

Guide for Design of Foundations and Shoulders for Concrete Pavements

Reported by ACI Committee 325

Methods are suggested for material selection, moisture control, and compaction or treatment of soils and materials to assure volume stability and uniform support for concrete pavements. Various environments are considered and appropriate methods of subgrade preparation are outlined. Subbase functions are defined and adaptability of types of subbases are discussed. Placement of materials to aid in subbase moisture control is emphasized in shoulder design.

A section on recognition of causes of deficiencies in existing pavements is included to alert the engineer to the consequences of improper construction or adverse environment.

Keywords: airports; cement-treated soils; concrete pavements; drainage; foundations; freezing; highways; moisture content; pavements; pumping; shoulders; soil cement; soil compacting; soil stabilization; subbases; subgrades.

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CHAPTER 1 - INTRODUCTION

1.1 - General

1.1.1 Adequate foundations are as essential to the endurance of concrete pavements as they are to the longevity of all structures. Although road and runway foundation failures are seldom catastrophic as is the case with vertical structures, inadequate foundations for pavements require continued costly maintenance with accompanying delays and inconvenience to users. Annual cost of a pavement with a poor foundation greatly exceeds that of a well-designed roadway or airfield.

1.1.2 The objective of this report is to show how to build a pavement foundation that will remain stable under anticipated traffic through all seasons and climatic conditions. As some soils are more adversely affected by excess water than others, the fundamental problems are: (a) rapid removal of water by good

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drainage and (b) replacement or confinement and protection of poor soils to minimize their adverse effects.

1.1.3 When preferred materials are available, utilization of the principles of soil mechanics makes the construction of an ideal foundation possible; for economy purposes, full use is usually made of the soils that comprise the roadway excavations and embankments. The diversities of soils, climates, and road use require that each street, highway, or airfield pavement be engineered individually, but the underlying objectives of stability and uniformity always prevail.

1.1.4 This committee effort is a brief review of materials, their basic properties, effects of environment, methods of stabilization, and principles governing design of pavement foundations and shoulders for optimum performance. This effort replaces the 1968 Committee report.

CHAPTER 2 - DEFINITIONS

2.1 - General

2.1.1 A review of classification systems, soil properties, and terms (AASHTO M146) associated with pavement design is given to facilitate discussion.

2.1.2 Soils have been classified by AASHTO M145, the Unified Soil Classification Systems Mil-Std-619B (Reference 17), the FAA System, and others. These systems are discussed by Yoder and Witczak, Reference 1. The commonly used AASHTO and Unified systems separate soils into divisions largely according to particle size and Atterburg Limits. Important soil properties are:

2.1.3 *Plasticity index (PI)*, also referred to as *plasticity* - The range in water content through which a soil remains plastic. It is the numerical difference between liquid limit and plastic limit as calculated according to AASHTO T90 or ASTM D4318.

2.1.4 *Permeability* - The susceptibility of soils to the passage of water, as determined by AASHTO T-215 and ASTM D-2434 for granular soils. The effect of gradation on soil permeability is illustrated in Reference 1, page 363.

2.1.5 *Expansive Soils AASHTO T-258* - Volume changes in soil caused by loss and gain of moisture, respectively.

2.1.6 *Frost-susceptible soil* - Material in which significant detrimental ice segregation will occur when the requisite moisture and freezing conditions are present.

2.1.7 *In-place density* - Weight per unit volume of soil as determined by AASHTO T191, T205, or T238 or ASTM D1556.

2.1.8 *Standard density* - Maximum density at optimum moisture according to procedure AASHTO Designation T99 and ASTM D698.

2.1.9 *Modified density* - Maximum density at optimum moisture as designated by AASHTO T180 and ASTM D1557.

2.1.10 *Modulus of soil reaction (k-value)* - The ratio of stress on a 30 in. (76 cm) diameter plate to the settlement of that plate when tested according to ASTM Designation D1196. Test procedures for military airfields are given in References 2 and 3.

2.1.11 A pavement foundation may consist of one or more components. Under favorable conditions a pavement for light traffic may rest directly on the subgrade. Less favorable conditions of soil type, climate, or heavier traffic may require intermediate layers. Definitions of these components are:

2.1.12 *Subgrade* - The basement soil in excavations (cuts), embankments (fills), and embankment foundation to such depth as may affect structural design.

2.1.13 *Subbase (also called base)* - A specified or selected layer or layers of material of planned thickness directly beneath the pavement. Two or more layers of subbase are often placed for support and drainage reasons.

2.1.14 *Filter course* - A layer of permeable material that restricts the infiltration of fine-grained soils into coarser material. Filter designs are given in References 4 and 5. Other terms applicable to foundations are:

2.1.15 *Drainage* - Control of water accumulations on or in foundations as necessary to insure satisfactory performance of the pavement. Methods to provide drainage at military installations and highways are described in References 4 and 5, respectively.

2.1.16 *Frost action* - Freezing and thawing of moisture in soils and resultant effects on the soil and the pavement. Freezing may result in increased volume and upward movement called frost heave. Thawing may cause reduction in ability of the foundation to support loads.

2.1.17 *Pumping* - The ejection of mixtures of water and subgrade or subbase material along joints, cracks, and pavement edges by the passage of wheel loads over the pavement.

CHAPTER 3 - SUBGRADES AND EMBANKMENTS

3.1 - General

3.1.1 Materials suitable for subgrade or embankments are described in AASHTO M57. Samples for identifications should be taken by the standard method, AASHTO T86 or ASTM D420.

3.2 - Preparation of subgrades

3.2.1 Preparation of subgrades is dependent on the type of soil and environment. To secure uniform support at lowest cost, cross-hauling is used to place the most stable soils in the upper layers. Proper compaction is necessary to prevent nonuniform support. Compaction procedures are those of AASHTO M57 with the additional requirement that clay soils (A-6 and A-7's) should be compacted at moisture contents not less than optimum as found by AASHTO T99. (See Reference 3 for compaction requirements for airfield pavements.)

3.2.2 In areas with expansive soils, embankments should be constructed with the most susceptible soils at the bottom restrained by the upper lifts. Cut sections should be allowed to rebound after restraint is removed before final grading. On projects with highly expansive soils the upper 1 to 3 ft (30 to 90 cm) of the subgrade

should be compacted at moisture contents slightly above AASHTO T99 optimum, but to avoid temporarily weakening the soil, compaction to densities exceeding AASHTO T99 maximums should not be attempted. Additional benefit may be obtained by treating the upper layers of these soils with lime. However, effectiveness in control of expansive soils depends primarily on depth of treatment.

3.2.3 When the water table is near the surface, treatment of the layer with lime prior to subbase placement may be effective in moisture control.

3.2.4 In areas of deep frost penetration, pockets of highly frost-susceptible soil should be replaced by soil with the same characteristics as that surrounding the pocket to avoid discontinuities in soil behavior. Under airfield pavement, some Federal agencies require that replacement be to the full depth of frost penetration (Reference 2). However, for the majority of roads the most effective protection from frost is a uniform subgrade irrespective of frost-penetration depths.

3.2.5 Other conditions that warrant special treatment are the existence of organic materials and prevalence of rocks and boulders in frost areas. Organic materials such as peat must be removed because these materials reduce in volume with moisture loss and cause excessive settlement.

3.2.6 Method of removal is determined by economics. Boulders in subgrades in frost areas work upward to the surface with freeze-thaw action and should be removed to a sufficient depth to assure uniformity of bearing and soil volume changes.

CHAPTER 4 - SUBBASES

4.1. -General

4.1.1 With adequate subgrade preparation, pavements for city streets with drainage systems and lightly traveled roads may be built directly on subgrades because moisture problems are not serious and strong slab support is not needed. For heavier traffic the soil should meet requirements of AASHTO Designation M155 or a subbase should be constructed.

4.1.2 The term "subbase" evolved from the fact that the select layer is not designed primarily for high-supporting value but is placed for bearing uniformity, pumping control, and erosion resistance. The fact that some stabilized materials used for this purpose improve bearing significantly permits the use of the term "base," and usage now allows free interchange of the terms for concrete pavements without reference to bearing quality.

4.1.3 Subbases are prescribed when they are needed for one or more of the following functions (Reference 6):

1. To control pumping of highway pavements carrying a substantial number of heavy truckloads - more than 1000 18 kip ESAL's.

2. To provide uniform support for pavement slabs in areas that vary in subgrade, types, and soil condition. Provision of a subbase may not sufficiently compensate for nonuniform subgrade conditions. Every effort

should be made to improve nonuniform subgrade conditions.

3. To aid in the control of differential shrinkage.

4. To aid in the control of excessive or differential frost heave.

5. To afford a more stable working platform during construction.

4.2 - Types of subbases

4.2.1 Because a subbase must remain stable under all climatic conditions, it must be built of durable materials, such as (1) granular aggregates that resist change in volume or bearing value with changes in moisture content, (2) soils of low plasticity which have been made more durable by treatment, and (3) relatively low-strength (lean) concrete.

4.2.2 Granular subbases can be open-graded with high permeability to remove water quickly before pumping can occur or the subgrade surface can be affected. These subbases may vary in composition from graded gravels or crushed stone to materials that are predominantly of uniform size. All have restricted amounts of fine material passing the No. 200 sieve (0.074 cm) and a plasticity index of usually 6 or less. They should not be used over expansive soils and it is essential that lateral drainage be continued through shoulders to ditches or to longitudinal drains. If an open-graded subbase has a grading that permits intrusion of the subgrade soil, a filter course or other medium is required. Filter designs are given in References 4 and 5.

4.2.3 Granular subbases can also be dense-graded with low permeability to divert the water from the subgrade to drains or ditches. They should have stability under service conditions to provide continuous uniform support. They are used to minimize the accumulation of water beneath pavements over moisture-sensitive subgrades. Appropriate gradations and plasticity requirements are given in AASHTO M147. Under heavy traffic, however, this type of subbase has pumped significantly.

4.2.4 Granular subbases vary in thickness according to their purpose and subgrade conditions. Normally they are in the range of 4 to 6 in. (102 to 152 mm) for highways and 4 to 9 in. (102 to 229 mm) for airfields. Greater thicknesses may be used for severe or unusual frost conditions, highly expansive subgrade soils, and for other very severe subgrade conditions. When pavements are built on subbases, design thicknesses should be based on the support afforded by the subbase-subgrade system.

4.2.5 Stabilized subbases are built with soils to which a cementitious, waterproofing, or modifying product has been added, and which, after compaction, form a hardened material of relatively lower permeability. These subbases are constructed from AASHTO Soil Classification Groups A-1, A-2-4, A-2-5, and A-3 soils which have less than 35 percent material passing No. 200 sieve and which have a PI of 10 or less. Enough cement is added to produce a compressive