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Rating Concrete Slab Bridges

Appréciation des ponts-dalles en béton

Einstufung von Betonplattenbrücken

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SUMMARY

Extensive experimental and analytical investigations have been conducted on the behaviour of concrete slab bridges, especially older slab bridges designed for AASHTO H15 truck loads. Experiments included testing 12 slab bridges, with and without skew, under elastic loads using truck loads, and testing to collapse one five-span continuous slab bridge. The analytical phase of the investigation included development of a three dimensional modelling technique, identifying reasons for observed large reserve strength in concrete slab bridges using the yield line analysis approach, and undertaking development of a reliability-based procedure to rate concrete slab bridges accurately.

RÉSUMÉ

Le comportement structural d'anciens ponts-dalles, dimensionnés pour une circulation (selon AASHTO, camions H15) a été étudiée de manière approfondie. Les essais ont porté sur 12 ponts droits et biais, sous sollicitations élastiques provoquées par le passage de camions, ainsi que sur un pont-dalle à cinq travées continues soumis à un chargement jusqu'à rupture. L'analyse fait appel à une technique de modélisation tridimensionnelle, mise au point pour identifier les causes des importantes réserves de résistance observées dans les ponts-dalles en béton, et pour définir les données d'évaluation précise de ces ponts-dalles à partir de la théorie de fiabilité.

ZUSAMMENFASSUNG

Zum besseren Verständnis des Tragverhaltens älterer Plattenbrücken, die für H15-Lastwagen (gem. AASHTO) bemessen waren, wurden ausgiebige experimentelle und analytische Untersuchungen durchgeführt. Der experimentelle Teil umfasste 12 Brücken, gerade und schiefwinklige, im elastischen Beanspruchungsbereich, sowie den Test einer über fünf Felder durchlaufenden Plattenbrücke bis zum Bruch. Im analytischen Teil wurde eine 3-D-Modellierungstechnik entwickelt, die Ursachen für die grossen beobachteten Tragreserven mit Hilfe des Bruchlinienverfahrens ermittelt und Ansätze zur genauen Beurteilung von Plattenbrücken aufgrund der Zuverlässigkeitstheorie unternommen.

Introduction

Many states own concrete slab bridges which were designed and constructed more than 40 years ago. Although their performance over the years has been exceptionally good, current rating procedures indicate that these bridges do not possess sufficient capacity to carry modern traffic loads. Comprehensive analytical and experimental investigations were carried out to develop simple models and a methodology for accurately assessing the load carrying capacity of these bridges at both service and ultimate load levels. To assess the performance of concrete slab bridges under normal traffic loads, a series of slab bridges representing different configurations was selected and tested under truck loads at both crawling and high speeds, hereafter referred to as *Service Load Tests*. The results were then utilized to develop simple models to predict response of concrete slab bridges to truck loads.

To assess the performance of these bridges at higher load levels and establish the available true factors of safety, a decommissioned concrete slab bridge built in 1938 was tested to collapse, hereafter referred to as *Ultimate Load Tests*. This particular bridge consisted of five spans, three continuous spans and two simply supported spans at either end. The end span of the continuous portion and one of the simply supported spans were subjected to numerous tests, including ultimate load tests, to collapse. Results indicate that these bridges possess large reserve capacities. The behavior of the bridge during the ultimate load test was very ductile and exhibited more than 12.7 cm of displacement before collapse (span length of 9.2 m).

Following these studies an investigation was then conducted to establish a reliability based procedure for rating concrete slab bridges using field testing.

The following sections present brief summaries of each phase of the investigation and conclusions. More detailed information is provided in Ref.1.

Service Load Tests

A total of 12 concrete slab bridges representing different geometry and structural configurations were selected for truck load tests. All 12 bridges were three span continuous. Table 1 gives a list span lengths, skew, slab thickness and year of construction for each of these bridges.

Loading of each bridge was accomplished by 1) using two trucks traveling side by side or 2) one truck on the bridge at a time. The weight of each truck used for testing bridges No. 1 through 6 was approximately 222.5 kN. The weight of each truck used in testing bridges 7 through 12 was approximately 170 kN. Table 1 lists the maximum observed deflection at mid span of the middle span for all 12 bridges tested. In general, the observed deflections were small.

Results of these tests were used to develop guidelines for elastic, three-dimensional finite element analysis of three-span continuous slab bridges with minimal input, and provide comparisons between two and three dimensional analyses approaches.

Finite Element Analysis

A preprocessor was developed requiring minimal input consisting only of span lengths, thickness at different regions of the slab, cross sectional properties of the railing system (if desired), and material properties. Using this minimal input, the preprocessor would then generate the necessary information to conduct three dimensional analysis of the bridge using the SAP90 program. In this modeling technique, the slab portion of the bridge is modeled using 780 four-node shell elements that are a combination of membrane and plate-bending elements. A three dimensional prismatic beam column element, which includes effects of biaxial bending, torsion and axial and shear deformations, is used to model the railing system. Table 2 gives comparisons of the results of three dimensional analyses of bridges No. 1 through 6 tested under elastic loads in terms of the maximum deflection at center of the mid span. Also shown in Table 2 are comparisons of the maximum moments as obtained from two and three dimensional analyses approaches. The three dimensional analyses were conducted using the package developed. The two dimensional analyses were conducted using the distribution factor, E, implied by the AASHTO manual (E = 1.22 + 0.06 x S, where S is the span length and with the limitation that E should not exceed 2.13 m). As noted from Table 2, good correlations are obtained between test and three dimensional analyses results. Further, Table 2 indicates that the maximum moment from two dimensional analyses is considerably larger than that obtained from the three dimensional analyses approach. Oftentimes, such a reduction in maximum moment using three dimensional analysis is sufficient to upgrade the load carrying capacity of the bridge.

Ultimate Load Test

A reinforced concrete slab bridge built in 1938 and located in northwestern Nebraska was used for the ultimate load test. Figure 1 shows the bridge dimensions. The superstructure is a cast-in-place five span reinforced concrete slab comprised of three continuous spans and two simply supported end spans. The abutments were constructed integrally with the superstructure. The piers were made of reinforced concrete and supported on driven steel H piles. The curb on each side of the roadway was cast monolithically with the slab.

A number of core samples taken from the bridge indicated average compressive strength of 22 MPa for the concrete. The bridge had been decommissioned since 1972 and no maintenance had been performed. As a result, an extensive amount of damage in the form of delamination of cover concrete at many locations over the slab surface was visible. The petrographic study indicated that most of the damage could be attributed to cyclic freeze-thaw damage and inadequately air entrained concrete. A number of steel samples taken from the bridge indicated that the mechanical properties of the reinforcing bars met the ASTM A616 Grade 50 standards, whereas the specified yield strength was only 70% of the actual values.

In accordance with AASHTO requirements, initial rating analysis of the bridge indicated a rating factor of 0.67 for HS20-44 truck loads, i.e. the maximum truck load permitted to cross the bridge was 67% of the weight of an HS20-44 truck (320 kN).

Using a specially built reaction frame around the structure, one of the end spans of the continuous portion of the bridge (hereafter referred to as continuous span) and one of the simple spans (hereafter referred to as simple span) was loaded to collapse. The loading of the continuous span was accomplished using 8 hydraulic rams positioned on the span to simulate two HS20 trucks side by side and having the front axle already off the span (i.e. only two axles of each truck remaining on the span). The locations of the rams were determined from detailed linear and non-linear analysis(see Ref. 1 for more detail). Figure 2 give the total applied load versus the deflection response of the continuous span at approximately the mid span. According to AASHTO rating procedures, the maximum truck weight permitted on this bridge would be approximately 214 kN. However, as shown in Fig. 2 the total applied load was approximately 3980 kN (that is, the equivalent of having two rear axles of 7 HS20-44 AASHTO trucks side by side on the bridge).

Figure 3 shows the total applied load versus the deflection response of the simple span measured at mid span. For the simple span the maximum truck load permitted by AASHTO and that obtained from tests were approximately 224 kN and 2220 kN, respectively.

Following the ultimate load tests a series of non-linear analyses were conducted [1] to investigate the reasons for the observed large reserve strength for the two spans tested to collapse. Results of these analyses indicated that the large ultimate strength of concrete slab bridges could be attributed to (in order of importance) a) actual material properties of the reinforcing bars versus the assumed values in current rating procedures, b) influence of non structural members such as railing systems and c) strain hardening of reinforcing bars.

Reliability based Rating Procedure

As discussed briefly above, the results of experimental and analytical investigations indicated that concrete slab bridges possess large reserve strength which is not reflected by current rating provisions outlined by AASHTO. In this section, the general outline of a reliability based procedure currently being developed is provided.

Service load test results indicate that the three dimensional analyses could very accurately predict the load effect while the ultimate load test assisted in identifying the reasons for large available reserve capacity in concrete slab bridges, which is due primarily to the difference between assumed material properties used in the rating process and actual values. On the other hand, the parameters involved in rating could be divided into two general categories a) load effect and b) strength, such as flexural and shear capacities.

Load effects such as maximum moment could be determined using simulation. In this approach, the possible truck combinations (referred to as events) are assumed. Figure 4 shows six events considered. The frequency distribution for weight and axle spacing of trucks are obtained from available data. A weighting factor is then assigned to reflect the probability of occurrence of each event. The distribution for the headway, h, is assumed to be uniform. Maximum moment due to each event is calculated using the influence surfaces which is three dimensional. As a result, the distribution factor as currently used in the rating process is completely eliminated. Using the Monte Carlo Simulation (MCS), the frequency distribution for maximum positive and negative moments within the slab is then obtained. The development of the frequency distribution for flexural capacities of the concrete slab reflect actual material properties. Having the frequency distribution for both the load effect and resistance, the rating factor is then established. The procedure described above could be conducted without resorting to field testing of bridges. However, a version of this method is under consideration whereby the lower end of the frequency distribution for resistance is truncated using information gained from field testing. In this approach, a known load could be applied to the bridge. If the bridge exhibits satisfactory behavior under this load, then one has proven that flexural and shear capacities of the bridge could not be less than a certain value, therefore justifying truncation of the lower end of the frequency distribution. Consequently, the rating factor could be improved.

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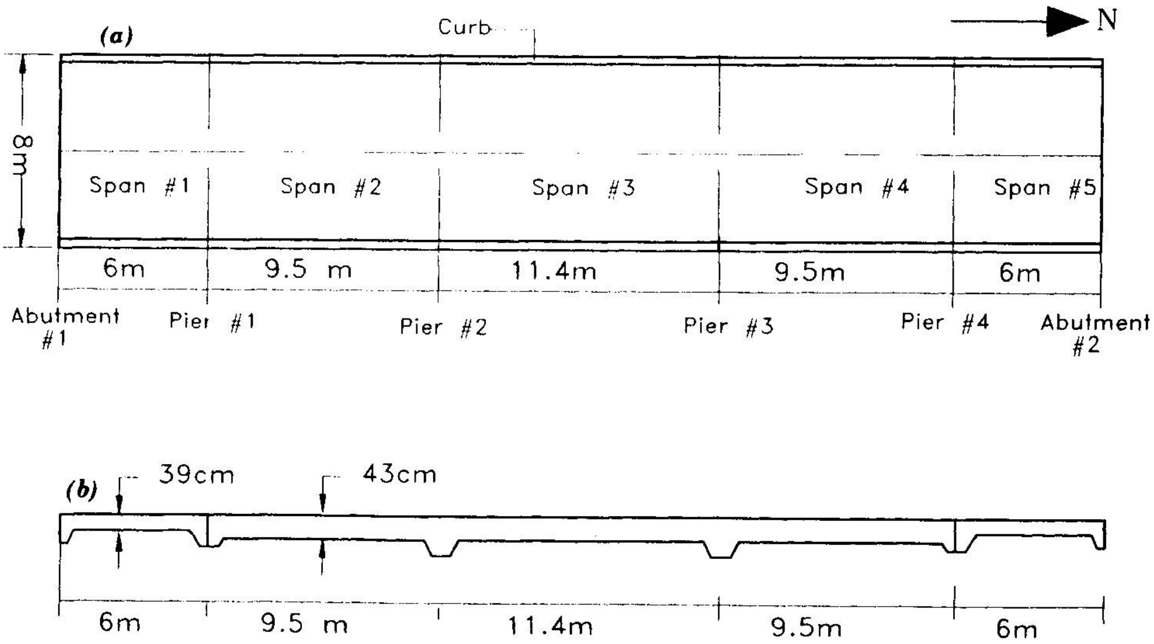

Fig. 1 - Dimensions of the bridge tested to collapse

Fig. 2 Load deflection response of the continuous span during the ultimate load test

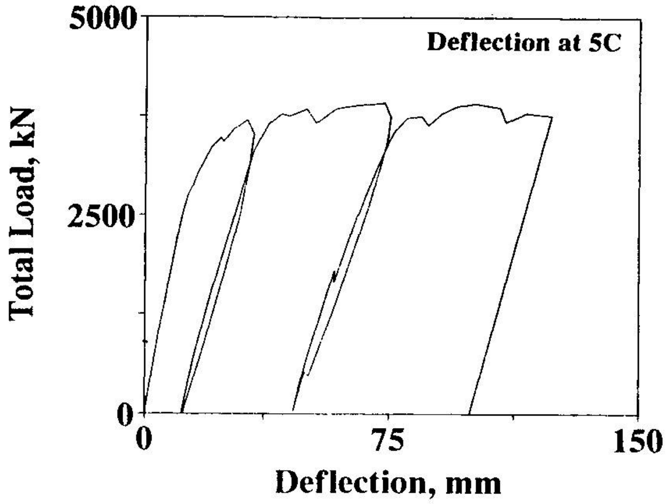

Fig. 3 Load deflection response of the simple span during the ultimate load test

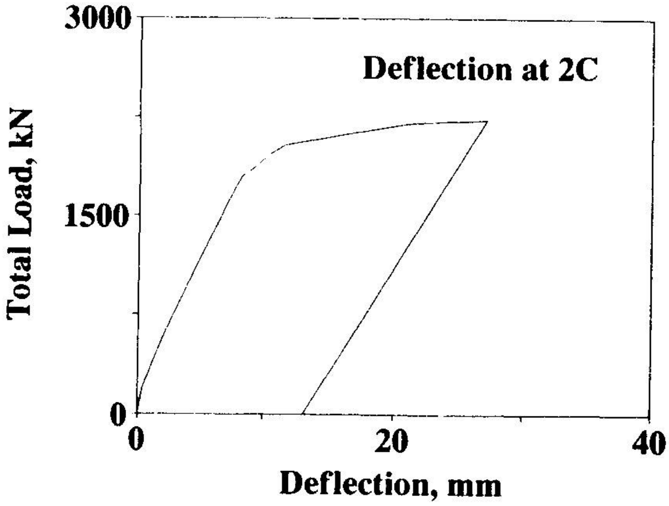

Fig. 4 Possible truck events considered in simulation process

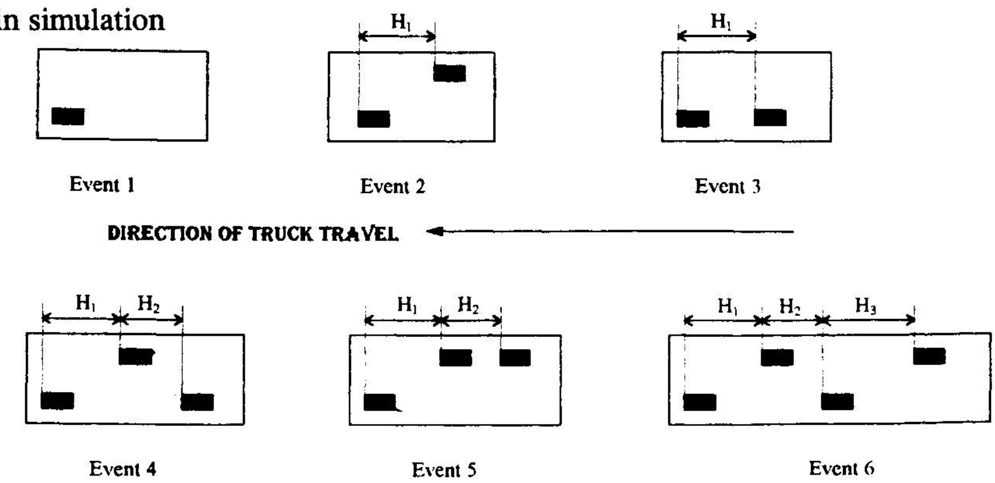

Table 1- Concrete Slab Bridges tested under elastic loads

Bridge Number	Length of First Span, m	Length of Middle Span, m	Length of Third Span, m	Skew Degree	Slab Thickness, cm	Year Constructed	Maximum Deflection, mm
1	9.6	12.8	9.6	30	39.4	1985	1.5
2	9.6	12.8	9.6	0	39.4	1985	1.6
3	6.6	9.0	6.6	0	33.0	1941	1.8
4	7.9	11.0	7.9	0	43.2	1967	2.0
5	9.1	12.3	9.1	0	40.6	1946	2.0
6	5.4	7.5	5.4	0	27.9	1965	0.6
7	5.3	7.3	5.3	30	31.8		0.1
8	8.4	10.8	8.4	10	35.6		0.4
9	11.0	14.6	11.0	25	43.2		0.7
10	5.8	7.9	5.8	35	25.4		0.7
11	5.4	7.5	5.4	30	29.2		0.5
12	9.1	12.2	9.1	50	38.1		0.5

Table 2- Comparison of the test and finite element analysis results

Bridge No.	Maximum Deflection at Mid Span, mm		Maximum Moment (m-kN/m)	
	Test	Three Dimensional Analysis	Three Dimensional Analysis	Two Dimensional Analysis
1	1.5	2.1	36.8	73.1
2	1.5	2.7	41.8	73.1
3	1.8	1.9	35.4	48.4
4	2.0	1.8	44.7	50.1
5	2.0	2.1	46.7	66.5
6	2.0	1.0	25.4	37.8