**FINAL REPORT**

**VOLUME II: REVISION OF LIST I IN SECOND SCHEDULE OF WRO 2003**

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1. **INTRODUCTION**
   1. **General**

The revision of List I in second Schedule of WRO 2003 involve three separate tasks which are inter-related.

* Task (i) involve establishing a correlation between MTAL & LTAL load effects on the bridges
* Task (ii) involve the structural capacity assessment of the Federal Bridges for compliance to vehicular loads as per First Schedule of WRO 2003 and
* Task (iv) is to identify and prioritise Federal Routes for upgrading to List I of the Second Schedule of WRO 2003

Task (i) of the Study was carried out first and follow by (task ii) and (task iv).

* 1. **Collection and Reviewing of Data**

The Consultant has collected and reviewed the relevant data required to complete the study. The documents are as follows:

* + - * Study on Inspection, Assessment and Inventorisation of Federal Bridges in Sabah and Sarawak (Sabah - Sarawak 2007 Study)
      * Inventory cards for bridges in Sabah and Sarawak.
      * JKR Specification for Bridge Live Loads – DJ 1/89
      * Axle Load Study – Appendices – Volume 6
      * Axle Load Study – final report
      * Determination of the Structural Capacity of Existing Bridges in Peninsular Malaysia – Volume III
      * Weight Restriction (Federal Roads) (Amendment) Order 2003
      * Bridge Evaluation Project – 1994
      * Arahan Teknik (Jalan) 8/86 – A Guide on Geometric Design of Roads
      * Kajian Semula Pembangunan Rangkaian Jalanraya HNDP Fasa 2
  1. **Reconnaissance**

The Consultant has identified the bridge types based on the preliminary data for the state Sabah, Sarawak and Labuan. Site visits to Sarawak and Sabah were carried out during the study period to inspect some of the typical bridges involved in this Study.

The Consultant has also held a presentation and discussion with the relevant authority in Sarawak and Sabah. The relevant comments from these discussions have been incorporated in the report.

1. **TASK (i) - ESTABLISHING A CORRELATION BETWEEN MEDIUM TERM AXLE LOAD (MTAL) AND LONG TERM AXLE LOAD (LTAL) LOAD EFFECTS ON THE BRIDGES**
   1. **General**

Task (i) involved the establishment of the correlation between Medium Term Axle Load (MTAL) and Long Term Axle Load (LTAL) load effects on the bridges. The correlation of Medium Term Axle Load (MTAL) and 20 units Special Vehicle (SV) load effects was also carried out in this study.

From the ‘bridge management’ study that was conducted between 2004-2007, bridges along Federal Routes in Sabah, Sarawak and Labuan had been rated in term of their structural capacities in withstanding the Long term Axle Load (LTAL) loading and 20 units Special Vehicle (SV) loading. If a correlation between MTAL and LTAL and between MTAL and 20SV can be determined, then the rating of the existing bridges can be easily converted to MTAL without having to carry out the rigorous structural analysis. Thus, it is within the scope of work of task (i) to study and eventually proposed a correlation of MTAL/LTAL that is simple to apply and also that can be adopted throughout Malaysia.

* 1. **Evaluation Load Rating (ELR)**

The assessment of the bridge capacity is based on the ratio of the available resistance of a member to the effect of live load. This ratio is known as Evaluation Load Rating (ELR) and with respect to MTAL axle load policy; the compliance shall be based on the following expression.

*(ELR-*MTAL) ≥ **β’ (**ELR-LTAL)

Where:

*ELR* is the *Evaluation Load Rating*

MTAL is *Medium Term Axle Load*

LTAL is *Long Term Axle Load*

**β'** is a function of load effects ratio.

From the above expression, it can be seen that various parameters need to be studied to determine the significant of its effect to the MTAL/LTAL load effects ratio.

* 1. **Methodology**

In carrying the study for task (i), the methodology/steps of work are as follows:

1. Determine load intensity of MTAL and LTAL
2. Preliminary determination of correlation based on load intensity only
3. Identify the parameters which may affect the MTAL)/LTAL load effects ratio
4. Determine the sensitivity of each parameter using grillage analysis
5. Determine the overall effect of these parameters.
6. Recommend the MTAL/LTAL load effect ratio
   1. **Loading Intensity**
7. ***Long Term Axle Load (LTAL)***

The Long Term Axle Load (LTAL) is based on the ‘*JKR Specification for Bridge Live Loads – DJ 1/89’.* The loading comprises of uniformly distributed load (UDL) which varies with loaded length and knife edge load (KEL) which is constant at 100kN per 2.5m notional lane. The loaded length is the length of the base of the positive or negative part of the influence line for a particular effect at the design point under consideration.

The uniformly distributed load for LTAL is given by the following expressions.

1. *L* <=20m *w*=176.8 (1/*L*)0.6
2. 20m <= *L* <= 40m *w*=(93.6+4.16).(1/*L*)0.6
3. 40m <= *L* <=50m *w*=260 (1/*L*)0.6

where *L* is the loaded length and *w* is the load intensity per notional lane width.

1. ***Medium Term Axle Load (MTAL)***

The Medium Term Axle Load (MTAL) is based on *Table 7.2* of the *‘Axle Load Study – Volume 6’.* The loading comprises of uniformly distributed load (UDL) which varies with loaded length and knife edge load (KEL) which is constant at 100kN per 2.5m notional lane. The uniformly distributed load of MTAL is always lower than the LTAL except at the loaded length of 2 meters and below.

The loading intensity against loaded length for MTAL, as extracted from the *‘Axle Load Study’*, is given in the following Table 1.

Table 1: MTAL load from extracted from ‘Axle Load Study’

|  |  |  |  |
| --- | --- | --- | --- |
| Loaded  Length (L)  (m) | UDL (w)  (kN/m) | Loaded  Length (L)  (m) | UDL (w)  (kN/m) |
| 2 | 117.5 | 24 | 27.4 |
| 4 | 68.8 | 26 | 27.2 |
| 6 | 53.6 | 28 | 27.0 |
| 8 | 44.5 | 30 | 26.6 |
| 10 | 40.4 | 32 | 26.3 |
| 12 | 37.7 | 34 | 26.0 |
| 14 | 34.8 | 36 | 25.7 |
| 16 | 32.5 | 38 | 25.4 |
| 18 | 30.6 | 40 | 24.9 |
| 20 | 29.1 | 45 | 23.9 |
| 22 | 28.0 | 50 | 23.1 |

1. ***Comparison of LTAL and MTAL***

The loading curves of the uniformly distributed load for Medium Term Axle Load (MTAL) and Long Term Axle Load (LTAL) are shown in Figure 1 below. Both the MTAL and LTAL are applicable up to a loaded length of 50 meters.

The difference in the load intensity between MTAL and LTAL is not constant but varies with loaded length. This difference is quite significant between the loaded lenght of 4 to 10 meters and between 38 to 42 meters. On the other hand, the difference in the loading intensity between the loaded length of 18 to 22 meters is very small. This invariably affects the MTAL/LTAL load effect ratio whereby the larger the difference in the load intensity, the lower will be the respective MTAL/LTAL load effect ratio.

The knife edge load (KEL) is taken as 100kN per notional lane for both LTAL and MTAL and is independent of the loaded length.

Figure 1 – UDL loading curve for MTAL and LTAL

1. ***Pedestrian Load***

The area of the carriageway whereby the notional lane width is less than 2.5 meters shall be loaded with pedestrian load of 5.0 kN/m2. The loading intensity is similar for both LTAL and MTAL and does not vary with loaded length. Since the load intensity is constant, the MTAL/LTAL load effects ratio due to pedestrian load is always 1.0. This invariably affects the overall ratio of MTAL/LTAL load effects. The extent of its effects depends on the width of the carriageway that the pedestrian load will occupies.

* 1. **Preliminary Analysis**

The correlations of MTAL/LTAL load effects are based on the maximum bending moment and maximum shear. A preliminary analysis based on line load was carried out on a simply supported bridge. The maximum bending moment and shear are calculated based on line load taking into consideration the uniformaly distributed load and the knife edge load only. The purpose is to get the overall view of the behaviour of MTAL and LTAL load effects ratio with respect to loaded length and it also serves as a check against any obvious error during the rigorous grillage analysis.

The bending moment and shear for a simply supported bridge was calculated from the following expression.

|  |  |
| --- | --- |
| Moment = | *WMTAL.L2/8 + P.L/4* |
| *WLTAL.L2/8 + P.L/4* |
| *=* | *L/4\*(WMTAL.L/2 + P)* |
| *L/4\*(WLTAL.L/2 + P)* |
| *=* | *WMTAL.L/2 + P* |
| *WLTAL.L/2 + P* |

|  |  |
| --- | --- |
| Shear *=* | *WMTAL.L/2 + P* |
| *WLTAL.L/2 + P* |

Where *W* is the uniformly distributed load (UDL) for LTAL or MTAL as indicated by the subscripts, *P* is the knife edge load (KEL) taken as 100kN per notional lane for both MTAL and LTAL and *L* is the loaded length

The derivation above showed that the ratio of MTAL/LTAL load effects for bending moment and shear force for a simply supported bridge is exactly similar.

The second set of calculations was based on grillage analysis using STAAD III. The grillage model is based on R2/U2 bridge geometry with a carriageway width of 10.0 meters as shown in the Figure 2 below. The load on the bridge comprises of 2 notional lanes of full (UDL+KEL) load intensity and 2 subsequent lanes of 0.6(UDL+KEL) load intensity for MTAL and LTAL. This bridge geometry was specifically chosen as there is no pedestrian load that will affect the results.

The grillage model adopted pre-stressed concrete beam at a spacing of 1.25 meters centres to centres. The deck slab is 200mm thick with no diaphragm being considered to reduce the transverse distribution of load which will affect the results. As it is, the deck slab still distributes the load to some extent.

The analysis on R2/U2 bridge geometry is given in Appendix A.

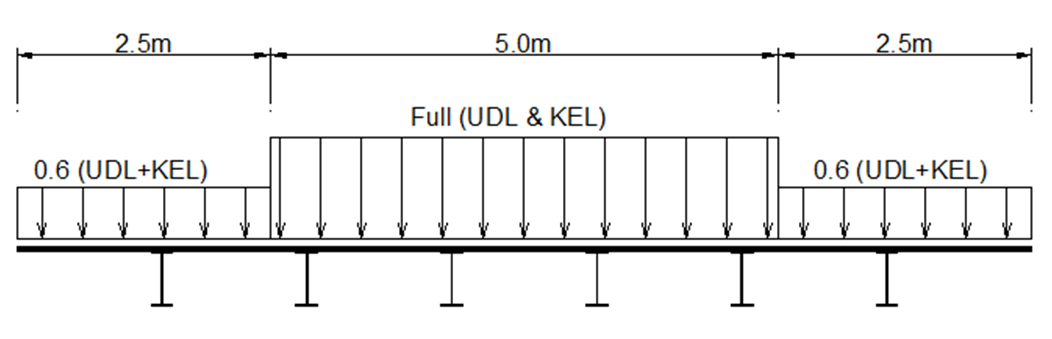


Figure 2: R2/U2 bridge geometry

From the results, the curves of MTAL/LTAL load effects ratio for bending moment and shear were interpolated against the loaded length for the line load analysis and the grillage analysis. This is as shown in Figure 3.

Figure 3: MTAL/LTAL curves from line load and R2/U2 bridge geometry

* 1. **Grillage Analysis**

The coefficient **β** given in the expression (*ELR-*(MTAL) ≥ **β** (ELR-LTAL) is a function of various parameters that may have an effect on the MTAL/LTAL load effect ratio. The rigorous grillage analyses include the various parameters such as pedestrian load, carriageway width, beam spacing, skew angles, etc. to determine their effect on the MTAL/LTAL load effects ratio.

A rigorous analysis involving grillage mesh was carried out to account for the transverse distribution of the load effects across the bridge deck. A typical grillage model is shown in Figure 4. The longitudinal grillage members represent the main girders and the transverse members represent the diaphragm or the deck slab. Each of the grillage models is based on the actual geometry of the specific bridge being considered in the analysis. The sectional properties, Young’s modulus and Poisson’s ratio are derived from each specific bridge.

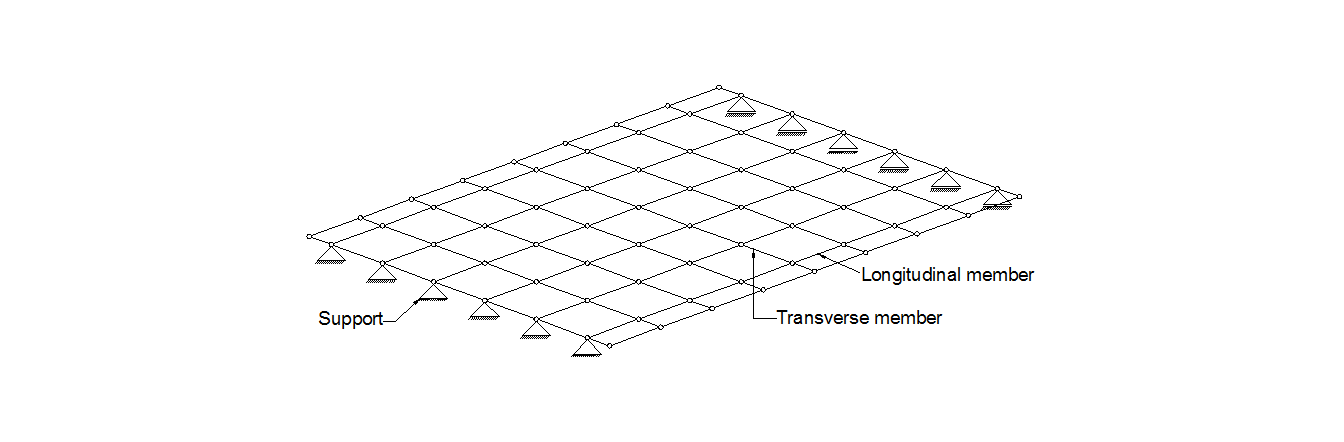


Figure 4: Typical grillage model

The uniformly distributed loads (UDL) are proportionately distributed as line loads along the longitudinal members and the knife edge loads are represented as point loads. The live loadings are not factored since the evaluation involved determining the load effects ratio of MTAL and LTAL and whatever factor will cancel each other out. Only the analysis results that yield the critical load effects, i.e. maximum bending moment and shear, are considered in the determination of the MTAL/LTAL load effects ratio.

* 1. **Parameters Affecting the MTAL/LTAL Load Effects Ratio**

The used of grillage analysis allow the evaluation of various parameters which may affect the MTAL/LTAL load effects ratio. The parameters listed below were incorporated in the respective grillage models.

* Bridge structural system
* Bridge span and loaded length
* Carriageway width
* Loading pattern
* Types of beams
* Spacing of beams
* Transverse rigidity of deck
* Skew angle of bridge
  + 1. ***Bridge Structural System***

From the inventory card of the previous study, the most common types of bridges are simply supported bridge, fixed support bridge, continuous span bridge and truss bridge.

* + 1. ***Bridge Span and Loaded Length***

The ranges of loaded length on a bridge span that were considered in the grillage analysis are from 2 meters to 50 meters. With reference to Figure 1 above, the load intensity of MTAL is slightly higher than LTAL at the loaded length of less than 2.0 meters. Initial calculation gives a value of 1.004 for MTAL/LTAL load effects ratio. Since the ratio is very small, it is proposed that the MTAL/LTAL load effects ratio of 1.00 be adopted for a loaded length of less than 2.0 meters.

The loading intensity of LTAL and MTAL as specified in ‘*JKR Specification for Bridge Live Loads – DJ 1/89’* for LTAL and *‘Axle Load Study – Volume 6’* respectively is up to a maximum loaded length of 50.0 meters. Thus, analysis beyond the 50.0 meters span length cannot be carried out. It is proposed that the MTAL/LTAL load effects ratio at the 50.0 meter loaded length be adopted for bridges with a span length exceeding the 50.0 meters range.

From the preliminary analysis based on line load, it is clear that the loaded length has a significant effect on the MTAL/LTAL load effect ratio. This is obvious as the uniformly distributed load intensity of LTAL and MTAL varies unevenly as the loaded length increases. The maximum MTAL/LTAL load effect ratio is 1.00 at loaded length of less than 2.0 meters and the minimum is about 0.90 at 40.0 meter loaded length. The difference of 0.11 is very significant and thus, even at the initial stage, it can be concluded that adopting a single correlation of MTAL/LTAL load effects ratio for the whole range of loaded length is not advisable.

Using the result of the preliminary analysis as a guideline, an appropriate range of loaded length was selected for the rigorous grillage analysis. The loaded lengths selected in the grillage analyses include 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.

* + 1. ***Carriageway Width***

Two different carriageway widths were considered in the grillage analysis; namely R5/U5 bridge geometry with a carriageway width of 13.0 meters and R1/U1 bridge geometry with a carriageway width of 9.0 meters. The R5/U5 and R1/U1 bridge geometry are shown in Figure 5 below.

The bridge geometry chosen represents the widest and the narrowest carriageway width for bridges as specified in *‘Arahan Teknik (Jalan) 8/86 – A Guide on Geometric Design of Roads’*

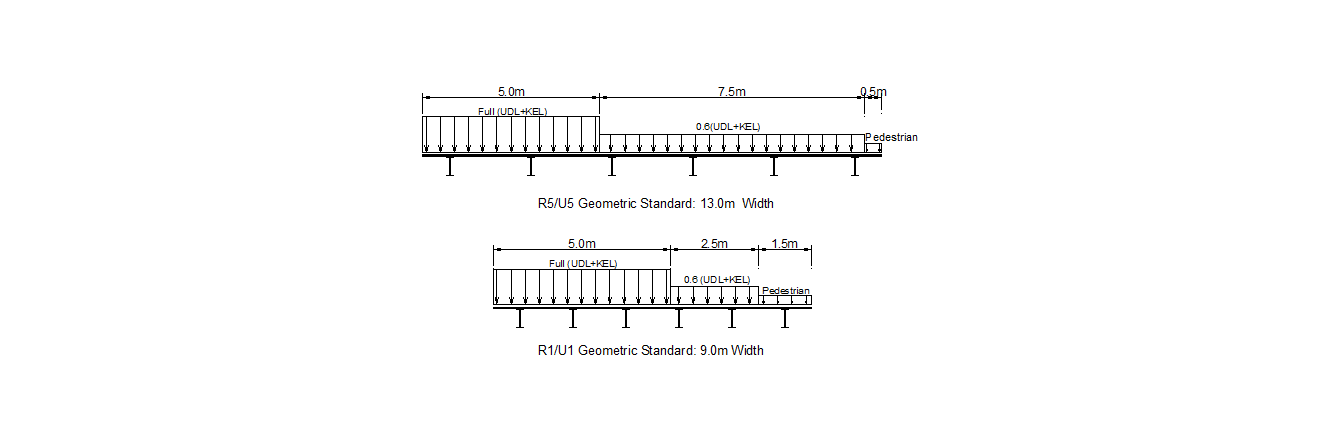


Figure 5: R5/U5 and R1/U1 bridge geometry

* + 1. ***Loading pattern***

Two load patterns were considered in the detail grillage analysis for the purpose of comparing the MTAL/LTAL load effects ratio. The two carriageway widths that were considered in the grillage analysis are R5/U5 bridge geometry with a carriageway width of 13.0 meters and R1/U1 bridge geometry with a carriageway width of 9.0 meters.

In load pattern 1, the full (UDL + KEL) load intensity for two notional lanes is placed at the edge of carriageway, the subsequent notional lanes are loaded with 0.6(UDL + KEL) and the remaining carriageway of less than 2.5 meters width is loaded with pedestrian load. The loading configuration in load pattern 1 for R5/U5 and R1/U1 bridge geometry is as shown below in Figure 6.

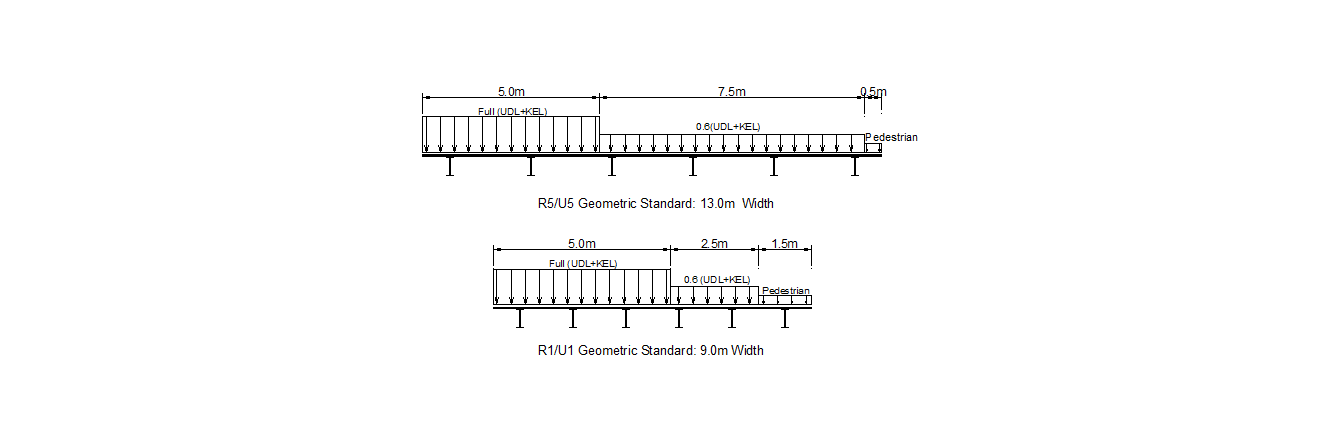


Figure 6: Load Pattern 1 - Maximum load at edge of carriageway

In load pattern 2, the full (UDL + KEL) load intensity for two notional lanes is placed at the centre of carriageway, the subsequent notional lanes on both sides are loaded with 0.6(UDL + KEL) and the remaining carriageway of less than 2.5 meters width is loaded with pedestrian load. The loading configuration in load pattern 2 for R5/U5 and R1/U1 bridge geometry is as shown below in Figure 7.

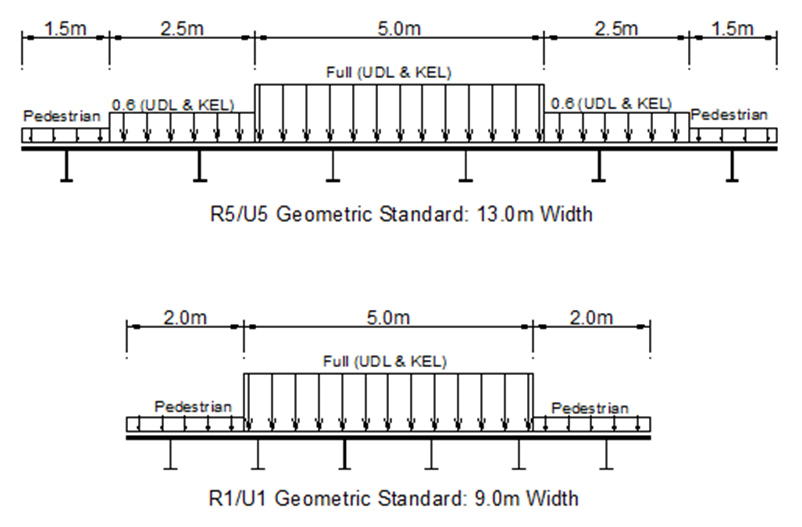


Figure 7: Load Pattern 2 - Maximum load at centre of carriageway

The loaded lengths selected for the comparison of MTAL/LTAL load effects ratio between load pattern 1, with full load at edge of carriageway, and load pattern 2, with full load at centre of carriageway, are confined to 10.0m, 30.0m and 50.0m loaded length. The selected range is considered sufficient to determine and compare the significance of the MTAL/LTAL load effects ratio between load pattern 1 and load pattern 2. Further detail analysis will be carried out if the results indicate a very significant difference for MTAL/LTAL load effects ratio with respect to the maximum bending moment and shear force.

* + 1. ***Spacing of Beams***

The spacing of beams that were considered in the grillage varies from 0.75 meter to 2.25 meters at 0.25 meter increment. Shorter bridge span adopted narrower beam spacing while longer bridge span adopted wider beam spacing. The spacing arrangements adopted in the grillage analysis are listed below.

Bridge span < 20m spacing: 0.75m – 1.75m

20m > Bridge Span <30m spacing: 1.00m – 2.00m

30m > Bridge Span <50m spacing: 1.25m – 2.25m

* + 1. ***Types of beams***

Three types of beams were considered in the grillage analysis and they comprises of inverted T-beam, JKR standard beam and steel composite beam as shown in Figure 8.

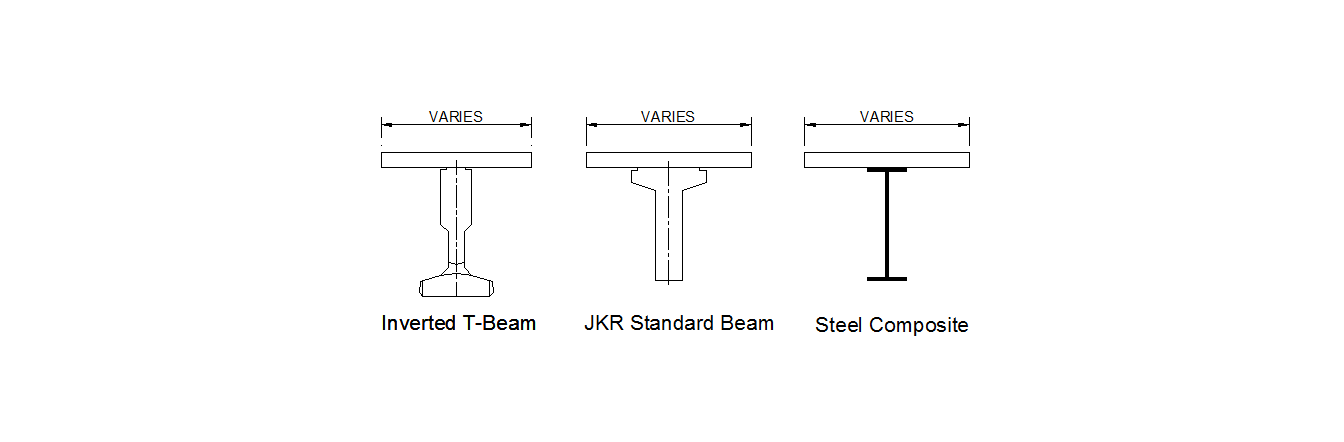


Figure 8: Types of beams for grillage analysis

The grillage models adopted the inverted T-beam for shorter span and JKR standard beam for longer span.

In load pattern 2, whereby the full (UDL + KEL) load is placed along the centre of the carriageway, both the concrete beams and steel composite beams were adopted in the respective grillage models. The effects between the two different types of beams can thus be evaluated and comparison can be made.

* + 1. ***Transverse rigidity of bridge***

The transverse distribution of load across the carriageway width is through the 200mm deck slab and diaphragm. Three types of transverse rigidity of the bridges were considered in the analysis which includes bridges with no intermediate diaphragm, one intermediate diaphragm at mid-span and three intermediate diaphragms at every quarter span. The thickness of the intermediate diaphragm is generally 200mm. Edge diaphragm of thickness 500mm is included in every grillage models.

* + 1. ***Skew of Bridge***

The skew range being considered in the grillage analysis includes 15 degrees, 30 degrees and 45 degrees skew.

* 1. **Results of Grillage Analysis for Simply Supported Bridge**

A large number of rigorous grillage analyses on a simply supported bridge were carried out to determine the effects of the various parameters on the MTAL/LTAL load effects ratio. The total numbers of grillage analyses that have been carried out are given in Table 2

Table 2: Numbers of grillage analyses for simply supported bridge

|  |  |  |  |
| --- | --- | --- | --- |
| Loaded Length  (m) | Full Load at Edge  Straight Bridge | Full Load at Edge  Skew Bridge | Full Load at Centre |
| 4  8  10  12  16  18  20  24  26  30  38  40  45  50 | 30  30  30  30  30  30  30  30  30  33  30  30  30  30 | 18  18  36  18  18  18  36  18  18  36  18  36  18  36 | -  -  48  -  -  -  -  -  -  48  -  -  -  48 |
| Total Numbers | 393 | 324 | 144 |

Samples of detail calculations for concrete bridge, steel composite, R5/U5 geometry and R1/U1 geometry are presented in Appendix A. The rest of the detail calculations are similar and the summary of results these analyses are presented in the Appendix B.

The modelling of the grillage mesh will require some basic data, such as the length, width, longitudinal members, transverse members and support condition, which are among the parameters that will affect the MTAL/LTAL load effects ratio. Comparing the effects due to each specific parameter is time consuming and perhaps counter-productive, especially when considering that the overall effect is more relevant toward establishing the correlation between MTAL and LTAL load effects. Never-the-less, some comparison between a particular set of parameters were carried. What is apparent, however, is that the loaded length and the difference in the loading intensity have a very significant effect on the MTAL/LTAL load effects ratio.

* + 1. ***Effect of Carriageway Width, Beam Spacing and Transverse Rigidity***

Comparison of MTAL/LTAL ratio was made between the R5/U5 and R1/U1 geometry for a straight bridge. The grillage analysis considered the loaded length of 4.0m up to 50.0m, the whole range of beam spacings and tranverse rigidity of the bridge. The MTAL/LTAL load effects ratio at the 2.0m loaded length is taken as 1.00 for all.

The results of the analyses are summarized in Table 3 and comparison of MTAL/LTAL load effect ratio between the upper and lower limit is presented in Figure 9.

Table 3: Summary of MTAL/LTAL load effect ratio for R5/U5 and R1/U1.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded  Length  (m) | R1/U1 Geometry:  Moment | | R1/U1 Geometry:  shear | | R5/U5 Geometry:  moment | | R5/U5 Geometry:  shear | |
| Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio |
| 2  4  8  10  12  16  20  24  26  30  38  40  45  50 | 1.000  0.936  0.919  0.939  0.963  0.979  0.995  0.965  0.963  0.950  0.913  0.896  0.918  0.939 | 1.000  0.936  0.916  0.936  0.961  0.977  0.995  0.963  0.961  0.947  0.909  0.891  0.914  0.937 | 1.000  0.936  0.920  0.940  0.964  0.979  0.995  0.966  0.964  0.952  0.916  0.900  0.921  0.942 | 1.000  0.935  0.916  0.936  0.959  0.977  0.995  0.962  0.960  0.948  0.909  0.891  0.914  0.937 | 1.000  0.940  0.918  0.938  0.963  0.978  0.995  0.964  0.963  0.950  0.912  0.894  0.916  0.939 | 1.000  0.935  0.917  0.937  0.962  0.978  0.995  0.963  0.962  0.948  0.910  0.893  0.915  0.937 | 1.000  0.937  0.919  0.940  0.964  0.980  0.995  0.965  0.963  0.951  0.914  0.897  0.918  0.940 | 1.000  0.935  0.917  0.937  0.962  0.978  0.995  0.964  0.962  0.948  0.910  0.893  0.915  0.938 |

Figure 9 – Comparison of R5/U5 and R1/U1 carriageway width

The difference between the upper limit and lower limit of MTAL/LTAL load effects ratio is well below 0.01 and can be considered as insignificant.

* + 1. **Effect of Loading Pattern**

The results from the analysis for load pattern 1, for full (UDL+KEL) at edge of carriageway, and load pattern 2, for full (UDL+KEL) at centre of carriageway, are given in Table 4 and the comparison is presented in graphical form in Figure 10 below.

The comparison is based on the upper limit of MTAL/LTAL load effects ratio for bending moment. The results indicated that load pattern 2 for R1/U1 geometry loaded at centre of carriageway give the highest MTAL/LTAL load effect ratio. The difference as compare with load pattern 1 varies from 0.007 at 10m span to 0.016 at 50m span.

Table 4: MTAL/LTAL load effects ratio for load pattern 1 and load pattern 2

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded  Length  (m) | Load at Centre  R1 | | Load at Centre  R5 | | Load at Edge  R1 | | Load at Edge  R5 | |
| *Moment* | *Shear* | *Moment* | *Shear* | *Moment* | *Shear* | *Moment* | *Shear* |
| 10 | 0.944 | 0.942 | 0.939 | 0.939 | 0.937 | 0.937 | 0.938 | 0.939 |
| 30 | 0.961 | 0.958 | 0.955 | 0.953 | 0.948 | 0.951 | 0.949 | 0.950 |
| 50 | 0.954 | 0.952 | 0.946 | 0.945 | 0.938 | 0.940 | 0.938 | 0.940 |

Figure 10: Comparison of load pattern 1 and load pattern 2

The obvious explanation for the difference lies in the fact that for R1/U1 geometry in load pattern 1, the pedestrian load occupies 4.0m width out of 9.0m total carriageway width. Since the load intensity of 5.0kN/m2 is the same for MTAL and LTAL, this will increase load effect ratio especially at the 50m span where the uniformly distributed load intensity is the lowest.

The maximum load effects due to bending moment and shears are extracted from the results of grillage analysis for R1/U1 geometry of load pattern 1 and 2 at loaded span of 10m, 30m and 50m. The beams spacing for both of the above R1/U1 geometry are similar at 1.5m c/c. Results of maximum bending moment and shear are given in Table 5 and the moment comparison is presented in Figure 11. Since the bending moment and shear at edge loading is critical, the MTAL/LTAL load effect ratio from this loading pattern is adopted.

Table 5: Results of moment and shear for R1/U1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Loaded Length  (m) | Load at Centre  R1 | | Load at Edge  R1 | |
| *Moment* | *Shear* | *Moment* | *Shear* |
| 10 | 383 | 172 | 451 | 180 |
| 30 | 1,784 | 267 | 2,208 | 297 |
| 50 | 4,046 | 356 | 4,914 | 402 |

Figure 11: Comparison of moment between load pattern 1 and load pattern 2.

* + 1. **Effect of Beam Types**

In load pattern 2, whereby the maximum load is placed along the centre of the carriageway, both the concrete beams and steel composite beams were adopted in the grillage models. The effect of different beam sectional properties can thus be evaluated. Results of maximum bending moment and shear are given in Table 6 and are presented in Figure 12.

Table 6: Summary of results for comparison of beam types

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded Length  (m) | Concrete beam  R1 | | Concrete beam  R5 | | Steel Beam  R1 | | Steel Beam  R5 | |
| Moment | Shear | Moment | Shear | Moment | Shear | Moment | Shear |
| 10 | 0.944 | 0.942 | 0.939 | 0.939 | 0.942 | 0.942 | 0.938 | 0.938 |
| 30 | 0.961 | 0.958 | 0.955 | 0.953 | 0.961 | 0.960 | 0.955 | 0.954 |
| 50 | 0.954 | 0.952 | 0.946 | 0.945 | 0.953 | 0.950 | 0.947 | 0.944 |

Figure 12: Effects of beam types on MTAL/LTAL load effect ratio

The results indicate that the effects of adopting different types of beams on the MTAL/LTAL load effects ratio are insignificant.

* + 1. **Effect of Bridge Skew**

The results of the grillage analysis for a straight bridge, 15 degrees, 30 degrees and 45 degrees skew bridges are summarized in Table 7 and the comparisons in graphical form are shown in Figure 13 below. The MTAL/LTAL load effects ratio in term of moment and shear for straight and skew bridges is almost similar and be considered as insignificant.

Table 7: Results of moment and shear for R1/U1

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded Length  (m) | Straight | | 15 Degrees Skew | | 30 Degrees Skew | | 45 Degrees Skew | |
| Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio | Maximum ratio | Minimum ratio |
| 2  4  8  10  12  16  20  24  26  30  38  40  45  50 | 1.000  0.940  0.918  0.938  0.963  0.978  0.995  0.964  0.963  0.950  0.912  0.894  0.916  0.939 | 1.000  0.935  0.917  0.937  0.962  0.978  0.995  0.963  0.962  0.948  0.910  0.893  0.915  0.937 | 1.000  0.935  0.917  0.938  0.963  0.978  0.995  0.964  0.963  0.949  0.911  0.894  0.916  0.939 | 1.000  0.935  0.917  0.937  0.962  0.978  0.995  0.963  0.962  0.948  0.911  0.893  0.915  0.938 | 1.000  0.936  0.918  0.938  0.963  0.978  0.995  0.964  0.963  0.949  0.911  0.894  0.916  0.939 | 1.000  0.934  0.918  0.937  0.962  0.978  0.995  0.963  0.962  0.949  0.911  0.893  0.915  0.938 | 1.000  0.936  0.918  0.938  0.963  0.978  0.995  0.964  0.963  0.949  0.911  0.894  0.916  0.939 | 1.000  0.936  0.918  0.937  0.962  0.978  0.995  0.964  0.962  0.949  0.911  0.893  0.916  0.938 |

Figure 13: Comparison of MTAL/LTAL load effect ratio between straight and skew bridges

* + 1. **Overall Effects of All the Parameters**

The summary of the combined effects of all the parameters in the above-mentioned paragraph on the MTAL/LTAL load effect ratio is shown in Table 8

Table 8: Summary of results for combined effects from all the parameters.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded Length  (m) | MOMENT : MTAL/LTAL | | | SHEAR : MTAL/LTAL | | | Upper Limit ratio | Lower Limit ratio |
| Maximum ratio | Minimum ratio | Median | Maximum ratio | Minimum ratio | Median |
| 2  4  8  10  12  16  20  24  26  30  38  40  45  50 | 1.000  0.940  0.919  0.939  0.963  0.979  0.995  0.965  0.963  0.950  0.913  0.896  0.918  0.939 | 1.000  0.934  0.916  0.936  0.961  0.977  0.995  0.963  0.961  0.947  0.909  0.891  0.914  0.937 | 1.00  0.94  0.92  0.94  0.96  0.98  0.99  0.96  0.96  0.95  0.91  0.89  0.92  0.94 | 1.000  0.937  0.920  0.940  0.964  0.980  0.995  0.966  0.964  0.952  0.916  0.900  0.921  0.942 | 1.000  0.935  0.916  0.936  0.959  0.977  0.995  0.962  0.960  0.948  0.908  0.891  0.914  0.937 | 1.00  0.94  0.92  0.94  0.96  0.98  1.00  0.96  0.96  0.95  0.91  0.89  0.92  0.94 | 1.000  0.940  0.920  0.940  0.964  0.980  0.995  0.966  0.964  0.952  0.916  0.900  0.921  0.942 | 1.000  0.934  0.916  0.936  0.959  0.977  0.995  0.962  0.960  0.947  0.908  0.891  0.914  0.937 |

The upper limits and lower limits of MTAL/LTAL load effects ratio based on the maximum bending moment and shear are presented in Figure 14. It is apparent that the difference in range due to the combined effect of all the parameters does not exceed 0.01 and thus can be considered insignificant. The individual effect of each specific parameter would not exceed these limits. Although these parameters do not have a significant effect on the MTAL/LTAL load effects ratio, they may have a substantial effect on the actual bending moment and shear of specific bridge structure.

Figure 14: Upper and lower limit of MTAL/LTAL load effects ratio

* 1. **Correlation of MTAL and LTAL Load Effects of Simply Supported Bridge**

The correlation of MTAL/LTAL load effect ratio between Medium Term Axle Load (MTAL) and Long Term Axle Load (LTAL) varies along the loaded length. The result from the upper limit ratio is adopted in the subsequent comparison with other bridge structural systems for establishing the final MTAL/LTAL load effect ratio to be adopted in the latter part of this study. This may sound conservative but not when considering that the difference between the upper limit and lower limit is less than 0.01.

From the above grillage analyses results on a simply supported bridge, the following observations were made:

1. The loaded length has a significant effect on the MTAL/LTAL load effect ratio. This is to be expected as the uniformly distributed load of LTAL and MTAL is of different intensity along the loaded length and thus, the MTAL/LTAL load effects ratio will vary with span length.
2. The MTAL/LTAL load effect ratio between each specific loaded length also varies. This due to fact that the difference between the MTAL and LTAL load intensity is not constant along the loaded length. For a loaded length of less than 2.0 meters, the MTAL load intensity is slightly higher than LTAL and thus the MTAL/LTAL load effect ratio exceed 1.00. However, it is proposed that a MTAL/LTAL load effect ratio of 1.0 is adopted as bridges with the ratio above 1.0 can be considered as able to carry LTAL load. For a loaded length of 40.0 meters, the MTAL/LTAL load effect ratio is the lowest at about 0.90 because the difference in the load intensity for MTAL and LTAL is the largest.
3. The loading configurations, maximum load at edge or at centre of carriageway, do affect the MTAL/LTAL load ratio. The highest difference, which is about 0.016, of MTAL/LTAL load effects ratio is at the 50m loaded length for R1/U1 geometry loaded along the centre of carriageway. However, the corresponding bending moment and shear are much lower. The MTAL/LTAL load effects ratio adopted is based on the maximum bending moment and shear.
4. The combined effects of all the parameters, which include carriageway width, beam types, spacing, transverse rigidity and skew angles, are less than 0.01 and thus can be considered insignificant.
   1. **Correlation of MTAL and 20SV Load Effects**

Grillage analyses were also carried to determine the load effects due to 20SV special vehicle. The various parameters such as the bridge geometry, beam spacing, transverse rigidity, skew, etc. were considered in the analysis. The results from the grillage analyses are summarised in Table 9.

Table 9: Summary of MTAL/20SV load effect ratio

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Loaded Length  (m) | MOMENT : MTAL/20SV | | | SHEAR : MTAL/20SV | | |
| Maximum ratio | Minimum ratio | Median | Maximum ratio | Minimum ratio | Median |
| 2  4  8  10  12  16  20  24  26  30  38  40  45  50 | 1.000  1.491  1.218  1.324  1.345  1.299  1.158  1.148  1.147  1.137  1.141  1.133  1.124  1.128 | 1.000  1.065  0.815  0.805  0.836  0.784  0.624  0.614  0.613  0.588  0.606  0.611  0.618  0.607 | 1.000  1.305  1.032  1.050  1.114  1.117  0.947  0.934  0.922  0.855  0.848  0.817  0.902  0.810 | 1.000  1.482  1.209  1.226  1.156  0.833  0.871  0.866  0.856  0.914  0.858  0.847  0.836  0.746 | 1.000  1.050  0.693  0.605  0.615  0.560  0.516  0.477  0.491  0.478  0.475  0.474  0.497  0.438 | 1.00  1.270  0.979  0.866  0.766  0.676  0.662  0.638  0.615  0.617  0.613  0.619  0.610  0.615 |

Figure 15: Comparison of MTAL/20SV load effect ratio

The upper limit and lower limit of MTAL/20SV load effect ratios for bending moment and shear force are presented in Figure 15. It is apparent that the variation of MTAL/20SV load effects ratio for moment and shear is very significant. Thus, there is no simple MTAL and LTAL correlation that can be derived from the analyses results.

* 1. **Grillage Analysis for Fixed Supported Bridge**

Grillage analysis was also carried out to determine the MTAL/LTAL load effects ratio for a fixed supported concrete bridge. The various parameters that have been incorporated in the grillage models are similar to those adopted for a simply supported bridge. These parameters include the different bridge span, carriageway width, spacing of beam, transverse rigidity of deck and the various skew angles. The load pattern is based on the maximum load intensity placed at the edge of the carriageway. How significant the effects of these parameters to the MTAL/LTAL ratio for a fixed support bridge can also be evaluated.

The total numbers of 423 grillage analyses have been carried out and the numbers of analysis for each specific loaded span length are given in table 10. Sample calculation on a fixed supported bridge is given in Appendix A.

Table 10: Numbers of grillage anayses

for fixed supported bridge

|  |  |
| --- | --- |
| Loaded Length  (m) | Number of analysis  (nos) |
| 4 | 33 |
| 8 | 33 |
| 10 | 30 |
| 12 | 33 |
| 16 | 33 |
| 20 | 30 |
| 24 | 33 |
| 26 | 33 |
| 30 | 33 |
| 38 | 33 |
| 40 | 33 |
| 45 | 33 |
| 50 | 33 |

* + 1. **Results of Grillage Analysis**

A total of 423 grillage analyses have been carried out and the summary of results from these analyses are presented in Appendix B. The summary of the MTAL/LTAL load effect ratio for support moment, mid-span moment and shear is given in Table 11.

Table 11: Summary of results for fixed support

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Loaded Length  (m) | Moment at Support: MTAL/LTAL | | | Moment at Midspan: MTAL/LTAL | | | Shear : MTAL/LTAL | | |
| Maximum ratio | Minimum ratio | Median | Maximum ratio | Minimum ratio | Median | Maximum ratio | Minimum ratio | Median |
| 2 | 1.000 | 1.000 | 1.00 | 1.000 | 1.000 | 1.00 | 1.000 | 1.000 | 1.00 |
| 4 | 0.929 | 0.928 | 0.929 | 0.947 | 0.946 | 0.947 | 0.937 | 0.935 | 0.936 |
| 8 | 0.910 | 0.909 | 0.910 | 0.930 | 0.928 | 0.929 | 0.919 | 0.917 | 0.918 |
| 10 | 0.933 | 0.932 | 0.932 | 0.948 | 0.945 | 0.946 | 0.940 | 0.936 | 0.938 |
| 12 | 0.960 | 0.959 | 0.960 | 0.968 | 0.967 | 0.967 | 0.964 | 0.962 | 0.963 |
| 16 | 0.977 | 0.976 | 0.977 | 0.981 | 0.980 | 0.981 | 0.979 | 0.977 | 0.979 |
| 20 | 0.995 | 0.994 | 0.995 | 0.996 | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 |
| 24 | 0.962 | 0.961 | 0.962 | 0.968 | 0.965 | 0.967 | 0.965 | 0.964 | 0.965 |
| 26 | 0.960 | 0.959 | 0.960 | 0.967 | 0.963 | 0.965 | 0.964 | 0.963 | 0.963 |
| 30 | 0.947 | 0.945 | 0.946 | 0.955 | 0.950 | 0.953 | 0.951 | 0.947 | 0.950 |
| 38 | 0.908 | 0.905 | 0.907 | 0.919 | 0.913 | 0.916 | 0.915 | 0.909 | 0.913 |
| 40 | 0.890 | 0.886 | 0.889 | 0.903 | 0.895 | 0.900 | 0.898 | 0.890 | 0.894 |
| 45 | 0.913 | 0.910 | 0.912 | 0.922 | 0.918 | 0.920 | 0.919 | 0.914 | 0.915 |
| 50 | 0.937 | 0.934 | 0.936 | 0.943 | 0.939 | 0.941 | 0.941 | 0.936 | 0.938 |

The curve of the MTAL/LTAL load effects ratio for the respective moment and shear are interpolated as shown in Figure 16. The results indicate that the effect due the moment at mid-span is the controlling factor.

Figure 16: MTAL/LTAL load effect ratio for fixed support bridge

The difference between the upper and lower limit load ratio for each specific moment at support, moment at mid-span and shear is less than 0.009, which can be considered as insignificant. However, the difference between the upper limit ratio due to moment at mid-span and the lower limit ratio due to moment at support is about 0.019. It seems that the effect due to the bridge structural system is more significant rather than the effects of the various parameters.

A quick check using line load analysis also indicated that the load effects ratio due to moment at mid-span is significantly higher than the load effect ratio due to moment at support. This, more or less, verifies the results of the grillage analysis.

* + 1. **Correlation of MTAL and LTAL Load Effect for Fixed Supported Bridge**

The correlation of MTAL/LTAL load effect ratio between Medium Term Axle Load (MTAL) and Long Term Axle Load (LTAL) for a fixed supported bridge varies along the loaded length. The result from the upper limit ratio is adopted in the subsequent comparison with other bridge structural systems for establishing the final MTAL/LTAL load effect ratio to be adopted in the latter part of this study.

From the grillage analyses results on a fixed supported bridge, the following observations were made:

1. The loaded length has a significant effect on the MTAL/LTAL load effect ratio.
2. The MTAL/LTAL load effect ratio at each specific loaded length also varies due to the difference in load intensity for MTAL and LTAL.
3. The upper limit of MTAL/LTAL load effect ratio is due to the effect of bending moment at mid-span.
4. The combined effects of all the parameters, which include carriageway width, beam types, spacing, transverse rigidity and skew angles, to the MTAL/LTAL load effect ratio from the moment at support, moment at mid-span and shear at are less than 0.01 and can be considered insignificant.
   1. **Analysis of Continuous Span Bridge**

The results from the simply supported and fixed support analysis clearly indicated that the loaded length and the difference in the loading intensity have a significant effect on the MTAL/LTAL load effects ratio. The bridge structural system, between simple and fixed support, do affects the MTAL/LTAL load effects ratio when comparing the maximum bending moment at mid-span.

On the other hand, the effects from various parameters such as carriageway width, types and spacing of beams, transverse rigidity of deck and the skew angle are not significant with the difference between the upper and lower limit ratio of less than 0.01. The obvious reason for this is that the loading type, i.e. uniformly distributed load, for MTAL and LTAL are similar and only the intensity varies with loaded length. Similarly, the same reasoning can be applied to continuous span bridge. As such, the analysis on the effects of the various parameters mentioned above was not carried out for continuous span bridge.

The determination of MTAL/LTAL load effects ratio for two-span and three-span continuous bridge was carried out using STAAD III based on a line model. The sectional properties of the grillage members are based on a rectangular concrete section of 2.5 meter constant width and the depth increases progressively in tandem with the loaded length.

The analyses for the two-span continuous and three-span continuous bridge are given in Appendix A.

1. Two Span Continuous Bridge

A two span continuous bridge of equal span length was adopted in the analysis. Two loading configurations were adopted in the evaluation which comprises of, first, both of the spans are fully loaded with uniformly distributed load (UDL) and, second, only one of the spans is fully loaded. The load loading configurations are shown in Figure 17 and Figure 18 respectively. The knife edge load (KEL) is applied at the centre of the span for deriving the maximum bending moment and near the support for the maximum shear.

The loading intensity of the UDL is based on a width of one notional lane and it shall correspond with the respective loaded length. The KEL is taken as 100 kN per notional lane.

Loaded Length = L

Span 1 = L/2

Figure 17: Loaded length over two span

Span 2 = L/2

Loaded Length = L

Span 1 = L

Figure 18: Loaded length over one span

Span 2 = L

The determination of the MTAL/LTAL load effect ratio is based on the loaded length and not the bridge span. Thus, for a two span bridge of equal span *L/2*, the loaded length for calculating the negative moment at support will equal to *L* as shown in Figure 17. However, for calculating the positive moment at mid-span for a similar loaded length of L, the bridge span would now be *L* instead of *L/2 as* shown in Figure 18. Otherwise, the comparison of MTAL/LTAL load effect ratio is not correct since the loading intensity varies for different loaded length.

The results of the analysis for a two span continuous bridge with both spans loaded are interpolated to arrive at the curves as shown in Figure 19.

The results indicate a significant different in MTAL/LTAL load effects ratio between the maximum moment at mid-span and maximum moment at support. The MTAL/LTAL load effect ratio due to shear lie between the two moment curves.

Figure 19: MTAL/LTAL load effect of two span continuous with both span loaded

The results of the analysis whereby only one span is fully loaded are also interpolated to arrive at the curves as shown in Figure 20. In this load configuration, the different in the MTAL/LTAL load effects ratio between the maximum moment at mid-span, maximum moment at support and maximum shear is relatively small and can be considered as insignificant.

Figure 20: MTAL/LTAL load effect of two span continuous with one span loaded.

The comparison of moment at mid-span and shear for a two span load and one span loaded are given in Figure 21 and Figure 22 respectively. The results showed that the moment at mid-span and shear from a one span loaded are much higher than the two span loaded. Hence, the MTAL/LTAL load effect ratios derived from the critical moment and shear are adopted.

Figure 21: Two Span Continuous – Comparison of moment

Figure 22: Two Span Continuous – Comparison of shear

The comparison between the moment at mid-span between a one span loaded and two span loaded are given in Figure 23 below.

Figure 23: Two span continuous – Comparison of mid-span moment of MTAL/LTAL load effect between one span and two span loaded.

The results indicate that the MTAL/LTAL load effects ratio of moment at mid-span due to two span loaded is much higher than one span loaded. However, the moment is at the maximum when considering only one span loaded. The result from the critical moment is adopted for establishing the MTAL/LTAL load effects ratio. It is also apparent that the MTAL/LTAL load effect ratio of the moment at support due to one span loaded and also two span loaded is lower than the ratio of moment at mid-span of one loaded span.

1. Three Span Continuous Bridge

The analysis of a three span continuous bridge of equal span length was also carried out. Two loading configurations were adopted in the evaluation which comprises of, first, both of the spans are fully loaded with uniformly distributed load (UDL) and, second, only one of the spans is fully loaded. The load loading configurations are shown in Figure 24 and Figure 25 respectively. The knife edge load (KEL) is applied at the centre of the span for deriving the maximum bending moment and near the support for the maximum shear.

The loading intensity of the UDL is based on a width of one notional lane and it shall correspond with the respective loaded length. The KEL is taken as 100 kN per notional lane.

Loaded Length = L

Span 1 = L/2

Figure 24: Loaded length over two span

Span 2 = L/2

Span 3 = L/2

Loaded Length = L

Span 1 = L

Figure 25: Loaded length over one span

Span 2 = L

Span 3 = L

The results of the analysis for a three span continuous bridge with both span loaded are interpolated to arrive at the curves as shown in Figure 26.

The results indicate a significant different in MTAL/LTAL load effects ratio between the maximum moment at mid-span and maximum moment at support. The MTAL/LTAL load effect ratio due to shear lie between the two moment curves.

Figure 26: MTAL/LTAL ratio for three span continuous with two span loaded

The results of the analysis whereby only one span is fully loaded are also interpolated to arrive at the curves as shown in Figure 27. In this load configuration, the different in the MTAL/LTAL load effects ratio between the maximum moment at mid-span, maximum moment at support and maximum shear is relatively small and can be considered as insignificant.

Figure 27: MTAL/LTAL ratio for three span continuous with one span loaded

The comparison of moment at mid-span and shear for a two span load and one span loaded are given in Figure 28 and Figure 29 respectively. The results showed that the moment at mid-span and shear from a one span loaded are much higher than the two span loaded. Hence, the MTAL/LTAL load effect ratios derived from the critical moment and shear are adopted.

Figure 28: Three Span Continuous – Comparison of moment

Figure 29: Three Span Continuous – Comparison of shear

The comparison between the moment at mid-span between a one span loaded and two span loaded are given in Figure 23 below.

Figure 30: Three span continuous – Comparison of MTAL/LTAL load effect between one span loaded and two span loaded.

The results indicate that the MTAL/LTAL load effects ratio of moment at mid-span due to two span loaded is much higher than one span loaded. However, the moment is at the maximum when considering only one span loaded. The result from the critical moment is adopted for establishing the MTAL/LTAL load effects ratio. It is also apparent that the MTAL/LTAL load effect ratio of the moment at support due to one span loaded and also two span loaded is lower than the ratio of moment at mid-span of one loaded span.

The comparison of moment at mid-span between a one span loaded and two span loaded for a two span continuous and three span continuous bridge are given in Figure 31 below.

Figure 31: Comparison of MTAL/LTAL load effect ratio between one span loaded and two span loaded.

The results indicate that the MTAL/LTAL load effects ratio of moment at mid-span due to two span loaded is much higher than one span loaded. However, the moment is at the maximum when considering only one span loaded. The result from the critical moment is adopted for establishing the MTAL/LTAL load effects ratio. It is also apparent that the MTAL/LTAL load effect ratio of the moment at support due to one span loaded and also two span loaded is lower than the ratio of moment at mid-span of one loaded span. Hence, MTAL/LTAL load effect ratio derived from mid-span moment will be adopted.

* 1. **Recommendation for MTAL/LTAL Load Effects Ratio**

In establishing the correlation of load effects between Medium Term Axle Load and Long Term Axle Load, the results from the upper limit ratio based on the maximum bending moment is adopted.

The results from the analysis for simply supported bridge, fixed support bridge, two span and three span continuous bridge compiled together as in Figure 32 for comparison.

Figure 32: MTAL/LTAL load effects ratio for Simple support , fixed support and continuous bridge

From the results, it can be seen that the difference in the MTAL/LTAL load effects ratio between the simply supported bridge and the fixed supported bridge is marginal except at the loaded span of about 6m to 8m. Thus it is convenience to combine these two curves so as to make it much simpler to used.

The MTAL/LTAL load effects ratio of moment at mid-span due to one span loaded for the continuous span bridges does not varies significantly from that of the simple and fixed supported bridges. However, the MTAL/LTAL load effects ratio of moment at mid-span due to two span loaded for the continuous span bridges is significantly higher than those metioned above. Since the maximum moment due to two span loaded is not the critical moment, it is not adopted in establishing the final MTAL/LTAL load effect ratio.

A best fit curve of MTAL/LTAL load effect ratio was introduced, as shown in Figure 33, to cover the simply supported bridge, fixed supported bridge and continuous bridges to make it simpler to apply.

Figure 33: Best fit curve of MTAL/LTAL load effects ratio for Simple support , fixed support and continuous bridge

The recommended best fit curve of MTAL/LTAL load effects ratio for simple support, fixed support and continuous span is given in tabulated form in Table 12 below and is further shown in the following Figure 34.

Table 12: Proposed MTAL/LTAL load effect ratio for simple, fixed support and Continuous Bridge

|  |  |
| --- | --- |
| Loaded Length  (m) | MTAL/LTAL load effect ratio |
| 2 | 1.000 |
| 4 | 0.945 |
| 6 | 0.930 |
| 8 | 0.927 |
| 10 | 0.945 |
| 12 | 0.966 |
| 14 | 0.974 |
| 16 | 0.980 |
| 18 | 0.990 |
| 20 | 0.995 |
| 22 | 0.980 |
| 24 | 0.970 |
| 26 | 0.965 |
| 28 | 0.960 |
| 30 | 0.953 |
| 32 | 0.945 |
| 34 | 0.935 |
| 36 | 0.925 |
| 38 | 0.914 |
| 40 | 0.901 |
| 45 | 0.921 |
| 50 | 0.942 |

Figure 34: Recommended MTAL/LTAL load effect ratio

1. **TASK (ii) - STRUCTURAL CAPACITY ASSESSMENT OF THE FEDERAL BRIDGES FOR COMPLIANCE TO VEHICULAR LOADS AS PER WRO 2003**
   1. **Structural Capacity Assessment**

Task (ii) involved structural capacity assessment of the Federal Bridges for compliance to the vehicular loads as per specified in the First Schedule of WRO 2003. The assessment shall be based on (ELR-MTAL) ≥ **β’** (ELR-LTAL) where the value of **β’** is the MTAL/LTAL load effects ratio which have been determined from Task (i) above. The ‘Evaluation Load Rating’ (ELR) for LTAL shall be based on the earlier *‘Bridge Management Study’* completed in 2007.

If the ELR-LTAL rating of a particular bridge is higher than the MTAL/LTAL load effect ratio, it means that the bridge has a structural capacity to carry MTAL loading. Thus, the bridge is in compliance with the First Schedule of WRO 2003. Otherwise, the bridge needs to be replaced to be in compliance with WRO 2003.

* 1. **List of Bridges for Compliance and Replacement**

Based on the proposed MTAL/LTAL load effects ratio under Task (i), the lists of bridge in Sabah, Sarawak and Labuan from the earlier *‘Bridge Management Study’* completed in 2007 have been updated. Bridges which comply with ELR-MTAL rating have been categorised under List I of WRO 2003 and those bridges with a lower rating than ELR-MTAL shall be recommended for replacement. There are bridges in Sabah and Sarawak which have been replaced and strengthened. These bridges are deemed to be able carry MTAL load. One bridge in Sabah and one bridge in Sarawak was load tested in this study and the results showed that these two bridges are able to carry the MTAL load.

The complete lists of bridges in Sabah, Sarawak and Labuan together with its specific recommendation are given in Appendix C, D and E.

* + 1. **List of Bridges in Sabah**

There are 8 Federal Routes involving 181 bridges in the study network for Sabah as listed below. The Federal Routes involved in the study are shown in Figure 35.

1. Federal Route FSU01 - 42 bridges
2. Federal Route FS001 - 29 bridges
3. Federal Route FS013 - 38 bridges
4. Federal Route FS022 - 33 bridges
5. Federal Route FS500 - 28 bridges
6. Federal Route FS501 - 5 bridges
7. Federal Route FS502 - 4 bridges
8. Federal Route FS503 - 2 bridges

Total Numbers = 181 bridges

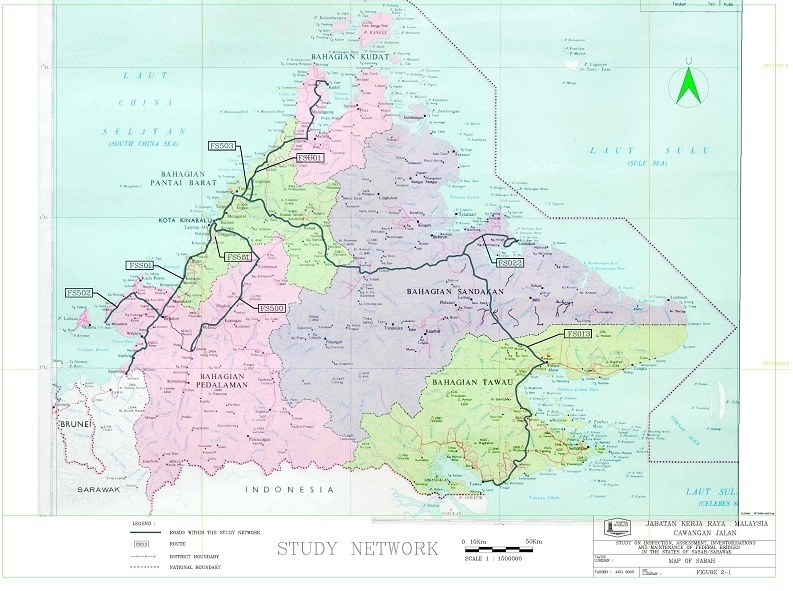


Figure 35 – Federal Routes in Sabah invoved in the Study

Out of these 181 bridges, there were 22 numbers of bridges where the bridge assessments were not carried in the previous study. Consequently, data on the *ELR-*LTAL rating were not available. The bridges involved are hybrid bridges which comprises of two or more different types of bridge structures at one particular location. Based on the discussion with JKR Sabah, their recommendation is that these bridges should be replaced.

The bridges which comply with ELR-MTAL and bridges which are to be replaced are listed below in Table 13. The bridges which are to be replaced have been prioritised based on the ELR-LTAL rating and the list is given in Appendix C.

Table 13: Summary of bridges in Sabah

|  |  |  |  |
| --- | --- | --- | --- |
| Federal Routes | Numbers of Bridges | Bridges Comply with MTAL | Bridges Proposed for Replacement |
| Federal Route FSU01  Federal Route FSS01  Federal Route FS013  Federal Route FS022  Federal Route FS500  Federal Route FS501  Federal Route FS502  Federal Route FS503 | 42  29  38  33  28  5  4  2 | 28  16  31  13  25  2  3  1 | 14  13  7  20  3  3  1  1 |
| Total Numbers | 181 | 119 | 62 |

Static Load test was carried out in this study on Structure FSS01/012/12 over Sg. Putatan and the result indicated that this bridge is capable to carry MTAL load intensity. Based on this result, the bridge was listed under the category of “bridges complying with MTAL”, although the moment rating is 0.89 ELR-LTAL which is less than the 0.95 ELR-MTAL required. There is another Structure FSS01/012/13 over Sg. Putatan nearby which is of similar structural system and configuration with the same ELR-LTAL rating for moment of 0.89. Since the bridge is similar, the consultant proposed this particular bridge be listed under the category of “bridges complying with MTAL”.

The earlier *‘Bridge Management Study’* completed in 2007 have listed the bridges shown in Table 14 as deficient structures due to the inadequacy of the axial capacity under design SV loadings although these bridges have the minimum ELR-LTAL rating of 1.08. Since these bridges not only able to carry MTAL load but also LTAL load, it is proposed that these bridges be listed under the category of “bridges complying with MTAL”.

Table 14: Bridges with inadequate ELR-SV units but adequate ELR-LTAL rating



* + 1. **List of bridges in Sarawak**

There are 8 Federal Routes involving 206 bridges in the study network for Sarawak as listed below. The Federal Routes involved in the study are shown in Figure 36

1. Federal Route FQA01 - 157 bridges
2. Federal Route FQB01 - 11 bridges
3. Federal Route FQC01 - 7 bridges
4. Federal Route FQ021 - 10 bridges
5. Federal Route FQ025 - 5 bridges
6. Federal Route FQ800 - 4 bridges
7. Federal Route FQ801 - 8 bridges
8. Federal Route FQ802 - 4 bridges
9. Total Numbers = 206 bridges

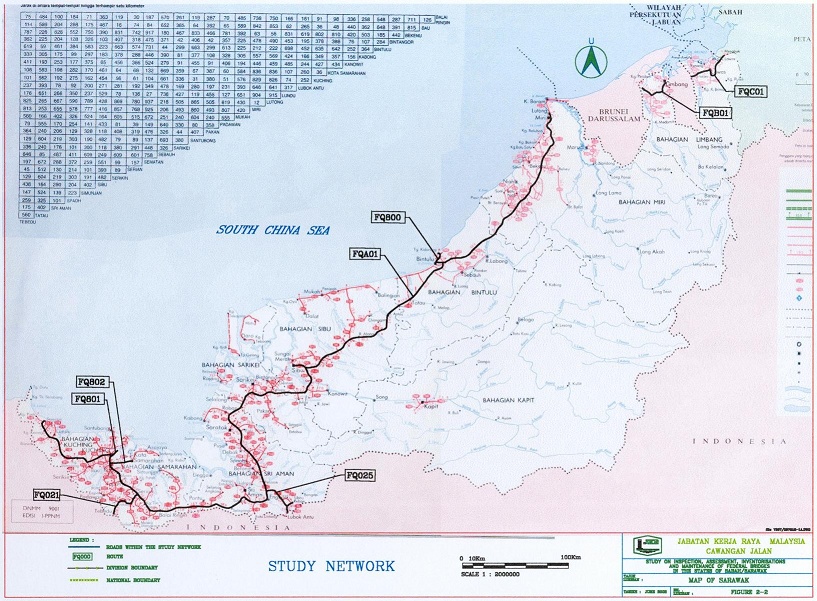


Figure 36 – Federal Routes in Sarawak Invoved in the Study

The summary of bridges which comply with MTAL and bridges which need to be replaced are listed in Table 15 below. The bridges which are to be replaced have been prioritised based on the ELR-LTAL rating and the list is given in Appendix D

Table 15: Summary of bridges in Sarawak

|  |  |  |  |
| --- | --- | --- | --- |
| Federal Routes | Numbers of Bridges | Bridges Comply with MTAL | Bridges Proposed for Replacement |
| Federal Route FQA01  Federal Route FQB01  Federal Route FQC01  Federal Route FQ021  Federal Route FQ025  Federal Route FQ800  Federal Route FQ801  Federal Route FQ802 | 157  11  7  10  5  4  8  4 | 128  10  4  10  3  4  8  4 | 28  1  3  -  2  -  -  - |
| Total Numbers | 206 | 172 | 34 |

Bridge assessment was not carried out on a suspension bridge FQC01/025/10 over Btg. Lawas and thus the ELR-MTAL rating cannot be determined. However, this bridge has been rehabilitated and thus, it is listed under the category of “bridges complying with MTAL”.

Static Load test was also carried out in this study on Structure FQA01/717/79 over Sg. Sibu No. 4B and the result indicated that this bridge is capable to carry MTAL load intensity. Based on this result, the bridge is listed under the category of “bridges complying with MTAL”, although the rating is 0.89 ELR-LTAL which is less than the 0.95 ELR-MTAL required.

* + 1. **List of Bridges in Labuan**

There are 6 Federal Routes involving 9 bridges in the study network for Labuan. The Federal Routes involved in the study are shown in Figure 24.

The summary of bridges which comply with MTAL and bridges which need to be replaced are listed in Table 16 below. The bridges which are to be replaced have been prioritised based on the ELR-LTAL rating and the list is given in Appendix E

Table 16: Summary of bridges in Labuan

|  |  |  |  |
| --- | --- | --- | --- |
| Federal Routes | Numbers of Bridges | Bridges Comply with MTAL | Bridges Proposed for Replacement |
| Federal Route FL700  Federal Route FL703  Federal Route FL704  Federal Route FL705  Federal Route FL745  Federal Route FL749 | 4  1  1  1  1  1 | 2  1  1  1  -  1 | 2  -  -  -  1  - |
| Total Numbers | 9 | 6 | 3 |

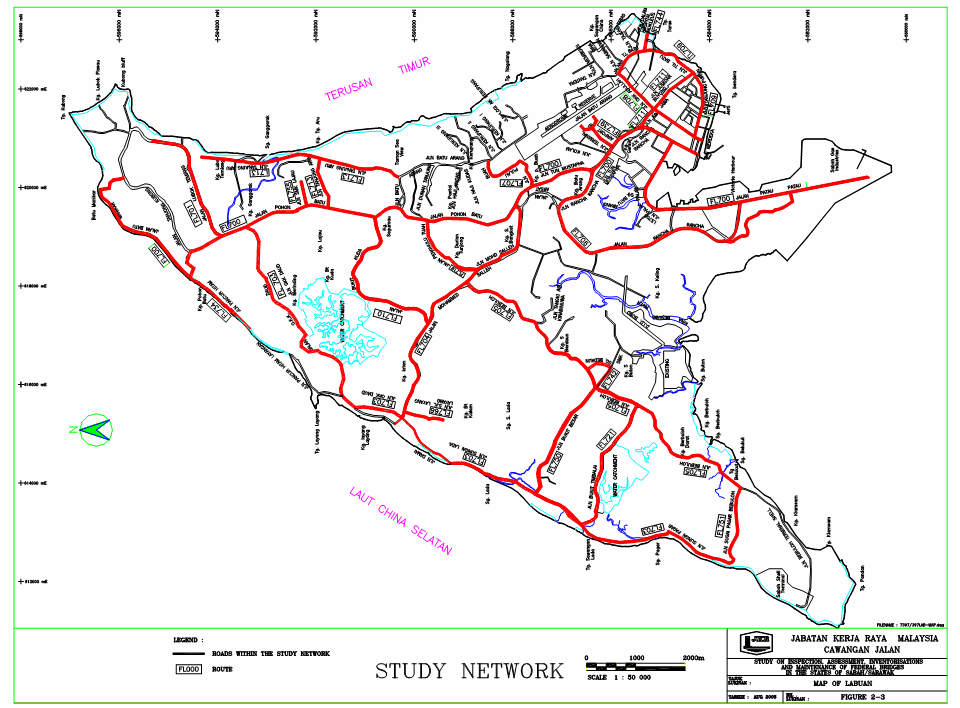
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Figure 37 – Federal Routes in Labuan Invoved in the Study

1. **TASK (iv) - IDENTIFY AND PRIORITISE FEDERAL ROUTES FOR UPGRADING TO LIST I OF THE SECOND SCHEDULE OF WRO 2003**
   1. **Parameters for Prioritisation**

In identifying the parameters for the prioritization of Federal Routes for upgrading to List I of the Second Schedule of WRO 2003, reference were made to the relevant sections from ‘Kajian Semula Pembangunan Rangkaian Jalanraya HNDP Fasa 2’. Discussions were also held with JKR Sarawak and JKR Sabah, whereby, the representatives from PDRM, JPJ and SCORE were also present.

From the above reference and discussion, the following parameters will be adopted to prioritize the Federal Routes for upgrading to List I of WRO 2003.

1. The Important of the Federal Routes

The important of the Federal Routes will be measured in term current and future traffic demands, socio-economic development, main road linkage and accessibility.

1. Bridge rating

The bridge structural capacity is one of parameters that will be under consideration. It is obvious the bridge with the lowest ‘Evaluation Load Rating’ shall be given the first priority for upgrading. Any sudden bridge failure will not only endanger the public but will make that particular route impassable to traffic.

1. Cost of bridge replacement.

It is not possible to replace all the bridges at once as the cost implication will be very high. Decision on any replacement work needs to take into consideration of the limited budget available. The cost estimation of bridge replacement per square metre is based on the local condition. The plan area of the respective bridges is calculated based on 13.9 meter width and the actual span length of the existing bridge.

* 1. **Prioritisation of Federal Routes**
     1. **Federal Routes in Sabah**

Based on the discussion and feedback from JKR sabah, the prioritization of the Federal Routes for upgrading to List I of WRO 2003 and the number of bridge replacement for each respective route are given in Table 17.

The general cost of bridge replacement is based on the information received from JKR Sabah:

1. Single span or less than 50m span: RM8,000/sq.m
2. Multiple span or more than 50m span: RM10,000/sq.m

The estimated cost of bridge replacement for the respective routes is also given in Table 17. Further details on the cost estimation on each particular bridge can be referred to in Appendix C.

Table 17: Priority of Federal Routes and estimated cost of bridge replacement in Sabah

|  |  |  |  |
| --- | --- | --- | --- |
| Priority of Routes | Federal Routes | Bridge Replacement  (nos.) | Estimated Cost  (RM) |
| Priority 1  Priority 2  Priority 3  Priority 4  Priority 5  Priority 6  Priority 7  Priority 8 | Federal Route FSS01  Federal Route FS501  Federal Route FS013  Federal Route FS022  Federal Route FSU01  Federal Route FS503  Federal Route FS502  Federal Route FS500 | 13  3  7  20  14  1  1  3 | 75,700,000  8,700,000  73,200,000  70,700,000  57,200,000  27,700,000  8,600,000  23,600,000 |
| Total | | 62 | 345,400,000 |

* + 1. **Federal Routes in Sarawak**

Based on the discussion and feedback from JKR Sarawak, the prioritization of the Federal Routes for upgrading to List I of WRO 2003 and the number of bridge replacement for each respective route are given in Table 18.

The general cost of bridge replacement is based on the information received from JKR Sarawak:

1. Normal beam and slab bridge: RM8,000/sq.m
2. Cantilever and box girder bridge: RM10,000/sq.m
3. Cable stayed bridge: RM11,000/sq.m

The estimated cost of bridge replacement for the respective routes is also given in Table 18. Further details on the cost estimation on each particular bridge can be referred to in Appendix D

Table 18: Priority of Federal Routes and estimated cost of bridge replacement in Sarawak

|  |  |  |  |
| --- | --- | --- | --- |
| Priority of Routes | Federal Routes | Bridge Replacement  (nos.) | Estimated Cost  (RM) |
| Priority 1  Priority 2  Priority 3  Priority 4  Priority 5  Priority 6  Priority 7  Priority 8 | Federal Route FQ800  Federal Route FQ801  Federal Route FQ802  Federal Route FQ021  Federal Route FQA01  Federal Route FQB01  Federal Route FQC01  Federal Route FQ025 | -  -  -  -  28  1  3  2 | -  -  -  -  320,000,000.00  69,500,000.00  24,800,000.00  10,600,000.00 |
| Total |  | 34 | 424,900,000.00 |

* + 1. **Federal Routes in Labuan**

The proposed prioritization of the Federal Routes in Labuan for upgrading to List I of WRO 2003 and the number of bridge replacement for each respective route are given in Table 19.

The general cost of bridge replacement is based RM7,000/sq.m and the estimated cost of bridge replacement for the respective routes is also given below in Table 19. Further details on the cost estimation on each particular bridge can be referred to in Appendix E.

Table 15: Priority of Federal Routes and estimated cost of bridge replacement in Labuan

|  |  |  |  |
| --- | --- | --- | --- |
| Priority of Routes | Federal Routes | Bridge Replacement  (nos.) | Estimated Cost  (RM) |
| Priority 1  Priority 2  Priority 3  Priority 4  Priority 5  Priority 6 | Federal Route FL703  Federal Route FL704  Federal Route FL705  Federal Route FL749  Federal Route FL700  Federal Route FL745 | -  -  -  -  2  1 | -  -  -  -  7,000,000.00  1,900,00.00 |
| Total |  | 3 | 8,900,000.00 |