# DESIGN AND CONSTRUCTION OF SUBBASES AND FOUNDATIONS FOR PAVEMENTS

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This report describes the physical requirements of the five most commonly used subbase materials and suggests how these materials may be used most effectively for varying traffic conditions. Minimum thicknesses of subbases for both rigid and flexible pavements are obtained by use of a combination of K-values, potential vertical rise, and conventional pavement thickness design methods. The problem of treating soils that have high volume changes at great depths is discussed, and its solution is used to remedy the subbase problem. Examples for both rigid and flexible pavements are presented, as is a procedure for determining the desired moisture contents of swelling soils at various depths below the pavement.

•SUBBASE has many connotations even for expert pavement designers. For instance, subbase might be construed to refer to a stabilized layer existing below any one of the following types of pavements: portland cement concrete (PCC), asphalt concrete, or untreated flexible base. Sometimes materials are imported for a subbase, and sometimes existing materials are stabilized that may serve as a subbase for another higher type of subbase placed above it. In other cases, one may find a stabilized subgrade below all types of these subbases.

The design of subbases that will be relatively free from pumping presents quite a challenge. The qualities of subbase materials, their position in the structure, and drainage conditions all have an influence on pumping. Although no one claims to know all of the answers to the subbase problem, it seems appropriate to try to define the proper use and placement of these materials.

This paper divides the five most commonly used types of subbases into four grades and establishes quality test requirements for each grade to ensure proper use of these materials. The types are untreated flexible base materials and materials treated with asphalt, lime, and cement. This paper also proposes a method for designing the thickness of subbases. The method for determining thickness of the subbase below PCC shows that the use of stabilized materials for a subbase can reduce the thickness of both the subbase and the PCC. Inasmuch as this part of the procedure involves calculation of the potential vertical rise (PVR), which is caused by swelling soils, much of this paper is devoted to the procedure used and to how the data can be used as an aid in determining which layer or layers need to have their swelling characteristics modified. Many suggestions and methods are presented for diminishing pavement roughness caused by a volume change of the subgrade.

The five most commonly used materials for subbases and their positions in the pavement structure have been arranged into four grades to facilitate solving the problem (Table 1). The desired minimum physical characteristics of the various materials used for a subbase are further explained in the following comments.

The ability of these five types of materials to serve satisfactorily as subbases depends on the traffic and the physical characteristics of the materials used. Untreated flexible base materials should not be expected to serve as a good subbase when placed

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immediately below stiff pavements that are expected to carry heavy traffic; however, they or granular materials will serve satisfactorily when placed below grade 1, 2, or 3 subbases. For untreated flexible base materials to serve satisfactorily as grade 2 subbase, the materials should conform to type A grades 1 or 2 of the Texas Standard specifications (1). In addition, the -No. 40 material should not contain more than 25 percent of -0.005-mm sizes nor more than 55 percent of sizes passing the No. 200 sieve.

Black base meeting grades 1, 2, or 3 of Texas test method Tex-126-E (2) will make a satisfactory subbase for all grades; however, its use for grades 3 and 4 is unlikely because of their high cost.

Soil-cement can be used for most any grade of subbase provided a high strength [minimum = 7-day compressive strength of 650 psi (4482 kPa)] is used where heavy traffic is anticipated. Because of the costs, it is not recommended as a sublayer below other layers of subbase grades 1, 2, and 3.

Lime stabilization is not recommended for a subbase immediately below stiff slab pavements intended to carry heavy traffic, but it does serve well for support layers for grades 1, 2, 3, and 4. If lime stabilization is to serve satisfactorily as a grade 2 subbase, traffic should not be heavy, and the mixture should have a minimum compressive strength of 100 psi (690 kPa) after 18 days of moist curing (2). Lesser strengths for similar curing periods for grades 3 and 4 are given.

Soil-asphalt may make a satisfactory subbase for either grade 1 or 2. It is not recommended for grades 3 and 4 because of problems encountered in aeration of volatiles and moisture from sublayer. In fact, soil-asphalt is not recommended at all in high rainfall areas [≥35 in. (89 cm)/year] because of this same problem. Minimum unconfined compressive strength should be obtained in accordance with the procedures given elsewhere (4).

Ordinarily the top of subbase will be located from 4 to 14 in. (10.2 to 35.6 cm) below the pavement surface depending on the subgrade, the amount of traffic anticipated, and the type of pavement to be constructed. The thickness of subbase will usually vary from 4 to 14 in. (10.2 to 35.6 cm) for rigid pavements and 4 to 25 in. (10.2 to 63.5 cm) for flexible pavements depending on traffic, type of subgrade, and grade of subbase material to be used. Subbases constructed of grades 1 and 2 subbase materials will probably vary from a minimum of 4 in. (10.2 cm) for asphalt mixes and 6 in. (15.2 cm) for cement and lime mixtures to as much as 8 in. (20.3 cm). The thickness of subbase used below the PCC may be determined as indicated in the following section. The wide variety of materials used in the design of flexible pavements make it difficult to establish a definite procedure for subbase thickness design; however, best results may be obtained by a procedure (6) used with the technique discussed later in examples 1 and 2.

## PROCEDURE FOR DETERMINING SUBBASE THICKNESSES

The following steps are for determining subbase thicknesses. Steps 1 through 9 are for PCC; steps 10 through 16 are for flexible pavements.

1. Determine the design value number (DVN) from Table 2.
2. Determine the PVR by using Figures 1 and 2 (use procedure and example 1 discussed later). If the PVR is excessive, consider the treatment needed to reduce it.
3. From Figure 3 determine total depth of subbase for materials with low tensile strengths by entering the DVN on the abscissa.
4. Determine modified tensile strength of the subbase material by multiplying tensile strength by $S_t$ from Table 3. Enter modified tensile value and total subbase depth plus depth of PCC [usually averages 10 in. (25.4 cm)] on Figure 4 and read the reduction depth.
5. On Figure 3, enter depth from step 3 minus reduction depth from step 4.
6. On Figure 3, project points from steps 3 and 5 vertically to the PVR curve for the value found in step 2. Then project them horizontally to the K-values expected for the untreated and stabilized materials.

## Table 1. Grades and types of subbases.

| | | Materials Used | | | | |
|---|---|---|---|---|---|---|
| Grades | Uses of Subbases | Untreated Flexible Base | Black Base | Cement Stabilization | Lime Stabilization | Soil-Asphalt |
| 1 | Directly under stiff or slab bases carrying heavy traffic[a] | Not recommended for use directly below slab because of pumping | Grades 1, 2, or 3 | 650 psi | Not recommended because of pumping | 35 psi, not recommended in areas of high rainfall |
| 2 | Same as grade 1 but for lighter traffic | Type A, grades 1 or 2 | Grades 1, 2, or 3 | 450 psi | 100 psi | 35 psi, not recommended in areas of high rainfall |
| 3 | Under untreated flexible base or under grade 1 and 2 subbases for all types of traffic | Select granular material[b] | Not likely | 450 psi | 50 psi | Not recommended |
| 4 | Under grade 1, 2, or 3 subbases for all types of traffic[c] | Select granular material[b] | Not recommended | Not recommended | Deep plow, 40 psi | Not recommended |

Note: 1 psi = 6.89 kPa.

[a] Over 2 million equivalent 18-kip (80-kPa) single-axle load applications.

[b] Impermeable types of granular or flexible base materials.

[c] Usually used to add strength to deep soft soils or to reduce volume changes of subgrade.

## Table 2. Correlation of CBR, triaxial, R-value, and design value numbers.

| CBR | Triaxial | R-Value | Design Value Number |
|---|---|---|---|
| 1 | 6.5 | 8 | 1 |
| 2 | 5.7 | 13 | 1.5 |
| 3 | 5.0 | 25 | 2.8 |
| 4 | 4.7 | 31 | 3.6 |
| 5 | 4.5 | 35 | 4.0 |
| 6 | 4.3 | 38 | 4.4 |
| 7 | 4.2 | 41 | 4.8 |
| 8 | 4.1 | 43 | 5.1 |
| 9 | 4.0 | 45 | 5.4 |
| 10 | 3.9 | 47 | 5.8 |
| 15 | 3.6 | 55 | 7.0 |
| 20 | 3.4 | 60 | 8.0 |
| 25 | 3.3 | 65 | 9.0 |
| 30 | 3.2 | 68 | 9.8 |
| 31 | 3.15 | 69 | 10.0 |
| 35 | 3.0 | 72 | 10.7 |
| 40 | 2.9 | 75 | 11.6 |

Note: If no strength test values are available and if the subgrade contains over 70 percent soil binder (-No. 40 mesh) and is not extremely high in organic matter, the soil constants may be used for estimating the design value number by referring to the following table:

| Plasticity Index Range | Design Value Number |
|---|---|
| 0 to 12 | 5.5 |
| 13 to 30 | 3.0 |
| 31 to 50 | 1.5 |
| )50 | 1.0 |

Admittedly this PI approach is conservative, and it is possible that some of the above design value numbers could be increased as much as 50 percent if strength tests were also performed. It is not safe to assume, however, that without any strength tests this much increase in design value is warranted.

Figure 1. PI versus volumetric change.

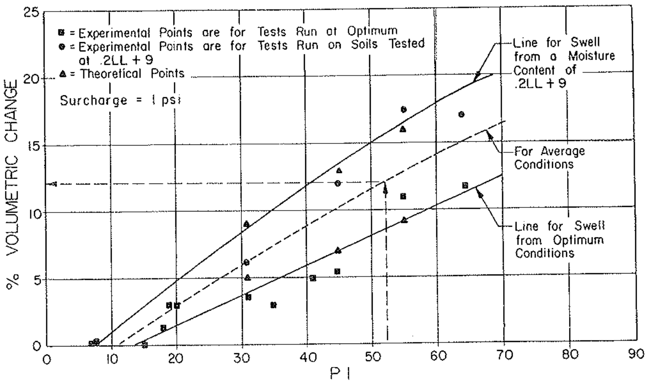


Figure 2. Determination of potential vertical rise.

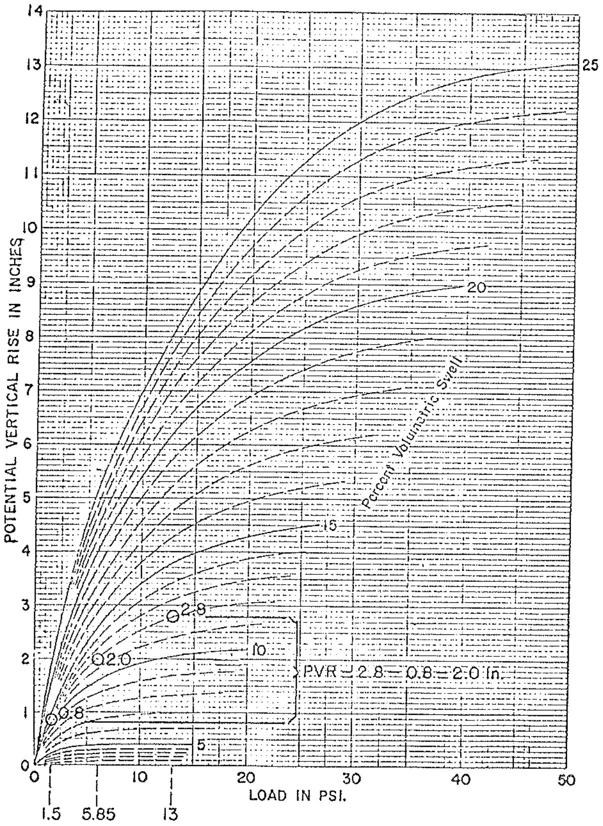


Figure 3. K-values for all compactible subgrades.

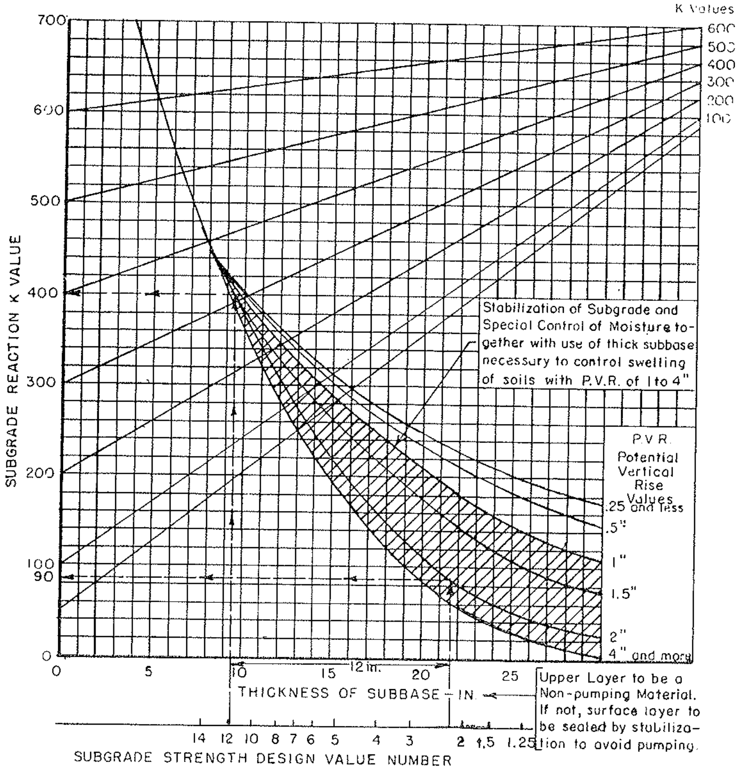


Table 3. Tensile strength modification factors.

| Subbase Thickness (in.) | $S_t$ Factor |  |
|---|---|---|
|  | For Cement and Lime Stabilization | For Asphalt Surface Courses and Treatments |
| 1 |  | 0.1 |
| 2 |  | 0.5 |
| 3 |  | 1.0 |
| 4 | 0.2 | 1.6 |
| 5 | 0.5 | 2.7 |
| 6 | 1.0 | 3.5 |
| 7 | 1.7 | 3.8 |
| ≥8 | 2.0 | 4.0 |

Note: 1 in. = 25.4 mm.

Figure 4. Reduction chart for pavement thickness.

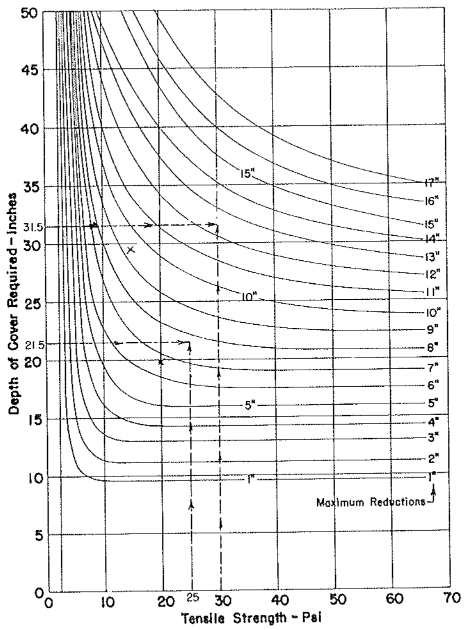
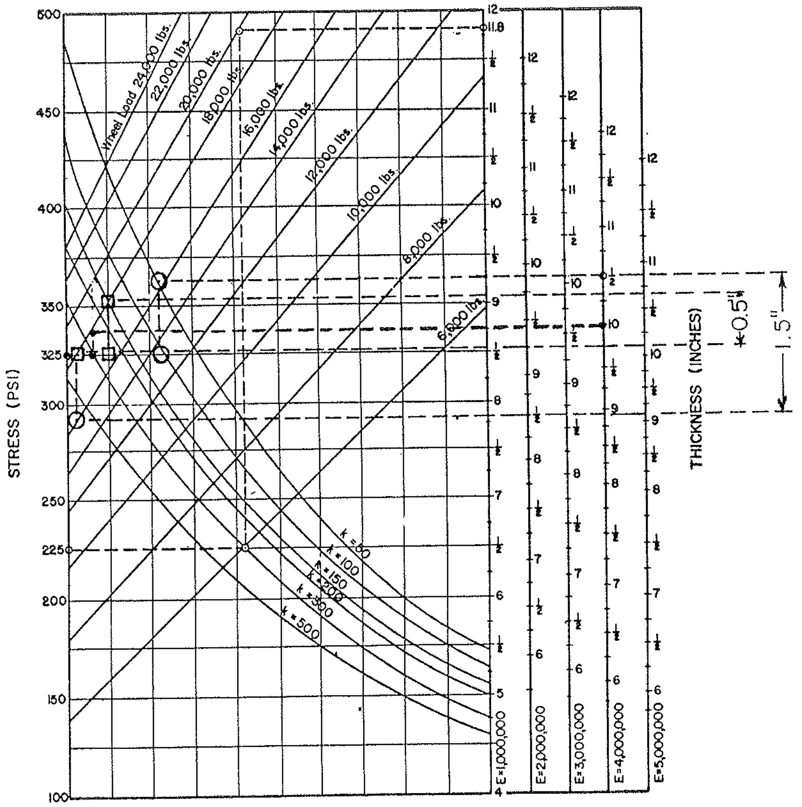


Figure 5. Design chart for jointed concrete pavement with unprotected corner.



NOTE: DESIGN THICKNESSES ARE USUALLY ROUNDED OFF TO A FULL INCH BY ROUNDING UPWARD TO THE NEXT FULL INCH WHEN THE THICKNESS IS GREATER THAN ONE FOURTH INCH i.e., IF A THICKNESS OF 9 3/8 INCHES IS READ, ROUND UPWARD TO 10 INCHES FOR THE DESIGN; AND ROUNDING DOWNWARD WHEN THE THICKNESS IS EQUAL TO OR LESS THAN ONE FOURTH INCH, i.e., IF A THICKNESS OF 9 1/4 INCHES IS READ, ROUND DOWNWARD TO 9 INCHES FOR THE DESIGN.

⊙ Example 1
⊡ Example 2

7. Enter K-values in Figure 5 to determine how much stabilization decreases thickness of the concrete slab.
8. Make total subbase thickness the depth from step 3 minus reduction from step 4. The upper 4 to 8 in. (10.2 to 20.3 cm) should consist of grade 1 or 2 subbases for heavy traffic and light traffic respectively. The remainder of the subbase could consist of grades 3 or 4.
9. Determine the number of inches of nonstructural lime soil by the formula

$$X - Y + 18 - Z$$

where

X = depth in inches of soil to be treated to prevent excessive PVR,
Y = depth in inches of conventional or semiconventional lime-stabilized soil subbase, and,
Z = depth of base and subbase consisting of PCC or hot-mixed asphalt concrete (HMAC), black base, or granular flexible base materials.

10. Use steps 1, 2, and 3 given above for PCC.
11. Determine modified tensile strength of base and subbase materials by multiplying tensile strength by $S_t$ value in Table 3.
12. Enter total depth of subbase (from step 3) and maximum modified tensile strength (step 11) on Figure 4 and, at their intersection, read the reduction.
13. Subtract the value in step 12 from the value in step 3. This depth may consist of several layers of different materials, usually grades 1 and 2 (Table 1).
14. Determine minimum thickness of surfacing and total depth of flexible pavements (6).
15. Make the thickness of grade 3 or 4 subbases equal to the total thickness (step 14) minus the minimum surface thickness (step 14) less the thickness of subbase (step 13).
16. Use step 9.

## ILLUSTRATIVE EXAMPLES

No attempt is made in this paper to design the thickness and other details relative to PCC. The approach used is based on the assumption that most roads and streets carrying medium to heavy traffic will require an average slab thickness of 10 in. (25.4 cm). Therefore, an average thickness of 10 in. (25.4 cm) is used in the following examples. The basic reasoning in regard to roads and streets is that, if support and volume change characteristics are provided for properly, the thickness of PCC slabs will not be of major concern. The design for extremely heavy loads such as airport runways is another matter and should be investigated more thoroughly.

Two examples are presented; each has two parts: rigid or PCC pavements and flexible pavements. Example 1 covers a swelling soil. Many examples could have been presented involving thinner sections, but these could be easily solved by using Figure 3, Table 1, and another procedure (6). Many other examples involving the use of other materials such as soil-cement could have been presented, but they would be solved in the same manner. Other examples involve high amounts of volume change, where ponding and liming of the subgrade are needed, but discussion of these would complicate the examples, and therefore the ponding procedure is discussed separately.

### Example 1

The type of facility in example 1 is a four-lane highway that carries heavy traffic. The conditions and requirements are given in Table 4.

Table 4. Conditions and requirements for example 1 and example 2.

| Item | Example 1 Value | Example 2 Value |
|---|---|---|
| Average of 10 heaviest wheel loads, lbf | 16,000 | 18,000 |
| Number of equivalent 18-kip single-axle load applications during life | 6,000,000 | 8,000,000 |
| Average daily traffic, vehicles in both directions | 20,000 | 40,000 |
| Average annual rainfall, in. | 30 | 35 |
| Subgrade | | |
| DVN | 2.2 | 3 |
| Plasticity index[a] | 42 | 30 |
| Liquid limit[a] | 60 | 51 |
| Average soil moisture conditions (see Fig. 4) | | |
| Subbase | | |
| Cohesiometer value for HMAC | 200 | 250 |
| Tensile strength of lime-stabilized subgrade, psi | 15 | 10 |

Note: 1 lbf = 4.4 N, 18 kip = 80 kN, 1 in. = 25.4 mm, 1 psi = 6.9 kPa.

[a] For upper 15-ft (4.6-m) layer underlaid with rocky, nonswelling soils.

## Solutions for Rigid Pavements

1. Determination of potential vertical rise (PVR)

   a. Enter a PI of 42 on the abscissa of Figure 1. For average moisture conditions, read 9 percent volumetric swell on ordinate. The percentage of free swell = 9 × 1.07 + 2.6 = 12.2.
   b. Enter on abscissa of Figure 2, 1.5 psi (10.4 kPa) for pavement load and 13 psi (15 ÷ 1.15) (89.6 kPa) for load of swelling soil layer.
   c. Project these points upward until they intersect the 12 percent volumetric curve line and read 0.8 and 2.8 on the ordinate. The difference in these values leaves a PVR value of 2 in. (5.1 cm).

2. Reduction of PVR by deep limewater treatment

   a. Scarify a 3-ft (0.91-m) layer and apply approximately 3 percent lime, based on dry weight of the soil.
   b. Mix lime and an excess of water into the soil several times with plows and scarifiers. If enough water is used each time, it is assumed that the top 2 ft (0.6 m) of the untreated base soil will be preswelled. [Two ft (0.6 m) of penetration of water is the maximum that should be allowed for swelling soils and only 1 ft (0.3 m) of penetration should be allowed for stiff, gummy, highly impermeable A-6 soils.]
   c. Enter on the abscissa of Figure 2 the surcharge weight of pavement and subbase plus weight of treated layer plus weight of preswelled layer [1.5 + 3 + 2 ÷ 1.15 = 5.85 psi (405 kPa)]. At the intersection with the 12 percent volume change curve, read a PVR of 2.0 on ordinate. Subtracting this value from 2.8 leaves a PVR of 0.8 in. (2.0 cm), which is fairly satisfactory.
   d. Treat the top layer of the lime-modified soil with additional lime to form a conventional lime-stabilized layer capable of supporting a layer of HMAC.

3. Modification of tensile strengths of subbase materials

   a. Modified tensile strength of HMAC = 200 × 1.0 [for 3-in. (7.6-cm) layer] ÷ 45.36 = 4.4 psi (30.4 kPa).
   b. Modified tensile strength for lime-stabilized subgrade = 15 × 2 [$S_t$ factor for >8-in. (20.3-cm) layer] = 30 psi (207 kPa).

4. Determination of subbase thicknesses and K-values

   a. Enter a DVN of 2.2 on the abscissa of Figure 3 and project it upward to read a thickness of 21.5 in. (54.6 cm) on other abscissa.

b. Continue upward projection until the curving line for 2-in. (5.1-cm) PVR is intersected. Then, project it horizontally to read a K-value of 90 on the ordinate.

c. On Figure 4, enter the maximum tensile strength of 30 psi (207 kPa) on the abscissa and 31.5 in. (10 + 21.5) (80 cm) on the ordinate and, at their intersection, read a reduction of 12 in. (30.5 cm).

d. Enter a subbase depth of 9.5 in. (21.5 - 12) (241 cm) on the abscissa of Figure 1 and project it upward until the curved line for 2-in. (5.1-cm) PVR is intersected. Then project it horizontally to read a corrected K-value of 400 on ordinate.

e. Enter on Figure 5 stress in concrete, K-values for lime-treated and untreated subgrades, wheel load, and modulus E of concrete. The concrete slab can be approximately 1 in. (2.5 cm) less thick when the subgrade is stabilized (7).

In summary, a section would consist of approximately 10 in. (25.4 cm) of PCC, 2.5 in. (6.4 cm) of asphalt concrete or black base (suitable for grade 1), and 7 in. (17.8 cm) of conventional lime stabilization (suitable for grade 3). All three materials total 19.5 in. (49.5 cm). This would be underlaid with 34.5 in. (87.6 cm) of deep-plow, lime-modified soil for volume change reduction and would not count as part of the pavement structure. The lime treatment eliminates a severe swelling problem, reduces the thickness of subbase required by 12 in. (30.5 cm), takes the place of 7 in. (17.8 cm) of other subbase materials, and increases the K-value sufficiently to justify a 1- or 2-in. (2.5- to 5.1-cm) reduction of PCC. This forms a working table for HMAC.

## Solutions for Flexible Pavements

1. Determination of PVR is the same as for rigid pavements
2. Reduction of PVR is the same as for rigid pavements
3. Modification of tensile strengths of subbase materials
   a. Modified tensile strength of HMAC or black base = 200 × 1.6 [$S_t$ for 4-in. (10.2-cm) layer] ÷ 45.36 = 7.1 psi (49 kPa).
   b. Modified tensile strength for lime-stabilized subgrade = 15 × 1.7 [$S_t$ for 7-in. (17.8-cm) layer] = 25 psi (172 kPa).
4. Determination of subbase thicknesses and K-values
   a. Enter a DVN of 2.2 on the abscissa of Figure 3 and read the thickness of 21.5 in. (54.6 cm) on the other abscissa scale.
   b. On Figure 4, enter the maximum modified tensile strength of 25 psi (172 kPa) on the abscissa and 21.5 in. (54.6 cm) on the ordinate and, at their intersection, read a reduction of 7.5 in. (19.1 cm).
   c. Depth of subbase = 14 in. (21.5 - 7.5) (35.6 cm).
   d. Total depth of flexible pavement (6) = 24 in. (61 cm) and consists of 4 in. (10.2 cm) of HMAC as a minimum surface course.

In summary, a section would consist of 4 in. (10.2 cm) of HMAC, 3 in. (7.6 cm) of HMAC or black base material (suitable for grade 1), 4 in. (10.2 cm) of type A grade 1 crushed stone (suitable for grade 2), 7 in. (17.8 cm) of conventional lime stabilization (suitable for grade 3), and 6 in. (15.2 cm) of semiconventional lime-treated soil (suitable for grade 4). All materials used a total of 24 in. (61 cm) and are underlaid with 30 in. (76.2 cm) of deep-plow lime-modified soil for volume change reduction, and would not count as part of the pavement structure. A total of 33 in. (83.8 cm) would have been required if all layers had been constructed with materials of a low tensile strength. The lime treatment eliminates a severe swelling problem, reduces required thickness of subbase by 7.5 in. (19.1 cm), and takes the place of 13 in. (24 - 11) (33 cm) of other subbase materials. This forms a working table for crushed stone and HMAC subbase layers.

Example 2

The type of facility in example 2 is a six-lane divided highway that carries heavy traffic. The conditions and requirements are given in Table 4.

Solutions for Rigid Pavements

1. Determination of the PVR is unnecessary because the PI is below 35 and the pavement is not located in an arid region.
2. Reduction of the PVR is unnecessary.
3. Modification of tensile strengths of subbase materials

    a. Modified tensile strength of HMAC = 250 × 1.3 [for 3.5-in. (8.9-cm) layer] ÷ 45.36 = 7.2 psi (49.7 kPa).
    b. Modified tensile strength for lime-stabilized subgrades = 10 × 1.7 [$S_t$ factor for 7-in. (17.8-cm) layer] = 17 psi (117.3 kPa).

4. Determination of subbase thicknesses and K-values

    a. Enter a DVN of 3 on the abscissa of Figure 3 and project it upward to read a thickness of 19.5 in. (49.5 cm) on other abscissa.
    b. Continue upward projection until the curving line for 0.25-in. (6.35-mm) PVR is intersected. Then, project it horizontally to read a K-value of 250 on the ordinate.
    c. On Figure 4, enter the maximum tensile strength of 17 psi (117.2 kPa) on the abscissa and 29.5 in. (10 + 19.5) ( 74.9 cm) on the ordinate and, at their intersection, read a reduction of 9.5 in. (24.1 cm).
    d. Enter subbase depths of 19.5 in. (49.5 cm) and 10 in. (19.5 - 9.5) (25.4 cm) on the abscissa of Figure 1 and project them upward until the curved line for a PVR of 0.25 in. (6.35 mm) is intersected. Then, project them horizontally to read K-values of 250 and 380 respectively on ordinate.
    e. Enter on Figure 5 stress in concrete, K-values for lime-treated and untreated subgrades, wheel load, and modulus E of concrete. A PCC slab can be 0.5 in. (1.3 cm) thinner because of lime stabilization.

In summary, a section would consist of 10 in. (25.4 cm) of PCC, 3 in. (7.6 cm) of asphalt concrete, and 7 in. (17.8 cm) of conventional lime stabilization. The total is 20 in. (50.8 cm). The lime treatment reduces the required thickness of subbase by 9.5 in. (24.1 cm), takes the place of 7 in. (17.8 cm) of other subbase materials, and increases the K-value sufficiently to decrease the thickness of PCC by approximately 0.5 in. (1.3 cm). This forms the working table for HMAC.

Solutions for Flexible Pavements

1. Determination of PVR is unnecessary.
2. Reduction of PVR is unnecessary.
3. Modification of tensile strength of subbase materials

    a. Modified tensile strength for HMAC or black base = 250 × 2.15 [$S_t$ for 4.5-in. (11.4-cm) layer] ÷ 45.36 = 12.4 psi (85.6 kPa).
    b. Modified tensile strength of lime-stabilized subgrade = 10 × 2 [$S_t$ for ≥8 in. (≥20.3 cm)] = 20 psi (138 kPa).

4. Determination of subbase thicknesses
    a. Enter DVN of 3 on the abscissa of Figure 3 and read the thickness of 19.5 in. (49.5 cm) on other abscissa.
    b. On Figure 4, enter maximum tensile strength of 20 psi (137.9 kPa) on the abscissa and 19.5 in. (49.5 cm) on the ordinate and, at their intersection, read a reduction of 6.5 in. (16.5 cm).
    c. Depth of subbase = 13 in. (19.5 - 6.5) (33 cm).
    d. Total depth (6) = 23 in. (58.4 cm) and consists of a minimum of 4.5 in. (11.4 cm) of HMAC surface course.

In summary, a section would consist of 4.5 in. (11.4 cm) of HMAC, 4 in. (10.2 cm) of HMAC or black base material (suitable for grade 1), 6 in. (15.2 cm) of A grade 1 crushed stone (suitable for grade 2), and 9 in. (22.9 cm) of conventional lime stabilization [including 3 in. (7.6 cm) of grade 3]. This section totals 23.5 in. (59.1 cm). A total of 31 in. (78.7 cm) would have been required if all layers had been constructed with materials of low tensile strengths. The lime treatment reduces the required thickness of subbase by 6.5 in. (16.5 cm) and takes the place of 9 in. (22.9 cm) of other subbase materials. This forms a working table for placing and compacting crushed stone subbase.

## QUALITY OF SUBBASES

Quality of the subbase depends on the position in which the subbase is to be placed and the amount of traffic anticipated during the life of the pavement.

Untreated flexible base materials should not contain more than 25 percent of -0.005-mm sizes in the -No. 40 material if they are placed below a slab pavement made of PCC or HMAC; otherwise, pumping is a distinct possibility. This prerequisite is not necessary for layers placed below the main subbase. Untreated flexible base materials are not recommended for the subbase if traffic is heavy (Table 1).

HMAC black base grades 1, 2, and 3 (2, 3) will make satisfactory subbases for all types of pavements and traffic conditions.

Soil-asphalt criteria of 35 psi (241 kPa) are based on another report (4). Soil-asphalt mixtures are not to be used in high rainfall areas or at great depths because of difficulties encountered during aeration of moisture and volatiles.

Two strength criteria are given in Table 1 for soil-cement mixtures tested in accordance with Tex-120-E (2) and moist cured for 7 days (2). The high value of 650 psi (4481 kPa) is required for the mix used for a sublayer directly below PCC or HMAC that will be subjected to heavy traffic.

Lime stabilization (Table 1) is recommended for subbases for all grades except grade 1 because damage occurs from heavy traffic before sufficient curing can provide adequate strengths. The strength referred to for grades 1, 2, and 3 of the subbases in Table 1 is based on 18 days of moist curing at room temperature, and tests are performed in accordance with Tex-121-E (2).

Both external and internal drainage should be considered when subbases are constructed because water should not collect under the pavement. The chances of building a good dense subbase on weak soils is remote unless some sort of working table is established. Lime or cement can play an important part as the lower portion of subbase. Deep-plow lime stabilization can be useful in reducing PVR (see example 1). Excessive volume change of the subgrade makes it difficult for any pavement or subbase to serve satisfactorily. Therefore, this subject is discussed in the next section.

## POTENTIAL VERTICAL RISE

PVR expresses the danger of movement or heaving due to the swelling characteristics of subgrade soils. Sometimes estimated PVR movements may not occur until the project has gone through a rigorous cycle of drying and wetting. This maximum cycle may or may not occur for many years, and, although the potential movement was always present, intermittent cycles may destroy the pavement before the maximum movement is ever achieved. PVR does not have to represent an accurate estimate of vertical rise for it to be a useful trouble indicator. When PVR is greater than 0.5 to 1 in. (1.3 to 2.54 cm), there is danger of roughness developing along the pavement surface (5, 8). Heaving subgrades need attention before placement of pavement. Since PVR will locate the layer or layers from which heaving can take place, it is also a useful tool for identifying which layer or layers to treat to counteract such movement.

The following is a short-cut method for estimating PVR for design purposes. A more accurate method can be obtained by use of Tex-124-E (2).

1. Determine the thickness moisture content and PI of all subgrade soil layers within about 20 ft (6.1 m) below the grade line. If the PI is below 35 for all layers, it may be assumed that PVR will be ≤0.5 in. (1.3 cm) unless the project is located in an arid region with an average annual rainfall of less than 20 in. (50.8 cm). In this case, a PI of 30 rather than 35 is critical.
2. Tabulate all data such as PI, moisture content, and color for various layers so that soil layers can possibly be matched for PI and moisture.
3. For each layer having uniform PI and moisture content, enter the PI on the abscissa of Figure 1 and extend it vertically until one of the three curves is intersected. The top curve is for dry conditions, the lower curve is for moist conditions, and the middle curve is for average conditions ranging between the two curves. Extend a line from the above point horizontally until a reading for percentage of volumetric swell is obtained on the ordinate. For design purposes, where moisture conditions at the time of paving are unknown, the average curve in Figure 1 may be used. This will eliminate the need for preliminary moisture studies.
4. Divide the thickness of layer in feet by 1.15 and enter this value and the weight of pavement [usually 1.5 psi (10.4 kPa)] on the abscissa of Figure 2 and extend it vertically until the line for the percentage of volumetric swell found in step 3 is intercepted. Read PVR values on the ordinate. The difference between these two PVR values represents the PVR value for the layer in question. Repeat procedure for all layers.
5. Total all PVR values found in step 4. This represents the PVR value to use in design (Figure 3).

When it has been determined that an excessive volume change condition exists, the problem of what to do about it must be dealt with. This is more easily done by determining the magnitude of the PVR values for each layer. The treatment to be used much depends on whether anticipated movements are expected to emanate from a thin, upper dry layer or from thick layers extending to great depths. When the source and magnitude of estimated movements are known, the following actions can be taken to diminish pavement roughness due to volume change.

1. Sometimes, grade lines can be changed or soil selection made so that movements due to volume change are diminished.
2. If a thin, upper dry layer exists, moisture may be altered by recompacting at higher moisture contents.
3. If anticipated movements stem from deep strata of swelling clays, the severity of movement may be reduced by ponding, deep-plow lime stabilization, lime slurry injection, or a combination of all of these. Ponding and lime slurry injection probably are not economically feasible on rural roads with light traffic.
4. In any of the preceding actions or any combination of them, drying should be restricted by membranes or preferably by layers of granular materials or stabilized soils. The stabilized soils and granular materials have the advantage of providing working tables. These layers should be extended under shoulders and to the ditch lines in most sections except for fills higher than 5 ft (1.5 m). Lime stabilization has proved satisfactory for this purpose because construction can proceed, and drying out much of the moisture from ponding will not be necessary. Removal of too much of the ponding

Figure 6. Load versus percentage of volumetric swelling in clay soil.

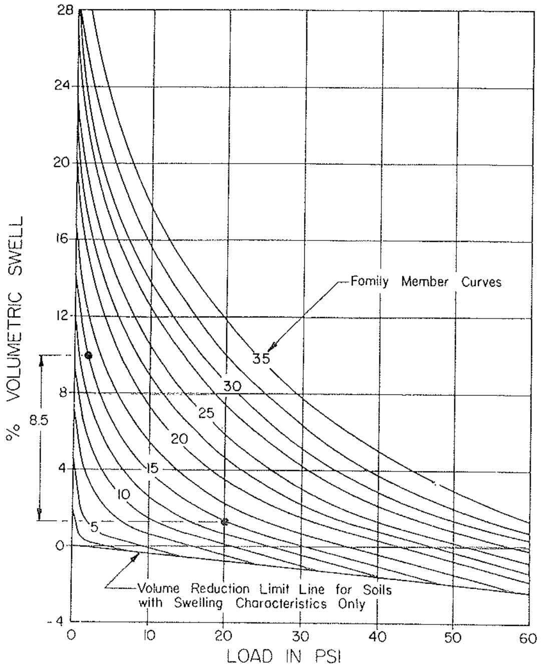
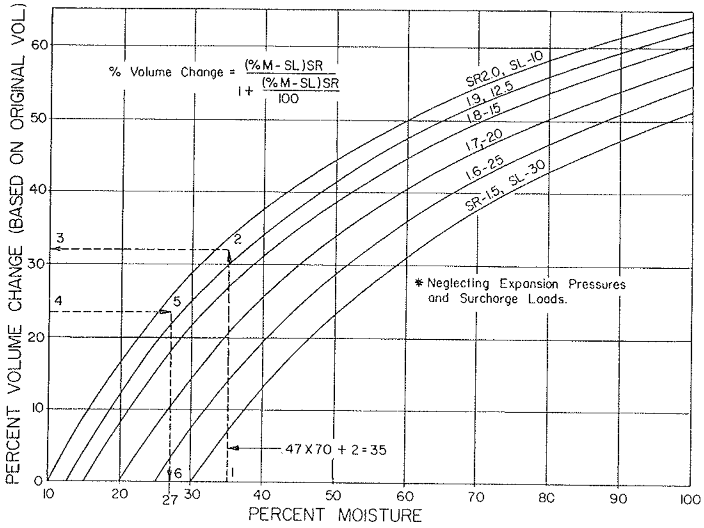


Figure 7. Moisture change versus free volume change.



moisture will defeat the purpose of ponding, which is to reduce swelling.

5. The surface water should not be allowed to percolate into the subgrade of the completed highway. Use of an impermeable surface course base and subbase will help accomplish this. Highly permeable layers should not be placed next to swelling subgrade soils because this will cause swelling cycles to continue throughout the life of the pavement and because the subgrade will lose practically all of its supporting power.

## DESIRED MOISTURE CONTENTS FOR SWELLING CLAYS BELOW PAVEMENTS

The desired moisture content for swelling soils below pavements is defined as the condition of the subgrade soil at which it will be susceptible to low amounts of volumetric swell and, at the same time, will have adequate bearing power to support the usual loads imposed on it. Moisture content will vary as the characteristics of the soil vary and also as the restraint from variation in depths of overburden varies. To solve the problem by the following method requires that soil samples be obtained at various depths and that tests on soil constants be performed on these samples.

1. Enter the PI on the abscissa of Figure 1 and project it upward until it intersects with the line for average conditions. Then project it horizontally and read the percentage of volumetric change on the ordinate.
2. On Figure 6, plot the value of volume change obtained in step 1 versus a load of 1 psi (6.9 kPa) for identification of the family swell curve or multiply the value from step 1 by 1.07 and add 2.6 to determine the family member curve.
3. Determine the load in psi for the depth in question. Usually, the depth divided by 1.15 plus weight of pavement will give a fairly accurate value of the load in psi.
4. On Figure 6, plot the load in psi (from step 3) on the family swell curve (from step 2) and the load of the pavement, usually 1 to 2 psi (6.9 to 13.8 kPa), on the same family swell curve. The difference in the ordinate readings represents the reduction in volumetric swell due to surcharge weight.
5. On Figure 7, enter a value on the abscissa equal to 0.47LL + 2 and project it upward until the curve representing the proper shrinkage limit or shrinkage ratio is intercepted. Project it horizontally until a value on the ordinate is obtained and subtract the value found in step 4. From this point on the ordinate, project it horizontally until the same curve for shrinkage limit or shrinkage ratio is intercepted. Then, project it downward to the abscissa and read the percentage of moisture desired.

## REFERENCES

1. Standard Specifications for Construction of Highways, Streets, and Bridges. Texas Highway Department, Item 248, Jan. 1972, pp. 125-134.
2. Manual of Testing Procedures. Texas Highway Department, 100-E Series.
3. C. McDowell and A. Smith. Design, Control and Interpretation of Tests for Bituminous Hot Mix Black Base Mixtures. Proc., Association of Asphalt Paving Technologists, Vol. 40, pp. 97-98.
4. C. McDowell. Progress Report on Soil-Bituminous Stabilization. Highway Research Record 405, 1972, pp. 132-136.
5. C. McDowell. Remedial Procedures Used in the Reduction of Detrimental Effects of Swelling Soils. Proc., Western Association of State Highway Officials, 1965.
6. Flexible Pavement Design Guide. National Lime Association, Bulletin 327, 1972.
7. Thickness Design for Concrete Pavements. Portland Cement Association, Chicago, 1961.
8. R. L. McKinney, J. E. Kelly, and C. McDowell. The Waco Ponding Project. Center for Highway Research, Univ. of Texas at Austin, Research Rept. 118-7.