Strength Evaluation and Load Testing of Bridges in Malaysia.

T. Tharmabala, Daniel Toutant - Dessau International Ltd, Laval, Quebec, Canada
Ku Mohd Sani, and Roshid Salleh - Bridge Unit, Roads Branch, Public Works Dept., Malaysia

ABSTRACT: Malaysia has about four thousand bridges on its federal routes. Most of these bridges were built soon after second world war and the capacity of these bridges to carry the current traffic loads was in doubt. A pilot project to carry out theoretical strength evaluation and load testing of two hundred bridges was initiated recently and the project is currently being carried out by a Canadian-Malaysian Consulting group. This paper describes the work carried out in the first and the second phase of the project. The first phase investigated the live loads, limit states, load factors, resistance factors, level of inspection and proposed the methodology to be adopted to evaluate the bridges. Load testing aspect of the study required selecting suitable test trucks, instrumentation and data gathering system. In the second phase the bridges were evaluated using the proposed methodology and four bridges were load tested. The evaluation and the test results showed that most of the bridges which were thought to be of lower live load capacity have the reserve strength to carry the current axle loads.

1. INTRODUCTION

Malaysia has one of the fastest growing economy in the world and is undergoing rapid industrial development. This industrial development requires a safe and efficient transportation network. Adequate load carrying capacity of bridges is essential to take the heavier truck traffic generated by the recent industrial growth. Malaysia has about four thousand bridges in its federal routes and most of these bridges were built soon after World War II. At that time the aim was to provide a basic transportation link between population centres and many of these bridges do not have complete design details or have the design capacity to carry the present traffic loads[1]. Before the 1980's, Malaysia did not have a systematic maintenance and rehabilitation program for these bridges. However, Malaysia has now implemented a Bridge Management System and as part of this endeavour, Public Works Department, Malaysia (JKR) has initiated a project for evaluating 200 bridges and to load test selected bridges on the federal routes. This project was awarded to a Canadian-Malaysian Consulting group and is funded by the World Bank.

This project is divided into three phases and the first and second phases of the project have been completed. The first phase involved the development of a methodology[2] by which the bridges were evaluated and load tested. A comparison was made between the legal loads, permit loads, legal load violations and the design and evaluation loads in United States of America, United Kingdom, Canada and Malaysia. This comparison was applied to determine the appropriate live loads to be used for evaluating 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 project required selecting suitable trucks to simulate the evaluation live loads and selecting suitable instrumentation and data gathering system. In the second phase, 20 representative bridges were selected from the sample of 200 bridges for evaluation based on the methodology developed in the first phase. For this part of the work, geometric data was gathered by field measurements, bridge member conditions were inspected for evaluation, and the evaluation carried out using data from available drawings and appropriate field data. In addition, four bridges which were either substandard or represented a specific bridge type were load tested to establish their actual capacity. In the third phase, the above methodology is being applied to evaluate the rest of the bridges in this study. The project is due to be completed by April 1995.

This paper describes some of the conclusions made in the first phase of the Study and the results of the strength evaluation and load testing of bridges carried out in the second phase of the Study.

2. STRENGTH EVALUATION

2.1 Design and Evaluation Loads

Due to historical links, Malaysian bridges were designed using British Standard specifications. Bridge design loads used in United Kingdom and that adopted by Malaysia since 1922 is summarised in Table 1. Malaysian bridges designed between 1945 and 1972 used lower load intensity than that specified in the British Standards. For example HA Loads and no HB vehicle or 2/3 HA was used on older minor roads (now part of federal routes) during this period. The bridges designed between 1972 and 1990's used HA Loads, but HB vehicles were placed on the centre line of the bridges only. Most of the bridges selected for this study were built before 1972 and hence designed for HA or 2/3 HA loads.

Public Works Department, Malaysia (JKR) carried out an Axle Load Study (ALS) between 1987-1989. In this Study the axle weights of trucks using federal routes were measured and these data were compared against the design load capacity of bridges. The major outcome of the Study was that the bridges on federal routes were grouped into four categories:

i) Sub-Standard Axle Loads (SSAL),
ii) Short Term Axle Loads (STAL),
iii) Medium Term Axle Load (MTAL), and
iv) Long Term Axle Loads (LTAL).

SSAL bridges required immediate replacement or some were with calculated capacities less than STAL but otherwise servicable. STAL bridges are designed for HA loads or reduced

HA loads and not checked for HB loads.

U.K. STANDARDS	MALAYSIANS STANDARDS
1922 - Wheel Trains Used 1932 - HA Load i.e. UDL + Knife Edge Load + Wheel Load to simulate local effects 1949 - HB load was introduced 1954,1972 - HA Load + 2 nos. 112.5kN wheels for local load effects , HB Load with fixed wheel spacing 1978 - HA Load + One 100kN wheel for local effects, HB with variable spacing	Upto 1942, most design done in U.K., therefore to U.K. Standards. 1945-1972 - HA Loads, No Abnormal(HB) Loads, 2/3 HA on Minor Roads. 1972 - HA + HB Loads. HB to travel on Bridge Centreline, 25% overstress not used. 1992 - JKR Loading, similar to HA + 20 Axle Special Vehicle with 200kN Axles

Table 1 : Bridge Loadings

STAL bridges have the capacity which matched the current Axle Weight regulations. Most of the bridges in the present study are STAL category. MTAL bridges are required to have the capacity to carry the next increase in the legal axle weights. MTAL bridges are generally designed for HA and HB loads on bridge centreline or short span bridges with HA design but passage of heavy vehicles have effectively proof loaded the bridges. LTAL bridges are those that satisfy the long term axle loadings (or bridges designed to the proposed LTAL loads), so that the future transportation system is not constrained by bridge capacity. It was thought that most of the older bridges will not be able to carry these axle loads, except for small bridges with span less than 2.5m or narrower bridges that were designed for HA loads and HB vehicles along bridge centreline.

The Axle Load Study lead to the formulation of a Weight Restriction Order in 1989 for truck legal axle weights. Existing regulation is based on STAL axle loads. In the near future it is to be increased to MTAL axle loads and in the long term to LTAL axle loads. Both STAL and MTAL was defined in the Axle Load Study report. The axle load limits for LTAL was not given in this report. It is assumed that limits similar to Construction and Use vehicles in UK will be used, since the derivation of LTAL loads were based on UK practice and the maximum axle weights measured during the axle load study. A comparison of the Malaysian Legal axle loads and that used in UK, Canada, and USA is given in Table 2. Comparison of the legal loads show that Malaysian single axle load limit are comparable to other jurisdictions. The tandem and triple axle load limits are some what lower. The gross weights for trucks with shorter axle spread are similar. It was found that for trucks with axle spreads longer than 10 meters, the gross vehicle weights are (up to 10 tonnes) lower than the trucks in other jurisdictions.

The Axle Load Study also lead to the formulation of Malaysian design loads. This loading consisted of UDL load similar to HA loads but on a fixed lane width of 2.5 metres, and a special vehicle with 20 axles and 200kN maximum on each axle. Malaysia does not have specific loadings for bridge evaluation. UK has a Specification BD21/84[3] which requires bridges to be evaluated for HA type loads and there is no need to consider HB loads. In this study, an attempt was made to find a representative loads for evaluating the Malaysian bridges. A comparison of factored load effects on bridges having spans 0 to 50 metres, and different number of bridge lanes were made, see Figure 1. The effects of legal loads and legal load violations observed in various jusridictions was also considered in the above comparison. This comparison showed that in most cases the LTAL load effects are higher than the load effects caused by the design loads used in UK, Canada and USA. Based on this comparison it was recommended that bridges in Malaysia be evaluated for 0.85 LTAL loads. Bridges satisfying 0.85 LTAL load are expected to sustain axle loads similar to Construction and Use vehicle limits in UK or legal loads described in other jurisdiction like Canada or USA. It was also conlcuded that the special vehicle loads need not be used for evaluation and this criteria is on par with the procedures adopted in UK, Canada or USA.

Country	UNITED KINGDOM			UNITED STATES			CANADA			MALAYSIA			
Axle Vehicle Type	No. of Axles	Axle Spread (m)	Max. Weight (Tonnes)	No. of Axles	Axle Spread (m)	Max. Weight (Tonnes)	No. of Axles	Axle Spread (m)	Max. Weight (Tonnes)	No. of Axles	Axle Spread (m)	Max. Weight (Tonnes) STAL	MTAL
Single	1	-	10.5	1	-	9.07	1	-	9-Single 10-Double	1	-	6-Single 10-Double	7-Single 12-Double
Tandem	2	1.02	16.3	2	1.18	15.4	2	1	15.4	2	1	14.0	-
	2	1.85	20.3		1.86	20.3		>1.8	19.1		1.2	15.0	-
											1.5	16.0	19.0
Triple	3	1.4	18	3	2.4	15.4	3	2.0	19.5	3	1.8	16.0	-
		2.7	22.5		to	19		3.0	22.4		2.4	17.0	-
					3.7	24.5		4.0	25.8		2.6	18.0	22.0
						29.9		>4.8	28.6				
Vehicle	2	-	17	5	33.5	36.2	3	8.0	26.3	2	2.6	16.0	19.0
	3	-	24.4	>5	33.5	40.8	6	17.7	52.4	3	4.0	20.0	26.0
	4	-	32.5	>5	33.5	47.8	7	19.7	60.5	3	6.6	21.0	33.0
	5	>10.6	38	>5	33.5	53.1	8	23.0	63.5	4	6.8	25.0	-
	6	>10.6	38	>5	33.5	69.8				4	8.5	25.0	-
	7	>10.6	38							3	8.5	26.0	30.0
										4	10.7	32.0	38.0
										5	11 3	35.0	40.0
										6	13.1	38.0	44.0

Table 2 : Comparison of Allowable Axle Loads and GVW

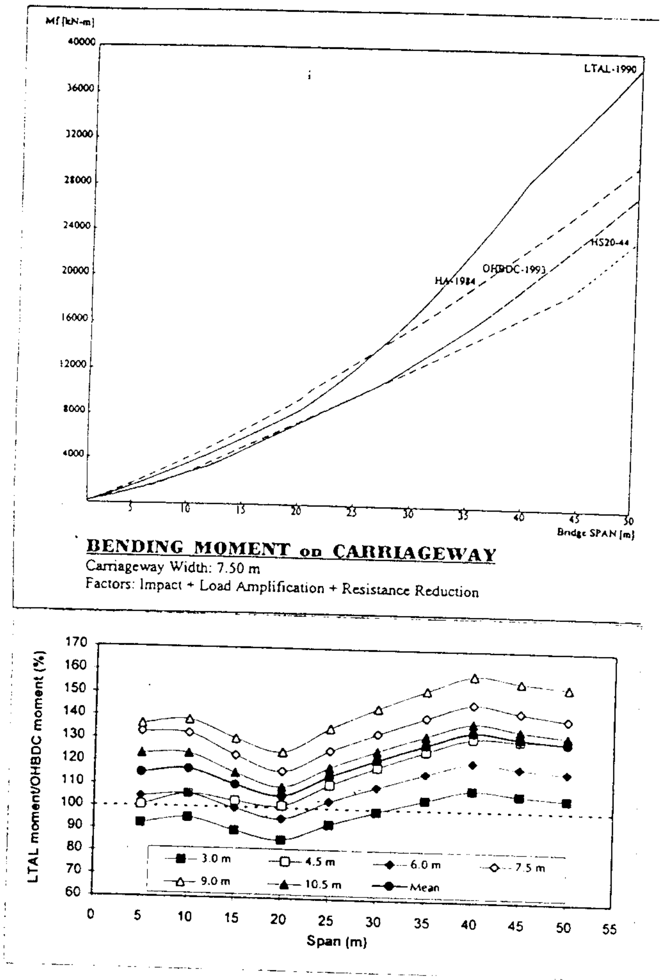

Fig. 1 : Comparison of Factored Load Effects

2.2 Evaluation Results

For evaluation, the bridges were analysed using grillage analysis for various combination of factored load effects. The member resistance were calculated using British Standard Specifications. Inspections for evaluation were carried out with the intention that the member resistance may have to be adjusted to account for member deteriorations. However, it was found that most of the bridges were generally in good condition and did not require adjustments to the calculated strength. The evaluation results are summarised in Table 3 and this shows that most of the bridges can carry 0.85 LTAL loads. However, bridge No. 7 had a poor design detail at the half-joints which give the bridge an ELR rating of zero for live loads. Otherwise the bridge has a good rating of 0.96 for 0.85 LTAL loads and 12.40 SV units. Recommendation were made to carry immediate repair of the half-joints and is now being carried out. It is noted that the original rating for most of the bridges obtained during the Axle Load Study is STAL. They are now found capable of carrying 0.85 LTAL loads i.e. Long Term Axle Load or axle loads equal to Construction and Use vehicles specified in U.K..

No.	Bridge No.	CAPACITY			Load Test Rating
		ALS Rating	ELR[#]	SV Units	
1	FT 001 + 149.2	STAL	0.35	5.00	*
2	FT 001 + 364.7	STAL	1.06	17.50	*
3	FT 001 + 528.7	STAL	1.13	10.20	
4	FT 002 + 372.0	STAL	0.94	16.70	
5	FT 003 + 365.5	STAL	1.95	38.20	
6	FT 003 + 373.5	STAL	0.91	23.70	
7	FT 003 + 710.0	-	0/0.96	0/12.40	
8	FT 005 + 328.5	STAL	0.99	13.30	
9	FT 005 + 342.9	SSAL	0.62	6.90	
10	FT 005 + 356.6	STAL	1.02	18.50	
11	FT 005 + 402.0	STAL	1.11	12.70	
12	FT 005 + 409.2	SSAL	0.35	5.90	*
13	FT 005 + 414.5	STAL	1.13	18.20	
14	FT 005 + 442.4	STAL	1.86	22.30	
15	FT 005 + 448.8	STAL	0.98	14.00	*
16	FT 005 + 465.6	STAL	0.74	3.70	
17	FT 005 + 469.8	STAL	0.65	8.80	
18	FT 005 + 495.5	STAL	1.14	17.80	
19	FT 008 + 006.2	STAL	1.47	31.50	

ELR : Evaluation Live Load Rating

* Capacity greater than : i) 0.85 LTAL
ii) SV 20 Loads

Table 3: Evaluation Summary

3.0 LOAD TESTING

3.1 Test Procedure

The aim of load testing in this Study is to proof load test the bridges, ie. to apply loading that will create factored 0.85 LTAL effects and then to measure the bridge responses using strain gauges and deflection transducers. Two Scania trucks loaded with concrete blocks were used to load the bridge. The loading is considered static type, because the trucks were moved on the bridge at a very low speed. Each truck can carry a maximum of 25 concrete blocks; one concrete block weighs 2 tonnes; and at the maximum load level the rear tandem axles develops 230 kN each. This is almost three times the legal loads allowed by the WRO Load Limits or generally develops 60 to 80 percent of factored 0.85 LTAL load effects on bridges with 5-10 metre span. The truck axle and gross loads for various truck load levels are given on Table 4. Although the capacity of the bridge may determine the final load level applied on a test bridge, most of the bridges tested were able to carry the full truck load.

Load Level	No. of Blocks	Axle Weight, kN					Gross Weight
		1	2	3	4	5	
1	0	57	44	41	38	40	220
2	12	70	88	88	108	108	462
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	704

Table 4 : Axle Loads and Truck Loads

3.2 Test Results

A brief description of the test result for a buckle plate bridge is given here and the load capacity of the other three bridges obtained by load test is given in Table 3. Complete details of the test results are available in individual reports prepared for each of the bridges tested in this Study.

The buckle plate bridge consists of longitudinal steel beam stringers, bolted with curved plates, filled with gravel which is then paved with asphalt. The bridge was built in 1955 and was widened on both sides in 1989. The original structure is 6.05 meter wide and the wideneded structure is approximately 3.5 metre wide on both sides. The span length is 6.6 meters. Structural details were obtained by site measurements and are shown Figure 2. The steel beams and the buckle plates were in good condition. The structure evaluated for 0.85 LTAL load showed that the older bridge has a rating fo 0.35 while the new bridge has a rating of 1.65. It is noted that the traffic loads are carried by the older structure whereas the new structures are being used as shoulders.

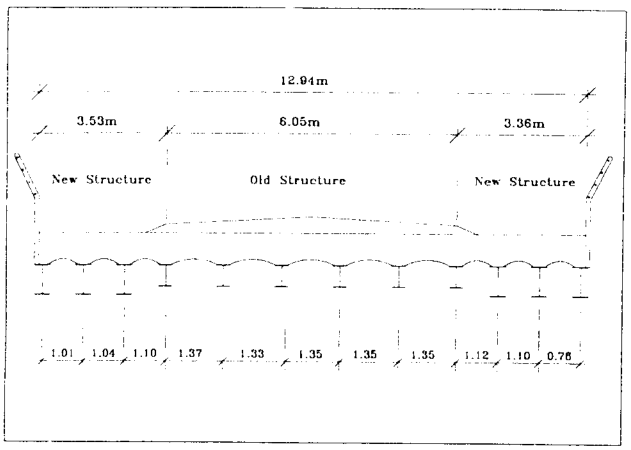

Fig. 2 : Cross Section of Buckle Plate Bridge

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 3.

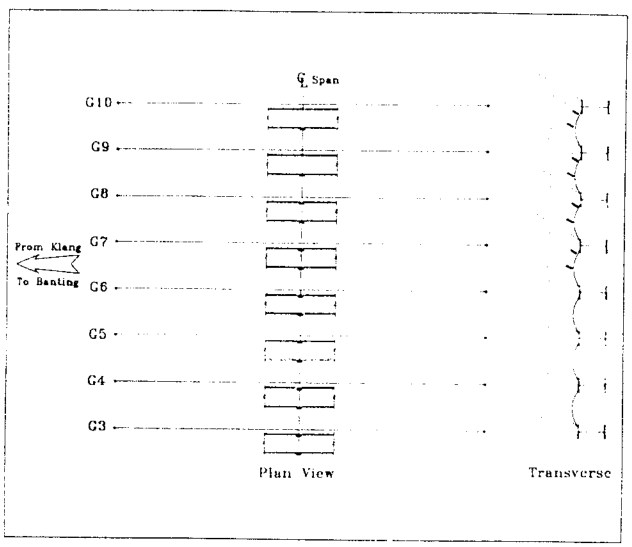

Fig. 3 : Instrumentation Details

The bridge was then load tested using the two Scania trucks with load positions as shown in Figure 4 and applying the loads as in Table 4.

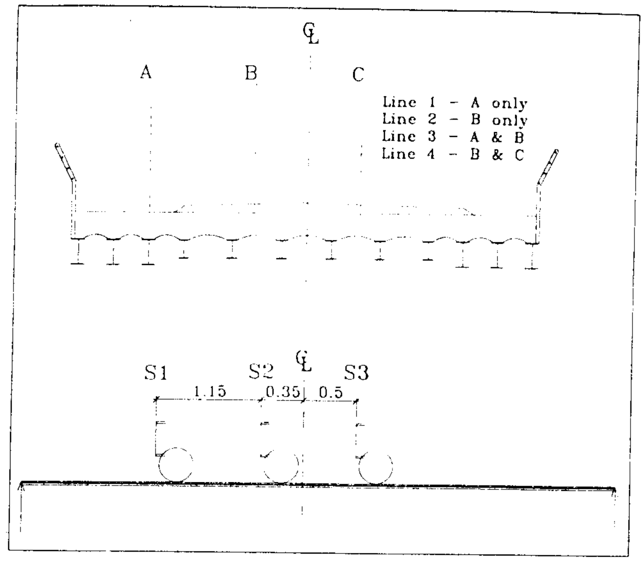

Fig. 4 : Truck's Tranverse and Longitudinal Positions

The strains measured on the girders and the buckle plate remained linear until the applied final load levels. Typical strains measured on the steel beams and the buckle plate are shown in Figure 5.

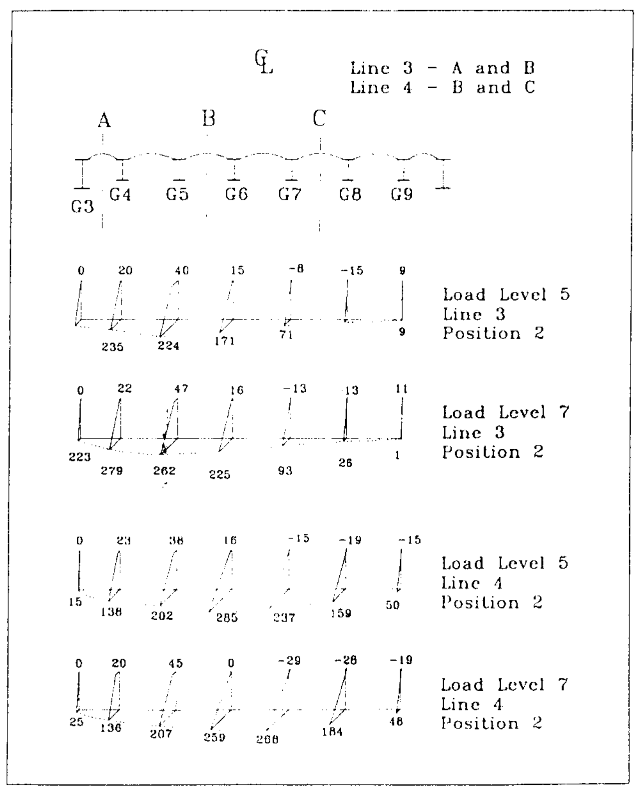

Fig. 5 : Typical Measured Strains on Beams

From the plots the following conclusions can be made:

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

2) For the load levels applied the neutral axis of the beams were generally above the top flange, and

3) There is considerable lateral load distribution between adjacent beams similar to those usually observed for reinforced concrete slab on steel girder bridges.

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 0.85 LTAL loads, and (iii) 20 units of SV loads, see Figure 6 .

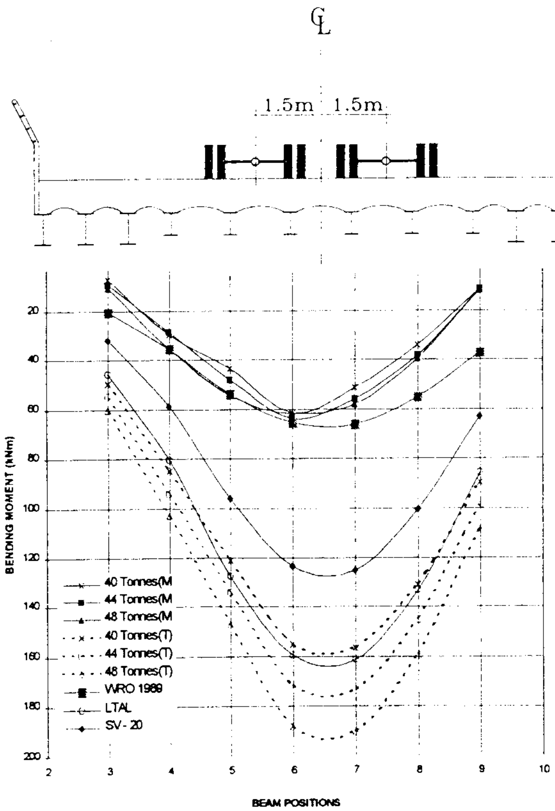

Fig. 6 : Comparison of Moment Induced by Various Loadings

It is observed that the load effects due to the unfactored 0.85 LTAL and 20 units of SV loads is lower than the test truck load effects. The maximum factored load effects due to 0.85 LTAL loads is 207kNm (1.5 x 0.85 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 (268 μs x 0.2 = 53.6), which was a fairly low stress compared to the yield stress of 230MPa. A plot of the theoretical moment vs the measured and the theoretical strains for girder 7 is shown in Figure 7. As evident the total measured strain for Level 7 loads was 400 μs and the yield strain for 230 MPa steel in 1150 μs. This means that the structure can carry more than twice the applied Level 7 truck loads before the girder attains

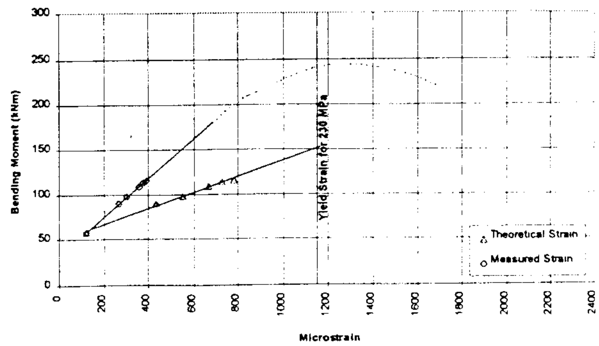

Fig. 7 : Moment vs Theoretical and Measured Strains

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 0.85 LTAL moment and induced moment under Load Level 7 was only 15.0 kNm and the above comparisons shows that the structure has ample capacity to carry this additional moment, it is concluded that the structure can carry the factored 0.85 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 factored effects of 0.85 LTAL loads and the test truck loads applied.

4. CONCLUSIONS

The conclusions made from the first and second phase of the study are as follows;

i. Malaysian bridges can be evaluated for 0.85 LTAL loads. Special vehicle having 20 axles and 200kN per axle line need not be used for evaluation of older bridges.

ii. Bridges with adequate capacity to carry factored 0.85 LTAL loads will be able to carry the Long Term Axle Load requirements of Malaysia.

iii. Evaluation of bridges for 0.85 LTAL loads showed that many bridges that were considered sub-standard for Long Term Axle Loads are now found to be adequate. Inspection of bridges carried out for evaluation also showed that the bridges are generally in good condition.

iv. Load test carried out on four bridges showed that the bridges are able to carry substantially higher axle loads than that estimated by theoretical analysis. Bridges with theoretical ELR rating as low as 0.35 were found to be adequate to carry the 0.85 LTAL loads.

5. REFERENCES

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