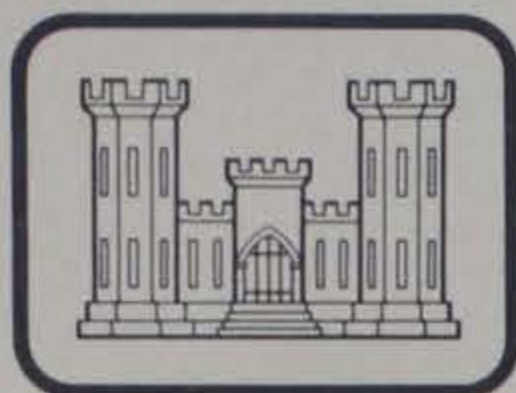


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MINIMUM CONCRETE STRENGTH FOR PAVEMENTS AND FLOOR SLABS

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report reviews existing literature to determine if a minimum allowable concrete strength can be established for portland cement concrete pavements and floor slabs. The range of concrete strengths shown on existing Corps of Engineers design charts for concrete pavements and floor slabs represents only a reasonable range of strengths, and lower-strength concrete may be used if the pavement and floor slab thickness are increased appropriately to (Continued)		

20. ABSTRACT (Continued)

ensure structural adequacy. However, a reduction in concrete strength will reduce the abrasion resistance of the concrete surface. Minimum strengths for warehouse and similar heavily loaded slabs are recommended for adoption in Army TM 5-809-12, "Concrete Floor Slabs on Grade Subjected to Heavy Loads," to ensure adequate abrasion resistance. These minimum strengths are drawn from current recommended practice in the U. S. Abrasion has not been a problem with concrete pavements so a recommended minimum strength is not justified at the present time.

Preface

The investigation reported herein was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Office, Chief of Engineers, Department of the Army, under Project No. 4K07812AQ61, Facilities Investigation and Studies Program, Work Effort, "Minimum Allowable Strength for Portland Cement Concrete Pavement Design." This investigation was conducted from July to September 1979.

The investigation was conducted under the general supervision of Mr. R. L. Hutchinson, Chief, Pavement Systems Division, and Mr. J. P. Sale, Chief, Geotechnical Laboratory. This report was prepared by Mr. R. S. Rollings.

Commanders and Directors of the WES during this investigation and the preparation of the report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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Conversion Factors, U. S. Customary to Metric (SI)
Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimetres
pounds (force) per square inch	6.894757	kilopascals

MINIMUM CONCRETE STRENGTH FOR
PAVEMENTS AND FLOOR SLABS

Introduction

1. The current Corps of Engineers specifications and designs require one quality of concrete for structural use and a second generally higher strength concrete for floors and pavements subject to vehicular traffic. The use of a single specification for both structural and pavement concrete could be economical on some projects. This report uses existing published literature to determine the minimum strength concrete that may be used for concrete pavements and floors subject to vehicular traffic.

2. The concrete used must provide sufficient strength to carry the required loads over the pavement or floor. Also, the concrete must provide sufficient durability to resist environmental effects and wear from the loads. The effects of concrete strength on structural capacity and on durability will each be considered in the following sections of this report.

Structural Requirements

3. Selection of a thickness for a concrete pavement or slab is based on limiting the critical tensile stresses at the bottom of the slab to less than the concrete modulus of rupture with appropriate factors to account for fatigue, temperature, moisture, impact, and similar parameters. Using this design method, a reduction in the strength of the concrete requires a corresponding increase in the slab thickness if the load magnitude and frequency remain the same.

4. Table 1 shows the required concrete strengths from six Department of the Army sources,¹⁻⁶ the American Concrete Institute (ACI),⁷ and the Portland Cement Association (PCA).⁸ Five of the six Army sources do not provide any specific minimum strength, and the values shown are the lowest values shown in the design charts. These five values are all in terms of flexural strength, and the appropriate equivalent compressive strength is shown based on the relation developed by Hammitt.⁹ There is no unique relationship between concrete compressive and flexural strength, and these compressive strengths are only general approximations (Neville).¹⁰

5. Carlton,¹¹ Hutchinson,¹² and Rice, Eberhardt, and Varga¹³ prepared technical reports documenting the original development of the design procedures used in TM 5-822-6, "Rigid Pavements for Roads, Streets, Walks, and Open Storage Areas;"³ TM 5-823-3, "Army Airfield and Heliport Rigid and Overlay Pavement Design;"⁴ TM 5-824-3, "Rigid Pavements for Airfields Other Than Army;"^{5,6} and TM 5-809-12, "Concrete Floor Slabs on Grade Subjected to Heavy Loads."² Only Carlton¹¹ addresses the problem of an allowable concrete strength. He specifically states that no limit has been set on the range of concrete strength and that the design charts simply show a reasonable range of values. Rice, Eberhardt, and Varga¹³ used Carlton's procedures as a basis for their design method for floor slabs, and since no further restrictions on concrete strength were made by them, Carlton's statement must still apply to their design charts. The available documentation on existing Army design methods for concrete pavements and slabs shows that no data

Table 1
Required Strengths for Pavement and Floor Slabs

Source	Subject	Load	Minimum Concrete Strength*
TM 5-809-2 (1967) ¹	Slab on grade	≤ 300 psf uniform	q_u^{**} 3000 psi
TM 5-809-12 (1977) ²	Slab subject to heavy load	Warehouse	f^{**} 540 psi q_u^+ 3300 psi
TM 5-822-6 (1977) ³	Pavements for Roads Streets, Walks, and Open Storage Areas		f^{**} 550 psi q_u^+ 3400 psi
TM 5-823-3 (1968) ⁴	Rigid Pavements for Army Airfields and Heliports		f^{**} 480 psi q_u^+ 2700 psi
TM 5-824-3 (1970) ⁵	Rigid Pavements for Airfields Other Than Army		f^{**} 480 psi q_u^+ 2700 psi
TM 5-824-3 (1979) ⁶	Rigid Pavements for Airfields Other Than Army (DRAFT)		f^{**} 400 psi q_u^+ 1900 psi
ACI 302-69 ⁷	Residential slabs	Light foot	q_u 3500 psi
	Office slabs	Foot	q_u 3500 psi
	Drives/sidewalks	Light foot and pneumatic	q_u 3500 psi
	Light industrial slabs	Foot and pneumatic	q_u 4000 psi
	Industrial slabs	Foot and wheel, abrasive	q_u 4500 psi
	Heavy industrial slabs	Foot and steel wheel, very abrasive	q_u 5000-8000 psi
PCA (1978) ⁸	Floors on ground	Industrial/commercial	q_u 4000 psi

* f = flexural strength, q_u = compressive strength.

** No minimum specified; value is lowest on design chart.

† Approximated from flexural strength.

were available when the design methods were developed to allow selection of a minimum concrete strength.

6. A review of the performance of 12 military airfields by Hutchinson and Vedros¹⁴ shows a range of concrete flexural strengths of 600 to 960 psi,* and generally airfields designed by the Corps of Engineers use concrete in this range. However, a review of several airfield pavement evaluation reports available at the Waterways Experiment Station found reported concrete flexural strength between 450 and 500 psi for taxiways and runways at Carswell, Ellsworth, Holloman, and Amarillo airfields. The thinnest pavements of 6 to 8 in. had been overlaid, abandoned, or were in poor shape, but thicker pavements from 12 to 21 in. thick were rated from good to excellent. Also, a recent test at the Waterways Experiment Station applied simulated C-141 and F-4 aircraft traffic to an 18-in.-thick section that had a concrete compressive strength of 2000 psi (approximately 410 psi flexural strength). Performance of this section was adequate.

7. The existing Corps design methods for pavements and slabs do not set a range of allowable concrete strengths for the designs. There is evidence that relatively low-strength pavements at existing airfields have performed well, and one test section with low-strength concrete is also proving structurally adequate. From the information available, structurally adequate slabs and pavements can be constructed of lower-strength concrete than shown on existing Corps of Engineers design charts. However, the reduction in strength must be accompanied by an increase in thickness.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is found on page 3.

Durability Requirements

8. Durability of concrete generally includes chemical resistance, freeze-thaw resistance, and abrasion resistance. Concrete that will be subjected to sulfate attack requires the use of sulfate-resistant portland cement or pozzolanic cement along with careful attention to density and permeability. Concrete exposed to acids and some industrial products requires a protective coating to prevent softening and disintegration of the concrete. Concrete strength does not have a direct effect on the chemical resistance of concrete.

9. The major factors that determine the freeze-thaw resistance of concrete are degree of saturation and the pore structure in the concrete.¹⁰ Entrained air effectively provides a pore structure that prevents development of destructive osmotic pressure during the freezing of concrete. The cement paste made of any portland cement and any reasonable water-cement ratio can be protected from freezing damage by the use of entrained air, while any portland cement paste made without entrained air will be destroyed the first time it is frozen while saturated.¹⁵ The permeability of the cement paste determines the period required to critically saturate the aggregate particles and make them vulnerable to freezing. Under severe conditions, rich air-entrained concrete lasts longer than lean air-entrained concrete. TM 5-822-7, "Standard Practice for Concrete Pavements,"¹⁶ provides requirements on air content, minimum cement content, and slump, which are three requirements that provide for freeze-thaw resistance. Concrete strength is not a valid indicator of freeze-thaw resistance.

10. A wide range of abrasion tests, such as the Los Angeles abrasion test, the Rattler test, the Davis steel ball test, sandblasting tests, and others, have been used as measures of abrasion resistance. Despite the variety of abrasion tests available, there has not been any correlation between these test results and specific wear and abrasion requirements for pavements and floor slabs. The concrete compressive strength is the best available guide for abrasion resistance.^{10,17}

11. The minimum strengths recommended in ACI 302-69⁷ and PCA (1978)⁸ are based on abrasion resistance and not structural requirements (Table 1). None of the Army technical manuals referenced earlier contains any guidance on abrasion resistance. The ACI and PCA guides (Table 1) appear to offer the best guidance available on the concrete strength required to ensure abrasion resistance in floor slabs.

12. Concrete compressive strength directly affects the abrasion resistance of a concrete surface but does not have a direct effect on other concrete durability factors, such as chemical resistance or freeze-thaw resistance. The ACI⁷ and PCA⁸ provide reasonable guidelines for minimum compressive strength requirements for abrasion resistance of floor slabs. Although some pavements, such as tank parking aprons, would appear to be subject to very abrasive traffic, no problems are known to exist with abrasive wear of concrete pavements. Since no pavement problems are currently known and there are no data available to evaluate required levels of abrasion resistance for concrete pavements, no minimum strength for concrete pavement can be justified on the basis of abrasion resistance. The minimum cement content, allowable range of air entrainment, aggregate specification, and allowable slump specified in TM 5-822-7, "Standard Practice for Concrete Pavements,"¹⁶ does provide a limit on the minimum strength of concrete mixes, but this minimum will vary depending on local aggregate quality and workability requirements.

Conclusions and Recommendations

Conclusions

13. Although lower-strength concrete than shown in existing design charts may be structurally adequate in floor slabs and pavements, the use of such concrete may result in excessive abrasion. There is no minimum limit in existing manuals on the concrete strength, and the designer may use designs for any strength of concrete. However, limits on minimum compressive strength rather than flexural strength should be established for TM 5-809-12,² which is concerned primarily with warehouse floors where abrasion can be a severe problem. The ACI 302-69⁷ and PCA⁸ limits provide the best available guidelines for abrasion resistance under these conditions. There is not any known problem with abrasion on concrete pavements, so no such limit would be necessary for TM 5-822-6,³ TM 5-822-7,¹⁶ TM 5-823-3,⁴ or TM 5-824-3.^{5,6}

Recommendations

14. The following sections should be added to the specified manual:

- a. TM 5-823-3⁴ and TM 5-824-3.^{5,6} The minimum concrete strengths shown in the design charts are representative of reasonable concrete mix designs. Lower-strength concrete may be used but will require increased pavement thickness. Methods of calculating the required pavement thickness will be found in "Basis for Rigid Pavement Design for Airfields," Miscellaneous Paper No. 5-7, U. S. Army Engineer Ohio River Division Laboratories, 1966.¹²
- b. TM 5-822-6.³ The minimum concrete strengths shown in the design charts are representative of reasonable concrete mix designs. Lower-strength concrete may be used but will require increased pavement thickness. Methods of calculating the required pavement thickness will be found in "Development of Rigid Pavement Thickness Requirements for Military Roads and Streets," Technical Report No. 4-18, U. S. Army Engineer Ohio River Division Laboratories, 1961.¹¹
- c. TM 5-809-12.² The minimum concrete compressive strength for floors subject to pneumatic traffic will be 4000 psi; for floors subject to abrasive conditions, such as steel wheels, the minimum concrete strength will be 5000 psi.

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