, it is common practice to increase these suggested thicknesses or to provide a high-quality asphalt base course immediately beneath these courses. See Note 2, Table V-4.

On the other hand, the thickness of asphalt surface and binder courses for normal axle loadings currently encountered may sometimes be reduced by replacing a portion or all of the binder course with an equal thickness of high-quality asphalt base.

---

Table V-2—Selection of asphalt surface types for different classifications of traffic, as influenced by service life, quality, and cost factors.

<table>
<thead>
<tr>
<th>Asphalt Pavement Type</th>
<th>Short Life</th>
<th>Medium Life</th>
<th>Long Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Surface Treatment</td>
<td>6th</td>
<td>1st</td>
<td>3rd</td>
</tr>
<tr>
<td>Multiple Surface Treatment</td>
<td>5th</td>
<td>2nd</td>
<td>3rd</td>
</tr>
<tr>
<td>Mixed-in-Place</td>
<td>4th</td>
<td>3rd</td>
<td>4th</td>
</tr>
<tr>
<td>Macadam (b)</td>
<td>3rd</td>
<td>2nd</td>
<td>3rd</td>
</tr>
<tr>
<td>Asphalt Concrete</td>
<td>1st</td>
<td>6th</td>
<td>1st</td>
</tr>
</tbody>
</table>

(a) May be used in stage construction when additional courses are to be added later.
(b) Cost data for this type of surface is variable, depending upon local conditions and the availability of crushed aggregates.
Table V-3
SUGGESTED THICKNESSES AND RECOMMENDED TYPES OF ASPHALT SURFACES

<table>
<thead>
<tr>
<th>Asphalt Surface Type</th>
<th>Asphalt Institute Spec.</th>
<th>Light Traffic</th>
<th>Medium Traffic</th>
<th>Heavy Traffic (a)</th>
<th>Very Heavy Traffic (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Treatment</td>
<td></td>
<td>1±</td>
<td>1±</td>
<td>1± (a)</td>
<td>1± (a)</td>
</tr>
<tr>
<td>Mixed-in-place</td>
<td>RM-1, RM-2, or RM-3</td>
<td>2</td>
<td>3 (b)</td>
<td>3 (a+b)</td>
<td>3 (a+b)</td>
</tr>
<tr>
<td>Plant Mix*</td>
<td>SS-1*, CL-2, CL-3, A-6, CL-4</td>
<td>2 (c)</td>
<td>3 (a+c)</td>
<td>3 (a+c)</td>
<td></td>
</tr>
<tr>
<td>Macadam*</td>
<td>MP-1, MP-2, SS-1*, or A-1</td>
<td>2 (d)</td>
<td>2-1/2 (e)</td>
<td>2-1/2 (e)</td>
<td>3 (a)</td>
</tr>
<tr>
<td>Asphalt Concrete*</td>
<td>SS-1*</td>
<td>2</td>
<td>3 (f)</td>
<td>3 (f)</td>
<td>4 (f)</td>
</tr>
</tbody>
</table>

* See Asphalt Institute Specification Series No. 1, "Specifications and Construction Methods for Hot-Mix, Asphalt Paving" for appropriate specification.

NOTES

a. May be used in stage construction when additional courses are to be added later. See Chapter VIII of this manual.
b. Asphalt Institute Specifications RM-1 and RM-2 only are recommended for this traffic condition.
c. Asphalt Institute Specifications SS-1 and A-6 only are recommended for this traffic condition.
d. Asphalt Institute Specification MP-1 provides for a maximum thickness of 11/2 in. This thickness may be used for Light Traffic conditions providing the base is “Excellent Base” as classified in Figure V-2.
e. Asphalt Institute Specifications SS-1 or A-1 are recommended for these traffic conditions.
f. Includes surface and binder courses. The total thickness of the surface and binder courses may be reduced by substitution of asphalt base of comparable strength on an inch for inch basis. For minimum total thickness of surface, binder and base courses, see Table V-4.

5.30 SURFACE COEFFICIENT OF FRICTION.—A very important property of the surface course is its coefficient of friction, or resistance to skidding. A satisfactory coefficient of friction can be obtained for asphalt surfaces through the following controls:

(1) Aggregate, both coarse and fine, must be of a type which will be resistant to polishing under the abrasive action of traffic.

(2) Mix must have sufficient voids to prevent flushing of asphalt in hot weather.

Where suitable non-polishing aggregates are very expensive, the thickness of surface course may be reduced to as little as 1/2 inch if the underlying course is a high-quality asphalt mixture. Generally, however, the surface course should be from 1 to 2 inches thick. On secondary roads of light or medium traffic, surface treatments of 1/2 inch or more are often used.

A rough, coarse-textured surface is inferior in skid-resistance to a uniformly “sand-paper” type of surface. To avoid over-asphalting is as important in preventing skidding as is proper grading. If not over-oiled or over-asphalted, practically any aggregate grading in common use by major engineering organizations is satisfactory.

5.31 TYPE AND THICKNESS OF THE BINDER COURSE.—From the pavement surface downward, the second course is usually called the binder course, but in some areas it is called the leveling course. The requirements for the binder course may differ from those for the surface course, principally because the binder course is not subject to abrasion and weathering. For example, while it might be necessary to use non-polishing crushed aggregate and sand in the surface course to withstand wear and polishing of traffic, it often is possible to use aggregate in the binder course with less resistance to abrasion or polishing. The strength of the binder course, however, must be substantially the same as that of the surface course. The void content, however, may be somewhat higher than for the surface course.

5.32 SAND EQUIVALENT OF COMBINED MINERAL AGGREGATE.—The mineral aggregate when combined in the portions required by the job-mix formula should be tested by the method of test for determining Sand Equiv-
alent*—AASHTO Method T176. When so tested, the Sand Equivalent value generally should be as follows:

- Combined aggregate for asphalt concrete for surface and binder courses: 50+
- Combined aggregate for plant-mix asphalt surface, base, or binder courses: 45+
- Aggregate for asphalt mixed-in-place surface courses: 35+

D.—Quality and Thickness Requirements for Bases

5.33 GENERAL.—The base course of an asphalt pavement structure is the layer of material immediately beneath the binder course. It may be composed of crushed stone, crushed slag, crushed or uncrushed gravel and sand, or combinations of these materials, and may be asphaltic or non-asphaltic. However, asphaltic bases are highly advantageous and they are often more economical to install and will perform more satisfactorily than non-asphaltic bases. Some locally available materials otherwise unsuitable for use as base material may be upgraded by the addition of an asphaltic binder and serve satisfactorily as a base.

5.34 ASPHALT BASES.—Asphalt bases may be asphalt concrete, asphalt macadam, asphalt plant-mix or mixed-in-place. More information on base courses of these materials may be found in Asphalt Institute publications as follows:

1. Specifications and Construction Methods for Hot-Mix Asphalt Paving, Specification Series No. 1
2. Mix Design Methods for Hot-Mix Asphalt Paving, Manual Series No. 2
3. Asphalt Plant Manual, Manual Series No. 3
4. Asphalt Handbook, Manual Series No. 4
5. Asphalt Road-Mix (Mixed-in-Place Macadam Aggregate Type), Specifications RM-1
6. Asphalt Road Mix (Mixed-in-Place Dense-Graded Aggregate Type), Specification RM-2
7. Sand-Asphalt Mixed-in-Place Course on Natural Sand Subgrade, Specification RM-3

* See also Manual Series No. 3, Asphalt Plant Manual.

8. Asphalt Macadam Base (Penetration Method with Hot Asphalt Cement), Specification B-7
9. Asphalt Plant Mix (Cold-Laid Macadam Aggregate Type), Specification CL-2
10. Asphalt Plant Mix (Cold-Laid Dense-Graded Aggregate Type), Specification CL-3
11. Cold-Mix Cold-Laid Emulsified Asphalt Plant Mix (Dense-Graded Aggregate Type), Specification CL-4

Such asphalt bases are of superior quality as a result of the waterproofing and bonding action of the asphalt. When liquid asphalts are used in such base construction, care should be taken to insure that they are properly cured before placing the asphalt wearing surface.

5.35 THICKNESS AND QUALITY REQUIREMENTS FOR NON-ASPHALT BASES. — Thickness and quality requirements for base courses depend primarily upon the volume and axle loading conditions of traffic, and, to some extent, upon the quality of the material to be placed beneath. Thickness and quality requirements for these materials are outlined in subparagraphs (a) through (d) below and in all cases the descriptive terminology used to denote the quality requirements of the material is consistent with that contained in the heading “General Soil Rating as Subgrade, Subbase or Base” on Figure V-3. Where in-place materials meet the requirements for base, as specified in subparagraphs (a) through (d) below, they may be used for the base provided they are scarified, thoroughly mixed at optimum moisture content and compacted for the full depth required. Compaction requirements for these base course materials should be determined on the basis of AASHO Designation T 180. For information on limits for frost susceptible materials, see Article 5.44. Where minimum requirements for base course thickness are given below, (a) through (d), they are considered to be applicable only to non-asphaltic base courses; thickness reductions may be made in these minimum values where high-quality asphalt bases are used, based on the equivalency given in Article 5.36. Detailed requirements for non-asphalt base courses are as follows:
(a) **Light Traffic.**—The base course should be of material classified in Figure V-3 as "Good Subbase" or better. It should be compacted to not less than 95% of the maximum AASHO density determined as noted above. Compaction should be accomplished so that compacted layers do not exceed six inches in depth (see Chapter VII, Sec. A). When a surface treatment is to be used as the asphalt pavement surface, however, the base course should be of material classified in Figure V-3 as "Medium Base" or better, meeting the compaction requirements outlined above.

The minimum thickness of non-asphaltic base should be such that the total thickness of base and pavement is not less than five inches. Where the required total thickness of the asphalt pavement structure exceeds the 5-inch minimum thickness of such base, binder and surface courses, additional base material may be used or, if more economical, a subbase may be included to provide the required total thickness.

(b) **Medium Traffic.**—The base course should be of material classified in Figure V-3 as "Excellent Base." It should be compacted to not less than 95% of the maximum AASHO density determined as noted above. Compaction should be accomplished so that compacted layers do not exceed six inches in depth (see Chapter VII). The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder and surface courses is not less than six inches. When the required total thickness of the asphalt pavement structure exceeds the 6-inch minimum thickness of such base, binder and surface courses, additional base materials may be used or, if more economical, a subbase may be included to provide the required total thickness.

(c) **Heavy Traffic.**—The base course should be of material classified in Figure V-3 as "Excellent Base." It should be compacted to not less than 100% of the maximum AASHO density determined as noted above. Compaction should be accomplished so that compacted layers do not exceed six inches in depth (see Chapter VII). The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder and surface courses is not less than eight inches. Where the required total thickness of the asphalt pavement structure exceeds the 8-inch minimum thickness of such base, binder and surface course, additional base may be used or, if more economical, a subbase may be included to provide the required total thickness.

For parking lots to be used only by passenger cars and light trucks of 6,000-lb axle load or less, the required minimum total thickness of non-asphaltic base and asphaltic binder and surface courses may be reduced to six inches with compaction requirements the same as noted above.

(d) **Very Heavy Traffic.**—Base course should be of material classified in Figure V-3 as "Excellent Base." It should be compacted to not less than 100% of the maximum AASHO density determined as noted above. Compaction should be accomplished so that compacted layers do not exceed six inches in depth (see Chapter VII). The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder and surface courses, is not less than ten inches. Where the required thickness of the asphalt pavement structure exceeds the 10-inch minimum thickness of base, binder and surface courses, additional base may be used or, if more economical, a subbase may be included to provide the required total thickness.

5.36 **ASPHALT-TREATED BASES.**—Where asphalt concrete or asphalt macadam bases are used, required thickness of base and pavement structure may be reduced. One inch of high-quality asphalt base may be regarded as equivalent to 1½ inch of non-asphalt base, provided the maximum reduction in total design thickness does not exceed 15 percent or three inches, whichever amount is greater. Further, surface and binder thickness may be reduced by substituting asphalt-treated base of comparable strength on an inch-for-inch basis.

Regardless of the amount of reduction, total thickness must not be less than that shown in Table V-4.

5.37 **SAND EQUIVALENT OF COMBINED MINERAL AGGREGATE.**—The Sand Equivalent value for base course materials generally should be as follows:
Combined aggregate for plant-mix asphalt base course ..................... 45+
Aggregate for asphalt mixed-in-place base course 35+
Non-asphaltic base course materials 30+

5.38 SUMMARY OF MINIMUM THICKNESS REQUIREMENTS.—The minimum thickness of surface and binder courses and of the base required for traffic classifications established in Section A are shown in Table V-4. This table includes minimum thickness requirements for both asphaltic and non-asphaltic bases.

Quality and Thickness Requirements for Subbases and Improved Subgrades

5.39 GENERAL.—Local materials are usually available near the construction site which are superior in quality to the subgrade material over which the asphalt pavement structure is to be built. These materials, however, may not meet the requirements for base course materials. Such local materials are usually available at a fraction of the cost of high-quality base materials and they may be entirely satisfactory for use in the lower portion of the asphalt pavement structure. These local materials may be used as a “subbase” and materially reduce the cost of the pavement structure.

Where an asphalt pavement structure is to be built for heavy concentrations of traffic and/or high axle loadings over a very weak subgrade, a substantial thickness of subbase may often be used. In some instances it may even be economical to consider two types of subbase material, one of quality superior to the other. In such instances, the superior quality material is placed immediately beneath the base and above the poorer quality subbase. Where two such subbases are used the upper one is usually referred to as the “subbase” and the lower may be designated as “improved subgrade.” The designer must often “balance out” thicknesses of base, subbase and improved subgrade to achieve the most economical utilization of available materials.

5.40 REQUIREMENTS FOR SUBBASE MATERIALS.—Having determined the required total thickness of the asphalt pavement structure and the thickness of base, binder, and surface courses, the required thickness of the subbase should next be considered. Minimum quality requirements for subbase material may be determined by use of Figure V-3 in a manner opposite to that used to determine total

<table>
<thead>
<tr>
<th>Traffic Classification</th>
<th>Very Heavy</th>
<th>Heavy</th>
<th>Medium</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asph. and Binder Course</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total Thickness in Inches</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Non-Asphaltic Base Course</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Total Thickness in Inches Using Non-Asphaltic Base</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: (1) For thickness of subbase and improved subgrade courses, see Article 5.39.4.
(2) Surface thickness may be reduced by substituting asphalt-treated base of comparable strength on an inch-for-inch basis. See Article 5.36.
thickness of the asphalt pavement structure. On the right-hand scale for "Total Thickness of Asphalt Pavement Structure in Inches" the minimum total thickness of the base, binder and surface courses should be located. A straight line is drawn from this point through the point representing the selected traffic classification and extended to the vertical axis on the left of the chart. From this latter intersection, a line is drawn horizontally to intersect the axle load curve being used to determine the required total thickness of the asphalt pavement structure. Then, a line is drawn vertically to the appropriate scale of bearing values for the selected test method. The value thus derived is the minimum bearing value for the subbase material which may be used where the minimum allowable thickness of base, binder and surface courses is to be employed.

For example, an asphalt pavement structure being designed for "Very Heavy" traffic and a 24,000-lb axle load may be assumed. The minimum allowable thickness of base, binder and surface courses previously discussed, is ten inches. Progressing from this 10-inch thickness as just described, it is determined that the subgrade or subbase must have a minimum Resistance Value (R) of 63. If enough of this material is economically available, the additional thickness needed to provide the required total thickness of the asphalt pavement structure may be of this subbase material.

If subbase material of the required quality is not economically available to fulfill these needs, it will be necessary to increase the base thickness. Again, Figure V-3 may be used for this purpose. Assume that the best subbase material economically available has a Resistance Value (R) of 55. The required thickness of base, binder, and surface to be placed over this material would be determined by starting with an R value of 55, progressing vertically to the 24,000-lb axle load curve, horizontally to the left-hand axis, through the Traffic Classification point for "Very Heavy" traffic and intersecting the scale for "Total Thickness of Asphalt Pavement Structures in Inches," the required thickness of base, binder and surface courses is indicated to be 14 inches instead of ten inches. The additionally required thickness of four inches must then be base material. The remaining thickness necessary to provide the required thickness of asphalt pavement structure may then be of the subbase material having an R-value of 55.

5.41 MATERIALS FOR THE SUBBASE COURSE.
-Such materials must be selected with regard to their strength to support loads and, in frost areas, with regard to their susceptibility to frost action. Susceptibility to water and water vapor is equally important in all areas. In considering moisture effects, rain water, ditch water and underground moisture seeps (these sometimes found in cuts) are not as important as capillary water or condensed water vapor often trapped under pavements. The former can usually be diverted by drainage but the latter occurs almost universally even in desert regions. Generally, any granular materials which are non-frost susceptible are adequate for the subbase course, when properly drained and compacted to 95% of AASHO maximum density, at optimum moisture. Where granular materials are economically available and otherwise satisfactory, except for high plasticity, consideration should be given to waterproofing and stabilization with asphalt.

In general, material having the following properties will produce good subbases:

(1) California Bearing Ratio, not less than 20
(2) Liquid limit not more than 25
(3) Plasticity Index, not more than 6
(4) Sand equivalent, not less than 25

Figure V-3 indicates that the following may be used for subbase courses:

(1) Unified Soil Classification (See Appendix A)
GW, GP, GMD, SV, SP, SMd, GMy, SMu, GC, SC, and some ML materials may also be used if waterproofed with asphalt.

(2) AASHO Soils Classification (See Appendix A)
Groups A-2-6 and A-2-7 may sometimes be used if waterproofed with asphalt.

Well-graded aggregate, while desirable for any course, is not essential for the subbase courses. Other limiting factors shown in this section may govern the selection of such materials. The maximum size of aggregate used in any subbase course should not exceed about 1/2 the thickness of the lift.
If a course made up of large, coarse aggregate containing only a small percent of fines is used over an underlying course containing plastic material, a blanket course, two to four inches thick, of stone or slag screenings or clean sand should be placed to prevent infiltration of the plastic material into the coarse aggregate of the overlying course. Since subbase materials usually come from pits of considerable irregularity, care should be taken that design tests are made on the poorest materials in the pit.

5.42 IMPROVED SUBGRADE.—Under conditions of heavy concentrations of traffic, high axle loads and very weak subgrades, it may be desirable, as noted previously, to consider the use of an “improved subgrade” material in addition to the subbase material. For example, assume the following conditions of design:

Traffic Classification .................. Very Heavy
Axle Load ............................... 36,000 lbs
CBR Value of Subgrade ............. 3%

By procedures previously discussed, it may be determined that the required total thickness of the asphalt pavement structure is 26 inches; that the required minimum thickness of base, binder and surface courses is ten inches; and that the minimum allowable CBR value for the subbase, when the minimum thickness of base, binder and surface courses is used, is 15%. It is assumed further that two subbase materials are available, one having a CBR of 20% and the other a CBR of 8%, the latter being the more economical. For convenience and clarity in this example, the material having a CBR of 20% is designated as “Subbase” and that having a CBR of 8% is designated as “Improved Subgrade.” It is apparent that both materials may be used in the asphalt pavement structure. Data contained in the preceding paragraph indicate that the 10-inch minimum thickness of base, binder and surface courses may be used in combination with the subbase (CBR of 20%). Reference to Figure V-3 indicates that the improved subgrade (CBR of 8%) requires over it a thickness of 15 inches. Thus, five inches of the subbase and 11 inches of the improved subgrade in combination with the 10-inch thickness of base, binder, and surface courses are adequate to meet the assumed design conditions.

5.43 MATERIALS FOR IMPROVED SUBGRADE. A guide to the requirements for materials suitable for improved subgrade is as follows:

(1) California Bearing Ratio, not less than 8
(2) Bearing Value, pounds per square inch not less than 45
(3) Resistance Value, not less than 60
(4) Liquid Limit, not more than 35
(5) Plasticity Index, not more than 10
(6) Sand Equivalent, not less than 25

In selecting materials for improved subgrade, a most important factor in cold climates is frost susceptibility. Generally, any non-frost susceptible material will have adequate load carrying capacity for this course. Any materials previously described as suitable for base and subbase will also be suitable for improved subgrade.

5.44 FROST CONSIDERATIONS.—Where deep frost is a problem, fine-grained soils which have proven to be non-frost susceptible can be used in the improved subgrades, in addition to those noted above. Requirements for such materials and the depths at which they may be used on heavy-duty highways are shown below. For lighter traffic, thickness may be reduced according to traffic and local practice.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Silt</th>
<th>Fine Sand and Silt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 24” from the pavement surface, not more than</td>
<td>40%</td>
<td>45%</td>
</tr>
<tr>
<td>Between 24” and 36” from pavement surface not more than</td>
<td>50%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Frost susceptibility is closely related to susceptibility to water. Hence either selection of materials, or treatment of materials, for resistance to the one will take care of the other.

In localities where freezing weather occurs, subbase and improved subgrade materials should be selected which are not susceptible to detrimental behavior upon freezing and thawing. Here, again, it should be recognized that the thickness design of subbase and improved subgrade materials may require some “balancing out” by the designer to utilize local materials most effectively.
To prevent damage from frost action, untreated materials used in the subbase or improved subgrade courses should be within the following limits for the type materials shown:

<table>
<thead>
<tr>
<th>Material</th>
<th>Limits for Non-Frost Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Graded Gravels</td>
<td>Not more than 8% passing No. 200</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index not more than 6</td>
</tr>
<tr>
<td></td>
<td>Liquid Limit not more than 25</td>
</tr>
<tr>
<td>b. Poorly Graded Sands generally</td>
<td>Not more than 10% passing No. 200</td>
</tr>
<tr>
<td></td>
<td>Not more than 5% passing No. 270</td>
</tr>
<tr>
<td>c. Fine Uniform Sand generally</td>
<td>Not more than 18% passing No. 200</td>
</tr>
<tr>
<td></td>
<td>Not more than 8% passing No. 270</td>
</tr>
</tbody>
</table>

5.45 COMPACTION.—Adequate compaction of subbase, improved subgrade and subgrade materials is essential to the satisfactory performance of the asphalt pavement structure. These materials should be compacted at optimum moisture content to not less than 95% of the maximum density as outlined in AASHO Method T180. Compaction should normally be accomplished in layers not exceeding 6 inches in compacted depth.

Miscellaneous Design Details

5.46 GENERAL.—The Asphalt Institute normally recommends that the base and subbase courses be placed to the full width of the roadway structure. An asphalt-paved shoulder is an excellent safety feature, and provides high lateral support which enhances the strength of the pavement proper. Increasingly, it is the practice to extend the same material used in the subbase, base and, in some cases, the surface of the pavement completely across the shoulder to the ditch slope during original construction. See Figure V-2. This permits uniform consolidation from ditch to ditch and eliminates possible settlement and infiltration of water at the pavement edge. Moreover, it greatly facilitates widening operations should they become necessary at some later date.

Of late years increasing importance has been given to full width construction because of the effect of “trench” or partial width construction in trapping water at low and level points of the grade. Such water may remain in place for weeks and months and progressively attack subgrade, base and subbase materials and even pavement.

In order to take proper advantage of full width construction, the side slopes must be maintained free of impervious covering materials above the subbase elevation.

5.47 SHOULDERS.—Design of shoulders depends upon volume and intensity of traffic. On heavy-duty highways, it is essential that shoulders be of ample width to accommodate the largest vehicles, and strong enough to support their loads without deformation or ravelling. Some consider that shoulders should be surfaced with material different in texture from the pavement proper, to prevent use as an additional traffic lane. Experience has shown, however, that it may be desirable to carry the same surface material completely across the shoulder. A solid painted band along the edge of the pavement proper, affords sufficient demarcation of the shoulder. If rumble under traffic is desired, a surface treatment may be placed on the shoulder area. If further contrast is desired it may be easily obtained by a surface treatment on the shoulder portion using colored aggregate.

Shoulder construction should not be considered a minor problem, for the reason that slow-moving and standing loads such as shoulders frequently support are actually more severe on a pavement structure than fast-moving loads. This tends to compensate in part for the relative infrequency of such loads.

For exceptionally wide shoulders, and where base and subbase materials are costly, full width construction may be uneconomical. In such cases, consideration should be given to the use of locally available, free-draining material for the shoulder construction or to the use of drains which will properly remove free water from the base and subbase courses.

5.48 DRAINAGE AND COMPACTION.—Good drainage and thorough compaction of all elements of the asphalt pavement structure are essential features for good service. Raised median areas between dual-lane roadways should not be used because such designs normally result in poor drainage conditions. Also they hamper snow removal.
5.49 ASPHALT ENVELOPING.—Asphalt enveloping of embankment materials which are subject to a loss in strength with increasing moisture content is a promising development worthy of consideration. In this application, the moisture-susceptible material is completely enveloped with a membrane of asphalt, preventing changes in its moisture content and thereby providing a uniformly high bearing capacity of the material. A typical asphalt membrane section is shown in Figure V-4.

Soil containing large sharp particles should not be placed next to the membrane under the traveled way, as they tend to work through it and make it permeable.

5.50 TYPICAL DESIGN EXAMPLES.—Typical design examples utilizing the principles discussed in this manual are given in Appendix B herein. A careful study of these typical examples by the user of this manual is strongly recommended.

5.51 SUMMARY.—In summary, the third step in the design of an asphalt pavement structure is the preparation of alternate designs from which economic analyses are prepared and the final pavement section selected. Every effort must be made to include those alternate sections which offer a promise of being the most economical and the most satisfactory for the anticipated service conditions.

E.—Economic Analysis and Selection of Design

5.52 GENERAL.—When alternate designs have been prepared, as previously discussed, the final step in the thickness design of an asphalt pavement structure is the selection
of the most appropriate design. To a large extent, such a selection is normally based upon economic considerations. Other factors should be considered, however.

5.53 ECONOMIC ANALYSIS.—One method used in comparing the costs of alternate design sections is on the basis of a “Total Cost Per Square Yard” estimate for each of the alternate sections. A form suggested for use in preparing such estimates is illustrated in Figure V-5. Data for the “Material Identification” and “Depth, Inches” columns are obtained from the alternate design section details. Data for the “Cost Per Square Yard Per Inch Depth” column may be obtained from previous contract bids for similar types of work or from one having a thorough and up-to-date knowledge of such costs. State highway departments and Asphalt Institute engineers will be able to supply such information. From these data, the estimated “Total Cost Per Square Yard” may be computed and compared for each of the alternate designs.

5.54 OTHER FACTORS.—In addition to a comparison of costs for the alternate design sections, consideration should also be given to such factors as:

(1) Availability of materials. Is the material in a pit of sufficient verified quantity as well as quality?
(2) Past performance of similar construction
(3) Availability of qualified contractors and suitable equipment
(4) Availability of trained inspectors and laboratory personnel
(5) Stage construction

5.55 SELECTION OF DESIGN.—Special circumstances surrounding a given project may also require the consideration of additional factors. A careful, engineering appraisal of all such factors is necessary in the selection of a design section which will best serve the intended purposes.

5.56 SUMMARY.—In summary, the final step in the thickness design of an asphalt pavement structure is the preparation of cost estimates for alternate sections, the comparison of such costs and consideration of additional factors which may govern the selection.

F.—Design of Airfield Pavements

5.57.—The Asphalt Institute is currently revising its asphalt airfields manual to include a variety of current information of value to engineers on the design and construction of modern airfields. When completed, this manual will be available from offices of the Institute, as shown in the back of this publication. Until this revision is completed, Asphalt Institute engineers should be consulted for advice on the design of asphalt pavement structures for airfields. After completion of the revision, appropriate details will be added to this Handbook.

Information on the design of asphalt pavement structures for airfields is currently available in manuals published by:

(7) Airfield Pavement, United States Navy, Technical Publication NAVDOCKS TP-Pw-4, Department of the Navy, Bureau of Yards and Docks, Washington 25, D. C.
discussed therein have been modified. Latest modifications of these methods are continued in references cited above.

G.—Design of Asphalt Mixes

5.58 GENERAL.—The design of asphaltic hot mixtures to carry very heavy traffic should be based on the following considerations:

(1) When thoroughly compacted, the mixture should develop not less than the minimum stability value specified.

(2) When thoroughly compacted, dense graded aggregate surface mixtures should contain not more than five nor less than three per cent voids. The maximum limit insures impermeability and the minimum limit prevents overfilling of voids in the aggregate. Overfilling of voids may result in bleeding and possible loss of stability under traffic in excessive summer heat, as well as slipperiness in following wet weather.

(3) The mixture should contain not less than 60 per cent of asphalt as possible, commensurate with requirements one and two. Maximum durability of the pavement under service conditions is thus obtained, and ravelling, due to a deficiency of asphalt, is prevented.

(4) The mixture should be readily workable when heated to the temperature specified for spreading in order to facilitate uniform spreading and compaction during construction of the pavement. There is no test for determining workability but a little experience will enable the laboratory operator or construction inspector to tell when a mixture is undesirably harsh, stiff, or gummy. Hardness may often be reduced by using a lower percentage of coarse aggregate, retained on the No. 8 sieve. Stiffness may be reduced by using a lower percentage of sand and filler. Gumminess may sometimes be reduced by lowering the percentage of asphalt and filler. Change should not be made without testing for effect on stability, because either reducing coarse aggregate (especially if crushed) or sand and filler, may reduce stability. If the mix shoveles or waves under the roller when rolled at proper temperature, the resulting pavement is likely to be unstable.
5.59 MIX DESIGN METHODS.—Asphaltic hot mixes are usually designed by the Marshall, Hveem, Hubbard-Field or Smith-Triaxial methods of mix design fully described in Asphalt Institute Manual Series No. 2, Mix Design Methods for Hot-Mix Asphalt Paving. Suitability of these laboratory design methods is shown in Table IV-8. Suggested criteria for test limits are shown in Table IV-9. For further information on other types of asphalt mixtures, see the following:

(1) Asphalt plant mixes, see Chapter VII, Section B
(2) Asphalt macadam, see Chapter VII, Section D
(3) Asphalt mixed-in-place, see Chapter VII, Section E

5.60 CLASSIFICATION AND COMPOSITION OF ASPHALT MIXES.—Asphalt mixes are classified on the basis of aggregate gradation as shown in the chart of mix types, Figure IV-1. A compilation of suggested mix compositions is shown in Table IV-7. More details on the usages of these mix compositions are contained in Asphalt Institute Specification Series No. 1, Specifications and Construction Methods for Hot-Mix Asphalt Paving for Streets and Highways.

5.61 SAND EQUIVALENT OF COMBINED MINERAL AGGREGATE.—The mineral aggregate when combined in the portions required by the job-mix formula, discussed below, should be tested by the method of test for determining Sand Equivalent referred to in Article 3.34. When so tested, the Sand Equivalent should not be less than the following values:
- Combined aggregate for asphalt concrete for surface and binder courses ............ 50+
- Combined aggregate for plant-mix asphalt surface, base, or binder courses .......... 45+
- Aggregate for asphalt mixed-in-place surface courses .............................. 35+

5.62 JOB-MIX FORMULA.—The term job-mix formula is generally used in the singular number but actually three or more job-mix formulas may be involved by the time a project is well under way. These are:

1. The Design Job-Mix Formula which is used in the preliminary stages of the project design when the specifications are prepared, the preliminary investigation of materials is made and the preliminary mix designs are studied in the laboratory.

2. The Preliminary Job-Mix Formula is tentatively determined on the basis of tests of samples taken (1) from the aggregate delivered and stockpiled on the project or (2) from the hot bins of the asphalt plant.

3. The Final Job-Mix Formula is determined after the asphalt plant is in regular operation and the characteristics of the mix have been determined from samples of the production mix, including its workability performance and other characteristics, on the roadbed.

5.63 FORMULA FOR DETERMINING THE AMOUNT OF ASPHALT.—The following formula may be used as a guide in determining the amount of asphalt for use in mix design studies. Formulas should not be used to determine the asphalt to be used in construction mixes unless laboratory equipment is absolutely unavailable for mix design at some location and the asphalt is to be placed as set out in Asphalt Institute Manual Series No. 2, Mix Design Methods for Hot-Mix Asphalt Paving.

A formula based on the so-called surface area method is as follows:

\[ P = 0.035a + 0.045b + 0.15c \text{ for } 11-15\% \text{ passing No. 200} \]
\[ 0.18c \text{ for } 6-10\% \text{ passing No. 200} \]
\[ 0.20c \text{ for } 5\% \text{ or less passing No. 200} \]

Wherein:
- \( P \) = The percentage of asphalt by weight of total mix
- \( a \) = The percentage of aggregate retained on No. 8 sieve
- \( b \) = The percentage of aggregate passing No. 8 sieve and retained on the No. 200 sieve
- \( c \) = The percentage of aggregate passing No. 200 sieve

For liquid asphalt of SC-2 grade the coefficient of “a” should be reduced to 0.02. For heavier liquid asphalt values between 0.02 and 0.035 should be used depending on the amount of actual residual asphalt.

The value of \( F \) is a variable to provide for conditions when:

1. Local experience indicates more or less asphalt should be used.
2. Additional asphalt may be necessary to compensate for absorptive aggregates.
3. Adjustments are necessary for light weight or un-
usually heavy aggregates. The formula is based on an average specific gravity of 2.60 to 2.70.

The value of F varies from 0 to 1.5% or occasionally with very absorptive aggregate up to 2.0%. In the absence of other data, a value of 0.7 to 1.0% should cover most conditions.

The above formula is also useful in plant control. After the mix has been properly designed for the particular aggregate used, the exact value of F can be computed as follows:

\[ F = P_l - P_r \]

Where:

- \( P_l \) = Optimum percentage of asphalt determined by laboratory design method.
- \( P_r \) = Percentage of asphalt determined by calculation according to the formula, using the same gradation as the laboratory samples, and an F value of 0.

When the exact value of F has been thus determined for a given type aggregate the required asphalt for any variations in the gradation of aggregate during plant operation can be quickly checked each time a gradation test is run on the aggregate.

5.64 GRADES OF ASPHALT CEMENT for various paving uses and climatic conditions are shown in Table 1-2.

Chapter VI

ASPHALT CONSTRUCTION EQUIPMENT

6.01 INTRODUCTION.—With modern equipment, any type of asphalt construction may be essentially a mechanical process. It is the intent of specifications to provide for the various steps which must be taken in the process to ensure that uniformly good results are obtained. To accomplish the purpose the trend is to provide new types of equipment and to further improve the ones already available. The construction specifications should encourage such development and take advantage of the improvements as rapidly as made.

This chapter is not intended to cover every type of equipment but rather to draw attention to some of the principal items in most common use. The Asphalt Institute is impartial as to the various types of equipment which may be used in any type of construction operation and as to the manufacturers of equipment for similar purposes.

To maintain this impartiality drawings of various types of equipment are used to show only the essential parts and their general relationship rather than to convey an exact picture. Occasionally, where drawings are not feasible, illustrations of a particular manufacturer are shown but this is not to be construed as an endorsement by The Asphalt Institute or recommendation of the particular make as against any other manufacturer of similar equipment.

6.02 RAILROAD TANK CARS.—Railroad tank cars are made in several sizes, the most common being of 10,000 gallons capacity, or approximately 40 tons. Smaller sizes of 8,000 and 6,500 gallons capacity are sometimes available. The cars are equipped with coils for heating when necessary. Insulated cars may be used, so that when loaded with hot asphalt at the refinery, unloading may be accomplished with little or no heating.

6.03 MOTOR TRANSPORT TRUCKS.—Transport trucks are steel or aluminum tanks which are equipped with baffle plates to prevent surging. They may be insulated and often contain heating flues. Pumping equipment is also desirable. Sometimes two trailer tanks are combined in tandem behind the motor unit. They are made in several
sizes, 2,400 to 5,000 gallons being most common. A tandem trailer combination thus may haul approximately the same amount as the railroad tank car.

6.05 STEEL DRUMS.—Steel drums are usually of 50 to 55 gallons capacity. Asphalt cements may be shipped in friction-top drums constructed of 24 to 28 gauge metal. Steel drums of 24 gauge metal can be used for asphalt up to 100 penetration while 28 gauge metal is usually strong enough for asphalt cement of 85 penetration or lower. Asphalt cements softer than 100 penetration and liquid asphaltic products require a heavier drum, usually of 18 gauge, equipped with bungs. Asphalt is also transported in bulk, in barges and ships.

6.06 ASPHALT HEATERS.—Asphalt heaters are of the following principal types:

1. Tank heaters which heat the asphalt by circulating steam or hot oil through coils in the tank.
2. Combination tank heater and booster may heat the asphalt in the tanks to pumping viscosity only; then the amount of asphalt required for immediate use may be heated to the desired use viscosity by the booster. This effects savings in heating costs and subjects the asphalt to the higher use temperatures for the minimum possible time.
3. Asphalt kettles are used for maintenance and repairs. They come in several sizes, 75 to 225 gallons being the most common. Some have a derrick attachment for hoisting steel drums when supplies are so delivered. They preferably should be equipped with pump and hand spray. Fuel oil, gas and electricity are all used in various types of asphalt heating equipment.

6.07 BROOMS AND CLEANING EQUIPMENT.—Prior to surface treatment, or the construction of a new surface course on an old pavement, it is necessary to thoroughly clean the existing surface and cracks. Surface cleaning brooms vary from small towed revolving cylindrical drum brooms to elaborate self-propelled combination flusher brooms with vacuum and magnetic debris lifters.

Crack cleaning equipment consists of (1) a hand-propelled machine with a motor-driven vertical cleaning device similar to a router by which the operator can follow the crack and not increase its width. These machines frequently may be equipped with a steel wire brush for cleaning the crack and for blowing the area clean of any dust resulting from the cleaning operation, (2) plow attached to tractor or motor grader, (3) grinders for truing and shaping fracture cracks for proper filling, and (4) compressed air jet. Areas not accessible to power equipment should be swept with hand brooms. Steel, rattan, fibre, and plastic are used for bristles in the brooms.

6.07 SCARIFIERS.—In maintenance and reconstruction it is frequently desirable to break up the old surface, reshape to proper grade and add new material. This breaking up is called scarifying and there are special tools for the purpose. The scarifiers may be attached to the blade frame of a motor grader or to the frame of a roller. For deeper and more difficult scarifying a tractor-towed scarifier is used. It consists of a heavy steel frame with large curved steel teeth. They are very heavy, can be adjusted for depth and as the tractor moves forward tend to dig in the full depth below the frame. See Figure VI-1.

6.08 PULVERIZERS.—After scarifying, the old surface material is broken down to approximately the original aggregate particle sizes by rotary type pulverizer similar to
those used in mixed-in-place construction, by traveling hammer mills, or by grid rollers. When the hammer mill or grid roller type pulverizer is used, the material may be broken into as small particles as desired by repeated passes of the equipment. Generally when using this equipment it is necessary to windrow the scarified material.

6.09 THE ASPHALT DISTRIBUTOR.—This is the key piece of equipment in the construction of surface treatments, mixed-in-place types and penetration macadam. It consists of a truck, or a trailer, on which is mounted an insulated tank with a heating system, usually oil burning, with direct heat from the flue passing through the tank. It is further supplied with a power driven pump, of design suitable to handle products ranging from light cold application liquid asphalt to heavy asphalt cements heated to spraying viscosity.* At the back end of the tank is attached a system of spray bars and nozzles through which the asphalt is forced under pressure upon the construction surface. The spray bar should be so constructed that there shall be full circulation of the asphalt through the bar when spraying is not being performed. These spray bars should have a minimum width of application of 10 feet, and on the larger equipment they will cover as much as 24 feet width in one pass when equipped with a suitable capacity pump. A suitable thermometer should be installed in the tank to readily ascertain the temperature of the contents. A connection should be available to attach a hose for single or double nozzle outlet, to cover areas not reached by the spray bars, or as a means of forcing a stream of asphalt to a desired point as in resurfacing rigid slab pavements. Distributors are made in sizes from 500 to 4,000 gallon capacity. Some maintenance distributors as small as 400 gallons are made. Figure VI-2 shows the essential arrangement of one type of distributor and its parts.

6.10 FUNCTION OF THE DISTRIBUTOR.—The function of the distributor is to apply the asphalt to a surface in accurately measured quantities and to maintain the specified rate uniformly through the width and length of the application of the entire load regardless of change in gradient.

* See Chapter IV for Temperature-Viscosity of Various Asphaltic Materials.
or direction and the load on the distributor. To assure a uniform rate of application of asphalt on the sprayed surface requires that:

1. The asphalt must be at the proper viscosity, usually 25 to 100 Saybolt-Furol seconds.
2. The correct pressure must be maintained continuously and uniformly throughout the full length of the spray bar.
3. The spray bar and nozzles must be heated to spray temperatures before spraying is started.
4. Each nozzle must be accurately cut so that all nozzles have a uniform fan spread.
5. The nozzles must be set at the proper angle, usually 15 to 30°, with the spray bar to prevent the spray fans from intermixing or interfering with each other.
6. The angle of application with the roadway should be so as to coat both sides of the aggregate. Normally this is a 90° angle.
7. The nozzle must be set and maintained at the proper height above the roadway to assure proper lap of the spray fans. Some distributors are equipped with adjustable dollys to hold the spray bar at a uniform height regardless of the load on the truck.
8. The speed of the distributor must be constant.

6.11 TACHOMETERS.—The speed of the distributor and on some makes the speed of the asphalt pump is controlled by tachometers. Knowing the spray bar width, the gallons per revolution of the pump, and the pump speed a simple calculation indicates the tachometer readings at which the truck must be driven in order to apply at given rate. The relationship between the spray bar output, distributor speed, and application of asphalt per square yard may be expressed by the following formulae:

\[ S = \frac{9G}{WR} \]
\[ R = \frac{9G}{SW} \]
\[ G = \frac{SRW}{9} \]
\[ S = \frac{9G}{R} \]
\[ R = \frac{9G}{S} \]
\[ G = \frac{SR}{9} \]
\[ G_i = G W \]
\[ W = \frac{G_i}{G} \]
\[ T = \frac{W}{9R} \]

Where:

- \( R \) = Rate of application (gallons per square yard)
- \( G \) = Spray bar output (gallons per minute per foot of spray bar)
- \( G_i \) = Total spray bar output in gallons per minute
- \( W \) = Sprayed width
- \( S \) = Speed of distributor in feet per minute
- \( L \) = the length of spread in feet
- \( T \) = total gallons* to be spread from the distributor load
- \( W \) = width of spread in feet

Tables XV-8-15 show the distance covered by various size distributors, widths and rates of application.

These relationships of course are based on the assumption that the spray bar output remains constant at constant revolutions per minute of the pump and at constant road speed of distribution. A final check of the amount of asphalt applied should be determined from measurements of the area covered and the asphalt actually used based on gauging of the distributor at the beginning and end of the spread.*

Figure VI-2 is a drawing showing the principal parts of one type of asphalt distributor. For more information on asphalt distributors and their operation, see Asphalt Institute Specification Series No. 8 (“Specifications and Construction Methods for Asphalt Surface Treatments.”)

Recently combination asphalt distributor and aggregate spreader units have been developed which spray the asphalt and spread the cover aggregate at one pass of the machine.

6.12 AGGREGATE SPREADER.—Aggregate spreaders are of four general types:

1. The revolving disc whirl type which attaches to or is built on to the aggregate truck. The aggregate is fed on to the spreader disc through an adjustable opening and the speed of the disc is usually adjustable to control the width of spread. (See Figure VI-3)

2. A box with adjustable opening which attaches to and is suspended from the tail gate of the dump truck. Some are equipped with vanes which tend to aid in the

---

*About 50 gallons of asphalt should be left in the distributor, otherwise sloshing in the tank will permit the pump to pull air, causing insufficient application of asphalt in the end area of the spread.
spread of the aggregate from one end of the box to the other. (See Figure VI-4)

(3) A spreader box mounted on its own wheels which is attached to and pushed by the dump truck. (See Figure VI-5) Some of this type have:

   a. Baffles or vanes and spreader screw or spiral or auger agitator which aid in the distribution of the aggregate throughout the length of the box.
   b. Spread or feed roll and adjustable gate to facilitate the control of the aggregate spread.

(4) The self-propelled aggregate spreader. Some of the features of a modern, self-propelled aggregate spreader are:

   a. Receiving hopper on the rear and spread hopper on the front.
   b. The spreader is steered by the operator and pulls the dumping truck facilitating proper alignment of spread.
   c. The width of spread is adjustable.
   d. Independently operated belt conveyors and baffles.
   e. Screw-type auger, baffle plates, and an adjustable deflector to prevent segregation of the aggregate.
   f. A rod screen or grizzly to reject all over-size and foreign objects.
   g. An adjustable hand-actuated control gate.
   h. A spreader roll.
   i. An adjustable screen to place the larger aggregate in the asphalt first and the finer aggregate on top.
   j. A self-propelled spreader usually operates at full throttle in a desired gear, working against the governor to assure constant speed.

**Equipment for Mixed-in-Place Construction**

6.13 GENERAL.—Equipment for Mixed-in-Place Construction—also called road mixing—is of the following principal types:

   (1) The rotary type with transverse shafts, mixes the
asphalt and aggregate by revolving tines under a hood; most are now equipped with a spray system which applies the asphalt while mixing. Most makes have only one rotor but others have up to four rotors all under a long hood.

(2) Power graders and various kinds of plows are still used extensively for small projects.

(3) Travel Plants. Intermediate between the mixed-in-place equipment and the stationary asphalt plant is a type of mixer known as a travel plant. It contains many of the parts found in the usual asphalt plant with exception of drier and screens. Travel plants are of two types:

a. One type, into the hopper of which the aggregate is dumped by the trucks, the aggregate and asphalt are mixed and the mixture spread in one pass of the machine.

b. The other type takes the aggregate from windrows, mixes the aggregate and asphalt and usually deposits the mix in a windrow behind. It is then spread by blade graders, aerated, if necessary, and compacted.

6.14 ASPHALT PLANTS.—An asphalt mixing plant is a factory for manufacturing asphalt paving mixtures in accordance with specification requirements. Its constituent parts and methods of operation may vary with the type of mixture.

The simplest and crudest form is an outfit for producing small quantities of cold-patch mixture. If emulsified asphalt is used as a binder, the only equipment required is a concrete mixer and wheelbarrows and buckets to proportion the aggregate and emulsion on a volumetric basis.

The trend is to larger more elaborate and fully automatic plants for producing high-type hot-mix asphalt concrete in batches of 1,000 to 8,000 lbs. each, and continuous plants with capacities up to over 200 tons per hour. The different units of these plants are discussed in the next chapter under “Manufacture of Asphalt Plant Mixes.” The flow of materials through a typical modern batch plant is shown on Figure VI-6; and through a modern continuous plant in Figure VI-7.

Equipment for Spreading Asphalt Mixes

6.15.—Asphalt mixes are spread by the following:
A. Power graders
B. Mechanical spreading and finishing machines usually called pavers
C. Spreader box towed by the dumping truck

6.16 SPREADING WITH A POWER GRADER.— Both hot and cold asphaltic mixtures are dumped from trucks through windrow eveners depositing the required amount of mixture between each station. The mix is then spread across the grade with power graders. Long wheel base graders are used for pavement construction. The necessity for attaining close surface tolerances for modern high-speed traffic has resulted in an increased use of this method for spreading base and levelling courses as a smooth foundation for paver-laid subsequent courses. Automatic electronic devices for controlling the transverse slope of the blade and the use of a pointer attached to the blade, guided by a string line for longitudinal control make possible very uniform surface. Power grader spreading is frequently done simultaneously with pneumatic-tired rolling.

6.17 PAVERS.—Asphalt finishing machines, commonly known as pavers, in current use are similar in many respects. For all intents and purposes these machines consist of two units, one of which is known as the tractor unit and the other the screed unit (See Figure VI-8).

The tractor unit contains the controls that regulate the flow of material to the screed. It has a hopper into which asphaltic mixtures are deposited from the trucks and from which the material is carried back to the screed unit by means of bar conveyors. The tractor unit also provides the motive power not only for itself and the screed unit, but also to push the truck that is unloading into the hopper.

The screed unit consists of leveling arms or screed arms, a screed plate, a compacting device and thickness controls. The basic connection between the screed unit and the tractor unit is through the screed arms which are pin connected at the track casing of the tractor. In theory this provides a screed with a so-called floating-action which spreads the material fed to it in the desired configuration. When the forces acting on the screed are balanced, it leaves a uniform mat. If these forces are changed, the screed will
either go up or down. Thickness control is achieved by changing the lift of the screed plate thereby disturbing the balance of forces acting on the screed mechanism. The screed mechanism reaches three charged forces until they are balanced again during which time a change in thickness is effected.

6.18 MAKES OF PAVERS—There are many makes of pavers in general use, including (1) Bates-Cititome, (2) Blaw-Knox, (3) Cedar-Rapids, and (4) Pioneer. These vary in the method of initial compaction: (1) The Bates-Citizen and Blaw-Knox have a tamping bar immediately in front of the screed for initially compacting the mix before strike-off. (2) The Cedar-Rapids obtains initial compaction by vibration of the screed. (3) The Pioneer has a vibrating strike-off bar, ahead of and parallel with the screed which gives some initial compaction. Further compaction is provided by vibration of the screed as with the Cedar-Rapids and Blaw-Knox.

All of the pavers operate on basically the same principle of control and control of thickness of spreading. As the tractor unit pulls the screen into the material the screen automatically seeks the level where the bottom of the screen is parallel to the direction of pull, having a mat of definite thickness until the hand wheels on the screed unit adjustment controls are turned. The screens are located and adjustable to the crown or slope desired for the surface.

6.19 SPREADER BOXES—Spreader boxes are towed by the dumping truck and are used for small jobs. These boxes are usually supported on their own wheels and have a screen or strike-off edge which is adjustable for depth of crown and crown. Some are equipped with spreading screws and an oscillating screen. For more information on operating asphalt mixers, see Asphalt Institute Manual Series No. 8, Asphalt Paving Manual.

Compaction Equipment

6.20 GENERAL—The equipment generally available for compaction of embankment, subgrade, subbase, base, binder and surface layers of the asphalt pavement structure are briefly described below. [See also Chapter VII.]

6.21 TAMPPING TYPE COMPACTORS—Most common compacting equipment used in earth work is called a
SOME TYPICAL TYPES OF

Blaw-Knox

Barber-Greene

— 126 —

ASPHALT PAVING MACHINES

Cedarapids

Pioneer

— 127 —
sheepsfoot roller. It consists of a drum from which shanks or feet protrude to provide the compactive effort. These rollers vary in size and weight and are normally towed by tractor. They are used in various combinations to achieve the desired compaction and are most effective in fine grain soils.

6.22 Pneumatic-Tire Rollers are of three types:

(1) Self-propelled tandem three to five wheels in front, four to six in rear; wheels generally oscillate (that is, the axle may move up and down); weights 3 to 35 tons.

(2) The towed type may be either single row of wheels or tandem, weights 2 to 50 tons with oscillating wheels.

(3) The chariot type has only two large wheels.

6.23 Steel-Wheel Rollers are of the following types:

(1) Three-wheel roller. Equipped with two drive wheels usually 60 in. to 70 in. in diameter by 20 in. to 24 in. wide, and a steering roll of smaller diameter but wider. Weights vary from five to seven tons up to 15 or 20 tons. Some have ballastable wheels to increase their weight. Some are equipped with scarifiers; others have shoe-type vibrating compactors attached to the rear which may be hoisted when not in use. Three-wheel steel faced rollers are used mostly for breakdown rolling of asphaltic mixtures and base courses.

(2) Tandem rollers
   a. Two wheel. These come in weights varying from three to 20 tons or more. They generally have ballastable rolls; some of the smaller sizes have auxiliary pneumatic tires for ease in moving between small jobs, and some have only one wide roller with pneumatic auxiliary and moving wheels.
   b. Three-axle tandem rollers. The center axle roll is so arranged that a large part of the total weight of roller can be applied thereon as required on high spots. These rollers are made in sizes ranging in weight from 10 or 12 to 20 or more tons. These rolls are usually ballastable. Some 3-axle tandem rollers are made with a separate power unit for vibrating the center axle roll, thereby functioning as a combination vibratory compactor and tandem roller.
6.24 Vibratory Compactors are generally of two types:

1. Vibrating shoes or plates. The vibratory shoe-type has from one shoe for patches, trenches and small areas, to six or more for regular road work. These can be arranged side by side or in tandem. Shoe-type vibratory compactors are mostly used for compaction of macadam and other granular base courses. The small units are used extensively for compaction of asphaltic mixtures used in patching in small areas inaccessible to large rollers.

2. Vibrating rollers. These have one or two smooth surfaced rolls three to five feet in diameter and four to six feet wide, and are of either the tow or tandem types. The static weight is usually from three to five tons; however, units up to 10 or 11 tons static weight are currently available. Also becoming available are self-propelled vibrating rollers with a static weight of four to six tons. As noted above, some large tandems have provision for vibrating the third axle unit. Vibratory rollers may be used for compacting most types of granular soils or asphaltic mixtures. With some, however, it is necessary to adjust the resonance to the dynamic force to the type of materials compacted.

6.25 Combination Types. There is an accelerated trend toward combination types of rollers. In addition to the 3-wheel tandem with vibrating third roll referred to above, there are a number of combination steel wheel and pneumatic-tired rollers. There is also a three wheel steel roller with shoe type vibrators which may be hydraulically lifted when not in use.

6.26 Asphalt Heater Planers. A heater planer consists of a combination surface heater and planer for heating the surface of asphalt pavement and planing off the heated asphalt-aggregate mixture. Large efficient machines are available, capable of speeds of from a slow creep to about thirty-five feet per minute. Some are equipped with both serrated and smooth cutting blades. The blades are usually positioned so that the planed material is deposited in a continuous window behind the planer. After the application of the heater planer an asphalt concrete overlay or surface treatment may be applied or the surface, as prepared by the heater planer, may be utilized.

6.27 Asphalt Curb Machines. See Chapter IX.
b. The Use, Manufacture and Inspection of Asphalt Plant Mixes
c. Hauling, Spreading and Compacting Asphalt Plant Mixes
d. Asphalt Macadam
e. Mixed-in-place
f. Asphalt Surface Treatments and Seal Coats
   Other Asphalt Institute Publications cover various phases of asphalt construction in detail as follows:
   (In preparation)
   (In preparation)
These publications and information on particular problems are available from Asphalt Institute engineers at offices listed in the end papers.

A.—Preparation of Foundation for Asphalt Pavements

Drainage and Moisture Control

7.03 GENERAL.—Accumulation of moisture in the courses of the pavement structure is probably the greatest single cause of pavement distress, a fact which is recognized and understood by all engineers. However, today’s wider pavements common to multi-lane highways, are approaching the dimensions of an airfield pavement, and call for the application of principles and methods used in airfield drainage, a fact not fully recognized by some highway engineers.

7.04 DRAINAGE SYSTEMS.—Drainage systems may be classified in two categories—surface and subsurface—and each functions independently of the other. Surface drainage entails the collection and rapid removal of water from the pavement and shoulder areas. Subsurface drainage must intercept, collect and remove ground water from the subgrade and prevent it from entering the pavement structure.

7.05 SURFACE DRAINAGE.—Surface drainage is most effectively accomplished by full-width paving. On elevated grades the water should be directed to asphalt spillways by means of asphalt dikes or curbs constructed on the extreme outside edge of the shoulder. The roadways and shoulders in cut sections also should be paved full width with surface water being directed to paved ditches or drains. In many cut sections there is need also for longitudinal subdrains to prevent water from higher ground accumulating under the pavement.

7.06 SUBSURFACE DRAINAGE.—Subsurface drainage methods are generally understood by civil engineers and details of drainage structures are available in many publications. However, the unpaved raised median which is widely used in geometric design of roads offers difficult drainage problems. Regardless of the number of transverse drains employed, quantities of rain water and snow-melt will drain from a raised median into the pavement structure and subgrade, weakening the pavement. The depressed median is recommended wherever possible, and if conditions make it mandatory to construct an elevated median, transverse drains should be connected with a longitudinal drain in the median deep enough to collect all ground water before it can find its way into the pavement structure.

Subsurface seepage may, under certain conditions, develop a hydrostatic head beneath the pavement sufficient to lift the pavement completely off the base, causing cracking and, in extreme cases, complete disintegration of the pavement structure. This problem is more acute when steep grades are involved. With steep gradients the water may travel longitudinally in the base along the direction of the gradient and cause excessive hydrostatic pressures at sag vertical curves or on the low side of superelevened horizontal curves. If not intercepted, water from a cut may flow out onto a fill and cause slumping of the fill slope and cracking of the pavement. The choice of filter material and the design of the drainage system must be given careful attention, considering both the type of material to be drained and the quantity of water expected.
If a coarse drain rock is used, contamination by the adjacent soil, particularly cohesionless silts and fine sands, may eventually result in complete clogging of the drain. Use of finer filter materials to prevent clogging may not provide the capacity necessary to accommodate the ground water flow. If heavy flows are expected in silty soils, a two-layer system, consisting of filter material to prevent contamination, and a coarse open drain rock to provide the required capacity, may be necessary.

7.07 SELECTION OF FILTER MATERIAL GRADING LIMITS.—The criterion suggested by Terzaghi and tested and adopted by the Corps of Engineers, to prevent intrusion in drain backfills, is based on the piping ratio determined by the relationship of the maximum size of the smallest 15% and the maximum size of the smallest 85% of both the soil and the filter material. The most important of these criteria are:

1. The ratio of the 15% size of the filter material to the 85% size of the material to be drained shall not be greater than 5.
2. The ratio of the 50% size of the filter material to the 50% size of the material to be drained shall not be greater than 25.
3. To avoid clogging of the drain pipe, the ratio of the 85% size of the filter material to the size of the pipe perforation must be not less than 2.

If plastic clays containing lenses or partings of sand or silt are to be drained, the size distribution of the silt or sand portion should be used rather than the clay fraction. If the soils to be drained are not homogeneous, the filter material grading necessary to prevent clogging in one area may not be sufficiently permeable to carry the volume of water encountered in another area and a two-layer system may be required. See trench design below.

7.08 TRENCH DESIGN.—Drains may be placed for a wide variety of conditions and purposes. The construction of the drain will be influenced by the existing conditions and the drain should be designed for ease of construction and economy with due regard to the functions it must perform.

For shallow drains used to remove water from the base course under a pavement, a V-trench is generally the most practical. The trench may be constructed with a motor grader; the shape more nearly fits the flow pattern of the water to be removed and placement of the pipe and filter material is facilitated. For deep drains used to intercept water from a pervious layer or to lower the water table in a uniform soil, a trench with vertical sides will usually be the most economical because of the lesser quantity of excavation. It is also more easily supported by shoring.

The following designs are suggested for consideration:

A. Wet Cuts—If the material encountered at grade is uniformly stratified it may be possible to remove seepage water by interceptor drains at the toe of the cut slope. A weakness of this type of construction, however, is that water very frequently will bypass the drain and rise to the surface beneath the pavement. This may be caused by variations or curvature in the stratifications or by shear zones caused by old earth movements. A much more positive means of control is obtained by placing a blanket of pervious subbase material completely across the roadway to collect any seepage water. This subbase material can then be drained by means of a relatively shallow V-trench at the low point in the cross-section.

If a heavy volume of water is expected, it may be advisable to construct a two-layer system in order to obtain greater capacity of the drain. (See Figure VII-1)

If an appreciable gradient is involved, a cross-drain should be placed at the down-hill end of the cut to intercept any water flowing longitudinally which might otherwise saturate the fills and cause slumping of the fill slopes.

When drains are placed in cuts, the trenches constructed must not undercut the side slopes. The seepage that necessitates the installation of drains may also result in unstable slopes requiring special treatment or flattening of cut slopes and a drain trench placed at the toe of the cut slope may cause a slide during construction. Trenches at the toe of the slope may also lead to construction difficulties. Trenches with vertical sides are usually dug with a trencher and a trencher cannot operate with one track up on the cut slope. (See Figure VII-2)
B. High Ground Water Table—Deep, vertical trenches may be placed on either side of the roadway to lower the ground water table beneath the pavement. Drains planned for this purpose should be analyzed by means of a flow net to provide all possible assurance that the drains will function as intended.

In areas of high ground water level it is better practice, and probably more economical in the final analysis, to raise the grade of the highway with granular material to provide a separation between the pavement and the ground water.

7.09 CONSTRUCTION CONTROL.—The importance of rigid inspection during construction cannot be over-emphasized. This is particularly true of the grading of the filter material. An increase in the dust content of only a few percentage points may cut the permeability of the filter material to one-tenth of that which would have been obtained. The inclusion of clay lumps may completely block the flow of water and segregation of the filter material can seriously impair the functioning of the drain.

7.10 MOISTURE CONTROL.—In addition to adequate drainage, both surface and subsurface, there should be an adequate thickness of base courses that have been waterproofed and stabilized with asphalt to sustain the traffic loads at all ambient moisture conditions. It must be remembered that (1) capillarity and moisture vapor action can cause an increase of moisture throughout the pavement structure unless the materials are waterproofed with asphalt, and (2) when the moisture in non-asphaltic materials rises above the optimum moisture at which they were compacted, the materials lose strength. For these reasons an adequate thickness of asphalt base is essential.

Compaction

7.11 GENERAL.—The importance of proper compaction of each layer of embankments, subgrade, improved subgrade, and base courses is universally recognized. Compaction greatly increases the supporting power of the subgrade. Where the subgrade is not sufficiently compacted during construction, additional consolidation may occur under traffic with resulting settlement and possible failure.
7.12 COMPACTION TESTS.—Compaction tests are made in the laboratory on materials to be used in the construction to determine the maximum practical density which may be obtained. These laboratory densities should be determined on the basis of AASHO Method of Test T180.

7.13 COMPACTION CRITERIA.—The following criteria for compaction are recommended for construction of asphalt pavement structures:

(1) Cohesive Subgrades.—Minimum 95% Modified AASHO (T180, Method D) density for the top 12 inches and minimum 90% for all fill areas below the top 12 inches. The water content for compaction of cohesive soils should be determined by tests and should be selected to provide the highest remolded strength consistent with expansion considerations. Generally, nonexpansive soils should be compacted one or two percent on the dry side of laboratory optimum moisture content for best results.

(2) Cohesionless Subgrades.—Minimum 100% of Modified AASHO (T180, Method D) density for the top 12 inches and minimum 95% below this for all fill areas.

(3) Bases, Subbases, and Improved Subgrade.—The compaction load and contact pressure should be as high as the material being compacted will support, in excess of 100% of Modified AASHO (T180, Method D) density, without rutting or displacement or both. As stronger layers are placed, the load and contact pressure should be increased up to or in excess of the contact pressures expected on the pavement.

7.14 COMPACTION EQUIPMENT.—Many kinds of compaction equipment are discussed in Chapter VI, including tamping compactors, pneumatic-tire rollers, steel-wheel rollers, vibratory compactors, and combination types.

7.15 USE OF COMPACTION EQUIPMENT.—The question may arise as to why so many types and sizes of compaction equipment are used. Research and experience have proved that there are many aspects to compaction of soils, base materials, and asphaltic mixtures. It is known, for instance, that:

(1) Moving loads can produce deflections for considerable depths.

(2) Weight alone tends to give maximum compaction near the surface only.

(3) Vibration tends to deepen compaction in certain materials.

(4) Certain kneading action increases density.

(5) Contact pressure and area are the best criteria for measuring the compactive capacity of pneumatic-tire rollers.

(6) Contact pressure varies with each type and size of tire and is a function of tire size, ply rating, wheel load, and tire inflation pressures.

(7) The contact pressure used for construction compaction should be the maximum that can be applied without undue displacement.

(8) Vibration increases in effectiveness as cohesion decreases and granularity of material increases, being highest in sands and lowest in clays.

This effectiveness is a variable with temperature in asphalt mixes, being more effective as temperature increases. It is a variable with water content in soils, being more effective as water increases. This is not to be construed as favoring overheating of pavement materials or overwatering soils; the proper limits in both cases are controlled by standard tests and specifications.

From these known facts it is reasoned that required compaction can be obtained most readily only by the proper combination of tire load, contact pressure, kneading action, and vibration. Surface and smoothness requirements limit the type of compaction equipment. Experience and research to date indicate that the type of compaction equipment most suitable for the materials listed is as follows:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Type of Compaction Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Fine grained embankment and subgrade soils</td>
<td>Sheepfoot rollers</td>
</tr>
<tr>
<td></td>
<td>Segmented steel-wheel rollers</td>
</tr>
<tr>
<td></td>
<td>Oscillating wheel pneumatic-tire rollers</td>
</tr>
<tr>
<td></td>
<td>Vibratory steel-wheel rollers</td>
</tr>
<tr>
<td>b. Granular base, subbase, and improved subgrade courses</td>
<td>Pneumatic-tire rollers</td>
</tr>
<tr>
<td></td>
<td>Vibratory compactors (both shoe and steel-wheel type)</td>
</tr>
<tr>
<td></td>
<td>Oscillating wheel pneumatic-tire rollers</td>
</tr>
<tr>
<td></td>
<td>Segmented steel-wheel rollers</td>
</tr>
<tr>
<td>c. Macadam and other coarse aggregate base courses</td>
<td>Shoe-type vibratory compactors</td>
</tr>
<tr>
<td></td>
<td>Steel-wheel vibratory rollers</td>
</tr>
<tr>
<td></td>
<td>Steel-wheel rollers</td>
</tr>
<tr>
<td></td>
<td>Pneumatic-tire rollers</td>
</tr>
</tbody>
</table>
d. Mixed-in-place asphalt base courses

Pneumatic-tire rollers
Steel-wheel rollers
Segmented wheel rollers
Vibratory compactors (either shoe or steel-wheel type)

e. Asphalt macadam

Steel-wheel vibratory rollers
Steel-wheel rollers (tandem or three wheel)

f. Plant-mix base, leveling, or surface courses

Pneumatic-tire rollers
Breakdown rolling
Steel-wheel three-wheel rollers
Steel-wheel rollers (two-axle tandem rollers)

Intermediate rolling
Pneumatic-tire rollers (self-propelled)
Two- and three-wheel tandem rollers
Final rolling

7.16 THICKNESS OF LIFTS.—Fill sections generally should be built in layers not exceeding six inches after compaction. Heavy pneumatic-tire and vibratory compaction rollers may be satisfactory for lifts up to 12 inches but these thicker lifts should be used only if tests show that adequate and uniform density is obtained. In some cases it may be desirable to construct a small test fill to obtain pertinent information on moisture content, thickness of lift, and number of passes with compacting equipment.

In determining the thickness of lifts, it should be remembered that the effectiveness of a compactive effort on a lift decreases with depth. Hence, each lift will usually be more highly compacted at the top than at the bottom, and the less thorough the compaction, the greater will be the difference. This depth effect is reduced by vibration in materials responding to it (dry or saturated cohesionless materials). Kneading action also is an aid, especially in materials whose resistance to compaction is derived from both cohesion or viscosity and granular interference.

The same considerations apply in lesser degree to asphaltic lifts, because they usually are thinner.

7.17 COMPACI0N OF CUT SECTIONS.—The compaction criteria for subgrades should apply for cut sections also. It may be possible to compact some soils with available equipment, especially cohesionless sands, to the depths required without removal. In some instances, however, removal of the soil, adjustment to proper moisture content, replacement, and recompaction may be required to produce the specified density.

This rearrangement also tends to produce uniformity in the subgrade and thus avoid differential settlement. In any case, the required densities must be obtained if the pavement is to provide proper service.

7.18 SPECIAL CASES.—Although compaction increases the stability of most soils, some soils decrease in stability when scarified, worked, and rolled. There are also some soils that shrink excessively during dry periods and expand excessively when allowed to absorb moisture. When these conditions are encountered, special treatment is required and a soils engineer should be consulted. Soils in which these conditions occur are:

1. Clays which lose strength when remolded
2. Silts that become "quick" when remolded
3. Soils with expansive characteristics

Pneumatic-Tire Compaction

7.19 GENERAL.—Care should be used in the preparation of specifications for the compaction of embankment layers and asphalt pavement structure courses to assure that they are not restrictive or tend to limit usage of new and improved equipment. This applies especially to pneumatic tire and vibratory compaction equipment which is in a period of rapid development.

7.20 FACTORS INFLUENCING CONTACT PRESSURE.—The ability of pneumatic-tire compactors to exert a given contact or ground pressure is dependent on the following factors:

1. Tire size
2. Ply rating
3. Wheel load
4. Tire inflation pressures

It would be possible to specify all of the above factors and still have a restrictive specification because rollers equipped with other size tires under different wheel loads would be capable of exerting comparable contact pressures. Contact pressure and area should be the principal criteria in rating the pneumatic rollers to be used. The contact pressure range varies with each size and type of tire, wheel load, and tire inflation pressure.
Some specifications contain the following requirement:

"The contractor shall furnish to the engineer charts or tabulations showing the contact areas and contact pressures for the full range of tire inflation pressures and for the full range of tire loadings for each type and size compactor tire furnished."

Table VII-1 shows contact areas and ground or contact pressures for various loadings and tire pressures of one size and type of compaction tire. Similar tables and graphs (Figure VII-3) for developing this information are available for other sizes and types of compactor tires.

### Table VII-1

**CONTACT AREAS AND CONTACT PRESSURES FOR VARIOUS INFLATIONS AND WHEEL LOADS**

**9.00-20-12 PLY SMOOTH WIDE TREAD COMPACTOR TIRE**

<table>
<thead>
<tr>
<th>Wheel Load lbs.</th>
<th>Inflation Pressure PSI</th>
<th>Defl. in.</th>
<th>Length in.</th>
<th>Width in.</th>
<th>Area sq. in.</th>
<th>Contact Pressure PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>40</td>
<td>.78</td>
<td>8.33</td>
<td>6.33</td>
<td>41.6</td>
<td>48.2</td>
</tr>
<tr>
<td>&quot;</td>
<td>60</td>
<td>.68</td>
<td>7.80</td>
<td>5.79</td>
<td>36.2</td>
<td>55.3</td>
</tr>
<tr>
<td>&quot;</td>
<td>80</td>
<td>.58</td>
<td>7.37</td>
<td>5.36</td>
<td>31.5</td>
<td>63.6</td>
</tr>
<tr>
<td>&quot;</td>
<td>100</td>
<td>.52</td>
<td>6.91</td>
<td>5.11</td>
<td>28.4</td>
<td>70.5</td>
</tr>
<tr>
<td>&quot;</td>
<td>120</td>
<td>.50</td>
<td>6.78</td>
<td>4.96</td>
<td>26.3</td>
<td>76.2</td>
</tr>
<tr>
<td>3500</td>
<td>40</td>
<td>1.24</td>
<td>10.45</td>
<td>7.96</td>
<td>67.0</td>
<td>52.3</td>
</tr>
<tr>
<td>&quot;</td>
<td>60</td>
<td>1.01</td>
<td>9.54</td>
<td>7.20</td>
<td>55.7</td>
<td>42.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>80</td>
<td>.85</td>
<td>8.84</td>
<td>6.63</td>
<td>47.8</td>
<td>73.3</td>
</tr>
<tr>
<td>&quot;</td>
<td>100</td>
<td>.77</td>
<td>8.48</td>
<td>6.37</td>
<td>43.7</td>
<td>80.0</td>
</tr>
<tr>
<td>&quot;</td>
<td>120</td>
<td>.74</td>
<td>8.20</td>
<td>6.14</td>
<td>40.2</td>
<td>87.0</td>
</tr>
<tr>
<td>5000</td>
<td>40</td>
<td>1.75</td>
<td>12.25</td>
<td>9.02</td>
<td>90.4</td>
<td>55.4</td>
</tr>
<tr>
<td>&quot;</td>
<td>60</td>
<td>1.34</td>
<td>10.98</td>
<td>8.34</td>
<td>73.9</td>
<td>67.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>80</td>
<td>1.10</td>
<td>10.19</td>
<td>7.96</td>
<td>64.1</td>
<td>78.0</td>
</tr>
<tr>
<td>&quot;</td>
<td>100</td>
<td>1.00</td>
<td>9.73</td>
<td>7.27</td>
<td>57.2</td>
<td>87.5</td>
</tr>
<tr>
<td>&quot;</td>
<td>120</td>
<td>.94</td>
<td>9.41</td>
<td>7.04</td>
<td>53.8</td>
<td>93.0</td>
</tr>
<tr>
<td>6000</td>
<td>40</td>
<td>2.06</td>
<td>13.38</td>
<td>9.30</td>
<td>107.0</td>
<td>56.0</td>
</tr>
<tr>
<td>&quot;</td>
<td>60</td>
<td>1.58</td>
<td>11.92</td>
<td>8.88</td>
<td>86.0</td>
<td>69.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>80</td>
<td>1.28</td>
<td>10.99</td>
<td>8.34</td>
<td>74.0</td>
<td>81.1</td>
</tr>
<tr>
<td>&quot;</td>
<td>100</td>
<td>1.13</td>
<td>10.39</td>
<td>7.86</td>
<td>65.4</td>
<td>91.7</td>
</tr>
<tr>
<td>&quot;</td>
<td>120</td>
<td>1.07</td>
<td>9.94</td>
<td>7.48</td>
<td>60.8</td>
<td>98.6</td>
</tr>
</tbody>
</table>

7.21 AVERAGE CONTACT PRESSURE.—From data in tables similar to Table VII-1, it is possible to compute...
### Table VII-2—AVERAGE CONTACT PRESSURES FOR CONVENTIONAL TYPE TRUCK TIRE
(Dual Wheel Conditions)

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>Axle Load</th>
<th>Wheel Load</th>
<th>COLD INFLATION</th>
<th>HOT INFLATION</th>
<th>Suggested Roller Pressure Range psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.00x20 - 14 ply (Rated, 5540 lbs at 85 psi)</td>
<td>18,000</td>
<td>4,500</td>
<td>85</td>
<td>62.6</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>22,400</td>
<td>5,600</td>
<td>85</td>
<td>69.9</td>
<td>105</td>
</tr>
</tbody>
</table>

Note: Some of the contact pressure values are approximate and were obtained by interpolation. Probable accuracy 1.0± psi.

1 Wheel loads of this magnitude may also be carried by front axle tires.

2 Based on an average of 25% voids in tire contact pattern.

### Table VII-3—AVERAGE CONTACT PRESSURES FOR HIGHER PRESSURE TRUCK TIRES
(Dual Wheel Conditions)

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>Axle Load</th>
<th>Wheel Load</th>
<th>COLD INFLATION</th>
<th>HOT INFLATION</th>
<th>Suggested Roller Pressure Range psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00x20 wire cord (Rated, 5210 lbs at 100 psi)</td>
<td>18,000</td>
<td>4,500</td>
<td>95</td>
<td>72.2</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>22,400</td>
<td>5,600</td>
<td>100</td>
<td>79.2</td>
<td>120</td>
</tr>
<tr>
<td>10.3-2C/10.3-22.5 (9.00x20)</td>
<td>18,000</td>
<td>4,500</td>
<td>95</td>
<td>75.1</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>22,400</td>
<td>5,600</td>
<td>95</td>
<td>84.0</td>
<td>115</td>
</tr>
</tbody>
</table>

Note: Some of the contact pressure values are approximate and were obtained by interpolation. Probable accuracy 1.0± psi.

1 Wheel loads of this magnitude may also be carried by front axle tires.

2 Based on an average of 25% voids in tire contact pattern.
the average contact pressure for the various size tires. The term "average contact pressure" is used because the pressure is not constant throughout the elliptical contact pattern of the tire. The average contact pressure is obtained by dividing the contact area into the wheel load to obtain pounds per square inch (psi). Contact areas are obtained for different wheel loads and inflation pressures by tracing the contact patterns on a glass or steel plate with the tire in a static position.

Tables VII-2 and VII-3 show average contact pressures for truck tires and suggested contact pressure range for pneumatic rollers. Ruts and ridges may appear in the warm asphalt concrete during the intermediate rolling if the contact pressures are too high for viscosity and stability conditions. In this case, contact pressures should be lowered by reducing the tire pressure or wheel load, or both. As rolling progresses, the pressures should be increased to the range recommended in the tables.

Table VII-4

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>Wheel Load</th>
<th>Infl. Lbs.</th>
<th>Contact Area Sq. In.</th>
<th>Contact Width In.</th>
<th>Contact Pressure psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.50 x 15 - 10 ply</td>
<td>5000</td>
<td>80</td>
<td>60.5</td>
<td>7.36</td>
<td>82.6</td>
</tr>
<tr>
<td>9.00 x 20 - 12 ply</td>
<td>5000</td>
<td>85</td>
<td>62.4</td>
<td>7.79</td>
<td>80.1</td>
</tr>
<tr>
<td>10.00 x 15 - 14 ply</td>
<td>5000</td>
<td>90</td>
<td>61.4</td>
<td>7.38</td>
<td>81.4</td>
</tr>
<tr>
<td>12.00 x 24 - 22 ply</td>
<td>5000</td>
<td>120</td>
<td>62.5</td>
<td>6.00</td>
<td>80.0</td>
</tr>
</tbody>
</table>

Note: Wheel load and inflation pressures shown are for illustration only and should not be used as a guide for rolled requirements. (See Table VII-5 and VII-6.)

This tabulation also shows that for equal wheel loads the larger the compactor tire the more inflation pressure is required to obtain a contact pressure of 80± psi.

It is also apparent that "inflation pressure" is not a reliable indicator of compacting effort when comparing a number of different size compactor tires, which is necessary in developing non-restrictive requirements. Tire inflation pressures and wheel loads for a given tire size can be used on construction to control the desired contact pressure. These data are available from tire charts or tables.

7.22 WHEEL LOADS AND INFLATION PRESSURES.—Compactor tires are rated for given wheel loads and inflation pressures which should not be exceeded.
Table VII-5 shows the wheel or tire loads and inflation pressures which have been recommended by the Tire and Rim Association, Inc., for compaction service (5 miles per hour). Undercutting in the table denotes maximum recommended loads for tire sizes and ply ratings shown.

Any load-inflation combination shown on Table VII-5 may be used if the rated load and inflation for a given ply tire is not exceeded. For example, a 9.00x20-12 ply compactor tire with a load of 5,020 pounds could be used with any inflation pressure between 35 psi and 90 psi. Such flexibility in pressure-load variations provides a wide range of contact, or ground, pressures for numerous compaction conditions. To illustrate, the initial rolling of asphalt mixes and weaker materials may require inflation pressures of from 35 psi to 50 psi and an appropriate reduction in wheel loads.

Table VII-6 shows, for the more commonly used compactor tires, the complete contact pressure range within the tire load and inflation ranges established by the Tire and Rim Association, Inc. The unballasted weight of a roller may prevent the attainment of the lower ranges. The contact pressures shown were developed from information furnished by several tire and rubber companies and are intended as average values. Because of slight variations in tire design features, unit contact pressures of tires manufactured by different companies may vary up to ±5 percent. For field compaction control, tire data of the applicable manufacturer are recommended.

By referring to Table VII-5 and one similar to Table VII-1, for tires on the compactor being used, the engineer can determine the proper balance between the tire inflation pressures and ballast loading for the layer being rolled. The contact pressure should be as high as the material being rolled will support without rutting.

Examination of Table VII-6 reveals that for the 9.00x20-12 ply tire shown in Table VII-5, the contact pressure can be varied from 31.0 psi, when inflated to 35 psi and loaded at 5,020 pounds per tire, to 92.0 psi, or nearly doubled, when inflated to 90 psi and loaded to 8,720 pounds per tire. Similar flexibility in contact pressures can be obtained by varying the inflation pressure and tire loadings for all other compactor tires within the previously stated limits and the maximum inflation allowed by the rim design.

### Table VII-5 — EXPERIMENTAL PRACTICE TIRE LOADS FOR COMPACTOR VEHICLES

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>7.50-15 (L1)</th>
<th>7.50-18 (L2)</th>
<th>7.50-20 (L3)</th>
<th>8.25-20 (L5)</th>
<th>9.00-20 (L6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Speed — 5 MPH</strong></td>
<td><strong>13.00-24</strong></td>
<td><strong>16.00-21</strong></td>
<td><strong>21.00-25</strong></td>
<td><strong>28.00-33</strong></td>
<td><strong>35.00-40</strong></td>
</tr>
<tr>
<td><strong>Inflation</strong></td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>3000</td>
<td>3300</td>
<td>3600</td>
<td>3900</td>
<td>4200</td>
</tr>
<tr>
<td><strong>Contact Pressure</strong></td>
<td>5280</td>
<td>5750</td>
<td>6200</td>
<td>6680</td>
<td>7150</td>
</tr>
<tr>
<td><strong>Note 1.</strong> Normal inflation pressures are for compactor tires.</td>
<td>Note 2. Bold-face type denotes recommended loads for tire sizes and ply ratings shown.</td>
<td>Note 3. (L1) indicates light truck rim.</td>
<td>Note 4. For inflation in excess of 100 psi, consult the rim supplier for rim strength and wheel design.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table VII-6 — APPROXIMATE TIRE CONTACT PRESSURE RANGES FOR TIRE LOADS AT VARIOUS INFLATION PRESSURES

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>Contact Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ply Rating</td>
<td>7.00-15</td>
</tr>
<tr>
<td>6</td>
<td>42</td>
</tr>
<tr>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>14</td>
<td>42</td>
</tr>
<tr>
<td>16</td>
<td>42</td>
</tr>
<tr>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>22</td>
<td>42</td>
</tr>
<tr>
<td>24</td>
<td>42</td>
</tr>
<tr>
<td>26</td>
<td>42</td>
</tr>
<tr>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>32</td>
<td>42</td>
</tr>
<tr>
<td>34</td>
<td>42</td>
</tr>
<tr>
<td>36</td>
<td>42</td>
</tr>
</tbody>
</table>

Notes: 1. Average tire contact pressure and flat tire pressure shown are for 50 psi inflation. 2. Full load available in smooth wide trend. For treaded tires, values shown are for gross contact area.

Such flexibility in contact pressures when using the same pneumatic tire compactors is the reason for their increasing popularity, but it also emphasizes the need for their judicious handling. They are both useful and dangerous tools. The same roller can do either an excellent job of compaction or only halfway compact the material depending on how the tire inflations and wheel loads are controlled.

The curves shown in Figure VII-4 were developed through field density determinations at several contact pressure values of the compactor tires and for two ranges of coverages. The curves show that density is directly dependent on these two factors if moisture is constant, provided the shear strength of the material is not exceeded. Low load supporting soils are an exception since most designs would require their exclusion. The curves show that if a density of 95 percent of AASHO, T180, Method D, is required, it can be achieved at an average contact pressure of 80 psi with eight passes of the pneumatic roller. However, if the contact pressure is increased to about 90 psi, the same density can be achieved in half the number of passes.

Vibratory Compaction

7.23 GENERAL.—Vibratory compactors are being increasingly used in the compaction of embankment layers and the courses of asphalt pavement structures. Indications are that a combination of these vibratory compactors and pneumatic-tire rollers with a proper load and contact pressures result in densities considerably higher and more uniform than can be obtained without the use of vibratory compactors. However, criteria for determining and governing the many facets of vibratory rolling are not yet specific. From a practical standpoint, it is not difficult to determine the proper resonant frequency for given equipment and material and, with a little experience and a few tests, proper operating procedures can be developed for each condition.

Proof Rolling

7.24 GENERAL.—Surface irregularities in asphalt pavement structures usually result from traffic densification of the underlying courses, usually in the wheel paths. Such irregularities indicate that one or more courses were not
adequately compacted during construction or that soft, unstable areas exist in the structure. To overcome these deficiencies, the use of proof rolling of the underlying courses is rapidly increasing.

7.25 DESCRIPTION.—Proof rolling is accomplished by the application of heavy, rubber-tire rollers over the course, usually as a supplement to initial compaction of the course by conventional means. The principal purposes of proof rolling are:

1. To locate unstable areas
2. To achieve additional compaction

When first introduced, the very heavy rollers were used only to proof roll or test the uniformity of compaction accomplished with conventional rollers. However, the ease with which additional compaction may be attained by their use has tended to make them a working compaction tool. They are used with and immediately following conventional equipment throughout the construction of each course of embankment, subgrade, improved subgrade, and base courses.

Proof rollers can benefit soils which are below design optimum moisture content. They will impart additional compaction less effort than conventional compaction equipment and increase the density up to or in excess of the design density. If the moisture content is at design optimum, additional compactive effort, beyond that required for design density, may weaken the soil. Therefore, when the design moisture content is in the soil, proof rolling should be done with care. If the moisture content is above optimum, proof rolling readily establishes this condition and correction can be made during construction.

Proof rolling should not be used as a substitute for field moisture and density tests. They should all be used together to assure the desired results.

7.26 EQUIPMENT.—Proof rolling equipment consists of a rigid steel frame, mounted on rubber-tire wheels, with a suitable body for ballast loading, to a gross weight of from 25 to 50 tons for highways, and 200 tons for airfields. Usually two to four wheels per axle are used. If there are more than two wheels, they are arranged so all wheels will carry approximately equal loads when operating over an uneven surface.

7.27 TIRES.—Tires should be capable of operating at inflation pressures ranging from 50 to 150 pounds per square inch. Usually the tires are partially filled with liquid to reduce hazards if blowouts occur. Charts or tabulations showing the contact areas and contact pressures for the full range of inflation pressures, and for the full range of loadings, for the particular tires should be available so adjustments can be made for the material being rolled.

7.28 BALLAST AND LOADING.—Ballast may consist of ingots, concrete blocks, or other materials of known weight such that the total weight of the ballast can be readily determined. Sufficient ballast should be available to load the roller to a maximum gross weight which will produce contact pressures of up to 135 psi for highways. Rubber-tire tractive equipment should be used on base courses. Other types of tractive equipment may be used for operation on subgrade. For highway compaction, the entire assembly, including the tractor, should be capable of turning 180° in a 27-foot width.

7.29 CONSTRUCTION METHODS.—Each layer is placed to specified thickness at optimum moisture and rolled initially with conventional equipment. It is then further compacted with the proof roller. Proper moisture control is as important in proof rolling as it is in all rolling. The moisture content should be limited to a range of from optimum moisture to not more than 3% below optimum moisture for the particular layer of material being rolled. For cohesive soils whose optimum moisture is near its plastic limit, the range should be from 1 to 2% below optimum moisture.

The load and tire pressures of the proof rollers are adjusted for contact pressures as nearly as practical to the maximum supporting value of the layer being rolled. As stronger layers are placed, the load and tire inflation pressures are increased to the maximum contact pressure specified. A minimum of two coverages of the proof roller is usually required. Each succeeding trip with the proof roller should be offset by not greater than one tire width to obtain complete area coverage. The roller should be operated in a systematic manner so that the number of coverages over all areas can be readily determined and recorded. Best results are obtained when the roller is operated at speeds of from 2½ to 5 miles per hour.

When the proof rolling of any layer shows an area to be unstable or non-uniform, such an area should be brought to satisfactory stability and uniformity by additional com-
paction or by removal of unsuitable materials, replacement with suitable materials, and recompaction. The surface should then be checked for conformance to the plan lines and grades, and any irregularities corrected to specified tolerances.

7.30 METHOD OF MEASUREMENT AND PAYMENT.—Specifications generally provide that proof rolling will be paid for at the contract unit price per hour for the actual number of hours of rolling time; no payment being made for time for which equipment is idle for repairs, servicing, loading or unloading ballast, increasing or decreasing tire pressure, bad weather, wet subgrade, standing by to be available when next needed, or for any other such reason. They also usually provide that no payment will be made for the equipment used at times or locations other than as prescribed in the specifications or directed by the engineer.

Preparation of Old Pavements Used as Bases

7.31 PREPARATION OF OLD PAVEMENTS WHEN USED AS BASES.—Material is covered in other parts of this Handbook as follows:

(1) Priming non-asphaltic bases, Chapter VII, Sect. F.
(2) Tack coats, Chapter VII, Sect. F.
(3) Widening, Chapter VIII, Sect. A.
(4) Reconstruction of old asphalt pavements, Chapter VIII, Sect. A.
(5) Overlaying old rigid type pavements, Chapter VIII, Sect. A.

For various types of asphalt bases see other sections of this Handbook as follows:

(1) Hot and Cold Laid Mixes, Chapter VII, Sections B and C.
(2) Asphalt Macadam, Chapter VII, Sect. D.
(3) Asphalt Mixed-in-Place, Chapter VII, Sect. E.

B.—Use, Manufacture and Inspection of Asphalt Plant Mixes

7.32 QUALITY AND ECONOMY OF HOT PLANT MIXES.—Because of the superior quality of accurately controlled asphalt plant mixes and the economies inherent in plant mixing, its use has greatly increased, and should be given first consideration for any course in the asphalt pavement structure for the following reasons:

1. Aggregate can be accurately proportioned, dried, heated and mixed so that all particles can be completely coated with a uniform film of asphalt.

2. Large highly efficient asphalt plants are generally within hauling distance of any proposed project or an asphalt plant can be moved into a nearby pit or quarry at reasonable cost in a few hours.

3. Mixing is relatively independent of weather conditions, because the aggregate can be dried immediately after a rain and full construction resumed.

4. Central plant mixtures can be placed mechanically; spreading mixers (or with long wheel base motor graders for leveling courses) at a minimum cost for placing, and with the assurance that a smooth surface may be obtained.

5. The amount of asphalt can be accurately controlled and heated to provide proper viscosity of the asphalt* for thorough mixing.

Manufacture of Asphalt Plant Mixes

7.33 MODERN ASPHALT PLANTS.—Modern hot-mix asphalt plants have been improved to such a state of mechanical perfection that when properly set and adjusted the production of uniform specification mix is almost automatic. Figure VI-6 shows the flow of materials through a modern batch plant, and Figure VI-7 through a modern continuous plant. With the use of electric and hydraulic controls and timing devices, one man can start the process and watch the plant go through the various cycles of automatic batching, dry mixing, weighing and introduction of asphalt, wet mixing, and discharge the mix to trucks. Should the quantity of any size of aggregate in the storage bin be inadequate for the requirements of a batch, the mixing operation automatically stops until the required amount of aggregate of each size is discharged to the weigh hoppers, then the mixing cycle automatically continues. With these

* See Article 4.10 for temperature-viscosity data.
automatic controls it is possible to accurately proportion all sizes of aggregate simultaneously, also to have some cycles overlap, such as weighing the second batch while the first batch is being mixed and discharged from the pugmill. The automatic timing assures the proper sequence and prevents the starting of one operation until the previous operation has been completed. Such automatic operations reduce the possibility of human error.

7.34 UNIFORMITY AND BALANCE.—In order to produce the highest quality asphalt concrete in the most efficient manner, it is essential that there be uniformity and balance in the over-all operation of the plant. The uniformity of the material, both as to quantity and quality being fed to the plant, is of equal importance. The uniformity with which the plant components operate also contributes to the quality of the end product.

Balance among all phases of the production is necessary to maintain a continuous and uniform operation. This includes balance among the plant components, one to the other, as well as the balance among the materials that are being handled. Proper balance of these items contributes to the uniformity of the plant operation and what it will produce.

7.35 STORAGE OF ASPHALT.—Asphalt should be stored in sufficient quantity to keep the plant supplied with due allowance for delays in deliveries. Provision should be made for circulation of asphalt throughout the feeding and storage system. The entire system should have facilities for heating the asphalt to the required temperature as indicated by thermometers, preferably of recording type, located both in the storage tanks and as near as feasible to the point where asphalt is discharged into the bucket or mixer. The asphalt lines, pump, weigh bucket and mixer should be jacketed for heating with steam, hot oil or electricity.

7.36 TEMPERATURE OF ASPHALT FOR MIXING.—For proper coating of the aggregate the asphalt must be at the proper viscosity.* Asphalt is a thermoplastic material that decreases in viscosity with increasing tempera-

ture. The relationship between temperature and viscosity, however, may not be the same for different sources or types and grades of asphaltic material.

7.37 PREPARATION OF OTHER ASPHALTIC MATERIAL.—Cut-back asphalt binder should be carefully heated to between the limits shown in temperature-viscosity chart for the particular type and grade being used, by means of closed steam or oil coils in tanks, designed to secure uniform heating of the entire contents. The contractor should provide all necessary facilities for determining its temperature during heating and prior to application.

7.38 STOCKPILE SEPARATION.—Stockpiles should be separated to prevent intermingling. This may be accomplished with clearly defined stockpiles or bins, or by using adequate bulkheads. Bulkheads should extend to the full depth of the stockpiles and should be strong enough to withstand the pressures that will be exerted under operating conditions.

7.39 STOCKPILE CONSTRUCTION AND HANDLING.—Stockpiles should be constructed in layers, rather than in cones. The thickness of the layer should not exceed five feet. Individual truckloads should be spotted close together over the entire stockpile surface.

When stockpiling with a crane, each bucketload should be deposited adjacent to another over the entire area so that the thickness of the stockpile layer is uniform.

When aggregate is discharged from chutes, baffles should be arranged to prevent the coarse aggregate from rolling to the far side while the fine aggregate collects beneath the chute.

When cars, barges, or trucks are used as stockpiles, care should be exercised in loading and unloading to prevent segregation. In some cases, it may be necessary to recombine segregated materials by blending.

When constructing, maintaining, or withdrawing from stockpiles, care should also be taken to prevent aggregate degradation by handling equipment.

7.40 COLD AGGREGATE FEED.—The cold aggregate feed is one of the critical control points in the production flow-line. It is significant that while most of the problems in asphalt plant production occur elsewhere, the causes can usually be traced back to the cold feed.
7.41 COLD FEED SUPPLY.—The cold aggregate feed is the first major component of the hot-mix asphalt plant. The cold feeder may be charged by one or a combination of three methods:

1. Open-top bins with two, three or four compartments, usually fed by a crane with clam-shell bucket.
2. Tunnel under stockpiles separated by bulkheads. Materials are stockpiled over the tunnel by belt conveyor, truck, or crane.
3. Bunkers or large bins. These are usually fed by trucks, car unloaders, or bottom-dump freight cars emptying directly into the bunkers.

7.42 LOADING OF COLD FEED STORAGE UNITS.—When charging the cold bins, care should be exercised to minimize segregation and degradation of the aggregate. These can be prevented by taking the same precautions outlined for proper stockpiling. There should be sufficient material in all bins to provide a positive and uniform flow. Except for very large bins, no single bin should be permitted to run less than half-full, nor should it be loaded to overflow.

When the cold feed is stockpiled over a tunnel and belt, care should be taken in handling material over the feeders. The use of bulldozers should be discouraged. When they are permitted on stockpiles there is serious danger of segregation and degradation. Vibration from the dozer can cause fine particles in the coarse stockpile to filter down into a layer which later will be pushed to the feeder.

If the stockpile level above the tunnel is maintained by a dragline or clamshell, the operator must be careful not to pick up material from the same position in the stockpile in successive withdrawals.

When a front-end loader is used, the operator should be cautioned not to pick up material from the storage stockpile at ground level. The scoop should be held about 6 inches above the ground when filling.

When trucks are used to charge the bin, they should deposit their loads directly above the feeder.

When the stockpile is replenished by overhead belts, the flow of material should be controlled by baffles or perforated chimneys.

7.43 TYPES OF FEEDERS.—Aggregate storage units should have gates that can be accurately set and secured, and so located beneath the bins or stockpiles as to insure a uniform flow of aggregate to the feeders.

There are several types of feeders, including the continuous belt, reciprocating plate, vibratory, and gravity flow types. Generally, the belt and vibratory feeders are considered best for fine aggregates.

7.44 FUNCTIONING OF FEEDERS.—For a uniform output from the asphalt plant, input must be accurately measured. The importance of feeding the exact amounts of each size aggregate into the drier at the correct rate of flow cannot be over-emphasized.

The following conditions will best insure a uniform flow of the proper aggregate sizes:

1. Correct sizes of aggregate should be in the stockpiles.
2. Segregation should be prevented.
3. Intermixing of stockpiles should be prevented.
4. Feeder gates should be accurately calibrated, set and secured.
5. Gates should be kept free of obstruction. An occasional stone, stick, or root can clog the gate. The use of a grissley placed over the cold bins will reduce this hazard.
6. Excessive arching in the fine aggregates should not be allowed. This can be minimized by using rectangular
openings above the feeders rather than square ones, and/or by placing vibrators on the outside of the fine aggregate bins. The vibrators should be installed near the feed gate, and should be wired to cut off automatically when the feeder is stopped.

Why proper cold feeding is essential:

1. A sudden rush of cold sand may cause a considerable change of temperature in the aggregate leaving the drier.

2. A sudden increase in the cold feed can overload the screens, creating a carry-over of the fine aggregate into the coarse aggregate bins.

3. Erratic feeding may cause some bins to over-fill while starving others. In addition:
   a. Layers of variable grading in the hot bins, especially in the fine bin, can lead to alternating rich and lean batches.
   b. The dust collection system may become overloaded.
   c. It may reduce drier draft.

7.45 CALIBRATING AND SETTING FEEDERS.—Where required by specifications or requested by the contractor, cold aggregate feeder gate calibrations should be made by the inspector.

Most manufacturers furnish approximate calibrations for gate openings of their equipment. When these are available, they are helpful in making the initial gate setting. But the only accurate way to set the gates is by making calibration charts for each gate, using the aggregate to be employed in the mix.

The gate opening (in inches or square inches) is plotted on the chart as the abscissa and the pounds of material per revolution of the feeding mechanism (or per minute) as the ordinate. See Asphalt Institute Manual Series No. 3, Asphalt Plant Manual, for details.

In calculating the output of a gate for a given opening, the inspector should deduct the weight of surface moisture on the aggregate being weighed. This factor is very important when calibrating gates through which fine aggregates are flowing.

Gates that feed coarse aggregate should not be set at less than 1½ to 2 times the largest aggregate size. For example, if a gate is feeding aggregate with 1 inch maximum size, the gate should not be set at less than 1½ or 2 inches. Sometimes it may be necessary to restrict the opening width to provide the necessary opening height.

Grading of the individual cold aggregate is determined by use of AASHO Method T-27 and Washed Sieve Analysis of Fine and Coarse Aggregate. Percentage of each aggregate to be used is calculated by trial and error.

The proportions required on the basis of these percentages will determine the gate settings. These settings should be checked by the same method used in calibrating the gates originally.

The setting should be considered tentative because the cold aggregate may vary in grading and moisture with weather and other conditions which will affect its bulking and flow.

The gates should be watched carefully and regulated to keep the hot bins properly filled.

7.46 THE DRYER.—The dryer is a revolving cylinder, usually from three to ten feet in diameter and from 20 to 40 feet long, in which aggregate is dried and heated by an oil or gas burner. The cylinder is equipped with longitudinal cups, or channels, called “lifting flights,” which lift the aggregate and drop it in unison through the burner flame and hot gases. The slope of the cylinder, its speed, diameter and the arrangement and number of flights control the length of time required for the aggregate to pass through the dryer.
The dryer performs two functions in removing moisture from the aggregate:

(1) The heat of the dryer vaporizes the moisture, and
(2) The vapor is drawn off by the draft.

There are two basic types of oil burners used in dryers. One uses steam for atomizing the fuel oil; the other uses low pressure air. There are also low and high pressure gas burners.

7.47 DRYER OPERATION.—Most dryers are designed for average aggregate moisture content. Very wet aggregate will reduce the dryer capacity and require corrective measures, two of which are: the amount of heat can be increased by burning more fuel while the flow of aggregate remains constant, or the aggregate flow can be reduced. There is a limit to the increase in heat that is possible. Beyond that limit the rate of aggregate flow must be reduced.

Aggregates with highly absorptive characteristics may require longer drying periods. This can be accomplished by reducing the incline of the dryer drum or by rearranging the dryer flights. Increasing the dryer time, incidentally, will remove more moisture than increasing the heat.

In very humid areas, or when the aggregates are exceptionally wet or highly absorptive, two dryers may be operated in tandem linked by a long open belt.

If the blower air, draft air, and amount of fuel oil are not in balanced adjustment, it may cause incomplete combustion of the fuel, leaving on the aggregate particles an oily coating harmful to the finished mixture. Black smoke from the exhaust stack indicates that the oil being introduced into the burner is not being completely burned. If a wet wash system is in operation with the dust collector, it may be necessary to shut it off while observing the exhaust smoke.

Lack of balance between the blower air and the draft air also can cause back pressure within the dryer drum, causing “puff back” at the burner end of the dryer. “Puff back” indicates that the draft is not sufficient to accommodate the air pressure being introduced by the burner blower.

Dryers burning natural gas or liquid petroleum gas rarely develop combustion problems. However, an unbalance between the gas pressure, combustion air and draft still can occur.

7.48 AGGREGATE TEMPERATURE MEASUREMENT.—An aggregate heat-measuring device should be installed in the dryer discharge in full view of the burner operator. This device is one of the most important plant control accessories and should be a reliable and accurate instrument. Overheating of the aggregate can damage the asphalt during mixing. Underheating makes the aggregate difficult to coat with the asphalt and difficult to place.

The sensing element of the heat indicator should have a protective shield, sturdy enough to protect it from aggregate abrasion, but not so thick that it will give a disturbed temperature reading. Dust accumulating on the sensing element also may cause a time lag in temperature measurement.

Heat measuring instruments should be checked frequently for accuracy. A simple way to do this is to put the sensing element, with an accurate thermometer, in an oil or asphalt bath, then heat the oil or asphalt and take comparative readings from both devices. These readings should be taken at temperatures below, through, and above the expected operating temperature range.

7.49 DUST COLLECTOR.—The dust collector fan(s) furnishes the draft that draws the flame and hot gases through the dryer. Dust particles from the dryer and other
parts of the plant are also carried in the current of draft air, which enters the dust collector at the upper periphery and goes into vortical motion. The heavier dust particles in the air stream are separated by centrifugal force into the collector shell and fall to the bottom. The finer dust may remain in suspension and be carried out the exhaust stack with the air.

When required by specifications or by ordinance a wet wash system is added to the dust collecting system. Use of a wet wash system usually will increase fan requirements by 10 to 15 percent because of pressure loss in the tower.

7.50 COLLECTED DUST.—If the material removed in the dust collector meets specifications some or all of it may be returned to the plant to be included in the mix. The amount returned will depend upon the combined grading of finished mix. If the collected dust is unsatisfactory or is prohibited by the mix specifications, it is removed from the bottom of the collector and wasted.

7.51 HOT SCREENS.—Aggregate from the dryer is delivered to the hot screens, which are mounted over the plant bins. The function of the hot screens is to accurately separate the aggregate into the specified sizes. To properly perform this function the effective screening area must be large enough to handle the maximum feed. As a guide for checking the capacity of vibratory-type screens in continuous operation each square foot of screen area normally will process one ton of material per hour.

7.52 SCREEN EFFICIENCY.—The condition and cleanliness of the screens will, to a large extent, control their efficiency. If the effective screening area is reduced by plugged screen openings, or if more material is fed to the screens than they can handle, the usual result is “carry-over.”

Excessive wear of the screen wire causes enlarged openings resulting in oversized material in bin. See Figure VII-8.

In some instances screening effectiveness can be improved by using screens having small wire diameter or different shaped openings. Uniform distribution of aggregate over the full width of the screens and the use of a madre (especially on the sand screen) to decrease choking or blinding will also increase efficiency.

7.53 CARRY-OVER.—Carry-over is the depositing of finer material in a bin that should contain the next larger size aggregate. When this occurs, uniformity of aggregate grading is often impaired. Carry-over increases the amount of fine aggregate in the total mix, and since fine aggregate has much more surface area per unit of weight requiring asphalt coating, this condition should be kept at a minimum.

Excessive carry-over, or its fluctuations, will be apparent to the inspector from the sieve analyses made from the contents of the individual hot bins.

Daily visual inspection of the screens for cleanliness is recommended, preferably before the start of the day’s operations. When conditions warrant, the screens should be cleaned.

7.54 HOT BINS.—Plant bins hold the heated, screened aggregates in various size fractions required. Their partitions should be tight, free from holes, and of sufficient height to prevent intermingling of aggregates.

Each hot bin should be equipped with an overflow pipe to prevent aggregate from backing up into other bins, and to prevent overfilling to the point where the vibrating screen will ride on the aggregate. This can result in heavy carry-over. The overflow vents should be checked frequently to make sure that they are free-flowing and thus prevent contamination by intermingling from adjacent bins.