Load Testing of Bridges in Malaysia

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ABSTRACT

Jabatan Kerja Raya (JKR) initiated a Bridge Capacity Study in November 1993 to institute a methodology to evaluate bridges on the federal routes. A sample of 200 bridges was selected for his study. Load testing of bridges forms a major part of this study. This paper describes in detail the results of an evaluation and a load test carried out on a buckle plate bridge. Buckle Plate bridges are one of the oldest type of bridges in Malaysia and constitute 15% of the bridges on the federal routes. The evaluation of the test bridge gave a rating of 0.35 for 85% LTAL loads. A load test was carried out by instrumenting the structure and loading the structure using two heavily loaded trucks. Each test trucks weighed 708 kN gross with back dual axle weight of 460 kN. The test result showed that the gravel/premix layer acts compositely with the steel beam/buckle plates. The buckle plates retained its shape and the geometry was unchanged under heavy axle loads by the stiffened effect of the gravel/premix layer. The measured moments on the steel girders were found to be much lower than those calculated from grillage analysis. The present test results was compared against an earlier failure test carried out on a buckle plate structure by JKR. This comparison showed that the failure load capacity of the present structure can be about two to three times the applied test truck loads. The load test also showed that the buckle plate structure can be evaluated by allowing 30 to 50 percent overstress in the beam elements.

1.0 Introduction

There are about three thousand bridges along the federal routes in Peninsular Malaysia. Many of these bridges were built soon after World War II and they may not have the capacity to carry the current traffic loads. Jabatan Kerja Raya (JKR) carried out an axle load study between 1987 and 1989([1]. In this study the axle weights of trucks on the federal routes were measured and these data were compared against the design load capacity of bridges. This lead to the formulation of the Weight Restriction Order 1989[2] (WRO) for trucks legal weights and a JKR design load provision[3] for designing new bridges. The study also classified the bridges into the following four categories: (i) Sub-standard Axle Loads (SSAL), (ii) Short Term Axle Loads (STAL), (iii) Medium Term Axle Loads (MTAL), and (iv) Long Term Axle Loads (LTAL). A bridge management program has also been implemented for the inspection and evaluation of bridges and to rehabilitate or to replace older bridges according to priorities. In line with this bridge management program, a new study called *Bridge Capacity Study* was initiated in November 1993 to institute a methodology for load capacity eveluation of bridges. A sample of 200 bridges was selected for the study. Load testing of some bridges to determine bridge load is a major part of the study and is being carried out by a Canadian-Malaysian consulting group and funded by the World Bank.

This study is divided into three phases and the first and second phases of the study are completed. The first phase involved the development of a methodology[4] to evaluate and load test the bridges. The legal loads, permit loads, legal load violations and the design and evaluation loads in United States of America, United Kingdom, Canada and Malaysia were reviewed. A comparison was made to select the appropriate live loads to evaluate the bridges. Other aspects investigated were the limit states, load factors and resistance factors to be used for evaluation, and the level of inspection required for evaluation. The load testing aspect of the study required selecting suitable trucks to simulate the evaluation live loads and selecting suitable instrumentation and data gathering system. In the second phase, 23 representative bridges were evaluated based on the methodology developed in the first phase. In this phase, geometric data were gathered by field measurements, the bridge members were inspected for evaluation, and the evaluation carried out using data from available drawings and field data. Four bridges were load tested to establish their capacity. In the third phase, the tested methodology would be applied to the rest of the bridges.

This paper describes in detail the results of an evaluation and a load test carried out on a buckle plate bridge under the study. The buckle plate bridge constitutes about 15% of the bridges on the federal routes. They are the oldest type of bridge on the federal route constructed with steel stringers and thin curved plates (called buckle plates) bolted to the beams. The deck is formed generally by 200 mm to 400 mm gravel fill and overlayed with premix riding surface. Many of these bridges were categorised to have Sub-standard Axle load capacity and require replacement. However, these bridges were carrying the current traffic loads without any sign of distress. Hence it was of much interest to load test a buckle plate bridge.

2.0 Bridge Details

This bridge is located north of Banting, Selangor on Route 5 and was built in 1955. The structure is 6.05 meters wide and was widened in 1989 with two new buckle plate structures of approximately 3.5 wide each on both sides of the bridge. The bridge has a simply supported span. The span length is 6.6 meters for both the new and the old structures. Structural drawings for this bridge were not available and most of the structural details were obtained from field measurements. The cross section of the bridge is shown in Figure 1. Inspection of the bridge showed that it is generally in a good condition. The steel beams and the buckle plates were in good condition, and the substructures were in a moderate to good condition.

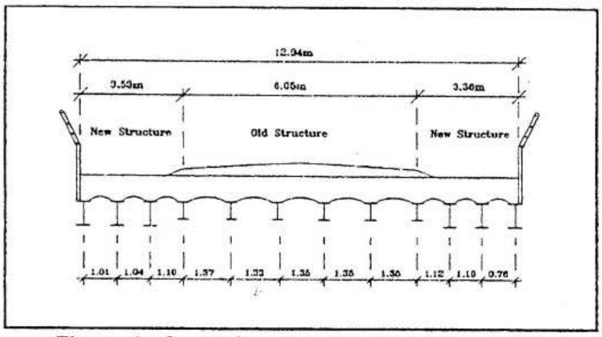


Figure 1: Cross Section of Buckle Plate Bridge

The structure was evaluated according to the method described in the Pilot Project Methodology report and for both the LTAL and SV loadings. The evaluation was carried out by assuming that only the steel beam elements carry the loads without any transverse distribution. Calculation details for the evaluation are given in a report[5]. A summary of the evaluation results are given in Table 1.

Structure	Dead Load	S.I.Dead Load	LTAL	SV-20	Total	
					LTAL	SV-20
Old structure						
Max bending	10.2	71.2	392	396	475	478
Max shear	6.6	43.2	231	265	281	315
New structure						
Max bending	11.2	55.8	307	317	374	384
Max shear	6.8	33.8	181	211	222	252

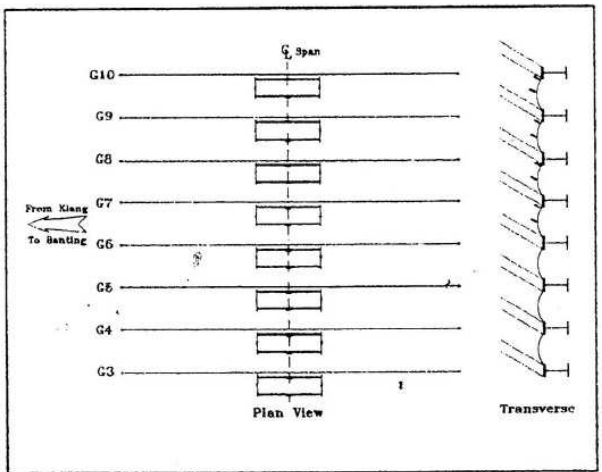
Structure	Factored Forces		Factored Resistance	Beam Rating	
	LTAL	SV-20		LTAL	SV-20
Old structure					
Max bending	475	478	203	0.3	
Max shear	281	315	307	1.1	
New structure					
Max bending	374	384	503	1.4	
Max shear	222	252	584	3.0	

Table 1: Beam Ratings for LTAL and SV Loads

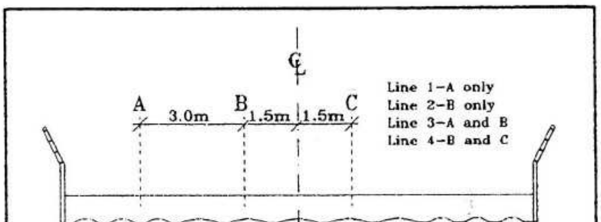
According to the recommendations made in the Pilot Project Methodology report, bridges with a rating factor of 0.85 or more for the full LTAL loads can be considered adequate to carry the Malaysian legal loads. The bridge capacity for controlled movement of SV loads is also reported in terms of the number of SV units. The evaluation yielded a rating factor of 0.35 for 85% LTAL loads for the old structure and it can carry 5.9 units of SV loads. The new structures have a rating factor of 1.65 for 85% LTAL loads and it can carry 27.3 SV units. It is noted that the traffic loads are carried by the older structure whereas the new structures are being used as shoulders.

3.0 Load Testing

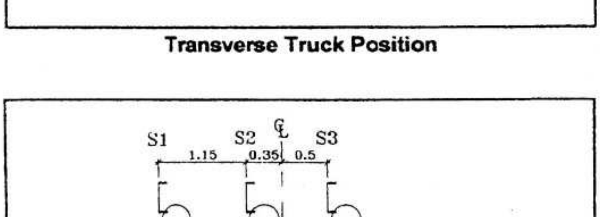
The bridge was instrumented with foil strain gauges which were connected to a TML data logger. The location of the strain gauges used are given in Figure 2 below.



Instrumentation Details



Transverse Truck Position



Longitudinal Truck Position

Figure 2: Instrumentation Details and Truck Positions

Load Level	No. of Blocks	Axle Weight, kN					Truck Gross
		1	2	3	4	5	
1	0	57	44	41	38	40	220
2	12	70	88	88	108	108	460
3	16	70	88	88	148	148	542
4	18	70	90	90	167	167	584
5	20	70	90	90	187	187	624
6	22	70	90	90	207	207	664
7	24	70	90	90	227	227	700

Table 2: Truck Loads and Axle Loads

Trucks used for the load test were two Scania trucks with low bed trailers (low loaders). Load positions of the test trucks and the truck axle loads for various truck load levels used for the test are given in Figure 2 and Table 2, respectively. The transverse and longitudinal positions of the trucks were selected to produce maximum load effects on the old and the new bridge spans. Two tonne concrete blocks were used to load the trucks. Additional details on the selection of the type of strain gauges used and the selection of trucks for load testing are given in another report[6].

Initially the trucks loaded with twelve concrete blocks were passed over the bridge and strain values for each truck load position were recorded on the data logger. The measured strain values for critical members were compared against the theoretical values during testing. A plot of the truck axle loads versus member strains at critical locations was made to check for possible non linear behavior of the structural and the test was repeated. Although the rating factor was very low for the old structure, it was able to carry the two trucks, each with a back dual axle weight of 460 kN.

4.0 Test Results

A plot of the truck axle loads versus the measured strains on selected gauges is shown in Figure 3. This plot shows that the axle load-strain relationship is linear. Hence the structure remained within the elastic limits for the applied truck loads.

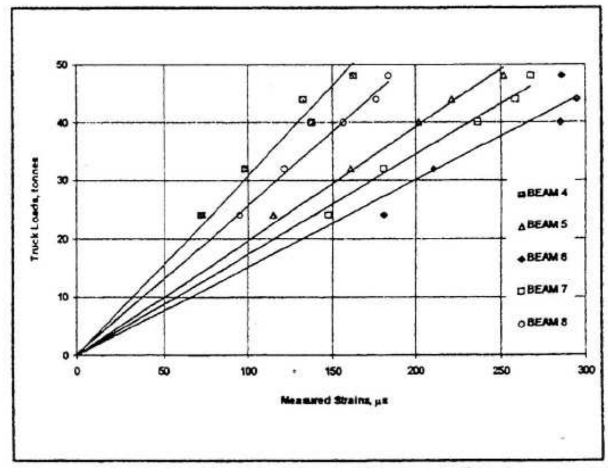


Figure 3: Truck Loads vs Measured Strains

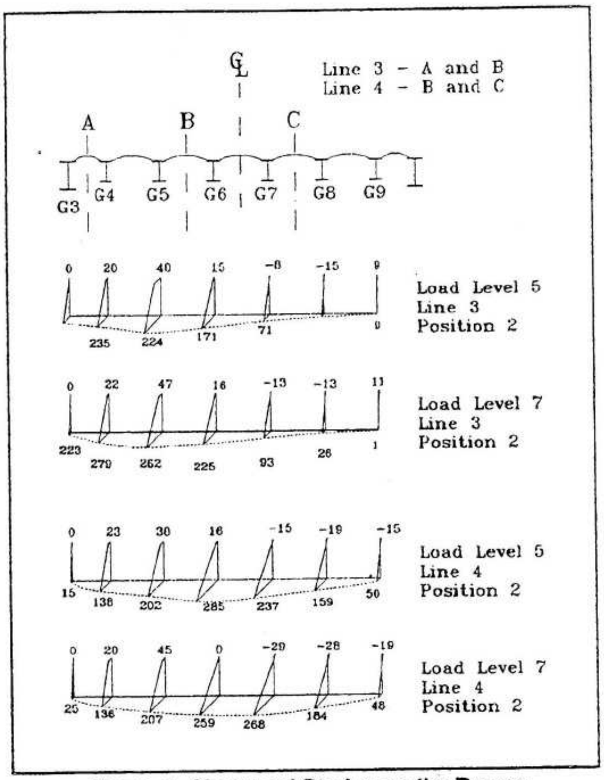


Figure 4: Measured Strains on the Beams

The strains measured on the steel beams and the buckle plates for Load Levels 5 and 7, and for truck locations at transverse Lines 3 and 4, longitudinal Position 2 are plotted and shown in Figure 4. From these plots the following conclusions can be drawn:

i. The beams act compositely with the buckle plates, the gravel and premix riding surface placed above the buckle plates,

ii. For the level of loads applied the beams neutral axis are generally above the top flange, and

iii. There is considerable lateral load distribution between adjacent beams similar to those usually observed on a reinforced concrete slab on steel girder bridge.

The above results suggest that the gravel and premix provide longitudinal and transverse stiffness to the buckle plate and the girder. The results also show that the gravel and premix top layers provide adequate stiffening effect to the buckle plate to make the full width of the buckle plate stiff (even though the buckle plate is thin and would buckle under unstiffened conditions) and to act compositely with the girder. Therefore, it is proposed to analyze the buckle plate structure using the buckle plate as deck element. Due to a lack of suitable analytical method to include the possible longitudinal composite action between the steel beam/buckle plate and the gravel/premix deck, the beneficial effects provided by the gravel/premix deck on the structure are not considered in the proposed analysis.

The bridge was reanalyzed using grillage analogy with the buckle plates being considered to act as deck elements. The resulting moments for the applied truck loads obtained from analysis were compared to the moments obtained from the test results. The actual moments from the load test were computed using strain values measured from the bottom flange of the steel beams. The section modulus was calculated for the combined section of the steel beam and the buckle plate element. A comparison of these moments for truck locations at Lines 4, Position 2 is shown in Figure 5. These figures show the following:

i. The shape of the transverse moment distribution curves for the measured moments and the theoretical moments are generally similar.

ii. The measured moments are much lower than the theoretical moments calculated for the same loading.

iii. The ratio of theoretical moments to the measured moments generally varies between 2.0 and 3.0.

iv. At least 30% to 50% overstress could be allowed on buckle plate structures to obtain realistic evaluation results.

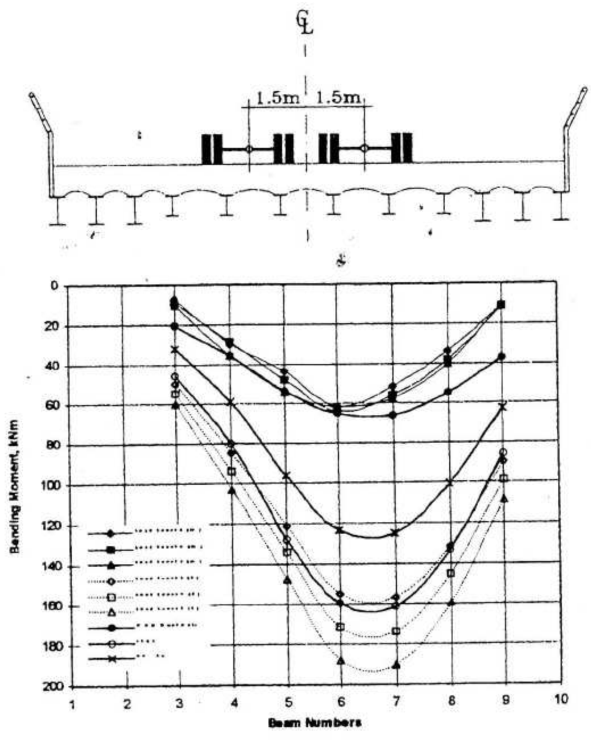


Figure 5: Comparison of Moment Induced by Various Loadings

The reasons for the above findings that the measured moments are much lower than the theoretical moments are as follows:

i. The bridge acts as a system and achieves greater load distribution.

ii. Bearing restraints on the beams, longitudinal arching action provided by the deep fill on a short span bridge are not accounted for in the current analysis.

iii. The interaction between the gravel/premix layer and the steel beam/buckle plate is not modelled in the theoretical analysis.

4.1 Comparison with Evaluation Loads

A comparison is also made between the moments induced by the applied truck loads and the unfactored load effects due to: (i) the WRO dual axle, (ii) the LTAL loads, and (iii) 20 units of SV loads. The comparison is also shown in Figure 5. It is clear that the load effects due to the unfactored LTAL and 20 units of SV loads are lower than the test truck load effects. For this bridge the load effects due to 20 units of SV loads is lower than the LTAL loads. The maximum factored load effects due to LTAL loads is 243 kNm (1.5 x 162 kNm), whereas the maximum load induced by the trucks at Load Level 7 is 192 kNm. The maximum induced stress by the test trucks (Line 4, Load Level 7) on the girders were only 53.6 MPa (268µs x 0.2 = 53.6), which was a fairly low stress compared to the yield stress of 230 MPa. This is further illustrated by a plot of the theoretical moment vs the measured and theoretical strains for girder 7 as shown in Figure 6. As evident the total measured strain for Level 7 loads was 400 µs and the yield strain for 230 MPa steel is 1150 µs. This means that the structure can carry almost twice the applied Level 7 truck loads before the girder attains the yield stress. It is assumed, however, that localized failure of the deck or girder and instability would not set in as the girder reaches the yield stress. Since the difference between the factored LTAL moment and the induced moment under Level Load 7 was only 51kNm and the above comparison shows that the structure has ample capacity to carry this additional moment, it is concluded that the structure has adequate capacity to carry the factored LTAL loads. Similarly, the structure has adequate capacity to carry the 20 units of SV loads. The factored effects of the WRO dual axle are well below the unfactored effects of LTAL loads and the test truck loads applied.

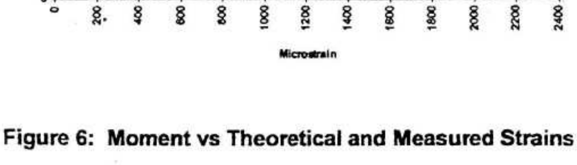


Figure 6: Moment vs Theoretical and Measured Strains

4.2 Comparison with Previous Load Test Results

To estimate the level of additional safety factor available on buckle plate structures, the results of an earlier failure load test[7] carried out by JKR on a buckle plate structure was studied. This bridge had a 7 meters span and its beams were spaced at approximately 1.2 meters. The buckle plate was filled with mass concrete (note: the previous bridge discussed above has gravel and premix for fill). Steel beams on this bridge showed moderate corrosion, whereas beam in this test were in good condition. This bridge was loaded up to a total load of 275 tonnes before the inception of failure. It was not loaded to total collapse. After the inception of failure and the loading removed approximately 40% to 50% of the deformation remained permanent. The load deformation diagram obtained for this test is reproduced in Figure 7. The bridge was loaded with concrete blocks stacked within the span of the bridge. Since only 40% to 50% of the deformation remained permanent, this confirms that the bridge was not taken to full failure or in other words the structure could have taken additional loading.

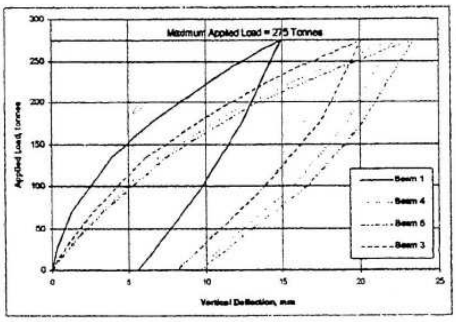
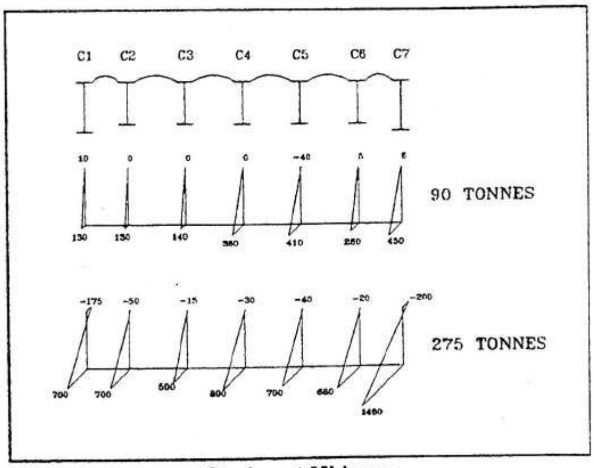
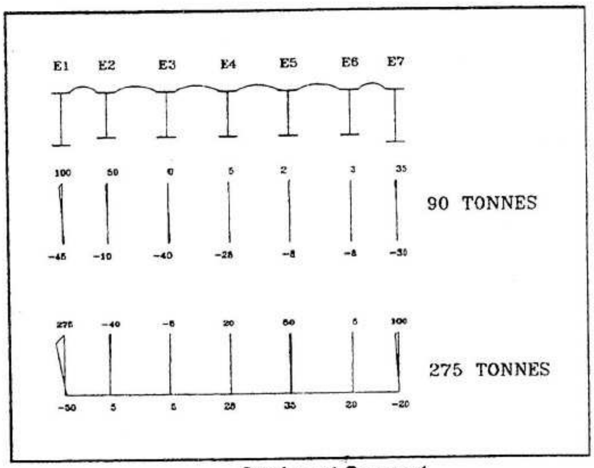


Figure 7: Load Deformation Diagram

The beams were strain gauged at the midspan and near the supports. A plot of the strain values at the mid span and near the supports for applied loads of 90 tonnes and 275 tonnes are shown in Figure 8. The strain diagrams on this test for the 90 tonnes loads are almost similar to those on the above test for the maximum applied test truck loads. These diagrams show that there exist considerable composite action as the neutral axes were well above the beam centroid. It can also be seen that the transverse distribution of the loads is good. At the supports, the beams show compression at the bottom flanges and some tension at the top flanges. This is mainly due to end restraint effects provided by the bearings. The edge beams show much higher tensile strain at the top and this may be due to torsion produced by unbalanced loading. At the applied load of 275 tonnes, one of the edge beams was strained to 1500µs at the bottom flange. Other beams exhibited strains of 500µs to 800µs at the bottom flange. The top flange of thesebeams showed compressive strains varying from 15µs to 200µs.



Strains at Midspan



Strains at Support

Figure 8: Strains on Bridge Load Tested to Failure

Although the neutral axes for the beams were at a lower level than the neutral axis for the 90 tonnes load level, a reasonable level of composite action still existed (at or near failure loads) between the deck and the steel beams as shown by the strain distribution. At the supports, the strains at both the top and bottom flanges were tensile indicating that the beams were restrained by the bearings and by the deck elements for the forward movement of the beams under heavy midspan loads. The following useful observations could be made from this test:

i. The magnitude of strains (maximum 285μs) induced by the test trucks weighing 93 tonnes on the present study test were almost similar to those observed (maximum 410μs) on the failure load test with a 90 tonnes load, the differences in magnitude may be attributed to beam size, span length and beam condition,

ii. The load distributing characteristics are similar for both the bridges and hence both the structures show similar behaviour under 90 tonnes load,

iii. The bridge load tested to failure was able to carry a load of 275 tonnes at the inception of failure and this is about 2.8 times the 93 tonnes load applied to the structure under consideration, and

iv. The bridge did not show localized failures or instability until the applied load of 275 tonnes.

v. This comparison suggests that the present bridge could have a failure load capacity that is at least 2 to 3 times higher than the test truck loads.

5.0 Conclusions

The conclusions that can be drawn from this load test are as follows:

i. The gravel/premix fill layer acts compositely with the steel beam/buckle plate.

ii. The buckle plate retains its shape and keeps its geometry under heavy axle loads by the stiffening effects of the gravel/premix layer.

iii. The test results show that the gravel/premix layer and the steel beam/buckle plate act as a stiff deck to achieve a good lateral load distribution of the applied truck loading on the bridge.

iv. The measured moments are much lower than the theoretical moments calculated from the grillage analysis.

v. The existing buckle plate structure could be evaluated by allowing 30 to 50% overstress on the beam elements.

vi. The failure load capacity of the structure can be about two to three times the test truck loads applied.

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