Minimizing Concrete Costs

The most expensive ingredient in concrete is the cement, so minimizing concrete costs means minimizing the amount of cement. Is there a practical minimum? Sure!

Ideally, each piece of fine or coarse aggregate should be totally surrounded by cement paste and all the voids between aggregate particles should be filled in. The former depends on the specific surface of the aggregate and the latter depends on the void content of the aggregate.

Specific surface is surface area per unit volume. In general, specific surface increases with:

1. decreasing particle size (because surface area varies with the square of particle size while volume varies with the cube of particle size),

2. increasing aggregate angularity (a sphere uses the least surface area to enclose a given volume),

3. increasing surface roughness (a rough surface texture wastes a lot of surface area while covering the same volume as a smooth surface)

You can therefore minimize the amount of cement needed by using large, round aggregate such as river gravel.

Unfortunately, there are limits on the amount by which you can reduce the surface area because low surface area typically means low strength. The weak point in most concrete is the strength of the cement-aggregate bond. By increasing the surface area available for bonding, you increase the amount of load you can apply to the concrete before exceeding the bond strength. That’s why mortar is stronger than concrete—by eliminating the coarse aggregate, you increase the specific surface of the aggregate and increase the area of the bonding interface.

That leaves void content as the next path to reducing cement content. There are actually two void contents to worry about. The void content of the coarse aggregate determines the amount of mortar (sand + cement paste) per unit volume of concrete. while the void content of the fine aggregate determines the amount of cement paste needed per unit volume of mortar. Each depends on the gradation of the aggregate (as we learned previously) and the angularity of the aggregate—a random assemblage of angular aggregate generally has a higher void content than a random assemblage of rounded aggregate.

Just as there are limitations on the amount by which you can reduce surface area before adversely affecting strength, there are limitations on the amount by which you can decrease void content before adversely affecting workability. You need enough mortar to push the coarse aggregate particles apart so they’ll slide past each other more easily and you need enough cement paste to push the sand particles apart so they’ll slide past each other more easily.

Maximizing Strength

In normal concrete, the aggregate is far stronger than the cement paste, so the strength of the cement paste controls the strength of the concrete. Believe it or not, the strength of the cement paste is determined almost entirely by the volume of air entrained in the paste.

Once you’ve chosen your ingredients (gravel, sand, cement, admixtures, etc.), the two things that most influence the amount of air in the mix are the water/cement ratio and the degree of consolidation of the fresh concrete.

Theoretically, a 0.42 w/c ratio is required for complete hydration of the cement. If the w/c ratio is greater than that, not all of the water is consumed during hydration. The excess water (called unreacted water) eventually evaporates, leaving behind microscopic air voids. The result is a relatively porous cement paste that has less internal strength and less bond strength.

If the w/c ratio is less than 0.42, some of the cement remains unhydrated and acts, instead, like extremely fine aggregate. The cement that does hydrate is just as strong as when the w/c ratio is 0.42 and, providing you have enough cement paste to go around, the leftover cement particles create a denser aggregate gradation and more surface area for cement bonding, resulting in increased strength.

The increased strength produced by low w/c ratios may not be fully realized if the mix cannot be properly consolidated. Initially, there are lots of air voids between the cement, sand, and gravel particles. If enough water is added, almost all of that air is displaced by the water, leaving very little air in the mix. At low w/c ratios, though, some of the air remains trapped in the mix because there's just not enough water to displace all of the air. The remaining air must be forced out of the concrete by enticing the concrete to consolidate under its own weight. On the job site, this is often done using vibrators. In the laboratory, hand compaction (rodding) is not nearly as good as vibration at forcing the trapped air out of the mix, so laboratory beams and cylinders can have a higher air content than concrete placed in the field.

Maximizing Workability

Workability defines the ease with which concrete can be placed, compacted, and finished without segregation or bleeding. Workability depends on many things:

1. The amount of cement – concrete with too little cement can be very harsh because there's not enough of a lubricating layer between sand particles (even if there's enough mortar to lubricate the coarse aggregate particles); concrete with too much cement can be sticky and hard to finish (not to mention expensive).

2. The amount of water – concrete with too little water will not flow properly (the water lubricates the sand and cement particles) and cannot be adequately placed or compacted; concrete with too much water can exhibit segregation and/or bleeding (addressed next).

3. The angularity of the sand – rounded sand particles give better workability than angular sand grains because they need less "lubricant" (i.e., cement paste) to slide past each other.

4. The fineness modulus of the sand – finer sand has a higher specific surface and thus more surface area to have to lubricate with the cement paste available.

5. The angularity of the coarse aggregate – angular coarse aggregate particles need to be pushed further apart in order to get past each other. If there's not enough mortar to achieve this, the concrete will be harsh.

If the concrete is too harsh, you can try increasing the amount of <u>sand</u> (not the amount of water) because that increases the volume of the mortar separating the coarse aggregate particles without changing the water/cement ratio. If the concrete is still harsh, you could increase the amount of cement paste by increasing both the cement and the water while maintaining the w/c ratio. This lets the sand particles slide past one another more easily and increases the volume of mortar, which lets the gravel particles slide past one another more easily. Alternatively, you could add a water reducing admixture (such as a superplasticizer).

Segregation and Bleeding

The components of concrete (sand, cement, water) have different specific gravities and so will tend to separate from one another if given the chance. The mortar (sand, cement, and water) will almost always have a lower density than the coarse aggregate, so the coarse aggregate wants to sink to the bottom of the form. In a well-designed concrete mix, the mortar is viscous enough (and the resulting drag forces on the aggregate particles high enough) that the coarse aggregate won't sink despite the difference in density. In other words, the combination of drag forces and buoyant forces are sufficient to offset the weight of the aggregate particles.

If the mix is too wet, though, the mortar will be lighter (since water is the lightest ingredient in the concrete) and its viscosity will be lower. The buoyant forces and drag forces are no longer sufficient to offset the weight of the coarse aggregate particles, so they sink within the mortar. This is called segregation.

If the mix is especially wet, the sand within the mortar may also want to sink because it’s much denser than the cement paste. The result is that cement and water to rise to the surface as the sand sinks. This phenomenon is called bleeding.

In general, the wetter the mix, the more likely it is to segregate or bleed. Even fairly dry mixes can segregate or bleed if vibrated too much. Vibration momentarily eliminates the drag forces on the aggregate particles, allowing them to sink in the less dense maxtix. Overworking the surface of the concrete can also cause bleeding near the surface for similar reasons.

One admixture, silica fume, virtually eliminates bleeding and segregation because the particles are so small and their water demand so high (remember the concept of specific surface) that all the excess water remains attached to the silica particles, leaving very little free water to float to the surface or to reduce the viscosity of the mortar.