DEVELOPING AN ASSESSMENT CRITERION FOR MEDIUM-TERM AXLE LOAD BRIDGE CAPACITY IN MALAYSIA

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Abstract

The assessment of a bridge structural capacity can be determined by computing the Evaluation Load Rating (ELR) of the bridge. In a study carried out in 2007, the structural capacity of some 400 federal bridges in East Malaysia had been evaluated based on Long-Term Axle Load. The bridges were subsequently rated in terms of ELR_{LTAL}. This paper describes an assessment criterion for Medium-Term Axle Load bridge capacity to comply with Weight Restriction Order (WRO) 2003 which allows a legal load limit of 12 tonnes single axle load and 44 tonnes Gross Vehicle Weight. The assessment was aimed at upgrading some Federal Routes in East Malaysia from List II to List I of the Second Schedule of WRO 2003, thus, allowing them to carry higher vehicular loads.

Keywords: Bridge capacity assessment, medium-term axle load, evaluation load rating.

1.0 INTRODUCTION

In 1985, The Government of Malaysia had commissioned a National Axle Load Study for bridges in Peninsular Malaysia [1]. The objective of the study was to assess the load-carrying capacity of the existing bridge stock with respect to the motor vehicle regulations in the country. Three axle load policies were recommended in the National Axle Load Study, i.e., Short-Term Axle Load (STAL), Medium-Term Axle Load (MTAL) and Long-Term Axle Load (LTAL) policies. Each policy represents the bridge loading standard expected of the bridges and thus the vehicle loads that can be allowed to run on the bridges. LTAL policy was meant for new bridge design. STAL and MTAL were interim policies to regulate the vehicle fleets in the country with respect to the capacity of existing bridge stock.

The Road Transport Department (RTD) Malaysia implemented the STAL policy upon completion of the study through the enactment of Weight Restriction Order (Federal Roads)

(WRO1989) [2]. The WRO (1989) was gazetted under the Malaysia Roads Transport Act and the maximum allowable axle load limit for a single axle is 10 tonnes, whereas the maximum Gross Vehicle Weight (GVW) allowed is 38 tonnes (corresponding to a 6-axled vehicle with a wheelbase of at least 13.1m).

In July 2003, the RTD implemented the MTAL Policy through Weight Restriction Order (WRO) 2003 [3]. The order allowed an increase in the legal load limits to 12 tonnes single axle load and 44 tonnes GVW for some of the major Federal routes in the Peninsula and these routes are listed in List I of the Second Schedule of WRO 2003. However, bridges in Sabah, Sarawak and Labuan were, not included in the National Axle Load Study and their load-carrying capacities were not known. As a result, all federal routes in the three states were placed in List II of the Second Schedule which enlists routes that are allowed to carry vehicles corresponding to STAL policy.

A recent study carried out by PWD [4] in 2011 was aimed to assess the possibility of upgrading some Federal Routes in Sabah, Sarawak and Labuan from List II to List I of the Second Schedule of WRO 2003, thus, allowing a higher load limit on the routes.

2.0 ASSESSMENT OF EXISTING BRIDGE CAPACITY

Logically, the decision to upgrade a particular route from List II to List I shall be preceded by first determining the load-carrying capacity of the bridges to ensure that they are capable of carrying the vehicular loads complying with MTAL Policy.

Indeed, the load-carrying capacity of the federal bridges in Sabah, Sarawak and Labuan had been evaluated in another study [5] conducted between the year 2004 and 2007. The load-carrying capacity of the bridge was assessed based on the ratio of the available resistance of a member to the effect of the live loading. The ratio is known as Evaluation Load Rating (ELR). The ELR (based on LTAL) of some 400 federal bridges in Sabah, Sarawak and Labuan had been determined in the previous study [5].

2.1 Evaluation Load Rating

The assessment of a bridge capacity, based on Long-Term Axle Load (LTAL), is determined by computing the Evaluation Load Rating (ELR) of the bridge from Eqn.(1) [6].

$$ELR_{LTAL} = \frac{R^* - D^*}{L^*_{LTAL}} \qquad \text{.............. Eqn.(1)}$$

where

R^* is the factored resistance of a member, D^* is the factored dead load effect on a member, the difference gives the live load capacity of a member. L^*_{LTAL} is the factored live load effect on a member due to LTAL.

An ELR is calculated for each structural component of the bridge and the smallest ratio becomes the governing rating for the bridge. Similarly, the assessment of a bridge capacity, based on Medium-Term Axle Load (MTAL), is determined by computing the Evaluation Load Rating (ELR) of the bridge from Eqn.(2).

$$ELR_{MTAL} = \frac{R^* - D^*}{L^*_{MTAL}} \qquad \text{.............. Eqn.(2)}$$

2.2 LTAL and MTAL Loading Intensity

2.2.1 *Long-Term Axle Load*

The Long-Term Axle Load (LTAL) is based on the "JKR Specification for Bridge Live Loads (DJ 1/89)" [7]. The LTAL comprises a uniformly distributed load (UDL) which varies with loaded length and knife edge load (KEL) of 100 kN per 2.5m fixed-width notional lane. LTAL was developed in the National Axle Load Study [1] in 1987 based on the United Kingdom's vehicle fleet used in the development of BD21/84. The LTAL was a design load for new bridges in the 1990s in Malaysia and that the motor vehicle limits derived from it would not be particularly restrictive. The uniformly distributed load for LTAL is given by the following expressions, where L is the loaded length and w is the load intensity per 2.5 m notional lane width.

i. $L \leq 20m$ $\quad w=176.8\ (1/L)^{0.6}$

ii. $20m < L \leq 40m$ $\quad w=(93.6+4.16).(1/L)^{0.6}$

iii. $40m < L \leq 50m$ $\quad w=260\ (1/L)^{0.6}$

2.2.2 *Medium-Term Axle Load*

The Medium-Term Axle Load (MTAL) was developed in the Axle Load Study [1] for capacity evaluation of existing bridge stock in Malaysia. MTAL was developed based on vehicle fleet intended for use in Malaysia. The MTAL comprises a uniformly distributed load (UDL) and knife edge load (KEL) of 100 kN per 2.5m fixed-width notional lane. A comparison between LTAL and MTAL uniformly distributed load, for loaded lengths up to 50m, is shown in Figure 1.

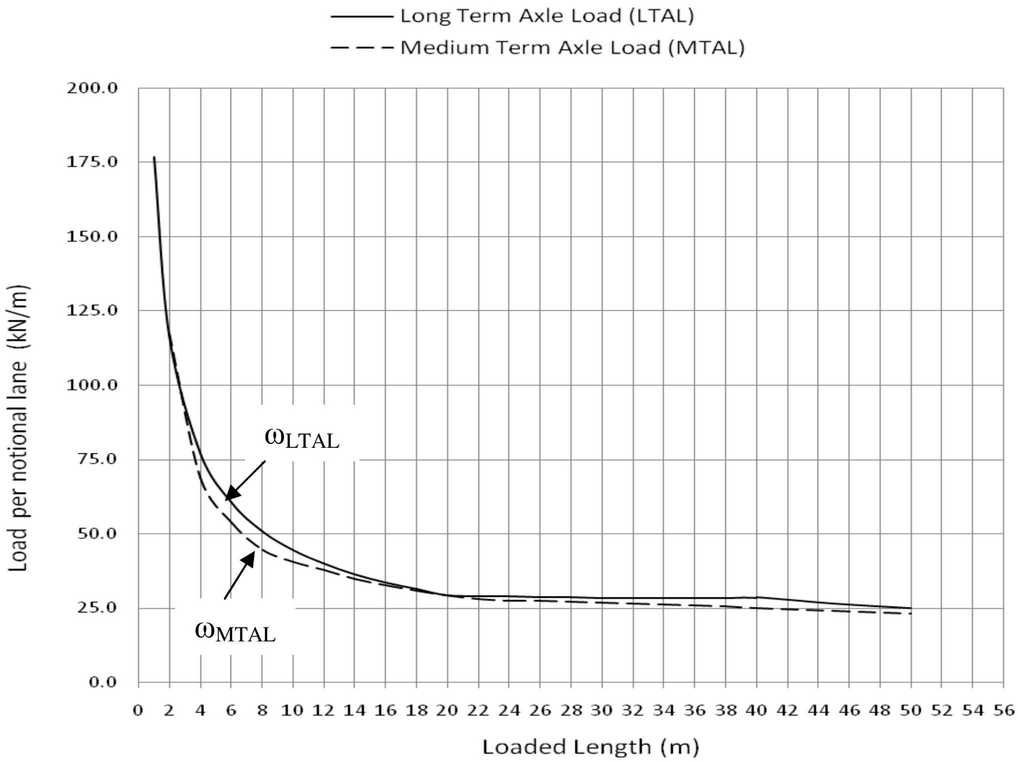


Figure 1 – A Comparison Between LTAL and MTAL Uniformly Distributed Load

3.0 ESTABLISHING A CORRELATION BETWEEN ELR_{LTAL} AND ELR_{MTAL}

If a relationship between ELR_{LTAL} and ELR_{MTAL} can be established, then the capacity of a bridge complying with MTAL Policy can be easily determined from the results of bridge evaluation in the previous study [5] without having to do a rigorous structural analysis on all the 400 bridges. The relationship between ELR_{LTAL} and ELR_{MTAL} can be expressed as a ratio of the load effects of MTAL and LTAL, designated as β.

3.1 Definition of MTAL/LTAL Load Effect Ratio, β

For a bridge that has MTAL capacity, Eqn.(1) can be re-written as Eqn.(3). In this case, the value of β shall be less than unity, i.e., β < 1.0. Similarly, Eqn.(2) shall be equal to 1.0 for bridges with MTAL capacity, as shown in Eqn.(4).

$$ELR_{LTAL} = \beta = \frac{R^* - D^*}{L^*_{LTAL}} \quad \text{........................} \quad \text{Eqn.(3)}$$

$$ELR_{MTAL} = 1.0 = \frac{R^* - D^*}{L^*_{MTAL}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eqn.(4)}$$

Dividing Eqn.(3) by Eqn.(4), yields the following relationships:-

$$\frac{ELR_{LTAL}}{ELR_{MTAL}} = \beta = \frac{L^*_{MTAL}}{L^*_{LTAL}} = \frac{L_{MTAL}}{L_{LTAL}} \quad \ldots\ldots\ldots\ldots \quad \text{Eqn.(5)}$$

From Eqn.(5), it becomes clear that β is indeed the ratio of load effects of MTAL and LTAL. The factors on the load effects can be omitted because the load factors for both MTAL and LTAL are the same. Hence, β can be used as a limiting value to identify MTAL bridges from the list of 400 bridges in Sabah, Sarawak and Labuan that had been previously evaluated in terms of LTAL criterion. Alternatively, the ELR ratings already in terms of LTAL can first be converted to ratings in terms of MTAL by Eqn.(5). The filtering criterion in this case is $ELR_{MTAL} \geq 1.0$.

4.0 DETERMINATION OF MTAL/LTAL LOAD EFFECT RATIO (β)

From Eqn.(5), it is clear that a detailed and comprehensive bridge analysis has to be carried out to determine the load effects due to the LTAL and MTAL, and hence, to establish the corresponding value of β. In this study, the following parameters were considered in the grillage analyses to establish the values of β:

i. Carriageway width: 9.0m and 13.0m
ii. Span length: 4.0m, 8.0m, 10.0m, 12.0m, 16.0m, 20.0m, 24.0m, 26.0m, 30.0m, 38.0m, 40.0m, 45.0m and 50.0m
iii. Beam spacing: (a) span < 20m; beam spacing 0.75m to 1.75m
(b) 20m < span < 30m; beam spacing 1.0m to 2.0m
(c) 30m < span < 50m; beam spacing 1.25m to 2.25m
iv. Diaphragm: (a) End diaphragm – 2 no. per span
(b) Intermediate diaphragm – None, 1 No. and 3 No. per span
v. Span type: Simply-supported and fixed-supported bridges
vi. Bridge deck skew angle: 15°, 30° and 45°

4.1 Grillage Model

A rigorous analysis involving grillage mesh was carried out to account for the transverse distribution of the load effects across the bridge deck. Each of the grillage models is based on the actual geometry of the specific bridge being considered in the analysis. Typical Young's modulus and Poisson's ratio are used in all analyses. Two support conditions are considered in the model, i.e., simply-supported and fixed-supported. Fixed-supported bridge is modelled after steel-buckled plate bridge or integral bridge where the superstructure is fixed to the substructure. No expansion joint between span.

4.2 Application of LTAL and MTAL

The notional lane is fixed at 2.5m wide each. Full (LTAL or MTAL) is applied to 2 no. of 2.5m wide notional lanes, 0.6 (LTAL or MTAL) to remaining 2.5m wide notional lanes, and a pedestrian load of 5MPa on any fractional notional lane, i.e., less than 2.5m wide [1]. Two loading patterns were used. Figure 2 shows the loading pattern for maximum load effects (moment and shear) on the edge beam. Figure 3 shows the maximum load effects (moment and shear) on the interior beams. As shown in Eqn.(5), the MTAL (UDL and KEL) are not factored in the grillage analysis because the load factors are the same for LTAL and will cancel out in the process of determining the load effect ratio of MTAL and LTAL. For a given grillage analysis, the value of β is determined from the least value of L_{MTAL}/L_{LTAL} obtained from the two loading patterns.

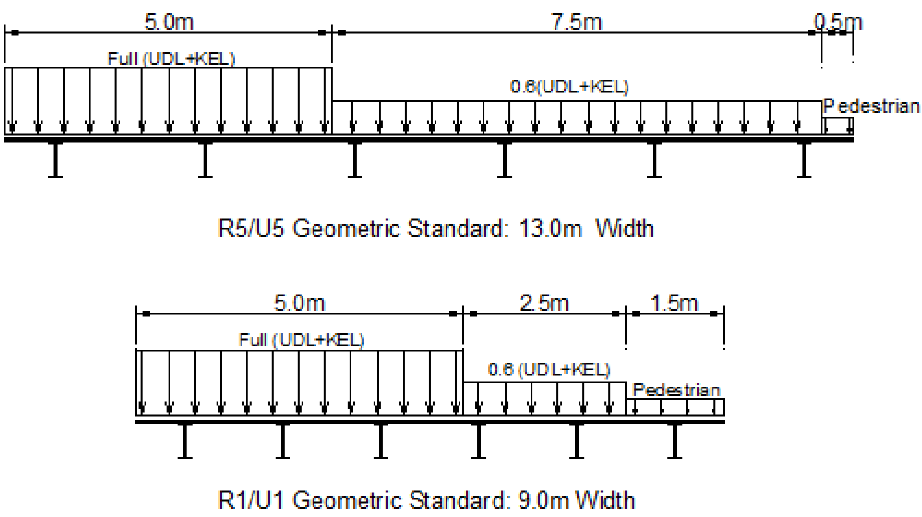
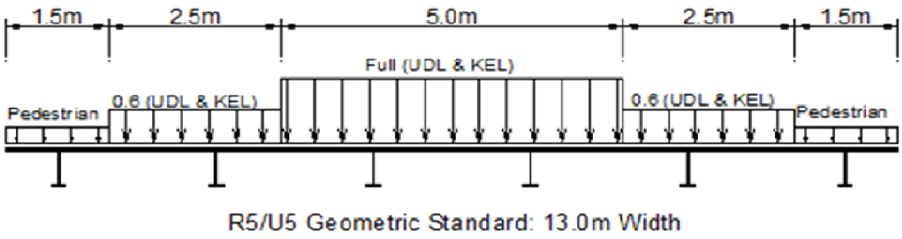


Figure 2: Application of LTAL or MTAL (UDL+KEL) on 2.5m Wide Fixed Notional Lane (Max Load Effect on Edge Beam)



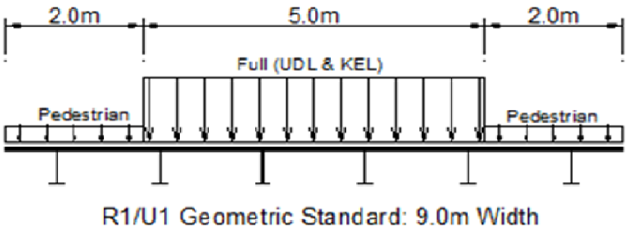


Figure 3: Application of LTAL or MTAL (UDL+KEL) on 2.5m Wide Fixed Notional Lane (Max Load Effect on Interior Beam)

5.0 RESULTS OF GRILLAGE ANALYSES

It is found that the carriageway width, beam spacing, bridge deck skew angle and number of diaphragms do not significantly affect the MTAL/LTAL load effect ratio or β value. The full results of the analyses are reported in Volume II of Reference 4.

5.1 Simply-Supported Bridges

For simply-supported bridges, the upper and lower limit of MTAL/LTAL load effect ratio versus loaded length (or this case equal to span length) is shown in Figure 4. The plot is based on results of some 900 grillage analyses on all the parameters (discussed in section 4.0) combined. It is apparent from Figure 4 that, at a given loaded length, the difference in the MTAL/LTAL load effect ratio between the two curves does not exceed 1%. In other words, the carriageway width, beam spacing, transverse rigidity and skewness do not affect the MTAL/LTAL load effect ratio significantly. However, the MTAL/LTAL load effect ratio is found to vary between approximately 0.9 and 1.0 for loaded lengths up to 50m. It is useful to discuss at this juncture the pattern of the β curve, which has a distinct turning point at 7.5m, 20.0m and 40.0m loaded lengths. The magnitude of β therefore depends on the difference between the respective load intensity curves. It can be seen from Figure 1 that the difference is large at 7.5m loaded length, very small at 20.0m loaded length and large again at 40.0m loaded length, which correspond to the turning points.

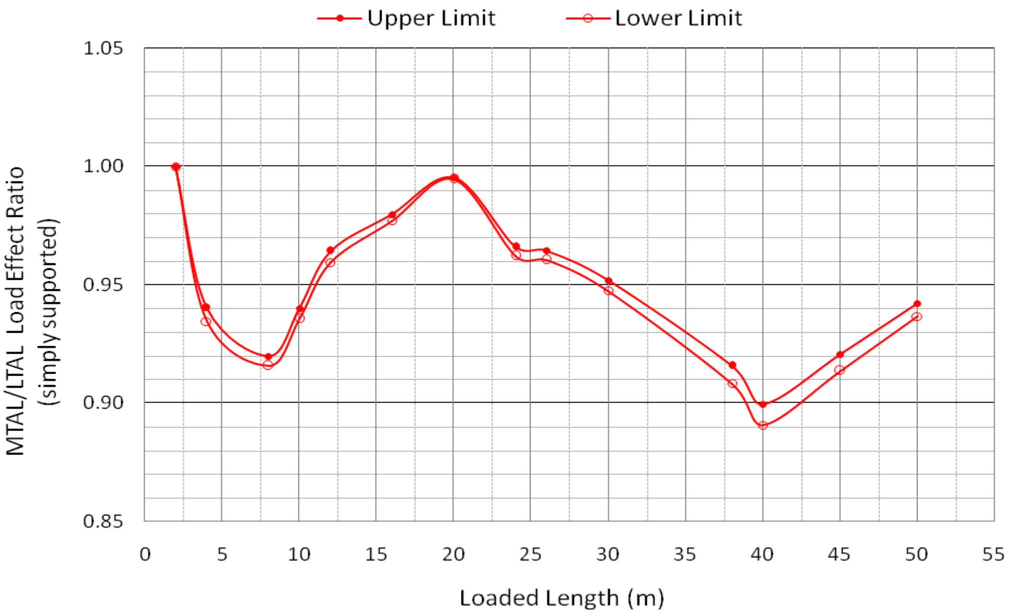


Figure 4: MTAL/LTAL Load Effect Ratio (β) Envelope
for Simply-Supported Bridges

5.2 Fixed-Supported Bridges

For fixed-supported bridges, the MTAL/LTAL load effect ratio versus loaded length is shown in Figure 5. The plot is based on results of some 420 grillage analyses on all the parameters (discussed in section 4.0) combined.

Figure 5: MTAL/LTAL Load Effect Ratio (β) Envelope
for Fixed-Supported Bridges

The difference in the MTAL/LTAL load effect ratio between the upper and lower bound curves is less than 2%. The MTAL/LTAL load effect ratio from maximum midspan moment on edge beam gives the upper limit for all loaded lengths.

5.3 Recommended MTAL/LTAL Load Effect Ratio (or β-value)

The value of β is found to vary with loaded length due to the fact that MTAL load intensity and LTAL load intensity are both a function of loaded length. The results in Figures 4 and 5 also show that besides the loaded length, other parameters such as carriageway width, types and spacing of beams, transverse rigidity of deck and the bridge skew angle do not influence the MTAL/LTAL load effect ratio (or β-value) significantly. The recommended curve of MTAL/LTAL load effect ratio for simply-supported and fixed-support bridges is shown in Figure 6. The recommended curve is not a best-fit curve but a "reasonable compromise" between the simply-supported and fixed-supported curves.

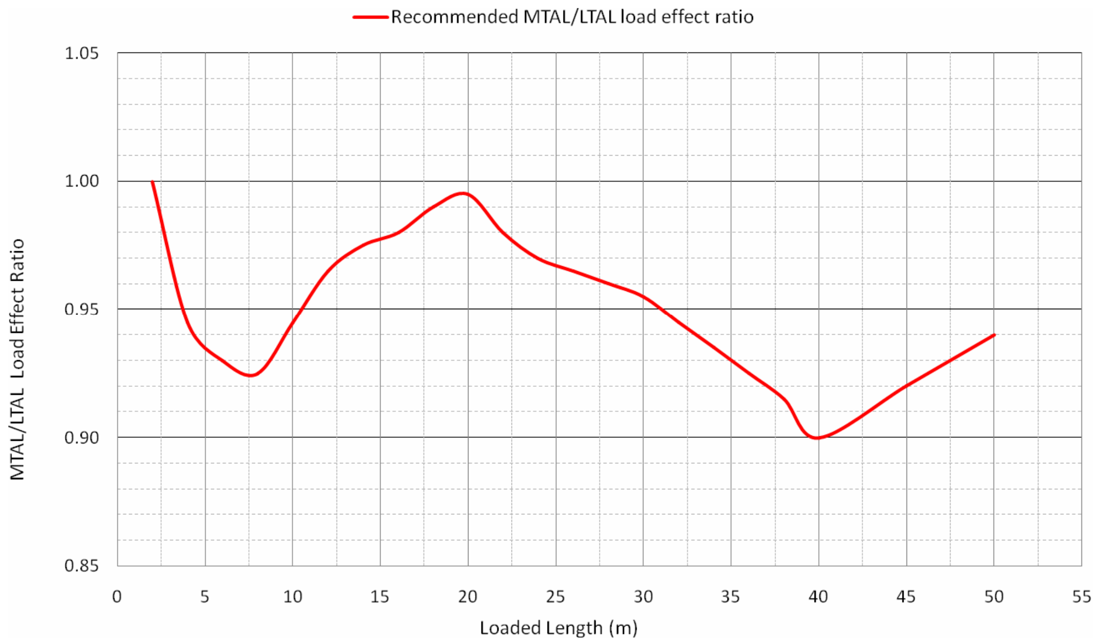


Figure 6: Recommended MTAL/LTAL Load Effect Ratio (β-value)

6.0 DETERMINATION OF MTAL BRIDGE CAPACITY

Based on the proposed MTAL/LTAL load effect ratio in Figure 6, the bridges in East Malaysia from the previous study [5] which have been rated in terms of ELR_{LTAL} can now be re-evaluated for compliance with MTAL capacity. Table 1 is an extract of the full list of bridges from the report [4]. For a bridge to be MTAL capacity, the MTAL/LTAL load effect ratio shall not exceed the value of ELR_{LTAL}. For example, structure no. FSU01/014/81 with span length of 23.47m, the MTAL/LTAL load effect ratio from Figure 6 is 0.97 which exceeds the ELR_{LTAL} value of 0.93. Hence, the bridge is not MTAL capacity and is recommended for replacement before that particular route (i.e., FSU01) can be upgrade to List I of WRO 2003.

Static proof load tests were also conducted on some bridges to ascertain its actual carrying capacity. It was however found that although the MTAL/LTAL load effect ratio may be higher than its ELR_{LTAL} value, some of the bridges may still comply with MTAL capacity. This is seen in Bridge No. FSS01/012/12 and FQA01/717/79. This is due to the fact that the MTAL/LTAL load effect ratios derived in Figure 6 are the upper bound values.

Table 1: Determination of MTAL Bridge Capacity

No.	Bridge No.	Structural System	Span No.	Span Length (m)	[1]ELR_{LTAL}	[2]MTAL/LTAL Load Effect Ratio (β-value)	Status
1.	FSU01/014/81	Steel Girder	1	23.47	0.93	0.97	Replace
2.	FSU01/023/30	Steel Girder	1	23.57	1.1	0.97	Comply
3.	FSU01/055/77	Steel Girder	1	29.25	1.21	0.96	Comply
4.	FSS01/012/12	Prestressed Girder	1	14.27	0.89	0.97	Load Tested to MTAL. OK.
			2	14.27	0.89	0.97	
5.	FQA01/717/79	Steel Girder	1	14	0.89	0.97	Load Tested to MTAL. OK.
			2	29.6	0.89	0.95	
			3	14	0.89	0.97	
6.	FSU01/063/83	Steel Girder	1	19.07	0.97	0.99	Replace
7.	FSU01/075/70	Steel Girder	1	31.63	0.29	0.95	Replace
			2	42	0.76	0.91	
			3	42	0.76	0.91	
			4	31.63	1.29	0.95	
8.	FSU01/143/50	Steel Girder	1	35.26	1.25	0.93	Comply

1. Previous Study [Ref.5]. 2. Present Study

7.0 CONCLUSIONS

This paper gives an overview of the findings on a departmental study to investigate the bridge capacity evaluation based on two assessment loads for normal vehicles in Malaysia, i.e., Medium-Term Axle Load (MTAL) and Long-Term Axle Load (LTAL). The MTAL/LTAL load effect ratio was established for load lengths up to 50m. The carriageway width, beam spacing, transverse rigidity and bridge skewness do not affect the MTAL/LTAL load effect ratio significantly. The difference in the MTAL/LTAL load effect ratio between the upper and lower bound curves is less than 2%. However, the ratio was found to vary significantly between a value of 0.9 and 1.0 for loaded lengths up to 50m. The MTAL/LTAL load effect ratio derived from the study was used to determine bridges in East Malaysia that comply with Malaysia Roads Transport Department Weight Restriction Order (WRO) 2003 which allows a legal load limit of 12 tonnes single axle load and 44 tonnes Gross Vehicle Weight. Some Federal Routes in East Malaysia have been identified to be upgraded from List II to List I of the Second Schedule of WRO 2003, thus, permitting the roads to carry a heavier load limit.

8.0 ACKNOWLEDGEMENT

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