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Load Testing of an Old Bridge

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노후 교량의 하중 실험

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본 논문은 미시간주에 있는 약 70년된 강거더교의 입증하중 실험 결과를 제시한다. 교량의 강재 거더의 하부 플랜지는 심하게 부식되어 있다. 철근콘크리트 상판은 좋은 상태를 유지하고 있다. 하중 실험 이전에는 평가계수는 0.45에 불과하였다. 목표 입증 차선 모멘트는 법정 하중 한계의 약 1.7배로 계산되었다. 트레일러 위에 두 대의 군용 탱크를 재하에 사용하였으며 점진적으로 하중 재하를 위하여 지간 중앙을 향하여 이동시켰다. 지간 중앙 근처에서 변형률과 변위를 측정하였다. 목표 입증하중 모멘트는 어떤 이상징후도 없이 성공적으로 도달되었다. 따라서, 교량은 정상적인 트럭 교통하중을 지지하는 것이 안전하다고 결정되었다.

This paper presents the proof load test result of about 70 year old steel girder bridge in Michigan. The bridge is severely corroded in the lower flanges of steel girders. Reinforced concrete slab was in good condition. Rating factor before load testing was only 0.45. The target proof lane moment was estimated about 1.7 times the legal load limit. Two military tanks on trailers were used for loading and moved toward midspan for the incremental loading. Strains and displacements were measured near midspan. Target proof load moment was successfully reached without any indication of distress and bridge was found to be safe to carry the normal truck traffic.

Key words : bridges, bridge rating, nondestructive test, diagnostic test, proof load test

Introduction

About half of the nation's highway bridges are considered to be deficient and therefore, are in need of repair or replacement. Half of these are functionally obsolete and others do not have required strength. To avoid high costs of rehabilitation the evaluation must accurately reveal the present load carrying capacity. In order to estimate the inherent extra capacity in bridges, several nondestructive load tests have been in use for many years. A recent NCHRP report by Lichtenstein (1993) provides guidelines and procedures to standardize nondestructive load testing of bridges.

This paper presents the proof load test results of about 70 year old steel girder bridge in Michigan. Several concrete and steel girder bridges in Michigan were tested as part of a study sponsored by Michigan Department of Transportation (MDOT). In Michigan, the legal gross vehicle weight of an 11-axle two unit truck (154 kips) is more than twice the HS20 design loads (72 kips) or more than five times the H15 design loads (30 kips). Therefore, for all pre-war bridges designed with H15 or less, design load should be carefully evaluated.

Bridge Description

The tested bridge is about 70 years old with 10 steel girders and reinforced concrete slab. It is a simply supported single span structure located on state route M-50 over Grand River in Jackson County, Michigan, with ADT(Average Daily Traffic) of 11,900. It is 48 ft long and 45.3 ft wide. The reinforced concrete slab thickness is 6.5 in with quite thick concrete wearing surface of 6 in and bituminous surface of 6.7 in. It was designed as a non-composite section. The cross-section and plan view of the bridge are shown in Figs. 1 and 2. The design compressive strength of concrete was estimated as 2,000 psi and the yield stress of steel girders as 30,000 psi, from the Michigan Bridge Analysis Guide (MDOT, 1983). Lower flanges of steel girders were found heavily corroded during initial inspection. Web was also corroded at some places but the damage was found to be insignificant. There was not much corrosion in steel girders near the supports and reinforced concrete slab was found to be in good condition.

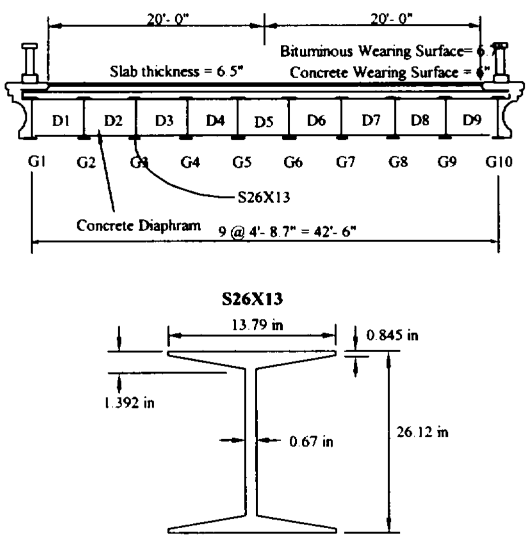


Fig. 1. Cross-section of the bridge.

Preliminary Analysis

Rating factors for H15 and other legal trucks were calculated based on the Michigan Bridge Analysis Guide (MDOT, 1983). Preliminary rating by MDOT indicated a H15 rating of 29 kips and the operating rating for two-unit 11 axle truck was 147 kips. The moment capacity was reduced only by 5 percent, based on visual inspection of the deterioration.

However, before proof load test, each bridge component was carefully inspected. Lower flanges of steel girders were found heavily corroded at several locations including the midspan. In some girders the actual remaining thickness of lower flange was only 40 percent of the original thickness. Accordingly, the moment capacity wasreduced by 25 percent, which would further reduce the inventory and operating rating factors. Shear capacity and serviceability conditions were found satisfactory. New rating factors for H15 and other trucks were calculated considering the reduction in capacity due to deterioration and listed in Table 1. Rating factor for two unit 11 axle truck was only 0.45. The unintended composite action could not be taken into consideration for capacity calculations. Therefore, to determine the exact moment carrying capacity the proof load testing was found necessary.

Table 1. Rating factors

Load Testing	Inventory Rating	Operating Rating		
	H15	1 unit 6-axle (42 tons)	2 unit 11-axle (77 tons)	3 unit 11 axle (77 tons)
Before	0.60	0.65	0.45	0.51
After	1.97	1.40	1.00	1.08

Two analytical models were considered using computer program SECAN (Jaeger and Bakht, 1989). In the first model, the interaction between deck and steel girder was ignored and the section was considered to be non-composite as in the original designs. Second model was prepared considering the possibility of unintended full composite action of deck and girder. The maximum analytical deflections under target proof load were 0.471 in and 0.244 in for non-composite and composite models, respectively.

Instrumentation

Since the moment at the mid-span was considered to be the critical limit state, it was decided to place strain transducers on girders near mid-span. The strain was measured in the lower flanges of steel girders. Displacements of the girders at midspan were measured using LVDTs. Strain and displacements in the exterior girders were not measured because they were expected to be very small due to the presence of concrete parapet and the fascial concrete on exterior face of these girders. Strain gages and LVDTs were also placed at quarter points on selected interior girders (Fig. 2).

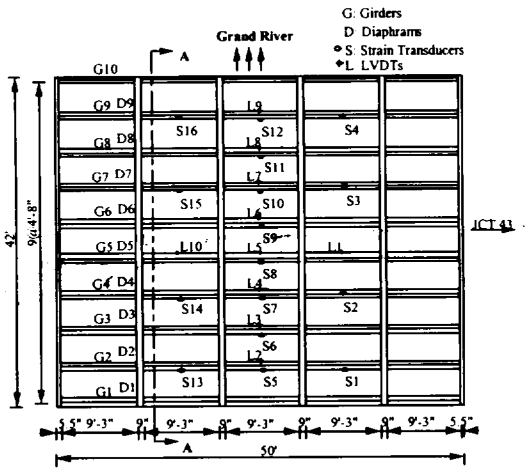
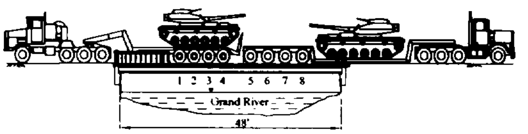


Fig. 2. Plan view of the bridge.

Load Application

Selection of proof load level was based on the Manual for Bridge Rating through Load Testing (Lichtenstein, 1993). The 11 axle two unit truck with gross vehicle weight of 154 kips is the governing legal load in Michigan for bridges with span greater than 20 ft. Midspan moment caused by this truck was calculated. According to the manual, the moment due to legal load was multiplied by the factor of safety 1.4. These moments were then increased by 15 percent since only one lane was to be loaded at a time. It was further reduced by 5 percent as the bridge was considered ratable, and there were no hidden details. To incorporate the dynamic impact, the factored legal load moments were multiplied by the impact factor. Previous studies by Nassif and Nowak (1995) have shown that the dynamic amplification of loads is lower for heavy trucks and the simultaneous occurrence of two trucks side by side. Therefore, the impact factor was taken to be 1.12 instead of 1.28 as suggested by the manual (Lichtenstein, 1993). The target proof lane moment was 1,585 kip-ft, which is about 1.7 times that from two unit 11 axle truck.

For proof load testing of a bridge, usually a truck is placed on the bridge. Then, load is applied to the truck in steps until the target proof load is reached or any sign of distress is observed. In previous similar tests by Florida DOT (Pinjarkar, 1988) and Michigan DOT (Juntunen and Isola, 1995) concrete barrier blocks, each weighing 5 kip, were used to load a flat bed truck standing still on the bridge. Due to the very high allowable legal load in Michigan, too many concrete blocks were required, specially for larger spans. A special vehicle is required to carry such a heavy load, which makes the proof load testing slow as well as expensive. Therefore, an alternative loading scheme was applied. Two M60A2 military tanks, each weighing about 60 tons, placed on flat-bed trailers were used. The tanks were provided by the Michigan National Guard. Only four rear axles of these trailers were used to load the bridge. Trailers facing away from the bridge were moved from support to the midspan in several steps to increase the midspan moment. The trailer configurations and the corresponding axle weights are shown in Fig. 3. The combination of two trailers was used to achieve the full target load. Loads were also moved in transverse direction to three different locations namely upstream, center and downstream. Strains and displacements were recorded for each load case and for the cases when there was no load on the bridge, before and after the test. Fig. 3 shows both trailers and tanks on the bridge at the maximum load position.



Axle Number	1	2	3	4	5	6	7	8
Spacing		4'	4'	4'	7'-9"	4'-4"	4'-4"	4'-4"
Axle Weight (kips)	39	38	28*	28	21	20	21	21

Fig. 3. Loading configuration.

Results

Maximum lane moment of 1,562 kip-ft was achieved during the test. The load test results are shown in Fig. 4. The analytical deflections from composite slab-girder-interaction model were in good agreement with experimental deflections. Load was well distributed between the girders. The experimental deflections were linearly proportional to the applied lane moment. The strains in lower flanges of steel girders were also plotted with applied lane moment. No noticeable sign of inelastic behavior was observed. New rating factors calculated after the test are listed in Table 1. Due to the unintended composite behavior of slab and girder, considerable increase in rating factors was observed. Target proof load moment was success- fully reached without any indication of distress and bridge was found to be safe to carry the normal truck traffic.

Conclusions

As expected, the bridge was stiffer as compared to the analytical models. A steel girder bridge with a concrete slab, which is designed as a non-composite section, can be expected to behave as a composite

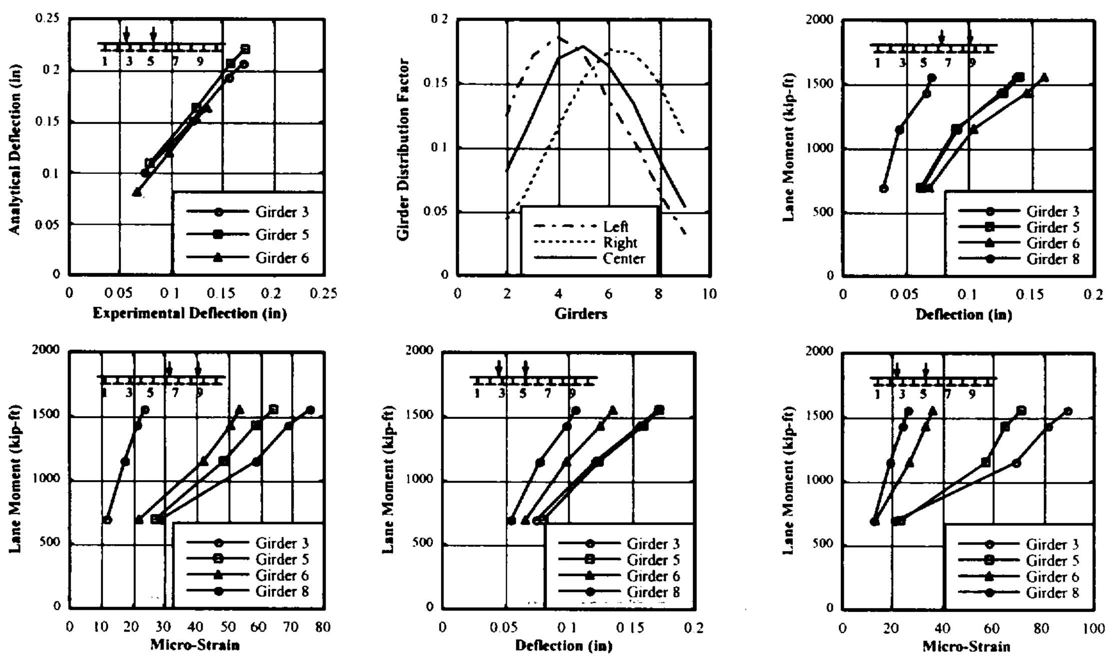


Fig. 4. Load test results.

section under smaller loads. However, even for the loads as high as proof load, composite action is observed. This effect increases the moment carrying capacity significantly. The extra safety reserve in a bridge can be checked by proof load test to avoid expensive repair or replacement. Use of concrete blocks for proof load testing can be limited because of time, considerable effort and risk involved in placing very heavy loads on the bridge. However, use of tanks was found to be a fast, efficient and economical way to conduct proof load testing of bridges with moment capacity as the critical limit state.

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