Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete (Fig. 4-1). However, some waters that are not fit for drinking may be suitable for use in concrete.

Six typical analyses of city water supplies and seawater are shown in Table 4-1. These waters approximate the composition of domestic water supplies for most of the cities over 20,000 population in the United States and Canada. Water from any of these sources is suitable for making concrete. A water source comparable in analysis to any of the waters in the table is probably satisfactory for use in concrete (Fig. 4-2).

Water of questionable suitability can be used for making concrete if mortar cubes (ASTM C 109 or AASHTO T 106) made with it have 7-day strengths equal to at least 90% of companion specimens made with drinkable or distilled water. In addition, ASTM C 191 (AASHTO T 131) tests should be made to ensure that impurities in the mixing water do not adversely shorten or extend the setting time of the cement. Acceptable criteria for water to be used in concrete are given in ASTM C 94 (AASHTO M 157) and AASHTO T 26 (see Tables 4-2 and 4-3).

Excessive impurities in mixing water not only may affect setting time and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Therefore, certain optional limits may be set on chlorides, sulfates,

### Table 4-1. Typical Analyses of City Water Supplies and Seawater, parts per million

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (SiO₂)</td>
<td>2.4</td>
<td>0.0</td>
<td>6.5</td>
<td>9.4</td>
<td>22.0</td>
<td>3.0</td>
<td>—</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>5.8</td>
<td>15.3</td>
<td>29.5</td>
<td>96.0</td>
<td>3.0</td>
<td>1.3</td>
<td>50 to 480</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>1.4</td>
<td>5.5</td>
<td>7.6</td>
<td>27.0</td>
<td>2.4</td>
<td>0.3</td>
<td>260 to 1410</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>1.7</td>
<td>16.1</td>
<td>2.3</td>
<td>183.0</td>
<td>215.0</td>
<td>1.4</td>
<td>2190 to 12,200</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>0.7</td>
<td>0.0</td>
<td>1.6</td>
<td>18.0</td>
<td>9.8</td>
<td>0.2</td>
<td>70 to 550</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃)</td>
<td>14.0</td>
<td>35.8</td>
<td>122.0</td>
<td>334.0</td>
<td>549.0</td>
<td>4.1</td>
<td>—</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>9.7</td>
<td>59.9</td>
<td>5.3</td>
<td>121.0</td>
<td>11.0</td>
<td>2.6</td>
<td>580 to 2810</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>2.0</td>
<td>3.0</td>
<td>1.4</td>
<td>280.0</td>
<td>22.0</td>
<td>1.0</td>
<td>3960 to 20,000</td>
</tr>
<tr>
<td>Nitrate (NO₃)</td>
<td>0.5</td>
<td>0.0</td>
<td>1.6</td>
<td>0.2</td>
<td>0.5</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>31.0</td>
<td>250.0</td>
<td>125.0</td>
<td>983.0</td>
<td>564.0</td>
<td>19.0</td>
<td>35,000</td>
</tr>
</tbody>
</table>

* Different seas contain different amounts of dissolved salts.
alkalies, and solids in the mixing water or appropriate tests can be performed to determine the effect the impurity has on various properties. Some impurities may have little effect on strength and setting time, yet they can adversely affect durability and other properties.

Water containing less than 2000 parts per million (ppm) of total dissolved solids can generally be used satisfactorily for making concrete. Water containing more than 2000 ppm of dissolved solids should be tested for its effect on strength and time of set. Additional information on the effects of mix water impurities can be found in Steinour (1960) and Abrams (1924). Over 100 different compounds and ions are discussed.

Following is a synopsis of the effects of certain impurities in mixing water on the quality of normal concrete:

### ALKALI CARBONATE AND BICARBONATE

Carbonates and bicarbonates of sodium and potassium have different effects on the setting times of different cements. Sodium carbonate can cause very rapid setting, bicarbonates can either accelerate or retard the set. In large concentrations, these salts can materially reduce concrete strength. When the sum of the dissolved salts exceeds 1000 ppm, tests for their effect on setting time and 28-day strength should be made. The possibility of aggravated alkali-aggregate reactions should also be considered.

### CHLORIDE

Concern over a high chloride content in mixing water is chiefly due to the possible adverse effect of chloride ions on the corrosion of reinforcing steel or prestressing strands. Chloride ions attack the protective oxide film formed on the steel by the highly alkaline (pH greater than 12.5) chemical environment present in concrete. The acid-

### Table 4-2. Acceptance Criteria for Questionable Water Supplies (ASTM C 94 or AASHTO M 157)

<table>
<thead>
<tr>
<th>Limits</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength, minimum percentage of control at 7 days</td>
<td>90</td>
</tr>
<tr>
<td>Time of set, deviation from control, hr:min. from 1:00 earlier to 1:30 later</td>
<td>from 1:00 earlier to 1:30 later</td>
</tr>
</tbody>
</table>

*Comparisons should be based on fixed proportions and the same volume of test water compared to a control mixture using city water or distilled water.

### Table 4-3. Chemical Limits for Wash Water used as Mixing Water (ASTM C 94 or AASHTO M 157)

<table>
<thead>
<tr>
<th>Chemical or type of construction</th>
<th>Maximum concentration, ppm*</th>
<th>Test method**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride, as Cl</td>
<td></td>
<td>ASTM D 512</td>
</tr>
<tr>
<td>Prestressed concrete or concrete in bridge decks</td>
<td>500†</td>
<td></td>
</tr>
<tr>
<td>Other reinforced concrete in moist environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms</td>
<td>1,000†</td>
<td></td>
</tr>
<tr>
<td>Sulfate, as SO₄</td>
<td>3,000</td>
<td>ASTM D 516</td>
</tr>
<tr>
<td>Alkalies, as (Na₂O + 0.658 K₂O)</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Total solids</td>
<td>50,000</td>
<td>AASHTO T 26</td>
</tr>
</tbody>
</table>

* Wash water reused as mixing water in concrete can exceed the listed concentrations of chloride and sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources, does not exceed the stated limits.
** Other test methods that have been demonstrated to yield comparable results can be used.
† For conditions allowing use of CaCl₂ accelerator as an admixture, the chloride limitation may be waived by the purchaser.
soluble chloride ion level at which steel reinforcement corrosion begins in concrete is about 0.2% to 0.4% by mass of cement (0.15% to 0.3% water soluble). Of the total chloride-ion content in concrete, only about 50% to 85% is water soluble; the rest becomes chemically combined in cement reactions (Whiting 1997, Whiting, Taylor, and Nagi 2002, and Taylor, Whiting, and Nagi 2000).

Chlorides can be introduced into concrete with the separate mixture ingredients—admixtures, aggregates, cementitious materials, and mixing water—or through exposure to deicing salts, seawater, or salt-laden air in coastal environments. Placing an acceptable limit on chloride content for any one ingredient, such as mixing water, is difficult considering the several possible sources of chloride ions in concrete. An acceptable limit in the concrete depends primarily upon the type of structure and the environment to which it is exposed during its service life.

A high dissolved solids content of a natural water is sometimes due to a high content of sodium chloride or sodium sulfate. Both can be tolerated in rather large quantities. Concentrations of 20,000 ppm of sodium chloride are generally tolerable in concrete that will be dry in service and has low potential for corrosive reactions. Water used in prestressed concrete or in concrete that is to have aluminum embedments should not contain deleterious amounts of chloride ion. The contribution of chlorides from ingredients other than water should also be considered. Calcium chloride admixtures should be avoided in steel reinforced concrete.

The ACI 318 building code limits water soluble chloride ion content in reinforced concrete to the following percentages by mass of cement:

- Prestressed concrete: 0.06%
- Reinforced concrete exposed to chloride in service: 0.15%
- Reinforced concrete that will be dry or protected from moisture in service: 1.00%
- Other reinforced concrete construction: 0.30%

ACI 318 does not limit the amount of chlorides in plain concrete, that is concrete not containing steel. Additional information on limits and tests can be found in ACI 222, Corrosion of Metals in Concrete. The acid-soluble and water-soluble chloride content of concrete can be determined by using ASTM C 1152 and C 1218.

**SULFATE**

Concern over a high sulfate content in mix water is due to possible expansive reactions and deterioration by sulfate attack, especially in areas where the concrete will be exposed to high sulfate soils or water. Although mixing waters containing 10,000 ppm of sodium sulfate have been used satisfactorily, the limit in Table 4-3 should be considered unless special precautions are taken.

**OTHER COMMON SALTS**

Carbonates of calcium and magnesium are not very soluble in water and are seldom found in sufficient concentration to affect the strength of concrete. Bicarbonates of calcium and magnesium are present in some municipal waters. Concentrations up to 400 ppm of bicarbonate in these forms are not considered harmful.

Magnesium sulfate and magnesium chloride can be present in high concentrations without harmful effects on strength. Good strengths have been obtained using water with concentrations up to 40,000 ppm of magnesium chloride. Concentrations of magnesium sulfate should be less than 25,000 ppm.

**IRON SALTS**

Natural ground waters seldom contain more than 20 to 30 ppm of iron; however, acid mine waters may carry rather large quantities. Iron salts in concentrations up to 40,000 ppm do not usually affect concrete strengths adversely.

**MISCELLANEOUS INORGANIC SALTS**

Salts of manganese, tin, zinc, copper, and lead in mixing water can cause a significant reduction in strength and large variations in setting time. Of these, salts of zinc, copper, and lead are the most active. Salts that are especially active as retarders include sodium iodate, sodium phosphate, sodium arsenate, and sodium borate. All can greatly retard both set and strength development when present in concentrations of a few tenths percent by mass of the cement. Generally, concentrations of these salts up to 500 ppm can be tolerated in mixing water.

Another salt that may be detrimental to concrete is sodium sulfide; even the presence of 100 ppm warrants testing. Additional information on the effects of other salts can be found in the references.

**SEAWATER**

Seawater containing up to 35,000 ppm of dissolved salts is generally suitable as mixing water for concrete not containing steel. About 78% of the salt is sodium chloride, and 15% is chloride and sulfate of magnesium. Although concrete made with seawater may have higher early strength than normal concrete, strengths at later ages (after 28 days) may be lower. This strength reduction can be compensated for by reducing the water-cement ratio.

Seawater is not suitable for use in making steel reinforced concrete and it should not be used in prestressed concrete due to the risk of corrosion of the reinforcement, particularly in warm and humid environments. If seawater is used in plain concrete (no steel) in marine application...
tions, moderate sulfate resistant cements, Types II or MS, should be used along with a low water-cement ratio.

Sodium or potassium in salts present in seawater used for mix water can aggravate alkali-aggregate reactivity. Thus, seawater should not be used as mix water for concrete with potentially alkali-reactive aggregates.

Seawater used for mix water also tends to cause efflorescence and dampness on concrete surfaces exposed to air and water (Steinour 1960). Marine-dredged aggregates are discussed in Chapter 5.

**ACID WATERS**

Acceptance of acid mixing water should be based on the concentration (in parts per million) of acids in the water. Occasionally, acceptance is based on the pH, which is a measure of the hydrogen-ion concentration on a log scale. The pH value is an intensity index and is not the best measure of potential acid or base reactivity. The pH of neutral water is 7.0; values below 7.0 indicate acidity and those above 7.0 alkalinity (a base).

Generally, mixing waters containing hydrochloric, sulfuric, and other common inorganic acids in concentrations as high as 10,000 ppm have no adverse effect on strength. Acid waters with pH values less than 3.0 may create handling problems and should be avoided if possible. Organic acids, such as tannic acid, can have a significant effect on strength at higher concentrations (Fig. 4-3).

**ALKALINE WATERS**

Waters with sodium hydroxide concentrations of 0.5% by mass of cement do not greatly affect concrete strength provided quick set is not induced. Higher concentrations, however, may reduce concrete strength.

Potassium hydroxide in concentrations up to 1.2% by mass of cement has little effect on the concrete strength developed by some cements, but the same concentration when used with other cements may substantially reduce the 28-day strength.

The possibility for increased alkali-aggregate reactivity should be considered.

**WASH WATER**

The U.S. Environmental Protection Agency and state agencies forbid discharging into the nation’s waterways untreated wash water used in reclaiming sand and gravel from returned concrete or mixer washout operations. Wash water is commonly used as mixing water in ready mixed concrete (Fig. 4-4) (Yelton 1999). Wash water should meet the limits in Tables 4-2 and 4-3.

**INDUSTRIAL WASTEWATER**

Most waters carrying industrial wastes have less than 4000 ppm of total solids. When such water is used as mixing water in concrete, the reduction in compressive strength is generally not greater than about 10%-15%. Wastewaters such as those from tanneries, paint factories, coke plants, and chemical and galvanizing plants may contain harmful impurities. It is best to test any wastewater that contains even a few hundred parts per million of unusual solids.
WATERS CARRYING SANITARY SEWAGE

A typical sewage may contain about 400 ppm of organic matter. After the sewage is diluted in a good disposal system, the concentration is reduced to about 20 ppm or less. This amount is too low to have any significant effect on concrete strength.

ORGANIC IMPURITIES

The effect of organic substances on the setting time of portland cement or the ultimate strength of concrete is a problem of considerable complexity. Such substances, like surface loams, can be found in natural waters. Highly colored waters, waters with a noticeable odor, or those in which green or brown algae are visible should be regarded with suspicion and tested accordingly. Organic impurities are often of a humus nature containing tannates or tannic acid (Fig. 4-3).

SUGAR

Small amounts of sucrose, as little as 0.03% to 0.15% by mass of cement, usually retard the setting of cement. The upper limit of this range varies with different cements. The 7-day strength may be reduced while the 28-day strength may be improved. Sugar in quantities of 0.25% or more by mass of cement may cause rapid setting and a substantial reduction in 28-day strength. Each type of sugar influences setting time and strength differently.

Less than 500 ppm of sugar in mix water generally has no adverse effect on strength, but if the concentration exceeds this amount, tests for setting time and strength should be made.

SILT OR SUSPENDED PARTICLES

About 2000 ppm of suspended clay or fine rock particles can be tolerated in mixing water. Higher amounts might not affect strength but may influence other properties of some concrete mixtures. Before use, muddy water should be passed through settling basins or otherwise clarified to reduce the amount of silt and clay added to the mixture by way of the mix water. When cement fines are returned to the concrete in reused wash water, 50,000 ppm can be tolerated.

OILS

Various kinds of oil are occasionally present in mixing water. Mineral oil (petroleum) not mixed with animal or vegetable oils probably has less effect on strength development than other oils. However, mineral oil in concentra-

trations greater than 2.5% by mass of cement may reduce strength by more than 20%.

ALGAE

Water containing algae is unsuited for making concrete because the algae can cause an excessive reduction in strength. Algae in water leads to lower strengths either by influencing cement hydration or by causing a large amount of air to be entrained in the concrete. Algae may also be present on aggregates, in which case the bond between the aggregate and cement paste is reduced. A maximum algae content of 1000 ppm is recommended.

INTERACTION WITH ADMIXTURES

When evaluating waters for their effect on concrete properties, it is important to also test the water with chemical admixtures that will be used in the job concrete. Certain compounds in water can influence the performance and efficiency of certain admixtures. 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.

REFERENCES


ACI Committee 201, Guide to Durable Concrete, ACI 201.2R-92, American Concrete Institute, Farmington Hills, Michigan, 1992, 41 pages.

ACI Committee 222, Corrosion of Metals in Concrete, ACI 222R-96, American Concrete Institute, Farmington Hills, Michigan, 1997, 30 pages.

ACI Committee 318, Building Code Requirements for Structural Concrete and Commentary, ACI 318-02, American Concrete Institute, Farmington Hills, Michigan, 2002, 369 pages. Available through PCA as LT125.


