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Deck Cracking of Shelby Creek Bridge

Fissuration du tablier du pont de Shelby Creek

Rissbildung in der Fahrbahnplatte der Shelby Creek Brücke

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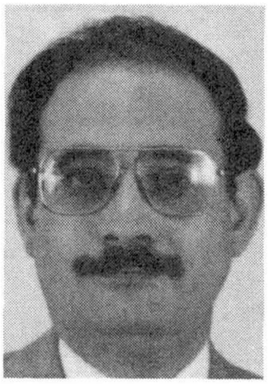

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SUMMARY

Early cracking of a cast-in-place reinforced concrete overlay of a sandwich concrete deck of Shelby Creek Bridge is investigated. Independent numerical checking proved that the bridge design was correct. Shrinkage cracking was enhanced by several factors. This enhancement was due to the special features of the bridge.

RÉSUMÉ

La fissuration prématurée de la couche supérieure du béton armé dans le tablier composite du pont de Shelby Creek est discutée. Une vérification numérique, indépendante, montre que le calcul était correct. Les fissures de retrait du béton ont été influencées par plusieurs facteurs, dûs aux particularités de ce pont.

ZUSAMMENFASSUNG

Die frühzeitige Rissbildung in der Fahrbahnbetonplatte von der Shelby Creek Brücke wurde untersucht. Die unabhängige numerische Prüfung hat bewiesen, dass der Brükkenentwurf korrekt ist. Die Schwindrisse sind durch mehrere Faktoren verstärkt. Diese Vergrösserung ist durch die spezielle Brückenbeschaffenheiten verursacht.

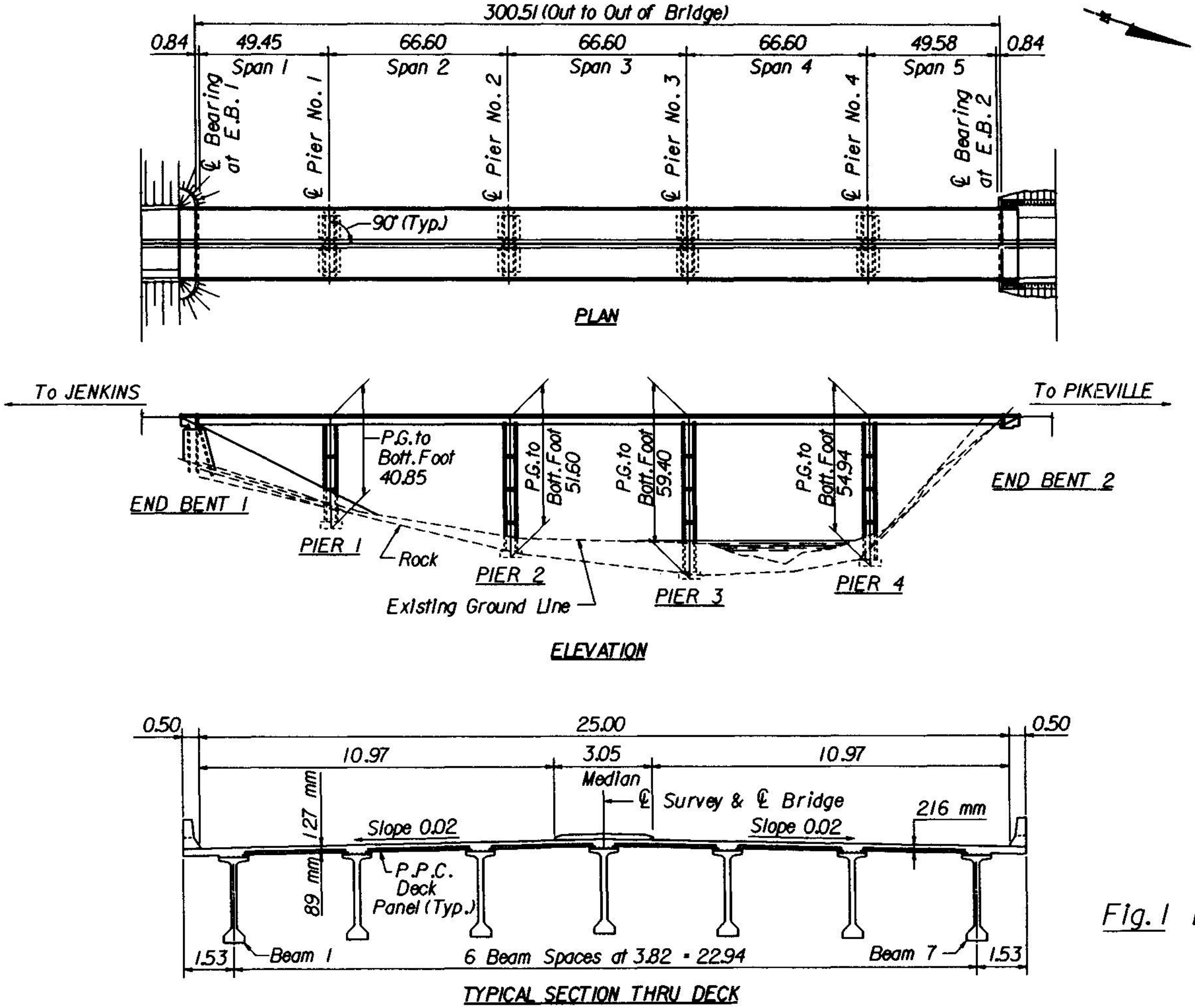
300.51 (Out to Out of Bridge)
0.84
49.45
Span 1
66.60
Span 2
66.60
Span 3
66.60
Span 4
49.58
Span 5
0.84
℄ Bearing at E.B. 1
℄ Pier No. 1
℄ Pier No. 2
℄ Pier No. 3
℄ Pier No. 4
℄ Bearing at E.B. 2
90° (Typ.)
PLAN
To JENKINS
To PIKEVILLE
P.G. to Bott. Foot 40.85
P.G. to Bott. Foot 51.60
P.G. to Bott. Foot 59.40
P.G. to Bott. Foot 54.94
END BENT 1
END BENT 2
PIER 1
PIER 2
PIER 3
PIER 4
Rock
Existing Ground Line
ELEVATION
0.50
25.00
0.50
10.97
3.05
10.97
Median
℄ Survey & ℄ Bridge
127 mm
89 mm
Slope 0.02
Slope 0.02
216 mm
P.P.C. Deck Panel (Typ.)
1.53
Beam 1
6 Beam Spaces at 3.82 = 22.94
Beam 7
1.53
TYPICAL SECTION THRU DECK

Fig. 1 Layout

1.0 INTRODUCTION

Over the last 15 years of the highway bridge construction history in U.S.A., occurrences of early concrete deck cracking have been recorded although no errors in bridge design and construction ever occurred. Shelby Creek Bridge is one such case.

Shelby Creek Bridge on US 23/US 119 in Kentucky is a four lane, five span (49.45m + 3 x 66.60m + 49.58m) beam type segmental bridge with two-way traffic as separated by a 3m wide raised median, Fig. 1. The bridge deck is 25m wide and it is composed of precast prestressed 41 MPa concrete panels (PPC) 9 cm thick used as formwork for 13cm cast-in-place reinforced 34 MPa concrete deck overlay (Fig. 4). The superstructure consists of seven precast 48 MPa lightweight concrete beams of constant depth at a spacing of 3.82m. The bridge is supported on four piers and two end-bents. The height of the piers varies from 35.74 to 50.09m. Piers are supported on spread footings on rock. Each pier consists of two twin curtain walls 0.90 x 3.66m spaced at 4.57m. They are battened together at 11.60m height intervals and post-tensioned.

The vertical curve, 213.36m long between the grades +0.5% and 7.0%, starts 16.84m before pier 3. This curve corresponds to a velocity of 80-90 km/h. Heavy loaded coal haul trucks, going mainly downhill in southbound lanes, are traveling with a speed of 100-110 km/h.

1.1 <u>Description of Deck Cracking</u>

<u>General.</u> The construction of Shelby Creek Bridge was opened to traffic at the end of December, 1991 and was fully completed on April 20, 1992. The cracks developed in the bridge deck were noticed in Fall, 1992. These cracks are developed only in the top, poured-in-situ, 13 cm concrete deck.

Cracks are mainly transverse and/or longitudinal with some which are semicircular. Two distinct patterns of cracks are identified: 1) above the piers, i.e. between their two diaphragms

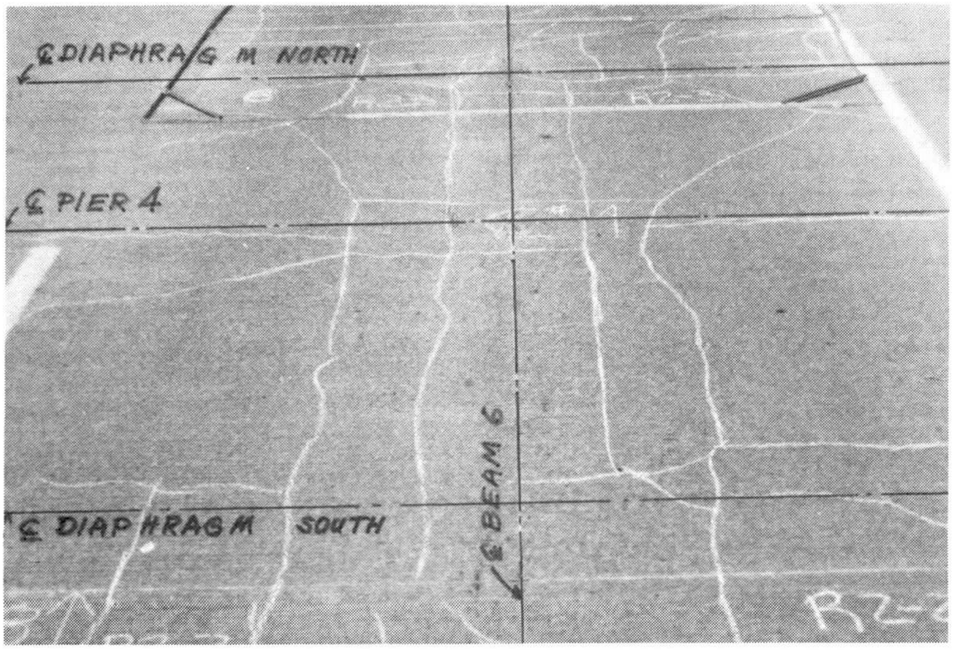

Fig. 2 Cracks at Pier 4

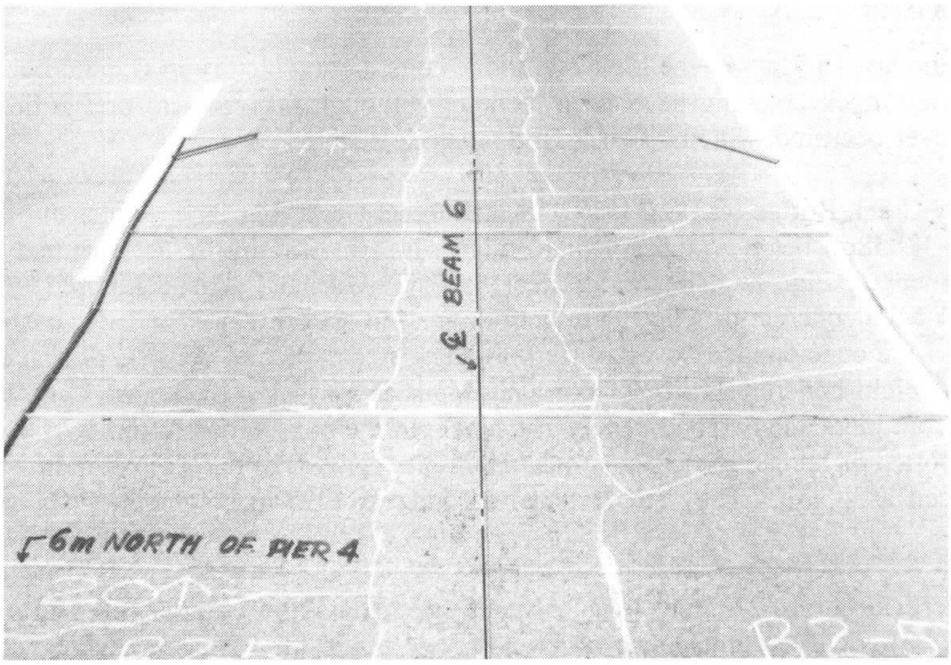

Fig. 3 Cracks Away of Piers

(curtain walls) Fig. 2 and 2) in the spans, away from piers, Fig. 3. Common to all cracks is more intense cracking in the exterior lanes of both traffic directions, than in the other two interior lanes, i.e., between the second and third beam of both bridge side faces . Next, cracks are more pronounced at piers 3 and 4 than piers 1 and 2, and the longitudinal cracks in spans are mainly developed along one or both sides of top flanges of both first interior beams.

Cracks at Piers. In Fig. 2, the typical pattern of enhanced cracks at pier 4 are shown. Both external lanes are almost centered on the first interior beams, and the longitudinal cracks are developed on both sides of beam's top flange. Transverse cracks crisscross them in the deck within the two pier curtain walls (diaphragms) in a way almost symmetrical to the pier centerline. Longitudinal beams and transverse diaphragms (curtain walls) produce deck panels 3.82 by 4.57m exposed to two dimensional restraints for any overlay displacement, including one due to the shrinkage. Due to this two-dimensional restraining effect, the corresponding stresses, developed in deck, produce tensile principle stresses at variable angles with bridge axis, i.e. the corresponding cracks in the overlay are semicircular.

Cracks in Spans. In Fig. 3, enhanced longitudinal cracks in the last span from 6 to 11m north of pier 4 are shown. Cracks are almost parallel, and they are centered above the first interior beams, i.e. beams 2 and 6. They are spaced about 0.65 to 0.85m apart. This distance is approximately equal to the space (0.75m) between ends of precast prestressed concrete panels (P.P.C.) above the beam flanges. Later on in the span, the interior crack eventually stops and only the exterior one runs further and then stops.

Major transverse cracks are developed only in interior bridge spans, leaving two end spans with mainly longitudinal cracks. There are about 26 cracks in southbound lanes and 23 cracks in northbound lanes. Very few of the cracks reach the raised median. Their spacing is between 0.60 and 2.50m and they are again more pronounced above piers than in spans.

2.0 SPECIAL BRIDGE FEATURES

No errors that could explain the deck cracking were found through an independent numerical checking of the design of composite deck slab, an analysis of live load static and some dynamic effects, and a partial checking of construction documents and activity.

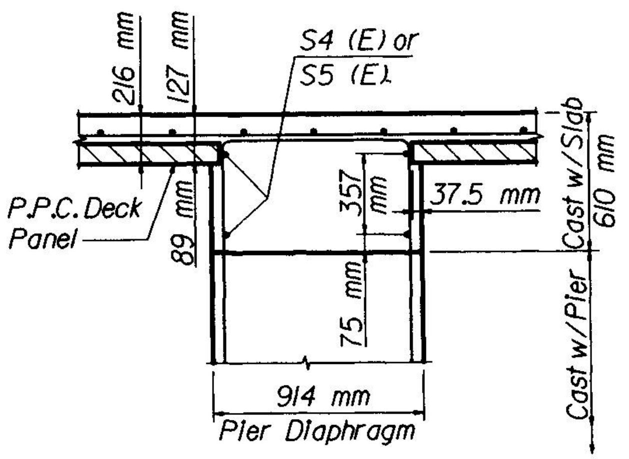

Fig. 4 Section at pier diaphragm

Therefore, differential shrinkage, as enhanced by some bridge characteristics, resulted in the described cracking. The special features and their contributions to cracking are:

- PPC Panels. First, they produce above main beams (between panels' longitudinal edges), longitudinal gaps 0.64m wide, where overlay depth is suddenly increased from 13cm to 22cm. Second, at their beveled transverse edges having a spacing of every 2.5m, the similar increase is 10.2cm. This means that a rectangular pattern of differential shrinkage is already set-up by use of PPC panels. Third, the end of panels resting on beam flanges are not rigidly fixed by the overlay and small rotations under live load have enhanced longitudinal cracks, which are started by shrinkage, to be more pronounced in the lanes with higher traffic volume, i.e. in the outside lanes.

- Two diaphragms at curtain walls of piers. These massive diaphragms, 0.91cm thick and 4.57m apart, Fig. 4, with main beams produce rigid two dimensional restraints in addition to the previous rectangular pattern. Therefore, cracking above piers is more intense than in the spans.

- Bridge vertical alignment. Heavily-loaded 623 kN trucks travel southbound downhill with speeds over the design speed for vertical curve as stated in Section 1.0, producing more crack enhancement by PPC at Piers 3 and 4, than 1 and 2 and more in the outside southbound lane than in the northbound lane.

- Bridge pier height and configuration. Due to the bridge almost north-south orientation, each pier curtain wall facing south is exposed to direct sun radiation as opposed to the other twin wall being always shaded. Therefore, a differential temperature of 10 to 20°C is created between the two walls. This produces a relative raising in the deck slab, e.g. at pier 3 of 0.7 to 1.4cm at a distance of only 4.57m and therefore a hogging moment as well. This introduces a slab tension of 0.57 MPa to 1.14 MPa respectively.

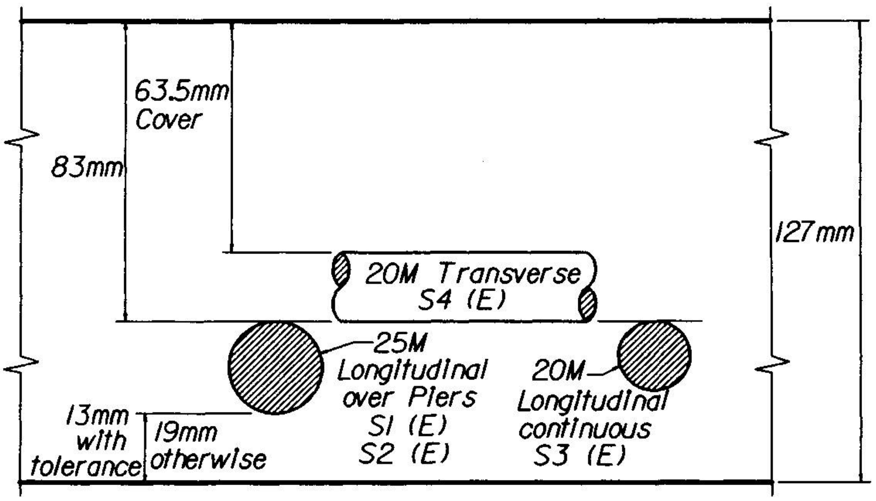

Fig. 5 Detail of topping overlay

3.0 CONCLUSION

Unwanted cracks caused by inadequate design or construction were not present. The cracks are "restraining cracks" caused by the restrained volume changes due to shrinkage, creep, elastic shortening and temperature gradient. It is known that about two thirds of any slab shortening is due to shrinkage. Many of the restrainers previously discussed, as well as sudden volume changes, produce differential shrinkage and hydration temperature gradient, which consequently can cause the cracking. Large clear cover of epoxy-coated bars also contributed to the cracking, Fig. 5.

A percentage-wise distribution of the causes for the overlay cracking on the Shelby Creek Bridge was estimated to be as follows: 65% shrinkage, 10% PPC panels, 5% temperature gradient between overlay and PPC, 10% temperature in walls, 1% pouring sequence, 4% large concrete cover and 5% still unknown.

As the cracks proved to be stabilized after three months of observation and measurement (March 1993-May 1993) and the concrete was already 1.5 years old, the only repair required was sealing the cracks.