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Diagnosis of cracking in concrete bridges structures

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Summary

A large percentage of the bridge structures in the nation's highway network are constructed out of reinforced concrete or prestressed concrete. Therefore it is important to have a very good knowledge of the basic characteristics of concrete in order to efficiently inspect bridge components build of this material.

The behavior of a bridge under traffic loads is strongly influenced by the properties of the materials used for the bridge. Therefore, the properties of construction materials are of great importance to the bridge inspector. Both physical properties, related to the intrinsic nature of the material and mechanical properties describing the structural behavior of the material are important to know these various strengths and weaknesses in order to understand the structural behavior of the entire bridge, as well as its many elements.

Assessing the integrity and safety of a bridge is possible if the various types of deterioration which can reduce the bridge's strength are understood.

KEYWORDS: concrete, cracking, classification, bridge

1. INTRODUCTION

Strength - plain, unreinforced concrete has a compressive strength ranging from about 175 MPa to about 415 MPa; 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. Modulus of elasticity varies as the square root of compressive strength. In addition to elastic deformation, concrete exhibits long-term, irreversible, continuing deformation under application of a sustained load ranging from 100% to 200% of initial elastic deformation, depending on time.
Five principal factors that increase concrete strength are:

• Increased cement content
• Sound aggregates
• Decreased water to cement ratio
• Decreased entrapped air
• Increased curing time (extent of hydration)

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

Steel reinforcement has approximately 100 times the tensile strength of concrete. Therefore, in reinforced concrete structures, the concrete resists the compressive forces and the steel reinforcement resists the tensile forces. Steel reinforcement for reinforced concrete is often referred to as "mild steel". The steel reinforcement is located close to the tension face.

Reinforcing bars are also perpendicular to the primary tension steel 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. The gripping pattern improves the bond with the surrounding concrete. Modern reinforced concrete bridges are generally constructed with "deformed" reinforcing steel.

2. CAUSES OF CONCRETE CRACKING AND TYPES OF CRACKS

Concrete is by nature a brittle material, so reinforced concrete structures are destined to suffer cracking. Concrete is a mixture of cement, fillers and water. The cement, usually Portland cement, acts as a binder. Fillers are sand, gravel or other aggregate that make up the bulk of the concrete structure. Water reacts with the cement, causing it to harden. The ratios of the components depend upon the requirements for the particular concrete construction. Fillers are about 60 to 75 percent of the concrete, cement 10 to 15 percent and water 15 to 20 percent. Generally, less water in the mix makes stronger concrete, but it also makes the concrete mix harder to work with.

Cracking cannot be prevented completely using present techniques. Not all types of concrete cracking, however, pose problems; some are detrimental to structures but others are not. Damaging cracking induces those types that cause water leakage due to cracking throughout the element, excessive deflection, aesthetic concerns and damages to the durability of the structure.

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Concrete is remarkably stable under even pressure loads, but concrete lacks tensile strength. If it is placed a sufficiently uneven load on a concrete structure it will crack. Particularly, thin or long concrete structures like slabs, beams or columns bear uneven stresses, so they are commonly reinforced with steel bars or fiberglass meshing.

Cracking can be categorized by phenomenon and causes as follows:
• cracking after reinforcement corrosion owing to the increase of corrosion of reinforcement;
• cracking before reinforcement corrosion that induces the corrosion of reinforcement;
• cracking representing the deterioration of concrete.
There are many common defects that occur on concrete bridges:

- cracking;
- scaling;
- delamination;
- spalling;
- chloride contamination;
- honeycombs;
- pop-outs;
- wear;
- collision damage;
- abrasion;
- overload damage;
- reinforcing steel corrosion;
- prestressed concrete deterioration.

A crack is a linear fracture in concrete. Cracks may extend partially or completely through the concrete member. Cracks occur in most civil engineering structures. Unexpected cracking of concrete is a frequent cause of complaints. Cracking can be the result of one or a combination of factors, such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, subgrade settlement, and applied loads. Concrete cracks are inevitable. Cracks are an inherent characteristic of concrete, and almost all concrete eventually develops cracks. In some cases, cracks do not harm the structural integrity of concrete. Other times, cracks can cause catastrophic failure of bridges. Regardless of the potential consequences of concrete cracks, they all arise from common causes. Understanding the causes helps prevent costly and dangerous flaws in concrete constructions of all sorts. Concrete is not a ductile material, it doesn't stretch or bend without breaking. That's both its greatest strength and greatest weakness. Its hardness and high compressive strength is why it used so much of it in construction. But concrete moves, it shrinks, it expands, and different parts of a bridge move in different ways.

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As it moves, if it is tied to another element in the structure or even to itself, called restraint, which causes tensile forces and invariably leads to cracking. Restraint simply means that the concrete element (whether it's a slab or a wall or a foundation) is not being allowed to freely shrink as it dries or to expand and contract with temperature changes or to settle a bit into the subgrade.

Cracking can be significantly reduced when the causes are taken into account and preventative steps are utilized.

Causes of the cracks in generally are:
• cracking due to material problems;
• abnormal cracking due the structural problems;
• cracking due to shrinkage.
The major physical property of concrete that can lead to cracking is thermal expansion - concrete expands as temperature increases and contracts as temperature decreases.

Temperature rise (especially significant in mass concrete) results from the heat of hydration of cementitious materials. Hydration of cement is an exothermic process meaning it generates heat. As the concrete cools it contracts and in extreme conditions may contract in three days as much due to cooling as it could in a year due to drying conditions.

As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the differential temperature between the surface and center is too great. The width and depth of cracks depends upon the differential temperature, physical properties of the concrete and the reinforcing steel.

After concrete is poured, the concrete increases in strength very quickly for a period of 3-7 days. Concrete cured for 7 days is about 50% stronger than uncured concrete. Ideally, concrete elements could be water cured for 7 days.
• 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.

On reinforced concrete, cracking will usually be large enough to be seen by the naked eye. However, on prestressed concrete, a crack gauge is the proper instrument needed to measure and differentiate cracks. Rust and efflorescence stains often appear at cracks. Both large and small cracks in main elements, especially in prestressed elements, should be carefully recorded.

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3. TYPES OF CRACKS

There are several types of cracks depending on the chosen classification criteria:

3.1. The width

Cracks can be classified as hairline, medium, or wide cracks. Hairline cracks are usually cracks that cannot be measured with normal equipment. On conventionally reinforced structures, these hairline cracks are usually insignificant to the structural capacity of the structure. Medium and wide cracks are cracks that can be measured by simple means. These cracks can be very significant and should be monitored and recorded in the inspection notes. On prestressed structures, all cracks are significant. When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted. The presence of rust stains or efflorescence or evidence of differential movement on either side of the crack should be indicated.

3.2. The depth, surface and developing direction

Craze cracks are fine, random cracks or fissures in a surface of concrete. Crazing is a pattern of fine cracks that do not penetrate much below the surface and are usually a cosmetic problem only. They are barely visible, except when the concrete is drying after the surface has been wet.

Figure 1. Craze cracks (Source: http://www.concreteconstruction.net)

D-cracking represent a series of cracks in concrete near and roughly parallel to joints, edges, and structural cracks. D-cracking is a form of freeze-thaw deterioration that has been observed in some bridge elements after three or more years of service. Due to the natural accumulation of water in some exposed elements, the aggregate may eventually become saturated. Then with freezing and thawing cycles, cracking of the concrete starts in the saturated aggregate at the

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bottom of the element and progresses upward until it reaches the wearing surface. D-cracking usually starts near edges or joints of elements.

Figure 2. D-cracking (Source: http://www.concrete.org)

Pattern cracking are fine openings on concrete surfaces in the form of a pattern and results from a decrease in volume of the material near the surface, an increase in volume of the material below the surface, or both.

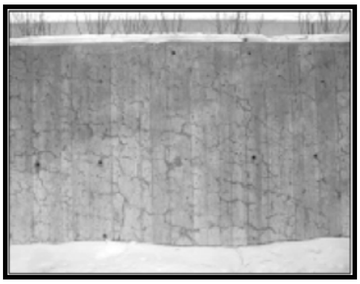

Figure 3. Pattern cracking (Source: http://irc.nrc-cnrc.gc.ca)

3.3. The cause that leaded to cracking:

a) Plastic Shrinkage Cracking

Contrary to popular terminology, concrete does not dry. Rather, it hardens, or cures. It is during curing that concrete becomes strong. The chemical process, called hydration, is a set of reactions that occur when water molecules bond with calcium trisilicate and calcium disilicate in cement. The hydrated compounds form a dense crystalline structure that binds the sand and aggregate into a single solid form. Other components in cement, tricalcium aluminate, tetracalcium aluminoferrite and gypsum – take part but are less important in the curing process. Plastic shrinkage cracking is the shrinkage that occurs in the surface of fresh concrete within the first few hours after it has been placed. Plastic shrinkage occurs as fresh concrete loses its moisture after placement but before any strength development has occurred. This type of shrinkage is affected by environmental effects of temperature (concrete and ambient), wind and relative humidity. It is a particular problem in hot weather concreting. This is an early age crack. While concrete is still plastic and before it has attained any significant strength. All concrete undergoes volumetric changes after placement. This volume change is caused by the loss of moisture as the concrete begins to dry. Approximately 80% of all water loss will occur within the first 24 hours. As the concrete hardens, due to restraint, it is unable to transfer the tensile stresses. When the tensile stress is greater than the tensile strength - first microscopic cracks, then large cracks will appear. Other factors that affect shrinkage cracking are: weather conditions, such as humidity, ambient temperature and wind velocity, a 40% drop in relative humidity can increase the evaporation rate by five times. Concrete temperature, mix proportions and aggregate type will also have an influence on the shrinkage.

Figure 4. Plastic shrinkage cracking (Source: http://www.cadman.com)

When water evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth. These cracks are often fairly wide at the surface.

Actually, there are no specific admixtures developed to handle this type of cracking.

b) *Drying Shrinkage*

Because almost all concrete is mixed with more water than is needed to hydrate the cement, much of the remaining water evaporates, causing the concrete to shrink. Restraint to shrinkage, provided by the base, reinforcement, or another part of the structure, causes tensile stresses to develop in the hardened concrete. Restraint to drying shrinkage is the most common cause of concrete cracking. In many

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applications, drying shrinkage cracking is inevitable. Therefore, contraction joints are placed in concrete to predetermine the location of drying shrinkage cracks.

Since water is necessary for the hydration reaction of curing, evaporation on the surface of the concrete may cause the surface to cure more slowly than the interior. This uneven curing may lead to cracking. Low humidity and the heat released during the hydration reaction contribute to surface evaporation. This is why new concrete structures are commonly dowsed with water for several hours after the concrete is placed.

Figure 5. Drying shrinkage cracking (Source: http://www.members.optusnet.com.au)

Control joints are planned for cracks which allow movements caused by temperatures changes and drying shrinkage. In other words, if the concrete does crack, it is be better to have an active role in deciding where it will crack and that it will crack in a straight line instead of randomly. Joints in concrete can serve both to prevent cracking and as a decorative element.

c) Corrosion

Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration of concrete. When steel corrodes, the resulting rust occupies a greater volume than steel. The expansion creates tensile stresses in the concrete, which can eventually cause cracking and spalling.

Figure 6. Corrosion crack (Source: http://www.upload.wikimedia.org)

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d) Alkali-aggregate reactivity

Alkali-aggregate reactivity is a type of concrete deterioration that occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete. Alkali-aggregate reactivity occurs in two forms: alkali-silica reaction and alkali-carbonate reaction.

Indications of the presence of alkali-aggregate reactivity may be a network of cracks, closed or spalling joints, or displacement of different portions of a structure.

Figure 7. Alkali-aggregate reactivity cracks (Source: http://www.cement.org)

4. CRACKING DUE TO INTERNAL DEGRADATIONS OF CONCRETE

4.1. Honeycomb cracking

Honeycomb cracking is a condition of irregular voids caused by failure of the mortar to effectively fill the spaces between coarse aggregate particles. It may arise from congested reinforcement, insufficient cement content, improper sand-aggregate ratio, or inadequate placement techniques.

This kind of cracks is frequent to the top of works that has internal degradation of the concrete, being random and having an interrupted, intermittent path. It may take the shape of honeycomb cracking, with elements of 10 to 50 mm length and a depth of some centimeters. The width is variable upon the advancing degree of the reaction but remains of some 1/10 of a millimeter.

This type of cracking is sometimes underlined by the humidity. The contraction given by the drying is susceptible to provide the same type of cracking. Honeycomb cracking may be reduced with better vibration and improvement of workability.

Figure 8. Honeycomb cracking (Source: Handbook of concrete bridge management De Jorge de Brito)

4.2. Network cracking

Network cracking may appear to elements of bigger dimensions (10-40 cm) than of the honeycomb cracking. This type of cracking is observed especially in cases of alkali reactions. The width of cracks increases with the advance of the reaction. It can reach some millimeters in the case of a network with big elements. Like the width, the depth of cracks is developing and may have more than 10 cm.

Big elements may be crossed by smaller elements affected by network cracking, thus having a very complicated network and different dimensions. The cleaning of the top of works with water facilitates the cracks to be seen. The contractions due to drying (if the observed network is still formed by fine cracks), sulfated attack or freeze-thaw are susceptible to give the same type of cracking.

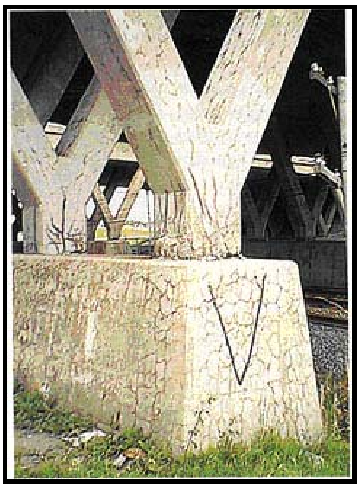

Figure 9. Network cracking (Source: http://www.filer.case.edu)

4.3. Oriented cracking

a) Cracking with one direction

When compression efforts opposes to the internal swelling the cracks are oriented preferentially on the direction of these efforts. It is the case of columns where vertical cracks may be observed. These vertical cracks may have also as origin an excess of compression or the corrosion of the vertical rebars with an inadequate concrete cover.

This is also the case of prestressed structures where the widening has a non prestressed direction. In the case of prestressed beams bridges the cracking is oriented perpendicularly on the longitudinal axis of the prestressing cables. These types of cracks appear at the building time, in the moment of tensioning the cables or during exploitation due to the corrosion of the prestressing duct and of the cables.

In some cases the superposing of the efforts given by an internal swelling reaction and the resulting efforts of classic actions applied on a structure leads to cracking with a preferential direction is identical with a mechanical one.

The mechanical origin cracking given by insufficient dimensioning of the elements may lead to confusion with the ones given by repeated loads applying cracking.

b) Two directions cracking

This cracking is due to internal swelling and alkali or sulfated reactions and appears on the direction of rebars on the surface layer.

The reinforcement is responsible for the normal shrinkage cracking. In the case of internal swelling all happens as the rebar is the start for cracking.

Conclusions on the cracking due to internal degradations of the concrete

In several cases of cracking through alkali reactions, particularly in the case of not reinforced elements of light reinforced, the depth of cracks is so that cracks cross each other. The element is presented as assemble of concrete blocks. The cracking favors the water penetration and aggressive agents. This water ‘fuels’ the internal swelling reactions but it provokes also the corrosion of the rebars, as shows the rusty colors on the exposed faces of the concrete elements.

The apparition and evolution of the cracking depends of the reaction’s kinetics. The time of the cracking depends especially on the period after the curing. Generally, deteriorations appear few years after the construction (2-5 years) and, rarely, 20-30 years after the construction.

Regarding the evolution of the cracking, the speed of widening of the main cracks may vary between 0,05 and 0,5 mm a year.

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Cracking, like other deteriorations does not appear uniformly on the ensemble of a work. There is some heterogeneity in the area of deteriorations, function of several parameters as the reactive area extent, or the quantity of alkali in a certain area, the presence of water of humidity, the quantity and disposal of passive and active rebars, etc.

5. BRIDGE ELEMENTS AND ITS SPECIFIC CRACKS

5.1. Superstructure

a) Beams

On concrete beams, the two basic types of cracks are structural cracks and nonstructural cracks.

Structural cracks are caused by dead load and live load stresses and are divided into two categories:

The principal cracks of the reinforced concrete beams are the following:
- flexural cracks
- shear cracks
- both flexural and shear cracks

The presence of vertical cracks in the center of a vault or an arch or above the supports of a continuous beam can indicate a failure due to bending.

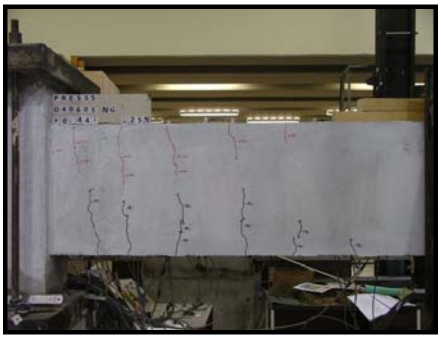

Figure 10. Flexural cracks (Source: http://www.methvin.org)

These vertical cracks develop from the extreme tensioned fiber of the concrete, meaning that it is starting from the bottom of the beam to the center of the vaults or arches or starting from the top of the beam above the supports of a continuous beam. They generally make the contour of the beam and attenuate while approaching its middle height. Their importance and their number decreases with the distance from the critical sections. Flexure cracks are vertical and start in the maximum tension zone or the maximum moment region and proceed toward the compression zone. At the mid-span of members, flexure cracks can sometimes be found at the bottom of the member where bending or flexure stress is greatest. Also look for flexure cracks at the top of continuous members near the piers.

The shear cracks are diagonal (approximately 45°) and are situated mainly close to the bearings. These cracks generally make the contour of the beam and attenuate with the closing up to its middle height. Their importance and their number decreases with the distance from the bearings. These cracks can generate three types of ruptures: the rupture by horizontal compression, the rupture by horizontal tension and the rupture by crushing or buckling oblique of web. The rupture by horizontal compression is characterized by a rotation of the beam compared to the top of the most critical crack and producing crushing of the concrete. The rupture by horizontal tension is due to insufficiency of anchoring of longitudinal reinforcements crossing the cracks. The rupture by crushing or oblique buckling of web occurs especially on beams with thin web. Shear cracks are diagonal cracks that usually occur in the web of a member. Normally, these cracks are found near the bearing area and begin at the bottom of the member and extend diagonally upward toward the center of the member.

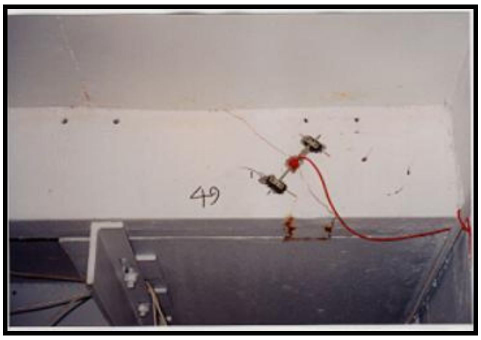

Figure 11. Shear cracks (Source: http://www.peterlindsell.co.uk)

Very rare torsion cracks may appear to the beams and are due to design or execution errors.

Torsion cracks generally propagate in a member making 45 degrees with a member's longitudinal axis. If torsional reinforcement is not provided, the initiation of torsion cracks means the failure of a reinforced concrete member.

When torsional reinforcement is provided in a member, the increase in applied torsion after the torsion cracking can be resisted depending on the amount of reinforcement. A number of torsional cracks can be observed. However, the tangential stiffness is gradually decreasing with the increase in the torsion angle. Finally, due to the crushing of concrete, a member will lose its strength.

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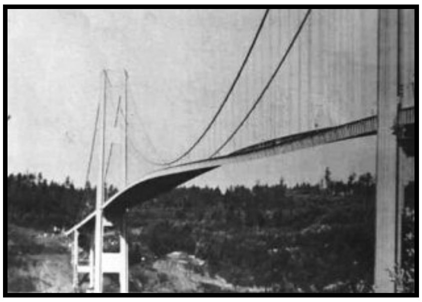

Figure 12. Torsion cracks (Source: http://www.damninteresting.com)

Nonstructural cracks of the beams are divided into three categories:

- Temperature cracks
- Shrinkage cracks
- Mass concrete cracks

These cracks are relatively minor and generally do not affect the load-carrying capacity of the member. They can, however, 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.

Figure 13. Temperature cracks (Source: http://www.irc.nrc-cnrc.gc.ca)

Shrinkage cracks are due to the contraction of concrete caused by the curing process.

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.

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Figure 14. Shrinkage cracks (Source: http://www.inspect-ny.com)

b) Slabs

The principal cracks of the slabs are the following:

- transverse cracks
- longitudinal cracks

The transverse cracks generally develop in the intrados in the center of the span or above the supports in the extrados for a continuous slab. These cracks are structural and indicate a weakness to flexion of the slab.

The longitudinal cracks are due to the heat gradient, especially for the slabs of big width and including several continuous spans. Longitudinal cracks can also appear between the bearing supports, due the lack of braces in this area. In the angles of the very oblique bridges, a network of cracking perpendicular to the line of support may develop. The dissociation can result from the corner of the slab when the reinforcements are insufficient and that the directions of the longitudinal and transverse reinforcements are such that they form between them an acute angle.

c) Frames

The principal cracks of the frames are the following:

- transverse and horizontal cracks
- longitudinal and vertical cracks
- oblique cracks

Transverse and horizontal cracks can develop to the intrados of the frame in its center or to the extrados, to the junction of the intrados and the side walls and to the brackets if there's space for it. They can also be present in the side walls, generally to its middle height. These cracks are structural.

The longitudinal and vertical cracks are due to the heat gradient, especially for the frames of big width and including several continuous spans. The vertical cracks

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develop primarily in the side walls and in certain cases are prolonged in the brackets and may become longitudinal cracks in the intrados. These cracks are generally nonstructural.

Oblique cracks develop in the angles of the intrados and appear to the oblique bridges.

d) Arches

The principal cracks of the arches are the following:
- transverse cracks
- longitudinal cracks

Transverse cracks of concrete arches generally occur on the key or to the births. The transverse cracks on the key are due to differential settlement of supports. The transverse cracks to the births are specifically to the arches with deck on top or in the middle. Their positions are on the intrados of the arch to the births side and are active under thermal effect. The cause is given by the deformations of the arch that are limited by the births transmitting important efforts.

Longitudinal cracks of the concrete arches generally occur to the tympanum or on the arch. The longitudinal cracks on the tympanum are due to differential settlement of bearings or a differential settlement on a same bearings line. The longitudinal cracks on an arch are due to the insufficiency, even an absence, of the transverse reinforcement. The concrete is not enough disposed to face the tractions resulting from the compressive forces in the arch. Such cracks occur also when the arches are made up of box girders, because of different rigidities of the web and the frame.

e) Cross Beams

This vertical or tilted cracking appears to the connections between the principal beams and the cross beams. This cracking corresponds primarily to the phenomena of differential shrinking of the concrete or, eventually, to the setting in tension of the prestressing reinforcement provoking dissymmetrical deformations between beams, soliciting abnormally the cross beam. In the case of the bearing cross beams, a cracking of the cross beam is often revealing its insufficient resistance, following differential settlements of the bearings, or a too big solicitation of the cross beams under the life loads.

f) Other Decks

In concrete bridge decks, temperature and shrinkage cracks can occur in both the transverse and longitudinal directions.

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Prestressed concrete sections can lose their strength through several forms of concrete deterioration. Prestressed concrete members are especially sensitive to corrosion and fatigue in isolated cracks. The corrosion of prestressing wire can lead to a failure of the member. Loss of bond between the prestressing steel and the concrete can result in member failure. Unbonded members are subject to zipper effects. Relaxation of prestressing steel due to high, sustained tensile stress can cause a gradual decrease in strength over time. Shrinkage of the concrete causes a further relaxation in the prestressing steel, thereby lowering the strength of the member. In addition, creep in the concrete will cause the member to shorten, causing further relaxation in the steel tendons, which results in additional strength loss.

5.2. Substructure

In retaining walls and abutments, temperature and shrinkage 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.

The vertical cracks that develop in the sole and the front wall of the abutments may be caused by:

- non uniform shrinking of the concrete
- errors in design
- differential settlement.

The exposed surface of the concrete front wall of the abutment is drying while the surface which is in contact with the embankment remains humid. Under these conditions, the contraction can cause tension cracks in the wall.

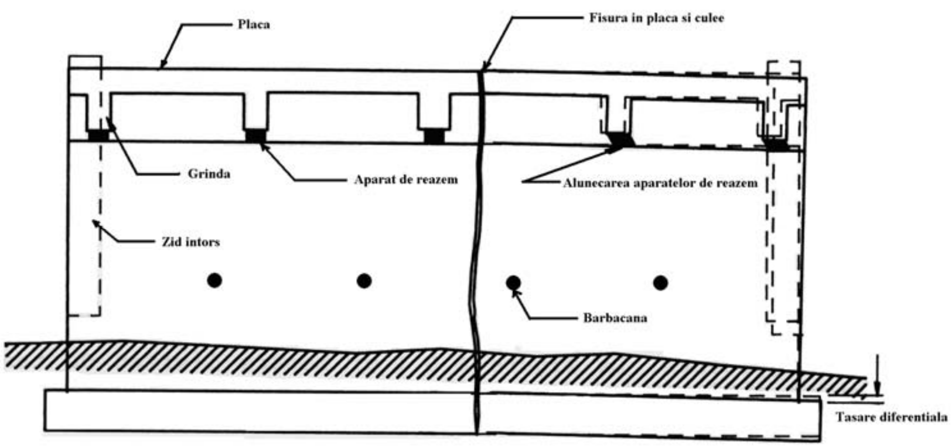

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Figure 15. Differential settlement cracks

In the design of the abutments, one assumes that the retaining walls have no influence on the abutment, but in reality they act like buttresses. In this respect, the front wall of the abutment may be solicited to longitudinal flexion between the buttresses, which requires horizontal reinforcements in the front face of the wall. In the older abutments, the horizontal reinforcements are often concentrates at the back of the walls; it is possible that vertical cracks develop on the front face of these abutments. The wing walls and the retaining walls are also designed like they are independent of the abutment, but they are always connected. The least compressing of the wing walls and the retaining walls causes traction efforts not envisaged and cracks on the junction with the front wall of the abutment. The differential settlement which occurs in the longitudinal direction of the abutment causes usually cracks in the guard-strike, the front wall and same in the sole of the abutment.

6. RESISTANCE AND DURABILITY AGAINST CRACKS

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

In addition to reinforced concrete, prestressed concrete, using high strength steel wires, can be used in bridge applications. To reduce the tensile forces in a concrete member, internal compressive forces are induced through prestressing steel tendons or wires. 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 are typically within the tensile strength limits of plain concrete. Therefore, properly designed prestressed concrete members do not develop flexure cracks under service loads.

In pretensioned members, transfer of tendon tensile stress occurs through bonding, which is the secure interaction of the prestressing steel with the surrounding concrete.

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. This is accomplished by casting the concrete in direct contact with the prestressed steel. In post tensioned members, bonding is accomplished by injecting grout into the ducts after the high tensile steel is stressed.

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For purposes of crack control in end sections of pretensioned members, the prestressing steel is sometimes unbonded. This is accomplished by providing a protective cover on the steel, preventing it from contacting the concrete. 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.

Cracking in concrete can be reduced significantly or eliminated by observing the following practices:

1. Use proper subgrade preparation, including uniform support and proper subbase material at adequate moisture content.

2. Minimize the mix water content by maximizing the size and amount of coarse aggregate and use low-shrinkage aggregate

3. Use the lowest amount of mix water required for workability; do not permit overly wet consistencies.

4. Avoid calcium chloride admixtures.

5. Prevent rapid loss of surface moisture while the concrete is still plastic through use of spray-applied finishing aids or plastic sheets to avoid plastic-shrinkage cracks.

6. Provide contraction joints at reasonable intervals, 30 times the slab thickness.

7. Provide isolation joints to prevent restraint from adjoining elements of a structure.

8. Prevent extreme changes in temperature.

9. To minimize cracking on top of vapor barriers, use a 100 mm thick layer of slightly damp, compactible, drainable fill choked off with fine-grade material. If concrete must be placed directly on polyethylene sheet or other vapor barriers, use a mix with low water content.

10. Properly place, consolidate, finish, and cure the concrete.

11. Avoid using excessive amounts of cementitious materials.

12. Consider using a shrinkage-reducing admixture to reduce drying shrinkage, which may reduce shrinkage cracking.

13. Consider using synthetic fibers to help control plastic shrinkage cracks.

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7. CRACK MONITORING

One method for cracks monitoring is the crack diagram on four directions.

Two perpendicular axes are drawn on the monitored element, the equal angles line and its equal segments. The widths of cracks on the four directions are drawn for each segment. The sum of crack widths divided by the length of each axis is the cracking index on each direction. These measurements must be repeated regularly to monitor the evolution in time.

Monitoring the widening evolution of some cracks may be realized using movement sensors.

From the point of view of mechanisms that leaded to the apparition of the crack in concrete we may have one of the following mechanisms:

a) Settlement of the soils supporting the concrete element

Loss of support beneath concrete structures, usually caused by settling or washout of soils and sub base materials, can cause a variety of problems in concrete structures, from cracking and performance problems to structural failure. Loss of support can also occur during construction due to inadequate formwork support or premature removal of forms. Settlement cracking takes place when the soils or fill beneath the element have not been adequately compacted to provide a consistent level of support for the element to limit the bending stresses which crack the concrete. Settlement can be controlled with consistent preparation (compaction) of the base supporting the element.

b) Restraint of horizontal movement due to fixed foundation elements

Elements placed against fixed foundation elements (frost foundations, light standards, etc.) produce cracks caused by bending forces as the element moves on the surface while the fixed foundation does not. This mechanism is controlled by placing isolation joint material between the element and the fixed foundation to allow the elements to move independently, thus limits the bending stresses and subsequent cracking.

c) Overloading, applying a load larger than the element was designed to support

Overload cracking is easily controlled with proper thickness design of the element considering the largest load that may be applied to its surface.

d) Environmental cracks

Tree roots can crack concrete.

Stresses on concrete don't come only from the intended use of the concrete. Freezing and thawing places stress on concrete. Plant roots infiltrate small fissures in concrete. Chemical exposure weakens the molecular structure of concrete. These are common environmental factors that also promote concrete cracking.

Figure 16. Environmental cracks (Source: http: //www. www.ehow.com;

http://www.imagination.lancaster.ac.uk)

When examining the deterioration conditions of a concrete member, access to the previous inspection report is desirable. This allows the inspector to note the progression of concrete deterioration and provides a more meaningful evaluation and inspection report.

The inspection of concrete should include both a visual examination and a physical examination.

One of the primary forms of deterioration observed during the visual examination is cracking. All cracking should be described and recorded. Future inspections will detect changes in the crack patterns or sizes which indicate active distress.

Monitoring the changes in crack width is an important diagnostic technique for determining the cause and specifying the remedial work. Crack depth gauge is to be used.

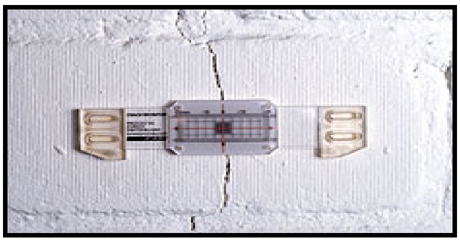

Figure 17. Crack depth gauge

8. REHABILITATION

Rehabilitation requires the selection and combination of appropriate methods according to the type and extent of damage. The deteriorated concrete must be removed. Representative rehabilitation is crack repair, improving the waterproofness and durability of cracked areas. Possible methods to be used are: surface treatment, injection, filling, waterproofing.

Cracking is caused by almost all of the factors that cause deterioration of concrete. An appropriate method should be selected according to the purpose (waterproofness or durability), state and cause of cracking, and crack width.

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