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Maintenance Inspection and Monitoring of Segmental Bridges

Contrôle de la maintenance et surveillance des ponts à voussoirs préfabriqués

Wartungs-Inspektion und Überwachung von Segmentbrücken

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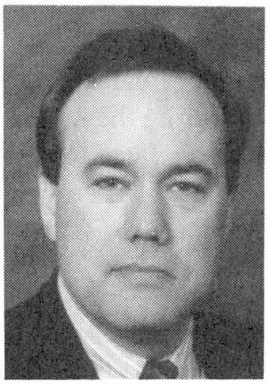

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SUMMARY

Dynamic load-testing of three retrofitted externally post-tensioned segmental bridges in the Washington Metropolitan Area Transit Authority heavy-rail system was conducted as part of a continuing integrity monitoring program. Results from dynamic testing are compared with benchmark values from previous testing. The development of a maintenance inspection manual for the structures is summarised.

RÉSUMÉ

Les essais de charge dynamique de trois ponts à voussoirs préfabriqués, renforcés par précontrainte extérieure appartenant au Réseau de transport public de la région de Washington, furent menés conformément au programme de surveillance continue des ouvrages concernés. Les résultats des essais dynamiques sont comparés aux valeurs-repères obtenues lors des essais précédents. L'élaboration d'un manuel d'inspection et de maintenance des structures y est aussi abordée.

ZUSAMMENFASSUNG

Dynamische Tragfähigkeitsproben von drei neu verstärkten äusserlich vorgespannten Segmentbrücken im Washington Areal Bahnsystem wurden durchgeführt als Teil eines kontinuierlichen Einheits-Überwachungsprogramms. Resultate von den dynamischen Proben wurden verglichen mit Massstabswerten von vorhergehenden Proben. Die Entwicklung eines Wartungsinspektionshandbuch für diese Brücken wird hier zusammengefasst.

1. HISTORY OF STRUCTURES

In the process of expanding Metrorail services further into Fairfax County, Virginia (USA), the Washington Metropolitan Area Transit Authority (WMATA) approved a value engineering change proposal in June, 1986, to substitute simply supported, single cell, external tendon, segmental box girders for three (3) continuous, twin cell, cast-in-place box girders. The substitute structures, collectively referred to as the J-2e bridge structures, include the Cameron Run Bridge (three spans of 33.5m, 39.6m, and 33.5m), Eisenhower Bridge (two spans each 33.5m), and the Van Dorn Street Bridge (two spans, each 30.5m).

Erection of the three bridge structures began during October , 1987. By February, 1988, significant cracking was observed in the diaphragm of all pier segments. In addition, three tendon deviator saddles of the Cameron Run Bridge were damaged during the longitudinal post-tensioning. Web concrete on the exterior of the Van Dorn Street structure was later reported to have delaminated at a pier segment.

Due to the observed distress in the J-2e bridge structures, an independent consultant evaluated the distress in the J-2e bridge structures and reviewed the proposed methods for repairing the structures. The consultant's report [1] identified and addressed four primary concerns related to the bridges, which reflected the concerns of WMATA at that time:

1) Cracking of pier-segment diaphragms and their strength
2) Cracking in tendon deviations and evaluation of retrofit measures
3) Delamination of web concrete in pier segments
4) Long-term behavior of bridge structures.

During the Spring and Summer of 1989, redesign of the damaged and undamaged tendon deviators were performed and a retrofit scheme for the pier segment diaphragms in two of the three bridges was designed. The pier-segment retrofit was initiated early in the Summer of 1989. In late 1989, based upon the recommendations of the independent consultant, additional modifications and additions to the retrofit of the pier segments was installed.

Based upon the performance history of the J-2e structures, the independent consultant recommended [1] that a series of static and dynamic load tests be performed on the structures. It was recommended that both a short- and long-term testing program be initiated to monitor the integrity of the J-2e structures.

As an outgrowth of those recommendations, a comprehensive static load test program and a follow-up dynamic load test were conducted the Fall of 1990 and Summer of 1991, respectively [2]. Based upon the favorable finding from the comprehensive short-term test program on the repaired structures, the WMATA Blueline which contains the J-2e structures opened for revenue operation on June 15, 1991.

Based upon favorable results from the short-term testing program, the original recommendation was relaxed from the prescribed annual inspection and second and fifth year comprehensive static load testing, to a program of annual inspection and less extensive testing during the second and fifth year of service for the purpose of monitoring the integrity of the retrofitted J-2e aerial structures.

Consistent with the previous recommendations, WMATA selected KCI Technologies, Inc. to conduct the second year revenue operation monitoring and inspection of the J-2e structures in 1993. The second year inspection and testing program examined the structural integrity of the aerial structures through a program of real-time dynamic testing consistent with the previous recommendations.

As a parallel task to conducting the second year testing and inspection program, a maintenance inspection manual was developed by KCI Technologies, Inc. for the J-2e structures. The development of this maintenance inspection manual was needed because of the uniqueness of the externally post-tensioned segmental construction of the J-2e structures in the WMATA bridge inventory, the unusual cracking experienced by the structures and the retrofit procedure implemented. The maintenance inspection manual was developed to provide guidelines and procedures for WMATA personnel to follow during their routine inspection of the J-2e structures.

2. SECOND YEAR DYNAMIC LOAD TEST PROGRAM

In the static load testing conducted in Fall 1990 [2], the J-2e structures were subjected to full design service loads including the effects of centrifugal forces, rolling forces and dynamic impact. This testing simulated the rare event of two fully loaded inbound and outbound trains passing over the same span simultaneously. The information taken during the initial static load testing serves as a benchmark for revenue operation monitoring of the J-2e structures at future points in its service life.

Analysis of the static load tests clearly indicated that the structures were behaving as linear-elastic, uncracked concrete structures. Thus, the basic premise by which the structures were evaluated for the second year testing program was that the behavior should be linearly proportional to the behavior observed during the static load test program and nearly identical to that measured during the first month of revenue operation since the trains generally had very light passenger loads, and generally only one train was crossing the bridge at any given time. The basic proportion of expected load during the second year monitoring was approximately 30% of that measured during the program of static load testing.

2.1 Instrumentation and Testing

Real-time measurements of the aerial structures as revenue trains passed over the span required the use of a high-speed field data acquisition system. A sampling rate of 100Hz was used in the testing since preliminary dynamic analysis revealed the predominant structural modes were well below 50Hz [3].

Real-time measurements were conducted for each bridge span independently. Field testing provided real-time strain readings at the bottom of the top flange and the top of the bottom flange. Accelerations were monitored at the longitudinal and transverse centerline of the midspan box segments.

During the testing program, elevation and tilt meter readings were taken on all spans. Elevation readings were used to determine the midspan camber of the bridge spans. Any significant decrease in camber from previously recorded benchmark values would signal a loss of effective prestressing, and thus a decrease in structural integrity.

2.2 Analysis Models

Based on the results from the static load test program, it was reasonable to assume that the measured structural behavior during the dynamic testing would also be linear-elastic and proportional. Accordingly, any significant loss of structural integrity would be signaled by a deviation from this premise.

It was anticipated that the principal structural response of a simply supported span subjected to a moving point axle load was from the fundamental mode of vibration [3]. Accordingly, a single-degree-of-freedom (SDOF) dynamic analysis model was used for general comparison purposes. An in-house computer program that calculates the response of a structural system using a frequency domain analysis was used to perform the analysis. The field monitoring during dynamic testing provided real-time strain readings at the bottom of the top flange and the top of the bottom flange. For evaluation purposes, an expression was derived for computing the strain versus time from the SDOF dynamic analysis. For the assumed shape function of

$$\phi\,(x) = \sin \frac{\pi x}{L},$$

the theoretical strain, ϵ, in the concrete box section at midspan as a function of time can be shown to be as follows:

$$\epsilon\,(x = L/2,\, t) = \frac{\pi^2 y}{L^2}\, Y(t)$$

where

y = distance from the neutral axis
L = span length
and Y(t) = displacement with time computed from the SDOF dynamic analysis.

2.3 Comparison of Test Results with Analyses

A comparison of longitudinal strain histories measured in the 1993 test program to the upper and lower bound strains measured during the short-term load testing program conducted in Fall 1991 is shown in Figure 1. The measured strain in the second year testing program is slightly greater (~ 3$\mu\epsilon$) than the upper bound measured during the earlier benchmark test program. In all probability, this is probably due to the increased passenger load on the trains compared to the virtually zero passenger load when the Blueline extension opened in 1991.

Figure 1 also shows the percentage (30%) of the strain measured in the static load test program in Fall 1990 with full design live loads. The measured strains are slightly higher than the 30% value which is based upon no passenger load. From a review of Figure 1 and examination of other data collected during the 1993 testing program [3], it is clearly evident that the response after two years of service is virtually identical to values established during the benchmark load testing program. This indicates that there has been no measurable loss of prestressing, which translates into no loss of structural integrity. Comparison of measured acceleration records also shows very close correlation to calculated values [3].

Midspan camber measurements for all three bridges have increased slightly with time (≈ 2.5mm to 5 mm). This slight increase in the J-2e structures is due to long-term creep effects and is normal. These measurements provide additional data that indicate that there has been no measurable loss of prestressing.

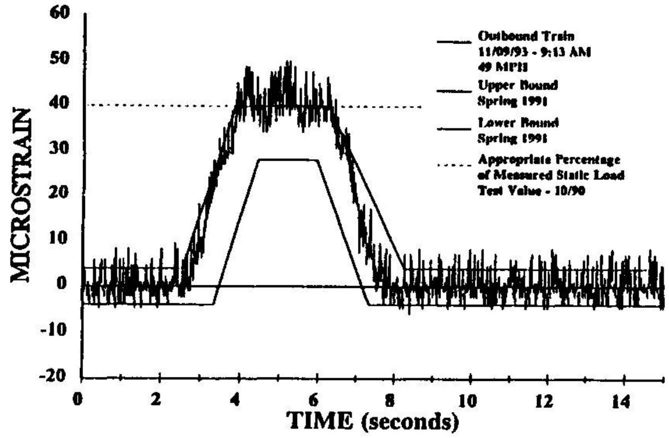

Fig. 1 Comparison of longitudinal strains measured on bottom of 39.6m Cameron Run span

3. MAINTENANCE INSPECTION MANUAL

3.1 Development of Manual

To insure long-term serviceability, durability and integrity, it is recognized that the J-2e structures would require a program of on-going maintenance and inspection. To the extent that KCI could determine, there are no known standards for inspection of existing post-tensioned concrete segmental bridges. Accordingly, the maintenance inspection manual was developed to provide WMATA inspection forces with appropriate guidance to insure the continued safety, long-term serviceability and durability of the J-2e structures [4].

3.2 Elements Addressed

The J-2e structures are currently one of only a few post-tensioned, segmental structures in the WMATA inventory. This, coupled with the unique nature of distress exhibited by various structural components and the attendant retrofit procedures implemented, necessitated a detailed structural element inventory be included in the maintenance inspection manual.

The maintenance inspection manual provides WMATA personnel with detailed description of the elements and their function in the structure. Element descriptions are backed up by photographs and drawings that identify the individual components to the inspectors. Also included in the manual are appendices which indicate the location of all existing cracks in the structures and the location of previously repaired items. These appendices serve as a condition benchmark for the structures. Guidelines are included in the manual that provide acceptable levels of variation from benchmark values for measured quantities such as midspan chamber.

3.3 Review Checklist/Element Rating

The procedure for inspection of the J-2e structures is laid out in a flow chart, as seen in Figure 2 [4], which identifies the items to be inspected at each structural element. Any observed defects are recorded on checklist sheets. Individual checklist sheets are used for condition assessments of existing repairs and for camber determination and bearing pad movement.

All elements assessed by the inspection team are assigned a numerical rating (0-5 scale, with 5 indicating good condition) to assess their condition. Upon completion of the inspection all items rated 3 or below must be reviewed by a WMATA Engineer. Additionally, the entire inspection package, including all checklists, must be reviewed by the Engineer to complete the inspection of the J-2e structures. This system will allow the inspection to be conducted by WMATA field personnel with a built in review by a WMATA Engineer.

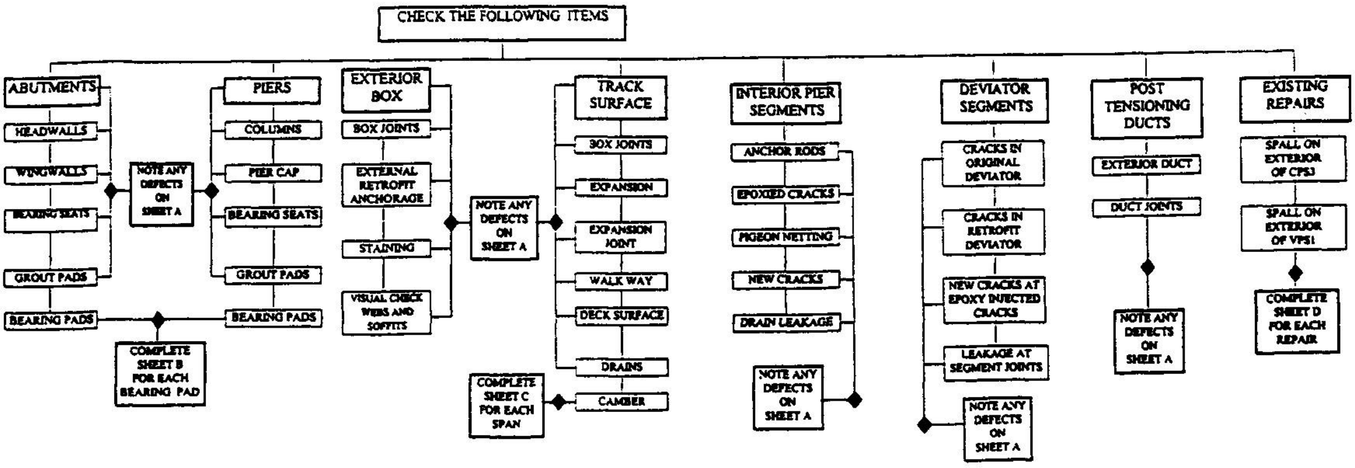

Fig. 2 Flowchart used for inspection of J-2e Aerial Structures

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