R&T UPDATE
Concrete Pavement Research & Technology

STABILIZED SUBBASES AND AIRFIELD CONCRETE PAVEMENT CRACKING

The number of airfield concrete pavement construction projects that experience early-age uncontrolled cracking appears to be on the rise. There are numerous recent reports of projects built on very rigid subbases that have experienced early distress phenomena. The cause appears to be associated with the faulty axiom that "thicker and stronger means better," which does not necessarily hold true in the design and construction of concrete pavement. An approach to resolving the uncontrolled cracking distress involves much more than specifying a thickness and strength. Other factors must be considered for the expected pavement performance to be realized. If the pavement is going to support safe aircraft operations, it must be designed as a balanced system.

Why Concrete Cracks

The reasons concrete cracks at an early age are numerous. Because concrete does crack, the practice of sawing joints in early age concrete pavements is used to control the location of these cracks. But, uncontrolled cracks may still occur. The reasons are the same as for controlled cracks, except that the variables have been influenced by the design or material choices to exacerbate the potential for uncontrolled cracking. The four most common causes of uncontrolled cracking are:

1. Plastic shrinkage due to loss of surface moisture
2. Excessive drying shrinkage
3. Artificial restraint of volume change
4. Internal thermal & moisture gradients

Random, uncontrolled cracking on new construction projects is usually the result of a combination of design and construction factors. Factors like materials selection, concrete mix design, joint spacing, and subbase rigidity, when combined influence the risk. This R&T Update describes the influence of the stabilized subbase to uncontrolled cracking potential.

Subbase Considerations

The three factors that must be considered in the selection of materials for subbase design and construction for airfield pavements are:

- Strength of stabilized subbase materials
- Potential bonding of plastic concrete to subbase
- Joint spacing (panel size dimensions)

In June 2000 the Federal Aviation Administration (FAA) circulated a proposed change to the Advisory Circular 150/5320-6D to limit the maximum panel size for pavements 12 in. (300 mm) and thicker to 20 feet (6 m). That proposal was predicated on studies that document the increase in curling stress in pavements constructed on stabilized subbase. Curling stresses on stabilized subbases may be up to two times higher than curling stresses in conventional construction. In addition, the FAA proposed that joint spacing of pavements constructed on stabilized subbase be a function of the relative stiffness of the slab. The proposal was not adopted.

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The fact remains that stabilized subbases induce higher curling stresses. The only practical mitigation is to reduce joint spacing. But, there are also other factors that contribute to the excess stress conditions that can be mitigated.

FAA guide specifications include provisions in the form of notes that discourage the construction of *very rigid* subbase materials. The reason for this is because as the strength and thickness of the subbase increases, the quantitative value of the radius of relative stiffness[1] of the pavement decreases, effectively reducing the ability of the slabs to spread out stress from the load. For equivalent panel sizes, very rigid stabilized subbase materials impose an increase in the stress conditions of the pavement.

Table 1. Coefficient of friction for various subbase materials.

Subbase	Coefficient of Friction
Natural subgrade	1.0
Lime-treated clay soil	1.5
Dense-graded granular	1.5
Crushed stone	6.0
Bituminous surface treatment	3.0
Asphalt stabilized (rough)	15.0
Asphalt stabilized (smooth)	6.0
Asphalt-treated open-graded	15.0
Cement-treated open-graded	15.0
Cement-stabilized	10.0
Lean concrete or econocrete	15.0

Plastic concrete shrinks as it hydrates. As the concrete shrinks it slides along the subbase. As the stiffness of the base increases, the coefficient of friction between subbase and slab increases. Any bonding of the plastic concrete to the subbase significantly increases the friction value, increasing restraint and the risk of cracking. Table 1 shows the typical coefficient of friction of various subbase materials.

The FAA guide specification for econocrete base (Item P-306) recommends an upper limit of 1200 psi (8.3 MPa) for compressive strength because higher strengths "may induce cracking in the overlying pavement." A similar clause is used by the American Association of State Highway and Transportation Officials (AASHTO) for an upper limit of 1,500 psi (10.3 MPa) for lean concrete base (LCB). When LCB strength exceeds 1,500 psi (10.3 MPa), there is an increased risk of cracking in the concrete pavement caused by the underlying LCB.

The potential for bonding between the concrete and subbase can be minimized with the application of a bond-breaking medium. For lean concrete or econocrete subbases, current practice includes two heavy spray applications of wax-based curing compound on the subbase surface. Table 2 provides some alternative materials that may be used to reduce friction and prevent bonding of concrete pavement to subbase layers.

Table 2. Alternatives for reducing friction or bond between concrete pavement and stabilized subbase materials.

Material	Comments
Curing compound	Two coats of white pigmented wax-based compound works well.
Sand	Dusting about 12 lb/SY (5.5 kg/m^3) works well.
Bladed fines	Recycled jobsite material works well as thin layer.
Asphalt emulsion	Works well on smoother subbase surfaces. Must be even coating.
Polyethylene sheets	Works well but difficult to use when windy; could pose traffic hazard in urban areas.
Tar paper	Works as debonding medium directly over shrinkage cracks in subbase. Not recommended for application on entire subbase area.
Choker stone	For stabilized open-graded materials only – chip-size material to fill near-surface voids and minimize penetration of concrete into subbase.

[1] The radius of relative stiffness, ℓ, is affected by the Modulus of Elasticity of the pavement (E_c), the thickness of the pavement (h), the Poisson's ratio of the concrete (μ), and the Modulus of Subgrade Reaction (k-value). As the strength and thickness of the subbase increase, the k-value increases, and the radius of relative stiffness decreases. A lower radius of relative stiffness causes higher stresses in the pavement.

$$l = \sqrt[4]{\frac{E_c h^3}{12(1-\mu^2)k}}$$

Mix Design for Concrete Pavements on Stabilized Subbases
Attention to concrete mixture design should be a priority for airfield concrete pavements. When stabilized subbases are specified, this aspect becomes even more critical. The combination of a high-strength subbase and a concrete mixture susceptible to uncontrolled cracking should always be avoided. Careful attention to concrete mixture will help reduce the probability for uncontrolled cracking.

The cracking potential for a given mix is influenced by three factors:

- The quantity of cementitious material
- Fineness of the sand (fine aggregate)
- Type of coarse aggregate (size or quantity)

The first two factors influence the quantity of water required, and total water content is directly related to volume shrinkage. Consequently, the potential for uncontrolled cracking is directly related to water demand. The coarse aggregate influences the temperature sensitivity of the concrete. Concrete that is more temperature sensitive will expand or contract more with temperature change thus increasing cracking potential.

Cementitious Material — The strength of concrete is directly influenced by the quantity of cement and the water cement ratio. Increasing the quantity of cement and lowering the water cement ratio generally helps produce a denser and more durable mixture with higher early strength, but it may also contribute to a higher potential for uncontrolled cracking. Cement factors used in concrete for airfield pavements typically average over 500 lb/yd^3 (297 kg/m^3). Mixtures with higher quantities of portland cement require more mixing water and consequently shrink more. Even if the water to cementitious materials ratio is minimized, the actual volume of water increases with higher cementitious material content.

Conversely, mixtures containing certain fly ashes or ground-granulated blast furnace slag (GGBFS) may experience a retarded early-age strength development, particularly in cooler weather. Depending upon the ambient air, subbase, and concrete temperature, this could delay the concrete set time. This could result in severe strength differences when there is a sudden temperature drop and the subbase remains warm. This may not only delay the time until sawing begins but it increases the risk of uncontrolled cracking in cooler weather because of strength and shrinkage gradients in the pavement.

Sand — Most concrete specifications reference the requirements of ASTM C-33. ASTM C-33 specifies the acceptability of aggregates and sand based upon upper and lower limits for material sizes based upon percentage passing. When applied indiscriminately, the use of the ASTM C-33 requirements may actually increase the potential for uncontrolled cracking of pavement concrete.

Generally, concrete with a high cement factor should include coarse sand. ASTM C-33, Paragraph 6.2 enforces this by allowing a reduction of the portion of sand passing the 300 μm and 150μm (No. 50 and No. 100) sieves to 5 and 0 percent, respectively for:

- Pavement-grade concrete (more than 3% entrained air).
- Air-entrained concrete with a cementitious content more than about 400 lb/yd^3 (237 kg/m^3).
- Non-air-entrained concrete with cementitious content more than about 500 lb/yd^3 (297 kg/m^3).

In practice this clause is mostly ignored. It is not uncommon for sands to meet the grading requirements of ASTM C-33 and yet lack the characteristics that are desired for use in pavement concrete. Paragraph 6.3 of ASTM C-33 stipulates additional acceptability characteristics for sands:

- No more than 45% of material may be retained on any one sieve.
- Fineness Modulus (FM) from 2.3 to 3.1.

Here is where the discontinuity of ASTM C-33 begins. A Fineness Modulus (FM) limit of 3.1 is not high enough. In fact, sand that meets the ASTM C-33's recommended lower gradation limit of 5 and 0 percent, respectively would have a Fineness Modulus of 3.45 by calculation. In reality, a FM of up to 3.8 is acceptable for pavement quality concrete.

Therefore, when the concrete specification is written, the necessary amendments for ASTM C-33 must be included. The contractor or supplier may have to use a manufactured sand to obtain the desirable characteristics because coarse sands that would meet the higher FM may not be locally available.

Coarse Aggregate — The coarse aggregate type will influence the amount of temperature expansion or contraction of concrete. Limestones, granites, and basalts have lower Coefficients of Thermal Expansion than quartz, sandstones, or siliceous gravels. Concrete that is more temperature sensitive has an increased potential for uncontrolled cracking. A shorter joint spacing should be applied to concrete that includes aggregates that are more temperature sensitive. The time of cracking may also be earlier for more temperature-sensitive concrete. Field tests show that cracks form at the saw cut sooner and more frequently with concrete made from river gravel than concrete made with crushed limestone.

Combined Aggregates — The combined aggregate gradation can be used to predict the workability characteristics of the concrete. Shilstone (*Concrete International*, June 1990) and others have demonstrated a useful evaluation technique for predicting the constructability of concrete mixtures. While this technique cannot cover every possible combination, it can provide insight into the response of most concrete mixtures to consolidation. A clear benefit of using the combined aggregate gradation technique is that it identifies concrete mixtures that will finish poorly or may segregate under vibration. Mixtures prone to segregation are prone to early distress.

Summary

A stabilized subbase is an excellent design feature for heavy-duty airfield pavement because of the extended fatigue life of the pavement. However, precautions must be taken in the design and the construction of pavement to be sure that the stabilized subbase is not the cause of an early pavement failure. These precautions include but are not limited to:

- Specify a *maximum allowable* subbase strength – the specification should reward consistency and acceptable strength limits
- Be sure that a bond between concrete and subbase does not develop during construction
- Reduce joint spacing (panel size)
- Notch high strength rigid subbases and align notches with planned joints
- Avoid high cementitious factor for pavement concrete mixes
- Perform a mix design/gradation analysis to check for potential problems

With care and attention to detail, the probability of unexpected and uncontrolled cracking on stabilized subbases can be minimized.

For More Information please see ACPA's newest publication, *Early Cracking of Concrete Pavement – Causes and Repairs*, code no. TB016P, available August 2002.

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