

FUNDAMENTALS OF CONCRETE MIX DESIGNS

Concrete has become, in the minds of many, a construction material commodity. However, when one considers the versatility of this "moldable stone" one begins to appreciate the true value of this particular construction material. The core of the performance of this product is the effective application of proportioning principles. The intent of this document is to review some of the fundamentals of concrete mix designs specific to concrete materials, and the development of concrete mixes.

The concept of concrete proportioning is relatively simple: **Appropriately combine the materials used in the concrete mix into a moldable, workable product that will form a dense, durable mass.**

CONCRETE MATERIALS

Aggregates:

The first consideration in proportioning a concrete mix is the aggregates since they will make up the largest portion of most concrete mixes - about 65% to 80% by volume. Consideration should be given to all properties of both the coarse and fine aggregates including: hardness, absorption, specific gravity, alkali reactivity and gradation.

The coarse (also referred to as stone) aggregate and fine (also referred to as sand) aggregate are graded materials - that is they are a compilation of multiple sized particles as opposed to only one or two particle sizes. This graded characteristic results in a denser product than the same volume of like-sized particles due to fewer voids between the particles. The extent of this grading and the number of particle sizes present in a given aggregate can be controlled by the aggregate supplier through a sieving process.

The coarse and fine aggregates are then combined at the optimum proportions to create the optimum density. Several coarse and/or fine aggregates may sometimes be used in the same mix. The optimum combination can be determined through empirical testing or by computer programs. This optimum combined gradation represents the best "fit" of coarse and fine aggregates and leaves the minimum voids which must be filled with cementitious material and water to bind the aggregate particles together.

Another important consideration regarding aggregates that should be considered is the maximum size particles that can be allowed given the intended use of the concrete. In general, the largest size that is practical should be used since larger

particles have less total surface area per unit of volume to bind together than do smaller particles. This produces greater strengths for a given volume of cementitious material (binder) or requires less cementitious material for a given strength requirement. Maximum size may be restricted by such things as the spacing of steel reinforcement, the type of equipment used to place the concrete, etc.

Concrete aggregates may be natural or manufactured (crushed) but all must meet the requirements of ASTM C 33 except those requirements pertaining to gradation in the case of concrete pipe aggregates.

Cementitious Materials:

Since the cementitious material and water form the paste or "glue" that binds the aggregates together, maximizing it's quality is prudent. The cementitious material for concrete pipe may consist of the following combinations according to ASTM standards for concrete pipe and boxes:

- Portland cement only: cement must conform to ASTM C 150 (includes requirements for several types of cement developed for a range of applications).
- Portland blast furnace slag cement only: conforming to ASTM C 595.
- Portland pozzolan cement only: conforming to ASTM C 595 except the pozzolan constituent in Type 1P shall be flyash and not exceed 25% by weight.
- Portland cement and flyash: the flyash portion must be between 5% and 25% by weight of total cementitious material.

The paste serves to fill the voids between the coarse and fine aggregate particles as well as to bind these particles into a solid mass.

Cementitious material is sometimes referred to in units of sacks. One sack is equivalent to 94 lbs. of cementitious material.

Water:

Water combines with the cementitious material during a reaction referred to as hydration to create hardened concrete. The weight of the water in the mix (added water plus free moisture on the aggregates) divided by the weight of cementitious material forms what is referred to as the water-cementitious material ratio (w/c). This characteristic of the concrete mix determines, to a great extent, the overall quality of the concrete relative to it's engineering properties such as density, strength, abrasion resistance, and shrinkage to name a few.

Two portions of water exist in a concrete mix. The first portion is that water necessary to hydrate the cementitious materials. The second is that portion necessary to make the concrete workable enough to be molded into the shape of its

intended purpose. This is referred to as the "water of convenience". This second portion of water should be held to a minimum since the engineering properties of the hardened concrete, in particular strength, are inversely proportional to the water-cementitious material ratio. For this reason some engineers have felt it necessary to specify cementitious minimums per unit volume of concrete (e.g. 5 sacks cementitious minimum per yard of concrete) to ensure a high quality concrete mix is obtained.

In the case of pre-cast construction, however, the need for excessive water is often avoided. For example, since most concrete pipe is manufactured by machines, most of the water of convenience can be eliminated resulting in relatively low w/c ratios. As a matter of fact, most manufactured pipe production processes used today depend on a low w/c ratio concrete mix since the pipe product is required to free stand within minutes of manufacture. An excessively wet mix will result in collapsed pipe during manufacture. Therefore, the manufacturing process itself guarantees a low w/c ratio, thus, eliminating the necessity to specify cement minimums for the purpose of maintaining low w/c.

The water-cementitious materials ratios of concrete used to produce concrete pipe are typically in the 0.33 to 0.40 range compared to the 0.50 to 0.70 range for ready-mixed concrete such as that used for concrete paving, building slabs, walls and the like. This indicates that concrete used in the production of concrete pipe is some of the highest quality concrete in production today.

Admixtures:

A wide range of chemicals have been developed to enhance the performance of concrete and/or its engineering properties. These products are usually liquids or powders which are added to the concrete during the batching process. Some of their effects to the concrete include:

- Reducing the amount of water of convenience needed to place the concrete, thereby, reducing the overall water cementitious material ratio while maintaining acceptable workability.
- Retarding the "set" or hardening rate of the concrete.
- Accelerating the "set" or hardening rate of the concrete.
- Reducing adherence of concrete to forms during manufacturing of pre-cast concrete products.
- Various combinations of the above.

The products listed above are used primarily in wet mix applications such as paving, slabs, etc. and are not typically utilized in dry mixes used in the production of concrete pipe.

CONCRETE MIX DESIGNS

Once the concrete materials are understood the development of concrete mix designs can take place. Some of the considerations for developing a concrete mix are as follows:

- Required compressive strength - Impacts water-cementitious materials ratio.
- Type of structure (slab, wall, footing, columns, etc.) - Can impact workability requirements and coarse aggregate selection.
- Minimum structural dimensions (e.g. clear spacing of reinforcing steel or other embedded items) - Will impact sizing of the coarse aggregate.
- Service conditions (e.g. exposure to sulfate soils) - Impacts water-cementitious materials ratio, cement type and /or types of aggregates.
- Placement techniques (e.g. paving machine, concrete pump, vibration during placement, etc.) - Impacts workability requirements and/or aggregate size.

Knowledge of the above factors sets the stage for development of an appropriate mix design. Most concrete mixes are designed volumetrically, meaning that the sum of the absolute volumes of the mix constituents is equivalent to the desired physical volume (e.g. 27 cubic feet or 1 cubic yard). Consequently, the specific gravity of each of the mix constituents is required.

Once workability requirements, service conditions and maximum aggregate size establish required water content, empirical relationships between water-cementitious materials ratios and compressive strength are used to establish cementitious content. Coarse and fine aggregates make up the remaining mix volume. The ratio of coarse to fine aggregate can be optimized for maximum density allowing more efficient use of the cementitious paste.

Once the mix design is developed, laboratory or field tests are conducted to confirm the performance of the mix. Necessary adjustments are made before the mix goes into production.

Concrete's enormous versatility allows it to be specifically designed to meet the particular needs of a myriad of applications. When properly designed and employed by concrete professionals, this time tested construction material simply has no peer.