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# Topic 2.2 Concrete

## 2.2.1

### **Introduction**

A large percentage of the bridge structures in the nation's highway network are constructed of reinforced concrete or prestressed concrete. It is important that the bridge inspector understand the basic characteristics of concrete in order to efficiently inspect and evaluate a concrete bridge structure.

Concrete, commonly mislabeled as "cement", is a mixture of various components that, when mixed together in the proper proportions, chemically react to form a strong durable construction material ideally suited for certain bridge components. Cement is only one of the basic ingredients of concrete. It is the "glue" that binds the other components together. Concrete is made up of the following basic ingredients:

- Portland cement
- Water
- Air
- Aggregates
- Admixtures (reducers, plasticizers, retarders)

### **Portland Cement**

The first ingredient, Portland Cement, is one of the most common types of cement, and it is made with the following raw materials:

- Limestone - provides lime
- Quartz or cement rock - provides silica
- Claystone - provides aluminum oxide
- Iron ore - provides iron oxide

The cement is produced by placing the above materials through a three process high temperature kiln system. During the three process kiln system, the temperature can range from 100° C to 1510° C (212° F to 2750° F). The first zone in the kiln process is known as the drying process. During this process, the materials are dehydrated due to the high temperature. The calcining zone is the next step and results in the production of lime and magnesia. The final step, called the burning zone or clinkering zone, produces clinkers or nodules of the sintered materials. Upon cooling, the clinkers are ground into a powder and finish the Portland cement production process.

### **Water**

The second ingredient, water, can be almost any potable water. Impurities in water, such as dissolved chemicals, salt, sugar, or algae, produce a variety of undesirable effects on the quality of the concrete mix. Therefore, water with a noticeable taste or odor may be suspect.

## **Air**

The third ingredient of concrete is air. Small evenly distributed amounts of entrained air provide:

- Increased durability against freeze/thaw effects
- Reduced cracking
- Improved workability
- Reduced water segregation

Air entrainment also reduces the weight of concrete slightly. Many tiny air bubbles introduced into the plastic concrete naturally create lighter weight concrete. The typical air entrainment additive is a vinsol resin. Air entrainment additives act like dishwashing liquids. When mixed with water, they create bubbles. These bubbles become part of the concrete mix, creating tiny air voids. Through extensive lab testing, it has been proven that when exposed to freeze/thaw conditions, the voids prevent excess pressure buildup in the concrete.

## **Aggregates**

The fourth ingredient, aggregates, comprise approximately 75% of a typical concrete mix by volume. Some aggregate qualities which result in a strong and durable concrete are:

- Abrasion resistance
- Weather resistance
- Chemical stability
- Chunky compact shape
- Smooth, non-porous surface texture
- Cleanliness and even gradation

Normal weight concrete has a unit weight of about 2240 to 2400 kg/m<sup>3</sup> (140 to 150 pcf). Typical aggregate materials for normal weight concrete are sand, gravel, crushed stone, and air-cooled, blast-furnace slag.

Lightweight concrete normally has a unit weight of 1200 to 1840 kg/m<sup>3</sup> (75 to 115 pcf). The weight reduction comes from the aggregates and air entrainment. Lightweight aggregates differ depending on the location where the lightweight concrete is being produced. The common factor in lightweight aggregates is that they all have many tiny air voids in them that make them lightweight with a low specific gravity.

## **Admixtures**

The fifth ingredient of most concrete mixes is one or more admixtures to change the consistency, setting time, or concrete strength. Pozzolans are a common type of admixture used to reduce permeability. There are natural pozzolans such as diatomite and pumicite, along with artificial pozzolans which include admixtures such as fly ash.

Admixtures can either be minerals or chemicals. The mineral admixtures include fly ash, silica fume, and ground granulated blast-furnace slag. Chemical admixtures can include water reducers, plasticizers, retarders, high range water reducers, and superplasticizers.

Fly ash is a by-product from the burning of ground or powdered coal. Fly ash was added to concrete mixes as early as the 1930's. This turned out to be a viable way to dispose of fly ash while positively affecting the concrete. The use of fly ash in concrete mixes improves concrete workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulfate resistance.

The use of fly ash in concrete mixes also has some drawbacks, however, such as increased set time and reduced rate of strength gain in colder temperatures. Admixture effects are also reduced when fly ash is used in concrete mixes. This means, for example, that a higher percentage of air entrainment admixture is needed for concrete mixes using fly ash.

Silica fume (microsilica) results from the reduction of high purity quartz with coal in electric furnaces while producing silicon and ferrosilicon alloys. It affects concrete by improving compressive strength, bond strength, and abrasion resistance. Microsilica also reduces permeability. Concrete with a low permeability minimizes steel reinforcement corrosion, which is of major concern in areas where deicing agents are used. These properties have contributed to the increased use of high performance concrete in recent bridge design and construction.

Some disadvantages that result from the use of silica fume include a higher water demand in the concrete mix, a larger amount of air entraining admixture, and a decrease in workability.

Ground granulated blast-furnace slag is created when molten iron blast furnace slag is quickly cooled with water. This admixture can be substituted for cement on a 1:1 basis. However, it is usually limited to 25% in areas where the concrete will be exposed to deicing salts and to 50% in areas that do not need to use deicing salts.

Water reducing admixtures and plasticizers are used to aid workability at lower water/cement ratios, improve concrete quality and strength using less cement content, and help in placing concrete in adverse conditions. These admixtures can be salts and modifications of hydroxylized carboxylic acids, or modifications of lignosulfonic acids, and polymeric materials. Some of the potentially negative effects that are encountered when using water reducers and plasticizers include loss of slump and excess setting time.

Retarding admixtures are used to slow down the hydration process while not changing the long-term mechanical properties. This type of admixture is needed when high temperatures are expected during placing and curing. Retarders slow down the setting time to reduce unwanted temperature and shrinkage cracks which result from a fast curing mix.

### **2.2.2**

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## **Properties of Concrete**

It is necessary for the bridge inspector to understand the different physical and mechanical properties of concrete and how they relate to concrete bridges in service today.

### Physical Properties

The major physical properties of concrete are:

- Thermal expansion - concrete expands as temperature increases and contracts as temperature decreases
- Porosity - because of entrapped air, the cement paste never completely fills the spaces between the aggregate particles, permitting absorption of water and the passage of water under pressure
- Volume changes due to moisture - concrete expands with an increase in moisture and contracts with a decrease in moisture
- Fire resistance - quality concrete is highly resistant to the effects of heat; however, temperatures over 370°C (700°F) may cause damage
- Formability - concrete can be cast to any shape prior to curing

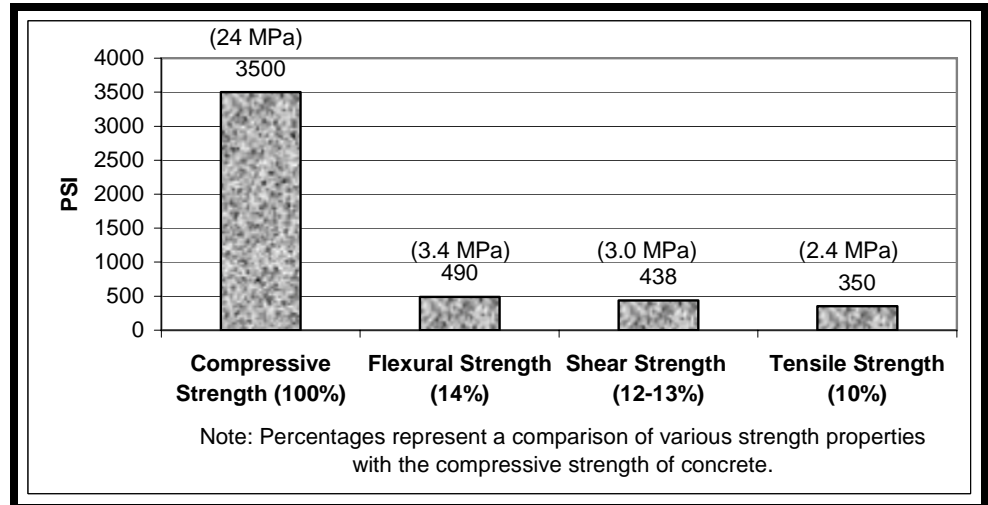
### Mechanical Properties

The major mechanical properties of concrete are:

- Strength - Plain, unreinforced concrete has a 28-day compressive strength ranging from about 17 MPa (2500 psi) to about 41 MPa (6000 psi). Higher strength concrete, with compressive strengths ranging from 41 MPa (6000 psi) to about 76 MPa (11,000 psi), is also available and becoming more commonly used. However, its tensile strength is only about 10% of its compressive strength, its shear strength is about 12% to 13% of its compressive strength, and its flexural strength is about 14% of its compressive strength (see Table 2.2.1).

Six principal factors that increase concrete strength are:

- Increased cement content
- Increased aggregate strength
- Decreased water-to-cement ratio
- Decreased entrapped air
- Increased curing time (extent of hydration)
- Use of pozzolanic admixtures and slag
- Elasticity - Within the range of normal use, concrete is able to deform a limited amount under load and still return to its original orientation when the load is removed (elastic deformation). Elasticity varies as the square root of compressive strength. See Topic P.2 for modulus of elasticity and how it affects elastic deformation.
- Creep - In addition to elastic deformation, concrete exhibits long-term, irreversible, continuing deformation under application of a sustained load. Creep (plastic deformation) ranges from 100% to 200% of initial elastic deformation, depending on time.
- Isotropy - Plain, unreinforced concrete has the same mechanical properties regardless of which direction it is loaded.



**Table 2.2.1** Strength Properties of Concrete (24 Mpa) (3500 psi Concrete)

### High Performance Concrete

High performance concrete (HPC) has been used for more than 25 years in the building industry. Under the FHWA's Strategic Highway Research Program (SHRP) Implementation Program, four types of high performance concrete mix designs were developed (see Table 2.2.2). High performance concrete is distinguished from regular concrete by its curing conditions and proportions of the ingredients in the mix design. The use of fly ash and high range water reducers play an important role in the design of HPC, as well as optimizing all components of the mix. Due to the increased strength and reduced permeability of HPC, bridge decks using HPC are expected to have double the life of conventional concrete bridge decks. The type and strength characteristics of concrete used to construct bridge components can be found in the bridge file under design specifications.

HPC Type	Minimum Strength Criteria	Water-Cementitious Ratio	Minimum Durability Factor
Very Early Strength (VES)	13.8 MPa (2,000 PSI)/ 6 hours	≤ 0.4	80%
High Early Strength (HES)	34.5 MPa (5,000 PSI)/ 24 hours	≤ 0.35	80%
Very High Strength (VHS)	69 MPa (10,000 PSI)/ 28 hours	≤ 0.35	80%
Fiber Reinforced	HES + (steel or poly)	≤ 0.35	80%

**Additional information on the definition of HPC:**

- "HPC Defined for Highway Structures," Charles Goodspeed, Suneel Vanikar, a1 Cook; *Concrete International*, February 1996, *The American Concrete Institute*
- "Workshop Showcases High-Performance Concrete Bridges," *Focus Newslette* May 1996.

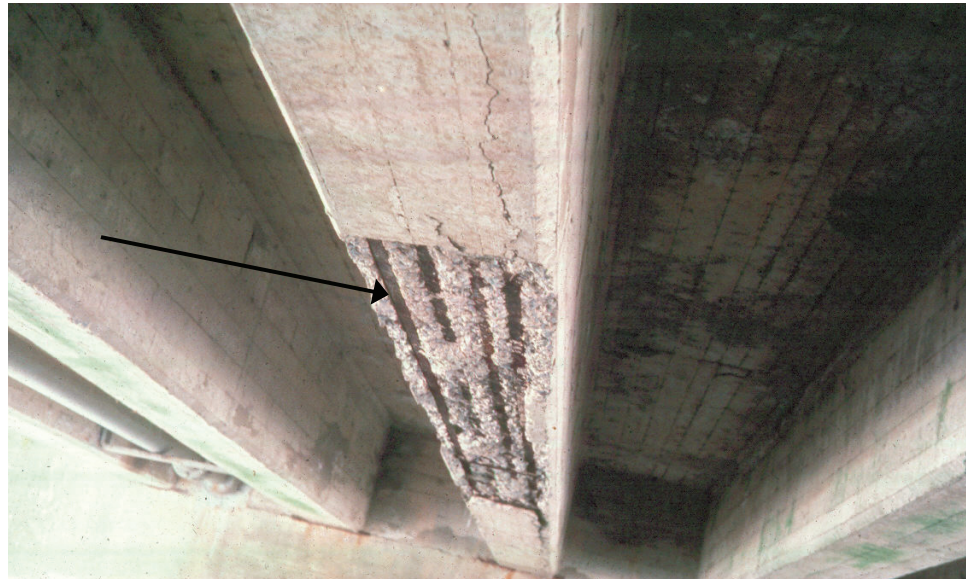
**Table 2.2.2** FHWA's SHRP Implemented HPC Mix Designs

### 2.2.3

## Reinforced Concrete

Concrete is commonly used in bridge applications due to its compressive strength properties. However, in order to supplement the limited tensile, shear and flexural strengths of concrete, steel reinforcement is used.

Steel reinforcement has a tensile yield strength of 276 MPa (40 ksi) or 414 MPa (60 ksi) and therefore has approximately 100 times the tensile strength of commonly used concrete. Therefore, in reinforced concrete members, the concrete resists the compressive forces and the steel reinforcement primarily resists the tensile forces. The type of steel reinforcement used in reinforced concrete is "mild steel", which is a term used for low carbon steels. The steel reinforcement is located close to the tension face of a structural member to maximize its efficiency (see Figure 2.2.1).



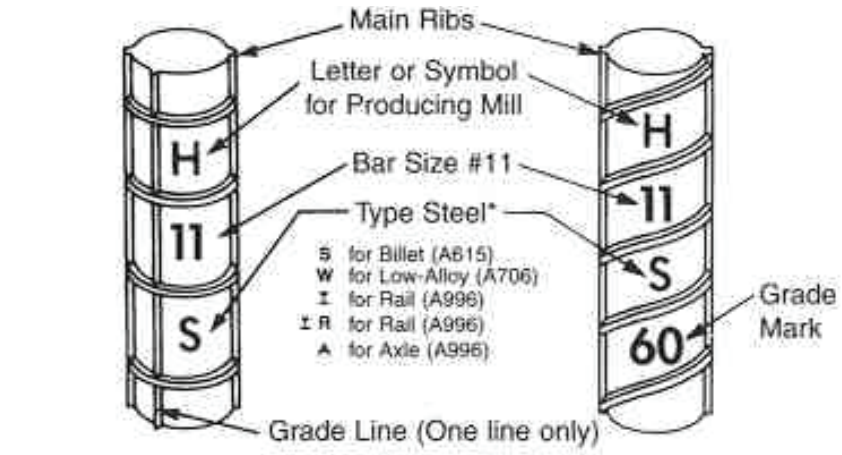
**Figure 2.2.1** Concrete Member with Tensile Steel Reinforcement Showing

Shear reinforcement is also needed to resist diagonal tension (refer to Topic P.1). Shear cracks start at the bottom of concrete members near the support and propagate upward and away from the support at approximately a 45° angle. Vertical or diagonal shear reinforcement is provided in this area to intercept the cracks and to stop the cracks from opening wider.

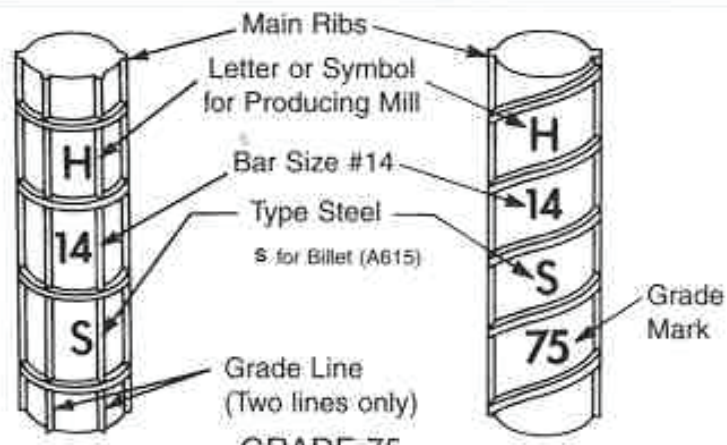
Reinforcing bars are also placed uniformly around the perimeter of a member to resist stresses resulting from temperature changes and volumetric changes of concrete. This steel is referred to as temperature and shrinkage steel.

Steel reinforcing bars can be "plain" or smooth surfaced, or they can be "deformed" with a raised gripping pattern protruding from the surface of the bar (see Figure 2.2.2). The gripping pattern improves bond with the surrounding concrete. Modern reinforced concrete bridges are generally constructed with "deformed" reinforcing steel.





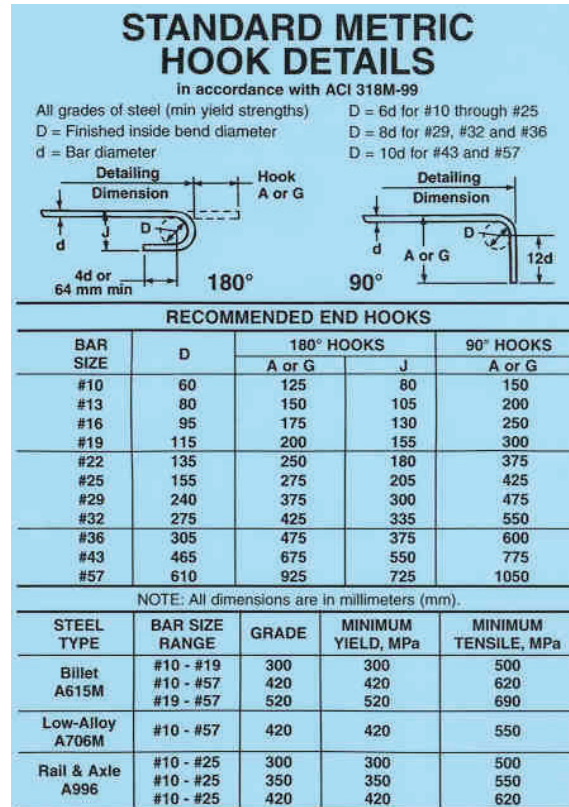
\* Bars marked with an S and W meet both A615 and A706  
**GRADE 60**



**GRADE 75**

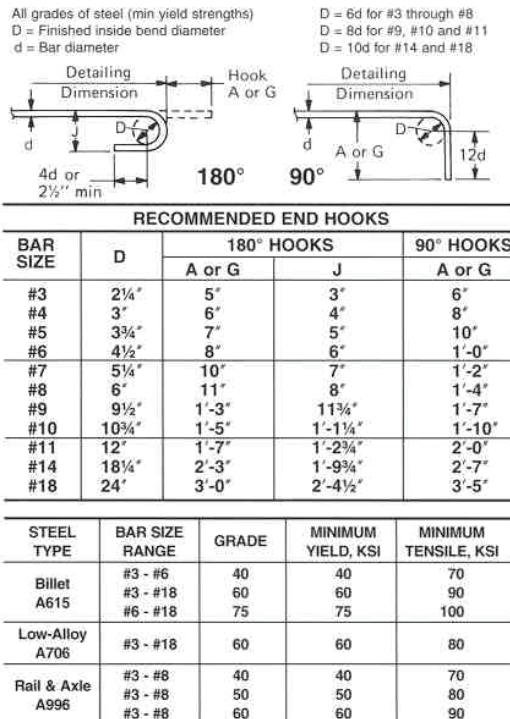
INCH- POUND BAR SIZE	DIAMETER (in.)	AREA (in. <sup>2</sup> )	METRIC BAR SIZE	DIAMETER (mm)	AREA (mm <sup>2</sup> )
#3	0.375	0.11	#10	9.5	71.0
#4	0.500	0.20	#13	12.7	129.0
#5	0.625	0.31	#16	15.9	200.0
#6	0.750	0.44	#19	19.1	284.0
#7	0.875	0.60	#22	22.2	387.0
#8	1.000	0.79	#25	25.4	510.0
#9	1.128	1.00	#29	28.7	645.0
#10	1.270	1.27	#32	32.3	819.0
#11	1.410	1.56	#36	35.8	1006.0
#14	1.693	2.25	#43	43.0	1452.0
#18	2.257	4.00	#57	57.3	2581.0

**Figure 2.2.2** Standard Deformed Reinforcing Bars (Source: Concrete Reinforcing Steel Institute)



### STANDARD HOOK DETAILS

in accordance with ACI 318-99



**Figure 2.2.2** Standard Deformed Reinforcing Bars (Source: Concrete Reinforcing Steel Institute) (Continued)

In US units, reinforcing bars up to 1" nominal diameter are identified by numbers that correspond to their nominal diameter in eighths of an inch. For example, a #4 bar has a 1/2 inch nominal diameter (or 4 times 1/8 inch). For the remaining bar sizes (#9, #10, #11, #14, and #18), the area is equivalent to the old 1", 1 1/8", 1 1/4", 1 1/2", and 2" square bars, respectively.

Reinforcing bars can also be used to increase the compressive strength of a concrete member. When reinforcing bars are properly incorporated into a concrete member, the steel and concrete acting together provide a strong, durable construction material.

Reinforcing bars can be protected or unprotected from corrosion. Unprotected reinforcement is referred to as "black" steel because only mill scale is present on the surface.

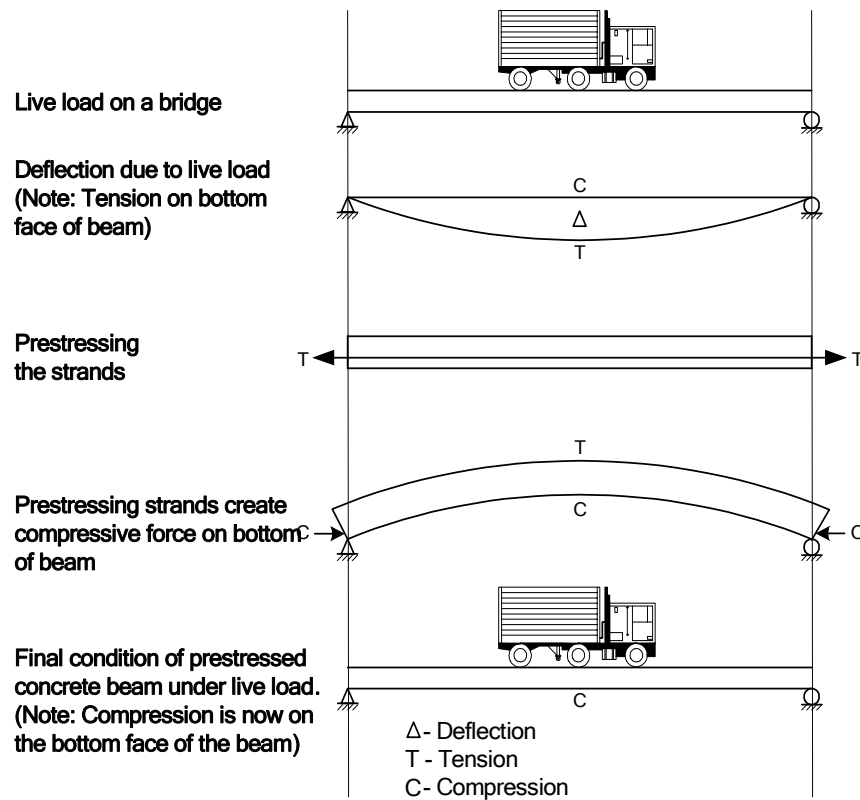
The deformed epoxy coated bar is the most common type of protected reinforcing bar used. It is commonly specified when a concrete member may be exposed to an adverse environment. The epoxy provides a protective coating against corrosion agents such as de-icing chemicals and brackish water, and is inexpensive compared to other protective coatings. Another type of protected reinforcing bar is the galvanized bar. Unprotected bars are given a zinc coating, which slows down or stops the corrosion process. See Topic 2.2.9 for a detailed description of reinforcement protective coatings.

In the near future, tensile reinforcement made of Fiber Reinforced Polymer (FRP) composites may become common. Currently the FHWA and other government agencies and universities are performing research to better understand the properties and appropriate methods for use of this material in new construction. FRP is lighter weight than traditional steel reinforcement, can be designed with a wide range of mechanical properties including tensile, flexural, impact and compressive strengths and provides a viable alternative in areas where deicing salts are used due to the fact that the deck does not deteriorate due to steel reinforcement corrosion. Current holdbacks to widespread use of FRP reinforcement are the relative cost when compared to steel, the limited amount of contractors with experience, and not having much performance data.

#### **2.2.4**

### **Prestressed Concrete**

Another type of concrete used in bridge applications is prestressed concrete, which uses high tensile strength steel strands as reinforcement. To reduce the tensile forces in a concrete member, internal compressive forces are induced through prestressing steel tendons or strands. When loads are applied to the member, any tensile forces developed are counterbalanced by the internal compressive forces induced by the prestressing steel. By prestressing the concrete in this manner, the final tensile forces under primary live loads are typically within the tensile strength limits of plain concrete. Therefore, properly designed prestressed concrete members do not develop flexure cracks under service loads (see Figure 2.2.3).

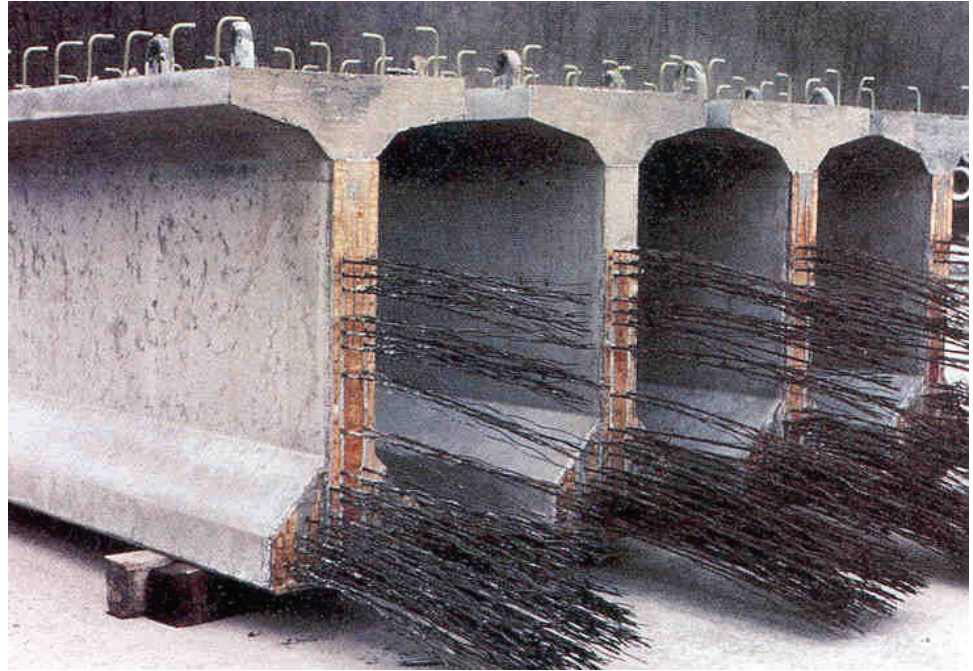


**Figure 2.2.3** Prestressed Concrete Beam

There are three methods of prestressing concrete:

- Pretensioning - during fabrication of the member, prestressing steel is placed and tensioned prior to casting and curing of the concrete (see Figure 2.2.4)
- Post-tensioning - during fabrication of the member, ducts are cast-in-place so that after curing, the prestressing steel can be passed through the ducts and tensioned (see Figure 2.2.5)
- Combination method - this is used for long members for which the required prestressing force cannot safely be applied using pretensioning only





**Figure 2.2.4** Pretensioned Concrete I-Beams



**Figure 2.2.5** Post-tensioned Concrete Box Girder

Steel for prestressing, which is named high tensile strength steel, comes in three basic forms:

- Wires (ASTM A421) - single wires or parallel wire cables; the parallel wire cables are commonly used in post-tensioning operations; the most popular wire size is 6 mm (1/4 inch) diameter and the most common grade

of steel is the 1860 Mpa (270 ksi) grade.

- Strands (ASTM A416) - fabricated by twisting wires together; the seven wire strand is the most common type of prestressing steel used in the United States, and the 1860 Mpa (270 ksi) grade is most commonly used today
- Bars (ASTM A322 and A29) - high tensile strength bars typically have a minimum ultimate stress of 1000 Mpa (145 ksi); the bars have full length deformations that also serve as threads to receive couplers and anchorage hardware

Epoxy coated prestressing strand is a newer alternative to help minimize the amount of corrosion that occurs to otherwise unprotected strands. The epoxy is applied to the ordinary seven wire low relaxation prestressing strand through a process called “fusion bonding”. Once the epoxy is applied, the strand has very little bond capacity and an aluminum oxide grit has to be applied to aid in the bonding. From recent testing by the FHWA, the epoxy coated strands have a tendency to slip when advanced curing temperatures are 63°C (145°F) and above. This slip occurs because the epoxy material begins to melt at these temperatures. Since the epoxy coating has a tendency to melt, this type of alternative is not used unless protection of the prestressing strand is critical.

In pretensioned members, transfer of tendon tensile stress occurs through bonding, which is the secure interaction of the prestressing steel with the surrounding concrete. This is accomplished by casting the concrete in direct contact with the prestressed steel.

For purposes of crack control in end sections of pretensioned members, the prestressing steel is sometimes debonded. This is accomplished by providing a protective cover on the steel, preventing it from contacting the concrete. Crack control at the beam ends may also be obtained by using draped strands. A number of strands are draped from both ends of the beam to the beam’s third points resulting in end strand patterns with center of gravities near the beam center of gravity.

In post-tensioned members, transfer of tendon tensile stress is accomplished by mechanical end anchorages and locking devices. If bonding is also desired, special ducts are used which are pressure injected with grout after the tendons are tensioned and locked off.

For post-tensioned members, when bonding is not desirable, grouting of tendon ducts is not performed and corrosion protection in the form of galvanizing, greasing, or some other means must be provided.

In prestressed concrete beams, shear strength is enhanced by the local compressive stress present. However, mild shear reinforcement is still required. Similar to reinforced concrete, prestressed concrete also requires mild steel temperature and shrinkage reinforcement.

## 2.2.5

### **Types of Concrete Deterioration**

In order to properly inspect a concrete bridge, the inspector must be able to recognize the various types of defects or deterioration associated with concrete. The inspector must also understand the causes of the defects or deterioration and how to examine them. There are many common defects or deterioration that occur on reinforced concrete bridges:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

### **Structural Cracks**

A crack is a linear fracture in concrete. It may extend partially or completely through the member. There are two basic types of cracks: structural and non-structural cracks. Structural cracks are caused by dead load and live load stresses. Cracking is considered normal for mildly reinforced concrete (e.g., in cast-in-place tee-beams) as long as the cracks are small and there are no rust stains or other signs of deterioration present. Larger structural cracks indicate potentially serious problems, because they are directly related to the structural capacity of the member. When cracks can be observed opening and closing under load, they are referred to as “working” cracks. See Table 2.2.3 for crack width guidelines. There are two types of structural cracks: flexure and shear (see Figure 2.2.6).

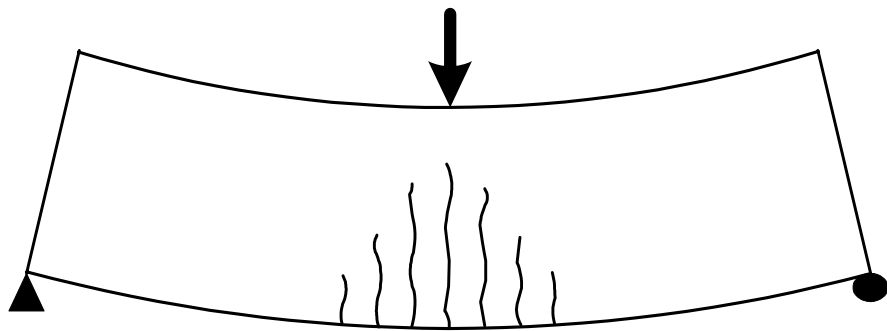
#### **Flexure Cracks**

Flexure cracks are caused by tensile forces and therefore develop in the tension zones. Tension zones occur either on the bottom or the top of a member, depending on the span configuration. Tension zones can also occur in substructure components. Tension cracks terminate when they approach the neutral axis of the member. If a beam is a simple span structure (refer to Topic P.2.9), flexure cracks can often be found at the mid-span at the bottom of the member where bending or flexure stress is greatest (see Figure 2.2.7). If the beams are continuous span structures (refer to Topic P.2.9), flexure cracks can also occur at the top of members at or near their interior supports.

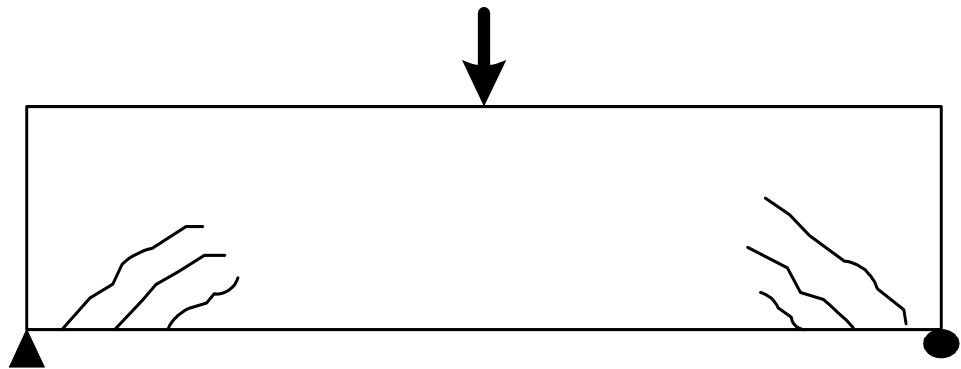
### Shear Cracks

Shear cracks are caused by diagonal tensile forces that typically occur in the web of a member near the supports where shear stress is the greatest. Normally, these cracks initiate near the bearing area, beginning at the bottom of the member, and extending diagonally upward toward the center of the member (see Figure 2.2.8). Shear cracks also occur in abutment backwalls, stems and footings, pier caps, columns, and footings.

Although structural cracks are typically caused by dead load and live load forces, they can also be caused by overstresses in members resulting from unexpected secondary forces. Restricted thermal expansion or contraction such as caused by frozen bearings, or forces due to the expansion of an approach slab or failure of a backwall can induce significant forces which result in cracks (see Figure 2.2.9).



Flexure Cracks



Shear Cracks

Figure 2.2.6 Structural Cracks

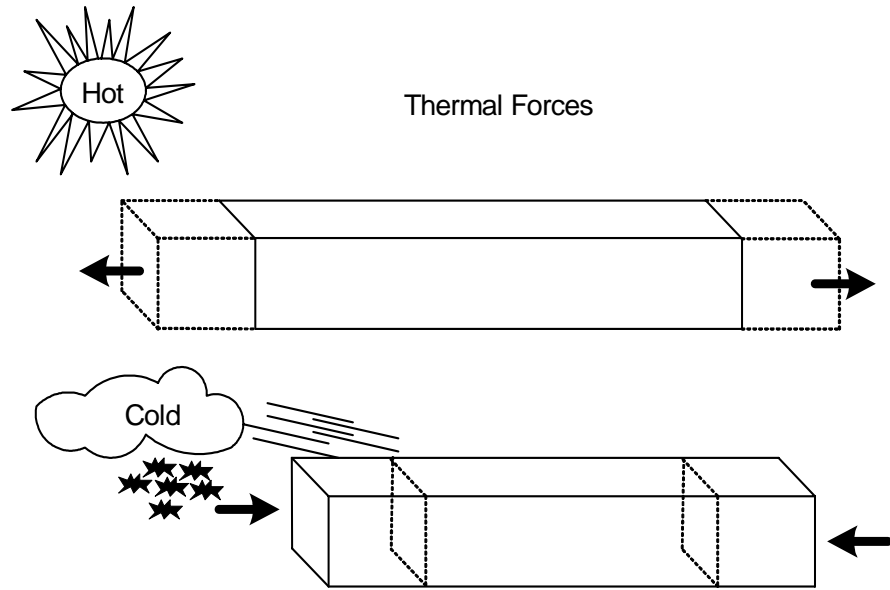




**Figure 2.2.7** Flexural Crack on a Tee Beam



**Figure 2.2.8** Shear Crack on a Slab Beam



**Figure 2.2.9** Thermal Forces

### Crack Size

Crack size is very important in assessing the condition of an in-service bridge. Cracks may extend partially or completely through the concrete member. On reinforced concrete, cracking will usually be large enough to be seen with the naked eye. A crack comparator card can be used to measure and differentiate cracks (see Figure 2.2.10 and Table 2.2.3).



**Figure 2.2.10** Crack Comparator Card

<b>CRACK WIDTH GUIDELINES</b>				
	<b>REINFORCED CONCRETE</b>		<b>PRESTRESSED CONCRETE</b>	
	English	Metric	English	Metric
<b>HAIRLINE (HL)</b>	< 1/16" (0.0625)	< 1.6mm	< 0.004"	< 0.1mm
<b>NARROW (N)</b>	1/16" to 1/8" 0.0625" – 0.125"	1.6 to 3.2mm	0.004 to 0.009"	0.1 to 0.23mm
<b>MEDIUM (M)</b>	1/8" to 3/16" 0.125" – 0.1875"	3.2 to 4.8mm	0.010 to 0.030"	0.25 to 0.76mm
<b>WIDE (W)</b>	>3/16" >0.1875"	> 4.8mm	> 0.030"	> 0.76mm

**Table 2.2.3** Crack Width Guidelines

Cracks can be classified as hairline, narrow, medium, or wide. Hairline cracks are small and cannot be measured with normal equipment, such as a six-foot rule. Medium and wide cracks are cracks that can be measured by simple means or a crack comparator card. On conventionally reinforced structures, hairline cracks are usually insignificant. All other crack widths may be significant and should be monitored and recorded in the inspection notes.

On prestressed structures, all cracks are significant and an optical crack gauge is the proper instrument needed to measure and differentiate cracks.

When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted. Both large and small cracks in main members, especially in prestressed members, should be carefully recorded. The presence of rust stains or efflorescence or evidence of differential movement on either side of the crack should be indicated.

**Nonstructural Cracks**

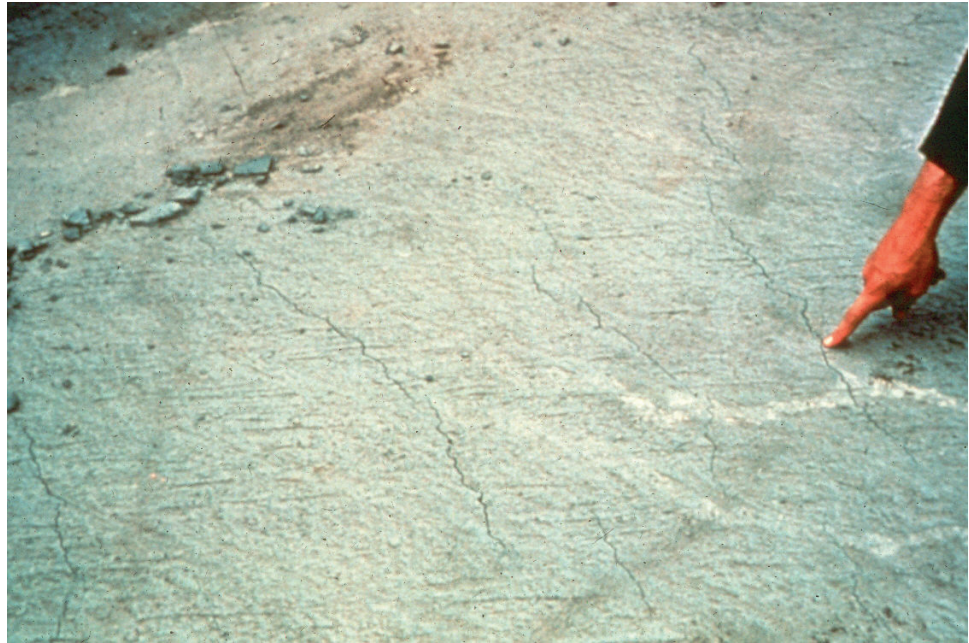
Nonstructural cracks result from internal stresses due to dimensional changes. Nonstructural cracks are divided into three categories:

- Temperature cracks (see Figure 2.2.11)
- Shrinkage cracks (see Figure 2.2.12)
- Mass concrete cracks

Though these cracks are nonstructural and relatively small in size, they provide openings for water and contaminants, which can lead to serious problems. Temperature cracks are caused by the thermal expansion and contraction of the concrete. Concrete expands or contracts as its temperature rises or falls. If the concrete is prevented from contracting, due to friction or because it is being held in place, it will crack under tension. Inoperative bearing devices and clogged expansion joints can also cause this to occur. Shrinkage cracks are due to the shrinkage of concrete caused by the curing process. Volume reduction due to curing is also referred to as plastic shrinkage. Plastic shrinkage cracks occur while the concrete is still plastic and are usually short, irregular shapes and do not extend the full depth into the member. Mass concrete cracks occur due to thermal gradients (differences between interior and exterior) in massive sections



immediately after placement and for a period of time thereafter. Temperature, shrinkage, and mass concrete cracks typically do not significantly affect the structural strength of a concrete member.



**Figure 2.2.11** Temperature Cracks



**Figure 2.2.12** Shrinkage Cracks

In concrete bridge decks, temperature and shrinkage cracks can occur in both the transverse and longitudinal directions. In retaining walls and abutments, these cracks are usually vertical, and in concrete beams, these cracks occur vertically or transversely on the member. However, since temperature and shrinkage stresses exist in all directions, the cracks could have other orientations.

Inspectors must exercise care in distinguishing between nonstructural cracks and structural cracks. However, regardless of the crack type, water seeps in and causes the reinforcement to corrode. The corroded reinforcement expands and exerts pressure on the concrete. This pressure can cause delaminations and spalls.

### **Crack Orientation**

In addition to classifying cracks as either structural or nonstructural and recording their lengths and widths, inspectors must also describe the orientation of the cracks. The orientation of the crack with respect to the loads and supporting members is an important feature that must be recorded accurately to ensure the proper evaluation of the crack. The orientation of cracks may generally be described by one of the following five categories:

- Transverse cracks – These are fairly straight cracks that are roughly perpendicular to the centerline of the bridge or a bridge member (see Figure 2.2.13).
- Longitudinal cracks - These are fairly straight cracks that run parallel to the centerline of the bridge or a bridge member (see Figure 2.2.14).
- Diagonal cracks - These cracks are skewed (at an angle) to the centerline of the bridge or a bridge member, either vertically or horizontally.
- Pattern or map cracking - These are inter-connected cracks that form networks of varying size. They vary in width from barely visible, fine cracks to cracks with a well defined opening. Map cracking resembles the lines on a road map (see Figure 2.2.15).
- Random cracks - These are meandering, irregular cracks. They have no particular form and do not logically fall into any of the types described above.



**Figure 2.2.13** Transverse Cracks



**Figure 2.2.14** Longitudinal Cracks



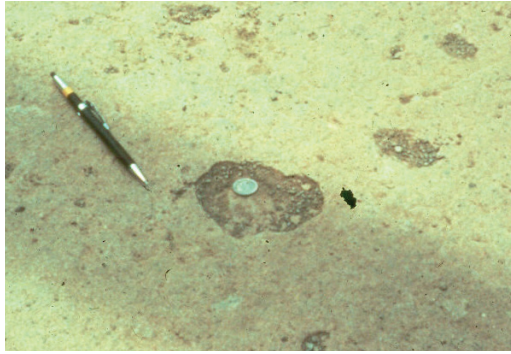


**Figure 2.2.15** Pattern or Map Cracks

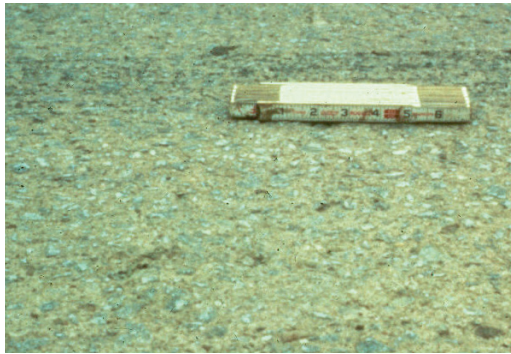
### Scaling

Scaling is the gradual and continuing loss of surface mortar and aggregate over an area due to the chemical breakdown of the cement bond. Scaling is accelerated when the member is exposed to a harsh environment. Scaling is classified in the following four categories:

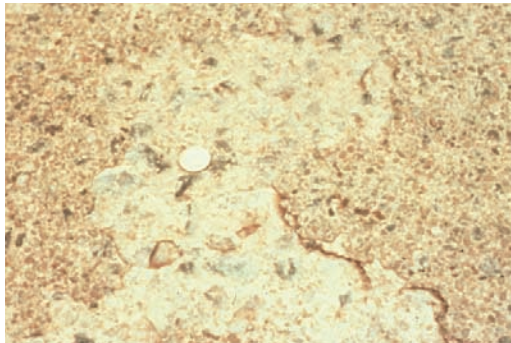
- Light or minor scale - loss of surface mortar up to 6 mm ( $\frac{1}{4}$  inch) deep, with surface exposure of coarse aggregates (see Figure 2.2.16)
- Medium or moderate scale - loss of surface mortar from 6 to 13 mm ( $\frac{1}{4}$  inch to  $\frac{1}{2}$  inch) deep, with mortar loss between the coarse aggregates (see Figure 2.2.17)
- Heavy scale - loss of surface mortar from 13 to 25 mm ( $\frac{1}{2}$  inch to 1 inch) deep; coarse aggregates are clearly exposed (see Figure 2.2.18)
- Severe scale - loss of coarse aggregate particles, as well as surface mortar and the mortar surrounding the aggregates; depth of the loss exceeds 25 mm (1 inch); reinforcing steel is usually exposed (see Figure 2.2.19)



**Figure 2.2.16** Light or Minor Scaling



**Figure 2.2.17** Medium or Moderate Scaling



**Figure 2.2.18** Heavy Scaling



**Figure 2.2.19** Severe Scaling



When reporting scaling, the inspector should note the location of the defect, the size of the affected area, and the scaling classification. For severe scale, the depth of penetration of the defect should also be recorded.

### **Delamination**

Delamination occurs when layers of concrete separate at or near the level of the top or outermost layer of reinforcing steel. The major cause of delamination is expansion of corroding reinforcing steel. This is commonly caused by intrusion of chlorides or salt. Another cause of delamination is severe overstress in a member. Delaminated areas give off a hollow “clacking” sound when tapped with a hammer. When a delaminated area completely separates from the member, the resulting depression is called a spall.

When reporting delamination, the inspector should note the location and the size of the defect.

### **Spalling**

A spall is a depression in the concrete (see Figure 2.2.20). Spalls result from the separation and removal of a portion of the surface concrete, revealing a fracture roughly parallel to the surface. Spalls can be caused by corroding reinforcement, friction from thermal movement, and overstress. Reinforcing steel is often exposed in a spall, and the common shallow pothole in a concrete deck is considered a spall. Spalls are classified as follows:

- Small spalls - not more than 25 mm (1 inch) deep or approximately 150 mm (6 inches) in diameter
- Large spalls - more than 25 mm (1 inch) deep or greater than 150 mm (6 inches) in diameter



**Figure 2.2.20** Spalling on a Concrete Deck

When concrete is overstressed, it gives or fractures. Over time, the fracture opens wider from debris, freeze/thaw cycles, or more overstress. This cycle continues until a spall is formed. Spalls caused from overstress are very serious and should be brought to the attention of the Chief Bridge Engineer. Most spalls are caused from corroding reinforcement, but if the spall is located at or near a high moment

region, overstress may be the cause. Examples that might indicate a spall was caused by overstress include:

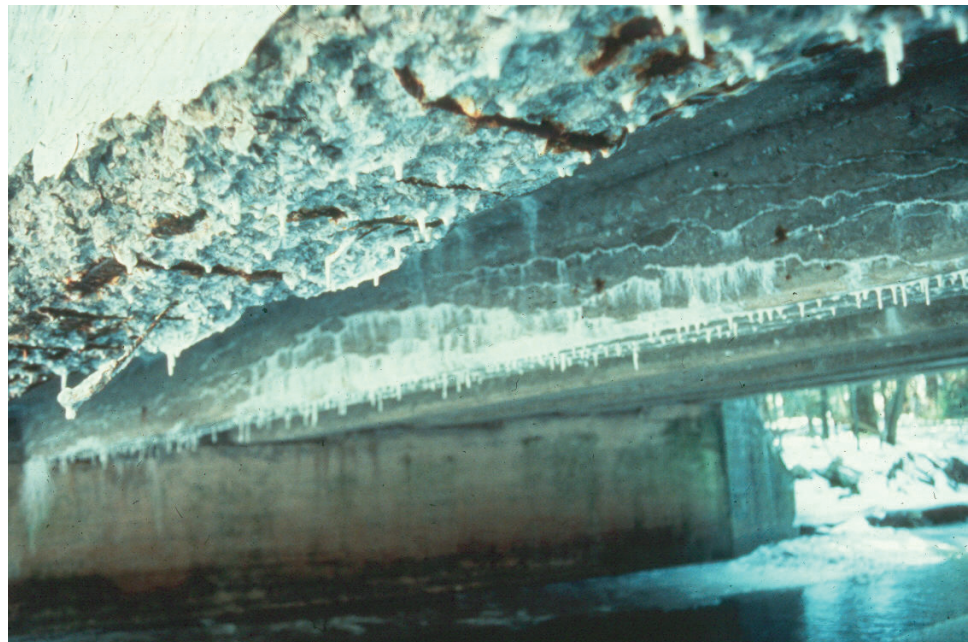
- A spall that is at or near flexure cracks in the lower portion of a beam at mid-span
- A spall that is at or near flexure cracks in the top of a continuous member over a support

Similarly, when concrete is overstressed in compression, it is common for the surface to crush and then spall.

When reporting spalls, the inspector should note the location of the defect, the size of the area, and the depth of the defect.

**Chloride Contamination** Chloride contamination in concrete is the presence of recrystallized soluble salts. Concrete is exposed to chlorides in the form of deicing salts, acid rain, and in some cases, contaminated water used in the concrete mix. It causes accelerated reinforcement corrosion that leads to cracking of the concrete.

**Efflorescence** The presence of cracks permits moisture absorption and increased flow within the concrete that is evidenced by dirty-white surface deposits called efflorescence. Efflorescence is a combination of calcium carbonate leached out of the cement paste and other recrystallized carbonate and chloride compounds (see Figure 2.2.21). In order to estimate the percent of concrete contaminated by chloride, nondestructive testing is required (refer to Topic 13.2.2).



**Figure 2.2.21** Efflorescence

**Ettringite Formation** Ettringite formation is an internal defect that occurs in concrete from the reaction of sulfates, calcium aluminates, and water. From this reaction, ettringite, which is a crystalline mineral, expands up to eight times in volume compared to the volume of the tricalcium nitrates ( $C_3A$ ). Ettringite formation is initially formed when water is added to the cement but prior to the concrete's initial set. The initial formation

does not harm the concrete. A secondary or delayed ettringite formation occurs after the concrete has hardened. This formation creates very high forces in hardened concrete and is the cause of the deterioration. The only way to identify ettringite formation as a cause of premature concrete deterioration is through advanced inspection techniques such as petrographic analysis. Recent studies have shown that ettringite formation is linked to alkali-silica reaction (ASR), but further research is still needed.

### **Honeycombs**

Honeycombs or construction voids are hollow spaces or voids that may be present within the concrete. Honeycombs are construction defects caused by improper vibration during concrete placement, resulting in the segregation of the coarse aggregates from the fine aggregates and cement paste. In some cases, honeycombs are the result of insufficient vibration, where the entire concrete mix does not physically reach the formwork surface (see Figure 2.2.22).



**Figure 2.2.22** Honeycomb

### **Pop-outs**

Pop-outs are conical fragments that break out of the surface of the concrete, leaving small holes. Generally, a shattered aggregate particle will be found at the bottom of the hole, with a part of the fragment still adhering to the small end of the pop-out cone. Pop-outs are caused by aggregates which expand with absorption of moisture. Other causes of pop-outs include use of reactive aggregates and high alkali cement.

### **Wear**

Wear is the gradual removal of surface mortar due to friction and occurs to concrete surfaces, like a bridge deck, when exposed to traffic. Advanced wear exhibits polished aggregate, which is potentially a safety hazard when the deck is wet. The scraping action of snowplows and street sweepers also wears the deck surface and damages curbs, parapets, and pier faces.



**Collision Damage**

Trucks, derailed railroad cars, or marine traffic may strike and damage concrete bridge components (see Figures 2.2.23 and 2.2.24). The damage is generally in the form of cracking or spalling, with exposed reinforcement. Prestressed beams are particularly sensitive to collision damage, as exposed tendons undergo stress corrosion and fail prematurely.



**Figure 2.2.23** Concrete Column Collision Damage



**Figure 2.2.24** Collision Damage to Prestressed Concrete I-Beam

### **Abrasion**

Abrasion damage is the result of external forces acting on the surface of the concrete member and is similar to wear. Erosive action of silt-laden water running over a concrete surface and ice flow in rivers and streams can cause considerable abrasion damage to concrete piers and pilings. In addition, concrete surfaces in surf zones may be damaged by the abrasive action of sand and silt in the water. Abrasion damage can be accelerated by freeze-thaw cycles. This will usually occur near the water line on concrete piers. The use of the term "scour" to indicate "abrasion" is incorrect. The term scour is used to describe the loss of streambed material from around the base of a pier or abutment due to stream flow or tidal action (see Topic 11.2).

### **Overload Damage**

Overload damage or serious structural cracking occurs when concrete members are sufficiently overstressed. Concrete decks, beams, and girders are all subject to damage from such overload conditions. Note any excessive vibration or deflection that may occur under traffic, which can indicate overstress. Other visual signs that can indicate overstress due to tension include excessive sagging, spalling, and/or cracking at the mid-span of simple span structures and at the supports of continuous span structures. Diagonal cracks close to support points may be an indication of overstress due to shear or torsion. Permanent deformation is another visual sign of overstress damage in a member. If overload damage is detected or suspected, the Chief Bridge Engineer should be notified immediately (see Figure 2.2.25).



**Figure 2.2.25** Overload Damage

### **Reinforcing Steel Corrosion**

Due to the chemistry of the concrete mix, reinforcing steel embedded in concrete is normally protected from corrosion. In the high alkaline environment of the concrete, a tightly adhering film forms on the steel that protects it from corrosion. However, this protection is eliminated by the intrusion of chlorides, which enables water and oxygen to attack the reinforcing steel, forming iron oxide (i.e., rust). Chloride ions are introduced into the concrete by marine spray, industrial brine, or deicing agents. These chloride ions can reach the reinforcing steel by diffusing through the concrete or by penetrating cracks in the concrete. An inspector may see rebar rust stains on the outer concrete surfaces before a spall occurs. The corrosion product (rust) can occupy up to 10 times the volume of the corroded steel that it replaces. This expansive action creates internal pressures up to 20.7 MPa (3000 psi) that will cause the concrete to yield, resulting in wider cracks, delaminations, and spalls (see Figure 2.2.26).





**Figure 2.2.26** Loss of Bond: Concrete / Corroded Reinforcing Bar

### **Prestressed Concrete Deterioration**

Prestressed concrete members deteriorate in a similar fashion to ordinary concrete members. However, the effects on Prestressed concrete member performance are usually more detrimental. Significant defects include:

- Structural cracks
- Exposed prestressing tendons
- Corrosion of tendons in the bond zone
- Loss of camber due to concrete creep
- Loss of camber due to lost prestress forces

Structural cracks indicate an overload condition has occurred. These cracks expose the tendons to the environment, which can lead to corrosion.

Exposed steel tendons via cracks or collision damage corrode at an accelerated rate due to the high tensile stresses carried and can fail prior to any measurable section loss due to environmentally induced cracking (EIC).

Environmentally induced cracking in steel prestressing strands can occur when the steel prestressing strands are subject to high tensile stresses in a corrosive environment. Rust stains may be present. The strands, which are normally ductile, undergo a brittle failure due to the combination of the corrosive environment along with the tensile stresses.

There are two types of environmentally induced cracking. The first is called stress corrosion cracking (SCC). This type of cracking grows at a slow rate and has a branched cracking pattern. The corrosion of prestressing steel along with the tensile stress in the steel causes a cracking pattern perpendicular to the stress direction.

The second type is called hydrogen-induced cracking (HIC) and occurs due to hydrogen diffusing into the prestressing steel. Once in the steel, hydrogen gas is formed. The hydrogen gas applies an internal pressure to the prestressing steel. This internal pressure, in conjunction with the tensile stress due to prestressing, has the ability to create very brittle, non-branching, fast growing cracks in the prestressing steel strands. The specific type of environmentally induced cracking can only be positively identified after failure through the use of advanced inspection techniques.

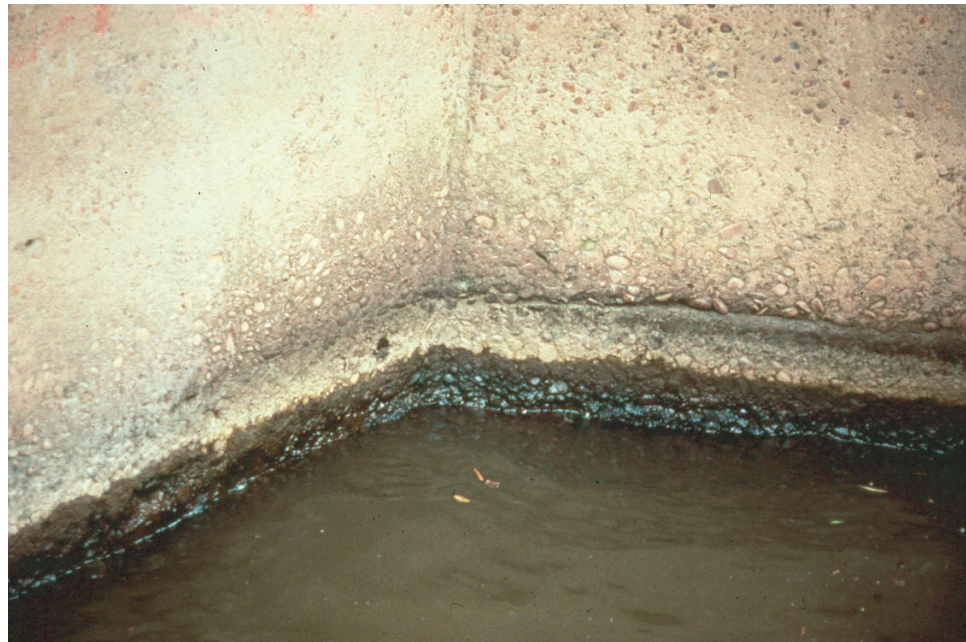
When deteriorated concrete cover allows corrosion of the tendons in the bond zone (the end thirds of the beam), loss of development occurs which reduces prestress force. This can sometimes be evidenced by reduced positive camber and ultimately structural cracking. Prestress force can also be reduced through a beam-shortening phenomenon called creep, which relaxes the steel tendons. Loss of prestress force is followed by structural cracking at normal loads due to reduced live load capacity.

## 2.2.6

### Other Causes of Concrete Deterioration

#### Temperature Changes

Freezing and thawing are common causes of concrete deterioration (see Figure 2.2.27). Porous concrete absorbs water, and when this water freezes, high expansive pressures are created due to the larger volume created by ice formation. These pressures often produce cracking and light spalling. Freeze/thaw damage should not be confused with scaling.



**Figure 2.2.27** Freeze-Thaw Damage on a River Pier

#### Chemical Attack

Aside from accelerated rebar corrosion, the use of salt or chemical deicing agents contributes to weathering through recrystallization. This is quite similar to the



effects of freezing and thawing.

Sulfate compounds in soil and water are also a problem. Sodium, magnesium, and calcium sulfates react with compounds in cement paste and cause rapid deterioration of the concrete.

Alkali-silica reaction (ASR) is a reaction between the alkalis in cement with the silica molecules of various aggregates. When the reaction takes place, a gel-like substance is formed. Once exposed to moisture, the gel expands and causes cracking in the concrete.

**Moisture Absorption**

All concrete is porous and will absorb water to some degree. As water is absorbed, the concrete will swell. If restrained, the material will burst or the concrete will crack. This type of deterioration is limited to concrete members that are continuously submerged in water.

**Differential Foundation Movement**

Foundation movement can also cause serious cracking in concrete substructures. Differential settlement induces stresses in the supported superstructure and can lead to concrete deterioration.

**Design and Construction Deficiencies**

Some conditions or improper construction methods that can cause concrete to deteriorate are:

- Insufficient reinforcement bar cover - Insufficient concrete cover over rebars may lead to early corrosion of the steel reinforcement.
- Weep holes and scuppers - Improper placement or inadequate sizing of scuppers and weep holes can cause an accumulation of water with its damaging effects.
- Leaking deck joints
- Improper curing - A primary cause of concrete deterioration (loss of strength).
- Soft spots - Soft spots in the subgrade of an approach slab will cause the slab to settle and crack.
- Premature form removal - If the formwork is removed between the time the concrete begins to harden and the specified time for formwork removal, cracks will probably occur.
- Improper vibration - If the concrete is not properly vibrated, internal settling of the concrete mix can cause surface cracking above the reinforcing bars as the mix settles around the bars. Excessive vibration may cause segregation (separation of water, aggregate, and cement) of the concrete mix.
- Impurities - The inclusion of clay or soft shale particles in the concrete mix will cause small holes to appear in the surface of the concrete as these particles dissolve. These holes are known as mudballs.
- Internal voids - If reinforcing bars are too closely spaced, voids, which collect water, can occur under the reinforcing mat if the mix is not

properly vibrated.

### Fire Damage

- Extreme heat will damage concrete. High temperatures (above 370°C (700°F)) will cause a weakening in the cement paste and lead to cracking.

## 2.2.7

### Protective Systems

#### Types and Characteristics of Concrete Coatings

Coatings form a protective barrier film on the surface of concrete to preclude entry of water and chlorides into the porous concrete. The practice of coating the concrete surface varies with each agency. Two primary concrete coatings are paint and water repellent membranes.

#### Paint

Paint is applied in one or two layers. The first layer fills the voids in a rough concrete surface. The second layer forms a protective film over the first. On smooth concrete surfaces, only one layer may be necessary.

Several classes of paint are used to coat concrete:

- Oil-based paint
- Latex paint
- Epoxy paint
- Urethanes

#### Oil-based Paint

Oil-based paint is declining in use but is still found on some older concrete structures. Oil paint is subject to saponification failure in wet areas. Saponification is a chemical attack on the coating caused by the inherent alkalinity of the concrete. The moisture may be from humidity in the atmosphere, rain runoff, or ground water entering the porous concrete from below. Saponification does not occur over dry concrete (or occurs at a greatly reduced rate).

#### Latex Paint

Latex paint consists of a resin emulsion. Latexes can contain a variety of synthetic polymer binding agents. Latex paint resists attack by the alkaline concrete. Acrylic or vinyl latexes provide better overall performance, in that they are more resistant to alkaline attack than oil-based paint. Latex paints, however, are susceptible to efflorescence. Efflorescing is a process in which water-soluble salts pass outward through concrete and are deposited at the concrete/paint interface. This can cause loss of coating adhesion. If the paint is also permeable to water, the salts are deposited on the paint surface as the water evaporates.

Acrylics do not chalk as rapidly as other latexes and have good resistance to ultraviolet rays in sunlight. Polyvinyl acetate latexes are the most sensitive to attack by alkalis.

### Epoxy Paint

Epoxy paint uses a cross-linking polymer binder, in which the epoxy resin in the paint undergoes a chemical reaction as the paint cures, forming a tough, cross-linked paint layer. Epoxies have excellent resistance to chemicals, water, and atmospheric moisture. Most epoxies are sensitive to the concrete's moisture content during painting. Polyamide-cured and water-base epoxy systems, however, have substantially overcome the moisture intolerance problem. For other epoxy systems, the concrete moisture should be measured prior to painting.

### Urethanes

Urethanes are usually applied over an epoxy primer. They provide excellent adhesion, hardness, flexibility, and resistance to sunlight, water, harmful chemicals, and abrasion. They are, however, sensitive to temperature and humidity during application. The urethanes used on concrete require moisture to cure. In high humidity, the paint cures too quickly, leaving a bubbly appearance.

Many states now apply moisture-cured urethane anti-graffiti coatings on accessible concrete structures (see Figure 2.2.28). These are smooth, clear coatings applied without a primer coat. Spray paint and indelible marker ink adhere poorly to the smooth urethane, permitting easier cleaning than if they were applied to porous concrete.



**Figure 2.2.28** Anti-Graffiti Coating on Lower Area of Bridge Piers

### Water Repellent Membranes

Water repellent membranes (sealers) applied to concrete bridge decks, piers, abutments, columns, barriers, or aprons form a tight barrier to water and chlorides.

The membrane penetrates up to 10 mm (3/8 inch) into the concrete to give strong adhesion. Membranes have good resistance to abrasion from weathering and traffic. Methyl methacrylate, silane, and silicone are three common water repellent coatings.

### **Surface Preparation**

Concrete, as with any other surface, must be properly cleaned prior to coating. The surface may also require roughening to improve coating adhesion, as the forms used to mold concrete leave a surface that is too smooth for good coating adhesion. In addition, the oils applied to wooden forms to facilitate removal may impede coating adhesion.

### **Blast Cleaning**

Blast cleaning with dry abrasives, high pressure water (up to 380 Mpa (55,000 psi)), or a water/abrasive mix is used to remove dirt, old paint, grease, and deteriorated concrete. It is also the best method to roughen the surface.

Open nozzle blast cleaning uses compressed air free of oil and moisture to propel the abrasive at speeds up to 645 kilometers per hour (400 miles per hour). Centrifugal wheel blast cleaning uses a rotating wheel to propel abrasive. The most common abrasive is sand, although many others, such as steel shot and grit, silica, aluminum oxide, and silicon carbide, are also available. Unlike dry abrasive blast cleaning, high pressure water can penetrate deep into concrete. The concrete must be allowed to dry thoroughly before a coating is applied.

### **Acid Etching**

Acid etching is an efficient method of cleaning concrete. Hydrochloric acid (also called muriatic acid) reacts with the alkaline concrete surface, allowing surface contaminants to easily wash away. It leaves a roughened surface profile for good coating adhesion. All acid must be removed prior to coating application.

### **Types and Characteristics of Reinforcement Coatings**

Because unprotected steel reinforcement corrodes and has adverse effects on concrete, some type of protective coating should typically be used on all steel reinforcement placed in concrete structures to ensure minimal steel corrosion. Steel reinforcement can be protected by the following methods:

- Epoxy coating
- Galvanizing
- Cathodic protection

### **Epoxy Coating**

Epoxy coating is resistant to chemicals, water, and atmospheric moisture. Epoxies utilize an epoxy polymer binder, which forms a tough, resilient film upon drying and curing. Drying is by solvent evaporation, while curing entails a chemical reaction between the coating components. Epoxy coatings have excellent atmospheric exposure characteristics, as well as resistance to chemicals and water. They are often used as the intermediate coat in a three layer paint system. There

are also two- and three-layer systems, which use only epoxies. One disadvantage of epoxies is that they chalk when exposed to sunlight. This chalking must be removed prior to topcoating with another layer of epoxy or another material. If not removed, the chalking will compromise subsequent adhesion.

### **Galvanizing**

Another method of protecting steel reinforcement is by galvanizing the steel. This also slows down the corrosion process and lengthens the life of the reinforced concrete. This occurs by coating the bare steel reinforcement with zinc. The two unlike metals form an electrical current between them and one metal virtually stops its corrosion process while the other's accelerates due to the electrical current. In this situation, the steel stops corroding, while the zinc has accelerated corrosion.

### **Cathodic Protection**

Steel reinforcement corrosion can also be slowed down by cathodic protection. Corrosion of steel reinforcing bars in concrete occurs by an electrical process in a moist environment at the steel surface. During corrosion, a voltage difference (less than 1 volt) develops between rebars or between different areas on the same rebar. Electrons from the iron in the rebar are repelled by the negative anode area of the rebar and attracted to the positive cathode area. This electron flow constitutes an electrical current, which is necessary for the corrosion process. Corrosion occurs only at the anode, where the electrons from the iron are given up.

By cathodic protection, this electrical current is reversed, which slows or stops corrosion. By the impressed current method, an electrical DC rectifier supplies electrical current from local electrical power lines to a separate anode embedded in the concrete. The anode is usually a wire mesh embedded just under the concrete surface. Another type of anode consists of an electrically conductive coating applied to the concrete surface. The wires from the rectifier are embedded in the coating at regular intervals.

When the impressed current enters the mesh or coating anode, the voltage on the rebars is reversed, turning the entire rebar network into a giant cathode. Since natural corrosion occurs only at the anode, the rebars are protected.

The natural corrosion process is allowed to proceed with electrons leaving the iron atoms in the anode. With impressed current cathodic protection, however, the electrons are supplied from an external source, the DC rectifier. Thus, the artificial anode mesh or coating is also spared from corrosion.

During the bridge inspection, check that all visible electrical connections and wiring from the rectifier to the concrete structure are intact.

## **2.2.8**

### **Inspection Procedures for Concrete and Protective Coatings**

There are three basic procedures used to inspect prestressed and reinforced concrete members. Depending on the type of inspection, the inspector may be required to use only one individual procedure or all procedures. They include:

- Visual
- Physical
- Advanced inspection techniques

### **Visual Examination**

There are two types of visual inspections that may be required of an inspector. The first, called a routine inspection, involves reviewing the previous inspection report and visually examining the members from beneath the bridge. All concrete surfaces should receive a thorough visual assessment to identify obvious defects during a routine inspection.

The second type of visual inspection is called an in-depth inspection. An in-depth inspection is an inspection of one or more members above or below the water level to identify any deficiencies not readily detectable using routine procedures. Hands-on inspection may be necessary at some locations. This type of visual inspection requires the inspector to visually assess all defective concrete surfaces at a distance no further than an arm's length. The concrete surfaces are given close visual attention to quantify and qualify any defects. The hands-on inspection technique may be supplemented by non-destructive testing.

### **Physical Examination**

Areas of concrete or rebar deterioration identified visually should also be examined physically using an inspection hammer. This hands-on effort verifies the extent of the defect and its severity.

High stress areas should be sounded for defects using an inspection hammer. Hammer sounding is commonly used to detect areas of delamination and unsound concrete. For large horizontal surfaces such as bridge decks, a chain drag may be used. A chain drag is made of several sections of chain attached to a handle (see Figure 2.2.29). The inspector drags this across a deck and makes note of the resonating sounds. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

The location, length and width of cracks found during the visual inspection and sounding procedures should be given special attention. For typical reinforced concrete members, a crack comparator card can be used to measure the width of cracks. This type of crack width measuring device is a transparent card about the size of an identification card. The card has lines on it that represent crack widths. The line on the card that best matches the width of the crack lets the inspector know the measured width of the crack. For prestressed members, crack widths are usually narrower in width. For this reason, a crack gauge, which is a more accurate crack width-measuring device, should be used. For crack width guidelines, see Table 2.2.3.



**Figure 2.2.29:** Inspector Using a Chain Drag

### **Advanced Inspection Techniques**

If the extent of the concrete defect cannot be determined by the visual and/or physical inspection procedures described above, advanced inspection techniques should be used. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing
- Smart concrete which is a coating that allows sensing of strain similar to a

strain gauge

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength
- Petrographic examination

Other methods for protective coatings include:

- Paint dry film thickness (Tooke Gauge)

## **Physical Examination of Protective Coatings**

### **Areas to Inspect**

While inspecting protective coatings, pay close attention to the following areas:

- Areas open to direct weathering by wind, rain, hail, or seawater spray.
- Roadway splash zones along curbs, parapets, and expansion dams. These areas are subject to impact abrasion by debris from passing vehicles.
- Inaccessible or hard-to-reach areas where coatings may be missing or improperly applied.
- All concrete joints.
- Areas that retain moisture or salt. Horizontal surfaces of concrete beams and piers are common examples. Also inspect areas where drainage systems deposit salt and water, such as beneath catch basins, scuppers, downspouts, and bearing areas.
- Impact areas on bridge decks and parapets where snowplows or vehicle accidents damage coatings.



### Coating Failures

The following failures are characteristic of paint on concrete:

- Lack of adhesion/peeling can be caused by poor adhesion of the primer layer to the concrete or by poor bonding between coating layers. Waterborne salts depositing under a water-impermeable coating (efflorescence) will also cause a coating to peel.
- Chalking is a powdery residue left on paint as ultraviolet light degrades the paint.
- Erosion is a gradual wearing away of a coating. It is caused by abrasion from wind-blown sand, soil and debris, rain, hail, or debris propelled by motor vehicles.
- Checking is composed of short, irregular breaks in the top layer of paint, exposing the undercoat.
- Cracking is similar to checking, but with cracking, the breaks extend completely through all layers of paint to the concrete substrate.
- Microorganism failure occurs as bacteria and fungi feed on paint containing biodegradable components. The damp nature of concrete makes it susceptible to this type of paint failure.
- Saponification results from a chemical reaction between concrete, which is alkaline, and oil-based paint. It destroys the paint, leaving a soft residue.
- Wrinkling is a rough, crinkled paint surface due to excessive paint thickness or high temperature during painting. It is caused by the surface of the paint film at the air interface solidifying before solvents have had a chance to escape from the interior of the paint film.

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