Load Rating of Timber Bridges in Western Australia

ABSTRACT
Main Roads Western Australia (MRWA) inspects, load rates, and maintains (repairs, upgrades or replaces) all bridges for which it is responsible. In addition, MRWA also inspects, load rates and gives advice for other road bridges throughout the State as part of the statutory responsibility given under the Road Traffic Act 1974 to load post all bridges on public roads and through a long standing arrangement with Local Government Authorities.

Many timber bridges were built in the past owing to the easy availability of hardwood trees. Although no new timber bridges have been built in the State by MRWA for the last 30 years the majority of Western Australia’s road bridges are still timber. The condition assessment and maintenance of existing timber bridges will continue until their eventual replacement with non-timber bridges. The present MRWA policy is to inspect these bridges in detail once every five years. Last year approximately 300 timber bridges were inspected and 140 load rated.

The load rating of this many bridges is a considerable task and has been greatly facilitated by use of a suite of in-house developed programs. The main program is TIMBAR. TIMBAR develops a grillage model using ACES as its analysis engine to assess the load effects for a variety of vehicles on the various bridge elements (stringers and piles). Load rating of timber bridges is carried out based on the working stress design methodology of the now superseded Australian timber structures design standard AS 1720.1-1988 and not to the ultimate limit state design methodology of AS 1720.1-1997 as the ultimate limit state methodology has been found to give overly conservative results for MRWA type standard timber bridges. The working stress methodology has been used successfully by MRWA over many years to load rate these bridges. Several additional spreadsheet-based programs have been developed to automate the rating of other elements, halfcap bearing, deck planks and wingwall piles. This paper describes the suite of programs and their roles in strength assessment and load rating of key components of existing timber bridges.

BIOGRAPHIES
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Robert (Jock) Scanlon is the Senior Engineer Structures for Main Roads Western Australia and has had extensive experience in the design, construction and management of structures. He received an Associate in Civil Engineering from the Institute of Technology WA in 1974.
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SYNOPSIS

Main Roads Western Australia (MRWA) inspects, load rates, and maintains all bridges for which it is responsible. In addition, MRWA also inspects, load rates and gives advice for other road bridges within the State.

Many timber bridges were built in the past. Although no new timber bridges have been built in the State by MRWA for the last 30 years the majority of Western Australia’s road bridges are still timber. The condition assessment and maintenance of these bridges will continue until their eventual replacement with non-timber bridges. Last year approximately 300 timber bridges were inspected and 140 load rated.

The in-house load rating of this many bridges is greatly facilitated by using a suite of programs developed in-house. Ratings are carried out using the working stress design methodology based on the now superseded Australian timber structures design standard AS 1720.1-1988. This methodology has been used successfully by MRWA over many years. This paper describes the suite of programs and their roles in strength assessment and load rating of key components of existing timber bridges.

1. INTRODUCTION

Main Roads Western Australia (MRWA) inspects, load rates, and maintains (repairs, upgrades or replaces) all bridges for which it is directly responsible. In addition, MRWA also inspects, load rates and gives advice for other road bridges throughout the State as part of the statutory responsibility given under the Road Traffic Act 1974 to load post all bridges on public roads and through a long standing arrangement with Local Government Authorities.

Many timber bridges were built in the past owing to the easy availability of hardwood trees. There are more than 1500 timber and timber hybrid bridges in Western Australia, with approximately 340 on highways and major roads. Although no new timber bridges have been built in the State by MRWA for the last 30 years the majority of Western Australia’s road bridges are still timber. The condition assessment and maintenance of existing timber bridges will continue until their eventual replacement with non-timber bridges. The present MRWA policy is to inspect these bridges in detail once every five years. Last year 940 timber spans (from approximately 300 bridges) were inspected and 140 load rated.

The load rating of this many bridges is a considerable task and has been greatly facilitated by use of the suite of in-house developed programs. (In this paper, Excel workbooks with user pre-written equations are considered to be programs.) The
main program is TIMBAR. TIMBAR develops a grillage model using ACES (ACES Analysis Systems, 2007) as its analysis engine to assess the load effects for a variety of vehicles on the various bridge elements (stringers and piles).

Load rating of timber bridges is carried out based on the working stress design methodology of the now superseded Australian timber structures design standard AS 1720.1-1988 and not to the ultimate limit state design methodology of AS 1720.1-1997 as the ultimate limit state methodology has been found to give overly conservative results for MRWA type standard timber bridges.

The working stress methodology has been used successfully by MRWA over many years to load rate these bridges. The main factors (MRWA, 2009) causing the inconsistency between the working stress standard and the ultimate limit state standard are:

- ultimate load factors used for the dead load and the live load, and
- conservative capacity reduction factors adopted in the ULS standard when considered in conjunction with the ultimate load factors adopted.

Several additional spreadsheet-based programs have been developed to automate the rating of other elements, halfcap bearing, deck planks and wingwall piles. This paper describes the suite of programs and their roles in the strength assessment and load rating of the key components of existing timber bridges.

2. HISTORY OF THE DEVELOPMENT OF THE LOAD RATING PROGRAMS

The main TIMBAR program is the end result of numerous development iterations. The first version was a similar purpose program (Timbrid/Timpro) developed in 1992 (MRWA, 2008). TIMBAR was developed for MRWA as a Windows version of Timbrid/Timpro in 2002. Updates and revisions are carried out in-house.

Timbrid/Timpro was developed to improve the efficiency in load rating timber bridges. Before its implementation, load ratings were carried out manually, a tedious process (hence error-prone) and time consuming. It was also difficult to maintain consistency between individuals performing similar load ratings.

While the use of Timbrid/Timpro somewhat automated the load rating process, it was still time-consuming as information from the output files from the structural analysis had to be manually input into the Excel spreadsheet program used for load rating. The development of TIMBAR resulted in the automation of this process.

Since then, TIMBAR has undergone numerous improvements based on feedback from users as well as operational changes, and these improvements include the following features:

- Inclusion of the AS 5100 design load, M1600.
- Facility to load rate special vehicles with variable and multiple axles with variable width and length for use in heavy load assessments.
- Addition of a further defect type (elliptical) for stringer sections to match changes to inspection procedures.
• Input of both overall span and clear span to enable effective span lengths to be determined for stringer analysis, taking into account corbel action.
• Vehicle loads applied at the face of support for shear in accordance with provisions in AS 1720.1.

Other elements which require hand calculations, and were not load rated by TIMBAR included halfcaps, fullcaps, decking, sill beams, bed logs, steel piles, bearers and wingwall piles. To improve efficiency, two Excel workbook programs have been developed, one to load rate timber decking and the other to load rate halfcap bearings. A third program to assess wingwall piles is currently under development.

3. ROLES OF PROGRAMS IN LOAD RATING PROCEDURE

The roles of these programs in the load rating procedure are shown in Figure 1. Timber bridges are inspected, in turn, at least once every five years, and a detailed inspection report (DIR) is produced from each inspection. The inspection includes measuring key dimensions of the bridge, drilling of timber piles and stringers at key locations to determine the extent of any voids or rot zones, and visual inspection of the condition of bridge elements. Elements identified to have substantially deteriorated are load rated using TIMBAR and the other Excel programs. However, other elements such as timber halfcaps and sill beams suspected to be deficient are still required to be load rated manually.

Figure 1: Flow diagram showing load rating process for timber bridges
These programs have other applications in addition to the load rating of bridges. They are also used when considering refurbishment works on timber bridges. An example is the sizing of steel stringers for replacement of deteriorated timber stringers using TIMBAR. These programs have also been used to load rate as-built refurbished bridges. External consultants engaged by MRWA to carry out timber bridge refurbishment works use these programs. Having all parties involved with load rating using the same programs promotes consistency in the load ratings of timber bridges within Western Australian.

4. TIMBAR PROGRAM SUITE

The TIMBAR suite consists of two main programs, Timbar.exe and Timbar.xls. The subsections below describe the major features of TIMBAR.

4.1 Deck and Stringer Modelling
TIMBAR allows users to input three different defect types as shown in Figure 2. Figure 3 shows a photograph of an elliptical defect. Much effort has been made to minimise the opportunity of introducing human error into the input. The input screen for stringer section shapes provides an immediate visual feedback to users of the user’s input for section shapes (see Figure 4). The condition of the material for each section, either “good”, “friable” or “rot” is obtained from the DIR. The permissible stress is reduced accordingly if a condition is rated as “friable” or “rot”.

Stringer configuration and condition is entered at three locations, at both ends for the determination of shear capacity and at midspan for bending capacity.

![Defect types in TIMBAR (MRWA, 2008)](image)

Figure 2: Defect types in TIMBAR (MRWA, 2008)

![An elliptical shaped defect in a stringer section](image)

Figure 3: An elliptical shaped defect in a stringer section
The input screen for the deck gives visual feedback of the deck properties; Figure 5 shows part of a typical screen display for the deck. A grillage model is developed by the program based on these section properties and other input information.

The deck is assumed to be of uniform thickness, and it is usually either timber deck planks or a concrete overlay. Timber bridges with a concrete overlay placed on top of the timber decking can be modelled as a timber bridge with a concrete decking, and the timber deck considered non-structural.

TIMBAR automatically generates loadings on the grillage model for the stringers and piles from the transverse member input information described above. Loading from other materials such as non-structural decking, paving materials, kerbing and bridge barriers (railings) are included using patch loads. Each patch is rectangular in plan with its load intensity at any point defined by density and thickness. The use of
different corner thicknesses allows the modelling of patch loads with a cross fall (see Figure 6).

![Figure 6: Part of a typical screen showing patch material with a constant slope](image)

**4.2 Pier and Abutment Piles Modelling**

Pier and abutment piles are assumed to be vertical. Only the position of the piles is required in Timbar.xls to represent the support location. The configuration of the halfcaps is input to determine the distribution of loading to the pier and abutment piles. The program then displays the configuration based on the input locations of both piles and stringers and the nominated halfcap types. Part of a typical output screen for an abutment is shown in Figure 7.

![Figure 7: Part of a typical screen display for abutment piles](image)

The section shape information and condition for piles are input in Timbar.xls, not in Timbar.exe. For an abutment, the properties of the retained soil are also input in Timbar.xls.

**4.3 Output from the Program**

Timbar.exe generates an ACES grillage model with all load cases (dead and live). The vehicular live loads are run at various longitudinal and transverse positions so as to produce the controlling load case for each element. The load effects are output for each element to enable load rating.
Timbar.xls then performs the load rating of the stringers and the abutment and pier piles using these action effects. Table 1 shows a typical load rating table produced by the program for the stringers in a span. The general equation used for load rating is:

$$\text{Load Rating} = \frac{\text{Section Capacity} - \text{Permanent Effects}}{\text{Vehicular Load} \times (1 + \text{Dynamic Load Allowance})}$$

<table>
<thead>
<tr>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Rating (%)</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>T44</td>
</tr>
<tr>
<td>M Truck</td>
</tr>
<tr>
<td>Tandem</td>
</tr>
<tr>
<td>Triaxle</td>
</tr>
<tr>
<td>Quadaxle</td>
</tr>
<tr>
<td>484-Quad</td>
</tr>
<tr>
<td>HLP320</td>
</tr>
<tr>
<td>HLP400</td>
</tr>
<tr>
<td>M1600</td>
</tr>
</tbody>
</table>

5. OTHER EXCEL PROGRAMS

5.1 Halfcap Bearing Rating
Halfcap bearing is an important element to check in load rating of timber bridges. There must be sufficient bearing area between the halfcap and pile to transfer the superstructure stringer loads into the substructure. Figure 8 shows a photograph of a steel halfcap with only 30 mm of seating for the halfcap on the pile and also shows the resulting distress on the pile. The rating of halfcap bearing was carried out by hand. To improve efficiency, an Excel workbook has recently been developed to perform this tedious task. This program allows the bearing capacity of a timber halfcap, steel halfcap or a combined steel and timber halfcap on a timber pile to be assessed.

![Figure 8: A steel halfcap with only 30 mm bearing](image)
Figure 9 shows a typical section through a pier pile, showing halfcaps. The dimensions labelled as “bearing” are measured and reported in the DIR. On one side, the halfcap has been strengthened by the addition of a steel section. The bearing capacity of each bearing interface depends on the allowable bearing stresses of the pile and the halfcap. The bearing capacity of a combined steel and timber halfcap is equal to the sum of capacities of the two individual halfcaps.

![Diagram of pier pile with halfcaps]

Figure 9: Plan and section views of a pier pile with halfcaps

The spreadsheet requires the user to input the halfcap configuration and condition as well as the forces acting on the pile, from Timbar.exe, at the location of the halfcap bearing under consideration.

The program automatically calculates the halfcap bearing area and associated bearing capacity using allowable stress design. This is compared to the bearing loads imparted from dead and vehicle loads with load rating values as per the equation outlined in Section 4.3. The program also enables users to determine the minimum bearing width required for refurbishment design when a steel halfcap is used to strengthen a weakened timber halfcap.

5.2 Deck Plank Rating

Transverse timber decking (without concrete overlay) is required to span between the stringers and transfer wheel loads into these major longitudinal members. Without an effective waterproof layer, however, they are also an element that is prone to deterioration.

From the site inspection, the percentage rot is determined for the timber deck planks and this value is reported in the DIR. In the analysis, the decking is assumed to be of uniform thickness, with a reduced thickness based on this parameter.

T44 wheel load is used as the reference vehicle load, and the effect of other vehicles of the same width is obtained by scaling.

Other information required for the analysis includes width of the deck plank, depth of the deck plank, timber type, condition of the timber (good, friable or rot) and the depth of paving material. The depth of the paving material enables the effect of the
The program automatically calculates the dead and T44 load action effects required for further structural analysis. This gives a calculated partial UDL and length of each patch load for input into any linear-elastic analysis for continuous beams. Figure 11 shows an example of the location of the wheel loads for maximum shear effect on the decking. The location is calculated by taking half the bearing width on top of the stringer (0.1 m) and 0.096 m effective depth of the decking (corrected for the effect of percentage rot) for a total of 0.196 m. On each side within 0.196 m from the centreline of the stringer, wheel loads are assumed to be transmitted directly to the supports (stringers) in bearing rather than shear. The top line beam model shows the location of the loads for maximum shear, and the second line beam shows the loads after trimming off those loads acting over the “bearing” regions. It is the second line beam model that is used in the analysis.

The program automatically calculates the timber deck plank shear and bending capacity using allowable stress design. These values are then compared to the maximum shear and bending moments imparted from dead and vehicle loads with load rating values output as per methodology outlined in Section 4.3.
5.3 Wingwall Pile Strength Assessment

To automate the strength assessment of wingwall piles, an Excel workbook is currently under development. This program considers the effect of the surcharge live load and soil retention dead loads on the wingwall piles. Figure 12 shows a typical wingwall with piles. As the program is still under development and review, further details of the program are not provided here. However, the aim is to automate the load assessment process with user-defined input of wingwall configuration and wingwall pile condition using defect types consistent with TIMBAR methodology.

![Figure 12: Configuration of piles for a wingwall](image)

6. CONCLUDING REMARKS

Programs have been developed in-house and used for load rating of existing timber bridges in Western Australia. The main suite TIMBAR is used to load rate the major elements, namely pier and abutment piles and stringers, of timber bridges. Supporting Excel workbooks have been developed to load rate halfcap bearing, deck planks and wingwall piles. The main features of these programs have been described in this paper.

These programs improve the efficiency of the load rating process in MRWA, reducing the effort required to carry out and check the load rating of timber bridges. They promote consistency in the methodology used. In addition, they make it easier for new employees to acquire load rating skills through using the programs and supporting documentation of these programs.

As these programs are developed and maintained in-house, innovative suggestions for improvement from people involved directly with the inspection or load rating process can be accommodated easily. The programs have been tailor-made to tie seamlessly into the in-house inspection and other load rating procedures of MRWA.
7. REFERENCES

