

Concrete Cooling Towers - Salt Water

DESIGN CONSIDERATIONS

What is Salt Water?

For cooling tower service, any circulating water with more than 750 parts per million chloride expressed as NaCl is generally considered as "salt water". However, the effects of chlorides will be much less severe at 750 ppm than they will at higher concentrations. Salt water may be from the open ocean, brackish (estuarine) or from brine wells. Since an open recirculating system concentrates the dissolved solids in the makeup water, a cooling tower may be exposed to salt water service even though the makeup contains less than 750 ppm NaCl.

If makeup for the cooling tower is from the open ocean, the hypothetical composition will be:

185 ppm	_____	Ca(HCO ₃) ₂
1,200 ppm	_____	CaSO ₄
2,150 ppm	_____	MgSO ₄
3,250 ppm	_____	MgCl ₂
27,000 ppm	_____	NaCl
500 ppm	_____	KCl
100 ppm	_____	KBr
Salinity	_____	35,000 ppm
Total Alkalinity	_____	15 ppm as CaCO ₃
pH	_____	About 8

How Does It Affect the Cooling Tower?

Materials—The primary effect of salt water is to increase the corrosion rate of metal in the cooling tower and the cooling system and the cooling system. All metals, fasteners, inserts, and anchors should be Monel Alloy 400 or Aluminum Bronze (UNS No. C62300)

Corrosion of Steel Reinforcement in Concrete—The mechanism of steel reinforcement is presented in **Figure 1**. There are three conditions necessary to make the electrochemical process possible, namely,

- Disruption of the passive gamma-Fe₂O₃ film: The film can be destroyed by penetration of the aggressive chloride ions, which may promote corrosion at anode.
- Oxygen supply: After reaction, chloride ions are released for reuse. The corrosion process is an oxygen diffusion limited system: the reaction can progress only as fast as oxygen is supplied.
- Current flow between anodic and cathodic areas: This current flow is controlled by the electrolytic resistance of the matrix and is inversely affected by moisture content, temperature, soluble salts content and permeability.

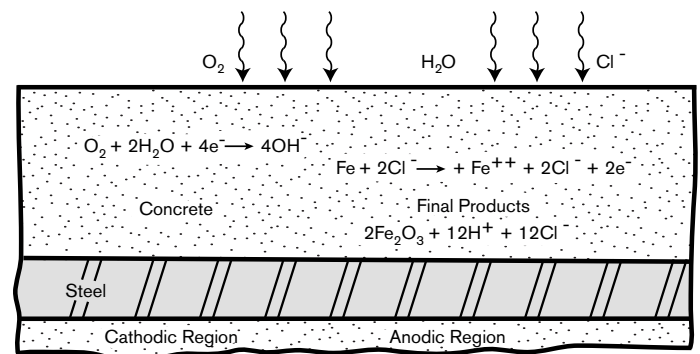


FIGURE 1 Corrosion of steel reinforcement in concrete in the presence of chloride.

To prevent the deteriorations of concrete and the corrosion of rebar due to the attack of chloride ion in salt water, a special concrete mix must be designed. Concrete mix design parameters are described as follows:

- 1. Minimum Cement Content** Cement content shall not be less than 415 kg per cubic meter.



2. Highly Reactive Pozzolan (HRP, i.e. silica fume or metakaolin) Content HRP content should be determined based on trial mixtures and HRP supplier recommendations. The HRP contents, expressed as percent of weight of cement is typically as high as 10% but also depends on use of other admixtures such as fly ash and blast furnace slag.

3. Water to Cement Ratio plus HRP Ratio Ratio of water weight to cement plus HRP weight should generally not exceed 0.36. However, a well designed and tested mix can successfully use mixes with ratios as high as 0.38 and frequently lower than 0.35. This is affected by the other mix constituents such as aggregate and other pozzolanic materials (fly ash or blast furnace slag).

Nominal Maximum Aggregate Size		Average Air Content, Percent (%)	
inches	mm	Severe Exposure	Moderate Exposure
3/8	9.5	7½	6
½	12.5	7	5½
¾	19	6	5
1½	38	5½	4½
3	75	4½	3½
6	150	4	3

Recommended Air Contents for Frost-Resistant Concrete

4. Air Entrainment Concrete, at the point of placement, shall contain entrained air as indicated in Table 1.4.3. of ACI 201.2R for severe exposure.

5. Chloride Content Chloride shall not be added to concrete mix in any form. Total acid soluble chloride ion (Cl⁻) content of the concrete prior to exposure, expressed as percent by mass of the cement shall be as follows:

Normal reinforced concrete - 0.20

6. Compressive Strength Minimum 28 day concrete strength (fc' of 6" dia. x 1'-0 standard cylinder) shall be consistent with the design requirements but not less than 7000 psi (equivalent to 20cm cube R= 615 kg/cm², fc'= 0.8 - 0.85 R). Acceptable value of fc' shall be based on the mix designs finalized for use in the structure.

7. Admixtures Use air entraining, water reducing and high range water reducing admixtures as required.

8. Chloride Permeability Chloride permeability of concrete shall not exceed 1000 coulombs at an age of 28 days.

9. Slump Use appropriate quantities of high range water reducer to obtain a minimum slump of 4" (10 cm) at the point of concrete placement to assure proper concrete placement and consolidation. Slump shall not be more than 8" (20 cm) at the point of placement.

10. Mix Design

Constituents (1 cubic meter mix):

Type II Portland Cement	415kg
Coarse Aggregate (#57, crushed granite)	749kg
Fine Aggregate	834kg
Water, liters	66

Admixtures:

Air Entrant Agent	139g
High Range Water Reducer -Daracom 100	6.7kg
Microsilica Slurry -Force 10000	59.8kg
Water/(Cement + Microsilica Fume	0.36

10. Reinforcing Steel Reinforcing bars shall be deformed Grade 60 bars. Rebars shall be epoxy coated.

Epoxy patching material, compatible with the coating material used for the bars.

Bar supports shall be made from either type 316 stainless steel, plastic or engineer approved equal.

Tie wire shall be black, epoxy coated annealed steel, or engineer approved equal.

12. Silica Fume

Silica fume is commercially available in three forms:

- Water-slurry
- Dry-uncompact powder
- Dry-densified powder

Chemical Requirements The chemical requirements shall be specified as follows:

SiO ₂ , minimum	92%
Loss on Ignition, maximum	3.0%
Moisture content, maximum	3.0%
Solid content of slurry	50% ± 2%
Available alkalis as Na ₂ O maximum	1.5%

Effects of Salt Water on Thermal Performance

Salt has three basic effects upon water which effect thermal performance. It lowers the vapor pressure, increases the density of the solution, and reduces the specific heat. The lower vapor pressure will reduce the rate of evaporation which will reduce the thermal performance. **Figure 2** shows the variation in density as a function of temperature and salt concentration. As shown in the figure, there is an increase in fluid density as the salinity level increases. **Figure 3** gives the variation in specific heat as a function of temperature and salinity.

To demonstrate the effect of density and specific heat of salt water on thermal performance, we consider the following design conditions:

Salinity = 50,000 ppm Water Temperature = 121°F.

We have the following relationship

	Fresh Water	50,000 ppm	Ratio
Density lb/cu ft	61.8	64.1	103.7
Specific Heat Btu/lb	0.998	0.944	94.5

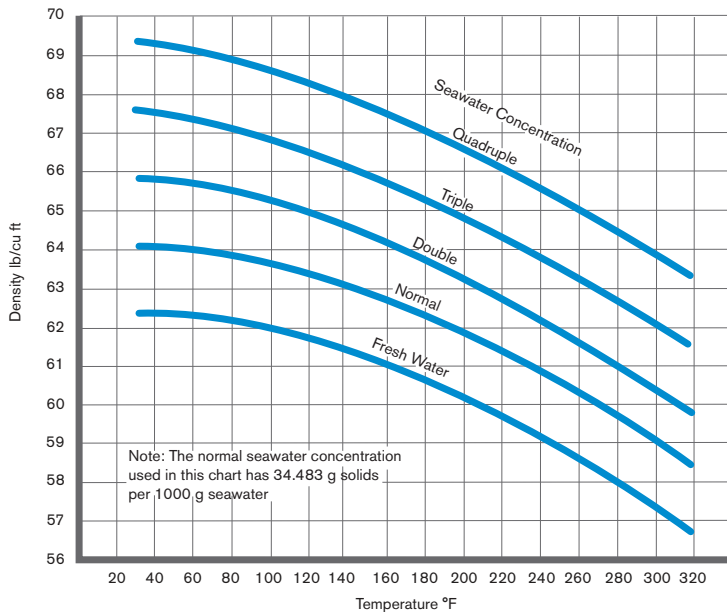


FIGURE 2 Density of seawater

As we see, the specific heat decreases more than the density increases. Consequently, the heat absorbing capacity of concentrated sea water is less than that of an equivalent volume of fresh water. To put it another way, for the same amount of volume, salt water is inherently slightly less efficient than fresh water as a coolant. A salt water tower, then, must have either greater water flow or more range in order to handle the same heat load.

Heat Load Equation

$$\text{Heat Load} = K \times \text{Flow (gpm)} \times \text{Range (°F)}$$

where

$$K = 0.1337 \times 60 \times \text{Density} \times \text{Specific Heat}$$

Example:

$$\text{Hot water temperature} = 121^\circ\text{F}$$

$$\begin{aligned} \text{Fresh water: density} &= 61.8 \text{ lb/cu ft} \\ \text{specific heat} &= 0.998 \text{ Btu/lb} \end{aligned}$$

$$K_f = 0.1337 \times 60 \times 61.8 \times 0.998 = 494.768 \text{ Btu/gpm hr } ^\circ\text{F}$$

$$\begin{aligned} 50,000 \text{ ppm salt water: density} &= 64.1 \text{ lb/cu ft} \\ \text{specific heat} &= 0.944 \text{ Btu/lb} \end{aligned}$$

$$K_s = 0.1337 \times 60 \times 64.1 \times 0.944 = 485.414 \text{ Btu/gpm hr } ^\circ\text{F}$$

With 635,000 gpm of water flow and 26°F, the total heat load for the salt water is

$$485.414 \times 635,000 \times 26 = 8.014 \times 10^9 \text{ Btu/hr}$$

To dissipate the same heat load with fresh water, the product of gpm and range required will be:

$$8.014 \times 10^9 \div 494.768 = 1.620 \times 10^7$$

If we maintain the same range, then we only need $1.620 \times 10^7 \div 26 = 622,995$ gpm which is 98% of the salt water. On the other hand if we maintain the same gpm, then the range can be decreased to 25.51°F.

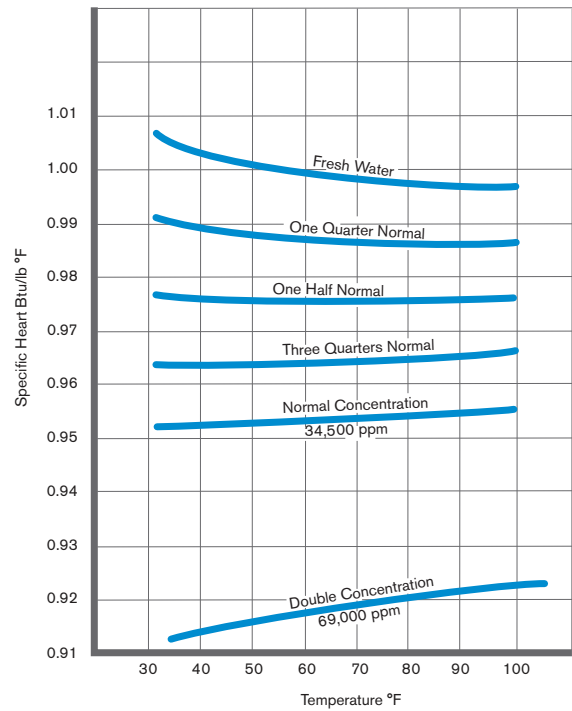


FIGURE 3 Specific heat of seawater

Vapor pressure effect on thermal performance Approximately 80% of the cooling effect of a natural draft cooling tower is evaporative cooling (latent heat transfer), a change in vapor pressure has a direct effect on the tower's efficiency. **Figure 4** shows vapor pressure of sea water as a function of concentration and temperature.

The table below shows the variation of vapor pressure in psia for 0 to 3 concentrations in the temperature range of 50°F to 150°F together with the relative reduction compared to fresh water.

Concentration	50°F	100°	150°F
0	0.178	0.950	3.74
1 (34,500)	0.174	0.926	3.65
2 (69,000)	0.170	0.905	3.56
3 (103,000)	0.165	0.880	3.46

The vapor pressure decreases approximately 2.5% for one concentration, 5% for two concentrations and 7.5% for three concentrations. Within the temperature range involved and the accuracy of the available data, this reduction can be considered independent of temperature. To demonstrate the effect of vapor pressure of sea water on thermal performance, we use the following numerical example.

	Fresh Water	Sea Water (50,000 ppm)
Water Temperature (°F)	95°	95°
Air Temperature (°F)	87°	87°
Air Relative Humidity (%)	60	60
Liquid Vapor Pressure (psia)	0.815	0.786
Air Vapor Pressure (psia)	0.381	0.381
Difference (psia)	0.434	0.405
Difference (%)	100	93.32

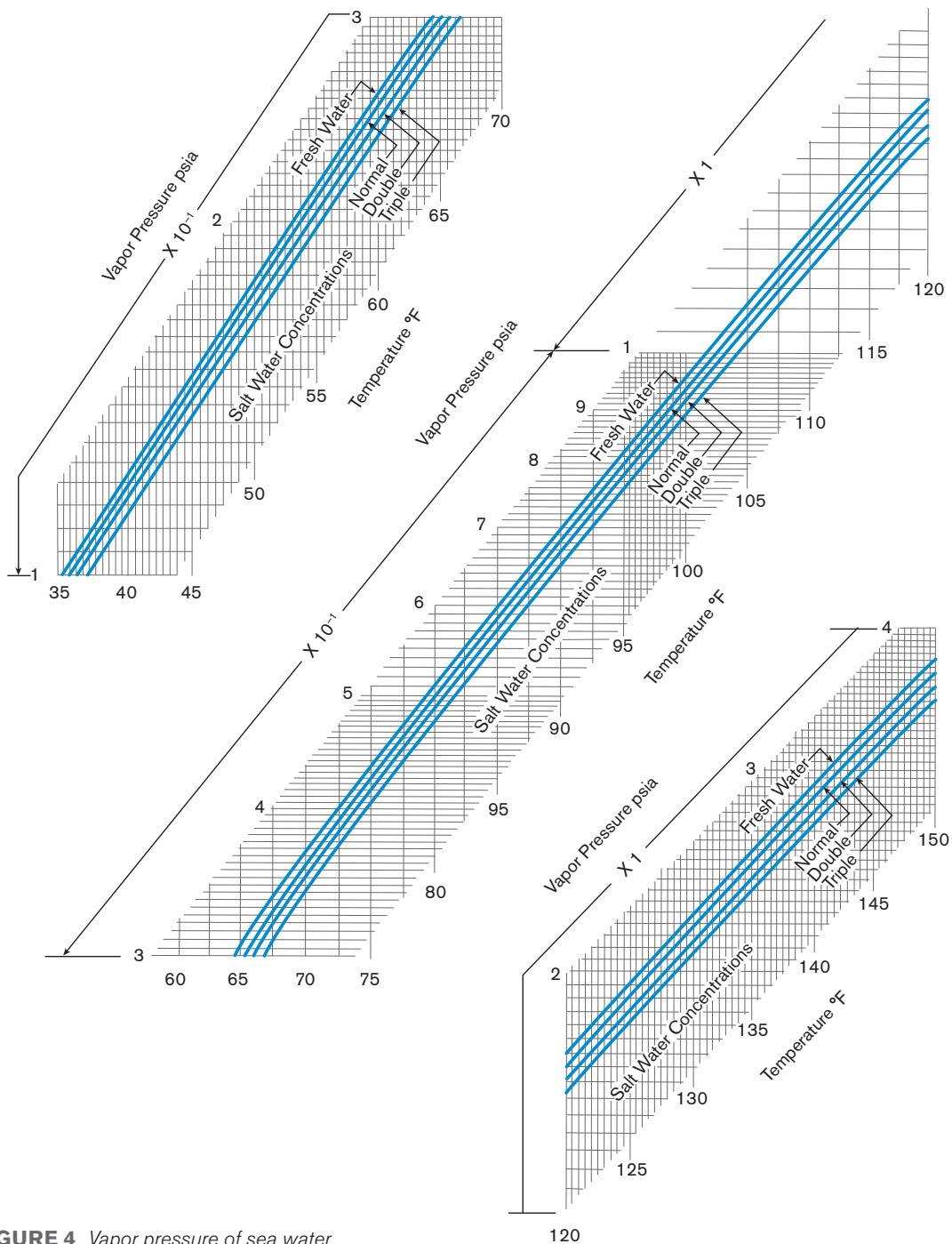


FIGURE 4 Vapor pressure of sea water

In this case, the performance of the sea water tower is approximately $0.8 \times (1 - 0.933) = 0.054$ or 5.4% short in comparison to that of fresh water tower.

The above mentioned three factors density, specific heat, and vapor pressure are the major influences that make salt water tower operating data vary from similar fresh water towers.

Another factor should be considered is thermal conductivity of the water. The film of water flowing on the film-fill sheets is so thin that it can be considered as a laminar flow, and without random stream flow mixing, heat transfer between the surface layer and the underlying layers can only be achieved by thermal conductivity. **Figure 5** shows thermal conductivity of sea water as a function of concentration and temperature.

For practical purpose, we can rate the cooling tower with fresh water and use a correction factor to adjust for a salt water tower.

SPX Cooling Technologies has conducted testing programs to determine the effects of salt water on thermal performance. It is found that if salt water with 1 normal concentration or less, the effect on thermal performance can be neglected. Using the testing data a correction factors for 2 concentrations of salt water is developed as shown in **Figure 6**.

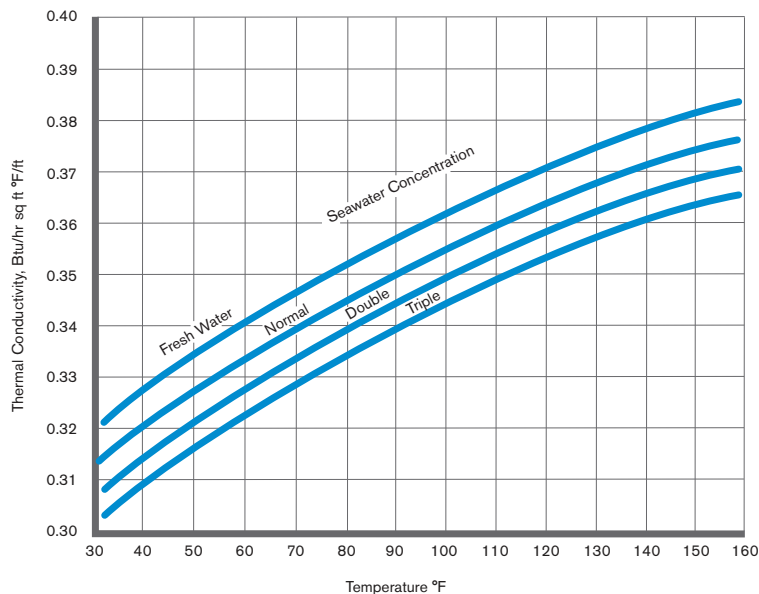


FIGURE 5 Thermal conductivity of sea water

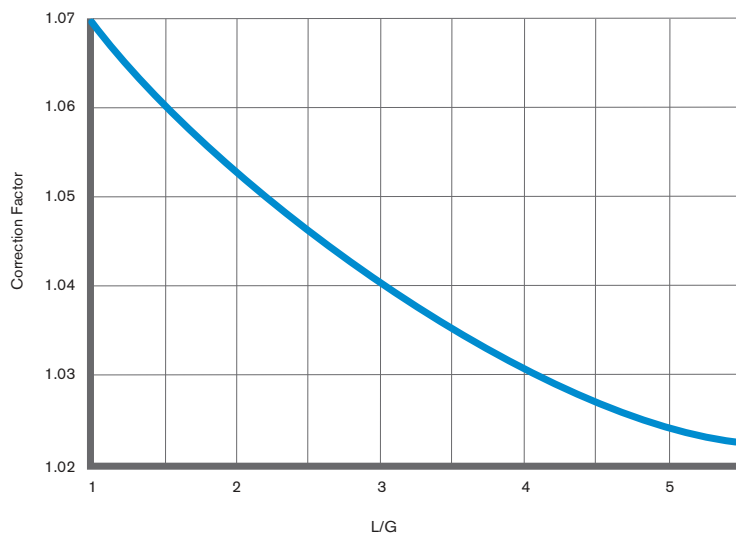


FIGURE 6 Correction factors for 2 concentrations of sea water

Effects of a Salt Water Cooling Tower on the Environment

The primary concerns in a salt water cooling tower are drift and blowdown. For all practical purposes, the drift and blowdown will contain the same concentration of total dissolved solids as the circulating water. The drift rates from most modern cooling towers will range from 0.002 to 0.2% of the circulating water rate. Drift rates below 0.002% are attainable with special attention to the eliminator designs and details. Even though low levels of drift are achievable, a salt water cooling tower should not be located close to sensitive equipment such as switch yard.

Blowdown from a salt water cooling tower will contain some multiple of the total dissolved mineral matter in the makeup but in the case of sea water makeup the final concentration in the cooling towers will not exceed two times that of the makeup. At the present time, there appears to be no major problem with the disposal of blowdown from salt water cooling towers providing toxic materials have not been added to the circulating water.

Microsilica Content

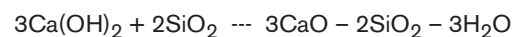
New types of materials which dramatically improve concrete are currently being used by producers of concrete and concrete products. These materials are composed of a high percentage of active silica, SiO_2 , and have an extremely fine particle size. An example of this type is condensed silica fume. The addition of microsilica to concrete can dramatically increase concrete strength, durability and impermeability, allowing concrete to be used in ways never before possible.

Microsilica refers to condensed silica fume, microsilica, fume silica and other names, are collected in a bag house, a system for filtering the hot air and gases vented from the furnace.

How Microsilica Works

Microsilica reacts with portland cement concrete in two ways: by altering the hydration reaction, and by the "microfiller effects."

When water is added to portland cement, hydration occurs, forming two primary products. The first is calcium silica hydrate gel, the "glue" that binds the aggregate together in a concrete mix. The other product formed is calcium hydroxide, the generation of which can comprise up to 25% of the volume of hydration products. Calcium hydroxide does not provide any benefit to concrete and may actually become detrimental. When a high amount of calcium hydroxide is present, concrete may be more susceptible to sulfate attack, alkali aggregate reaction or efflorescence. The chemical reaction of calcium hydroxide and microsilica can be expressed:



Any pozzolanic material added to concrete alters the hydration reaction. (A pozzolan is defined as a finely divided material that is siliceous or siliceous/aluminous in nature that has little or no cementitious value by itself.) Pozzolans react with the calcium hydroxide and water to produce more aggregate-binding calcium silicate gel while simultaneously reducing the calcium hydroxide content. The net effect is an increase in overall strength and durability.

Researchers discovered that microsilica is actually a "super pozzolan" when compared to other materials such as fly ash. The main reasons are its high percentage of reactive silica (SiO_2) and its fine particle size. Microsilica that is used in concrete typically has an SiO_2 content in excess of 85%, while fly ashes typically have an SiO_2 content of 30 to 60 percent. In addition, the extreme fineness of microsilica when compared to most pozzolans allows it to react almost immediately with the free calcium hydroxide in concrete, while conventional pozzolans react more slowly.

The second mechanism by which microsilica improves concrete is through the so called "microfiller effect." Most microsilica has an average particle size of 0.1 micrometers, while a typical portland cement has an average particle size of 15 micrometers. The extreme fineness of microsilica allows it to fill the microscopic voids between cement particles. The microfiller effect will greatly reduce permeability and increase paste-to-aggregate bond of microsilica concrete compared to conventional concrete. **Figure 7** shows concrete matrix without microsilica, note the porosity at the paste-to-aggregate interface. **Figure 8** shows concrete with microsilica, note the tighter paste interface.

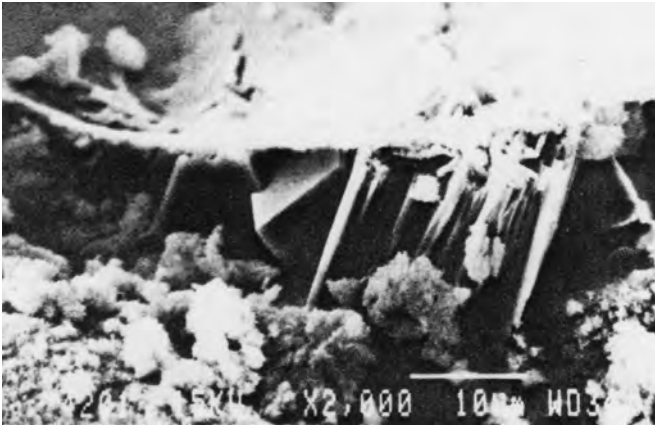


FIGURE 7 Concrete matrix without microsilica



FIGURE 8 Concrete with microsilica

Water Demand

The water demand of concrete can increase dramatically when dry bulk microsilica is added to the mix. This can cause a significant increase in water/cement ratio, which, without mix adjustment, could negate the benefits of adding microsilica. Field and laboratory experience has shown that adding high-range water reducers or super plasticizers will overcome the problem and assure full performance from the microsilica content.

However, because slurries containing silica fume are easier to handle than dry microsilica powders, few people use powders. Use of slurries will not increase water demand, and in fact, many microsilica slurries are proportioned to reduce water demand.

Rheology

Adding microsilica to concrete as a slurry or powder affects the rheological or flow properties of the mix. The rheology of concrete is measured by the slump test, as well as a subjective observation of its ability to flow and its workability. Microsilica concrete is more cohesive and sticky than conventional concrete. If the microsilica concrete contains super plasticizers, both the shear resistance and the cohesiveness of the concrete will be reduced.

Microsilica concrete with a measured slump of 5" (12.7cm) is typically similar in behavior to conventional concrete with a 4" (10 cm) slump. However, note that microsilica concrete placed with a concrete pump usually requires lower pumping pressure.

Finishing and Curing

The addition of microsilica to concrete will virtually eliminate bleed water. This requires close attention to the surface of the concrete to prevent premature drying that could lead to plastic shrinkage cracks. In most cases the concrete will need to be treated with a finishing film or misted with water to prevent premature drying.

Strength Enhancement

Under average plant conditions the addition of microsilica to a conventional concrete mix will significantly increase compressive and flexural strengths. **Figure 9** shows a mix that normally would give 5,500 psi (387 kg/cm²) in 28 days. Adding 7.5% microsilica by weight of cement and a high-range water reducer to maintain a constant water/cement ratio produces a concrete that reaches 9,500 psi (668 kg/cm²) in 28 days. Adding 15% microsilica by weight of cement brings the 28-day compressive strength to 10,300 psi (724 kg/cm²)

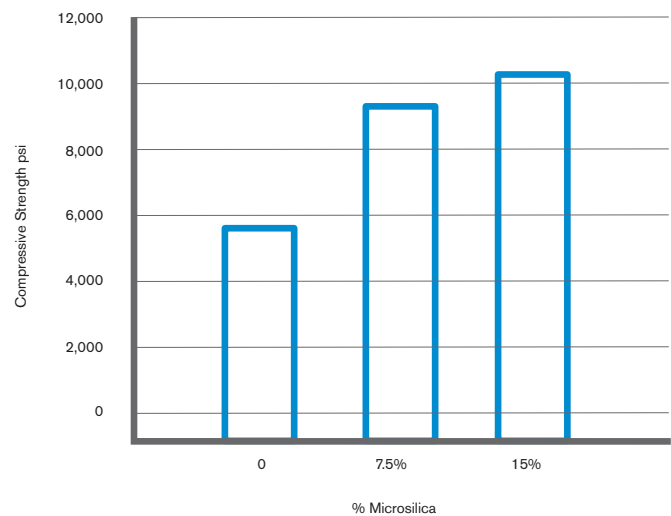


FIGURE 9 Microsilica concrete 28-day compressive strength (550 # Type 1 cement, water/cement ratio 0.45)

Permeability

Concrete permeability is measured by the rapid determination of the chloride permeability of concrete. When measured by this test method, conventional concrete typically gives a reading of 3,500 to 4,500 coulombs passed. The addition of 7.5% microsilica to the same mix will give a reading of 250 to 1000 coulombs passed. (The lower the number of coulombs passed, the less permeable the concrete.) Latex-modified concrete typically gives a reading of 100 to 1000 coulombs passed when measured by this method. These results can be seen in **Figure 10**.

Reduction of Porosity

The addition of microsilica will significantly reduce the total porosity of the cement paste as shown in **Figure 11**.

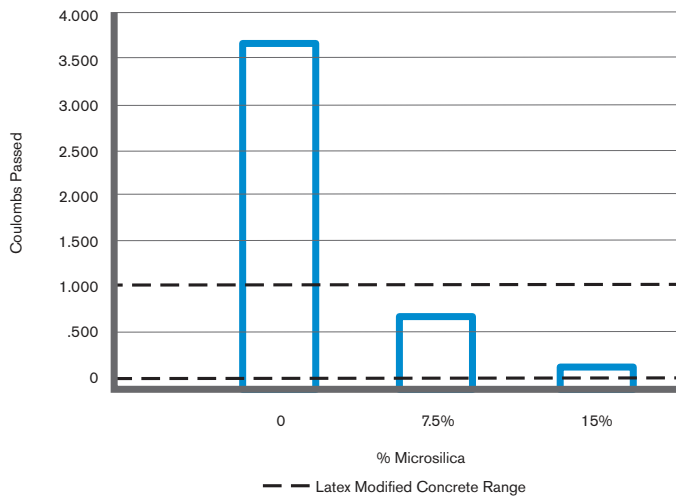


FIGURE 10 Rapid chloride permeability (550# Type 1 cement, water/cement ratio 0.37)

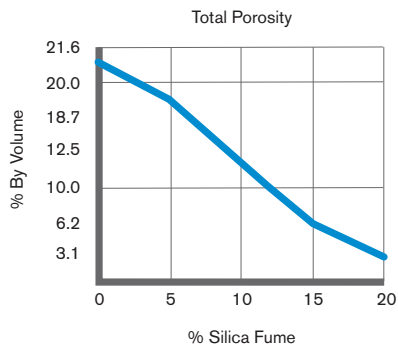


FIGURE 11 Microsilica content and porosity

Maximum Crack Width

Gergely-Lutz Equation

$$w = 0.076 \beta f_s \sqrt[3]{d_c A}$$

where:

w = crack width in units of 0.001"

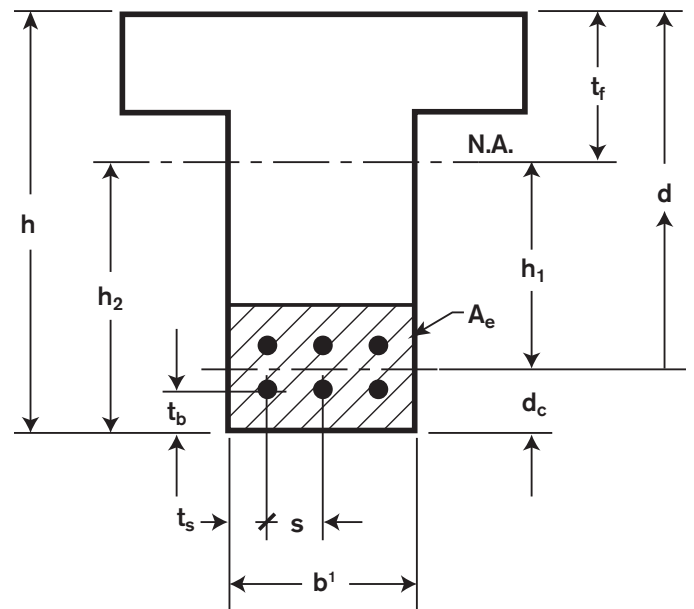
$$\beta = h_2/h_1$$

f_s = calculated steel stress (ksi) at service load

d_c = concrete cover from bottom to center of reinforcement

$$A = A_e / \text{number of rebars}$$

w shall not be greater than 6 for salt water applications



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