

## CODE

## COMMENTARY

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

| Exposure Class | Max. $w/cm^2$ | Min. $f'_c$ , psi | Additional minimum requirements   |   |                     |                                  |
|----------------|---------------|-------------------|---|---|---------------------|----------------------------------|
|                |               |                   | Air content   |   |                     | Limits on cementitious materials |
| F0             | N/A           | 2500              | N/A   |   |                     | N/A                              |
| F1             | 0.45          | 4500              | Table 4.4.1   |   |                     | N/A                              |
| F2             | 0.45          | 4500              | Table 4.4.1   |   |                     | N/A                              |
| F3             | 0.45          | 4500              | Table 4.4.1   |   |                     | Table 4.4.2                      |
|                |               |                   | Cementitious materials <sup>†</sup> —types  |   |                     | Calcium chloride admixture       |
|                |               |                   | ASTM C150   | ASTM C595   | ASTM C1157          |                                  |
| S0             | N/A           | 2500              | No Type restriction   | No Type restriction   | No Type restriction | No restriction                   |
| S1             | 0.50          | 4000              | II <sup>‡</sup>   | IP(MS), IS (<70) (MS)   | MS                  | No restriction                   |
| S2             | 0.45          | 4500              | V <sup>§</sup>  | IP (HS) IS (<70) (HS)   | HS                  | Not permitted                    |
| S3             | 0.45          | 4500              | V + pozzolan or slag <sup>  </sup>  | IP (HS) + pozzolan or slag <sup>  </sup> (<70) (HS pozzolan or slag <sup>  </sup> ) |                     |                                  |
| P0             | N/A           | 2500              | None  |   |                     |                                  |
| P1             | 0.50          | 4000              | None  |   |                     |                                  |
|                |               |                   | Maximum water-soluble chloride ion (Cl <sup>-</sup> ) content in concrete, percent by weight of cement <sup>#</sup> |   | Related provisions  |                                  |
|                |               |                   | Reinforced concrete   | Prestressed concrete  |                     |                                  |
| C0             | N/A           | 2500              | 1.00  | 0.06  | None                |                                  |
| C1             | N/A           | 2500              | 0.30  | 0.06  |                     |                                  |
| C2             | 0.40          | 5000              | 0.15  | 0.06  | 7.7.6, 18.16**      |                                  |

\*For lightweight concrete, see 4.1.2.

<sup>†</sup>Alternative combinations of cementitious materials of those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in 4.5.1.

<sup>‡</sup>For seawater exposure, other types of portland cements with tricalcium aluminate (C<sub>3</sub>A) contents up to 10 percent are permitted with the  $w/cm$  does not exceed 0.40.

<sup>§</sup>Other available types of cement such as Type III or Type I are permitted in Exposure Classes S1 or S2 if the C<sub>3</sub>A contents are less than 8 or 5 percent, respectively.

<sup>||</sup>The amount of the specific source of the pozzolan or slag to be used shall not be less than the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag to be used shall not be less than the amount tested in accordance with ASTM C1012 and meeting the criteria in 4.5.1.

<sup>#</sup>Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218 at age between 28 and 42 days.

\*\*Requirements of 7.7.6 shall be satisfied. See 18.16 for unbonded tendons.

content. For Exposure Class S1 (moderate exposure), Type II cement is limited to a maximum C<sub>3</sub>A content of 8.0 percent under ASTM C150. The blended cements under ASTM C595 with the MS designation are appropriate for use in Exposure Class S1. The appropriate types under ASTM C595 are IP(MS) and IS(<70)(MS) and under C1157 is Type MS. For Exposure Class S2 (severe exposure), Type V cement with a maximum C<sub>3</sub>A content of 5 percent is specified. Blended cements Types IP (HS) and IS (<70) (HS) under ASTM C595 and Type HS under ASTM C1157 can also be used. In certain areas, the C<sub>3</sub>A content of other available types such as Type III or Type I may be less than 8 or 5 percent and are usable in moderate or severe sulfate exposures. Note that sulfate-resisting cement will not increase resistance to some chemically aggressive solutions, for example, sulfuric acid. The project specifications should cover all special cases.

The use of fly ash (ASTM C618, Class F), natural pozzolans (ASTM C618, Class N), silica fume (ASTM C1240), or ground-granulated blast-furnace slag (ASTM C989) also has been shown to improve the sulfate resistance of concrete.<sup>4.1-4.3</sup> ASTM C1012 can be used to evaluate the sulfate resistance of mixtures using combinations of cementitious materials as determined in 4.5.1. For Exposure Class S3, the alternative in ACI 318-05 allowing use of Type V plus pozzolan, based on records of successful service, instead of meeting the testing requirements of 4.5.1, still exists and has been expanded to consider the use of slag and the blended cements.

Table 4.2.1 lists seawater under Exposure Class S1 (moderate exposure), even though it generally contains more than 1500 ppm SO<sub>4</sub>. Portland cement with higher C<sub>3</sub>A content improves binding of chlorides present in seawater and the Code permits other types of portland cement with C<sub>3</sub>A up to 10 percent if the maximum  $w/cm$  is reduced to 0.40.

In addition to the proper selection of cementitious materials, other requirements for durable concrete exposed to water-soluble sulfate are essential, such as low  $w/cm$ , strength, adequate air entrainment, adequate consolidation, uniformity, adequate cover of reinforcement, and sufficient moist curing to develop the potential properties of the concrete.

**Exposure Class P1:** The Code includes an Exposure Class P1 for concrete that needs to have a low permeability when in direct contact with water and where the other exposure conditions defined in Table 4.2.1 do not apply. The primary means to obtain low permeability is to use a low  $w/cm$ . Low permeability can be also achieved by optimizing the cementitious materials used in the concrete mixture. One standard method that provides a performance-based indicator of low permeability of concrete is ASTM C1202, which is more reliable in laboratory evaluations than for field-based acceptance.