Chapter 3
Construction Requirements and Special Studies

3-1. Construction Requirements

a. General. As the concrete materials design of a project nears its conclusion, adequate data should be available related to likely sources of aggregate, water, and locations of haul roads and access roads to determine if an onsite or offsite plant is required, and if an onsite plant is required, the site location. In addition, requirements for batching plants, mixers, conveying, and placing equipment must be established and included in the appropriate DM to guide in the preparation of the plans and specifications.

b. Batch-plant location. The batch plant may be located onsite or offsite. For a very large dam being built in a remote location, an onsite plant would be a certainty, and for a culvert headwall in a metropolitan area, the concrete would certainly be supplied by a ready-mix firm acting as a supplier to the Contractor. Between these two extremes, there are numerous possibilities that will depend on the scope and location of the work, the nominal maximum size aggregate required, the desired placing rate, the anticipated workload of the local ready-mix producers during the period of construction of the Corps projects, and the availability or nonavailability of a government-controlled aggregate source. Specifically, the concrete batching plant is normally required to be located onsite when the closest source of ready-mixed concrete is remote from the project, the nominal maximum size aggregate required makes ready-mixed concrete impractical and the required placing capacity cannot be maintained by an offsite plant. An offsite plant should be considered when the maximum size aggregate is 37.5 mm (1-1/2 in.) or less, commercial concrete plants exist in the project area, the plants are close enough that the interval between concrete batching and final placement will be 1-1/2 hr or less, and the required placement rate can be maintained. Obviously, on many projects, the decision between an onsite or offsite plant is not clear cut. The type of batching and mixing equipment at each commercial plant should be surveyed and summarized in the concrete materials DM. If more than one source exists as potential supplier, all such sources should be investigated and, if acceptable, be listed in the concrete materials DM. If the potential exists for either an onsite plant or the use of offsite commercial source, it should be possible for the bidders to have the option of setting up and operating an onsite plant or procuring concrete offsite.

c. Batch-plant type. Available options in batching equipment include automatic, semiautomatic, partially automatic, manual, and volumetric batching (ACI 304R, CRD-C 514, and ASTM 685 (CRD-C 98)). The choice of the batch-plant control system is dependent on the type of concrete, the volume of concrete required, the number of coarse aggregate sizes, and the importance of the structure. If mass concrete is being placed, an automatic plant will be specified when four sizes of coarse aggregate are used, where three sizes of coarse aggregate are used and 75,000 yd^3 or more of concrete is involved, or when two sizes of coarse aggregate are used and more than 100,000 yd^3 of concrete is involved. A semiautomatic batch plant may be specified for mass concrete if not more than three sizes of coarse aggregate are used and less than 100,000 yd^3 of concrete is involved. If cast-in-place structural concrete is the type of concrete that will be predominant on the project, the batching equipment specified may be automatic, semiautomatic, or partially automatic. For major projects involving important structures or where critical smaller structures are involved, the optional interlocks and recorders should be required. If the concrete to be placed on a project is only for minor structures, any of the above plants are suitable, plus batch plants having manual controls or incorporating volumetric batching. The selection of batching and mixing plant requirements must take into account both economy and technical requirements for adequate control of quality. Economic considerations include initial plant cost, economy of operation (production rates), and economy in concrete materials, particularly cement. It may be noted that either an automatic or semiautomatic plant may be specified where three sizes of coarse aggregate are used, depending on volume of concrete involved and the nature of the work. The choice in these cases is largely dependent on economy. Batch plant types, including volumetric batching, are discussed in ACI 304R.

d. Mixer type. Stationary tilting-drum mixers should be used for mixing concrete containing 150-mm (6-in.) NMSA. For mixing concrete containing 75-mm (3-in.) NMSA, stationary tilting-drum, pugmill, spiral blade, or vertical shaft mixers may be used. However, for concrete containing 75- or 150-mm (3- or 6-in.) NMSA, the Contractor may choose any stationary mixer if it meets the required capacity and complies with the uniformity requirements when tested in accordance with CRD-C 55. Concrete containing 37.5-mm (1-1/2-in.) and smaller NMSA may be mixed in stationary mixers or truck mixers. For minor structures, any of these types of mixers may be used as well as a continuous mixer with volumetric batcher. When volumetric batching and continuous mixing are used for minor structures, the equipment must meet the requirements of ASTM C 685 (CRD-C 98).

e. Batching and mixing-plant capacity. Careful consideration must be given to the determination of the required concrete production capabilities. This determination is important for both large concrete locks and dams using an onsite batching and mixing plant and for smaller structures that may use an offsite plant and trucks for mixing or hauling or both.

(1) Monolith size. A likely construction progress schedule should be developed during the PED phase of a concrete structure. The fixed constraints such as committed power-on line or lock operation dates and seasonal constraints should be incorporated into the schedule. Recently completed similar projects in the area should be reviewed to determine the maximum placement rates achieved. The likely placement methods such as crane and bucket, pump, or conveyor have to be determined and the structures analyzed so that the largest continuous placements are identified. The size of the placements are defined by the placement of construction joints. Construction joints should be shown on the drawings and should be placed by the structural designer to coincide with structural features and reinforcing locations. The thermal study will also provide input for maximum size of monolith and maximum lift heights. Construction joints should be located to provide for as many placements as possible to be approximately the same volume. If one placement is several times the volume of all other placements on a project, this will require a much larger batching and mixing plant capacity than would be necessary if smaller placements were used. For many smaller structures, a plant size that will prevent cold joints will be too small to meet the tentative construction progress schedule. Regardless of the daily requirements, the plant capacity has to be such that fresh concrete does not remain in the form prior to placement of contiguous concrete long enough to develop a cold joint. The time that concrete may remain in the form before a cold joint develops is highly variable. For example, in warm dry climates the time may have to be reduced 50 percent or more. The time may be extended by the use of a retarder (ASTM C 494 (CRD-C 87)). As a rule of thumb for initial computation, 2 hr may be considered the maximum time that cooled concrete is uncovered before a cold joint will form between the concrete in place and the new concrete. For uncooled mass and structural concrete, 1 hr is the maximum time that it should be uncovered. A cold joint is defined as concrete that is beginning to set and in which a running vibrator will not sink under its own weight and a hole is left in the concrete when the vibrator is slowly withdrawn. When a cold joint is formed, concrete placement should be stopped and the cold joint should then be treated as another construction joint. The selection of the plant size should provide adequate safety factors to cover the variables.

(2) Traditional placing method. For massive structures such as locks and dams, the traditional placement method has been buckets that are moved on trucks and placed with cranes. There should be a limit of 4 yd^3 as the maximum amount of concrete placed in one pile prior to the consolidation. A typical lift height of 5 or 7-1/2 ft with an approximate horizontal layer thickness of about 1-1/2 ft would require five successive horizontal layers in stepped progression in 7-1/2-ft lifts and three successive horizontal layers in stepped progression in 5-ft lifts.

(3) Equation for minimum placing capacity. The minimum plant capacity may be estimated by using the following equation or by calculating graphically as illustrated in paragraph 3-1e(4):

$$Q = (n+1)\frac{WB}{bh} \tag{3-1}$$

where

Q	=	Plant capacity, yd^3/hr
W	=	Width of placement (monolith), ft
B	=	Bucket size, yd^3
b	=	Width of block per bucket, ft. A block is assumed to be a square with a height equal to approximately 1-1/2 ft. For 4-yd^3 bucket, b = 8-1/2 ft
h	=	Maximum time before cold joint forms, hr. For estimating purposes, use h = 2 for cooled concrete and h = 1 for uncooled concrete.
n	=	Number of layers per lift, normally three layers for 5-ft lift and five layers for 7-1/2-ft lift.

(4) Graphic calculation of minimum placing capacity. Figures 3-1 and 3-2 illustrate graphically the placing sequences for 7-1/2- and 5-ft lifts, respectively, with a 4-yd^3 bucket. As shown in Figure 3-1, the required plant output will reach the maximum after 60 buckets of concrete have been placed. Each bucket placed after 60 buckets will be exposed, while 36 additional buckets are being placed. Therefore, for cooled mass concrete while each placement may be exposed for 2 hr before cold joint forms, the required minimum plant capacity will be 36 × 4 = 144 yd^3 in a 2-hr period or 72 yd^3 per hour. In Figure 3-2, where a 5-ft lift is used, the maximum plant output will be reached at the sixteenth bucket, and 20 buckets will be placed before it will be covered. Therefore, for cooled concrete, the required minimum capacity will be 20 × 4 = 80 yd^3 in a

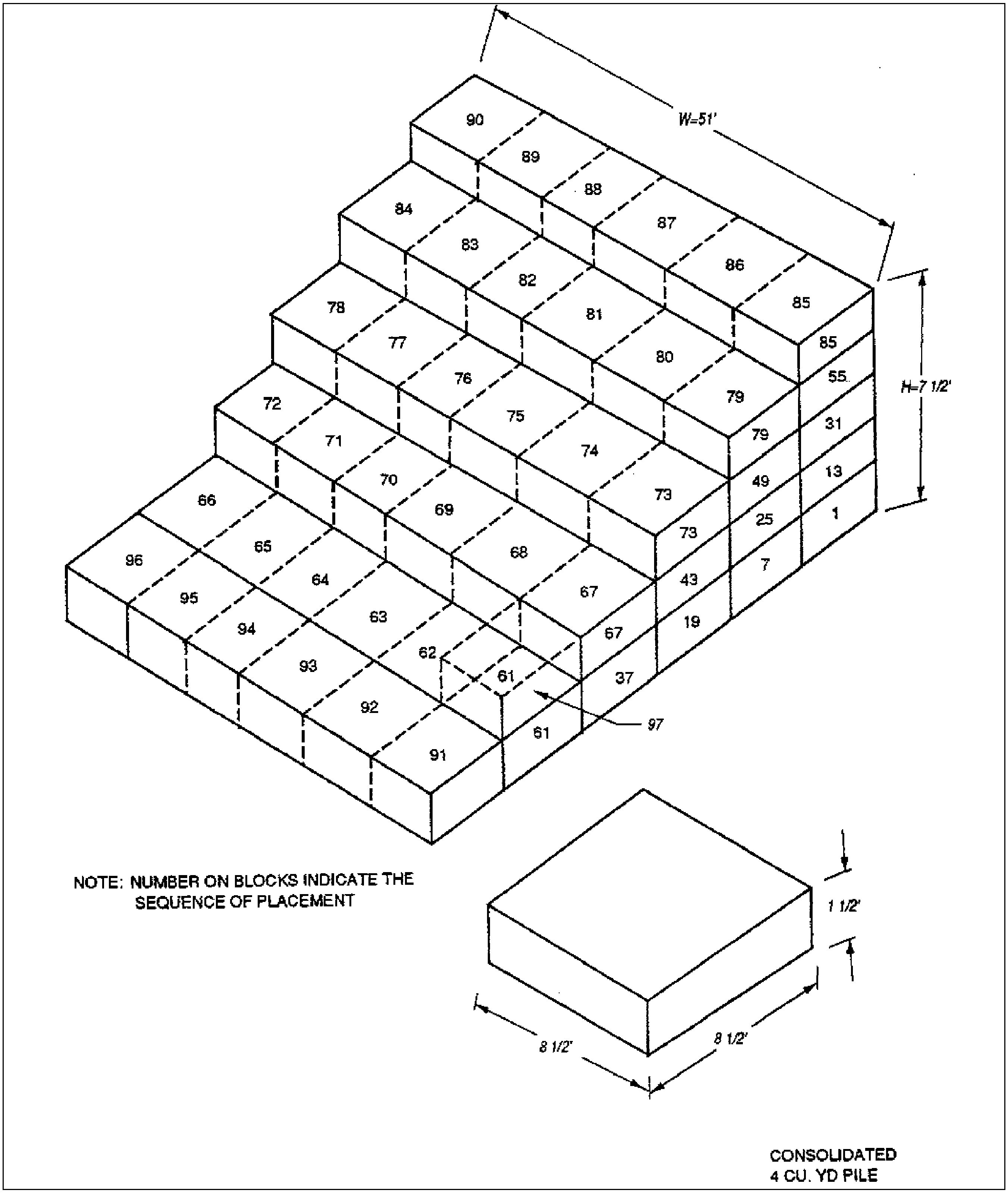

Figure 3-1. Stepped placement sequence and plant capacity, 7-1/2-ft lift height

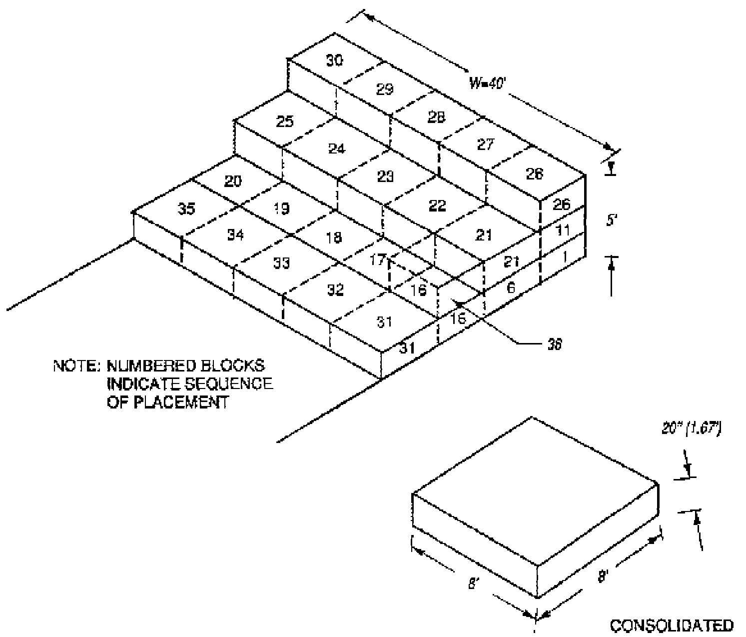

Figure 3-2. Stepped placement sequence and plant capacity, 5-ft lift height

2-hr period or 40 yd^3 per hour. The same results can be obtained from Equation 3-1.

(5) Other placing methods. If other placing techniques are likely to be used such as a pump or conveyor, the plant capacity has to be adequate to supply the unit at a rate near its rate capacity to avoid plugs or segregation. The capacity of the plant and placing equipment will have to be adequate to prevent cold joints in the placements. The capacity calculated for bucket placement may be used as a beginning point for plant capacity calculations.

f. Conveying and placing considerations. Historically, most concrete for Corps structures has been placed by crane and bucket. Recently, however, the preferred placing equipment has changed, and conveyors and pumps are being used to place an increasing amount of mass and structural concrete, respectively. Mixture proportions, conveying methods, and placing restrictions must be considered for each portion of the project during PED to assure that appropriate concrete is placed in each feature. For example, it is impossible to pump lean mass concrete with 75-mm (3-in.) maximum size aggregate, and therefore buckets, or conveyors must be used. The proportions of the concrete mixtures must meet the designer's requirements for strength, slump, maximum size aggregate, etc., and must be capable of being placed by the Contractor. The mixture proportions should not be altered to accommodate a Contractor's placing equipment if the designer's requirements would be compromised.

g. Use of epoxy resins. All epoxy resin shall be specified to meet ASTM C 881 (CRD-C 595). The type and grade for specific uses should be as follows:

Dowels in drilled holes	Type IV, Grade 3
Patching and overlays	Type III
Bonding new concrete to old	Type V
Crack injection	Type IV, Grade 1

Refer to ASTM C 881 for the correct "class" for use at the anticipated temperature of the surface of the hardened concrete. During cooler weather, the epoxy resin should be stored at room temperature for several days prior to use.

3-2. Special Studies

a. General. Often it will be necessary to conduct tests that extend in scope beyond those listed above. The need for such tests may develop as a result of the size or complexity of a project, an unusual characteristic of the available cementitious materials or aggregates or the climatic conditions at a project site. The most commonly required studies are thermal studies followed by abrasion-erosion studies and mixer grinding studies. Such studies, when required, should be identified during the feasibility phase and funding and scheduling should be included in the project management plan. The results of these studies will be documented in the appropriate DM.

b. Thermal studies. During the PED for projects involving concrete structures, it is necessary to assess the possibility that temperature changes in the concrete will result in strains exceeding the strain capacity of the concrete. Although temperature control is generally associated with large mass-concrete structures, it should be noted that small, lightly reinforced structures may also crack when subjected to temperature extremes. Therefore, thermal studies are required for any important concrete structure. This may include, but not be limited to, dams, locks, powerhouses, and large pumping stations.

(1) Material properties needed for a thermal study. The following concrete material properties should be determined. Information on cost and time requirements for the following material properties tests may be obtained from CEWES-SC.

(a) Heat of hydration. The heat generated will depend on the amount and type of cementitious materials in the concrete. The heat of hydration is obtained experimentally and forms part of the basis for predicting the temperature rise and decline with time for a concrete (ASTM C 186 (CRD-C 229)).

(b) Adiabatic temperature rise. The temperature rise in concrete under adiabatic conditions is determined according to CRD-C 38. The cementitious material types and aggregates in the concrete so tested should be similar to those proposed for use in the structure.

(c) Thermal conductivity. Thermal conductivity is a measure of the ability of the material to conduct heat and may be defined as the ratio of the rate of heat flow to the temperature gradient. Numerically, thermal conductivity is the product of density, specific heat, and diffusivity.

(d) Thermal diffusivity. Thermal diffusivity is a measure of the facility with which temperature changes take place within a mass of material (CRD-C 37); it is equal to thermal conductivity divided by specific heat times density.

(e) Specific heat. Specific heat is the amount of heat required per unit mass to cause a unit rise of temperature, over a small range of temperature (CRD-C 124).

(f) Coefficient of thermal expansion. The coefficient of thermal expansion can be defined as the change in linear dimension per unit length per degree of temperature change (CRD-C 39, 125, and 126).

(g) Creep. Creep is time-dependent deformation due to sustained load (ASTM C 512 (CRD-C 54).

(h) Strain capacity. The ultimate tensile strain capacity of concrete is determined by measuring the unit strain at the outer fibers of unreinforced beams tested to failure under both rapid and slow loading (CRD-C 71).

(2) Time of completion of thermal study. The thermal and mechanical properties of the concrete are very dependent on the mineralogical composition of the aggregates and the cement type used. Therefore, it is imperative that thermal studies not be undertaken until such time as the aggregate investigations have proceeded to the point that the most likely aggregate sources are determined, and the availability of cementitious material is known. If changes occur related to the aggregate source or the type of cementing material as a result of the Contractor exercising options, supply difficulties, or site conditions, it may be necessary to rerun a portion of the study to verify the earlier results. The initial study must be completed before plans and specifications are finalized.

(3) Temperature control techniques. All the temperature control methods available for consideration have the basic objective of reducing temperature rise due to all factors including heat of hydration, reducing thermal differentials within the structure, and reducing exposure to cold air at the concrete surfaces which would create a sharp thermal differential within the structure. The most common techniques, in addition to selection of slow heat-gain cementitious materials, are the control of lift thickness, placing interval, maximum placing temperature, and surface insulation. On very large structures, post cooling has been used (ACI 224R).

(4) Numerical analysis of temperature control techniques. The analysis of the various temperature control techniques to determine the combination best suited to a particular project may be done by computer using a finite-element analysis program. Interdisciplinary coordination between materials engineers, structural engineers, and construction engineers is essential to ensure that the complex numerical analysis is based on reliable concrete and foundation properties and realistic construction techniques. Requests for consultation and assistance in performing numerical analysis should be made to CECW-EG. For structures of limited complexity, such as base slabs, satisfactory results may be obtained by the use of equations in ACI 207.4R.

c. Abrasion-erosion studies.

(1) General. Damage to the floor slabs of stilling basins due to abrasion by waterborne rocks and other debris is a constant maintenance problem on existing Corps projects. Abrasion-erosion on various projects has ranged from a few inches to 10 ft, and on occasion, severe damage has been noted after only a few years of operation. Hydraulic characteristics have a large effect on erosion and abrasion and should be considered in the design of spillways, conduits, and stilling basins.

(2) Test method. An underwater abrasion test method, ASTM C 1138 (CRD-C 63), is available to allow comparisons between materials proposed for use in stilling basins. Results of tests with several types of materials commonly thought to offer abrasion resistance suggest that conventional concrete of the lowest practical w/c and with the hardest available aggregates offer the best protection for new construction and for repair to existing hydraulic structures where abrasion-erosion is of concern. The abrasion tests should be performed to evaluate the behavior of several aggregate types for use in the stilling basin when more than one type is available.

(3) Application of test results. Because the costs of stilling basin repair is often substantial, it may prove feasible to import aggregate over a long distance for the concrete in the stilling basin slab if the aggregate in the project area is soft and the results of the abrasion test shows the potential for severe erosion. A discussion of stilling basin erosion should be included in the concrete materials DM. In some cases where hard aggregate is not economically available, silica-fume concrete with very high compressive strength may be used. Apparently, the hardened cement paste in the high-strength silica-fume concrete assumes a greater role in resisting abrasion-erosion, and as such, the aggregate quality becomes correspondingly less important.

d. Mixer grinding studies. During the investigation of an aggregate, it may be determined that the material degrades during handling and mixing. The tendency may be first noted as a high loss in the Los Angeles abrasion test (ASTM C 535 (CRD-C 145)). The result of this degrading is a significantly finer aggregate, and the result will be a loss of slump during mixing which will result in an increase in water demand. Tests should be run by mixing the actual materials for a time similar to that anticipated on the project and the mixture proportion adjusted to reflect the finer grading of the aggregate.

e. Concrete subjected to high-velocity flow of water.

(1) General. Wherever concrete surfaces are to be subjected to water velocities in excess of 40 ft/s for frequent or extended periods, special precautions should be taken. Examples of such surfaces include conduits, sluices, tunnels, spillway buckets, spillway faces, baffles, and stilling basins.

(2) Quality of concrete. The concrete should have excellent workability and a low w/c as indicated in Table 4-1. The nominal maximum size of aggregate should be limited to 37.5 mm (1-1/2 in.) except for the formed portions of the downstream face of spillways for gravity dams where the maximum size aggregate may be up to 75 mm (3 in.). In many projects, a special layer of high-quality concrete, at least 1-ft thick, is specified to be placed over a lower quality concrete. This is done to keep the overall heat of hydration lower and for economy. The thickness of high-quality concrete adjacent to the critical surface should be the practical minimum that can reasonably be obtained with conventional placing equipment and procedures, but in no case less than 1 ft. The high-quality concrete should be placed integrally with the normal concrete.

(3) Construction joints. Wherever possible, construction or lift joints should be avoided in the water passages. Where joints cannot be eliminated, care must be exercised during the construction to obtain required alignment and smoothness within the specified tolerance. For example, grade strips should be used at the tops of lifts to guide the placement. After the concrete has been placed to grade, the strip should be promptly removed and the lift surface adjacent to the form should be smoothed to provide an even joint when the overlying lift is placed.

(4) Unformed surfaces. Unformed surfaces subjected to a high-velocity flow of water should be finished with a steel trowel finish with no abrupt edges, pits, or roughness.

(5) Formed surfaces. Formed surfaces should be given a Class AHV finish. See paragraph 5-4e for definitions of classes of finish.

f. Unusual or complex problems. Occasionally during design or construction, problems may be encountered which require specialized knowledge not available within the district or division organization. At this point, consideration should be given to obtaining the services of CEWES-SC. The selection of a consultant knowledgeable in concrete materials will be made with the advice of the Office of the Chief of Engineers, ATTN: CECW-EG.