iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IV **Month of publication:** April 2021

DOI: https://doi.org/10.22214/ijraset.2021.33997

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

A Control of Cracking in Reinforced Concrete (RC) Bridge Deck: A Review

Shivank Tamrakar[1], Dr. Umesh Pendharkar[2]
[1]M.E. Student, [2]Professer, Department of Civil Engineering, Ujjain Engineering Collage, Ujjain (M.P.), India

***Abstract:** In present days, bridge deck crack problem we normally see on many bridges. This study is to inform the cracking of concrete bridge decks, and the sealant used in repairing for various types of cracks. There are several factors affecting concrete cracking, such as bridge design, concrete mixture design, mixture materials and placing, finishing and curing practices. The cause of cracking is primarily attributed to effects such as plastic settlement cracks, plastic shrinkage cracks, drying shrinkage cracks, thermal expansion and contraction cracks, cracks due to corrosion of reinforcement and alkali aggregate reaction. Classification of cause of concrete cracking give Based on loading and independent of loading criteria. This study gives formula for crack width calculation for different type of section and provides criteria for design crack width, and its environment as per surfaces exposed to weather and surface protected against weather conditions.*
***Keyword:** Bridge Deck, Overley, Concrete cracking, deck cracking, crack width.*

I. INTRODUCTION

Bridge deck crack problem we normally see on every bridge. Its occurs when the concrete deck changes its volume but is restrained from movement. The amount of volume change in the concrete is dependent on the properties, and proportion of the cementitious materials, aggregate and admixtures, along with environmental conditions such as ambient temperature changes, and humidity. Causative factors of volume change in concrete have been found to be plastic shrinkage, plastic settlement, autogenous shrinkage, drying and creep of the factor affecting the volume change. Visible cracking in bridge deck occur when tensile stresses exceed with tensile strength of the material. Visible cracks are often a concern as these cracks provide easy access to other components. Which play a leading role for the intrusion of aggressive solution into concrete and access to strong steel or other structure deterioration.

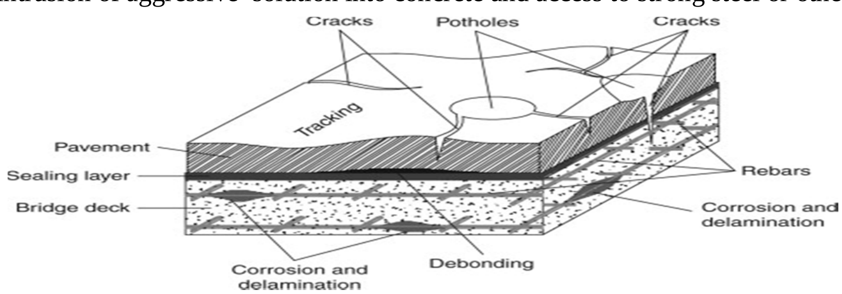

Fig.1 Common defects and deteriorations in concrete bridge deck

A. *Causes of Concrete Cracking in Bridge Deck*

1) There are two categories of classification of concrete cracking-
   a) Crack caused by loading- In this category, when concrete has hardened, then flexural and shear crack occur.
   b) Crack caused by independent of loading- In this category, when concrete is freshly placed, then plastic shrinkage cracks, settlement cracks, shrinkage cracks, thermal cracks occur.
2) There are two approaches for control of concrete cracking-
   a) Prevent the crack if possible
   b) To ensure that adequate reinforcement is present to control crack width if cracking occur.
3) There are some factors are known to affect deck cracking including bridge design, concrete mixture design, mixture materials, and placing, finishing and curing practices. In this, the primary source of deck cracking is attributed to a combination of shrinkage (plastic, autogenous, and drying) and thermal stresses, which are influenced by such factors as bridge design, concrete mixture design, material properties, environmental condition, and construction practices.

B. Type and Cause of Concrete Cracking in Bridge Deck-

1) *Plastic Settlement Crack:* This type of crack is form over and align with reinforcement, subsidence under reinforcing bar. The main cause of this crack is poor mixture design leading to excessive bleeding and vibrations, its occur when concrete continues to consolidate under its own weight after initial placement. The time of appearance of this type of cracking is approx 10 min. To 3 hr.
2) *Plastic Shrinkage Crack:* This type of crack is diagonal or random form. The main cause of this crack is excessive early evaporation of water, its occur near the surface of freshly placed concrete when moisture evaporates from the surface. The time appearance of this cracking is approx 30 min. to 6 hr.
3) *Drying Shrinkage Crack:* This is in the form of transverse or map cracking and the cause of this crack is loss of moisture from the cement paste, excessive mixture water, inefficient joints and large joint spacing. This is appear in 7 days to 28 days.
4) *Thermal Expansion and Contraction Cracks:* This type of crack is transverse form and this crack is caused by different heat of hydration, different cooling rates, and ambient temperature changes or excessive heat generate and high temperature gradients. The time of appearance of this cracking is 1 day to 21 days.
5) *Corrosion of Reinforcement:* This type of crack occur when structure is over reinforced or inadequate cover is provided and this is appear in more than 2 yr.
6) *Alkali-Aggregate Reaction:* This is longitudinal crack which is parallel to the least restrained side, and its time of appearance is more than 5 yr.

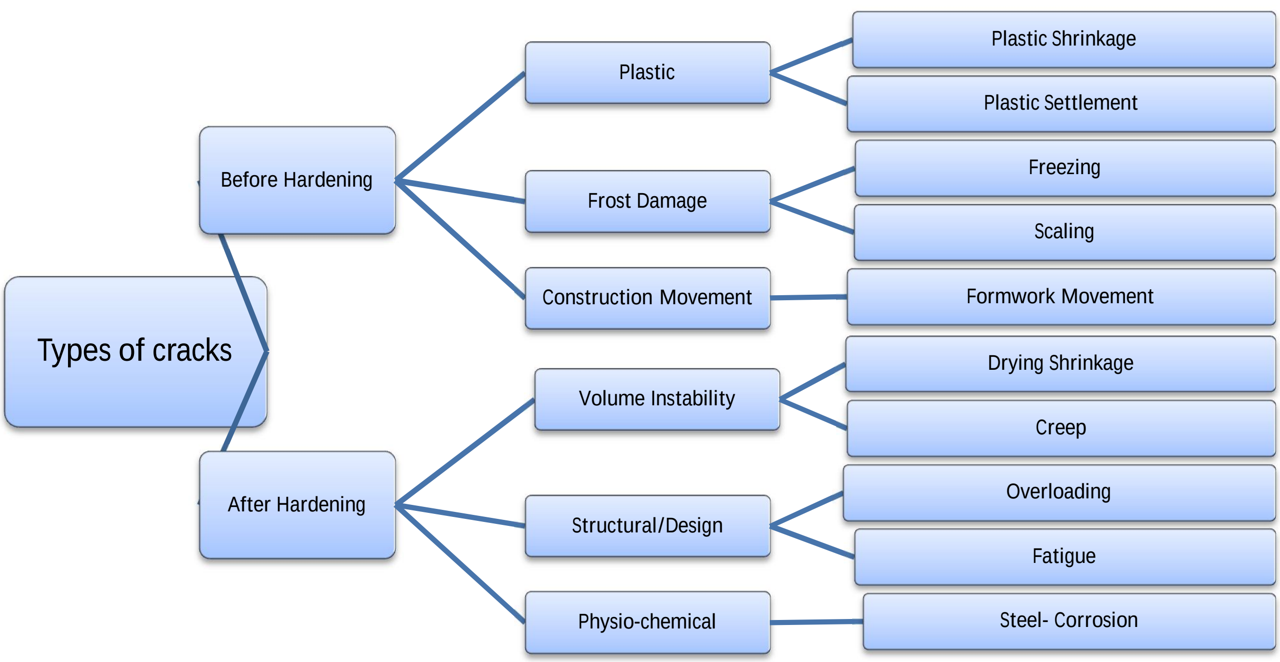

Fig.2 Common cause of cracking in bridge deck

II. CRACK WIDTH CALCULATION

In this for calculating crack width in RC bridge structure, using IRS concrete bridge code 1997. According to IRS Concrete bridge code for the crack width calculation formula for different section is-

1) For solid rectangular sections, stem of T beams and others solid sections shaped without re-entraint angle-

$$\text{Design crack width} = \frac{3a_{cr}\varepsilon_m}{1+2(a_{cr}-c_{nom})/(h-d_c)}$$

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2) For flanges in overall tension, including tensile zones of voided slabs and box beams-

$$\text{Design crack width} = 3\, a_{cr}\, \varepsilon_m$$

Where,

a_{cr} is distance from crack to nearest longitudinal bar

c_{nom} is required nominal cover to tensile reinforcement

d_c is depth of concrete in compression

h is overall depth of section

ε_m is calculated strain, where cracking is considered

$$\varepsilon_m = \varepsilon_1 - \left[\frac{3.8 b_t h(a' - d_c)}{\varepsilon_s A_s (h - d_c)}\right]\left[1 - \frac{M_q}{M_g}\right] 10^{-9}$$

Where,

ε_1 is calculated strain at the level where cracking is being considered, ignore stiffening effect of concrete in tension

b_t is width of section at level of centroid of tension steel

a' is distance from compression face to the point at which crack width is calculated

M_g is moment at section considered due to permanents loads

M_q is moment at section considered due to live loads

ε_s is calculated strain in tension reinforcement, ignore stiffening effect of concrete in tension

A_s is area of tension reinforcement where design moment and tension resisting moment are not normal to each other.

$$A_s = \sum (A_t \cos^4 \alpha_1)$$

Where,

A_t is area of reinforcement in particular direction

α_1 is angle between axis of design moment and tension resisting moment

Table I. Design Crack Width

Environment	Design crack width in mm
Mild	0.20
Moderate	0.20
Severe	0.10*
	0.20**
Very severe	0.10*
	0.20**
Extreme	0.10*
	0.20**

*Surfaces exposed to weather

**Surfaces protected against weather

III. CRACK SEALER

1) *Fiber-Reinforecd Concrete (FRC) Overlays:* When properly proportioned , mixed, and placed, a crack resistant topping layer of FRC can be the solution of certain field problem. Fibers are usually steel or polypropylene with length between 10 and 70 mm. The fibers arrest the growth of micro cracks in concrete is applicable to steel, polypropylene and glass fibers. Fibrillated polypropylene micro fibers are usually used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. They have good resistance to impact, vibration, and blasts. The disadvantages of fiber-reinforced concrete are the reduced workability and the possibility of corrosion stains if the fibers are exposed at the surface.

2) *Latex and Epoxy Modified Concrete Overlays:* Bonded overlays of styrene-butadiene latex-modified mortar and concrete with a minimum thickness of 20 to 40 mm respectively, have been used in the renovation of bridge decks and in new two-course construction to effectively resist the penetration of chloride ions from deicing salts and prevent the subsequent corrosion of the reinforcing steel and spalling of the concrete deck. The technology is similar to normal PCC since the polymer modifier is added similar to other admixtures to the mixture which is primarily PCC or mortar. It is less expensive than polymer concrete since less polymer is used, and the polymer is the most expensive component. Latex-modified concrete , sometimes referred to as polymer-modified concrete, is widely used as a repair material, particularly in overlays to resurface or repair concrete substrates. Epoxy mortars work well for repairs when existing concrete is being attacked by acid or some other aggressive substance. It is not advisable to use an overlay with a vapor barrier on slab-on-grade applications or concrete walls that are backfilled in freezing climate. Bridge decks are often resurfaced with latec-modified concrete overlays. Epoxy-modified concrete is also used for this type of repair.
3) *Epoxy and other Polymer Concrete Overlays:* These materials use a monomer or an epoxy as the binder, aggregate as the filler, and no water. Portland cement or fly ash is added as a mineral filler. Overlays made with these materials are normally thin and do not use coarse aggregate.

IV. LITERATURE REVIEW

A number of works have been presented on the structure cracking and bridge deck cracking. In this review paper some literature in brief is Presented by different Scholars and researchers.

Adel (2013) This paper presents the results of an experimental study of the transverse cracking and deterioration of concrete bridge deck problem. The cause of early age cracking and its influenced by material characteristics, climate condition, geometry and time dependent factors. In this experimental and field testing investigate the early age transverse cracking of bridge deck and evaluate the use of sealant materials. The research identifies suitable materials, for crack sealing, cracks width and achieve to performance criteria such as penetration depth, bond strength and elongation. This is also examining the effect of parameters in the development of cracking such as number of span, span length, girder spacing, deck thickness, temperature, shrinkage, and creep. In this, the deflection is found to be an important parameter to affect the cracking. It also represents the limitations of transverse deck crack.

N.Subramanian (2005) In this paper, the discussion on controlling the flexural cracking in flanges and side face reinforcement of large concrete structure. Control crack width and to enhance durability, different code prescribes limiting crack widths based on environment in which structure exists. For calculating crack width, Indian standard code is complex and similar approach was used in American code till 1999. After that simple formula, involving the clear cover and calculated stresses in reinforcement at service load is included in the latest American code and similar formula take for effect of epoxy coating on reinforcement is suggested for Indian code.

Kirti (2019) This Paper gives the idea for crack control in reinforced concrete structure using partial prestressing. Prestressed concrete has better mechanical properties and durability performance. Its have low ductility and produced less alarming sign than ordinary reinforced concrete via smaller deflection and limited cracking.

Eissa (2019) In this paper, the effect of crack orientation on the remaining fatigue life of reinforced concrete bridge deck is investigated for crack patterns with a wide range of possible crack orientations. The impact of crack direction on fatigue life is found to be associated with the coupled flexural-shear mode of failure, and the mechanism to arrest shear cracking by preceding crack is quantitatively estimated. It is demonstrated that the crack orientations that approximate the longitudinal and transverse directions of RC deck is more extending remaining fatigue life.

Aakash (2015) It investigates the early age shrinkage cracking in bridge deck slab. In this paper number of cause have identified, including thermal movement, plastic shrinkage and early age settlement. This study researched the properties of four polymer fibers which include macro fibers and micro fibers. Each fiber was tested at a several dosages rate to identify optimum dosage levels. Early age shrinkage, long-term shrinkage, compressive strength and tensile strength were investigated.

Md. Safiuddin (2018) This research paper help to identify the major cause of the early-age cracking problem in concrete and also useful to adopt effective remedial measures for reducing or eliminating the early-age cracking in concrete. Different type of early-age crack, the factor affecting initiation and growth of early-age crack, the cause of early-age cracking, and the modeling of early-age cracking are discussed in this paper. In this some recommendations are given for minimizing the early-age cracking in concrete.

David (2004) In this study investigated the crack density increases as a function of cement and water content, and concrete strength and crack density is higher in the end spans of decks that are integral with the abutments than deck with pin-ended supports.

Most of the cracking occurs early in the life of bridge deck. A major bright spot has the positive effect of efforts to limit early evaporation, and give the suggestion of early initiation of curing procedures was help to reduce crack in bridge decks.

Tayyebeh (2015) This work deals with finite element simulation methodology for assessing the role of shrinkage-induced strain in generating early-age bridge deck cracking are described. Drying shrinkage appears to be capable of causing transverse bridge deck cracks as early 9 -11 days after bridge deck placement and its induced stresses would result in transverse cracking over interior pier supports in a typical bridge superstructure considered in the finite element simulations conducted.

Yunping xi (2003) In this report, the extent and causes of the cracking problem were investigated, and necessary changes to alleviate the cracking problem were identified. This is a review and compared with others DOTs practices for construction of bridge deck. Based on the result of field inspection, the cracks typically from above supporting member, such as girders or piers, and have large number of spacing. This is a result of tensile stresses from negative bending moments in the deck above supports. The construction and environmental factors greatly affect the shrinkage of concrete.

ACI Committee 224 (2001) This code gives the information about control of cracking of concrete structures. It informs about different types of sealant materials for different cracks.

IRS Concrete bridge code (1997) In this code, plain, reinforced & prestressed concrete general bridge construction methods are available. This code is provides different formulas for the width of the crack for different types of sections.

V. CONCLUSION

These presented reviews reveal a better understanding of the issue of common faults and deterioration in concrete bridge decks. This study gives a classification of the cause of cracks and provides an approach to control cracks of concrete. It provides information about some factors that affect cracks in the deck of concrete bridges. This study investigated the major types and causes of cracks and their presence in reinforced concrete bridge decks and gave a formula for calculating the width of the cracks for different sections. It provides information about various crack sealers according to the type of crack.

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