CATEGORIZATION OF DAMAGES TO CONCRETE HIGHWAY BRIDGES

Mustafa Y. Al-Mandil

Department of Civil Engineering
King Fahd University of Petroleum and Minerals
Dhahran 31261, Saudi Arabia

ABSTRACT

As part of a National Project for the Study of Concrete Highway Bridges in Saudi Arabia, a large number of highway bridges have been surveyed during the period 1984-1990 for detection of various defects and damages. Several bridges manifested visible signs of damage and deterioration, a number of factors have been attributed as the leading causal factors for these damages to concrete bridges in Saudi Arabia.

This paper presents an overview of the types of damages identified to be most prevalent in concrete highway bridges in the Kingdom. Among the major causal factors of damages to concrete bridges are the following: (I) Natural Catastrophes, such as flash floods, earthquakes, slope slides and fires; (II) Environmental Causal Factors, such as the severe arid environment with high thermal gradients in the interior regions, and the high ambient humidity coupled with saline environment in the coastal regions; (III) Operational and Serviceability Factors, such as oversize vehicles, overloaded vehicles, lack of control over axle loads, etc.

INTRODUCTION

Over the past three decades, several hundreds of highway bridges had been built in Saudi Arabia as part of the development of modern highway network. Some of these bridges have suffered prematurely from excessive cracking, deterioration, loss of serviceability and failure. Although the durability problems and the causal factors for deterioration which are applicable to a concrete structure are equally applicable to concrete bridges, the severity and unpredictability of bridge loadings and the direct exposure of the bridges to hostile environments have combinedly paved the way for an aggravated assault on concrete bridges.

Realizing the seriousness and the scope of the cracking of concrete bridge decks phenomenon, the Ministry of Communications (MOC) in association with King Fahd University of Petroleum and Minerals (KFUPM) have embarked on a National Project to study this phenomenon in the Kingdom of Saudi Arabia. The project was sponsored in 1984 by the King Abdulaziz City for Science and Technology (KACST) for a duration of six years (Al-Mandil et al., 1989a).

This paper reports some of the salient findings gathered, as part of this National Project, from in-depth studies conducted on several defective bridge decks around the Kingdom. These bridges were selected as representative case studies for the types of damage identified to be most prevalent in short-span bridge decks.

CATEGORIZATION OF CAUSAL FACTORS

Damage to deck systems identified by the major contributing and causal factors can be categorized as below:

I) Natural Catastrophes:

Of all the major defects to concrete bridge decks, the natural disasters are the least predictable, and are the most difficult to design for. Such factors include among others, flash floods, slope slides and other less frequent natural disasters such as earthquakes and fires caused by traffic accidents.

Over 95% of all the highway bridges outside the major cities in Saudi Arabia are constructed over dry "wadis". A wadi is a natural low ground like a valley, where the rain runoff waters are channelled from high grounds to lower grounds. Some wadis are well known and well marked. Wadis are known throughout history to carry rain flash floods and in many cases are well marked on the ground, they are easily identifiable. Among the well known wadis in Arabia is the "Rimmah" which runs from Medinah to the west to Hafr Al-Batin to the east, travelling over 1400 km in length. Most wadis are somewhat narrow in width (100 m-400 m), but can be as wide as 2-3 kilometers. Hydrological studies can predict the required length and height of a highway bridge over a wadi, but occasional record rainfalls may prove the shortcoming of such predictions. The great flash flood of the Asir region in 1980 was a good example of the severity of natural disasters, where over twenty two highway bridges were washed out and totally destroyed in the "Dhillaa" valley near Abha (Plate 1).

Another natural disaster that affects highway bridges is the slope landslides that usually occur during or after heavy rainfalls. Geotechnical investigations of mountain terrain can predict the possibility of future slides, certain measures such as mountain rock anchoring and slope stabilization can prevent or reduce the probability of slope slides. But again, severe rainfalls and soil liquefaction can produce disastrous slope slides that shall wipe out large sections of roads as well as bridge decks, abutments and piers. Recent example is the major 1992 slides of the "Baha" region which destroyed sections of bridges on the Baha-Taif road (Plate 2).

A less frequent type of damage can be attributed to occasional accidental fires. A 40,000 litres diesel tanker was derailed from the side of a highway bridge in Akhal (near Medinah), and has caught fire. The tanker fuel kept burning for six hours under one of the deck slab bridge, affecting two spans and their columns (Plate 3).

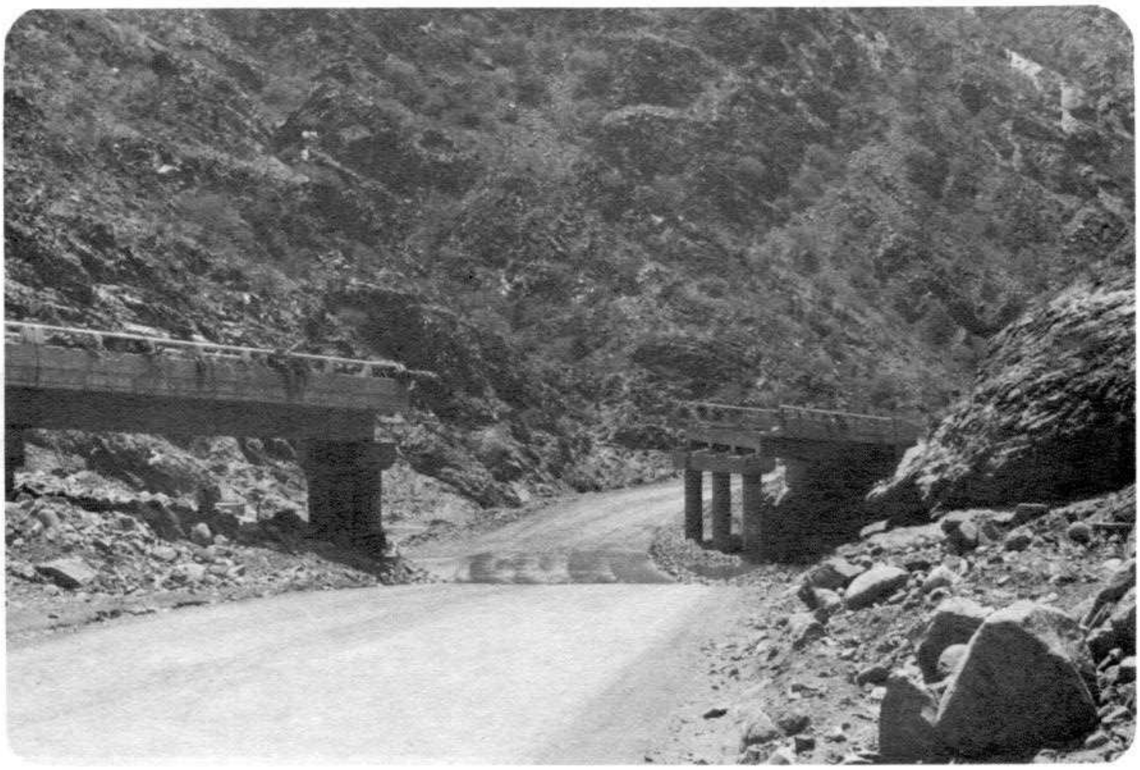

Plate 1. Flood-damaged bridge in Asir region

Plate 2. Slope slides-damaged bridge near Al-Baha region

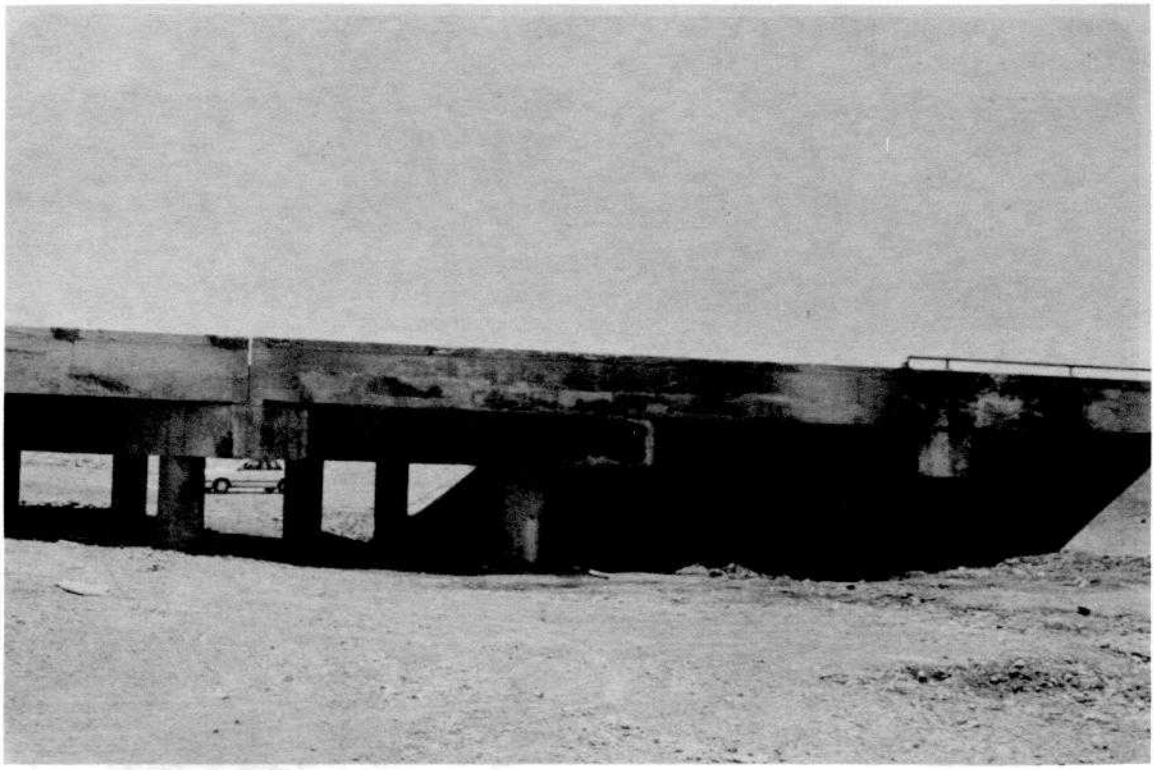

Plate 3. Fire-damaged bridge in Medinah region

II) Environmental Factors:

This category includes structural impairment due to a variety of factors arising from poor construction practices, lack of quality control and an aggressive environment as defined by existence of high temperatures/high humidity in conjunction with a hostile environment such as the sabkha region in the Eastern Province.

The form of non-structural damage most commonly observed was in the configuration of reinforcement corrosion and appeared most prevalent in the inhospitable sabkha environment of the Eastern Province Region and the terrain slightly north of this area (Nuayriyah). Several factors have contributed to the breakdown in structural function including (i) lack of availability of quality coarse aggregates and non-contaminated fine aggregate, (ii) lack of quality control leading to possible use of salt-laden mix and curing water and (iii) improper mix design followed by poor construction practices. Any combination of these factors, in conjunction with subsequent high temperature and humidity, can trigger a chain of events leading ultimately to reinforcement corrosion, concomitant with heaving and delamination and structural dysfunction (Nuayriyah) or localized cracking and loss of serviceability (Eastern Province bridges). Although the reinforcement corrosion damage observed during the course of the project was restricted to deck slabs, any exposed component of the bridge accessible to moisture is vulnerable to this form of attack and damage.

A factor contributing to distress in deck slabs is that of minimally functioning bearings leading to thermal stress buildup in thick slabs (e.g. Taif bridges). Thus, although it may be tempting to incorporate slab thicknesses in excess of hitherto designed magnitudes in order to preclude localized punching failures, attention must be focussed on ensuring that bearings retain their function through the design life of the deck slab.

An additional causal factor contributing to damage in the arid environment is cracking due to stresses produced as a consequence of thermal gradients, especially in thick slab type decks supported on minimally functional bearings which do not allow free movement at the ends.

III) Operational Factors:

This class of damage includes distress primarily caused by overloading of the structure due to passage of non-regulatory vehicular loading. Most common manifestation of this damage includes (i) localized slab failure in the form of potholes (Plate 4) and (ii) rectangular grid pattern cracking on soffit side of slab, characterized by cracks of significant width and depth (Plate 5).

In assessing the nature and mechanisms of the spalling and the pothole formation, it is noted that most potholes are formed in the severely cracked regions as a consequence of a punching shear type of failure, where pieces of concrete are pushed through the slab reinforcing bars. A quick check on the decks' punching shear capacity reveals that these decks entertain a high margin of safety against punching shear type of failure on the basis of the ACI punching-shear formula. Therefore, a punching shear design deficiency can be discounted.

However, it has been shown in a relevant study (Al-Mandil et al., 1989b and Kareem, 1989) that the punching capacity can be impaired by the existence of a flaw within the slab intricately developed by the active process of crack growth and crack nucleation. A deck slab will normally be subject to two types of cracking: (i) non-structural cracking related to environmental factors such as plastic settlement, shrinkage and thermal effects and (ii) structural cracking caused by stresses from the vehicular load action. Superimposed crack prints of these two represent the current state of cracking which is continually being altered by the progressive crack growth due to dynamic overloading effects. This may lead to the formation of concrete zone which is separated from the surrounding body along an enclosed perimeter of the nucleated crack surface. Existence of random cracking at the slab soffit is conducive to the formation of such a flawed zone which may be dangerous from the punching viewpoint.

Another form of operational damage is the presence of oversize tall vehicles which fail to comply with the maximum height requirements of (18) ft. Several highway bridges are constantly damaged on their soffit side due to impact of non-regulatory tall vehicles (e.g. Abha ring road bridges).

CONCLUSIONS & RECOMMENDATIONS

On the basis of data gathered for several defective bridge decks around the Kingdom, it may be concluded in retrospect that the shape and form of damage most likely to occur in a given situation is a function of bridge geometry, proportioning, construction materials &

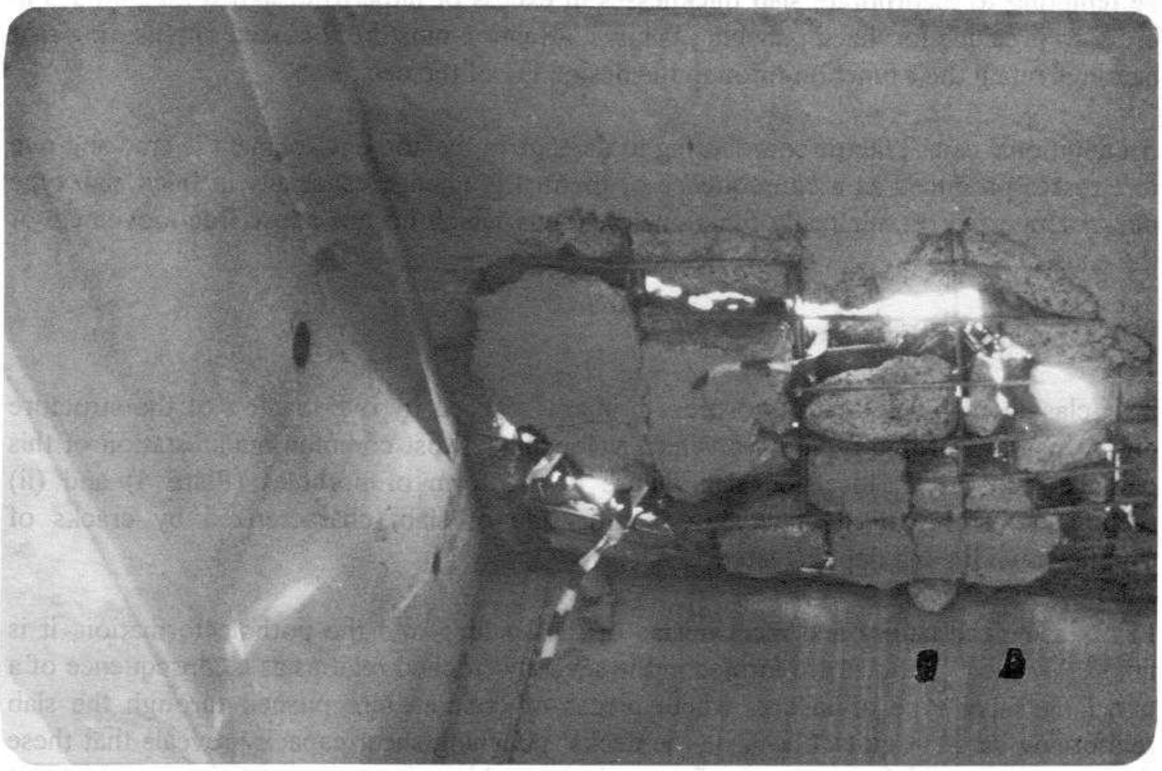

Plate 4. Pothole type failure in deck slab

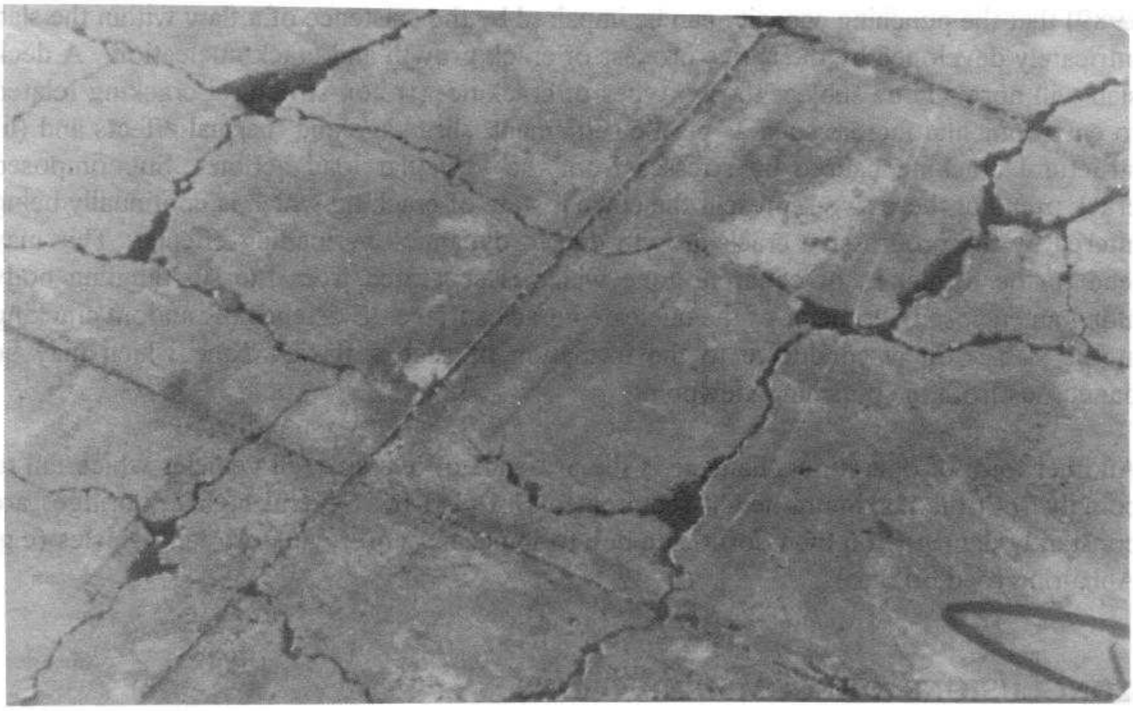

Plate 5. Extensive cracking of the deck slab

techniques and environment. Table 1 illustrates the damage likelihood chart for short span concrete bridge decks.

Table 1. Damage likelihood chart for bridge decks in the Kingdom of Saudi Arabia

Type of Bridge Deck	Environment	Possible Mode of Damage	Causal Factors
(i) Girder/Slab (ii) Box girder	Non-aggressive	(i) Pot hole in slab (ii) Rectangular-grid cracking on slab soffit (iii) Shear/flexural cracking in girder	(i) Overloading (ii) Low strength concrete (iii) Under-design
(i) Slab	Non-aggressive	Rectangular-grid cracking on slab soffit	(i) Overloading (ii) Low strength concrete (iii) Under-design (iv) Thermal effects
All types of concrete bridges	Aggressive	Reinforcement corrosion	(i) Chloride contaminated materials and/or mix, curing water (ii) Improper mix design

In order to minimize the likelihood of the occurrence of the most common forms of damage as identified earlier, it is recommended that a number of measures be adopted by the MOC before embarking on the last resort solution of replacing defective decks. Some of these measures are listed and discussed briefly below.

Repair and Load Rating of Defective Bridge Decks

A number of lightly to moderately cracked bridge decks exist in the Kingdom today. Most of these decks may survive for many years to come if care and precaution are exercised to guarantee the safety and proper performance of these decks. Among the measures that may be exercised are the following:

a) Repair and strengthening schemes need to be examined for possible implementation towards some of these defective decks. Epoxy injection and steel bonding are two examples of such schemes.

b) Load rating of existing defective decks and control of the loads to be subjected onto these decks. As the load carrying capacities of bridges are known to be adversely affected by the presence of deck cracks, elastic theories of bending are no longer effective in predicting the real stress levels caused by heavy vehicles. An actual in-situ load testing of these decks can shed some light on their actual carrying capacity and on their reserved strength values.

Control of Axle Loads

The majority of bridge decks in the Kingdom are currently in an excellent working condition. If this investment is to be protected, then a number of measures are to be taken to guarantee the future survival of these decks, so as to enable them to serve their planned service lives. Among these measures, for example, are immediate control over vehicular loads and the implementation of an effective bridge management and maintenance program.

Improve Design & Construction Practices

In order to tackle the problem of the bridge deck cracking at its origin, a number of currently used design provisions for new decks need to be reviewed and updated. An example of such provisions is the improvement of the punching shear capacity under concentrated dynamic loads (Al-Mandil et al., 1989b and Azad et al., 1986). Also, a stricter quality control over new bridge constituent materials and construction techniques need to be imposed and carefully implemented.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Y. Ziraba and Mr. G. Al-Sourti (Research Associates of the National Project). Also, sincere thanks to all the MOC staff and engineers who provided the raw data and offered every assistance in making these case studies possible. And finally, our sincere thanks to KFUPM and to KACST for their technical and financial support.

REFERENCES

Al-Mandil, M.Y., Azad, A.K., Baluch, M.H., Sharif, A.M., Pearson-Kirk, D. and Al-Dhalaan, M.A. (1989a), "A Study of Cracking of Concrete Bridge Decks in Saudi Arabia", *National Project Final Report*, KFUPM, Dhahran, Saudi Arabia.

Al-Mandil, M.Y., Azad, A.K., Baluch, M.H., Pearson-Kirk, D. and Sharif, A.M. (1989b), "Punching Shear Failure of Concrete Girder-Slab Type Bridge Decks in Saudi Arabia", *Proc., Fourth Int. Conf. on Structural Faults & Repair*, University of London, London, UK.

Azad, A.K., Baluch, M.H., Al-Mandil, M.Y. and Al-Suwaiyan, M. (1986), "Static and Fatigue Tests of Simulated Bridge Decks", *Proc., ASCE Convention, Engg. Mech. Div.*, Michigan, USA, pp. 30-41.

Kareem, K. (1989), "Load Induced Cracking and Failure of Concrete Deck Slabs in Girder-Slab Type Bridges", *M.Sc. Thesis*, Dept. of Civil Engg., KFUPM, Dhahran, Saudi Arabia.