CHAPTER 3
REVIEW OF CONCRETE MIX DESIGNS

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3 REVIEW OF CONCRETE MIX DESIGNS

Introduction

This chapter involves review of concrete mix designs, an essential factor ensuring contract compliance resulting typically in a product meeting its design objectives. Basic principles of concrete mixture design are initially addressed to give a brief overview as to how different types and amounts of materials affect the properties of concrete.

Design of Concrete Mixes

In a broad sense "designing" a concrete mix means selecting the proportions of fine and coarse aggregate, cementitious materials, admixtures, and water, that when combined will produce concrete having certain desired qualities and properties. Requirements to be met by the mix design are generally selected based on the intended use of the concrete, exposure conditions, dimensions of structural elements, and physical properties of the concrete required. Concrete quality is directly related to the amount and properties of the materials used, and methods and environment in which it is placed, finished, and cured. Concrete mixtures should be kept as simple as possible, as an excessive number of ingredients often make a concrete mixture difficult to control.

As a measure of the overall quality of the hardened concrete, strength should be set at the lowest value necessary to ensure that concrete having the desired quality will be obtained. As a measure of the workability of the plastic mixture, consistency must be compatible with job conditions. While in a plastic state concrete should ideally be of such consistency that it may be readily placed and consolidated without segregation.

A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, the volume of a mix is about 10 to 15% cementitious material, 60 to 75% aggregate, and 15 to 20% water. Entrained air in concrete mixes may also take up to 8%. A concrete mixture that does not have enough paste to fill all the voids between the aggregates will be difficult to place and will produce rough honeycombed surfaces and porous concrete. A mixture with an excess of cementitious paste will be easy to place and will produce a smooth surface; however, the resulting concrete is likely to shrink more and be uneconomical.

Definitions

The following definitions are basic to a complete understanding of concrete mix design principles:

- *Water - Cement Ratio (W/C)* is defined as the ratio of the quantity of water to the quantity of cementitious material (sum of Portland cement and supplementary cementitious material) in the concrete mixture. It is usually expressed in terms of weight. If units are not indicated a ratio by weight is understood; that is, a water - cement ratio of 0.50 is understood to mean a ratio of one-half pound of water for each pound of cementitious material in the mix.

- *Specific Gravity (S.G.)* is the ratio of the mass of a given volume of material to the mass of an equal volume of water.

- *Bulk Specific Gravity (Saturated Surface Dry)* is the ratio of a given volume of material with its permeable voids filled with water to the mass of a volume of water equal to the total volume of the material. The total volume includes the combined volume of solid matter, permeable voids, and impermeable voids.

- *Absolute Volume* of a loose material is defined as the actual volume occupied by the solid particles of the material. The absolute volume of a material may be computed from the known weight and specific gravity, as follows:

$$\frac{\textit{Mass of Loose Material}}{\textit{(S.G.)} \times \textit{Unit Weight of Water}} = \textit{Absolute Volume}$$

- *Density* is defined as the weight of a known absolute volume of a material, usually expressed in pounds per cubic foot (pcf). The density of any material is equal to the product of the specific gravity of the material and the unit weight of water. In terms of density, it may be computed as follows:

$$\frac{\textit{Mass of Loose Material}}{\textit{Absolute Volume}} = \textit{Density}$$

- *Cementitious Factor* is defined as the sum of cement and supplementary cementitious material in a unit volume of concrete. It is usually expressed in lb/yd^3.

- *Free Water* is the total water in the mixture minus the water absorbed by the aggregates in reaching a saturated surface-dry condition.

Supplementary Cementitious Materials

Cementitious materials will exhibit binding properties and characteristics similar to that of Portland cement. Most concrete used on State projects will incorporate Portland cement and any individual or combination of the following materials to meet the contract requirements:

- Ground Granulated Blast Furnace Slag
- Fly Ash
- Raw or Calcined Natural Pozzolans
- Metakaolin
- Silica Fume
- Rice Hull Ash (not approved for structural elements via the 2010 Special Provisions)

Since the cementitious materials along with water combine to form the paste or "binder" that holds the aggregates together, maximizing the paste's quality is prudent. In a properly proportioned concrete mixture the cementitious paste surrounds and separates the individual aggregate particles preventing the physical interlocking of the particles. Absent the strengthening effects of aggregate interlocking, the paste alone must carry the loads imposed on the concrete. As a consequence, the strength of hardened concrete depends almost entirely on the strength of the cement paste. Therefore, the properties of concrete are influenced by the properties of cementitious materials. The type(s) and proportion(s) of cementitious materials affect both the fresh and hardened properties of concrete. An understanding of structure concrete characteristics can provide insight into any issues that may arise with concrete construction.

When choosing the types and amounts of cementitious materials it is advantageous to know what effects/characteristics each has on the concrete properties. Table 2-5 in Chapter 2 provides some information that pertains to the different types of supplementary cementitious materials (SCMs) when considering both freshly mixed and hardened concrete.

Aggregate

The term "aggregate gradation" is defined as the particle size distribution as determined by separation with standard sieves. Sieve analysis, screen analysis, grading analysis and mechanical analysis are terms used synonymously in referring to the process by which aggregate gradation is determined.

A "grading analysis" is made by passing a representative sample through a graded series of sieves and recording the percent passing, retained on, and/or falling between successive sieves in the series. The standard sieves used for grading fine aggregates are Numbers 4, 8, 16, 30, 50, 100 and 200. The screen number is the number of square openings per square inch. So a No. 4 screen would have 4 openings and a No. 50 would have 50 openings per square inch. The standard sieves for grading coarse aggregate are those having square openings of 2, 1 1/2, 1, 3/4 and 3/8 inches, plus the No. 4 and No. 8 sieves from the fine aggregate series. Standard grading charts, which have lines at intervals representing successive standard sieves, are used to plot particle size distribution.

Aggregate gradation is a highly technical subject. Over the years a great deal of study and research has been devoted to grading theory and much has been learned about the influence of aggregate gradation on the properties of a concrete mixture. However, thus far no one has discovered a simple, reliable method of determining the "ideal" grading for a given aggregate. Consequently, most grading curves have been developed empirically and are based on experience rather than theory.

Coarse aggregate consists of natural gravel, crushed gravel, crushed rock, reclaimed aggregate or combinations thereof. Fine aggregate consists of either natural sand or a combination of natural sand and manufactured sand. Coarse aggregate will vary in size depending on the purpose for which the material is being produced. When good coarse aggregate is available, the best concrete is produced by using the greatest percentage of the largest size of aggregate per cubic yard of concrete, which is compatible with job requirements. With reinforced concrete construction the maximum size of coarse aggregate will be limited by wall thickness, space between adjacent reinforcing bars, and/or similar structural features.

Fine aggregate serves two purposes. First, it is an inexpensive filler of most of the voids that exist in even the best-graded coarse aggregate. Second, it improves workability acting as a lubricant to facilitate concrete placement. The minimum quantity of fine aggregate needed to accomplish both purposes is the proper amount to use. Other factors being equal, very fine sands are uneconomical and will increase the cement demand because of the additional surface area to be coated with cement paste. Conversely, very coarse sands will produce harsh, unworkable mixes. In general, uniformly graded aggregates having neither a deficiency nor excess of any one size, which give a smooth grading curve, will produce the most satisfactory results.

Aggregate gradation is an important consideration in the design of a concrete mix because it affects the workability and the consistency of the concrete mixture, and is an influencing factor on both cost and quality of the finished product.

Grading Limits

Grading limits for aggregates are found in the Standard Specifications or the Special Provisions for a particular project. The specifications and/or provisions will include limits for all primary sizes of aggregate (fine and coarse) as well as limits for the combination of sizes that are used in the actual concrete mixture.

The primary size grading limits are intentionally broad to allow for economy through the use of aggregate from various sources. Limits of proposed gradations, often termed "X-values," provide flexibility and allow the contractor independent design judgment (within specified limits) to establish their compliance and operating ranges for the listed sieve sizes. Aggregate from any given source, however, must have a specific grading which may neither vary significantly nor be changed during its use on a project, except under extenuating circumstances as discussed in the following paragraph.

Before beginning work the contractor submits, for approval, a proposed aggregate grading which must be within the broad limits of the contract requirements. When approved, the grading must be maintained within the limits of variation permitted by the specifications. In those few instances where reasonable plant adjustments will not compensate for a major change in gradation, such as a change caused by moving from one pit to another, the contractor may request a change from the previously approved gradation. Note, however, that all requested revisions should be justified before they are approved which may require a resubmittal and requalification of the mix design.

Aggregates of the various primary sizes must be combined in such a way that the grading of the resulting aggregate mixture will lie within the combined grading limits in the specifications.

Maximum Density and Balanced Grading

The term "maximum density" is not a reference to weight when used to describe aggregate proportioning. Rather, it refers to the particle size distribution that will produce a mixture with the least volume of voids; that is, a mixture in which the voids or spaces between the larger particles are filled with smaller particles. Maximum density will be achieved when the particle-size distribution is such that no size greatly predominates and all sizes are uniformly distributed within the grading limits. Uniform particle size distribution is called "balanced" grading.

To ensure maximum density and prevent segregation the specifications require the grading of the 1″ x No. 4 coarse aggregate and the fine aggregate to be balanced. This ensures that "gap" grading does not occur. In some applications, "Gap" grading (omitting a particular size aggregate like 3/8 inch) can be useful but the likelihood of segregation, lower density, harsh mixes, and reduced "workability" are more apt to take place. The requirement is considered in the following examples:

General Information

- Contract provisions require the difference between the No. 16 sieve and the No. 30 sieve to be within 10 to 40%.
- The specification limits for the No. 16 sieve are from 55% to 75% passing.
- The limits for the No. 30 sieve are 34% to 46% passing.

Scenario #1 - An aggregate sample has 75% passing the No. 16 sieve and 34% passing the No. 30 sieve, thus both percentages fall within the acceptable range. However, the difference exceeds 40% thus the design is unbalanced.

Scenario #2 - An aggregate sample has 55% passing the No. 16 sieve and 46% passing the No. 30 sieve, thus both percentages fall within the acceptable range. However, the difference is less than 10% thus the design is unbalanced.

Workability and Gradation

Uniformly graded aggregate will produce the most workable concrete mixes. As a general rule, a grading to achieve maximum density will produce a mix of satisfactory workability as well.

Other factors being equal, the grading of the fine aggregate will have a greater effect on workability than will the grading of the coarse aggregate. Workability is particularly sensitive to the amount of material between the No. 50 and No. 100 sieves. A deficiency in this size may cause excessive bleeding. A grading of sand in which one or two sizes greatly predominate should be avoided. Such sand has a large void content and will require a large amount of cement paste to produce a workable mixture.

Particle Shape and Surface Texture

Both shape and surface texture characteristics of the individual aggregate particles have a pronounced effect on the workability of a concrete mixture.

Rounded aggregates result in a smooth, easily worked mixture whereas angular, elongated particles tend to interlock with each other and behave in a manner similar to a log jam producing what is referred to as a "harsh" mix.

Smooth, rounded particles will have a higher volume per unit of surface area than will angular, rough-textured particles, so that a minimum amount of cement paste will be needed to completely coat all particles. Aggregates having a high percentage of rough, angular particles will require more water to produce workable concrete, and more cement to maintain a given water-cement ratio, than smooth rounded aggregates.

Aggregate particles should be free of excessive amounts of flat, elongated pieces. This is particularly important in thin members where the flat surfaces of the aggregate may have a detrimental effect on concrete strength by creating a "weakened plane" along an axis subject to shear or diagonal tension stresses.

Because of differences in shape characteristics, more spherical (rounded) material may be added to a given quantity of cement paste than either cubical or prismoidal material; therefore, natural gravel is generally more economical than crushed stone since it will permit the use of a leaner mix (and therefore less cement) to obtain the same strength and workability.

Historically California Test Method 515 was used to limit the angularity of the fine aggregates used on state projects which provided insurance that the sand proposed for use would not result in an excessive amount of water to obtain the required workability. However, in addition to the typical historical concrete ingredients of cement, aggregate, and water the concrete mixtures of today have evolved to include the incorporation of chemical admixtures and supplementary cementitious materials that are designed for a given strength and workability. Thus, it was deemed no longer necessary and the CT 515 requirement was eliminated as a fine aggregate specification in 2010

Water

Almost any natural water that is potable and has no pronounced taste or odor may be used as mixing water for concrete. Keep in mind some waters that are not fit for drinking may still be suitable for concrete.

Excessive impurities in mixing water may not only affect setting time and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. The Standard Specifications Section 90, sets limits on chlorides, sulfates, alkalis, and solids in mixing water. When using reclaimed water be sure to test water quality for compliance.

When using admixtures it is important to realize that performance and efficiency of chemical admixtures may be influenced by certain compounds in water. For example, the dosage of air-entraining admixture may need to be increased when used with hard waters containing high concentrations of certain compounds or minerals.

Admixtures

Those ingredients other than the basic components of concrete (Portland cement, supplementary cementitious materials, water, and aggregates) that are added to the concrete mixture prior to or during mixing are considered admixtures. Various types of admixtures, discussed in Chapter 2, can be used to help achieve desirable properties for concrete. The effectiveness of admixtures depends on factors such as:

- Type and Brand
- Water content of mix
- Amounts of materials in concrete
- Aggregate shape, gradation, and proportioning
- Temperature of concrete
- Consistency
- Mixing time

When a trial batch is necessary to prequalify the mix, the concrete should be batched in similar placement conditions (temperatures, humidity, etc.) to ensure the dosage(s) of admixture(s) used represent effects on the fluid and hardened properties or the concrete. Typically, the amount of admixture recommended by the manufacturer or the optimum amount determined by laboratory tests should be used. When liquid admixture dosages exceed 1/2 gallon (64 oz.) per cubic yard, the volume shall be included when determining the amount of free water in the mix.

If a water-reducing or water-reducing and retarding admixture is used, the specifications allow an optional 5% reduction by weight of cementitious material required in the mix as long as a minimum cementitious content of 505 pounds per cubic yard is maintained. If the reduction in cementitious material is made the dosage of the admixture shall be no less than the dosage used in determining approval of the admixture measured in fluid ounces per 100 pounds of cement. This qualifying dosage rate will be listed on the Authorized Materials List for the admixture. Also, when referencing the manufacturer's suggested dosage rates, be sure to note and distinguish whether the rate is suggested in fluid ounces per 100 pounds of cement or cementitious materials.

In general, the dosage of chemical admixtures should be used based on the Portland cement content of a mix, and not on the amount of cementitious material (Portland cement + supplementary cementitious), unless so stated in the manufacturer's published recommendations. Water reducing admixtures (Types A and F) increase set time but only affect Portland cement. As an example, Grace WRDA 64 at a dosage rate of 3 fluid ounces per 100 pounds of cement at 72^{o}F retards set time 1.4 hours beyond normal set time. An overdose caused by assuming supplementary cementitious material were comparable to Portland cement would cause a significant increase in set time, which could become another cause for plastic shrinkage should the surface water evaporate quickly.

Mix Design Procedure (Absolute Volume Method)

Concrete, in a plastic state, may be visualized as a mixture of cementitious paste and aggregate with the paste completely surrounding and separating the individual aggregate particles. Thus the volume of concrete produced by a given quantity of paste and aggregate will be the sum of the following:

- Absolute volume of the aggregates
- Absolute volume of cement
- Absolute volume of supplementary cementitious materials
- Volume of water
- Volume of entrained air, if any
- Volume of additional admixtures, if applicable

The yield of batched concrete is an exception to the rule that "the whole is the sum of its parts." For example, a concrete mixture might contain:

- 1.3 cubic yards cementitious material
- 2.9 cubic yards sand
- 3.9 cubic yards gravel
- 1 cubic yard water

The sum of the individual volumes is 9.1 cubic yards, yet when mixed the batch may yield only 7 cubic yards of concrete. The sand fills the voids in the gravel and the cement paste fills the remaining voids. The presence and volume of entrapped or entrained air in the cement paste also needs to be considered.

Example #1

For a normal cementitious mixture the absolute volume method of mix design first calculates the absolute volume of cementitious material and the volume of water, in cubic feet per cubic yard, using the specified cement content and the desired wate -cement ratio.

For example, assume a mix having a water-cement ratio of 0.5 with a total cementitious material content of 675 pounds per cubic yard (pcy). The following specific gravities and proportions are assumed as listed:

- 70% Portland Cement with S.G. = 3.15
- 10% Ground Granulated Blast Furnace Slag with S.G. = 2.90
- 20% Class F Fly Ash with S.G. = 2.30
- Fine and coarse aggregates with Bulk S.G. (SSD) = 2.72

The calculations are:

Absolute Volume of Cementitious Material ⇒

$$\left(\frac{0.70\times 675\ lb}{3.15\times 62.4\ lb/ft^3}\right)+\left(\frac{0.10\times 675\ lb}{2.90\times 62.4\ lb/ft^3}\right)+\left(\frac{0.20\times 675\ lb}{2.30\times 62.4\ lb/ft^3}\right)=3.72ft^3$$

Absolute Volume of Water ⇒ $\left(\frac{0.50\times 675\ lb}{62.4\ lb/ft^3}\right)=5.41\ ft^3$

The absolute volume of the aggregates is determined by subtracting the absolute volume of cement and the volume of water in the batch.

Absolute Volume of Aggregates ⇒ $27\ ft^3 - 3.72\ ft^3 - 5.41\ ft^3 = 17.87\ ft^3$

Relative amounts of fine and coarse aggregate are obtained by multiplying the absolute volume of all aggregates by the percentage of each aggregate used in the mix. Percentages of aggregate are dependent on the properties of the aggregate (size, shape, porosity, texture, etc). A mix designer could use tables based on empirical relationships to determine proper percentages. For this example we will assume a 40/60% ratio between fine and coarse aggregate. The calculations are:

Absolute Volume of Fine Aggregate ⇒ $0.40 \times 17.87\ ft^3 = 7.15\ ft^3$

Absolute Volume of Coarse Aggregate ⇒ $0.60 \times 17.87\ ft^3 = 10.72\ ft^3$

The theoretical batch weights per cubic yard of concrete are as follows:

Fine Aggregate ⇒ $7.15\ ft^3 \times 2.72 \times 62.4\ lb/ft^3 = 1{,}214\ lb$

Coarse Aggregate ⇒ $10.72\ ft^3 \times 2.72 \times 62.4\ lb/ft^3 = 1{,}820\ lb$

Portland Cement ⇒ $0.70 \times 675lb = 472.5\ lb$

Ground Granulated Blast Furnace Slag ⇒ $0.10 \times 675lb = 67.5\ lb$

Class F Fly Ash ⇒ $0.20 \times 675lb = 135\ lb$

Water ⇒ $5.41\ ft^3 \times 62.4\ lb/ft^3 = 338\ lb$

Mix design quantities would be as follows:

Fine Aggregate $\Rightarrow$ *1,214 lb*

Coarse Aggregate $\Rightarrow$ *1,820 lb*

Portland Cement $\Rightarrow$ *473 lb*

Ground Granulated Blast Furnace Slag $\Rightarrow$ *68 lb*

Class F Fly Ash $\Rightarrow$ *135 lb*

$$\text{Free Water} \Rightarrow \frac{338\ lb}{8.34\ lb/gallon} = 40.5 gallons$$

To batch concrete accurately, adjust the theoretical batch weights to account for the weight of free water in the fine aggregate. Free water is measured as a percentage of the weight of the fine aggregate, and is referred to as "moisture content" in mix design terminology.

Assuming moisture content is 6% the batch weights are adjusted as follows:

Weight of Free Water $\Rightarrow$ *0.06 x 1,214 lb = 73 lb*

Adjusted Fine Aggregate $\Rightarrow$ *1,214 lb + 73 lb = 1,287 lb*

Adjusted Weight of Free Water $\Rightarrow$ *338 lb - 73 lb = 265 lb*

Therefore, actual batch proportions could be as follows:

Fine Aggregate $\Rightarrow$ *1,287 lb*

Coarse Aggregate $\Rightarrow$ *1,820 lb*

Portland Cement $\Rightarrow$ *473 lb*

Ground Granulated Blast Furnace Slag $\Rightarrow$ *68 lb*

Class F Fly Ash $\Rightarrow$ *135 lb*

$$\text{Free water} \quad \frac{265\ lb}{8.34\ lb/gallon} = 31.8\ gallons$$

Example #2

When air entrainment is introduced into a concrete mixture there is some reduction in strength if no changes are made in the mix proportions. The reduction occurs because the total volume of concrete produced is increased by an amount equal to the volume of entrained air, thus reducing the cementitious factor.

The procedure usually followed when designing air-entrained mixes is to first design a mix assuming no air, and then adjust the proportions to compensate for the volume of the entrained air. Air-entrained concrete will have greater workability than normal concrete with other factors remaining constant. The reduction in volume is accomplished by reducing the water content and the amount of fine aggregate. Usually, no change will be necessary in the volume of coarse aggregate. Most air-entrained concrete used on State highway projects will require a minimum of 590 pounds of cementitious material per cubic yard with a 6% air content. Although some industry manuals may replace the sand solely with the volume of air content, experience shows that for 6% air in combination with 590 pounds of cementitious material, while maintaining the same degree of workability, the water content may be reduced by about 33% of the volume of the entrained air.

To maintain the same relative yield, the proportions of the ingredients used in an air-entrained concrete mixture must be adjusted to compensate for the increased volume of air. Since an air-entrained concrete also will require less water than normal concrete of similar design, the usual procedure is to design the concrete mix assuming no air and then reduce the volume of fine aggregate by an amount equal (volumetrically) to the difference between the volume of entrained air and the reduction in water.

For example, assume a mix having a water - cement ratio of 0.48 with a total cementitious material content of 590 lb/yd^3. The following specific gravities and proportions are assumed as listed:

- 75% Portland cement with S.G. = 3.15
- 5% Ground Granulated Blast Furnace Slag with S.G. = 2.90
- 20% Class F Fly Ash with S.G. = 2.30
- Fine and coarse aggregates with Bulk S.G. (SSD) = 2.70

Absolute Volume of Cementitious Material $\Rightarrow$

$$\left(\frac{0.75\times 590lb}{3.15\times 62.4\ lb/ft^3}\right)+\left(\frac{0.05\times 590lb}{2.90\times 62.4\ lb/ft^3}\right)+\left(\frac{0.20\times 590lb}{2.30\times 62.4\ lb/ft^3}\right)=3.24\ ft^3$$

$$\text{Absolute Volume of Water}\ \left(\frac{0.48\times 590lb}{62.4\ lb/ft^3}\right)=4.54\ ft^3$$

Assuming a 40/60% ratio between fine aggregate to coarse aggregate:

$$\text{Absolute Volume of Fine Aggregate} \Rightarrow (27\ ft^3 - 3.24\ ft^3 - 4.54\ ft^3) \times (0.4) = 7.68\ ft^3$$

$$\text{Absolute Volume of Coarse Aggregate} \Rightarrow (27\ ft^3 - 3.24\ ft^3 - 4.54\ ft^3) \times (0.6) = 11.53\ ft^3$$

Reducing the volume of fine aggregate and water to account for the volume of air in the mix gives the following adjusted mix design:

$$\text{Volume of Air} \Rightarrow 0.06 \times 27\ ft^3 = 1.62\ ft^3$$

$$\text{Coarse Aggregate (No adjustment)} = 11.53\ ft^3$$

$$\text{Cementitious Material (No adjustment)} = 3.24\ ft^3$$

$$\text{Water (adjustment)} \Rightarrow 0.33 \times 1.62\ ft^3 = 0.53\ ft^3 \Rightarrow 4.54\ ft^3 - 0.53\ ft^3 = 4.01\ ft^3$$

$$\text{Fine Aggregate (adjustment)} \Rightarrow 0.67 \times 1.62\ ft^3 = 1.09\ ft^3 \Rightarrow 7.69\ ft^3 - 1.09\ ft^3 = 6.60\ ft^3$$

$$\text{TOTAL VOLUME} = 27.0\ ft^3$$

Review of Concrete Mix Designs

Before using any Portland cement based concrete the contractor is required to submit in writing a copy of their mix design(s). An integral part of quality assurance is the review of submitted concrete mix design(s). Attention must be paid to details in the Plans, Special Provisions, and Standard Specifications to ensure a compliant concrete mix is used in the work. On most projects there will be multiple concrete mix designs. Care must be taken to ensure that the proper concrete mixes are designated to be used at the proper locations.

It is the contractor's responsibility to design a mix using ingredients that are in compliance with the contract requirements. If a submitted concrete mix design does not meet the contract requirements this must be brought to the contractor's attention. Except for rare cases, a mix design not in accordance with contract documents should not be used on the project. If the parameters of the mix design specifications are not met, a change order must be written to allow the use of the concrete mix design.

There are various Authorized Materials Lists available to ensure quality products are being incorporated into our structures. Authorized and/or prequalified lists are available for the following concrete ingredients:

- Portland cement
- Supplementary cementitious materials
- Innocuous aggregates
- Air-entraining admixtures
- Chemical admixtures

If products used in the mix design are listed as authorized, they are acceptable for incorporation into concrete mixes. However, it is still required for the contractor to provide manufacturers' information and/or certificates of compliance with their initial submittal.

Aggregate that is not on the "innocuous aggregate" list may still be used in the concrete mix but must be considered "non-innocuous aggregate."

Initial Submittal Review

Upon receipt of a submitted mix design, an initial review must take place to ensure you have received a complete submittal. If information is missing it should be brought to the contractor's attention promptly. Table 3-1 will provide you with a guideline regarding your initial review:

Table 3-1. Concrete Mix Design Submittal Checklist.

A) CEMENT	
□ Yes □ No	On Authorized Materials List?
□ Yes □ No	If type II, III, or V Portland cement does it contain more than 0.60% by mass of alkalies?
□ Yes □ No	Autoclave expansion > 0.50%?
□ Yes □ No	If type II Portland cement does Tricalcium silicate content exceed 65%?
B) BLENDED CEMEMT	
□ Yes □ No (If No, skip to C)	Blended cement used?
□ Yes □ No	Blended cement materials on Authorized Materials List??
C) SUPPLEMENTARY CEMENTITIOUS MATERIALS	
□ Yes □ No	All SCMs on Authorized Materials List?
C-1) Fly Ash	
□ Yes □ No (If no skip to C-2)	Is Fly Ash used?
□ Yes □ No	Meets AASHTO M295, Class F?
□ Yes □ No	Sodium oxide (Na_2O) total and equivalent included?
C-2) ULTRA FINE Fly Ash	
□ Yes □ No (If No, skip to C-3)	Is Ultra Fine Fly Ash used?
□ Yes □ No	Meets AASHTO M295, Class F?
□ Yes □ No	Sulfur trioxide (SO_3) content included?
□ Yes □ No	Loss on ignition percentage included?
□ Yes □ No	Sodium oxide (Na_2O) total and equivalent included?
□ Yes □ No	Particle size distribution included?

Table 3-1. Concrete Mix Design Submittal Checklist (continued).

☐Yes ☐ No	Strength Activity Index included?
☐Yes ☐ No	Expansion at 16 days via ASTM C1567 included?
C-3) RAW OR CALCINED NATURAL POZZOLAN	
☐Yes ☐ No (If no, skip to C-4)	Is Raw or Calcined Natural Pozzolan used?
☐Yes ☐ No	Meets AASHTO M295, Class N?
☐Yes ☐ No	Sodium oxide (Na_2O) total and equivalent included?
C-4) METAKAOLIN	
☐Yes ☐ No (If no, skip to C-5)	Is Metakaolin used?
☐Yes ☐ No	Meets AASHTO M295, Class N?
☐Yes ☐ No	Silicon dioxide (SiO2) and Aluminum oxide (Al_2O_3) content included?
☐Yes ☐ No	Calcium oxide (CaO) content included?
☐Yes ☐ No	Sulfur trioxide (SO_3) content included?
☐Yes ☐ No	Loss on ignition included?
☐Yes ☐ No	Sodium oxide (Na_2O) equivalent included?
☐Yes ☐ No	Particle size distribution included?
☐Yes ☐ No	Strength Activity Index included?
C-5) GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)	
☐Yes ☐ No (If no, skip to C-6)	Is Ground Granulated Blast Furnace Slag used?
☐Yes ☐ No	AASHTO M302 Grade 100 or 120?
C-6) SILICA FUME	
☐Yes ☐ No (If no, skip to C-6)	Is Silica Fume used?
☐Yes ☐ No	Meets AASHTO M307?
☐Yes ☐ No	Reduction in mortar expansion included?
D) AGGREGATE	
☐Yes ☐ No	Are proposed gradation(s) included?

Table 3-1. Concrete Mix Design Submittal Checklist (continued).

□ Yes □ No (If yes, reduced "X" allowed in Section B)	Aggregates on Innocuous Aggregates List?
D-1) COARSE AGGREGATE	
□ Yes □ No	Loss via CT 214 included?
□ Yes □ No	Loss in Los Angeles Rattler included (CT 211)?
□ Yes □ No	Cleanness value included (CT 227)?
D-2) FINE AGGREGATE	
□ Yes □ No	Loss via CT 214 included (waived if durability index of fine aggregate is 60 or greater)?
□ Yes □ No	Durability index via CT 229 included (only necessary if CT 214 does not meet qualifications)?
□ Yes □ No	Organic impurities results included (CT 213)?
□ Yes □ No	Sand equivalent included (CT 217)?
E) CHEMICAL ADMIXTURES	
□ Yes □ No (If No, skip to F)	Chemical admixture(s) used?
□ Yes □ No	On Authorized Materials List?
□ Yes □ No	Dosage verified per plans or manufacturer's recommendations
F) AIR - ENTRAINING ADMIXTURE	
□ Yes □ No (If No, skip to F)	Air-entraining admixture(s) specified or used?
□ Yes □ No	On Authorized Materials List?
□ Yes □ No	Dosage verified per plans or manufacturer's recommendations

Upon receipt of a complete submittal you should start with checking the mix design to ensure it meets all contract requirements including:

- Chemical and physical requirements for cement, SCMs, and admixtures.
- Aggregate properties, testing results and gradations.
- Manufacturer's recommended dosage rates for admixtures.
- Shrinkage limits met per AASHTO T160 if applicable.

Once you determine that all material prerequisites previously mentioned have been met you will want to proceed with checking the aggregate gradations and proportioning of materials to ensure they meet the contract requirements.

Checking Submitted Cementitious Material Requirements and Proportioning

First, you will need to determine if the type(s) of cementitious materials chosen to be used are on the Authorized Materials List. In addition, all applicable test requirements listed in the specifications need to be verified to ensure compliance

The Special Provisions and/or Standard Specifications will depict the minimum cementitious content requirement for the type of facility or structure you are building. The summation of submitted cementitious components must meet the minimum/maximum cementitious material content limits. If the submittal includes a blended-cement, the percentage of each component must be provided. Form DS-OS C70 can assist you with checking to ensure compliance with the specifications.

For the upcoming equations the following terms are defined:

UF = Silica fume, metakaolin, or UFFA, including the amount in blended cement, lb/yd^3.
FA = Fly Ash or natural pozzolan conforming to the requirements in AASHTO Designation: M295, Class F or N with a CaO content up to 10%, including the amount in blended cement, lb/yd^3.
FB = Fly Ash or natural pozzolan conforming to the requirements in AASHTO Designation: M295, Class F or N with a CaO content up to 15%, including the amount in blended cement, lb/yd^3.
F = Fly Ash or natural pozzolan complying with AASHTO M295, Class F or N, including the quantity in blended cement, lb/yd^3. F is equivalent to either FA or FB.
SL = GGBFS including the amount in blended cement, lb/yd^3.
MC = Minimum amount of cementitious material specified, lb/yd^3.
MSCM = The minimum sum of SCMs that satisfies Equation (1) for general concrete, lb/yd^3.
PC = The amount of Portland cement, including the amount in blended cement, lb/yd^3.
TC = Total quantity of cementitious material used, lb/yd^3.

Note the precision of the equations in the specification is intentional. If the value is listed to the nearest tenth (0.1) in the specifications then the calculated answer of the equation should likewise be calculated to the nearest tenth (0.1).

For general Portland cement concrete the SCM content shall conform to either Option A or B:

Option A: Any combination of Portland cement and at least one SCM, satisfying Equations 1 and 2:

Equation (1) $$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC} \geq X$$ *- Ensures minimal use of SCMs*

X = 1.8 for innocuous aggregate, 3.0 for all other aggregates.

Equation (2) $MC - MSCM - PC \geq O$ *- Limits amount of Portland cement*

Option B: 15% of Class F Fly Ash with at least 48 ounces of $LiNO_3$ solution added per 100 pounds of Portland cement. CaO content of the Fly Ash shall not exceed 15%.

If the concrete is designated for a freeze-thaw region (without exposure to de-icing chemicals) this additional equation must be met:

$$\frac{(41\times UF)+(19\times F)+(11\times SL)}{TC} \leq 7.0$$ *- Limits SCM amount in mix*

For concrete designated as exposed to de-icing chemicals, Equations 1 through 5 must be satisfied:

Equation (1) $$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{TC} \geq X$$ *- Ensures minimal use of SCMs*

Equation (2) $$\frac{4\times(FA+FB)}{TC} \leq 1.0$$ *- Limits Fly Ash to maximum of 25% of TC*

Equation (3) $$\frac{(10\times UF)}{TC} \leq 1.0$$ *- Limits UF to maximum of 10% of TC*

Equation (4) $$\frac{2\times(UF+FA+FB+SL)}{TC} \leq 1.0$$ *- Limits SCMs to maximum of 50% of TC*

Equation (5) $$\frac{27\times(TC-MC)}{MC} \leq 5.0$$ *- Limits TC to 18.5% maximum increase above MC*

Precast concrete is the one situation, only if the aggregates are listed as innocuous, in which the contractor can use 100% Portland cement. Precast concrete shall conform to one of the following options.

Option A: Any combination of Portland cement and SCM (if necessary), satisfying the following equation:

Equation (1) $$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC} \geq X \textit{ Ensures minimal use of SCM}$$

Where:

X = 0.0 if precast members are constructed with Portland cement concrete using aggregate that is "innocuous" in conformance with the provisions.
X = 3.0 for all other aggregates.

Option B: Fifteen percent of Class F Fly Ash with at least 48 ounces of $LiNO_3$ solution added per 100 pounds of Portland cement. CaO content of the Fly Ash shall not exceed 15%.

Option C: Any combination of supplementary cementitious material and Portland cement may be used if the expansion of cementitious material and aggregate does not exceed 0.10% when tested in conformance with the requirements in ASTM C1567.

Concrete designated for a corrosive enviroment must meet the prescriptive requirements of the Standard Specifications.

Due to the increased use of SCMs, the following applies:

- If the specified 28-day compressive strength is greater than 3,600 psi, 42 days will be allowed to meet the specified 28-day strength requirement.
- If the proportions of cementitious material satisfy the following equation, 56 days will be allowed to meet the specified 28-day strength requirement.

$$\frac{(41\times UF)+(19\times F)(11\times SL)}{TC} \geq 7.0$$

Checking Submitted Aggregate Gradations

You will need to determine what primary coarse size aggregate the contractor has chosen to use in their mix design and ensure that it meets the specified requirements of the contract. A contractor is allowed to use multiple stockpiles for their chosen primary coarse aggregate sizes if they deem necessary. If a primary coarse aggregate or fine aggregate is separated into two or more sizes, contractors are required to submit the gradation and proposed proportions of each size, both separately, and combined. The combined gradation of all aggregate must meet the contract requirements. They must show the percentage passing for each required sieve size.

The coarse aggregate(s) used may be any singular or combination of the following:

- Gravel
- Crushed rock
- Crushed gravel
- Reclaimed aggregate (must still meet all aggregate contract requirements)
- Iron blast furnace slag that has been air-cooled then crushed (not allowed in structures work containing reinforcement)

The fine aggregate(s) used may be any singular or combination of the following:

- Natural Sand
- Manufactured Sand (derived from crushing larger aggregates)

In order to provide contractors with some flexibility when designing their mix they are allowed to choose their "Limits of Proposed Gradation" otherwise commonly referred to as "X-values" for certain sieve sizes of their chosen primary aggregate nominal size and fine aggregate. Their submitted "Limits of Proposed Gradation" must lie within the range provided by the contract documents. The allowable window for percentage passing of the applicable certain sieve sizes will adjust based on the contractor's chosen X-values for primary coarse size and fine aggregate.

The final step will be to verify that the contractor's submitted gradation for the primary coarse aggregate, fine aggregate, and combined aggregate gradings meet the contract requirements. Form DS-OS C70A is available to assist you with checking of the submitted gradations.

In accordance with the State Contract Act, verify that the material and aggregate source(s) comply with the Surface Mining and Reclamation Act of 1975 (SMARA). Mining operations determined to be in compliance are listed on the AB 3098 SMARA Eligible list. You can obtain this list from the Division of Construction or the Department of Conservation's web site at:

http://www.consrv.ca.gov/OMR/ab_3098_list/index.htm

Also, see Section 7-103D, “Surface Mining and Reclamation Act” of the Construction Manual to determine if the proposed materials site is exempt from SMARA.

Checking Amount of Water and Penetration

You can determine the allowable penetration or slump pending on what type of facility or structure you are constructing via Section 90 of the Standard Specifications. Keep in mind that if a Type F or G chemical admixtures is used, a significant increase in slump is allowed.

The typical amount of free water allowed (unless adverse conditions are met) must not exceed 310 pounds per cubic yard (pcy) plus an additional 20 pcy for each 100 pounds of cementitious material in excess of 550 pcy. A gallon of water weighs approximately 8.34 pounds at 60°F. Remember that the amount of free water is defined as the total water in the mixture minus the water absorbed by the aggregates in reaching a saturated surface-dry condition.

When calculating the total quantity of free water, liquid admixtures must be accounted for in the mix design as equivalent to free water if the dosage is more than 0.5 gallon (64 fluid ounces) per cubic yard of concrete.

Checking Submitted Chemical or Air-Entraining Admixtures

Admixtures must be used if specified in the contract. Multiple chemical and/or air-entraining admixtures shall be compatible when used together, and the manufacturer’s recommendations must include a statement that the admixtures are compatible with the types and quantities of SCMs used. The amounts used shall be in accordance with the manufacturer’s recommendations.

Air-entrainment use is optional if not specified by the contract. Requirements regarding allowable or targeted air content are dependent on whether air entrainment is specified or used optionally. If air entrainment is specified, the target air content will be provided in the contract and may vary depending upon the location of the District where the project is being constructed.

Binary Mix Design Check

Example #1 uses the following mix design:

Concrete Mix Design
CM381016F
Specified Compressive Strength: 4,000 psi

Contractor:	Charismatic Construction
Project:	Hwy 52 – Contract 03-256804
Source of Concrete:	Poncherello's Quality Concrete
Construction Type:	Bridge Deck Concrete
Placement:	Pump or Tailgate

Weights per Cubic Yard (Saturated, Surface Dry)

	Quantity	Specific Gravity	Yield (ft^3)
ASTM C-150/Type II Mod. cement, lb	480.0	3.15	2.44
ASTM C-168/Class F Fly Ash, lb	165.0	2.43	1.09
Water, lb	285.0 (34.2 gal)	1.00	4.57
1″ x #4 Red Rock Aggregate, lb	1,804	2.89	10.0
Yosemite Sand, lb	1,425	2.69	8.49
322N – Type A (oz/100 lb Portland cement)			
Total Air,%	1.5 + - 0.5		

Total = 27.0 ft^3

Limits of Proposed Gradation (X-Values)

Aggregate		Sand	
3/4″	X = 80	No. 16	X = 69
3/8″	X = 17	No. 30	X = 46
		No. 50	X = 26

Aggregate Gradation Analysis Results (Percent Passing)

Aggregate		Sand	
1 1/2″	100%	3/8″	100%
1″	100%	No. 4	100%
3/4″	81%	No. 8	84%
1/2″		No. 16	61%
3/8″	8%	No. 30	37%
No. 4	1%	No. 50	20%
No. 8	0%	No. 100	7%
		No. 200	3%

Figure 3-1. Example Concrete Mix Design - Binary Mix.

Given:
Material sources:
Portland cement = Lehigh Southwest, Permanente Plant Type II/V
Class F Fly Ash, Headwaters Resources Inc., Delta Power Plant Class F Fly Ash
Coarse Aggregate = Teichert, Martis Valley Pit
Fine Aggregate = Western, Western Aggregate Mine

Initial Material(s) Check

Is Portland cement on Authorized Materials List?	YES
• Tricalcium Silicate Content ≤ 65%?	YES
• ≤ 0.60% by mass of alkalies?	YES
• Autoclave Expansion < = 0.50%?	YES
Is Class F Fly Ash on Authorized Materials List?	YES
• Calcium Oxide Content ≤ 15%?	YES
Is Coarse Aggregate source SMARA listed?	YES
Is Coarse Aggregate on Innocuous Aggregate List?	YES (SMARA 91-58-0001)
• (CT 214) ≤ 10% loss via Soundness test	YES
• (CT 211) Los Angeles Rattler ≤ 45%	YES
• (CT 227) Cleanness ≥ 75	YES
Is Fine Aggregate source SMARA listed?	YES (SMARA 91-29-0004)
Is Fine Aggregate on Innocuous Aggregate List?	YES
• (CT 213) Organic Impurities = "Satisfactory"	YES
• (CT 217) Sand Equivalent ≥ 75	YES
Is Type A Admixture (Polyheed 322N) on List?	YES
Shrinkage Information (AASHTO T 160) submitted/met?	YES

Materials:
Type II Portland cement = 480 lb/yd^3 (S.G. = 3.15)
Fly Ash, Class F (CaO content 14%) = 165 lb/yd^3 (S.G. = 2.35)
Aggregate Type = Innocuous

Calculate the Total Cementitious Material Content (TC)

Minimum cementitious (MC) content via the Standard Specifications for bridge deck concrete = 675 lb/yd^3. If a water reducing admixture is used, a 5% by weight reduction of cementitious material content is allowed via the Standard Specifications if the dosage meets or exceeds the dosage used in determining approval of the admixture. The mix dosage of 5 oz per 100 lb cement is greater than the dosage rate of 4 oz per 100 lb used to qualify the Polyheed 322N given on the Authorized Materials List, thus a 5% reduction is allowed if the contractor elects.

$$MC = 675\ lb/yd^3 \times (100\% - 5\%) = 641\ lb/yd^3$$

Total Cementious Material Content (TC)

$$TC = 480\ lb/yd^3 + 165\ lb/yd^3 = 645\ lb/yd^3$$

$$645\ lb/yd^3 > 641\ lb/yd^3$$

OK

Check Equation #1 for General Concrete:

$$\frac{(25 \times UF) + (12 \times FA) + (10 \times FB) + (6 \times SL)}{MC} \geq X$$

UF = 0 (No Silica Fume used in mix)
FA = 0 (No Fly Ash or Natural Pozzolan used with CaO content ≤ 10% in mix)
FB = 165 lb/yd³
SL = 0 (No ground granulated blast furnace slag in mix)
MC = 641 lb/yd³
X = 1.8 for innocuous aggregate

$$\frac{(25 \times 0) + (12 \times 0) + (10 \times 165) + (6 \times 0)}{641} = 2.57$$

$$2.60 \geq 1.8$$

OK

Calculate the Minimum Supplementary Cementitious Material (MSCM) to be used in Equation #2

Note: In order to calculate the MSCM of Equation #1, iterations are necessary. To simplify this calculation start from left to right and enter the SCM values, up to the actual amount in the mix until the left side of the equation is equal to the required X value (X = 1.80 in this case)

Equation #1

$$\frac{(25 \times UF) + (12 \times FA) + (10 \times FB) + (6 \times SL)}{MC} \geq X$$

Enter in the amount of UF up to the actual (in this case 0 lb/yd³)

$$\frac{(25 \times 0)}{641} = 0$$

Enter in the amount of FA up to the actual (in this case 0 lb/yd³)

$$\frac{(25 \times 0) + (12 \times 0)}{641} = 0$$

Enter in the amount of FB up to the actual (in this case 165 lb/yd³)

$$\frac{(25\times0)+(12\times0)+(10\times165)}{641}=2.57$$

2.57 > X = 1.8 so the Fly Ash (FB) quantity needs to be adjusted so the equation = 1.8. Solve for FB to obtain the MSCM value.

$$10 \text{ x } FB = (1.8\text{x}641) - (25\text{x}0) - (12\text{x}0)$$

$$FB=\frac{(1.8\times641)+(25\times0)(25\times0)}{10}$$

$$FB=115$$

<u>***MSCM = 115 lb/yd³***</u>

Check Equation #2

$$MC - MSCM - PC \geq 0$$

MC = 641 lb/yd³
MSCM = 115 lb/yd³
PC (total quantity of Portland cement) = 480 lb/yd³

641 - 115 - 480 = 46
46 lb/yd³ > 0
<u>**OK**</u>

Verify the allowed Strength Development Time

A total of 56 days is allowed to obtain the required compressive strength if the following equation is met:

$$\frac{(41\times UF)+(19\times F)(11\times SL)}{TC}\geq\ 7.0$$

UF = 0 (No Silica Fume used in mix)
F = (Fly Ash A and Fly Ash B combined) 165 lb/yd³
SL = 0 (No ground granulated blast furnace slag in mix)
TC (Total quantity of cementitious material in mix) = 645 lb/yd³

$$\frac{(41\times0)+(19\times165)+(11\times0)}{654}=4.79$$

4.8 < 7.0

Thus the 56-day total is not allowed to gain the specified strength. The contractor must abide by the specified time allowance of the contract.

Free Water

The allowable amount of free water per the Standard Specifications Section is 310 lb/yd^3 plus 20 lb/yd^3 for each 100 lb of cementitious material in excess of 550 lb/yd^3. Calculate the allowable amount of free water:

$$310 + \frac{(645\text{-}550)}{100} \times 20 = 329$$

Total allowable amount of free water = 329 lb/yd^3
or 329/(8.34 lb/gallon) = 39.4 gallons/yd^3
39.4 gallons/yd^3 > 33.9 gallons/yd^3
OK

Gradation Check

Given:

Aggregate Sizes

- Primary Coarse Aggregate = 1″ x No. 4
- Fine Aggregate = Sand

Check to see if the submitted X-values for the primary aggregate sizes are in compliance with the limits of proposed gradation.

Coarse Aggregate (1″x No. 4)

Sieve Size	Limits of Proposed Gradation	Submitted X-Value	Status
3/4″	52-85	80	OK
3/8″	15-38	17	OK

Fine Aggregate (Sand)

Sieve Size	Limits of Proposed Gradation	Submitted X-Value	Status
No. 16	55-75	69	OK
No. 30	34-46	46	OK
No. 50	16-29	26	OK

Next check the coarse and fine aggregate gradings individually. All values must lie within the operating ranges given in the specifications.

Table 3-2. Coarse Aggregate (1" x No. 4) Grading Checklist - Binary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
1.5″			100	100	OK
1″			88 - 100	100	OK
3/4″	80	X +/- 15	65 - 95	81	OK
3/8″	17	X +/- 15	2 - 32	8	OK
No. 4			0 - 16	1	OK
No. 8			0 - 6	0	OK

Table 3-3. Fine Aggregate (sand) Grading Checklist - Binary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
3/8″			100	100	OK
No. 4			95 - 100	100	OK
No. 8			65 - 95	84	OK
No. 16	69	X +/- 10	59 - 79	61	OK
No. 30	46	X +/- 9	37 - 55	37	OK
No. 50	26	X +/- 6	20 - 32	20	OK
No. 100			2 - 12	7	OK
No. 200			0 - 8	3	OK

Also, the Specifications state that in addition to the above required grading analysis, the fine aggregate sizes must be distributed such that:

- Difference between the total percentage passing the No. 16 and No. 30 sieves is from 10 to 40 (Check = 61 - 37 = 24) $\Rightarrow$ OK
- Difference between the percentage passing the No. 30 and No. 50 sieves is from 10 to 40 (Check = 37 - 20 = 17) $\Rightarrow$ OK

Next you need to check the combined gradation of the aggregates. You will need the percentage of volume of each primary aggregate size.

The proportions of each aggregate size can be calculated as follows:

Coarse Aggregate = (1,804 lb/2.89) / ((1,804 lb/2.89) + (1,425 lb/2.69)) = 54.1%
Fine Aggregate = (1,425 lb/2.69) / ((1,804 lb/2.89) + (1,425 lb/2.69)) = 45.9%

Table 3-4. Combined Aggregate Grading Checklist - Binary Mix.

Sieve Size	Percentage Passing Coarse Aggregate	Percentage Passing Fine Aggregate	Mix Percentage of Coarse Aggregate	Mix Percentage of Fine Aggregate	Combined Total Percentage Passing	Specifications Limits	Status
1.5″	100	100	54.1	45.9	100	100	OK
1″	100	100	54.1	45.9	100	90-100	OK
3/4″	81	100	54.1	45.9	89.7	55-100	OK
3/8″	8	100	54.1	45.9	50.2	45-75	OK
No. 4	1	100	54.1	45.9	46.4	35-60	OK
No. 8	0	84	54.1	45.9	38.6	27-45	OK
No. 16	0	61	54.1	45.9	28.0	20-35	OK
No. 30	0	37	54.1	45.9	17.0	12-25	OK
No. 50	0	20	54.1	45.9	9.2	5-15	OK
No. 100	0	7	54.1	45.9	3.2	1-8	OK
No. 200	0	3	54.1	45.9	1.4	0-4	OK

Example Calculation (for No. 4 sieve):
(0.541 x *1) + (0.459* x *100) = 46.4%*

The resulting gradation analysis would be plotted out as shown:

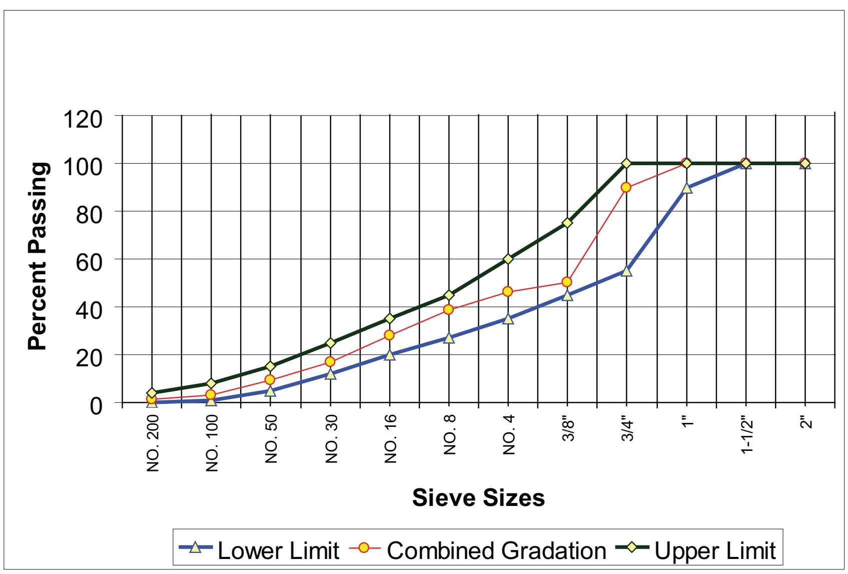

Figure 3-2. Aggregate Gradation Chart - Binary Mix.

Ternary Mix Design Check

Example #2 uses the following mix design for stem and soffit concrete with freeze-thaw exposure.

ARNIE'S REDI-MIX

A DIVISION OF MANPREET COMPANY, INC.

SHEET 1 OF 2

Date 5/23/2010

DESIGN OF CONCRETE MIX

Report To:	Michael Knight Construction	Project	CA. NO. 06-986524
	1564 Kitt Way	Location	Hwy 180, Beaver Dam Bridge
	Big Bend, CA 96532		PM 15.24

MATERIAL AND LABORATORY DATA

AGGREGATE SOURCE: F.A. Aggregrate Products C.A. Aggregrate Products

A.S.T.M.	C-29	C-127	C-40	C-117	C-127
AGGREGRATE	WEIGHT PER CU.FT.	SPECIFIC GRAVITY	ORGANIC	DECANTATION	ABSORPTION
1" x No. 4		2.67			1.7
3/8" x No. 8		2.65			2.3
Sand		2.62			2.5

MECHANICAL ANALYSES PERCENT PASSING U.S. STANDARD SIEVES

	1 1/2"	1"	3/4"	3/8"	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	F.M.
1" x No. 4	100	100	78	8	2						7.12
3/8" x No. 8		100	100	91	17	3					5.89
Sand				100	100	84	60	38	20	8	2.9
Combined	100	100	91	60	46	37	26	16	9	3	5.12

Cementitious Factor(lb/yd^3)	600 lb/yd^3(Cementitious)	Water/Cementitious Ratio	0.505
Minimum 28 Day Strength	4000 psi	Penetration	2" Max
		Admixtures	Darex II
Entrained Air Required	3.0%(Optional)	Cement Type	II - V

	Material	Percentage Parts	Quantities	
Mix No. CT-600-7F Location: Stem/Soffit			lbs	Based upon aggregates in saturated surface dry condition. Correction necessary for free moisture on aggregates
	1" x No. 4	42.0	1174	
	3/8" x No. 8	15.0	416	
	Sand	43.0	1180	
	Flyash		125	
	GGBFS		175	
	Cement		300	
	Total Water		303	
	Admixture	per mfr.		
	Totals	100.0	3673	

This mix will produce concrete meeting the design criteria when produced, sampled, and tested in accordance with ASTM C-94

Respectfully Submitted

By ____________________

Jeremy Jessup, Manager

Figure 3-3. Example Concrete Mix Design - Ternary Mix.

ARNIE'S REDI-MIX

A DIVISION OF MANPREET COMPANY, INC.
SHEET 2 OF 2

Date 5/23/2010

Report To: Michael Knight Construction
1564 Kitt Way
Big Bend, CA 96532

Project CA. NO. 06-986524
Location Hwy 180, Beaver Dam Bridge
PM 15.24

PROPOSED GRADATION OF PRIMARY AGGREGATE NOMINAL SIZES
PORTLAND CEMENT CONCRETE

AGGREGATE SOURCE - Aggregate Products

In Compliance with Section 90-1.02C(4), Aggregate Gradings, of the 2010 Standard Specifications the undersigned proposes to use Portland Cement Concrete Aggregate as follows:

	1.5" x 3/8" (Primary Size)			1" x No. 4" (Primary Size)			Fine Aggregates			Combined Gradation	
Individual Sizes Proposed Percentages	SRM Proposed Gradation	Caltrans Ind. Agg. Limits	Caltrans Operating Range	SRM Proposed Gradation	Caltrans Ind. Agg. Limits	Caltrans Operating Range	SRM Proposed Gradation	Caltrans Ind. Agg. Limits	Caltrans Operating Range	SRM Proposed Gradation	Caltrans Operating Range
Sieve Size											
2"											100
1.5"						100					100
1"				100		88-100				100	90-100
3/4"				X=80	52-85	X+-15				91	55-100
3/8"				X=30	15-38	X+-15			100	60	45-75
No. 4				6		0-16	100		95-100	46	35-60
No. 8				1		0-6	84		65-95	37	27-45
No. 16							X=60	55-75	X+-10	26	20-35
No. 30							X=38	34-46	X+-9	16	12-25
No. 50							X=20	16-29	X+-6	9	5-15
No. 100							8		2-10	3	1-8
No. 200							3.5		0-5	1.3	0-4

Respectfully Submitted

By ____________________
Jeremy Jessup, Manager

Figure 3-3. Example Concrete Mix Design - Ternary Mix (continued).

Given:

Material Source:

Portland cement = Cemex, Victorville Plant Type II/V
Class F Fly Ash = Headwaters Resources Inc., Bridger Power Plant Class F Fly Ash
GGBFS = LaFarge North America, Seattle Plant, Grade 100
Coarse Aggregate = (1″ x No. 4) = J.F. Shea Aggregate Products
Coarse Aggregate = (3/8″ x No. 8) = J.F. Shea Aggregate Products
Fine Aggregate = J.F. Shea Aggregate Products

Initial Material(s) Check

Is Portland cement on Authorized Materials List?	YES
• Tricalcium Silicate Content ≤ 65%?	YES
• ≤ 0.60% by mass of alkalies?	YES
• Autoclave Expansion ≤ 0.50%?	YES
Is Class F Fly Ash on Authorized Materials List?	YES
• Calcium Oxide Content ≤ 15%?	YES
Is GGBFS on Authorized Materials List?	YES
Are Coarse Aggregate sources SMARA listed?	YES (SMARA 91-45-0019)
Are Coarse Aggregates on Innocuous Aggregate List?	NO
• (CT 214) ≤ 10% loss via Soundness test	YES
• (CT 211) Los Angeles Rattler ≤ 45%	YES
• (CT 227) Cleanness ≥ 75	YES
Is Fine Aggregate source SMARA listed?	YES (SMARA 91-45-0019)
Is Fine Aggregate on Innocuous Aggregate List?	NO
• (CT 213) Organic Impurities = "Satisfactory"	YES
• (CT 217) Sand Equivalent ≥ 75	YES
Is Air-Entraining Admixture (Darex II AEA) on List?	YES

Given:

Type II-V Portland cement = 375 lb/yd^3 (S.G. = 3.15)
GGBF Slag = 175 lb/yd^3 (S.G. = 2.90)
Fly Ash, Class F (CaO content 10%) = 125 lb/yd^3 (S.G. = 2.30)
Aggregate Type =Non-Innocuous

Check the Total Cementitious Material Content (TCMC)

Minimum cementitious (MC) content via the Standard Specifications for stem/soffit concrete = 590 lb/yd^3

$$MC = 590\ lb/yd^3$$
$$TCMC = 375\ lb/yd^3 + 125\ lb/yd^3 + 175\ lb/yd^3 = 675\ lb/yd^3$$
$$675\ lb/yd^3 > 590\ lb/yd^3$$

OK

Check Equation #1 for General Concrete:

$$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC}\geq X$$

UF = 0 (No Silica Fume used in mix)
FA = 125 lb/yd^3
FB = 0 (No Fly Ash or Natural Pozzolan used with CaO content > 10% and < 15% in mix)
SL = 175 lb/yd^3
MC = 590 lb/yd^3
X = 3.0 for non-innocuous aggregate

$$\frac{(25\times 0)+(12\times 125)+(10\times 0)+(6\times 175)}{590}=4.32$$

$$4.30 \geq 3.00$$

<u>OK</u>

Calculate the Minimum Supplementary Cementitious Material (MSCM) to be used in Equation #2

Note: In order to calculate the MSCM of Equation #1 multiple iterations are necessary. To simplify this calculation start from left to right and enter the SCM values, up to the actual amount in the mix until the left side of the equation is equal to the required X value (X = 3.0 in this case). Equation #1 is intentionally set up with the largest multiplication factor on the left and the remaining factors follow in descending size (25, then 12, then 10 and finally 6). When checking a mix design, the minimum supplementary cementitious material (MSCM) can only be obtained by working sequentially from the left of the equation.

Equation #1

$$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC}\geq X$$

Enter in the amount of UF up to the actual (in this case 0 lb/yd^3)

$$\frac{(25\times 0)}{590}=0$$

Enter in the amount of FA up to the actual (in this case 125 lb/yd^3)

$$\frac{(25\times 0)+(12\times 125)}{590}=2.54$$

Since 2.54 is less than 3.0 continue moving left to right to satisfy the equation:
Enter in the amount of FB up to the actual (in this case 0 lb/yd^3)

$$\frac{(25\times 0)+(12\times 125)+(10\times 0)}{590} = 2.54$$

Continue moving left to right to satisfy the equation:
Enter in the amount of SL up to the actual (in this case 175 lb/yd^3)

$$\frac{(25\times 0)+(12\times 125)+(10\times 0)+(6\times 175)}{590} = 4.32$$

4.32 > X = 3.0 so the GGBFS quantity needs to be adjusted so the equation = 3.0.
Always solve for SL to obtain the MSCM value.

$$6 \text{ x } SL = (3.0 \text{ x } 590) -(25 \text{ x } 0) - (12 \text{ x } 125) - (10 \text{ x } 0)$$

$$SL = \frac{(3.0\times 590)-(25\times 0)-(12\times 125)-(10\times 0)}{6}$$

$$SL = 45$$

<u>MSCM = 125 lb/yd³ + 45 lb/yd³ = 170 lb/yd³</u>

Check Equation #2

MC = 590 lb/yd^3
MSCM = 170 lb/yd^3
PC (total quantity of Portland cement) = 375 lb/yd^3

590 - 170 - 375 = 120 lb/yd^3

45 lb/yd^3 > 0

<u>OK</u>

Check Equation #3 for Freeze Thaw Requirement:

$$\frac{(41\times UF)+(19\times F)+(11\times SL)}{TC} \leq 7.0$$

UF = 0 (No Silica Fume used in mix)
F = 125 lb/yd^3
SL = 175 lb/yd^3
TC (total quantity of cementitious material in mix) = 675 lb/yd^3

$$\frac{(41\times0)+(19\times125)+(11\times175)}{675} = 6.37$$

$$6.4 < 7.0$$

OK

Free Water

The allowable amount of free water per the Standard Specifications is 310 lb/yd^3 plus 20 lb/yd^3 for each 100 lb of cementitious material in excess of 550 lb/yd^3. Calculate the allowable amount of free water:

$$310 + \frac{(675\text{-}550)}{100}\times 20 = 335$$

Total allowable amount of free water = *335 lb/yd^3*

335 lb/yd^3 > 303 lb/yd^3

OK

Gradation Check

Given:

Aggregate Sizes

- Coarse Aggregate #1 = 1″ x No. 4
- Coarse Aggregate #2 = 3/8″ x No. 8
- Fine Aggregate = Sand

Check to see if the submitted X-values for the primary aggregate sizes are in compliance with the contract limits of proposed gradation.

Coarse Aggregate (1″x No. 4)

Sieve Size	Limits of Proposed Gradation	Submitted X-Value	Status
3/4″	52 - 85	80	OK
3/8″	15 - 38	30	OK

Fine Aggregate (Sand)

Sieve Size	Limits of Proposed Gradation	Submitted X-Value	Status
No. 16	55 - 75	60	OK
No. 30	34 - 46	38	OK
No. 50	16 - 29	20	OK

Next check the coarse aggregate grading. All values must lie within the operating range given in the specifications.

The proportions of each aggregate size can be calculated as follows:

Coarse Aggregate #1 = (1,174 lb/2.67) / ((1,174 lb/2.67) + (416 lb/2.65) + (1,180 lb/2.62)) = 42%
Coarse Aggregate #2 = (416 lb/2.65) / ((1,174 lb/2.67) + (416 lb/2.65) + (1,180 lb/2.62)) = 15%
Fine Aggregate = (1,180 lb/2.62) / ((1,174 lb/2.67) + (416 lb/2.65) + (1,180 lb/2.62)) = 43%

Coarse Aggregates

Calculations for Combined Gradings of Coarse Aggregates

- $1.5'' \text{ Sieve} = \dfrac{(100\% \times 42\%) + (100\% \times 15\%)}{(42\% + 15\%)} = 100\%$
- $1'' \text{ Sieve} = \dfrac{(100\% \times 42\%) + (100\% \times 15\%)}{(42\% + 15\%)} = 100\%$
- $3/4'' \text{ Sieve} = \dfrac{(78\% \times 42\%) + (100\% \times 15\%)}{(42\% + 15\%)} = 83.8\%$
- $3/8'' \text{ Sieve} = \dfrac{(8\% \times 42\%) + (91\% \times 15\%)}{(42\% + 15\%)} = 29.8\%$
- $\text{No. 4 Sieve} = \dfrac{(2\% \times 42\%) + (17\% \times 15\%)}{(42\% + 15\%)} = 5.9\%$
- $\text{No. 8 Sieve} = \dfrac{(0\% \times 42\%) + (3\% \times 15\%)}{(42\% + 15\%)} = 0.8\%$

Table 3-5. Coarse Aggregate Grading Checklist - Ternary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
1.5″			100	100	OK
1″			88 - 100	100	OK
3/4″	80	X +/- 15	65 - 95	83.8	OK
3/8″	30	X +/- 15	15 - 45	29.8	OK
No. 4			0 - 16	5.9	OK
No. 8			0 - 6	0.8	OK

Fine Aggregate (Sand)

Table 3-6. Fine Aggregate Grading Checklist - Ternary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
3/8″			100	100	OK
No. 4			95 - 100	100	OK
No. 8			65 - 95	84	OK
No. 16	60	X +/- 10	50 - 70	60	OK
No. 30	38	X +/- 9	29 - 47	38	OK
No. 50	20	X +/- 6	14 - 26	20	OK
No. 100			2 - 12	8	OK
No. 200			0 - 8	0	OK

Also, the Specifications state that in addition to the above required grading analysis, the fine aggregate sizes must be distributed such that:

- Difference between the total percentage passing the No. 16 and No. 30 Sieves is from 10 to 40 (Check = 60 - 38 = 22) ⇒ OK
- Difference between the percentage passing the No. 30 and No. 50 Sieves is from 10 to 40 (Check = 38 - 20 = 18) ⇒ OK

Next you need to check the combined gradation of the aggregates. You will need the percentage of volume of each primary aggregate size.

Table 3-7. Combined Aggregate Grading Checklist - Ternary Mix.

Sieve Size	Percentage Passing Coarse Aggregate	Percentage Passing Fine Aggregate	Mix Percentage of Coarse Aggregate	Mix Percentage of Fine Aggregate	Combined Total Percentage Passing	Specification Limits	Status
1.5″	100	100	57	43	100.0	100	OK
1″	100	100	57	43	100.0	90 - 100	OK
3/4″	83.8	100	57	43	90.8	55 - 100	OK
3/8″	29.8	100	57	43	60.0	45 - 75	OK
No. 4	5.9	100	57	43	46.4	35 - 60	OK
No. 8	0.8	84	57	43	36.6	27 - 45	OK
No. 16	0	60	57	43	25.8	20 - 35	OK
No. 30	0	38	57	43	16.3	12 - 25	OK
No. 50	0	20	57	43	8.6	5 - 15	OK
No. 100	0	8	57	43	3.4	1 - 8	OK
No. 200	0	3.5	57	43	1.5	0 - 4	OK

Example Calculation:
Combined total for the 3/8″ sieve = (29.8 x 0.57) + (100 x 0.43) = 60%

The resulting combined gradation analysis would be plotted out as shown:

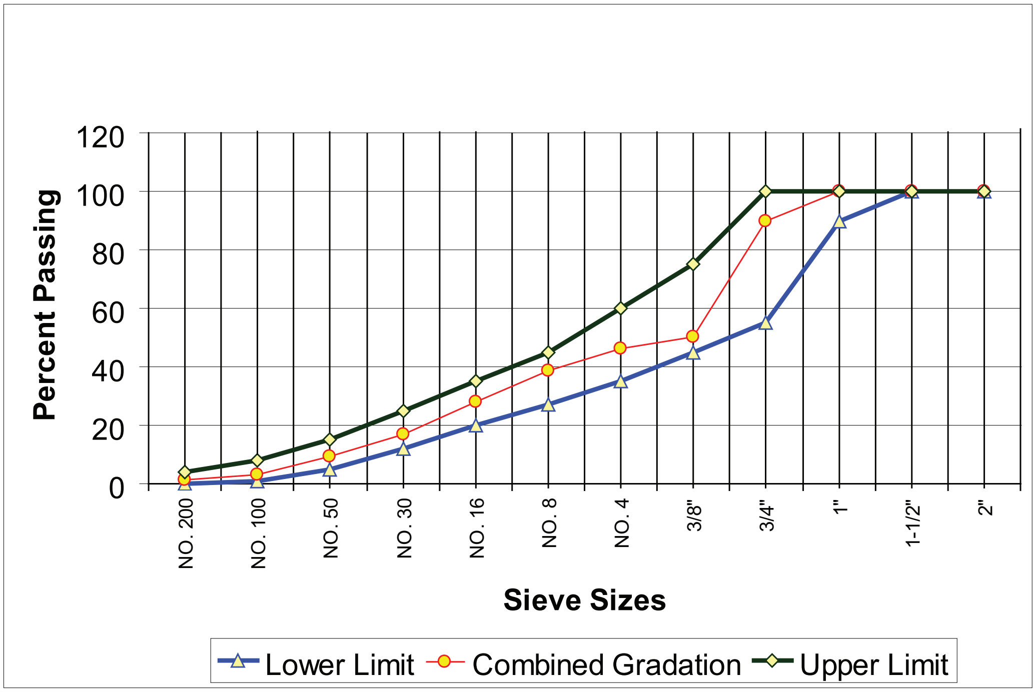

Figure 3-4. Aggregate Gradation Chart - Ternary Mix.

High Strength Binary Mix in Corrosive Enviroment

Example #3 uses the following mix design:

Below are listed current proportions for the mix as produced from the production facility scheduled to service the project referenced. Note that adjustments to proportions may be necessary to maintain contract performance in the case of delivery from another production location or in the event of material changes necessitated by supply issues.

Mix Description : SUPERSTRUCTURE **W/C Ratio :** 0.29
Design Strength : 8000 psi **Slump :** 5.00 in +/-1.00

Usage : Superstructure Frames

	MATERIAL	SSD	VOLUME
CEMENT :	Hanson Permanente Type II/V	690	3.51
FLYASH :	Headwaters Bridger Fly Ash	229	1.71
SAND :	Hanson Sechelt Sand	998	6.03
AGGREGATE :	Hanson 1" X #4 Sechelt	1318	7.76
AGGREGATE :	Hanson 1/2" Sechelt	564	3.36
AIR :	1.50 % +/-1.00		0.41
WATER :	ASTM C1602-04,C1603-04	263	4.21
ADMIXTURE :		4062	27.00

ASTM C-494 (G-3000) TYPE F 7.0 ozs./cwt +/- 3
ASTM C-494 TYPE B & D 4.0 ozs./cwt +/- 2
Tetraguard 7.0 ozs./cwt

Concrete Aggregates - Gradation Analysis

	Percent Passing							
CA & FA >	CA # 1	CA # 2	CA # 3	CA # 4	FA # 1	FA # 2	FA # 3	Combined
Sieve Size	45.80 %	19.60 %			34.70 %			100 %
2"	100	100			100			100 %
1 1/2"	100	100			100			100 %
1"	100	100			100			100 %
3/4"	85	100			100			93 %
1/2"	40	90			100			71 %
3/8"	25	60			100			58 %
#4	5	7			100			38 %
#8	2	2			87			31 %
#16	0	0			68			24 %
#30	0	0			45			16 %
#50	0	0			20			7 %
#100	0	0			5			2 %
#200	0	0			1			0 %
F. M.								
Specific Gravity	2.72	2.69			2.65			

X-VALUES
COARSE AGGREGATE
¾" = 85
3/8" = 25
FINE AGGREGATE
No. 16 = 68
No. 30 = 45
No. 50 = 20

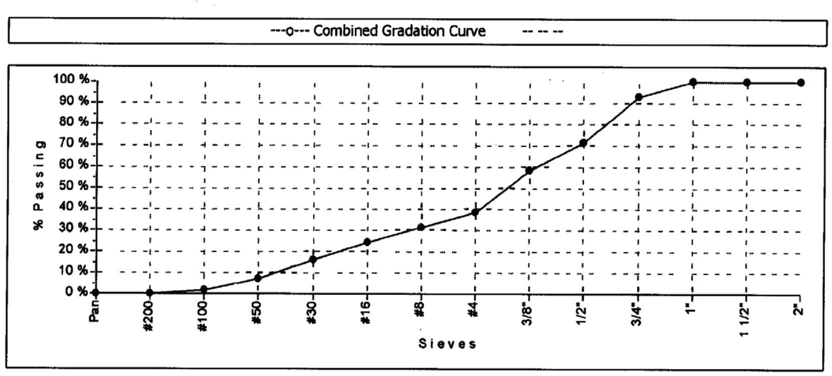

Figure 3-5. Example Concrete Mix Design - High Strength Binary Mix.

Given:

Material Sources:
Portland cement = Hanson, Permanente Plant Type II/V
Class F Fly Ash = Headwaters Resources Inc., Bridger Power Plant Class F Fly Ash
Coarse Aggregates = Hanson, Sechelt (British Columbia, Canada)
Fine Aggregate = Hanson, Sechelt (British Columbia, Canada)

Initial Material(s) Check

Is Portland cement on Authorized Materials List?	YES
• Tricalcium Silicate Content ≤ 65%?	YES
• ≤ 0.60% by mass of alkalies?	YES
• Autoclave Expansion < = 0.50%?	YES
Is Class F Flyash on Authorized Materials List?	YES
• Calcium Oxide Content ≤ 15%?	YES
Is GGBFS on Authorized Materials List?	YES
Are Coarse Aggregate sources SMARA listed?	N/A (IMPORTED FROM BC, CANADA)
Are Coarse Aggregates on Innocuous Aggregate List?	NO
• (CT 214) ≤ 10% loss via soundness test	YES
• (CT 211) Los Angeles Rattler ≤ 45%	YES
• (CT 227) Cleanness ≥ 75	YES
Is Fine Aggregate source SMARA listed?	N/A (IMPORTED FROM BC, CANADA)
Is Fine Aggregate on Innocuous Aggregate List?	NO
• (CT 213) Organic Impurities = “Satisfactory”	YES
• (CT 217) Sand Equivalent ≥ 75	YES
Is Type F Admixture on List?	YES
Is Type B&D Admixture on List?	YES
Is Type S Admixture (Tetraguard) on List?	YES
Shrinkage Information (AASHTO T 160) submitted/met?	YES

Given:

Type II/V Portland cement = 690 lb/yd^3 (S.G. = 3.15)
Class F Fly Ash, (CaO content 6%) = 229 lb/yd^3 (S.G. = 2.15)
Aggregate Type = Innocuous
Type F High Range Water Reducer Used
Type B, C Retarding and Water Reducing Admixture Used
Shrinkage Reducing Admixture Used (Tetraguard)

Notes:

- Shrinkage admixture used to control shrinkage due to high cementitious content of mix
- Note the low water - cementitious ratio of 0.29
- Retarders and water reducers necessary due to high cementitious content and low water - cementitious ratio

Calculate the Total Cementitious Material Content (TC)
Minimum cementitious (MC) content via the Standard Specifications for concrete in corrosive environment = 675 lb/yd^3. In this particular application there was no maximum given for the amount of cementitious material that could be used. The optional reduction in cementitious material (when using a water reducer or water reducing/retarding admixture) is not allowed for concrete in a corrosive enviroment.

$$MC = 675\ lb/yd^3$$

$$TC = 690\ lb/yd^3 + 229\ lb/yd^3 = 919\ lb/yd^3$$
$$919\ lb/yd^3 > 675\ lb/yd^3$$

OK

In a corrosive enviroment cementitious material must be comprised of one of the following via the Standard Specifications:

- Twenty-five percent of either Fly Ash or natural pozzolan with a calcium oxide (CaO) content of up to 10%, and 75% Portland cement
- Twenty percent of either Fly Ash or natural pozzolan with a calcium oxide (CaO) content of up to 10%, 5% silica fume, and 75% Portland cement
- Twelve percent of silica fume, metakaolin, or ultra fine Fly Ash (UFFA); and 88% Portland cement
- Fifty percent ground granulated blast furnace slag (GGBFS) and 50% Portland cement

This mix uses Fly Ash with a CaO content < 10%. There is no silica fume or GGBFS used in this mix thus #2 through #4 do not apply. Check to see if the mix complies with the #1 requirement that the total cementitious material shall consist of 25% Fly Ash by weight.

$$\text{Total Fly Ash \%} = \frac{229}{(229+690)} = 25\%$$

OK

Verify the Allowed Strength Development Time

A total of 56 days is allowed to obtain the required compressive strength if the following equation is met:

$$\frac{(41\times UF)+(19\times F)+(11\times SL)}{TC} \geq 7.0$$

UF = 0 (No Silica Fume used in mix)
F = 229 lb/yd^3
SL = 0 lb/yd^3
TC (total quantity of cementitious material in mix) = 919 lb/yd^3

$$\frac{(41\times 0)+(19\times 229)+(11\times 0)}{919} = 4.7$$

4.70 < 7.0

NOT OK

Thus the 56-day total is not allowed to gain the specified strength. The contractor must abide by the specified time allowance of the contract.

Free Water

The allowable amount of free water per the Standard Specifications is 310 lb/yd^3 plus 20 lb/yd^3 for each 100 lb of cementitious material in excess of 550 lb/yd^3. Calculate the allowable amount of free water:

$$310 + \left(\frac{(919\text{-}550)}{100}\right)\times 20 = 384$$

Total allowable amount of free water = *384 lb/yd^3*

384 lb/yd^3 > 263 lb/yd^3

OK

Gradation Check

Given:

Aggregate Sizes

- Coarse Aggregate #1 = 1″ x No. 4
- Coarse Aggregate #2 = 1/2″ x No. 4
- Fine Aggregate = Sand

Check to see if the contractor submitted X-values for the primary aggregate sizes and if they are in compliance with the contract limits of proposed gradation.

Coarse Aggregate (1″x No. 4)

Sieve Size	Limits of Proposed X-value	Submitted X-value	Status
3/4″	52 - 85	85	OK
3/8″	15 - 38	25	OK

Fine Aggregate (Sand)

Sieve Size	Limits of Proposed X-value	Submitted X-value	Status
No. 16	55 - 75	68	OK
No. 30	34 - 46	45	OK
No. 50	16 - 29	20	OK

Next check the coarse aggregate grading. All values must lie within the operating range given in the specifications in order to approve the mix design.

The proportions of each aggregate size can be calculated as follows:

Coarse Aggregate #1 = (1,318 lb/2.72) / ((1,318 lb/2.72) + (564 lb/2.69) + (998 lb/2.65)) = 45.2%
Coarse Aggregate #2 = (564 lb/2.69) / ((1,318 lb/2.72) + (564 lb/2.69) + (998 lb/2.65)) = 19.6%
Fine Aggregate = (998 lb/2.65) / ((1,318 lb/2.72) + (564 lb/2.69) + (998 lb/2.65)) = 35.2%

Coarse Aggregates

Calculations for Combined Gradings of Coarse Aggregates

- 1.5″ Sieve = $\frac{(100\%\times 45.2\%)+(100\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 100%
- 1″ Sieve = $\frac{(100\%\times 45.2\%)+(100\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 100%
- 3/4″ Sieve = $\frac{(85\%\times 45.2\%)+(100\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 90%
- 3/8″ Sieve = $\frac{(25\%\times 45.2\%)+(60\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 36%
- No. 4 Sieve = $\frac{(5\%\times 45.2\%)+(7\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 6%
- No. 8 Sieve = $\frac{(2\%\times 45.2\%)+(2\%\times 19.6\%)}{(45.2\%+19.6\%)}$ = 2%

Table 3-8. Coarse Aggregate Grading Checklist - High Strength Binary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
1.5″			100	100	OK
1″			88 - 100	100	OK
3/4″	85	X +/- 15	70 - 100	90	OK
3/8″	25	X +/- 15	10 - 40	36	OK
No.4			0 - 16	6	OK
No.8			0 - 6	2	OK

Fine Aggregate (Sand)

Table 3-9. Fine Aggregate Grading Checklist - High Strength Binary Mix.

Sieve Size	X-Value	Percentage Passing Based On X-Value	Percentage Passing Operating Range Limits	Contractor	Status
3/8″			100	100	OK
No. 4			95 - 100	100	OK
No. 8			65 - 95	87	OK
No. 16	68	X +/- 10	58 - 78	68	OK
No. 30	45	X +/- 9	36 - 54	45	OK
No. 50	20	X +/- 6	14 - 26	20	OK
No. 100			2 - 12	5	OK
No. 200			0 - 8	1	OK

Also, the Specifications state that in addition to the above required grading analysis, the fine aggregate sizes must be distributed such that:

- Difference between the total percentage passing the No. 16 and No. 30 Sieves is from 10 to 40 (Check = 68 - 45 = 23) ⇒ OK
- Difference between the percentage passing the No. 30 and No. 50 Sieves is from 10 to 40 (Check = 45 - 20 = 25) ⇒ OK

Next you need to check the combined gradation of the aggregates. You will need the percentage of volume of each primary aggregate size.

Table 3-10. Combined Aggregate Grading Checklist - High Strength Binary Mix.

Sieve Size	Percentage Passing Coarse Aggregate	Percentage Passing Fine Aggregate	Mix Percetage of Fine Aggregate	Mix Percentage of Coarse Aggregate	Combined Total Percentage Passing	Total Percentage Limits	Specification Status
1.5″	100	100	64.8	35.2	100.0	100	OK
1″	100	100	64.8	35.2	100.0	90-100	OK
3/4″	90	100	64.8	35.2	93	55-100	OK
3/8″	36	100	64.8	35.2	58	45-75	OK
No. 4	6	100	64.8	35.2	39	35-60	OK
No. 8	2	87	64.8	35.2	32	27-45	OK
No. 16	0	68	64.8	35.2	24	20-35	OK
No. 30	0	45	64.8	35.2	16	12-25	OK
No. 50	0	20	64.8	35.2	7	5-15	OK
No. 100	0	5	64.8	35.2	2	1-8	OK
No. 200	0	1	64.8	35.2	0.4	0-4	OK

Example Calculation:
Combined total for the 3/8″ sieve = (36 x 0.648) + (100 x 0.352) = 58%

The resulting combined gradation analysis would be plotted as shown:

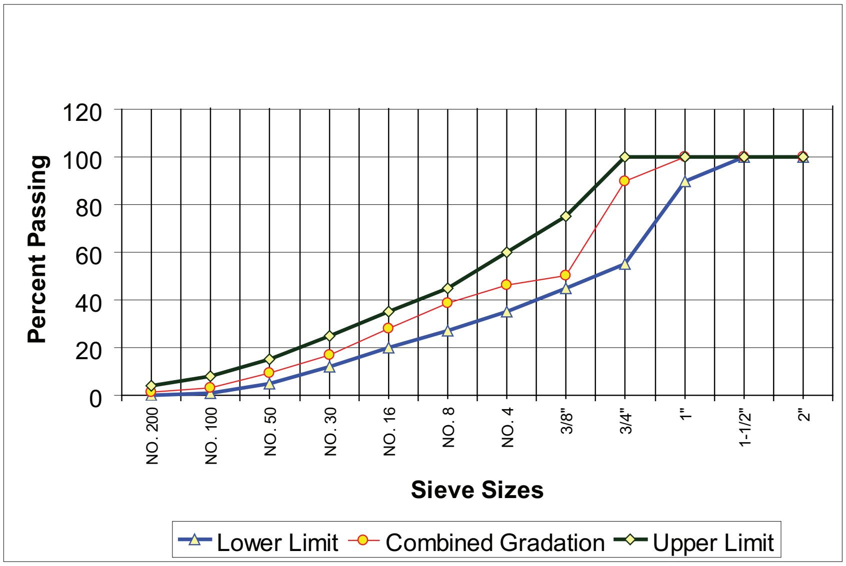

Figure 3-6. Aggregate Gradation Chart - High Strength Binary Mix.

Ternary Mix Design Check (Freeze-Thaw Region with Exposure to De-Icing Chemicals)

This example does not include the following mix design requirements:

- Authorized Materials List Verification and physical/chemical test requirements for the following:
  - Cementitious Materials
  - Innocuous Aggregate
  - Chemical and Air-Entraining Admixtures
- Aggregate Gradation Analysis
- SMARA Verification for Aggregates
- Free Water Check

Note: See Examples #1 through #3 for more information regarding the above topics. This example is solely provided to illustrate the equations used when concrete is designated as being exposed to freeze-thaw condition with exposure to de-icing chemicals.

<u>Given:</u>
Type II Portland cement = 375 lb/yd^3 (S.G. = 3.15)
Silica Fume = 50 lb/yd^3 (S.G. = 2.40)
Fly Ash, Class F (CaO content 14%) = 140 lb/yd^3 (S.G. = 2.30)
Aggregate Type = Innocuous
Air-Entrainment = 6 $\pm$ 1.5%
Water Reducing Agent used (Type A)
28-day Compressive Strength Requirement = 3,625 psi

Calculate the Total Cementitious Material Content (TC)

$$TC = 375 + 50 + 140 = 565\ lb/yd^3$$

Minimum cementitious (MC) content via the Standard Specifications for freeze-thaw regions is 590 lb/yd³. If a water reducing admixture is used, a 5% by weight reduction of cementitious material content is allowed via the Standard Specifications if the mix dosage meets or exceeds the dosage used in determining approval of the admixture. In this case we will assume the dosage requirement is met, thus a 5% reduction is allowed.

$$MC = 0.95\ (590\ lb/yd^3) = 561\ lb/yd^3$$
$$565\ lb/yd^3 > 561\ lb/yd^3$$

OK

For concrete designated as exposed to de-icing chemicals Equations 1 through 5 must be satisfied:

Check Equation #1

$$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC} \geq X$$

UF = 50 lb/yd³
FA = 0 (No Fly Ash or Natural Pozzolan used with CaO content $\leq$ 10% in mix)
FB = 140 lb/yd³
SL = 0 (No ground granulated blast furnace slag in mix)
TC = 565 lb/yd³
MC = 561 lb/yd³
X = 1.8 for innocuous aggregate

$$\frac{(25\times 50)+(12\times 0)+(10\times 140)+(6\times 0)}{565} = 4.7 \geq 1.8,\ OK$$

Check Equation #2

$$\frac{4\times(FA+FB)}{TC} \leq 1.0 \Rightarrow \frac{4\times(0+140)}{565} = 1.0 \leq 1.0,\ OK$$

Check Equation #3

$$\frac{(10\times UF)}{TC} \leq 1.0 \Rightarrow \frac{(10\times 50)}{565} = 0.90 \leq 1.0,\ OK$$

Check Equation #4

$$\frac{2\times\left(UF+FA+FB+SL\right)}{TC} \leq 1.0 \Rightarrow \frac{2\times\left(50+0+140+0\right)}{565} = 0.70 \leq 1.0,\ OK$$

Check Equation #5

$$\frac{27\times\left(TC\text{-}MC\right)}{MC} \leq 5.0 \Rightarrow \frac{27\times\left(565\text{-}561\right)}{561} = 0.20 \leq 5.0,\ OK$$

Verify the allowed Strength Development Time per SSP 90-1.02A
For concrete in freeze-thaw regions the qualification for a 56-day allowable strength gain time period does not apply. Thus, the contractor must abide by the allotted time allowance of the contract.

Minor Concrete Binary Mix

This example does not include the following mix design requirements:

- Authorized Materials List Verification and physical/chemical test requirements for the following:
  - Cementitious Materials
  - Innocuous Aggregate
  - Chemical and Air-Entraining Admixtures
- Aggregate Gradation Analysis
- SMARA Verification for Aggregate
- Free Water Check

Note: See Examples #1 through #3 for more information regarding the above topics. This example is solely provided to illustrate the use of equation requirements.

Given:
Type II Portland cement = 411 lb/yd^3 (S.G. = 3.15)
Rice Hull Ash = 137 lb/yd^3 (S.G. = 2.10)
Aggregate Type = Innocuous

Air Entrainment = 1.5 +/- .5%

Calculate the Total Cementitious Material Content (TC)
Minimum cementitious (MC) content via the Standard Specifications for Minor Concrete = 505 lb/yd^3.

$$MC = 505\ lb/yd^3$$

$$TC = 411\ lb/yd^3 + 137\ lb/yd^3 = 548\ lb/yd^3$$
$$548\ lb/yd^3 > 505\ lb/yd^3$$

<u>OK</u>

Check Equation #1

$$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC} \geq X$$

UF = 137 lb/yd^3 (Specifications state Rice Hull Ash to be considered Type UF if used)
FA = 0 (No Fly Ash or Natural Pozzolan used with CaO content $\leq$ 10% in mix)
FB = 0 (No Fly Ash or Natural Pozzolan used with CaO content $\geq$ 10% and $\leq$ 15% in mix)
SL = 0 (No ground granulated blast furnace slag in mix)
MC = 505 lb/yd^3
X = 1.8 for non-innocuous aggregate

$$\frac{(25\times 137)+(12\times 0)+(10\times 0)+(6\times 0)}{505} = 6.8$$

$$6.80 \geq 1.80$$

<u>OK</u>

Calculate the Minimum Supplementary Cementitious Material (MSCM) to be used in Equation #2
Note: In order to calculate the MSCM of Equation #1 iterations are necessary. To simplify this calculation start from left to right and enter the SCM values, up to the actual amount in the mix until the left side of the equation is equal to the required X value (X = 1.8 in this case)

Equation #1

$$\frac{(25\times UF)+(12\times FA)+(10\times FB)+(6\times SL)}{MC} \geq X$$

Enter in the amount of UF up to the actual (in this case 137 lb/yd^3)

$$\frac{(25\times 137)}{505} = 6.8$$

6.8 > X = 1.8 so the Rice Hull Ash (UF) quantity needs to be adjusted so the equation = 1.8. Solve for UF to obtain the MSCM value.

$$25 \times UF = (1.8 \times 505) - (12 \times 0) - (10 \times 0) - (6 \times 0)$$

$$UF = \frac{(1.80\times 505)-(12\times 0)-(10\times 0)-(6\times 0)}{25}$$

$$UF = 36$$

<u>MSCM = 36 lb/yd^3</u>

Check Equation #2

$$MC - MSCM - PC \geq 0$$

MC = 505 lb/yd^3
MSCM = 36 lb/yd^3
PC (total quantity of Portland cement) = 411 lb/yd^3

$$505 - 36 - 411 = 58$$
$$58\ lb/yd^3 \geq 0$$

<u>OK</u>

Verify the allowed Strength Development Time
A total of 56 days is allowed to obtain the required compressive strength if the following equation is met:

$$\frac{(41\times UF)+(19\times F)+(11\times SL)}{TC} \geq 7.0$$

UF = 137 lb/yd^3 (Specifications state Rice Hull Ash to be considered Type UF if used)
F = 0 (No Fly Ash used in mix)
SL = 0 (No Ground Granulated Blast Furnace Slag used in mix)
TC (total quantity of cementitious material in mix) = 548 lb/yd^3

$$\frac{(41 \times 137)+(19 \times 0)+(11 \times 0)}{548} = 10.3$$

$$10.3 > 7.0$$

OK

Thus the 56-day total is allowed to gain the specified 28-day minimum specified compressive strength.

References

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