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AIR FORCE TECHNICAL MANUAL

STANDARD PRACTICE FOR CONCRETE PAVEMENTS

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
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STANDARD PRACTICE FOR CONCRETE PAVEMENTS

* This manual supersedes TM 5-822-7/AFM 88-6, Chapter 8, 15 September 1975.

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STANDARD PRACTICE FOR CONCRETE PAVEMENTS

1. Purpose. This manual provides information on the materials and construction procedures for concrete pavements.

2. Scope. This manual describes the constituents to be used in concrete, the procedures to be used in manufacturing concrete, and the equipment and procedures to place, texture, and cure concrete for pavements.

3. Responsibilities, strength, and air content.

a. Responsibility for mixture proportioning. The responsibility for mixture proportioning must be clearly assigned to either the contractor or the contracting officer in the project specifications. When the contracting officer is responsible for mixture proportioning, he will approve all concrete materials as well as determine and adjust proportions of all concrete mixtures as necessary to obtain the strength and quality of concrete required for the pavements. Cement will be a separate pay item in the contract. When the contractor is responsible for mixture proportioning, he will control all proportions of the concrete mixture necessary to obtain the strength and quality of the concrete required for the pavements, and cement will not be a separate pay item in the contract. However, the contracting officer is responsible for approving the quality of all materials the contractor uses in the concrete.

b. Approval responsibility. The contracting officer is responsible for approval of all materials, mixture proportions, plants, construction equipment, and construction procedures proposed for use by the contractor. The contractor must submit proposed mixtures if he is responsible for mixture proportioning; samples of all materials; and detailed descriptions of all plants, construction equipment, and proposed construction procedures prior to the start of construction.

c. Flexural strength. Structural designs are based on flexural strengths that the concrete is expected to obtain at 28 days for road pavements and 90 days for airfield pavements. These ages are not adequate for quality control in the field since a large amount of low-strength concrete could be placed before strength tests on samples revealed the problem. Correlations can be established between a 14-day strength and the 28- or 90–day strength used in design, and this correlated 14-day strength can be used as a strength check for a more timely concrete mixture control in the field.

(l.) Materials and flexural strength. To select suitable flexural strengths for the design of pavements and for inclusion in contract specifications, the contracting officer should have reliable information regarding flexural strengths obtainable with acceptable concrete materials which are available in the vicinity of the project. Typical design values for flexural strength of paving-quality concrete vary from 500 to 750 pounds per square inch (psi). Numerous tests indicate considerable variation in the flexural strength of concrete when different aggregates or different cements are used. There are some indications that aggregate shape and modulus of elasticity are relatively more important in concrete flexural strength than in compressive strength. Also, after optimum flexural strength is reached, there usually is little increase in strength, even with a large increase in cement content. Mixture proportioning studies will be made in accordance with ACI 211.1 (see app A for referenced publications) to determine the flexural strengths to be used for the design of the project. The water-cement ratio-strength relations for mixture proportioning in ACI 211.1 are given in terms of compressive strength. Table 1 gives some approximate guidance for relating the concrete modulus of rupture to the compressive strength-water cement ratio relationships given in ACI 211.1. All aggregates, cementitious materials, and admixtures used in the mixture proportioning studies will be representative of materials available for use in pavement construction. In selecting a flexural strength for pavement design, suitable allowance will be made for variations in strength indicated by tests of different combinations of aggregate and cement. Pavement design will be based on a realistic and economical strength obtainable with available materials.

Table 1. Approximate relation between water-cement ratio and strengths of concrete (modified from ACI 211.1)

Compressive Strength at 28 days, psi	Approximate Range of Modulus of Rupture, psi[a]	Water-Cement Ratio by Weight[b]	
		Nonair-entrained Concrete	Air-entrained Concrete
6,000	700-800	0.41	--
5,000	625-700	0.48	0.40
4,000	525-625	0.57	0.48
3,000	450-525	0.68	0.59
2,000	350-450	0.82	0.74

[a]No unique general relationship exists between concrete compressive strength and modulus of rupture, but the relationship depends on the aggregates and cement used in a specific concrete mixture. Consequently these relationships are only for initial estimates.

[b]Normally pavement concrete will be air entrained and will have a maximum water-cement ratio of 0.45 if exposed to freezing and thawing conditions. For minor pavements in a moderate climate a maximum water-cement ratio of 0.50 may be considered.

(2.) Selecting a field control strength. Once a mixture proportion is selected to provide the required design flexural strength at 28 or 90 days and a correlated 14-day strength is developed from laboratory testing, a field control 14-day flexural strength must be established. This field control strength is selected such that 80 percent of the consecutive 14-day flexural strength test results fall above it. The 14-day field control strength will be determined as follows:

$$f_{fc} = f_{corr} - 0.84SD \qquad \text{(eq 1)}$$

where:

f_{fc} = the 14-day field control flexural strength

f_{corr} = the 14-day flexural strength that is correlated the required 28- or 90-day strength

SD = standard deviation of flexural strength results

If sufficient test results are not available to establish a reasonable standard deviation in the mixture, the coefficient of variation (standard deviation of the mixture flexural strength divided by the mean mixture flexural strength) may be estimated as 10 percent for large projects with good quality control and 15 to 20 percent for smaller jobs or jobs with relatively poor quality control.

(3.) Test specimens. Flexural strength tests will be made on molded beam specimens of 6-inch by 6-inch cross-sectional dimensions in accordance with American Society for Testing and Materials (ASTM) C 78. Standardization of the test specimen is necessary because of the variations in flexural strength obtained with specimens of different sizes. The 6-inch by 6-inch molded beam specimen must be used for all flexural strength determinations in both the laboratory and the field.

d. Air content.

(1.) Effects of air entrainment. Air-entrained concrete will be required for all concrete pavements. Air entrainment improves the workability and placing characteristics of freshly mixed concrete and is required for the freezing and thawing resistance of hardened concrete. The use of entrained air in concrete will reduce strength, but because of the improved workability in the freshly mixed concrete, adjustments in aggregate proportions and reduction of water are normally possible that will negate or at least minimize the loss of strength. Proper proportioning and control of the air-entrained concrete mixture are essential in order to derive maximum benefits from improvement in the placability and durability of concrete with a minimum effect on flexural strength.

(2.) Percentage of air content. The specified air content will be 6 ± 1½ percent for concrete pavements located in regions where resistance to freezing and thawing is a prime consideration, and will be 5 ± 1½ percent for concrete pavements located in regions where frost action is not a factor and air entrainment is used primarily to improve the workability and placability of freshly mixed concrete. Air content will be controlled in the field at the point within the specified range most appropriate for local conditions depending upon the severity of exposure and the quality and maximum size of aggregate. If slag aggregate is used, the air content will be determined by the volumetric method as described in ASTM C 173. Where the aggregate is of comparatively poor quality or when the maximum size is 1% inches or less, the air content will be controlled at 6 ± 1 percent. In such instances, where resistance to freezing and thawing is not a prime consideration, the air content will be 5 ± 1 percent. If further reduction in the air content or the use of non-air-entrained concrete is necessary, prior approval will be obtained from HQDA (DAEN-ECE-G), Washington, DC 20314-1000 or the appropriate Air Force major command.

e. Cement content. Either the contractor or the contracting officer may be responsible for mixture proportioning. When the contractor is responsible for mixture proportioning, no separate payment will be made for cement. When the contracting officer is responsible for mixture proportioning, no limits for the quantity of cement content will be included in the contract specifications; the quantity of cement used per cubic yard of concrete will be determined by the contracting officer, and cement will be paid for under a separate bid item. When the concrete proposed for use on a paving project has a cement content of less than 470 pounds per cubic yard, prior approval will be obtained from HQDA (DAEN-ECE-G) or the appropriate Air Force major command. When concrete proportioning is the responsibility of the contractor and the cement content is less than 470 pounds per cubic yard, the results should be verified by two Corps of Engineers Division laboratories or commercial laboratories prior to submittal. The results of mixture proportioning studies for proposed aggregates and cements and the results of qualitative tests on aggregates and on resulting concretes will be submitted with requests for approval.

4. Cement.

a. Five portland cements designated as Types I through V are marketed today. ASTM C 150 provides a detailed specification for these cements. Type I portland cement is common or ordinary cement that is supplied unless another type is specified. Type II is modified portland cement that provides moderate resistance against sulfate attack and a lower heat of hydration than Type I cement. It is common for cement to be manufactured to meet the physical and chemical requirements of both Type I and II cements.

b. Type III cement is high early-strength cement. Ultimate strength is about the same as Type I cement, but Type III cement has a 3-day compressive strength approximately equal to the Type I cement's 7-day strength. The cost of Type III cement in lieu of Types I or II cement can only be justified when early strength gain is needed to open pavements to traffic or the high heat of hydration is needed for cool construction periods. Type IV cement has a low heat of hydration that may be useful in mass concrete but is not likely to be encountered in pavement construction. Type V sulfate-resistant cement should be used when the concrete will be exposed to severe sulfate attack. The potential for severe sulfate attack exists when the concrete is exposed to water-soluble sulfate in soil or water in excess of 0.20 percent or 1,500 parts per million. The potential for moderate sulfate attack exists for sulfate contents in excess of 0.10, or 150 parts per million.

c. High alumina cement, also known as aluminous or calcium aluminate cement, gains most of its strength in one day, has a high exotherm, is resistant to chemical attack, and is a refractory material. When exposed to warm, moist conditions, it will undergo a long-term strength loss. High alumina cement may find some specialized applications in pavement construction where its rapid strength gain, high exotherm, or refractory properties outweigh its cost and long-term strength loss.

d. There are also some expansive cements, designated as Types K, M, and S in ASTM C 845, that may find some application where concrete shrinkage needs to be minimized or avoided. However, there is little experience with these cements, and they will require careful investigation before use in pavement construction.

e. At least one United States manufacturer is actively promoting a slag cement made by grinding iron blast furnace slag. This may be substituted for up to 50 percent of the portland cement in a pavement mixture if tests show the required final properties are achieved in the hardened concrete. Preblended mixes of portland-pozzolan (Type IP), and portland-slag cements (Type IS) are described in ASTM C 595 and are acceptable for use in pavements.

5. Aggregates.

a. Approval of aggregates. The contractor will use aggregates from approved sources. If the contractor proposes to use aggregates from an unapproved source, the Government will be responsible for conducting tests to determine whether the proposed aggregates will meet the requirements of the project. Sampling and aggregate delivery costs will be borne by the contractor. The contract specifications will state aggregate sample size, delivery location, and required evaluation time for the proposed aggregates. For small jobs requiring 1,600 cubic yards or less of concrete, all tests for aggregates from an unapproved source will be done by the contractor.

b. Quality. Aggregates must generally meet the requirements of ASTM C 33, as modified in the following paragraphs. These requirements can be adjusted as necessary to reflect local experience with specific aggregates to insure economical use of aggregates to meet project requirements. The magnesium or sulfate soundness test (ASTM C 88) required in ASTM C 33 has not been consistently successful in identifying frost-resistant aggregate. Consequently, if an otherwise suitable aggregate fails this test, it should be further investigated using freezing and thawing tests as described in ASTM C 666 or ASTM C 682 before it is finally rejected. Similarly, if an otherwise suitable aggregate fails the Los Angeles (LA) abrasion test (ASTM C 131 or C 535), it can be accepted if it has a history of local use showing that it can be processed without unacceptable degradation and that it is durable under weathering and traffic conditions comparable to the project under investigation.

c. Recycled concrete as aggregate. Existing concrete may be taken up, crushed to suitable gradation, and re-used as concrete aggregate. It must meet all the requirements for gradation and quality that conventional aggregates must meet. All reinforcing steel should be removed. During crushing, hammermill secondary crushers tend to produce excess fines and should not be used. The recycled concrete aggregates will not normally require washing unless they have been contaminated with base or subgrade material. If the original pavement that is being recycled is D-cracked, then the concrete should be crushed to a maximum size of ¾ inch. When crushed concrete is being used as fine aggregate, the inclusion of some natural sand may be required to improve the new concrete mixture's workability.

d. Alkali-aggregate reactions. Minerals in some aggregates can chemically react with the cement alkalis, resulting in an increase in volume that places the concrete under expansive stresses which may result in map cracking, popouts, strength loss, and concrete expansion. Once started, the reaction and the resulting progressive deterioration of the concrete cannot be stopped. These reactions are generally associated with aggregates containing poorly ordered forms of silica, such as opal, chalcedony, chert, or flint (alkali-silica reaction), complex layer-lattice, and silicate minerals such as graywackes, phyllites, siltstones, or argillites (sometimes differentiated as alkali-silicate reaction), or argillaceous, dolomitic limestone (alakali-carbonate reaction). A petrographic investigation in conjunction with results of tests in accordance with ASTM C 227 for alkali-silica expansion and ASTM C 586 for alkali-carbonate expansion is the most promising approach for identifying these problems. If possible, reactive aggregates should be avoided. If they cannot be avoided, low-alkali cement should be specified. If low-alkali cement is not available or is overly expensive, some pozzolans and slag cements have been successful in countering alkali-silica reactions, or reactive aggregate may be blended with non-reactive aggregate to lessen the effect of the reactions.

e. Coarse aggregate.

(l.) Composition. Coarse aggregate may be natural gravel, crushed gravel, crushed stone, crushed recycled concrete, or iron blast furnace slag. The crushing of gravel tends to improve the quality and the bond characteristics and generally results in a higher flexural strength of concrete than if uncrushed gravel is used. When mixture proportioning studies or local experience indicates that a low flexural strength will be obtained with uncrushed gravel, the possibility of obtaining higher strength by crushing the gravel will be investigated. Elongated particles with a width–to-thickness ratio in excess of 3 may not exceed 20 percent by weight as determined by CRD-C 119. This requirement attempts to avoid introducing structural planes of weakness in the finished concrete, workability problems associated with an excess of particles of these shapes, and durability problems that may develop if air and water are trapped under flat and elongated particles.

(2.) Size and grading. The maximum size of the coarse aggregate used in pavement concrete should not exceed one-fourth of the pavement thickness. In no case will the coarse aggregate exceed a 2-inch maximum size. However, for pavement construction in areas where aggregate popouts have been a problem or may occur, the coarse aggregate will not exceed 1½-inch nominal maximum size. In areas where "D" line cracking in pavements has been a problem, limestone aggregates should not exceed ½-inch nominal maximum size and should be of low absorption. When the nominal maximum size of coarse aggregate is greater than 1 inch, the aggregates shall be furnished in two size groups as shown in table 2, with gradings within the separated size groups conforming to the requirements of table 3. Where local practice provides size-group separations other than as shown in table 2, local size gradings may be specified if approximately the same size ranges are obtained and the grading of coarse aggregate when combined and batched for concrete is as required by mixture proportioning. For projects requiring 1,600 cubic yards or less of concrete, special grading requirements for coarse aggregate according to local practice may be substituted for the gradings shown. Local State Department of Transportation specifications for gradings may be used for those jobs requiring 1,600 cubic yards or less of concrete.

Table 2. Coarse aggregate size groups

Nominal Maximum Size	Size Groups
1½ in.	No. 4 to ¾ in. ¾ in. to 1½ in.
2 in.	No. 4 to 1 in. 1 in. to 2 in.

Table 3. Grading of coarse aggregate

Sieve Size U. S. Standard Square Mesh	Percentage by Weight Passing Individual Sieves			
	No. 4 to 3/4 in.	No. 4 to 1 in.	3/4 in. to 1-1/2 in.	1 in. to 2 in.
2-1/2 in.	--	--	--	100
2 in.	--	--	100	97 ± 3
1-1/2 in.		100	95 ± 5	50 ± ’20
1 in.	100	97 ± 3	37 ± 17	7 ± 7
3/4 in.	95 ± 5	--	7 ± 7	--
1/2 in.	--	43 ± 20	--	3 ± 3
3/8 in.	37 ± 17	--	3 ± 3	--
No. 4	5 ± 5	5 ± 5	--	--
No. 8	3 ± 3	3 ± 3	--	--

(3.) Deleterious substances.

(a) Pavements used by aircraft. Table 4 lists the common deleterious substances and specifies limits for these materials. The performance history of local aggregates contributing to pavement defects will be the determining factor in setting the limits for deleterious substances. The limits are intended to eliminate popouts and weatherouts in airfield pavements. Other deleterious substances known to contribute to popouts will be identified by the contracting officer, and suitable limits will be specified. Calcium oxide (CaO) and magnesium oxide (MgO) or a mixture thereof, in lumps, representing the hard burned oxides from fluxing stone or refractory brick should be added to the list of deleterious substances if air-cooled blast furnace slag is used as the aggregate. Since the types of materials producing popouts will vary for different areas, some adjustments of the limits may be desirable for individual projects. Reductions in specified limits may be made as necessary, but increases to permit the use of local aggregates that have an acceptable experience record will be governed by the following procedures. Air Force Regional Civil Engineers (AFRCE) have been authorized to instruct division engineers to waive table 4 requirements for Air Force pavements. Upon request, the AFRCE and the using command will be furnished available engineering information on local aggregates and behavior records on pavements made from them. A copy of the instructions and the revised requirements will be furnished for information to the HQDA (DAEN-ECE-G) or AFESC as applicable. In the case of Air National Guard and Army pavements, the using command will be furnished information on the costs of aggregates complying with specification requirements and on less costly local aggregates along with behavior records on pavements made with local aggregates. However, requirements will be waived only if requested by the Air National Guard Base Detachment Commander or the Army Installation Commander with his assurance that operational requirements will be satisfied by a performance that is equal to that of existing pavements constructed with these less costly aggregates. Requests will be submitted for approval to HQDA (DAEN-ECE -G) with proposed specification requirements, comparative cost estimates, and evidence that operational requirements will be satisfied.

Table 4. Deleterious materials in coarse aggregates for airfield and heliport pavements.

Materials	Areas with Major Popouts: Severe[a] Weather	Areas with Major Popouts: Moderate[a] Weather	Areas with Minor Popouts: Severe[a] Weather	Areas with Minor Popouts: Moderate[a] Weather
Clay lumps	0.2	0.2	2.0	2.0
Shale[b]	0.1	0.2	1.0	1.0
Material finer than No. 200 sieve[c]	0.5	0.5	1.0	1.0
Lightweight particles	0.2	0.2	0.5	0.5
Clay ironstone	0.1	0.5	1.0	1.0

(Continued)

[a]Severe, moderate, and mild weather are defined as follows:

Weather Severity	Air Freezing Index for Coldest Year in 30*	Average Precipitation for a Single Month During Period--1 Month Before Average Date of First Killing Frost to Average Date of Last Killing Frost
Moderate	*500* or less	Any amount
Moderate**	501 or more	Less than 1 inch
Severe	501 or more	1 inch or more

* Calculated as described in TM 5-818-2/AFM 88-6, Chapter 4.
** In poorly drained areas, the weather should be considered severe even though the other criteria indicate a rating of moderate.

[b]Shale is defined as a fine-grained thinly laminated or fissile sedimentary rock. It is commonly composed of clay or silt or both. It has been indurated by compaction or by cementation, but not so much as to have become slate.

[c]Limit for material finer than No. 200 sieve will be increased to 1.5 percent for crushed aggregates if the fine material consists of crusher dust that is essentially free from clay or shale.

[d]The separation medium shall have a specific gravity of 2.0. This limit does not apply to coarse aggregate manufactured from blast-furnace slag unless contamination is evident.

[e]Clay ironstone is defined as an impure variety of iron carbonate, iron oxide, hydrous iron oxide, or combinations thereof, commonly mixed with clay, silt, or sand. It commonly occurs as dull, earthy particles, homogeneous concretionary masses, or hard shell particles with soft interiors. Other names commonly used for clay ironstone are “chocolate bars” and limonite concretions.

Materials	Areas with Major Popouts: Severe[a] Weather	Areas with Major Popouts: Moderate[a] Weather	Areas with Minor Popouts: Severe[a] Weather	Areas with Minor Popouts: Moderate[a] Weather
Chert and/or cherty stone (less than 2.50 sp. gr. SSD)[f]	**0.1**	0.5	1.0	5.0
Claystone, mudstone, and/or siltstone[g]	0.1	0.1	1.0	1.0
Shaly and/or argillaceous limestone[h]	0.2	0.2	1.0	2.0
Other soft particles	1.0	1.0	**1.0**	2.0
Total of all deleterious substances exclusive of material finer than No. 200 sieve	1.0	2.0	3.0	5.0

[f] Chert is defined as rock composed of quartz, chalcedony, or opal, or any mixture of these forms of silica. It is variable in color. The texture is so fine that the individual mineral grains are too small to be distinguished by the unaided eye. Its hardness is such that it scratches glass but is not scratched by a knife blade. It may contain impurities such as clay, carbonates, iron oxides, and other minerals. Other names commonly applied to varieties of chert are flint, jasper, agate, onyx, hornstone, porcellanite, novaculite, sard, carnelian, plasma, bloodstone, touchstone, chrysoprase, heliotrope, and petrified wood. Cherty stone is defined as any type of rock (generally limestone) which contains chert as lenses and/or nodules or irregular masses partially or completely replacing the original stone. SSD = saturated surface dry.

[g] Claystone, mudstone, or siltstone is defined as a massive fine-grained sedimentary rock which consists predominately of clay or silt without lamination or fissility. It may be indurated either by compaction or by cementation.

[h] Shaly limestone is defined as a limestone in which shale occurs as one or more thin beds of laminae. These laminae may be regular or very irregular and may be spaced from a few inches down to minute fractions of an inch. Argillaceous limestone is defined as a limestone in which clay minerals occur disseminated in the stone in the amount of 10 to 50 percent by weight of the rock; when these make up from 50 to 90 percent, the rock is known as calcareous (or dolomitic) shale (or claystone, mudstone, or siltstone).

(b) Other pavements. For other pavements, the limiting amounts of deleterious substances in each size of coarse aggregate will be specified as shown in table 5. Other deleterious substances will be identified by the contracting officer, and suitable limits will be specified and materials defined when necessary.

Table 5. Deleterious materials in coarse aggregates for other pavements

Material	Percentage by Weight
Clay lumps and friable particles	2.0
Material finer than No. 200 sieve[a]	1.0
Lightweight particles	1.0
Other soft particles	2.0

Note: The total of all deleterious substances shall not exceed 5.0 percent of the weight of the aggregate. The percentage of material finer than No. 200 sieve shall not be included in this total.

[a]Limit for material finer than No. 200 sieve will be increased to 1.5 percent for crushed aggregates consisting of crusher dust that is essentially free from clay or shale.

[b]The separation medium shall have a specific gravity of 2.0. This limit does not apply to coarse aggregate manufactured from blast-furnace slag unless contamination is evident.

(4.) Slag aggregate. Iron ore blast-furnace slag aggregates vary widely in properties depending on the manufacturing and cooling processes used. Un-aged blast-furnace slag may contain free lime, but aging reduces this to acceptable levels. Properly aged iron ore blast- furnace aggregate has a good history of performance. Slag from steel mills, however, is not acceptable as concrete aggregate because of the various oxides it contains.

f. Fine Aggregate.

(l.) Composition and shape. Requirements for composition and particle shape of fine aggregate are purely descriptive, for example, natural and/or manufactured sand, spherical or cubical, and no limits are shown. A limit will be included for flat and elongated particles in fine aggregate, comparable with the limit specified for coarse aggregate, when tests indicate that poor particle shape will affect the workability and quality of the concrete. Shape will be determined in accordance with CRD-C 120.

(2.) Grading, uniformity of grading, and deleterious substances. The grading and uniformity of grading specified in table 6 for fine aggregate are desirable for pavement concrete and can generally be met at a reasonable cost within the continental United States. However, if conformance with these requirements will result in undue construction costs and if investigation of the available sources of fine aggregate in the locality indicates that limits other than specified are desirable, a request will be sub-mitted to HQDA (DAEN-ECE-G) giving complete results of all tests conducted to substantiate that concrete of comparable workability, durability, and strength can be produced without an increase in cement content. The amount of deleterious substances in the fine aggregate shall not exceed the limits shown in table 7.

Tabk 6. Gnading of fine aggregate

Sieve Size, U. S. Standard Square Mesh	Cumulative Percentage by Weight Passing Individual Sieves
3/8 in.	100
No. 4	97 2 3
No. 8	85 2 5
No. 16	70 ± 10
No. 30	45 ± 15
No. 50	20 ± 10
No. 100	6 ± 4

Note: In addition, the fine aggregate, as delivered to the mixer, shall have a fineness modulus of not less than 2.40 nor more than 2.90. The grading of the fine aggregate also shall be controlled so that the fineness moduli of at least nine of ten samples of the fine aggregate as delivered to the mixer will not vary more than 0.15 from the average fineness moduli of all samples previously taken. The fineness modulus shall be determined by CRD-C 104 (Appendix A).

Table 7 Deleterious substances in fine aggregate

Material	Percentage by Weight
Clay lumps and friable particles	1.0
Material finer than No. 200 sieve	3.0
Lightweight particles	0.5

Note: The total of all deleterious materials shall not exceed 3.0 percent of the weight of the aggregate.

g. Aggregate for calibration hardstands. To avoid inclusion in the pavement concrete of iron oxides or other iron-rich materials having magnetic properties that will interfere with the operation of the facility, the concrete aggregate proposed for paving calibration hardstands will be subjected to detailed petrographic analyses in accordance with ASTM C 295 prior to acceptance. Special attention will be given to the existence of magnetite in granites, high-iron minerals in traprock, pyrite in limestone, and free iron or iron oxide in slag aggregate. When a list of aggregate sources is included in the contract specifications, the sources not approved for concrete used in calibration hardstands will be indicated.

h. Aggregate for power check pads. Concrete that will be exposed to extended jet engine blast during maintenance can use igneous rocks with a low silica content and a high content of ferromagnesian minerals or slag as aggregate to improve its performance under high temperature. Aggregates rich in silica such as quartzite or chert should be avoided. Aggregate with a high silica content such as sandstone or granite, especially if coarse grained, can cause problems. Calcareous aggregates such as limestone or dolomite are acceptable.

6. Admixtures.

a. Admixtures are used to modify properties of fresh or hardened concrete. Admixtures may be used to improve workability, control initial set, reduce heat generation, accelerate strength gain, increase strength, and improve durability. Seven chemical admixtures are listed for use in portland cement concrete in ASTM C 494, as follows: Type A—water-reducing admixture; Type B —retarding admixture; Type C–accelerating admixture; Type D–water-reducing and retarding admixture; Type E—water-reducing and accelerating admixture; Type F—water-reducing, high-range admixture; and Type G–water-reducing, high-range and retarding admixture.

b. Air-entraining admixtures provide resistance to freezing and thawing and should meet the requirements of ASTM C 260, and will normally be required in all concrete for pavements. For small jobs under 1,600 cubic yards, air-entraining cements may be considered. The use of any other admixture will depend on the economics of its use and site conditions. The effect of an admixture will vary, depending on conditions such as cement type, specific mixture proportions, ambient temperature, or water quality. Furthermore, an admixture may affect several qualities of the concrete, and some desirable properties may be adversely affected. Consequently, the decision to use an admixture must be based on experience and tests with the cement, aggregates, and admixtures representative of those to be used on the project. It must be demonstrated that the final concrete proposed pavement quality is not adversely affected by the use of any proposed admixture. More extensive guidance on admixtures is provided in ACI 212.lR and ACI 212.2R.

7. Pozzolans.

a. Pozzolans are defined in ASTM C 618 as “siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.” This ASTM specification recognizes three classes of pozzolan and provides detailed requirements for each class. Class N pozzolans are raw or calcined natural pozzolans such as some diatomaceous earths, opaline cherts, tuffs, volcanic ashes, clays, and shales. Fly ash is divided into two classes. Class F is fly ash produced by burning anthracite or bituminous coal, and Class C fly ash is produced by burning lignite or subbituminous coal. Environmental Protection Agency (EPA) guidelines published in 1983 (40 CFR, Part 249) require that the use of fly ash must be allowed on all federal projects unless it can be proven technically unsuitable.

b. Pozzolans may be substituted for a maximum of 25 percent by volume of portland cement in concrete for pavements. If substitution of pozzolan above this limit is contemplated, a thorough test program must show that the proposed substitution limit will not adversely affect workability, admixture performance strength, and durability of the final concrete. Pozzolans typically have specific gravities appreciably lower than portland cement, and pozzolan limits are expressed as a percent of the volume of cementitious materials. In general, concrete containing pozzolans has improved workability, lower heat of hydration, and a slower strength gain. When pozzolans are to be used, the required time to gain the design strength may be increased beyond the standard 28 days for roads and streets and 90 days for airfield pavements to the extent that the concrete is not to be exposed to traffic.

c. Class N pozzolans will not generally be encountered in pavement construction. The use of fly ash, however, is becoming increasingly common. Fly ash produced by industrial burning of coal tends to be highly variable, depending on factors such as emission controls, load, and boiler design. This production variability is compounded further by the natural variability of lignite and subbituminous coal that produce Class C pozzolan. Also, Class C pozzolans have poor resistance to sulfate attack, and some have high alkali contents that may contribute to alkali aggregate reaction. Specifications for pozzolans should require that the ASTM C 618 specification be modified to require a maximum loss on ignition of 6 and 8 percent, respectively, for Class F and N pozzolans and a minimum pozzolanic activity index with lime of 900 psi at 7 days. Mixture proportioning studies should use the same pozzolans and cements that will be used on the project and must determine that the final concrete characteristics, strength gain, and durability are adequate.

8. Miscellaneous materials.

a. Other materials used in concrete pavement construction including curing materials, dowels, tie bars, reinforcement, and expansion-joint filler are covered by applicable specifications. When concrete is required to be free of magnetic materials, special instructions will be obtained from HQDA (DAEN-ECE-G) for the selection of dowels, tie bars, and reinforcement. Aluminum will not be used in concrete pavements.

b. Field welding of crossing bars (tack welding) is prohibited. All welded splices will conform to the requirements of the American Welding Society (AWS) D 1.4. Selection of the proper welding procedure depends on the actual chemical composition of the steel. A procedure suitable for one chemical composition can be totally unsuited for another composition of the same strength grade. It is essential that the composition of the steel to be welded be determined before the welding procedure is established. Where reinforcing bars are to be ordered for new work, the fabricator should be informed that welded splices are contemplated. The fabricator can provide the chemical composition of the reinforcing bars and in many cases can provide bars that are more suited to welding.

c. Epoxy-coated reinforcing steel and dowel bars are being used more frequently in areas such as bridge decks, coastal areas, and pavements subject to heavy applications of de-icing salts to minimize potential corrosion problems. If these materials are used, they should conform to ASTM A 775. Epoxy-coated dowels and reinforcing steel will rest on epoxy-coated wire bar supports or on bar supports made of dielectric material. Wire bar supports will be coated for a minimum of 2 inches from the point of contact with the epoxy-coated reinforcing bars. Adequate ventilation to dissipate fumes must be provided if epoxy-coated steel is welded.

d. Appendix **C** describes the materials and methods used for the construction of steel fiber reinforced concrete.

9. Water.

Water for mixing concrete will be free from materials that affect hydration of the cement. Potable water may be used without testing however, tests will be made in accordance with CRD-C 400 if the water source is a stream or another body of water of unknown quality. Seawater has been used successfully as mixing water, but this should only be done if there is no feasible alternative. There may be up to a 15 percent loss in ultimate strength, set times may be affected, and surface efflorescence may occur. The risk of steel corrosion maybe increased, so the use of coated dowels and reinforcing steel should be considered if seawater is to be used.

10. Sampling and testing of materials.

a. Cement. Cement to be used in pavements for aircraft traffic will be sampled and tested. Cement meeting all other test requirements may be accepted prior to the required 7-day age when the strength is equal to or greater than the 7-day strength requirement. Cement for pavement projects requiring 1,600 cubic yards or less of concrete may be accepted on the basis of the manufacturer's certified mill test reports showing compliance with cited cement specifications.

b. Aggregates.

(l.) Listed sources. Listing of aggregate sources will be based on a thorough investigation to determine that suitable aggregates are obtainable for the proposed use. Evaluation of the material will require complete laboratory testing including petrographic examinations, physical tests, durability tests, and alkali-reactivity tests. The service record of aggregates will be determined by inspecting structures that have had exposure equivalent to the proposed structure. When an aggregate source has been listed previously for use on the basis of a complete investigation, additional similar use of the source within a period of 3 years may be permitted on the basis of petrographic examinations and limited physical tests if the results show no change in the composition and quality of aggregate. For proper design and preparation of plans and specifications, it is necessary to investigate and determine suitable aggregate sources and concrete strengths obtainable with aggregates. It is essential that these investigations be conducted as early as possible during project planning.

(2.) Sources for calibration hardstands. When contract specifications cover the paving of calibration hardstands, the list of sources will indicate which sources are approved for such work.

(3.) Aggregate sources not previously listed. When the contractor proposes aggregate from a source not previously listed, the evaluation of samples of that aggregate will include all tests necessary to demonstrate that a concrete produced from the materials will have quality and strength comparable with that of concrete made with aggregate from the approved sources listed. When the contracting officer is responsible for mixture proportioning and cement is a separate pay item in the contract, aggregates of good quality that require an increase in the quantity of cement over that required by aggregates from listed sources to produce concrete of the specified flexural strength will be approved for use only if the contractor agrees in writing to pay for the additional cement required.

(4.) Unlisted source. When the contract specifications do not include a list of approved aggregate sources, the source(s) proposed by the contractor will be investigated as soon as possible after the award of the contract.

(5.) Aggregates for a small project. Evaluation of aggregates from non-listed sources and concrete mixture proportioning for projects requiring 1,600 cubic yards or less of concrete, except for airfield and heliport paving, will be performed by an approved commercial testing laboratory at no expense to the Government.

11. Delivery and storage of materials.

a. Cement and pozzolan. Separate storage facilities will be provided for each type of cementitious material. Storage facility will be thoroughly cleaned before changing the type of cementitious material stored init. Storage facilities must be weather-tight and must be properly ventilated.

b. Aggregates.

(l.) Control of grading. Aggregate-handling and aggregate-storage facilities may vary greatly for different projects, and only general requirements can be specified. Grading and uniformity of grading requirements will be determined as the aggregates are delivered to the mixer, and the contractor is responsible for meeting these requirements. Careful inspection of storage and handling operations, however, is desirable to assure satisfactory control of the aggregate grading and to prevent contamination by foreign material. Aggregate storage techniques that use coned piles or spread truck-dumped aggregate with a bulldozer cause segregation problems. Aggregates delivered by trucks are best dumped and left in individual adjacent piles. A clam shell spreading aggregate in thin layers has also been used to minimize segregation. Aggregate should be handled as little as possible to minimize segregation. Potential sources of contaminants include windblown foundation and adjacent materials and contaminants from equipment used in handling the aggregates.

(2.) Moisture control. Uniformity of free moisture in aggregate is essential for proper control of concrete consistency. A period of free-draining storage is required for fine aggregates and the smaller size of coarse aggregate. Normally, 24 to 48 hours will be sufficient. However, shorter or longer times may be specified if the tests of time to reach an equilibrium so indicate.

12. Grade control. The lines and grades shown for each airfield and heliport pavement category of the contract shall be established and maintained by means of line and grade stakes placed at the jobsite by the contractor. Elevations of all benchmarks used by the contractor for controlling pavement operations at the jobsite will be established and maintained by the Government. The finished pavement grade lines and elevations shown shall be established and controlled at the jobsite in accordance with benchmark elevations furnished by the contracting officer. The pavements shall be constructed to the thicknesses and elevations indicated. Provisions for line and grade control for roads, streets, and open storage areas shall be included in the contract specifications.

13. Proportioning.

a. Mixture proportioning. Before any concrete is placed, trial mixtures will be prepared with materials from the sources to be used for production of concrete on the project. When the contractor is responsible for mixture proportioning, trial mixtures will be prepared by a commercial testing laboratory approved by the contracting officer at no expense to the Government, and the results will be submitted to the contracting officer for approval. When the contracting officer is responsible for mixture proportioning, trial mixtures will be prepared by the Government with materials supplied by the contractor from the sources to be used for production of concrete on the project. Mixtures will be made in sufficient number to establish optimum proportions of the aggregates and to represent a wide range in cement contents and water–cement ratios within specified requirements for air content and workability. The water-cement ratio will not exceed 0.45 by weight for pavement mixtures. After the final proportions of the trial mixtures have been established, 6–inch by 6-inch cross-section test/beam specimens from each mixture will be made in accordance with ASTM C 192 and tested as described in ASTM C 78. A minimum of nine test specimens should be made to establish the flexural strength of each mixture at each test age. From these mixture proportioning studies, the controlling maximum water-cement ratio and hence the cement content required to produce concrete of specified strength will be determined. This same procedure will be used to establish new mixture proportions when necessary because of a change in the source or the character of the concrete ingredients after concrete placement has started.

b. Mixture proportions.

(l.) Contracting officer responsible for mixture proportions. When the contracting officer is responsible for the mixture proportions, proportions of all materials used in the concrete mixture will be as directed. The contracting officer will require such changes in the mixture proportions as necessary to maintain the workability, strength, and quality required by the contract specifications. The mixture proportions determined by mixture proportioning studies will be used in starting paving operations. Adjustments will be made by the contracting officer as necessary to establish the mixture proportions best suited for job conditions and materials used. Subsequent mixture adjustments will be made when necessary, but usually these adjustments will be of a minor nature as required to compensate for variations in gradings and the moisture content of the aggregate.

(2.) Contractor responsible for mixture proportions. When the contractor is responsible for the mixture proportions, proportions of all materials used in the concrete mixture will be as directed by the contractor. The contractor will require such changes in the mixture proportions as necessary to maintain the workability, strength, and quality required by the contract specifications. The mixture proportions determined by mixture proportioning studies will be used in starting paving operations. Adjustments will be made by the contractor as necessary to establish the mixture proportions best suited for the job conditions and materials used. Project specifications will require the contractor to notify the contracting officer prior to making any change to the approved mixture proportions and to indicate the changes to be made. Changes to the mixture proportions will be of a minor nature as required to compensate for variations in gradings and the moisture content of the aggregate unless laboratory mixture studies for the new mixture are submitted for approval.

c. Workability. The concrete slump shall not exceed 2 inches. Within this maximum limit, the slump will be maintained at the lowest practical value suitable for prevailing weather conditions and for equipment and methods used in placement of the concrete. For small paved areas, slump in excess of 2 inches may be permitted, but in no case will the slump exceed 3 inches. The concrete slump will be determined in the field by the method described in ASTM C 143. Slump for slipform paving of airfield and heliport pavements should be specified in a range of O to 1¼ inches.

d. Strength. Control of the strength of the concrete mixture will be based on tests of concrete specimens taken during the paving operations. Pavements to be used by aircraft are designed on the basis of the flexural strength that the concrete is expected to attain at 90 days, and specimens will be tested at this age for use in the evaluation pavements. Since the period necessary to obtain the 90-day field strengths is too great to exercise proper control of the concrete during pavement construction, a 14-day strength requirement will be included in the contract specifications. Flexural-strength tests will be made at 14 days to determine compliance with the 14-day strength requirement. In addition, 7-day strength tests will be made to provide an early indication of the concrete strength. The average strength at the age of 14 days of any five consecutive individual test values representing each concrete mixture will be not less than the specified strength at the age of 14 days, and not more than 20 percent of the individual values will be less than the specified strength. Adjustments of the concrete mixture proportions will be made as necessary to maintain this strength control. When sufficient 90-day strengths become available, further adjustment of the concrete mixture may be made as necessary to assure that the 90-day strength used for the design of the pavements will be obtained and that an economical mixture is being used.

14. Subgrade, base, forms, and string lines.

a. General. The setting and protection of forms and string lines and the final preparation of the subgrade, base course, or filter course require close attention to all details to assure that the pavement will have the required thickness and the surface will beat the required grade.

b. Subgrade. Subgrade is the natural soil or fill upon which the base and concrete pavement are placed. Special procedures may be necessary when dealing with frost-susceptible soils, expansive soils, pumping-susceptible soils, lateritic soils, or organic soils. Removing soft or troublesome soils that occur in pockets may be desirable, where possible.

c. Base. A base may perform many functions, such as drainage, construction platform, and structural strengthening of the pavement. A base may be a granular material or lime, cement, or an asphalt-stabilized material. Also a lean concrete, sometimes referred to as "Econocrete," is sometimes used as a base. There is no clearly accepted definition, but cement contents are typically lower, and sometimes poorer quality aggregates are used. The lean concrete base should meet the strength and durability requirements of cement-stabilized materials and can be treated as a high-quality stabilized material in design.

d. Form materials. Steel forms will be used for all formed pavement construction. Wood forms generally are unsatisfactory for paving work, and their use will not be permitted except for such miscellaneous areas as bulkheads and curved fillets. To avoid the excessive cost of pavement construction for small j ohs, wood forms may be allowed for pavements less than 8 inches thick in noncritical areas, such as open storage areas, helicopter parking pads, and vehicle parking.

e. Construction of forms. Provisions relating to built-up forms may be omitted from contract specifications when the contract plans require constant slab depth for each paved area. When this provision is retained in a contract specification, the contractor is required to furnish steel forms equal to the edge thickness of the majority of pavement slabs for each paved area. Built-up forms will be used only where edge thicknesses exceed the basic form depth. The base width of built-up forms will be equal to the width required for a comparable full-depth form. Side forms on sl.ipform pavers will be the full depth of the pavement.

f. Placement of forms and string lines. Forms and string lines should be installed well in advance of concrete paving operations so that the required checks and necessary corrections can be made without stopping or hindering concrete placement. The same reasoning applies to the final preparation of the underlying material, which should not be less than one full day's operation of the paving equipment ahead of paving.

g. String line. The string line will be of high-strength cord or wire. The choice will depend on the type of automatically controlled slipform paver used. Certain manufacturers recommend that high-tensile-strength wire be stretched tautly between supports. Other manufacturers recommend a large-diameter cord and do not require the tautness that is recommended for the wire. The use of wire requires firmly anchored supports. As a result, the wire is less likely to be disturbed than is the cord whose supports do not have to be so firmly anchored. The wire is difficult to see, and flagging should be attached between the supports to reduce the chance that it will be disturbed during construction. The cord does not require supports to be as firmly anchored as for the wire, and as a result, the cord is easier to install and maintain. However, the chance of sagging between the supports is greater. The cord is easy to see, and as a result, the chances of its being knocked out of alinement are less than for the wire. However, the cord is more easily disturbed than the wire and should be checked frequently.

h. Removal of forms. Pavement forms generally may be removed 12 hours after the concrete is placed. A longer period will be necessary when the strength gain of the concrete is retarded because of delayed or inadequate protection during cold weather. In some instances, earlier removal of forms maybe permitted so that the transverse joints may be sawed completely through to the edge of the slab without leaving a small fillet of concrete adjacent to the form.

15. Batching and mixing.

a. General. There are three types of plants: automatic, semi-automatic, and manual. For paving projects, either automatic or semi-automatic plants will be acceptable. Specifications will be prepared to allow either type of plant, and the contractor will have the option as to the type of plant to be used.

b. Plant capacity. The capacity to be specified for the batching plant and mixing equipment will be determined in accordance with the concrete-placement requirements for the project. Since the pavement slabs are comparatively small, the plant capacity generally will not be influenced by any requirements for maintaining the concrete in a plastic condition during placement. The main considerations will be the required placing schedule to meet the completion date for the construction or, when slipform pavers are used, the required amount of concrete to maintain a uniform forward movement of the paver of not less than 2.5 feet per minute. However, the placement rate specified for pavements constructed during hot weather should also be considered in determining plant capacity requirements.

c. Concrete mixers. Mixers having a capacity of at least 5 cubic yards of mixed concrete are required for airfield paving projects, but smaller mixers may be permitted for small road projects and other small miscellaneous construction. Contract specifications for jobs of suitable size and location will include an option for the contractor to reduce mixing time during progress of work from the mixing time required at the start of the job on the basis of mixer performance tests in accordance with CRD-C 55, provided the following requirements are met at all times:

Parameters Tested For:	Requirement, expressed as maximum permissible range in results of tests of samples taken from three locations in the concrete batch
Weight per cubic foot of mortar calculated to an air-free basis, lb/ft^3	1.0
Air content, volume percent of concrete	1.0
Slump, inches	1.0
Coarse aggregate content, portion by weight of each sample retained on No. 4 sieve, percent	6.0
Average compressive strength at 7 days for each sample based on average strength of all test specimens, percent	10.0
Water content, portion by weight of each sample passing No. 4 sieve, percent	1.0

In addition, no reduction in mixing time will be allowed if it results in a reduction in the 7-day flexural strength from the average strength of five consecutive sets of specimens made from batches mixed the full time. The requirements for stationary mixers and truck mixers will be included unless it is determined that concrete complying with the specifications cannot be manufactured by these types of mixers. Truck mixers often have difficulty in discharging the comparatively low-slump concrete mixtures required for airfield pavement construction, therefore, truck mixers should comply with ASTM C 94. The tendency of the concrete to hang up in discharge chutes may cause delays, which frequently lead to requests by the contractor that the concrete slump be increased. This difficulty also may occur with vehicles used for hauling concrete to forms when stationary mixers are used. The slump of ready-mix concrete will not be increased because of the inadequacy of the mixing or transportation equipment to mix and discharge the concrete.

d. Approval of mixers. Before truck mixers or stationary mixers are approved for use, careful consideration will be given to the proposed plant and facilities for storage and handling of materials, and for batching, mixing, transporting, and handling of concrete at the jobsite to assure that adequate control of the concrete can be exercised. When truck mixers are used with a long haul between the batching plant and the project, adequate control of the concrete may be difficult due to variations in slump and air content caused by differences in mixing time. In such cases, it will be necessary to require that mixing be done after the mixer trucks arrive on the job. Truck mixers will not be permitted for mixing concrete on slipform construction. Truck mixers shall be equipped with accurate revolution counters. In general, truck mixers should only be used on jobs requiring 2,500 cubic yards of concrete or less.

e. Transporting plant-mixed concrete. Vehicles for transporting concrete from stationary mixers to the forms will conform to the applicable requirements of ASTM C 94. Plant-mixed concrete may be transported in a truck agitator, in a truck mixer operating at agitating speed, or in approved non-agitating equipment. Non-agitating equipment will have smooth, watertight, metal bodies equipped with gates to permit control of the discharge of the concrete; covers will be provided for protecting concrete in transit, as required. Concrete transported in non-agitating equipment will be discharged into the pavement forms or to the slipform paver within 45 minutes after introduction of the mixing water and cement to the aggregates at the mixer. The major problem in using ready-mixed concrete in pavement construction is avoiding segregation in discharging and transferring the concrete from the transporting unit to the final position in the form or on the subgrade in front of the slipform paver. The use of ready–mixed concrete requires suitable transfer and spreading equipment capable of depositing and distributing the concrete in an unsegregated condition in the final position in the forms. When low-slump plant-mixed concrete is transported, trucks equipped with vibrators are often required to discharge the concrete and should be required unless it is satisfactorily demonstrated that the concrete can be discharged without delay.

16. Placing.

a. General. Concrete may be placed between fixed forms or using approved slipform paving equipment. Both methods produce satisfactory results, and when possible, the option should be left with the contractor as to the method to be used. With slipform equipment, the rate of placement can be significantly increased over the rate with fixed forms. In addition, the material for forms and the labor for setting forms are eliminated. As a result, the cost for large jobs will be less for slipform placement than for placement with fixed forms. However, on small jobs or larger jobs with special requirements, the use of fixed forms may be necessary or may be more economical than the use of slipform equipment. No guidelines can be given as to what size job will permit the economic use of slipform pavers.

b. Placing time. Concrete will be placed before obtaining its initial set and within 45 minutes after cement has been added to the batch. These provisions apply to all paving projects regardless of the type of mixing equipment used. The addition of water to the mixture in excess of that required by the mixture proportions to maintain slump during prolonged mixing will not be permitted.

c. Slipform paving. Approval of the slipform paving equipment for airfield pavement will be based on satisfactory performance in the field. Trial sections of sufficient length and located in low-volume aircraft traffic areas will be used to approve the paving equipment, considering both slipform and another for the fill-in operation when scheduled by the contractor. Furthermore, approval shall be based on the ability of the machine to consolidate the concrete and form the pavement to the desired cross sections. Plan grade and surface smoothness tolerances must be met. Particular attention should be paid to the ability of the machine to form the required edge without excessive slumping or tearing during slipform operations and to form a suitable longitudinal construction joint during fill-in operations. The machine shall not damage the surface or edge of the previously placed slab during fill-in operations. The suggested length of the trial section is 1,000 to 2,000 feet. Slipform pavers with a full-width auger are recommended. Traveling blades have been less satisfactory. If the slipformed pavement is 10 inches or greater in thickness, some of the lighter slipform pavers may have problems properly handling the low-slump concrete.

d. Spreading. Hand spreading of concrete will be permitted only when necessitated by odd widths or shapes of slabs, or in emergencies such as equipment breakdown.

e. Vibration. Vibration requirements are influenced by many factors, such as the type and size of aggregate, mixture proportions, air entrainment, slump, workability of mixture, and pavement thickness. The specified maximum spacing for vibrator units and the specified vibrating procedures are based on field experience with the vibration of pavements 12 inches or more in thickness. There has been only limited use of internal vibration for thinner slabs. If necessary for proper consolidation of the concrete, a closer spacing of vibrator units will be required. Particular attention should be paid to vibrators along the edge of the paving lane to ensure that the edge is properly consolidated. General experience has been that it is more satisfactory to use vibrators at a closer spacing and for shorter periods of vibration than to attempt to consolidate the concrete by prolonged vibration at a wider spacing. The duration of the vibration will be limited by the time necessary to produce a satisfactory consolidation of the concrete, and over-vibration will not be permitted. Vibrators must not be permitted to touch forms, dowels, tie bars, or other embedded items.

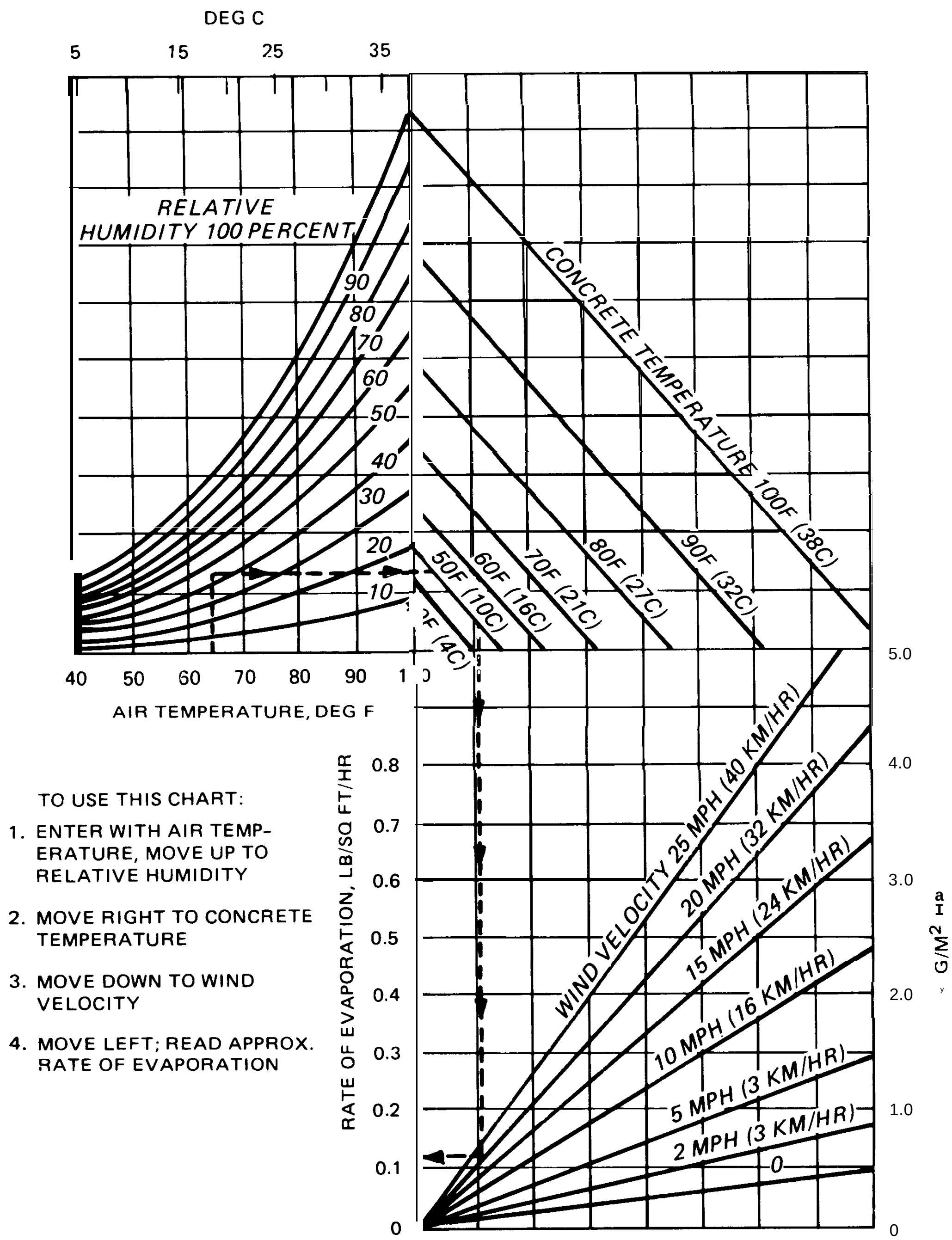
f. Surface vibrators. Surface vibrators will not be permitted because past experience with them has been generally unsatisfactory. Surface vibration tends to bring excess fine material and water to the surface, which in many instances contributes to surface deterioration and scaling. Surface-vibrator pans also tend to ride on high places in the concrete surface and thus cause non-uniform consolidation of the concrete.

g. Steel reinforcement. Project drawings will show typical details of all slab reinforcement and will indicate the pavements requiring reinforcement and the location and amount of steel required in the slabs. This information will supplement the specification requirements for reinforcement, and all requirements will be carefully checked to insure no discrepancies between drawings and specification requirements.

h. Placing during cold weather. Pavement concrete should not be placed when the air temperature is below 40 degrees F. If unusual job conditions require construction at these low temperatures, special provisions for placement and protection of the concrete will be needed. For additional information on winter concreting, refer to ACI 306R. The necessary covers and other means of protecting the concrete during cold weather should be available on the job before starting concrete placement. Calcium chloride as an admixture may be either required or approved to accelerate the setting time of concrete placed during cold weather. No changes will be made in the requirements for temperature of the concrete when placing or for protection of the concrete against freezing when calcium chloride or any other accelerator is used.

i. Placing during hot weather. During hot weather special precautions are necessary to prevent the formation of plastic-shrinkage cracks which result from an excessive loss of moisture from the concrete before curing is begun. The concrete needs to be placed at the coolest temperature practicable, and in no case should the temperature of the concrete as placed exceed 90 degrees F. Mixing and placing of concrete will be controlled to keep moisture loss at a minimum. Aggregates will be moist when added to the mixer, and the subgrade dampened so it will not absorb water from the concrete. The temperature of the concrete may be reduced by using cement with a lower temperature by sprinkling the stockpiles of aggregate to produce cooling by evaporation, by pre-cooking mixing water and by avoiding delays in mixing and placing concrete. The concrete needs to be placed and finished as rapidly as practicable, and the curing started without delay. If the application of the curing medium should for any reason lag placement for a time sufficient to permit surface drying, the surface should be kept damp with a fog spray, and placement should be discontinued until corrective action can be taken. The fog spray equipment will be capable of applying a very fine mist to the concrete to replace moisture lost by evaporation. In windy areas, screens may be needed to protect the concrete from rapid evaporation caused by wind. Steps shall be taken to avoid an evaporation rate in excess of 0.2 pound per square foot per hour as shown in figure 1. This is adequate for most conditions, but there are reports of plastic-shrinkage cracking occurring under adverse conditions when the indicated evaporation rate was as low as 0.15 pound per square foot per hour. Additional information is available in ACI 305R.

Figure 1. Prediction of concrete rate of evaporation



(From "Curing of Concrete," Concrete Information Sheet, 1966, with permission of the Portland Cement Association, Skokie, IL.)

j. Placing of small areas. For vehicular parking and paving projects of 1,600 cubic yards or less, machine spreading, finishing, and floating will not be required if the benefits derived from the use of the equipment are not commensurate with the cost of using the machines. In this case, hand spreading, finishing, and floating will be specified.

k. Overlay pavement construction.

(l.) General. Where overlay pavement construction is required, contract specifications will contain special provisions for preparation and treatment of the existing surface before placing concrete in the overlay pavement. Criteria herein pertain to construction of rigid overlays on existing rigid pavement. Construction of rigid overlays on existing flexible pavement or on existing rigid pavement with a bond breaking course is treated as new construction. Construction of thin bonded overlays is discussed in appendix B.

(2.) Bond between layers of pavement. Overlay pavements generally are designed on the assumption that a partial bond will develop between the two concrete layers. Concrete surfaces to receive partially bonded overlays will be thoroughly cleaned of dirt and other foreign material, loose or spalled concrete, extruding joint seal, bituminous patches, and material that would break the bond between the concrete layers. Different areas of pavement will require different treatment. The condition of the existing pavement will determine the cleanup measures necessary. Normally, sandblasting or surface-abrading equipment will be required to remove material adhering to the surface, and hand scaling of loose or spalled material will be required. No special treatment such as an acid wash of the prepared surface or the use of a grout bonding course will be required for partially bonded overlays. In areas where oil or grease is present on the surface, scrubbing with a detergent and a wire brush may be required. Cleaning of surfaces to receive the overlay with rotary grinding equipment will be permitted, but the surface must be swept clean prior to placing the concrete overlay.

(3.) Control of cracking in overlay pavements. Considerable difficulty has been experienced with uncontrolled cracking of overlay pavements at contraction joints. This cracking is likely to occur during hot weather when the temperature of the existing pavement is appreciably higher than that of the concrete being placed in the overlay. Contraction due to cooling of the base pavement results in movement at the existing joint, which may start a crack in the bottom of the overlay as the concrete hardens. This cracking may occur when the concrete is too green to saw. Often the crack is not visible at the surface of the pavement when the sawing is done. To prevent such cracking, it may be necessary to use inserts in the plastic concrete to form contraction joints.

1. Control of cracking in pavements placed on lean concrete and cement-stabilized bases. Occasional problems have developed when relatively thin concrete pavement has been placed directly on lean concrete bases or stabilized bases with high cement contents. Uncontrolled contraction cracks in the base material have on occasion reflected through the new pavement. If a thin pavement less than 9 inches thick is to be placed directly on a cement-stabilized or lean concrete base, it may be desirable to either place a bond-breaking material between the pavement and base or to saw cut contraction joints in the base to match those in the pavement surface. If a bond breaker is used between the pavement surface and the base, the design engineer must be aware of the lack of bond since this can affect the required design thickness of pavement. If contraction joints are to be sawed in the base to control cracking, it must be done at an early age just as discussed in paragraph 22d for concrete pavements.

m. Appendix D describes the methods and procedures for the construction of roller compacted concrete pavements.

17. Field test specimens.

a. General. Field tests other than those called for by contractor quality control will be conducted by the Government to determine the slump and air content of freshly mixed concrete, and specimens will be molded to test for flexural strength of hardened concrete. All tests will be performed under the supervision of the contracting officer. However, since the contractor will be required to furnish concrete samples, labor, and facilities for molding and curing test specimens, specifications must indicate the extent of testing required. Equipment for making air-content and slump tests will be furnished by the contracting officer when the Government is responsible for testing and by the contractor when the contractor is responsible for testing. Beam molds will be made of steel and will be rigid and watertight. Beam molds will be supplied by the contracting officer except when the contractor is responsible for testing. When molds are required to be furnished by the contractor, details necessary to assure that the molds furnished are satisfactory will be included in the contract specifications.

b. Specimens for strength tests. Test specimens for determining conformance with specified strength requirements will be moist-cured under field laboratory conditions. The size and number of curing tanks will depend on the number of specimens taken and the “ages at which the tests are made. For airfield paving projects, flexural-strength tests will be conducted at the ages of 7, 14, and 90 days. For other pavements, designed on the basis of 28-day flexural strengths, the test ages will be 7, 14, and 28 days. Where 90-day flexural strength tests are required, provision will be made for curing and testing of specimens after the project is completed.

c. Specimens for determining time of opening pavement to construction traffic. Ordinarily, no field-cured specimens will be required. However, for cold-weather construction when field-strength data may be necessary to permit the opening of the pavement or portions thereof to construction traffic prior to 14 days, test groups of at least three beams shall be taken, as required, from concrete placed in designated areas. The beams of each test group shall be made from a single batch of concrete and shall be cured in accordance with ASTM C 31.

18. Finishing.

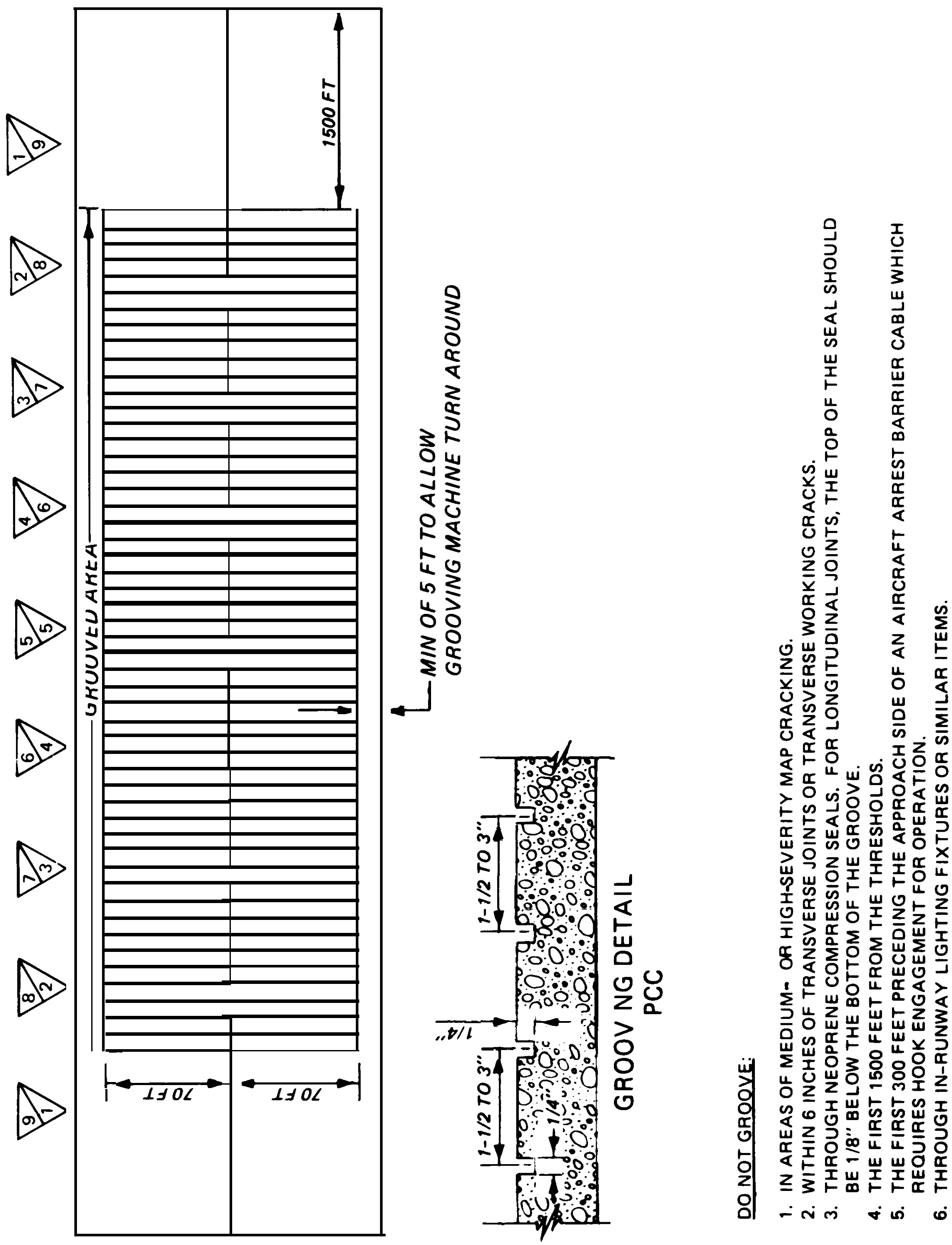
a. Equipment and methods. Types of finishing equipment other than conventional equipment may be used on a trial basis when capable of finishing concrete of the quality and consistency required. Equipment that fails under trial to perform in a satisfactory manner will be rejected and removed from the work area.

b. Surface finishing and testing. Finishing operations are designed to obtain a dense, smooth surface true to the required grade. Since the surface receives the greatest exposure to weathering and traffic, every precaution will be taken to obtain a high-quality concrete at the surface. The finishing operations will be kept to the minimum necessary to obtain the required surface finish. Excessive surface manipulation will not be permitted because it tends to bring a surplus of mortar, water, and undesirable soft materials to the surface which contributes to scaling and surface deterioration. Finishing should leave the surface at the proper grade. If the mechanical finishing operations are properly controlled, very little hand finishing will be necessary. Short floats will be used only as necessary to correct local surface uneveness. Straightedges of the required length will be used primarily to smooth and check the surface. To avoid later costly corrections of hardened pavement which fails to conform with specified surface tolerances, the surface will be thoroughly checked during the mechanical floating, and necessary corrections will be made.

c. Hand finishing and edging. Machine finishing is required, and hand finishing is only permitted for odd widths and shapes of slabs, areas adjacent to headers, and areas around outlets in the pavements. Hand-finished areas will have the same quality and the same surface characteristics as those areas finished by machine. Hand finishing along the edges of slipformed lanes to correct edge slumping or to repair areas damaged by tearing or sloughing shall be held to a minimum. The only manipulation permitted along the edges of slipformed lanes shall not disturb the edge or use the edging tools to correct deficiencies in the edge.

d. Surface texture. The final surface texture of the pavement will be provided by means of a burlap drag, broom, artificial turf, wire comb, or grooving. Dragging the surface of the concrete in the direction of concrete placement with moist burlap leaves a fine sandy surface that is adequate for low-speed traffic. At least 2 feet of burlap must be in contact with the concrete, and the burlap should be cleaned as necessary. An improved skid-resistant surface can be produced with a broom consisting of multiple rows of stiff bristles capable of producing serrations 1/16 to1/8 of an inch deep. The brooms will have to be cleaned frequently during texturing. Artificial turf has been used successfully for texturing concrete. This is applied in the same manner as the burlap with at least 2 feet of the artificial turf in contact with the concrete. One artificial turf that has provided a satisfactory texture consisted of 7,200 polyethylene turf blades approximately 0.85 inch long per square foot. The wire comb provides the most skid-resistant texture of the finishing techniques described so far. However, it is also the most difficult to use and adjustments to the concrete proportions may have to be made to find a mixture that can be wire-combed without objectionable surface tearing. The wire comb should consist of flexible spring steel lines spaced not less than 1/2 inch nor more than 1 inch apart. Closer spacing causes problems with raveling, and wider spacing results in objectionable road noise. The serrations left by the steel lines should be about 1/8 to 1/4 inch deep and 1/16 to 1/8 inch wide. A single pass of burlap or artificial turf can be made before the wire comb if desired. Because of problems with skid resistance for aircraft traveling at high speed, the Air Force requires that new runways have a burlap drag finish with saw-cut grooves. Figure 2 shows the grooving requirements for an Air Force runway. If the constructed pavement surface texture is inadequate due to poor texturing techniques, rainfall on insufficiently hardened concrete, or other causes, grooving or grinding will restore the skid resistance of the surface.

Figure 2. Air Force runway grooving requirements.



19. Curing.

a. Control of cracking. Plastic shrinkage (craze) cracking is caused by a combination of (1) high ambient air temperature, (2) high concrete temperature, (3) low relative humidity, and (4) wind velocity. These conditions need to be controlled when placing and protecting young concrete. It is essential that concrete be protected against the loss of moisture and rapid temperature change for the specified period of protection. All equipment, material, and supplies for adequate curing and protection of the concrete must be on hand and ready to install before actual concrete placement begins. In general, curing will be accomplished by using a pigmented membrane-curing compound. However, other methods may be specified if indicated by local conditions.

b. Membrane curing. The curing compound will be applied by means of a power-driven machine straddling the newly paved lane and operated so that the spray will cover the pavement surface completely and uniformly. Spray nozzles must be surrounded by a hood to prevent wind from blowing the curing–compound spray. The rate of advance and spacing of nozzles of the spraying machine will be controlled so that a two-coat overlapping coverage will be provided. Hand-operated pressure sprayers will be permitted only on indicated odd widths and shapes of slabs and on concrete surfaces exposed by removal of forms. The curing compound must form a continuous void-free membrane and be maintained in this condition throughout the curing period. Unsatisfactory or damaged areas will be resprayed. Any damage to the membrane during the sawing operation will be corrected by respraying. When forms are removed, the exposed faces of the concrete will be sprayed with curing compound.

c. Substituting curing provisions. Where it has been established from past experience in an area that membrane curing alone does not adequately protect pavement from shrinkage cracking, a combination of moist curing and membrane curing may be specified.

d. Selection of curing material for pavements to be painted. In selecting curing material for pavement surfaces to be painted, consideration will be given to the necessity of sandblasting to remove coatings and deposits that interfere with the bonding of paint. Curing compounds of the low-melting-point wax-base type tend to penetrate concrete and should not be used in the areas to be painted.

20. Grade and surface-smoothness requirements.

a. Heliport and airfield pavements. The specified grade and smoothness requirements applicable to airfield and heliport pavements are shown in table 8. The finished surfaces of airfield and heliport pavements shall have no abrupt change of 1/8 inch or more and shall not deviate from the testing edge of an approved 12-foot straightedge more than the tolerances shown in table 8.

Table 8. Surface smoothness - airfield and heliport pavements

Item No.	*Pavement Category*	*Direction of Testing*	*Tolerances inches*
1	Runways and taxiways	Longitudinal	1/8
		Transverse	1/4
2	Calibration hardstands and compass swinging bases	Longitudinal	1/8
		Transverse	1/8
3	Other airfield and heliport areas	Longitudinal	1/4
		Transverse	1/4

b. Road, street, and open-storage concrete pavements. Pavements shall be smooth and true to grade and cross section. When tested with a 10-foot straightedge on lines 5 feet apart parallel with the centerline of the pavement, the surface shall not vary more than 1/8 inch from the testing edge of the straightedge.

c. Requirements for other vehicular pavements. Parking area, motor-pool and motor-storage area, repair- yard, and open-storage area pavements shall be smooth and true to grade and cross section. When tested with a 10-foot straightedge on lines 5 feet apart parallel with and at right angles to the center-line of the paved area, the surface shall vary not more than 1/4 inch from the testing edge of the straightedge.

d. Slipform paving edge slump. Edge slump is the downward movement of the plastic concrete that occurs when the sliding form passes. Excessive slump is indicative of improper concrete mixture proportioning. If the concrete mixture cannot be redesigned to overcome the edge slump problem, fixed form paving should be used. When slipform paving is used, 85 percent of the pavement will not have an edge slump exceeding 1/4, inch, and 100 percent of the pavement will not have an edge slump exceeding 3/8 of an inch. The area of pavement affected by this slump will be limited to the outer 18 inches adjacent to the slab edge.

21. Tolerances in pavement thickness. Pavement will be constructed to thicknesses indicated, and pavement thickness will be checked by measurements of cores drilled from the pavement as required by the contracting officer. Cores generally will be taken at intervals of 2,000 feet or a fraction thereof from each pavement lane of paved area where the lanes are 1,000 feet or more in length and from every other lane of the paved area where the lanes are less than 1,000 feet in length. Additional core drilling to determine the extent of a pavement area deficient in thickness will be included in the contract specification. Cores for checking pavement thickness will have a diameter of no less than 4 inches. When cores are used for compressive-strength or splitting tensile-strength tests (ASTM C 496) as well as for checking pavement thickness, a 6-inch-diameter core will be drilled. Drilling and measurements of cores for checking pavement thickness will be done by the Government. Costs of drilling and testing additional cores requested by the contractor will be borne by the contractor. When the contractor is required to cut cores to check pavement thickness, additional core drilling requirements will be included in the contract specification. All core measurements will be made by the contracting officer, and the cores will become Government property.

22. Repairs of defective pavement slabs. Grooving and sealing or epoxy sealing of random cracks, filling of non-working contraction joints, repairing of spans along joints and cracks, and removing and replacing of broken slabs that occur in non-reinforced concrete pavements during construction will be accomplished according to the requirements in the contract specification. Additional and supplemental information is provided in TM 5-822-9. Areas not meeting smoothness and grade requirements will be repaired or replaced. High areas can be reduced by rubbing the freshly finished concrete with carborundum brick and water within 36 hours of the concrete placement or by grinding the surface after it is 36 hours old. Generally, grinding should not exceed 1/4 inch in depth. The final surface of the repaired area must retain the required skid resistance of the surrounding pavement.

23. Joints.

a. General. Joints are constructed in concrete pavement to permit contraction and expansion of a pavement without irregular cracking and as a construction expedient to separate the paved area into strips necessary for handling and placing of concrete. There are three general types of joints: construction, expansion, and contraction.

b. Construction joints.

(l.) Longitudinal construction joints. These joints formed between paving lanes at the spacing indicated will be either thickened edge, keyed, keyed and tied, or doweled. The dimensions of the keyed joint are critical. It is essential that both key dimensions and the location of the key in the joint conform with details on drawings. Key dimensions are based on pavement thickness with each thickness requiring a different key size. When stationary forms are used, metal molds for forming the keyway will be securely fastened to the concrete forms so that molds will not be displaced by paving operations. When slipform pavers are used to form keyed joints, the keyway shall be formed by means of pre-formed metal keyway liners, which are inserted during paving. The metal liners may be shaped as they are fed through the paver from continuous strips, or they may be pre-formed sections bolted together before insertion through the paver. It is recommended that the metal liners be left in place. When slipform pavers are used to form keyed and tied joints, bent tie bars shall be inserted into the plastic unconsolidated concrete through a metal keyway liner as described above. The tie bars shall be straightened after the concrete has hardened. The bent bars should be inspected to insure that the radius of curvature at the bend is equal to or greater than the specified minimum radius of curvature for the grade of steel being used. When stationary forms are used, all dowels will be placed by the bonded-in-place method. Either one-piece dowels or split dowels of the threaded type will be used. Dowels will be held accurately and securely in place by fastening to the forms. When slipform pavers are used, dowels shall be placed by bonding the dowels into holes drilled into the hardened concrete with rotary core-type drills that can be maintained in a position parallel to the surface of the pavement and perpendicular to the face of the edge of the slab in a longitudinal direction. Some low impact energy hydraulic and electro-pneumatic drills have been used to successfully drill dowel holes without spalling the concrete. These and similar types of drills can be allowed if the contractor is able to satisfactorily drill the specified holes without undue spalling around the hole. The diameter of the hole should be larger than the diameter of the dowel bar but should not be more than 1/8 inch larger than the diameter of the dowel bar. The contractor will be required to demonstrate to the contracting officer that the dowels can be securely bonded and proper alinement can be attained. Continuous inspection will be required thereafter to insure that the dowels are securely bonded and that they are alined properly both horizontally and vertically. The method used for inserting the epoxy-resin grout into the hole shall place sufficient grout to completely anchor the dowel.

(2.) Transverse construction joints. When concrete placement is stopped or interrupted for 30 minutes or longer, these joints are installed across the pavement lane. Insofar as practicable, these joints will be installed at the location of a planned joint.

c. Expansion joints. When expansion joints are required within a pavement, joint assemblies supporting both joint filler and dowels will be installed before placing concrete. Accurate location and alinement of joint filler and dowels are necessary for proper functioning of joints. Since checking of embedded items in joints installed within a paving lane is extremely difficult, it is essential that assemblies used for supporting embedded items be rigidly constructed and capable of resisting all movement and distortion during paving operations. Great care and continuous inspection are required during placing and finishing of concrete near joints to avoid displacement of joint filler and dowels. Additional hand vibration will be required around the joint assemblies to insure adequate consolidation. The contractor is required to provide a template for checking the position of the dowels.

d. Contraction joints.

(l.) General. Contraction joints use a groove to form a weakened plane in the concrete, as the concrete undergoes shrinkage, a fracture forms through the concrete below the groove. Load transfer is provided by aggregate interlock in the fracture plane below the joint groove or by an aggregate interlock and dowels. Where dowels are required across transverse contraction joints, suitable dowel-supporting assemblies will be used and care taken to assure proper alinement of dowels in the completed pavement. Requirements for dowel supports have been discussed in c above. Where tie bars are required in longitudinal contraction joints, suitable supporting devices will be provided for holding tie bars in place during paving operations, or the bars may be installed in front of the paver by insertion into the unconsolidated, freshly placed concrete. The device for inserting the bars shall be mounted on the paver and will automatically insert the bars to the specified depth and at the required spacing.

(2.) Joint types. Contraction joints may be constructed by sawing a groove in hardened concrete or installing a suitable insert in freshly placed concrete. Inserts will not be used on airfield pavements without the prior approval of AFESC. Sawing of joints eliminates manipulation of freshly placed concrete after placement and provides the best conditions for obtaining a smooth surface at the joint. However, sawing time is critical, and cracking will occur at the wrong place if the joints are not sawed at the proper time. The filler-type joint forms a weakened plane in the freshly placed concrete, which induces fracturing of concrete at the joint, permits continuous curing of pavement, and provides protection for the joint until removed or depressed in preparation for the sealing of joints. Although sawed joints have been used successfully on many projects, excessive cracking has occurred in some instances. This is usually due to delayed sawing. When sawing cannot be accomplished without undue uncontrolled cracking due to unusual conditions, provisions shall be made for using inserts. Filler-type joints maybe approved for longitudinal contraction joints when it is demonstrated that these joints can be properly installed with vibratory equipment. The filler must be maintained in a vertical position and in proper alinement in the finished pavement.

(3.) Installation of insert-type joints. Insert-type joints will be installed immediately after all machine finishing operations are completed. The macine for installing the insert shall have a vibratory bar that cuts a groove in concrete and simultaneously installed an insert in required locations. The intensity of vibration on the bar will be variable as necessary to form the groove in the freshly mixed concrete and to consolidate the concrete around the insert after it is in place. Inserts must be the proper depth for the concrete being placed because the load transfer between the slabs depends on the interlock of aggregate below the formed portion of the joint and material that is not deep enough will not produce cracking at the proper location. Insert material must be placed flush with the surface to not more than 1/8 inch below the surface. The surface of the pavement will be finished with a vibratory float; hand floating will not be permitted. When finishing concrete after installation of the insert, an excessive amount of fine material must not be worked to the surface and adjacent to the insert. Excessive fines will cause scaling of the surface and spalling of the joint.

(4.) Sawing of transverse contraction joints.

(a.) Method. Transverse and longitudinal contraction joints shall be constructed to conform with details and dimensions indicated. Saw cuts shall be made to the depth indicated to insure that cracking occurs as planned. Joints shall be constructed by sawing a groove in the hardened concrete with a power-driven saw.

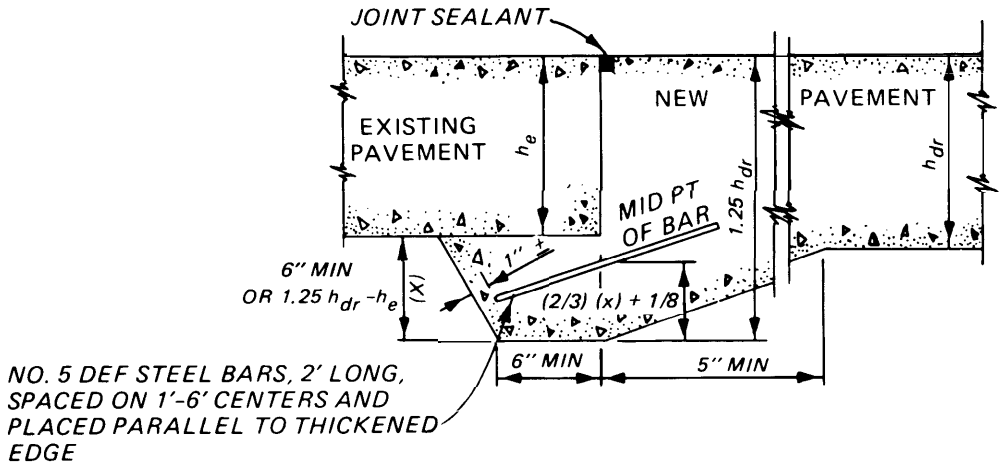
(b.) Time. No definite time for sawing joints can be specified because of the many factors that may influence the rate of hardening of concrete such as air and concrete temperatures during placement, ambient temperatures, weather conditions, curing and protection, cement content, and mix characteristics. The basic rule for satisfactory sawing is: "Be prepared to saw as soon as the concrete is ready for sawing regardless of the time of day or night. " During warm weather, when most pavements are constructed, the concrete usually will be ready for sawing about 6 to 12 hours after placing. Since concrete is placed mainly during daylight hours, a large portion of sawing will have to be done at night, and adequate lighting must be provided for this purpose. Although a clean, sharp cut is desirable, a small amount of raveling at the top of the saw cut is not objectionable when early sawing is necessary to avoid uncontrolled cracking. Sawing too early, however, will be guarded against to prevent excessive washing and undercutting of concrete in the joint. The proper time for sawing the joints will be determined for prevailing conditions on the job during each concrete placement. Since conditions may change from day to day, it is essential that the saw operator be experienced in sawing pavement joints.

(c.) Sawing sequence. Transverse joints will be sawed consecutively in the same sequence as the concrete is placed in the lane. Sawing of alternate joints in the pavement is undesirable because concrete tends to tear ahead of the saw cut when intermediate joints are sawed. This procedure also reduces the uniformity of fracturing of joints, which may result in excessive opening at some joints. Before sawing each joint, the concrete will be examined closely for cracks, and the joints will not be sawed if a crack has occurred near the joint. Sawing will be discontinued in any joint where a crack develops ahead of the saw cut.

(d.) Cuts. All areas of curing compound damaged by the sawing operation will be resprayed. A cord will be placed in the saw cut to retard evaporation of moisture.

e. Special joints. The special joint shown in figure 3 for placing new concrete pavement adjacent to old concrete pavement requires special care. The concrete placed under the old pavement must be thoroughly vibrated and must not be placed too rapidly or air voids will form under the old pavement. Use of a water-reducing admixture to improve workability may be helpful. Proper construction of this joint requires special inspection of construction technique. An alternate method of providing a load-transferring joint when abutting old and new concrete pavements is to drill and grout dowel bars into the vertical face of the old pavement.

Figure 3. Special joint between new and existing pavements.



24. Pavement protection. All vehicular traffic shall be excluded from the pavements for at least 14 days. As a construction expedient, earlier use of pavement is permitted for operations of construction equipment only as necessary for paving intermediate lanes between newly paved lanes. Approval for use of the pavements for construction purposes prior to 14 days maybe omitted from contract specifications if unnecessary or undesirable for local conditions. Operation of construction equipment on the edge of previously constructed slabs will be permitted only when concrete is more than 72 hours old and has a flexural strength of at least 400 pounds per square inch. In all instances, approval for the use of pavement will be based on adequate provisions for keeping pavements clean and protecting pavements against damage.

25. Measurements. When appropriate, contract specifications may require that concrete be measured and paid for on a square-yard basis. Whether concrete is paid for on a square-yard or cubic-yard basis, the unit-price schedule for bidding purposes will be prepared to show separate estimated quantities for different pavement thicknesses that may be required.

APPENDIX A
REFERENCES

Government Publications.

Department of Defense

MIL-STD-621	Test Method for Pavement Subgrade, Subbase, and Base-Course Materials

Departments of the Army and the Air Force

TM 6-818-2/AFM 88-6, Chap. 4	Pavement Design for Seasonal Frost Conditions
TM 5-822-6/AFM 88-7, Chap. 1	Rigid Pavements for Roads, Streets, Walks, and Open-Storage Areas
TM 5-822-9	Repair of Rigid Pavements Using Epoxy-Resin Grouts, Mortars, and Concrete
TM 5-824-3/AFM 88-6, Chap. 3	Rigid Pavements for Airfields Other Than Army

Environmental Protection Agency

40 CFR, Part 249	Guideline for Federal Procurement of Cement and Concrete Containing Fly Ash **Federal Register,** Vol 48, No 20, January 28, 1983

Department of the Army, Corps of Engineers
US Army Engineer Waterways Experiment Station, Structures Laboratory
PO Box 631, Vicksburg, MS 39180-0631

CRD-C 55-86	Concrete Mixer Performance
CRD-C 104-80	Method of Calculation of the Fineness Modulus of Aggregate
CRD-C 119-53	Method of Test for Flat and Elongated Particles and Coarse Samples
CRD-C 120-55	Method of Test for Flat and Elongated Particles in Fine Aggregate
CRD-C 400-63	Requirements for Water for Use in Mixing or Curing Concrete

Nongovernment Publications.

American Concrete Institute (ACI)
Box 4754, Redford Station, Detroit, MI 48219

ACI 207.5R	Roller Compacted Concrete
ACI 211.1-81	Standard Practice for Selecting Proportions for Normal, Heavy-weight, and Mass Concrete
ACI 211.3-75 (Revised 1980)	Standard **Practice** for Selecting Proportions for No-Slump Concrete
ACI 212.lR	Admixtures for Concrete
ACI 212.2R	Guide for Use of Admixtures in Concrete
ACI 305R-77	Hot Weather Concreting
ACI 306R-78	Cold Weather Concreting

ACI 544.lR-82	State-of-the-Art Report on Fiber Reinforced Concrete
ACI 544.2R-78	Measurement of Properties of Fiber Reinforced Concrete
ACI 544.3R-84	Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

American Society for Testing and Materials (ASTM)
1916 Race Street, Philadelphia,PA 19103

A 775-82	Standard Specification for Epoxy-Coated Reinforcing Steel Bars
C31-69 (R 1980)	Making and Curing Concrete Test Specimens in the Field
C 33-82	Standard Specification for Concrete Aggregates
C 78-75	Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)
C 88-76	Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C 94-81	Ready-Mixed Concrete
C 128-79	Specific Gravity and Absorption of Fine Aggregate
C 131-81	Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 138-81	Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 143-78	Slump of Portland Cement Concrete
C 150-82	Standard Specification for Portland Cement
C 173-78	Air Content of Freshly Mixed Concrete by the Volumetric Method
C 192-81	Making and Curing Concrete Test Specimens in the Laboratory
C 227-81	Standard Test Method for Potential Alkali Reactivity of Cement - Aggregate Combination (Mortar Bar Method)
C 260-77	Air-Entraining Admixtures for Concrete
C 295-79	Petrographic Examination of Aggregates for Concrete
C 494-82	Chemical Admixtures for Concrete
C 496-79	Splitting Tensile Strength of Cylindrical Concrete Specimens
C 535-81	Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 586-69 (R 1981)	Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)
C 595-83	Standard Specification for Blended Hydraulic Cements
C 618-83	Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 666-80	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C 682-75 (R 1980)	Standard Recommended Practice for Evaluation of Frost Resistance of Aggregates in Air-Entrained Concrete by Critical Dilation Procedures
C 685-83	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C 845-80	Standard Specification for Expansive Hydraulic Cement
D 558-82	Moisture-Density Relations of Soil-Cement Mixtures
D 2922	Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)

American Welding Society
2501 NW 7th Street, Miami, FL 33125

AWS D1.4-79	Structural Welding Code–Reinforcing Steel

APPENDIX B

THIN BONDED RIGID OVERLAYS FOR RIGID PAVEMENTS

B-1. Application. This appendix contains additional information and instructions for preparing contract specifications for thin bonded overlays for rigid pavements. A thin bonded overlay is generally for correction of surface problems, such as scaling or skid resistance, rather than structural upgrading of the pavement.

B-2. General. Although the volume of concrete required for a thin bonded overlay is comparatively small, this surface layer is the portion exposed to traffic and weathering and must be of the highest possible quality. A complete bond must be obtained between the rigid pavement and the overlay. The thickness of the overlay will be not less than 2 inches but not more than 5 inches. The required thickness of a thin bonded overlay for strengthening roads and streets will be determined in accordance with TM 5-822-6/AFM 88-7, chapter 1.*

B-3. Correction of defects in existing pavement. A condition survey should be made and the cause of cracking of slabs determined in order to develop an appropriate repair prior to overlaying. The existing pavement must be in good structural condition, and any broken or otherwise defective slabs will be repaired or replaced before the overlay is applied. The designer of the overlay should realize that cracks in the pavement being overlayed will likely reflect through the overlay pavement.

B-4. Flexural strength. In general, flexural strength for the thin bonded overlay should be about the same as that obtained for the original pavement construction at the corresponding age.

B-5. Aggregate sizes. The nominal maximum size aggregate used will not exceed one-fourth of the overlay thickness.

B-6. Mixture proportioning. It is desirable for the thin bonded overlay to be as similar as possible in strength, modulus value, and thermal characteristics. It should also be remembered that the surface of the concrete is exposed to traffic and weather and should be of high quality. Beyond this, the same guidance given for normal portland cement concrete applies.

B-7. Preparing the existing pavements. After any necessary repairs and slab requirements, the existing pavement surface must be thoroughly cleaned of all deteriorated concrete, oil, grease, and dirt. In order to thoroughly clean the surface, it is recommended that rotary-type grinders be used to remove at least 1/4 inch of the existing concrete, and in areas where the concrete has deteriorated, the material should be removed to sound concrete. After grinding with rotary grinders, the surface should be sandblasted to remove debris left from grinding. Before the pavement is placed, the surface of the existing pavement should be cleaned by brooming and followed with compressed air. In areas where equipment turns, such as trucks hauling concrete, the existing pavement should be covered with sand or some other protective cover to prevent rubber from scrubbing off of tires onto the existing concrete and forming a bond breaker.

B-8. Placement of overlay. Either a neat cement slurry or cement and sand grout is satisfactory for bonding the overlay to the existing surface. These may be applied by pressure spraying or by brooming over the existing surface, but they should be applied to a dry surface and applied only 6 to 10 feet ahead of concrete placing. If the grout or slurry dries before concrete is placed, it should be removed and fresh material applied. The concrete should be placed, finished, textured, and cured using normal procedures. Joints in the overlay must coincide with the joints in the base pavement.

B-9. Payment. Most thin bonded overlays have been paid by the square yard of overlay placed.

*** References are listed in Appendix A.**

APPENDIX C

STEEL-FIBER-REINFORCED CONCRETE

C-1. Introduction. Over the past 10 years fiber-reinforced concrete has been used in numerous trial pavement applications. This composite material consists of a concrete matrix containing a random dispersion of small steel fibers. It exhibits increased tensile strength, roughness, and span resistance when compared to plain or conventionally reinforced concrete. Even after an initial tight crack forms, fibers bridge across the crack providing additional load-carrying capacity until the steel fibers fail or the bond between the fiber and cement paste fails. Steel-fiber-reinforced concrete designed in accordance with TM 5-824-3/AFM 88-6, chapter 3, will be appreciably thinner than conventional concrete pavements. For this reason, steel-fiber-reinforced pavements offer particular advantages where the thickness of an overlay or pavement must be kept to a minimum to maintain clearances, grades, and drainage.

C-2. **Description.** Table C-1 shows typical characteristics of steel-fiber-reinforced concrete pavements used at several airfields. Cement contents are typically much higher than conventional concrete and the aggregate volume is lower. Maximum nominal size aggregate for these mixtures has varied from 3/8 to 3/4 inch. Fly ash is often used as a partial substitute for Portland cement to improve workability and lower the-heat of hydration. Steel fiber contents have ranged from 80 to 220 lb/yd^3. The addition of steel fibers and low water-cement ratios produce a stiff mix, and water-reducing admixtures have often been found to be beneficial. Additional information can be found in ACI 544.lR, ACI 544.2R, and ACI 544.3R.

Table C-1. Selected characteristics of fiber-reinforced airfield pavements

Project	Date Con-structed	Cement/Fly Ash lb/yd^3	W/C[a] Ratio	Type Cement	Steel Fiber lb/yd^3	Fiber Reinforcement Type	Estimated[b] Aggregate Vol, %	Type Pavement	Pavement Thickness (in.)
Norfolk apron	.977 to 1982	600/200	--	I	160	Straight	--	Unbonded overlay	5
			--		85	Deformed			
Denver apron	1981	575/210	0.37	II	83	Deformed	62	unbonded overlay	7
Las Vegas apron	1976	600 250	0.42	V	160	Straight	56	Unbonded overlay	6
									8
	1979	650 252	0.38	II	85	Deformed	60		
Fallon apron	1980	788/0	0.43	II	82	Deformed	60	Unbonded overlay	5
	1981	766/0			81	Deformed	58		
Reno apron	1975	658/216	0.36	--	200	Straight	51	Fully bonded overlay	4
Salt Lake City apron	1980	583/203	0.42	II	83	Straight	56	Unbonded overlay	7-8
	1981	620/215	0.38		85	Straight	57		
Tampa taxiway	1972	517/225	0.37	I	225	Straight	--	Partially bonded overlay	4-6

[a]Calculated as weight of water + (weight of cement + weight of fly ash).
[b]Calculated as aggregate volume = weight of aggregate per cubic yard of concrete + (specific gravity of aggregate × unit weight of water × 27); aggregate specific gravity is assumed to be 2.65.

C-3. Fibers. Fiber-reinforced concrete has been made with fibers of many different types of material. However, only steel fibers have been used in pavement applications. These steel fibers are typically either cut from wire or sheared from sheets. Typical fibers are 0.01 to 0.02 inch in diameter and 1 to 2 inches long. The fibers may be straight or the ends maybe deformed. Fibers with deformed ends are said to provide better anchorage. Ultimate tensile strength of available fibers varies from 50,000 to 300,000 psi. The maximum fiber aspect ratio (length divided by diameter) should usually not be over 100 to avoid mixing problems. Also, volume contents of over 2 percent are often difficult to mix.

C-4. Fiber clumps. If fiber clumps occur in the mix, it is usually due to fibers being added too fast at some point in the mixing operation so that they are already clumped by the time they get into the mixture. Usually if the fibers get into the mixture without clumps, no clumps will form. Fibers should not be allowed to pile up anywhere in the operation, and the mixer should disperse the fibers into the mixture as rapidly as they are added. Other potential causes of fiber clumping are mixtures with too many fibers, using fibers with too large of an aspect ratio, adding fibers too fast to a harsh mix, adding fibers first to the mixer, using equipment with worn out mixing blades, overmixing, and using a mixture with too much coarse aggregate. A common method of adding fibers to a mix is to add the fibers through a shaker or hopper onto the fine aggregate on a conveyor belt. Some fibers are also collated in bundles of about 30 fibers with a water-soluble glue. These may be added to a mix as the last step in the mixing process.

C-5. Testing. Fiber-reinforced concrete requires some modification in testing. The flexural strength should include the results of loading past the formation of the initial crack. The conventional slump test is not an effective evaluation of workability for fiber-reinforced concrete. Either Vebe or inverted cone tests are superior to the conventional slump tests. ACI 544.2R should be consulted whenever tests for fiber-reinforced concrete are planned.

C-6. Construction. Before vibration, steel-fiber-reinforced concrete mixtures appear harsh and unworkable, and a common mistake is to add water in a vain attempt to obtain workability. Conventional form riding and slipform paving equipment is adequate to place and level fiber-reinforced concrete. Use of a jitterbug, rollerbug, or a vibrating screed will help embed fibers into the concrete, but there is danger of over-using these techniques and floating paste to the surface with very adverse effects on durability. At least one agency has successfully specified a maximum of 18 exposed fibers per square yard of pavement, and required the contractor to demonstrate the ability to meet this in trial sections. A broom finish is generally used for texturing. A burlap drag should be avoided to prevent fibers from catching in the burlap and tearing the surface. Contraction joints should be saw cut 1/3 to 1/2 the depth of the slab to assure proper fracturing of the joint. Recommended joint spacings for fiber-reinforced concrete are shown in Table C-2. Other than these points, normal pavement construction and curing techniques are adequate for steel-fiber-reinforced concrete.

Table C-2. Interim suggested maximum joint spacing for steel-fiber-reinforced concrete

Slab Thickness in.	Suggested Maximum Joint Spacing ft
4-6	12.5
6-9	15.0
9-12	
>12	25.0

Sawed contraction joints must be cut deeper to insure opening of all joints. The saw cut must penetrate one-third to one-half of the slab thickness. Otherwise, some of the contraction joints will not open. Very large separations will then develop at those joints that do open, causing joint seal and load-transfer problems.

APPENDIX D

ROLLER-COMPACTED CONCRETE PAVEMENTS; DESIGN AND CONSTRUCTION

D-1. Application. Procedures and criteria described in this appendix are applicable to the design and construction of roller-compacted concrete (RCC) pavement (RCCP).

D-2. General. Roller-compacted concrete pavement employs a concrete paving technology that involves laydown and compaction of a zero-slump concrete mixture using equipment similar to that used in placement and compaction of asphaltic concrete pavement. By using these construction techniques, the potential exists to save one-third or more of the cost of conventional concrete pavement. Although the concept and technology behind RCCP is relatively new, RCCP has already proven itself cost-effective in several projects including log-sorting yards, port facilities, heavy equipment parking areas, tank trails, and haul roads.

D-3. Subgrade and base course preparation. The subgrade and base course should conform to the requirements outlined in TM 5-822-6/AFM 88-7, chapter 3, or TM 5-824-3/AFM 88-6, chapter 3. The freeze-thaw durability of RCCP is not fully understood yet, but is presently being studied at the US Army Engineer Waterways Experiment Station (WES) and the Cold Regions Research Engineering Laboratory (CRREL). Good performance has been observed in the field; however, marginal performance has been observed in the laboratory. For this reason, in areas where the pavement or base course might be subjected to seasonal frost action, particular attention should be given to providing a base course that will adequately drain any water that infiltrates through the pavement or subgrade. The base course should provide sufficient support to permit full consolidation of the RCCP through its entire thickness upon compaction.

D-4. Selection of materials.

a. General. One of the most important factors in determining the quality and economy of concrete is the selection of a suitable aggregate source. This is as true for RCC as for conventional concrete. Aggregate for RCC should be evaluated for quality and grading, and should comply with the provisions outlined in paragraph 4, with the exceptions noted in the following discussion.

b. Coarse aggregate. The coarse aggregate may consist of crushed or uncrushed gravel, recycled concrete, crushed stone, or a combination thereof. The quality of coarse aggregate used by the Corps of Engineers to date in RCCP has generally complied with ASTM C 33, although satisfactory RCC maybe possible with coarse aggregate not meeting these requirements. Local state highway department coarse aggregate grading limits, for example, should generally be acceptable. A primary consideration should be that, regardless of the grading limits imposed, the grading of the aggregate delivered to the project site be relatively consistent throughout the production of RCC. This is an important factor in maintaining control of the workability of the concrete mixture. The nominal maximum aggregate size normally should not exceed 3/4 inch, particularly if pavement surface texture is a consideration. When aggregate larger than 3/4 inch is used, segregation and resulting rock pockets are likely to occur.

c. Fine aggregate. The fine aggregate may consist of natural sand, manufactured sand, or a combination of the two, and should be composed of hard, durable particles. The fine aggregate quality should generally be based on the limits given in ASTM C 33 except that consideration should be given to relaxing the maximum 5.0 percent limit of material finer than the No. 200 sieve. The amount of material passing the No. 200 sieve has been increased in Canada to 8 percent of the total weight of aggregates with acceptable results. Sands with higher quantities of nonplastic silt particles maybe beneficial as mineral filler and may allow some reduction in the amount of cement required. However, mixtures made with fine aggregates having an excessive amount of clay may have a high water demand with attendant shrinkage, cracking, and reduced strength. Determination of the specific gravity and absorption of these sands with high quantities of fines should be made according to Note 3 in ASTM C 128.

d. Other aggregates. Recent experience with RCC has shown that aggregate produced for uses other than portland cement concrete may also be successfully used as aggregate for RCC. Material produced for asphalt paving and base courses have both been used effectively as RCC aggregate. These materials typically have a higher percentage of fines passing the No. 200 sieve than conventional concrete aggregates and, as a result, may produce a "tighter" pavement surface texture. Because these aggregates range in size from 3/4 inch to the No. 200 sieve, control of the grading may be more difficult due to segregation. Therefore, careful attention must be directed toward stockpile formation and subsequent handling of a single size group aggregate.

e. Cement. Any available portland cement except for Type III portland cement, any blended hydraulic cement, or combination of portland cement with pozzolan or blended hydraulic cement with pozzolan should be investigated. If sulfate exposure is a problem, either Type II, Type V, or a moderate sulfate-resistant blended hydraulic cement should be used. The use of Type III portland cement will almost never be justified or practical for use in RCC due to shortened working times with this cement.

f. Admixtures. A proper air-void system must be provided to prevent frost damage in concrete which freezes when critically saturated. Air-entraining admixtures have not proven to be effective in creating such air-void systems in RCC even when added at dosage rates 10 times that of conventional concrete. Therefore, to compensate for an inadequate air-void system, RCCP should have a low water-cement ratio, be fully compacted, and have a well draining base under the pavement. The low water-cement ratio and good compaction provide a material with a minimum amount of freezable water in the capillaries and has low permeability. As long as the RCCP is not critically saturated, it will not be damaged by freezing and thawing. Durability for resistance to freezing and thawing of RCCP is currently being investigated. Neither water-reducing nor retarding admixtures have been shown to improve the fresh properties of RCC in limited laboratory investigations. If the use of these admixtures is proposed, such use should be based on investigations which show them to produce benefits greater than their cost.

D-5. Mixture proportioning.

a. General. The basic mixture proportioning procedures and properties of conventional concrete and RCC are essentially the same; however, conventional concrete cannot be reproportioned for use as RCC by any single action such as (1) altering proportions of the mortar and concrete aggregates, (2) reducing the water content, (3) changing the water-cement ratio, or (4) increasing the fine aggregate content. Differences in mixture proportioning procedures and properties are mainly due to the relatively dry consistency of the fresh RCC and the selected use of nonconventionally graded aggregates. The primary differences in the properties of RCC are (1) RCC generally is not air entrained, (2) RCC has a lower water content, (3) RCC has a lower paste content, and (4) RCC generally requires a higher fine aggregate content to limit segregation. A number of methods have been used to proportion RCC including those found in ACI 211.3, ACI 207.5R, and ASTM D 558. The first two of these methods follow an approach similar to that used in proportioning conventional concrete. The third method treats the material as cement stabilized soils rather than concrete and establishes a relationship between moisture and the density obtained from a particular compactive effort.

b. ACI 207.5R method. WES has used the method described in ACI 207.5R, with some modifications, on all RCCP mixtures proportioned by WE S to date (further information on this procedure may be obtained at WESGP/SC, PO Box 631, Vicksburg, MS 39180). The primary consideration when using this method is proper selection of the ratio (P_v) of the air-free volume of paste (V_p) to the air-free volume of mortar (V_m). This selection is based primarily upon the grading and particle shape of the fine aggregate. The P_v affects both the compactability of the mixture and the resulting surface texture of the pavement. Ratios of 0.36 to 0.41 have been found to be satisfactory for mixtures having nominal maximum size aggregate of 3/4 or 1 1/2 inch. The fraction of fine aggregate finer than the No. 200 sieve should be included in V_p when calculations are made using P_v.

c. Consistency measurements. Since RCC has no slump, an alternative means of measuring mixture consistency must be used. Two consistency measurement methods have been used to date. One uses the Vebe apparatus as described in ACI 211.3, with the following modifications: (1) a 29-pound loose-filled sample is placed in the container and hand leveled, and (2) a total surcharge weight of 27.5 pounds is added. Consolidation is considered complete when mortar is visible around the bottom edge of the plastic surcharge disk. The second method follows the procedures generally described in ACI 207.5R. This method consists of measuring the time required to fully consolidate a sample of no-slump concrete by external vibration. Although both methods have been used successfully, the latter is more subjective and requires the use of a vibrating table having sufficient frequency and amplitude to fully consolidate the sample. Some commercially available tables have been found unsuitable without the use of a sample surcharge weight. A suggested minimum amplitude and frequency necessary to consolidate an RCC sample without using a surcharge weight is 0.0625 inch and 60 Hz, respectively.

d. Sample fabrication. The strength of an RCC mixture is controlled primarily by the water-cement ratio and the degree of compaction attained. All RCCP mixtures placed by the Corps of Engineers to date have had water-cement ratios ranging from 0.30 to 0.40. Laboratory strength determinations are made using fabricated flexural, compressive, and splitting tensile strength specimens. Conventional ASTM testing methods cannot be followed when fabricating these specimens due to the dry consistency of the concrete. The procedure being used is to fill cylinder molds in two layers and beam molds in a single layer, and consolidate each layer of concrete on a vibrating table. Vibration of each layer is continued until paste is discernible over the entire surface area. Use of a surcharge weight may be necessary to achieve this degree of consolidation. All specimens fabricated in the laboratory are to be cured according to ASTM C 192.

e. Strength results. Test specimens fabricated and cured in the laboratory generally exhibit higher strengths than those cored or sawn from an RCCP. This is probably due to the higher unit weights normally obtained with the fabricated specimens and the more efficient laboratory moist curing. Laboratory test specimens generally have unit weights which are 98 to 99 percent of the theoretical (air-free) weight of the mixture, while core samples taken from RCCP normally have unit weights ranging from 95 to 98 percent of the theoretical weight. Therefore, fabrication of a companion set of test specimens having the lowest relative density allowed by the contract specifications should be considered during the laboratory mixture proportioning studies.

f. ASTM D 558 method. Studies are currently being conducted to determine whether a proportioning method similar to ASTM D 558 is viable for RCC. Such a method would produce the optimum moisture content necessary to obtain maximum density for a particular set of materials and compaction procedures. Previous tests indicate that the optimum moisture content obtained by Method 100 (CE 55) of MIL-STD-621 may produce a mixture too wet to allow efficient operation of a vibratory roller.

D-6. Thickness design.

a. General. The thickness design procedure for RCCP is the same as that used for conventional non-reinforced concrete pavements with no load transfer considered as outlined in Army TM 5-822-6/AFM 88-7, chapter 1, and Army TM 5-824-3/AFM 88-6, chapter 3. Beams sawn from RCCP at Fort Stewart, Fort Hood, and Fort Lewis and tested for flexural strength indicate that the actual flexural strength of the pavement is 20 to 50 percent higher than the typical strength assumed in design for those pavements. This suggests that the thickness design for compacted RCCP should be modified based upon the 28-day strength of beams sawn from a test section constructed, using the same aggregate, cement, and construction procedure as planned for the entire work. However, until additional performance records and testing procedures are developed for RCCP, conventional pavement thickness design will be used.

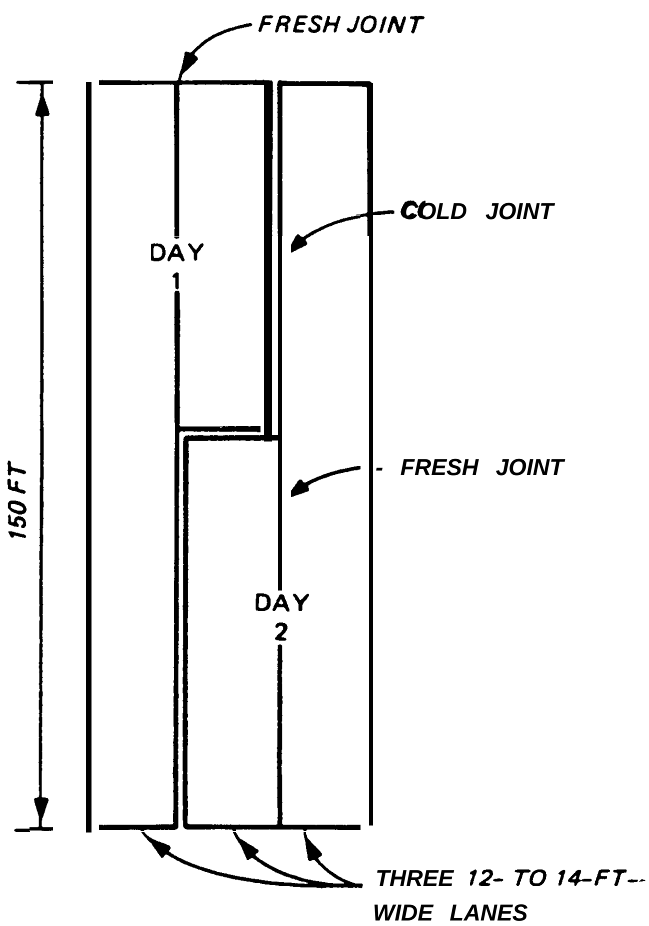
b. Lift thickness. The maximum thickness of a lift of RCCP is governed by the ability of the pavers to place the RCCP in a smooth and continuous fashion. This maximum uncompacted thickness is usually 10 to 12 inches. The maximum uncompacted thickness can be approximated by multiplying the design thickness by 1.25, thus accounting for the reduction in thickness due to compaction. The minimum thickness of any lift should be 4 inches.

c. Two-lift construction. If the total uncompacted thickness exceeds the capacity of the paver, the RCCP should be placed in two or more lifts, thus creating a horizontal joint (or horizontal plane between the layers) in the RCCP. Sufficient bond develops at a fresh horizontal joint in RCCP (top lift placed within 1 hour of bottom lift) to allow the use of a monolithic thickness design. If the top lift is not placed within 1 hour of the bottom lift, the thickness should be designed as a rigid overlay of a rigid base pavement. The surface of the lower lift should be kept moist and clean until the upper lift is placed, and the upper lift should be placed and compacted within 1 hour of compacting the lower lift to insure that a bond between lifts is formed. In two-lift construction, the uncompacted thickness of the first lift should be two-thirds the total uncompacted height of the RCCP (or the maximum lift thickness the paver can handle, whichever is smaller). The thinner section in the upper lift aids in creating a smoother final surface, and because of the smaller volume of material, allows the paver placing the second lift to move quicker than and follow closer behind the paver placing the first lift. Multiple lifts will be necessary if the total uncompacted thickness of the RCCP is greater than twice the maximum lift capacity of the paver.

D-7. Test section.

a. General. A test section should be constructed to determine the ability of the contractor to mix, haul, place, compact, and cure RCCP. The test section should be constructed at least one month prior to the construction of the RCCP at a location near the job-site. The test section should be large enough to establish the rolling pattern for the vibratory and finish rollers, the correlation between laboratory and nuclear gage densities, and the correlation between the number of passes and relative density. The test section should contain both longitudinal and transverse cold joints and a fresh joint. A suggested minimum size is three 12- to 14-foot-wide lanes, each 150 feet long, with one and one-half lanes placed the first day and the rest placed the next day (see fig D-l).

Figure D-1. Typical layout for RCCP test section



b. Optimum number of rolling passes. During the test strip construction, a nuclear gage operated in the direct transmission mode and standardized with a calibration block should be used to determine the optimum number of passes with the vibratory roller to reach maximum density. The density should be measured by inserting the nuclear gage probe into the same hole after each pass of the vibratory roller. The hole should be made with an instrument specifically designed for the purpose, and should be formed using the same method throughout the test section and main construction. This rolling and measuring procedure should be continued until there is less than a 1 percent change in successive readings. These data may be used in conjunction with correlation between the nuclear gage and the laboratory density to determine the minimum number of passes needed to achieve or slightly exceed the specified density in the RCCP construction. However, a minimum of four vibratory passes should be used, and this minimum will probably prevail in most cases.

c. Nuclear gage/laboratory density correlation. After a reasonable estimate is made of the optimum number of passes needed for compaction, a correlation between the value of in situ RCCP density as measured with the nuclear gage and the value obtained by weighing a sample of the RCCP in air and water should also be determined. This should be accomplished by measuring the final compacted density (after four or more passes with the vibratory roller) in 10 locations with the nuclear gage, which has been standardized with a calibration block. The measurement should be made by inserting the probe the full depth of the lane. Then, at 7 days, a pair of cores should be taken on either side of the remaining nuclear gage holes (within a 1- to 3-foot radius from the hole) and the density of the cores measured in the laboratory by weighing them in air and water. For each of the 10 holes, the average of the pair of the laboratory densities should be compared with their corresponding nuclear gage density, and a constant relationship between the nuclear gage and laboratory densities developed by averaging the algebraic differences in these readings. This difference should be combined with future field readings to obtain an adjusted reading which can be compared to the specified density. In the past a specified density of 96 percent of theoretical weight as defined in ASTM C 138 has been achieved. If the adjusted nuclear gage density is less than the specified density, additional passes should be made on the fresh RCCP until the specified density is reached. Two nuclear density gages should be calibrated (using the same holes) during the test section construction so that an extra one is available during final construction.

d. Strength tests. Ten cores and beams should be taken from the test section after 28 days to determine a correlation between flexural strength and splitting tensile strength and/or compressive strength of the RCCP. This reduces the amount of sawing necessary to obtain samples during further construction. Although both the splitting tensile and compressive strength data would be useful for historical reference, only one of these tests is needed for quality control testing of the RCCP construction. After the correlation is determined, the appropriate splitting tensile and/or compressive strength that correlates to the specified design flexural strength should be used in any further quality control testing.

D-8. Batching, mixing, and transporting. RCCP needs a vigorous mixing action to disperse the relatively small amount of water evenly throughout the matrix. This action has been best achieved by using a twin-shaft pugmill mixer commonly used in asphaltic concrete mixing. Batching of the concrete may be accomplished successfully in either a continuous-mixing or a weigh-batch asphalt plant. The continuous-mixing plant is recommended for batching RCC because it is easier to transport to the site, takes less time to set up, and has a greater output capacity than the weigh-batch plant. The weigh-batch plant allows more accurate control over the proportions of material in each batch, but generally does not have enough output capacity for larger paving j ohs. The output of the plant should be such that the smooth, continuous operation of the paver(s) is not interrupted, and for all but the smallest jobs (1,000 square yards or smaller), the capacity of the plant should be no less than 250 tons per hour. The output (or production) of the plant should not be greater than the laydown capacity of the paver(s) nor greater than the rolling capacity of the rollers. The plant should be located as close as possible to the paving site, but in no case should the haul time between the batch plant and the paver(s) exceed 15 minutes. The RCC should be hauled from the mixer to the paver(s) in dump trucks. These trucks should be equipped with protective covers to guard against adverse environmental effects on the RCC, such as rain, or extreme cold or heat. The truck should dump the concrete directly into the paver hopper.

D-9. Placing. For most pavement applications, RCCP should be placed with an asphalt paver or similar equipment. The paver should be equipped with automatic grade-control devices such as a traveling ski or electronic stringline grade-control device. A paver having a vibratory screed or one equipped with a tamping bar is recommended to provide a satisfactory surface texture and some initial compaction when the RCCP is placed. Necessary adjustments on the paver to handle the RCC include enlarging the feeding gates between the feed hopper and screed to accommodate the large volume of stiff material moving through the paver, and adjusting the spreading screws in front of the screed to insure that the RCC is spread uniformly across the width of the paving lane. Care should be taken to keep the paver hopper from becoming empty to prevent any gaps or other discontinuities from forming in the pavement. The concrete should be placed and compacted within 45 minutes after water has been added to the batch. When paving adjacent lanes, the new concrete should be placed within 90 minutes of placing the first lane (forming a "fresh" joint), unless procedures for cold joint construction are followed (see para D-11). The height of the screed should be set even with the uncompacted height of the adjascent lane, thus allowing simultaneous compaction of the edges of the adjacent lanes into a fresh joint. When paving rectangular section, paving should be in the short direction in order to minimize the length and number of cold longitudinal and transverse joints. Two or more pavers operating in echelon may reduce the number of cold joints by one half or greater, and are especially recommended in road construction where the entire width of the road can be placed at the same time.

D-10. Compaction.

a. General. RCCP is best compacted with a dual-drum (10-ton static weight) vibratory roller making four or more passes over the surface to achieve the design density (one back-and-forth motion is two passes). Table D-1 describes vibratory rollers that have been used on five recent RCCP projects. To achieve a higher quality pavement, the primary compaction should be followed with two or more passes of a 20-ton pneumatic-tired roller (90 psi minimum tire pressure) to close up any surface voids or cracks. The use of a dual-drum static (non-vibratory) roller may be required to remove any roller marks left by the vibratory or pneumatic-tired roller. A single-drum (l O-ton) vibratory roller has been used successfully to compact RCCP, but may require the use of a pneumatic-tired or dual-drum static roller to remove tire marks.

Table D-1. Vibratory rollers used in RCCP construction

Job	Construction Date	Type Roller	Shipping Weight lb	Static Drum Weight lb	Drum Width in.	Weight/ in. width lb/in.	Frequency Range vibrational min	Amplitude Range in.	Maximum Compacted Lift Thickness in.
Ft. Stewart, GA	July 1983	Tampo RS-28 (Single drum)	18,750	10,750	84.0	128.0	1,100 1,500	0.063	10.0
Ft. Hood, TX	July 1984	Tampo RS-188A (Double drum)	30,750	16,000	84.0	190.5	2,200	0.029 0.016	10.5
Ft. Lewis, WA	Nov 1984	Tampo RS-28A (Single drum)	19,250	11,300	84.0	134.5	1,500 1,700	0.020 0.061	8.5
Port of Tacoma, WA	April 1985	Dynapac CC50A (Double drum)	31,385	15,692	84.0	186.8	2,400	0.016 0.032	9.0
Portland International Airport	Aug 1985	ABG Puma 168A (Single drum)	16,755	7,275	65	111.9	2,000 3,000	0.075 0.029	7.0

b. Proper time for rolling. Ideally, the consistency of the RCCP when placed should be such that it may be compacted immediately after placement without undue displacement of the RCCP. However, no more than 10 minutes should pass between placing and the beginning of the rolling procedure. The rolling should be completed within 45 minutes of the time that water was added at the mixing plant. A good indication that the RCCP is ready for compaction is found by making one or two static passes on the RCCP within 1 foot of the edge of the lane before vibrating begins and observing the material during these two passes to insure that undue displacement does not occur. If the RCCP is too wet or too dry for compaction upon placing, the water content should be adjusted at the plant. Only minor changes in water content from the design mix should be made; otherwise, a new mix design may be needed. With practice, the roller operator should be able to tell whether the consistency of the RCCP is satisfactory for compaction.

c. Rolling pattern. After making the static passes, the vibratory roller should make four vibratory passes on the RCCP using the following pattern: two passes on the exterior edge of the first paving lane (the perimeter of the parking area or the edge of a road) so that the rolling wheel extends over the edge of the pavement 1 to 2 inches (done to "confine" the RCCP to help prevent excessive lateral displacement of the lane upon further rolling), followed by two passes within 12 to 18 inches of the interior edge. This will leave an uncompacted edge to set the height of the screed for an adjacent lane, and allows both lanes of the fresh joint to be compacted simultaneously. Any remaining uncompacted material in the center of the lane should be compacted with two passes of the roller. This pattern should be repeated once to make a total of four passes on the lane (or more if the specified density is not achieved) (see fig D-2). If the interior edge will be used to forma cold joint, it should be rolled exactly as the exterior edge was rolled, taking care to maintain a level surface at the joint and not round the edge. When the adjacent lane is placed, two passes should be made about 12 to 18 inches from the outer edge of the lane (again, to confine the concrete) followed by two passes on the fresh joint. The first two passes should extend 1 to 2 inches over the outer edge of this adjacent lane if the lane will form an outer edge of the completed pavement. Any remaining uncompacted material in the lane should be rolled with two passes of the roller. This pattern should be repeated to make a total of four passes over the RCCP. Additional passes may be necessary along the fresh joint to insure smoothness and density across the joint (see fig D-3).

Figure D-2. Compaction of first paving lane

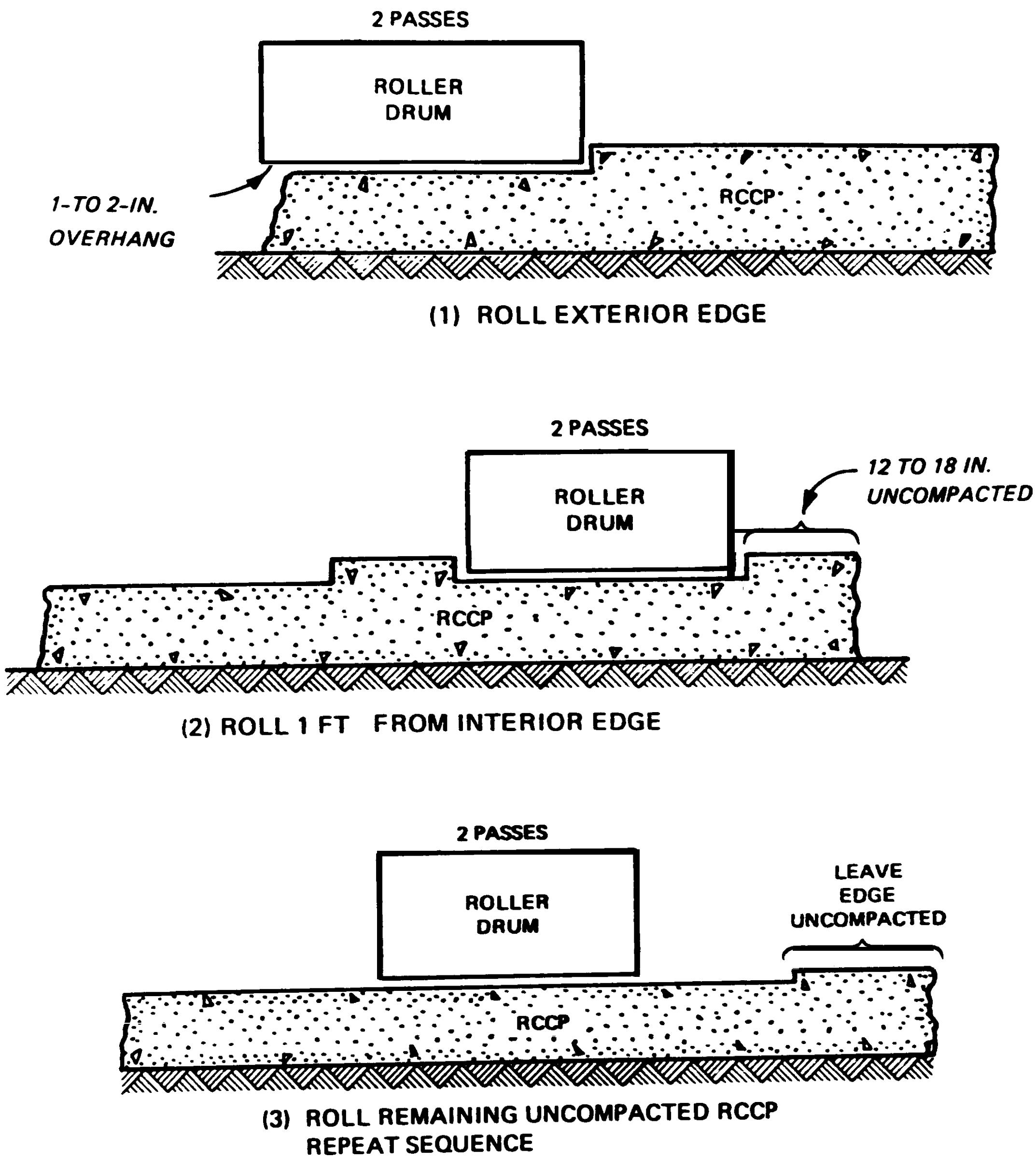
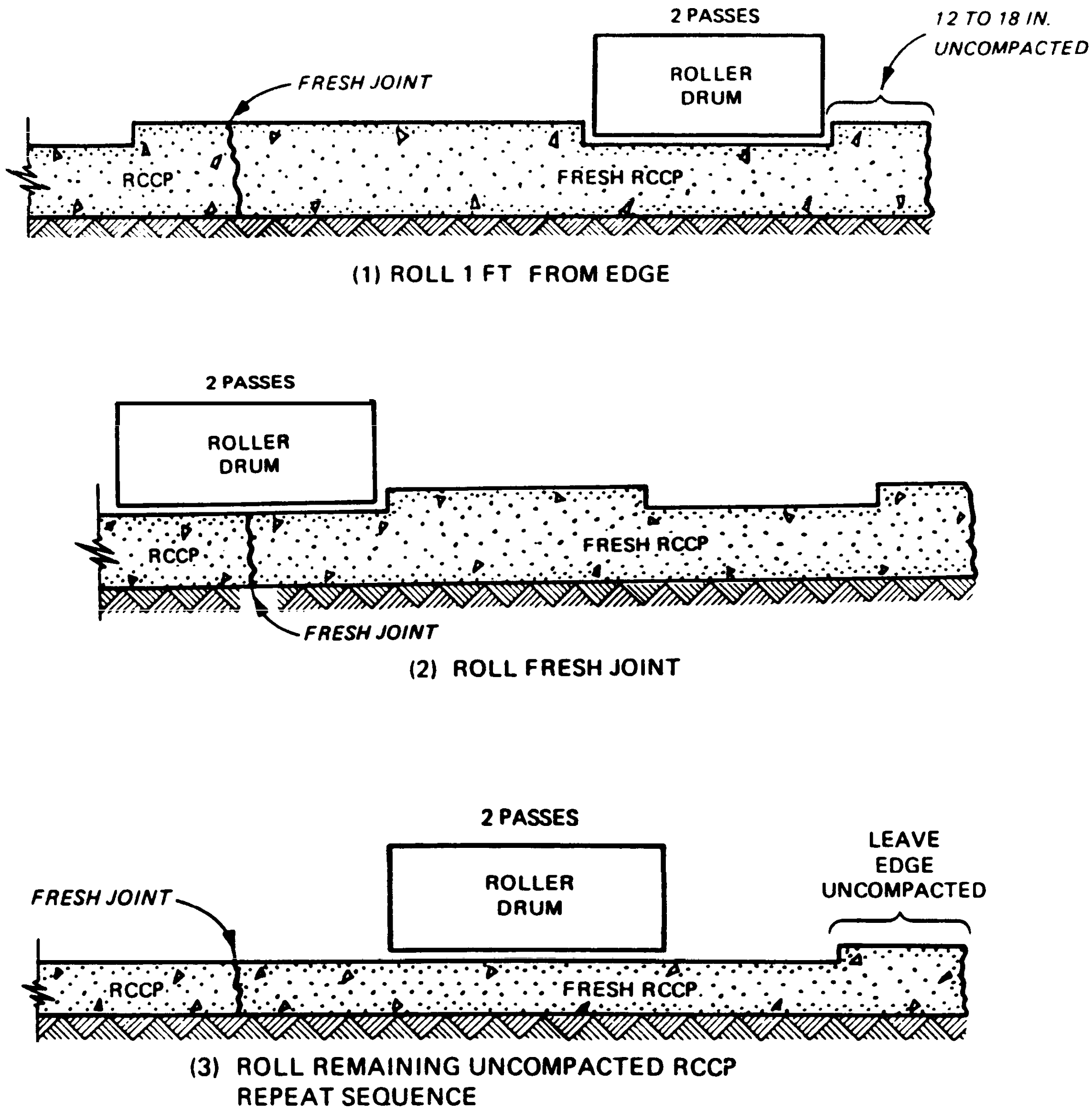


Figure D-3. Compaction of interior paving lanes



d. Compacting the end of a lane. When the end of a lane is reached, the roller should roll off the end of the lane, rounding off the end in the process. This rounded end should be trimmed with a motor grader or with shovels to form a vertical face through the entire depth of the pavement. An alternative method involves confining the uncompacted end of the lane with a crosstie or beam anchored to the base course, thereby forming a vertical face at the end of the lane after compaction.

e. **Proper roller operation.** During the course of the vibratory compaction, the roller should never stop on the pavement in the vibratory mode. Instead, the vibrator should be turned on only after the roller is in motion and should be turned off several feet before the roller stops moving. The stopping points of successive rolling passes should be staggered to avoid forming a depression in the RCCP surface. The roller should be operated at the proper speed, amplitude, and frequency to achieve optimum compaction. The best compaction will probably occur at a high amplitude and low frequency (because of the thick lifts) and at a speed not exceeding 2 miles per hour.

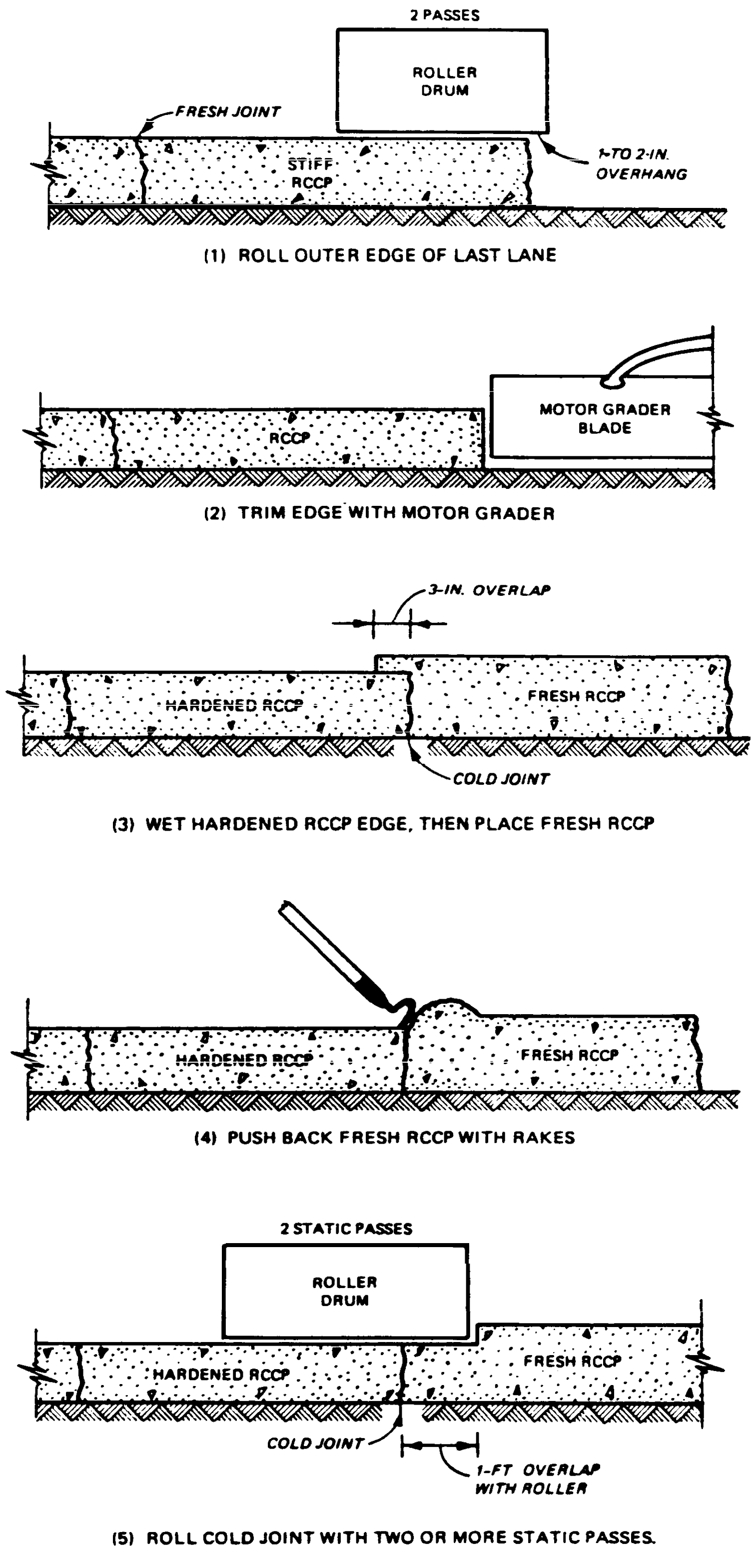
f. Finish rolling. The vibratory compaction should be followed immediately with two or more passes of the pneumatic-tired roller so that the surface voids and fissures close to form a tight surface texture. This rolling may be followed by a light dual-drum roller to remove any roller marks on the surface, but this will probably not be necessary. It is very important that all exposed surfaces of the RCCP be kept moist with a light water spray after the rolling process until the curing procedure is implemented.

D-11. Cold joints.

a. General. A cold joint in RCCP is analogous to a construction joint in conventional concrete pavement. It is formed between two adjacent lanes of RCCP when the first lane has hardened to such an extent that the uncompacted edge cannot be consolidated with the fresher second lane. This happens when there is some time delay between placement of adjacent lanes such as at the end of the day's construction. This hardening may take from one to several hours depending on properties of the concrete and environmental conditions. Nevertheless, the adjacent lane should be placed against the first lane within90 minutes or be considered a cold joint.

b. Cold joint construction. Before placing fresh concrete against hardened in-place pavement to form a longitudinal cold joint, the edge of the in-place pavement should be trimmed back to sound concrete to form a vertical face along the edge. This vertical face should be dampened before the placement of the fresh lane begins. The height of the screed should be set to an elevation approximately 25 percent higher than the desired thickness of the compacted concrete. The screed should overlap the edge of the hardened concrete lane 2 or 3 inches. The excess fresh concrete should be pushed back to the edge of the fresh concrete lane with rakes or lutes and rounded off so that a minimal amount of fresh material is left on the surface of the hardened concrete after compaction. The loose material should not be broadcast over the area to be compacted; this may leave a rough surface texture after rolling. The edge of the fresh lane adjacent to the hardened concrete should be rolled first, with about 1 foot of the roller on the fresh concrete, to form a smooth longitudinal joint (see fig D-4). Transverse cold joints are constructed in a similar manner. After cutting back the rounded-off edge and wetting the vertical face, the paver is backed into place and the screed set to the proper elevation using shims sitting on top of the hardened concrete. The excess material should be pushed back as mentioned before, and a static pass made in the transverse direction across the first 1 foot of the freshly placed lane. The joint should be carefully rolled to insure a smooth transition across the joint.

Figure D-4. Construction of a cold joint

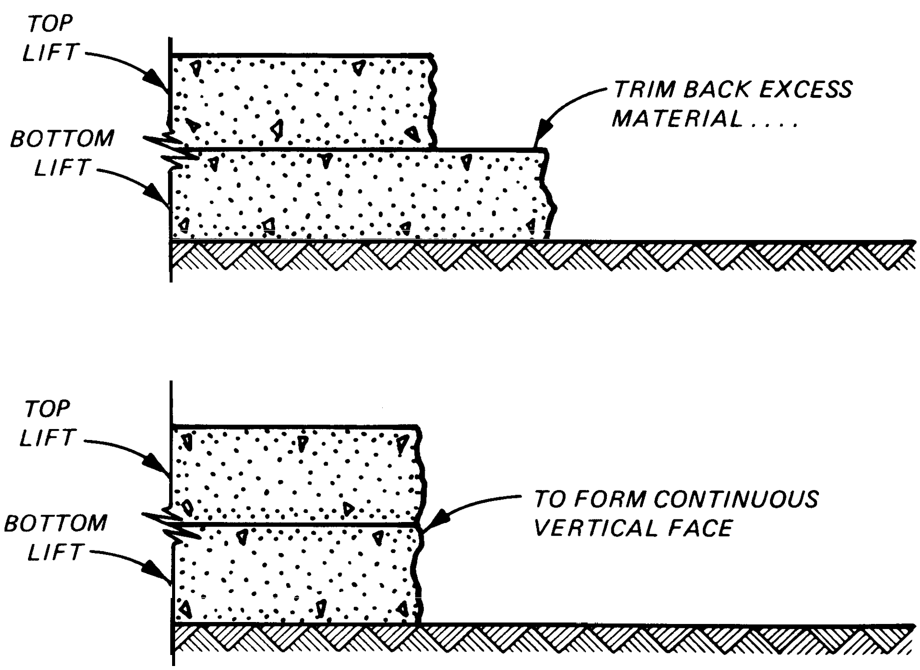


c. **Sawing.** The sawing of contraction joints in RCCP has proven to be unnecessary in past projects. Cracks were allowed to form naturally in all of the Canadian-built RCCP, and virtually no distress has been observed at the cracks. These pavements have endured over 7 years of very heavy loads and numerous freeze-thaw cycles. Attempts to saw joints at Fort Hood and Fort Lewis produced a ragged edge along the saw cut where pieces of cement paste and aggregate were kicked out by the saw blade. Until a suitable method is developed for sawing joints in RCCP, this method should not be used.

d. Load-transfer devices. The stiff consistency of RCCP does not lend itself to application of load-transfer devices such as dowels or keyed joints, although dowels were used in cold joint construction at Fort Stewart. There, the dowels were driven into the RCCP before final set, and the adjacent fresh lane was carefully worked around the dowels by hand. Until an efficient method is developed to insert and align dowels properly in RCCP, the use of dowels should be limited.

e. **Vertical joints in two-lift construction.** In two-lift construction, care should be taken to align the cold transverse and longitudinal joints in the upper and lower lifts to form a uniform, vertical face through the depth of the pavement along the joint. If the edge of the upper lift is not even with the edge of the lower lift, the lower lift should be cut back even with the edge of the upper lift (see fig D-5).

Figure D-5. Two-lift cold joint



D-12. Curing.

a. General. Because of the low water content used in an RCCP mixture, a combination of moist curing and membrane curing is recommended to prevent drying and scaling of the RCCP surface. The pavement surface should be kept continuously moist after final rolling for at least 24 hours by means of a water spray truck, sprinkler (fog spray) system, or wet burlap or cotton mat covering. If burlap mats are used, they should be thoroughly wetted, placed on the RCCP so that the entire surface and exposed edges are covered, and kept continuously wet. After the initial moist curing period, the RCCP should be cured until it is at least 7 days old by one of the following methods: water-spray curing, burlap or cotton mat covering, or membrane-forming curing material. The curing material may be a white-pigmented membrane curing compound or an asphalt emulsion. The curing compound or emulsion must form a continuous void-free membrane and should be maintained in that condition throughout the curing period. An irrigation sprinkler system has been used to cure RCCP in Canada and at Fort Lewis, but caution should be exercised so that the fines in the surface of the RCCP are not washed away by excessive spraying.

b. Moist curing. Continuous moist curing of the RCCP for at least 7 days should be considered if frost resistance is a concern. Preliminary results of laboratory freezing and thawing tests indicate that RCCP which has a sufficiently low water-cement ratio and has been moist cured for an extended period tends to be more frost-resistant. The improved frost resistance may be due to more complete hydration resulting in a reduction in fractional volume of freezable water at saturation.

c. Early loading. All vehicular traffic should be kept off the RCCP for at least 14 days. If it is absolutely necessary, a water-spraying truck and membrane-spraying truck may be driven onto the RCCP before that age, but this practice should be kept to a minimum.

D-13. Quality control/assurance.

a. General. Quality control and quality assurance consist of testing of materials going into the concrete; checking the plant calibration regularly; measuring the in-place density of the RCCP using a nuclear density gage; checking the smoothness of the finished RCCP with a straightedge; taking core samples from the RCCP for measurement of density, strength, and thickness; and, if desired, fabricating RCC cylinders and beams.

b. Tests at plant. Moisture contents of the fine and coarse aggregates should be determined daily as necessary and appropriate changes made in the amount of mixing water. Washed gradation tests should normally be performed on the combined aggregates three times per day: in the morning, at midday, and in the afternoon. The samples should be taken from the conveyor before the cement or fly ash is added to the combined aggregates. The amount of materials passing the No. 100 sieve should be determined during this analysis. After each gradation test, a washout test according to procedures in ASTM C 685 (para 6.5) may be performed on the combined dry ingredients on samples taken from the conveyor belt between the cement and fly ash hoppers and the pugmill. By washing the dry ingredients over the No. 4 and No. 100 sieves and weighing the material in each size category, the approximate proportions of coarse aggregate, fine aggregate, and cement and fly ash combined may be determined and checked against predetermined limits.

c. Field density tests. Field density tests should be performed on the RCCP using a nuclear density gage operated in the direct transmission mode according to ASTM D 2922. At least one field reading should be taken every 100 feet of each paving lane. The readings should be taken as closely behind the rolling operation as possible. The reading should be adjusted using the correlation determined in the test section construction and checked against a specified density. Areas that indicate a deficient density should be rolled again with the vibratory roller until the specified density is achieved.

d. Obtaining core samples. The acceptance criteria for the strength, density, and thickness of RCCP shall be based on appropriate tests conducted on cores taken from the RCCP. Cores should be taken from the RCCP when the pavement is 7 days old. One core should be taken at every fifth nuclear gage density test site, within a 1- to 3-foot radius of the test hole. The density and thickness of the core should be measured, and the core should be field cured under conditions similar to the RCCP curing conditions. The cores should be tested for splitting tensile strength (ASTM C 496) when they are 28 days old.

e. Smoothness. The finished surface of the RCCP should not vary more than 3/8 inch from the testing edge of a 10-foot straightedge. Smoothness should be checked as closely behind the finish roller as possible, and any excessive variations in the surface shall be corrected with the finish roller. Particular attention should be paid to the smoothness across fresh and cold joints because this is usually a critical area for surface variations. A skilled vibratory roller operator is essential in minimizing smoothness problems. The final surface texture of the RCCP should resemble that of an asphalt concrete pavement surface.

f. Cylinder and beam fabrication. The fabrication of cylinders and beams during RCCP construction would be highly desirable as (1) an aid to the coring operation in checking the RCCP strength and density, and (2) a means of establishing a data base for developing future quality control criteria. If fabricated cylinders and beams are to be used as a quality control aid during construction, a correlation between their strength and density and that obtained from cores and sawed beams should be made during test section construction. Results of this correlation and the ensuring quality control use of fabricated cylinders and beams should be sent to WESGP–EC, PO Box 631, Vicksburg, MS 39180, for addition to the above mentioned data base.

g. Method of cylinder and beam fabrication. Cylinders and beams should be fabricated in the field by filling cylinder molds in two layers and beam molds in a single layer and consolidating each layer of concrete on a vibrating table. Four beams (one group) should be fabricated during each shift of construction, two to be tested at 14 days and two at 28 days. The beams should be tested for flexural strength according to ASTM C 78. Eight cylinders (one group) should be fabricated for every 300 cubic yards (225 cubic meters) of RCC placed, with one group coming from the same batch of RCC used in the beams. Two cylinders should be tested each at 7, 14, 28, and 90 days. The cylinders should be tested for splitting tensile strength according to ASTM C 496.

h. Inspectors. Inspections are vital in the quality control operations. At least one inspector should be stationed at the mixing plant and at the jobsite to insure that a quality pavement is being built. At the mixing plant, the inspector should check mixing times occasionally and spot-check the consistency and appearance of the mix coming out of the plant. He should also coordinate the aggregate moisture content tests, the gradation tests, calibration of the plant, and washout tests to see that they are performed properly and at the right frequency. At the jobsite, the inspector should make sure that the base course and cold joints are moistened before the RCC is placed against them and that the RCC is placed and compacted within the proper time limitations. He should check the paver operation to insure that proper grade control is continuously maintained, and to make sure no gaps or discontinuities are left in the pavement before rolling. The inspector should make sure the roller begins compaction at the proper time and that the proper rolling pattern and number of passes is used. He should make sure adequate smoothness across joints is achieved and that the surface texture is tight after final rolling. The final compacted thickness of the RCCP should be spot-checked by the inspector and corrected accordingly, if appropriate. He should make sure that the curing procedures are implemented as specified. The inspector should also insure that all exposed surfaces of the RCCP are kept moist at all times and that the curing compound, if used, is applied properly and in a continuous fashion. He should also coordinate the nuclear gage density test, the coring procedures, cylinder and beam fabrication, and the surface smoothness test to see that they are performed properly and at the required frequency.

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