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Experimental Investigation of Load Sharing Behavior for Timber Half-Caps of Toodyay Bridge

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Abstract: This study investigates the load sharing capabilities for half-caps of a 190m long timber bridge. The bridge has 31 spans over the Avon River in Toodyay, Western Australia. It was constructed from local hardwood timbers and had a series of repairs. However as the width between kerbs was only 5.5 m and it was no footpath it was decided to replace the bridge by a new wider concrete structure. The proposed removal of the existing bridge provided an opportunity to carry out a research program aimed at bridge inspection, estimation of timber material properties, required for more accurate modeling of structural failure as well as selection of improved repair techniques and strengthening methods. Non-destructive evaluation of the bridge prior to construction of a new one was conducted using trucks to provide both static and dynamic loadings. Half-cap load sharing was examined for north and south loading of the bridge deck at the pier and span positions. This paper deals with the results obtained only the north loading case at the pier position. As Toodyay Bridge 631 is a typical timber bridge in Western Australia, the findings of this study can be applied to other bridges to prolong their lifetime.

Keywords: Timber bridge; experimental investigation; half-caps; load; sharing; pier; span.

INTRODUCTION

Over time, bridges may become structurally or functionally deficient. Structurally, the deficiency can result of deterioration, damage, or increased load requirements in excess of the design capacity. The original waterway opening under the bridge may become inadequate due to changing drainage patterns in the watershed or because the hydraulic parameters that formed a basis for the original design became inadequate. Bridges may also become functionally deficient when the roadway width, vertical clearance, or geometry does not satisfy the current traffic requirements.

In most cases, structural deficiencies are corrected by preventative or routine maintenance. If such maintenance is continually neglected, major maintenance may be required to restore the bridge to its original capacity. When hydraulic or geometric deficiencies are encountered, bridge rehabilitation can improve the conditions. If the bridge is severely deficient structurally, hydraulically, or geometrically, complete replacement may be the only option.

Onsite load testing of bridges has become a widely accepted method for obtaining the best possible estimate of a bridge's true load capacity. With such information in hand, the chances of unexpected deterioration of bridge deck that would occur with the passage of time can be controlled or minimized [1]. Bridge 631 is a 190m long timber structure with 31 spans over the Avon River in Toodyay (approximately 100 kilometers from Perth, the capital of Western Australia). The bridge had round log stringers, supporting sawn timber bearers, and a longitudinal timber deck overlain with a concrete deck (approximately 100 mm thick). It was constructed from local hardwood timbers (predominantly Wandoo with some Jarrah) in 1950 and had a series of repairs in 1965, 1980, 1994 and 1998 [2-5]. After flooding destroyed the previous bridges, it is the fourth bridge on the site [6]. However as the width between kerbs was only 5.5 m and it did not have a footpath. Hence it was decided to replace the bridge with a new wider concrete structure [6].

The removal of the existing timber bridge, proposed by designers, provided an opportunity to carry out a research program in order to select appropriate methods for bridge inspection, allowing estimation of timber material properties, required for modeling structural failure and developing improved repair techniques and strengthening methods. This paper presents results of that research.

Non-destructive evaluation of the old bridge prior to construction of the new one was conducted in 2000. To provide both static and dynamic loading trucks were used [7]. Further non-destructive evaluation of the same bridge took place in March 2002 just prior to its removal [6]. After the replacement of the old bridge the new one had been opened to traffic in 2002 [6].

The half-cap load sharing was examined for north and south loading of the bridge deck at the pier and span positions. This paper describes and discusses the analysis findings of the north loading case at the pier position only. As the tested bridge is a typical one in the surrounding area, the outcomes of this study could be applied to improved maintenance and load rating of the remaining timber bridges in the road network.

METHODOLOGY

Durrant [7] analyzed the experimental data for the dead load of the bridge superstructure and for live load configura-

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tions 4 and 5 (see Table **1**), to determine the load sharing capabilities of the timber half-caps on Toodyay Bridge 631. The bridge was tested for both static and dynamic loadings using two trucks, representing the extremes of the Austroads [8] T44 axle spacings with maximum load, limited by MRWA [9], concerns about the load capacity of some bridge elements. The strain and deflection measurements were allowed to be recorded for 17 of the 31 spans. For static tests the trucks were positioned in 3 lateral positions across the width of the bridge and multiple positions along the bridge with the rear axle group over a pier or mid-span. Dynamic tests were also conducted with the trucks, crossing the bridge at designated speeds of walking pace, 25, 40, 50, 60, 70 and 80 km/h and in one of the three lateral positions.

Measurements were recorded electronically by a purpose built data logging system with 32 channels. Linearly Variable Displacement Transducers (LVDT's) were used to measure deflections at mid-spans of stringers, ends of corbels and various locations on half-caps and piles. Strains were recorded at mid-span of stringers and various locations on the substructure [7]. Strains were obtained by measurement of the movement between two 6 mm diameter steel pins, inserted in drilled holes in the timber, at 500 mm centers. A purpose built extensometer was attached to the pins and recorded movement via a short travel LVDT. Following this testing methodology, the current research extends the available knowledge by considering the north loading case, for all five live load configurations (see Table **1**).

Fig. (**1**), illustrates the elevation view of half-cap notation. The eastern half-cap is the closest to the Goomalling end of Bridge 631, and the western half-cap is the closest to the Toodyay end [9]. The test data has been analysed and the results have been compared to previous research [7] and theories [10-12] on the load sharing capabilities of timber half-caps.

Table 1. Live Load (Tons) Exerted by Each Axle Group for Five Truck Configurations

Axle group	Configuration				
	1	2	3	4	5
Steer	6.5	6.5	6.6	6.5	6.6
Drive	16.5	16.6	16.6	16.2	16.8
Trailer	18.2	21.1	30.6	38.0	4.4
Total	41.2	44.2	53.8	60.7	65.8

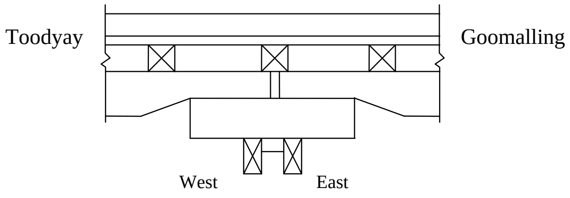


Fig. (1). Half-cap notation (elevation view).

The load sharing capabilities of the timber half-caps have been determined by analysing the half-cap load sharing for pier and span loading, at both ends of the bridge. The following load sharing situations have been examined:

a) distribution of the load between the corbels along the half-cap pair;

b) load sharing between the eastern and western half-caps at the corbels (Fig. **3**);

c) overall load sharing between the eastern and western half-caps (Figs. **20** and **21**);

d) distribution of the load between the piers (for span loading).

The results of the analysis were compared to known weaknesses in the structure [9]. The weaknesses that were present in Toodyay Bridge 631 are typical for this type of structures and were observed in other timber bridges in Western Australia [9]. However, the location and severity of these weaknesses vary from bridge to bridge, as there are no two identical bridges. For this reason the data analysis will not only include the typical half-cap load sharing percentages, but also the range of load sharing that may be found in other timber bridges.

ORIENTATION OF THE TRUCK ON THE BRIDGE DECK – ANALYSIS CONSIDERATIONS

In an idealized symmetric timber bridge structure [13], having consistent material properties and section sizes, it would be assumed that for span loading the load should be equally distributed between the adjacent piers, and for pier loading the load should be equally distributed into the half-cap pair. However, timber bridges contain weaknesses and irregularities that affect the distribution of the load [7]. Thus, the load may not be shared equally between the two half-caps on Bridge 631.

It should also be noted that aside from the weaknesses in the timber bridge structure, the jacking of the bridge deck during testing also affected the results. During testing the bridge superstructure was jacked over 100 mm at the piers to enable the insertion of the load cells between the half-caps and corbels (see Fig. **2a**). The inclined tray on the truck redistributes the load differently into the axle groups, and as a result, affects the distribution of the load at the piers [7].

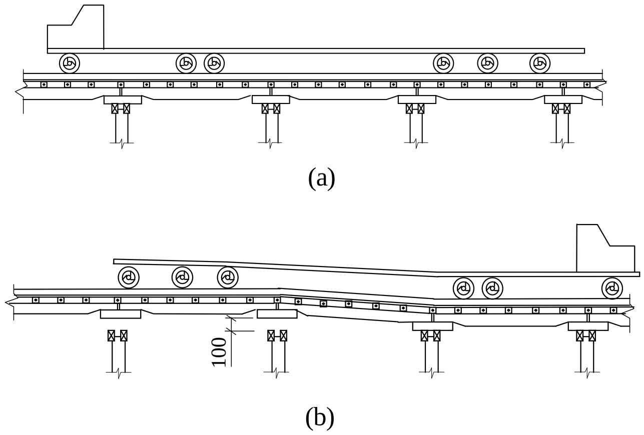


Fig. (2). Orientation of the truck on the bridge deck (**a**) typical elevation of the bridge during testing, and (**b**) truck position for span loads causes hogging to middle span.

The orientation of the truck on the bridge deck [14] also affected the half-cap load sharing results, obtained from the analysis. During testing the truck always faced towards the abutment, to which it was the closest. As a result, the loads from the front of the truck should be considered in the analysis. For example, during the testing of the Toodyay spans the tri-axle of the truck was positioned at the centre of the span and the drive wheels were located two spans closer to the abutment in the centre of the span. "Sagging" is caused in the two spans, supporting the drive wheels and trailer tri-axle, which results in "hogging" to the middle span, as shown in Fig. (**2b**). Hogging in the middle span causes more load to be distributed to the outer half-caps of the supporting piers. This corresponds to the eastern half-cap at the left piers for the Toodyay end, and the western half-cap at the right piers for the Goomalling one.

HALF-CAP LOAD SHARING ANALYSIS FOR PIER LOADS

This section deals with the load sharing capabilities of half-caps on Toodyay Bridge 631 for pier loads. The analysis is conducted for all available live load increments, at the north loading position.

Position of the Load on the Bridge Structure

For pier loading the centre wheel of the trailer tri-axle was placed directly over the pier, as shown in Fig. (**3**). The truck was positioned on the north side of the bridge deck, and faced towards abutment one during the Toodyay end tests and towards abutment two during the Goomalling end tests.

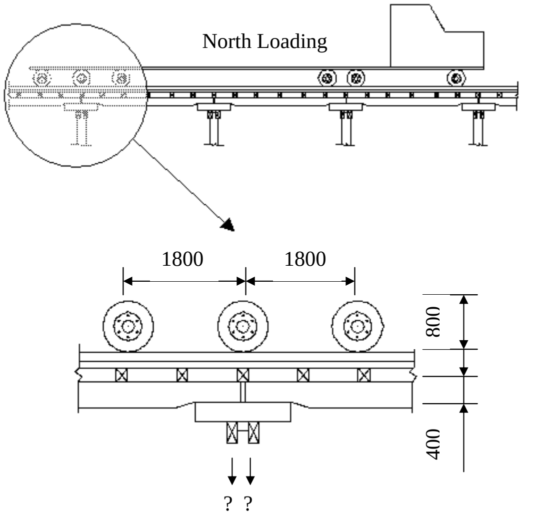


Fig. (3). Half-cap load sharing for pier loads under north loading (typical elevation).

"?%" in this and some of the following figures illustrates what was measured during the experimental program.

Analysis of the Corbel Load Distribution

Each pier of Bridge 631 contains four corbels along the length of the half-cap pair. When a live load is applied to the bridge, it is transferred from the deck, through the bearers and stringers, into the four corbels, which transfer the load to the half-cap pair. Fig. (**4**) illustrates the corbel percentage load distribution to be determined in the analysis.

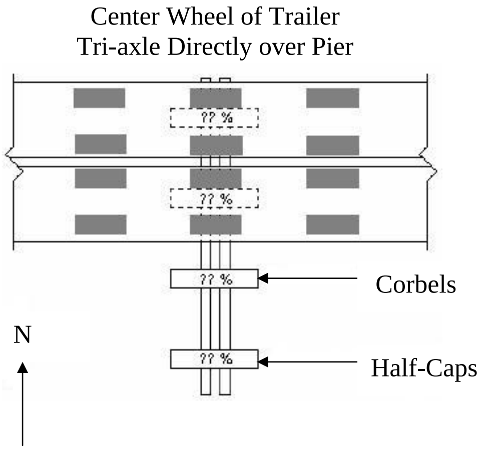


Fig. (4). Load distribution at corbels along length of half-cap pair (plan view - pier north loading).

Expected Load Distribution Along the Length of the Half-Caps

The expected percentage distribution of load along the half-caps in each of the piers can be approximated using simplified structural analysis [15]. Fig. (**5**) illustrates the pier model that will be used for the approximation. The model is a simplification of the real situation, as the load is shown to act directly on the bearers and assumes no distribution of load through the bridge deck. The model has consistent material properties, equal member sizes and spacings, as well as flexible pin supports at all corbels. Fig. (**6**) shows the expected corbel reactions from analysis of the model.

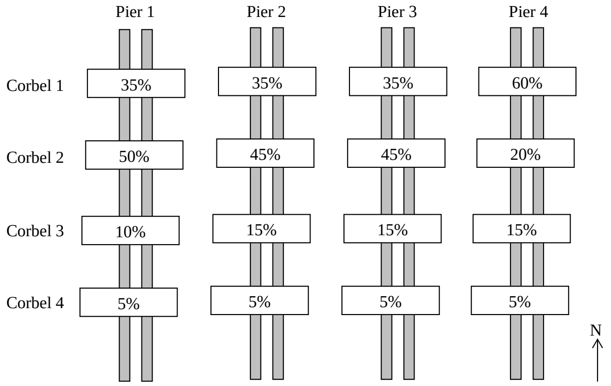
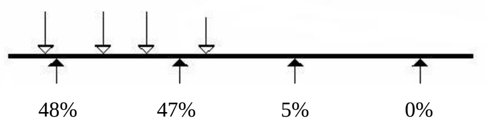


Fig. (5). Load distribution between corbels in toodyay end piers (pier - north loading).

The values, shown in Fig. (**5**), were determined by averaging the results of the corbel load distribution at each pier for load configurations 1, 2, 3 and 4. The figure shows that the load distributed at each of the corbels is the same for piers 2 and 3. These two piers, however, do not represent the expected values, shown in Fig. (**6**), as corbel 2 is takes 10% more load than corbel 1. Possible explanation for pier 2, corbel 1, behaving worse than expected, could be attributed to the condition of pile 1.

(a)



(b)

Fig. (6). Expected corbel load distributions along pier for north loading (**a**) elevation, (**b**) line diagram.

Pile 1 contains no solid timber, as rot has extended throughout the entire thickness of the pile. The deteriorated area of the pile has been shaded, and the numbers on each face of the pile represent how much solid timber remains. Because of the deterioration, a steel column was driven adjacent to pile 1 during the research, to carry the load. Before it was done, it is possible that the half-caps may have settled, resulting in the transfer of a portion of the load to pile 2. Further indicated that there were minor heartwood splits to the half-caps above pile 1. It is possible that it also lead to the transfer of load to corbel 2, as the heartwood is the hardest, most dense wood, and provides the majority of the half-caps stiffness. Hence, any damage or deterioration to the heartwood can reduce the strength of the half-caps [15].

Possible reasons for pier 3, corbel 1, behaving worse than expected, could also be attributed to the condition of pile 1 and the overlying half-caps. Pile 1 was found to have "major termite damage" to the outer bark layers on two faces of the pile. The western half-cap above pile 1 also contained a horizontal growth ring split. Thus, lower than expected percentage load, distributed to corbel 1, may be due to a combination of the split to the half-cap and the termite damage to the pile.

Pier 1 has a similar corbel percentage load distribution to piers 2 and 3. Corbel 1 was found to take 15% less load than corbel 2, which is most likely due to the condition of pile 1. Pile 1 is shown to have extensive rot to the heartwood, as shown in Fig. (**7**). It also contains a "knot" approximately 2.2 metres above the waler. Therefore, the load distribution at corbel 1 may have been affected by the deterioration and natural weaknesses in pile 1.

From Fig. (**5**), it is evident that the load distributed to corbels 1 and 2 in pier 4 are much different to that, found in piers 1, 2 and 3. In comparison to the expected values, shown in Fig. (**6**), corbel 1 carried approximately 12% more load than expected, and corbel 2 carried 27% less than expected. In all four piers, the percentage load distribution at corbels 3 and 4 were greater than the expected values, shown in Fig. (**6**). On average, corbels 3 and 4 carried, respectively, 10% and 5% more load than expected. This may be due to the weaknesses and irregularities in the northern end of the bridge, causing a greater distribution of load to the southern one.

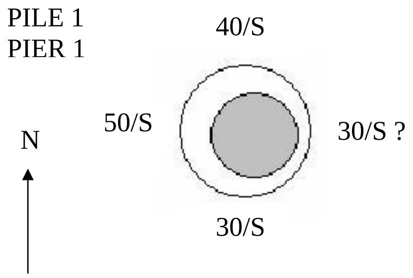


Fig. (7). Section view of rot to pile 1 on pier.

Corbel Load Distribution for Goomalling end Piers

The load distributions between the corbels in each of the Goomalling end piers are shown in Fig. (**8**). These values were determined by averaging the experimentally obtained results of the corbel load distribution at each pier for all five live load increments.

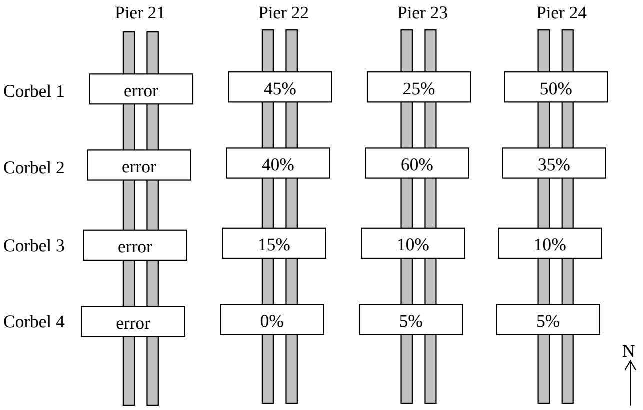


Fig. (8). Load distribution between corbels in Goomalling end piers (pier - north loading).

As it can be followed from Fig. (**8**), under north loading the corbel load distribution at the Goomalling end of the bridge is much different, compared to that, found at the Toodyay end. It is evident that corbels 1 and 2 in pier 22 supported slightly less loads than the expected values (see Fig. **6**). This load was transferred to corbel 3, which supported approximately 10% more load than expected. Possible reasons for the northern corbels in pier 22 performing worse than expected can be found in Fig. (**9**). There was termite damage to the half-caps above pile 1 (see Fig. **9**). There was also deterioration to pile 1 in pier 22, however, a universal column had been driven adjacent to pile 1 to support the load.

By analyzing the results, presented in Fig. (**8**), it can be concluded that the percentage load distribution at corbels 1 and 2 in pier 23 significantly differs from the expected values, shown in Fig. (**5**). Corbel 1 supported approximately 23% less load than expected. The load was transferred and supported by corbel 2. Possible reasons for the northern corbel in pier 23, behaving worse than expected, is due to the condition of the half-caps above pile 1.

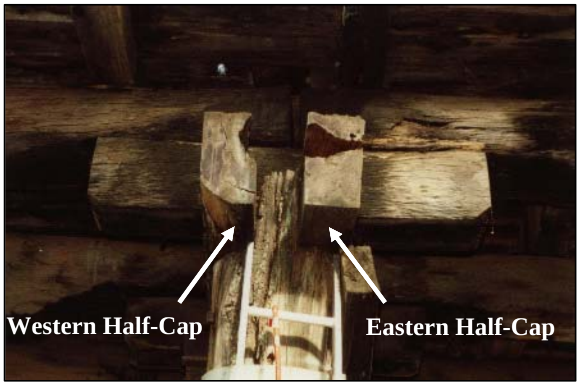


Fig. (9). Termite damage to half-caps above pile 1 on pier 22.

During inspection of the bridge 631, a large "pipe", located in the eastern half-cap, at the southern end of pier 23, was observed. This pipe was caused by deterioration (or rotting) of a tubular section of timber within the half-cap. This form of deterioration can reduce the strength of the half-cap significantly, affecting the distribution of load to the corbel. The pipe was approximately 120 mm in diameter and 1 m in length, as illustrated in Fig. (**10**). The values, obtained from the corbel load sharing analysis, at the southern end of pier 23, were similar to those, found at the other piers. Therefore it appears that the pipe in the half-cap did not affect the load sharing at the southern corbels in pier 23.

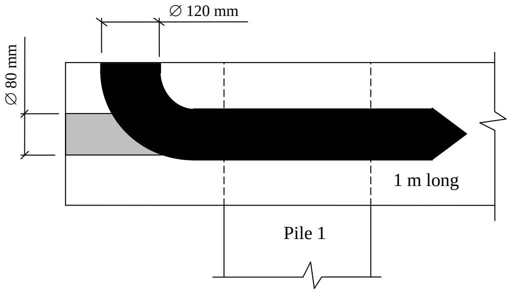


Fig. (10). Large "pipe" in the eastern half-cap above pile 3 at pier 23.

Corbel Load Distribution for a Typical Pier under North Loading

The approximate distribution of the load between corbels in percentage was estimated for each of the applied live load configurations. The values, obtained from analysis of the Toodyay and Goomalling end piers, were combined to determine the corbel load distribution for a typical pier. The average percentage of load that is distributed at each of the corbels on a typical for Bridge 631 pier, under north loading, is shown in Fig. (**11**). The Figure also indicates the range of corbel percentage load distribution that are possible on other Western Australian timber bridges.

As it follows from the figure, the average load sharing between the half-caps for a typical pier varied from 0% to 60%. However the range of possible load sharing included the case when one half-cap supported the entire live load and a portion of the dead load. Hence, the load sharing capabilities of the half-caps of timber bridges should be further investigated.

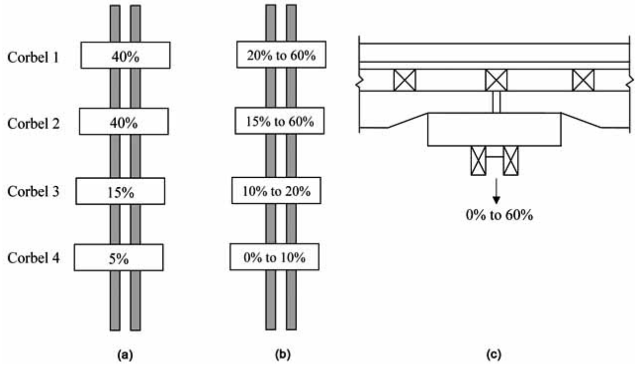


Fig. (11). Corbel load distribution for pier loads (north loading) (**a**) typical distribution, (**b**) range of distribution, and (**c**) possible distribution.

Further Analysis of the Load Sharing between the Half-Caps at each Corbel

The findings of the analysis, aimed at determining the load distributed at each of the corbels on a typical Bridge 631 pier, were summarised for north loading in the previous sections. These findings, however, represent the load sharing along the length of a full-cap, and may not accurately reflect the condition of the timber bridge structure. For this reason, the load sharing between the eastern and western half-caps at each of the Toodyay and Goomalling end piers will be determined. This analysis will yield percentage load distributions that represent the true condition of Bridge 631. The obtained values should give an indication of any irregularities in the structure, such as naturally occurring weaknesses and those, caused by deterioration and biological degradation. Fig. (**12**) illustrates the half-cap load sharing percentages that will be determined in the analysis.

Local Half-Cap Load Sharing for Toodyay End Piers

This section presents the findings from the analysis of the load distributed between the eastern and western half-caps, in each of the Toodyay end piers. The values, shown in Fig. (**13**), were determined by averaging the results from live load increments 1, 2, 3 and 4 for each of the Toodyay end piers under north loading.

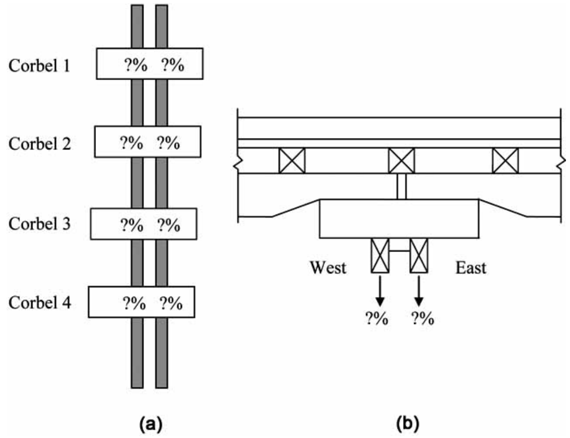


Fig. (12). Load sharing between the eastern and western half-caps at the corbels (plan view - pier north loading) (**a**) plan view, and (**b**) elevation view.

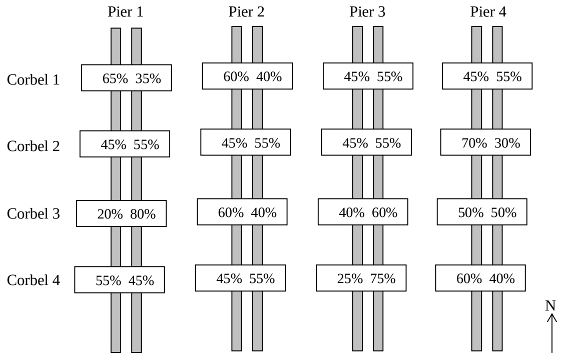


Fig. (13). Load distributed between the eastern and western half-caps in the Toodyay end piers (pier - north loading).

Fig. (**13**) shows that the load sharing ratios at corbels 2 and 4 in pier 1 have the same range, but they are much different to the ratios, found at corbels 1 and 3. The unexpected load sharing ratio at corbel 3 may be attributed to the condition of pile 3 and the western half-cap. Investigation of the bridge members after testing indicated that the top of pile 3 had deteriorated more on the western side. It was also found that the underside of the western half-cap had weathered where it sits upon pile 3, as shown in Fig. (**14**).

A combination of the deterioration to the half-cap and the top of pile 3 produced an uneven surface for the western half-cap to sit upon. Although this has not affected the load sharing ratio at corbel 4, it may be the cause of the unexpected values, obtained at corbel 3, as the western half-cap was found to support only 20% of the load. Fig. (**14**) demonstrates that these observations did not affect the load sharing at corbel 4.

In pier 2, corbels 2 and 4 had load sharing ratios, which were similar to the expected values. Corbels 1 and 3 also had the same load sharing ratios, but only 40% of the load was distributed to the eastern half-cap in both cases. The unexpected ratio at corbel 1 may be attributed to the replacement of pile 1. As it was mentioned above, the original timber pile 1 contained no solid timber as rot had extended throughout its entire thickness. The shaded portion in gray in the figure shows the area of the pile affected by rotting, reducing the bearing life of the pile. Prior to the new steel universal column being driven to replace pile 1, it is possible that the half-caps may have settled unevenly, producing an uneven distribution of load between the half-caps.

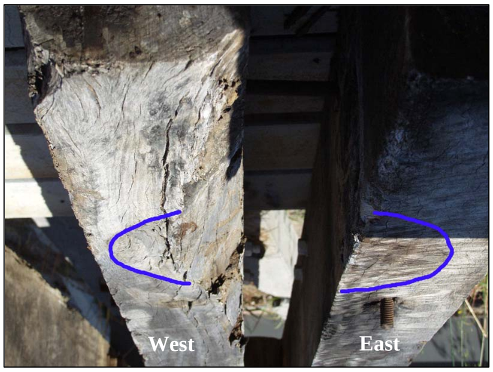


Fig. (14). Condition of the underside of the western half-cap on pier 1, pile 3.

It is evident from Fig. (**13**) that the northern corbels in pier 3 had different load sharing ratios, compared to the southern one. Northern corbels 1 and 2 had load sharing ratios, which were similar to the expected values. The southern corbels 3 and 4 were found to have uneven load sharing ratios. In particular, at corbel 4 only 25% of the load was distributed to the western half-cap. In pier 4, corbel 3 had the expected 50:50 load sharing ratio, and corbel 1 also had a similar distribution. Corbels 2 and 4, however, had uneven load sharing ratios with the western half-caps supporting a greater percentage of the load. Possible reasons for unexpected behaviour of corbel 4 could be the condition of pile 3.

Local Half-Cap Load Sharing for Goomalling End Piers

The results of the analysis to determine the load sharing between the eastern and western half-caps in each of the Goomalling end piers are shown in Fig. (**15**). Similar to the previous cases, the values, shown in the figure, were determined by averaging the results of the local half-cap load sharing at each pier for all five live load increments. Corbels 1 and 2 in pier 21 have been excluded from the analysis due to the significant number of unreliable load cell readings obtained during the Goomalling end testing.

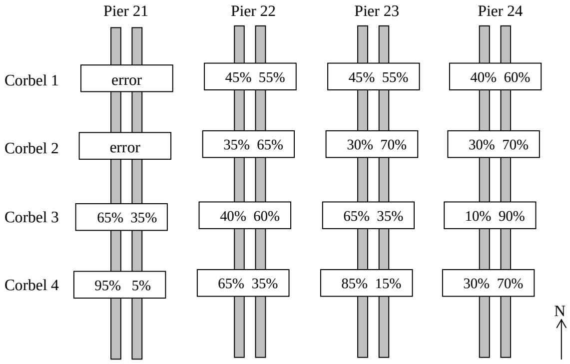


Fig. (15). Load distributed between the eastern and western half-caps in the Goomalling end piers (north loading).

From Fig. (**15**) it is evident that corbels 3 and 4 in pier 21 do not behave as expected. In particular, at corbel 4 the eastern half-cap supported only 5% of the load. The MRWA Inspection Report [9] and the observations, made during testing, did not indicate that there was any damage to the southern end of pier 21. However, inspection of the bridge structure after testing revealed a large crack at the entire length of the underside of the eastern half-cap. This crack is shown at the northern end of pier 21 in Fig. (**16**). It is the likely cause of the lower than expected distribution at the southern corbels.

Corbel 1 in pier 22 had a similar load sharing ratio to the expected values, whereas corbels 2, 3 and 4 were found to have unequal load distributions. It was also observed during testing that the eastern half-cap at the southern end of pier 22 was not vertical and as a result, could not support as much load as the western half-cap. It has moved up to 5 mm under loading, when the jacking frame was in place. These are the likely reasons for the eastern half-cap supporting less load than expected.

Fig. (16). Crack on the underside of the eastern half-cap at pier 21.

The percentage load distribution to the eastern and western half-caps at corbel 1 in pier 23, were very similar to the expected values. It has not affected the load transferred to the western half-cap as it was only slightly less than expected. In pier 23 the western half-cap at corbel 2 supported only 30% of the load. Fig. (**15**) indicates that corbel 4 in pier 23 has load sharing values much different than the expected ones. The eastern half-cap was found to support on average only 15% of the load. The likely cause of this is the large pipe that was located in the eastern half-cap at the southern end of pier 23 (see Fig. **10**). This pipe has reduced the cross-sectional area of the eastern half-cap, and in turn, caused a reduction in its transverse compressive stiffness. This explains why the majority of the load was supported by the stiffer western half-cap. The pipe may have also contributed towards the lower than expected distribution of load to the eastern half-cap at corbel 3.

From Fig. (**15**) it can be seen that the load sharing percentages at all four corbels in pier 24 are very different from the expected values. At all four corbels the lowest percentage of load was distributed to the western half-cap indicating that it possibly contained a flaw or weakness. The western half-cap supported 40% of the load at corbel 1, 30% at corbels 2 and 4, and only 10% at corbel 3. The MRWA Inspection Report [9] did not indicate that there were any weaknesses in either half-cap, and neither did the observations that were made during testing. However, upon completion of the testing, inspection of the bridge structure revealed a large crack running down the inside of the western half-cap, as shown in Fig. (**17**).

Half-Cap Load Sharing for a Typical Pier Under North Loading

To determine the half-cap load sharing for a typical pier under north loading, the results from the Toodyay and Goomalling end analysis were combined. Fig. (**18**) shows the average percentage of load, distributed to the eastern and western half-caps, at each of the corbels on a typical Bridge 631 pier. The figure also presents the range of possible percentage distributions that can be found at each corbel in a typical pier.

The typical load sharing ratios, shown in Fig. (**18a**), are similar to the expected ones. Fig. (**18**) further shows that it is possible for one half-cap to support 100% of the live load under symmetric pier loading. However, this occurred at corbel 4, supporting only about 5% of the applied live load for north loading of the bridge deck.

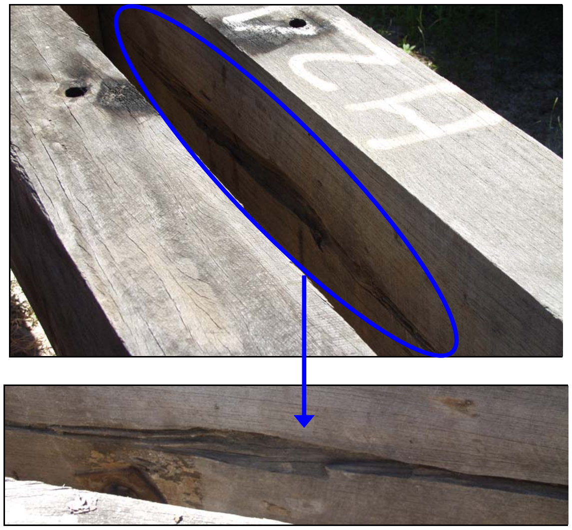


Fig. (17). Crack at the inside face of the western half-cap on pier 24.

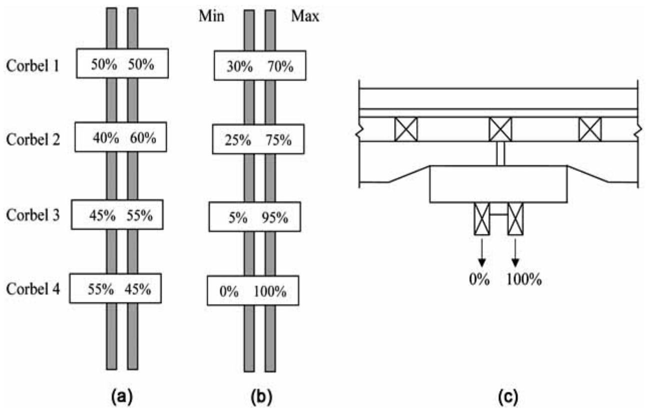


Fig. (18). Load sharing between the half-caps at the corbels for pier loads (north loading) (**a**) typical distribution, (**b**) range of distribution, (**c**) possible distribution.

The results from the Toodyay and Goomalling end analysis have been combined to determine the half-cap load sharing percentages for symmetric pier live loading. Fig. (**19**) shows the typical half-cap load sharing for pier north loading. The values, shown in the figure, have been determined by analyzing the test data obtained from north loading of the bridge deck. The figure shows both the average and the expected range of half-cap load sharing percentages for a typical pier on Bridge 631. Following the figure, the half-cap load sharing for a typical pier of the bridge is similar to the expected values. It is also shown that the worst possible percentage of load that was supported by one half-cap of the bridge was 70% of the total pier load.

SUMMARY OF THE TOTAL HALF-CAP LOAD SHARING FOR PIER NORTH LOADING

The total half-cap load sharing for pier north loading was determined by finding the total load, supported by each of the half-caps. This was achieved by summing the loads, supported by the eastern and western half-caps, at each of the corbels. The results of the total half-cap load sharing for the Toodyay and Goomalling end piers are shown in Fig. (**20**).

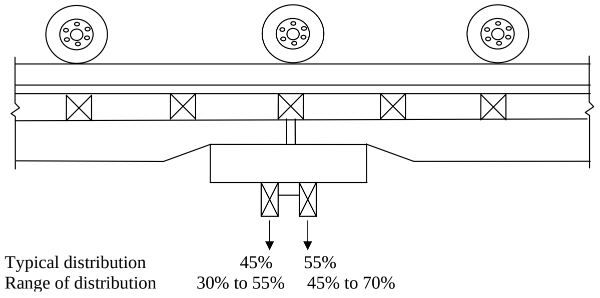


Fig. (19). Typical half-cap load sharing for pier north loading.

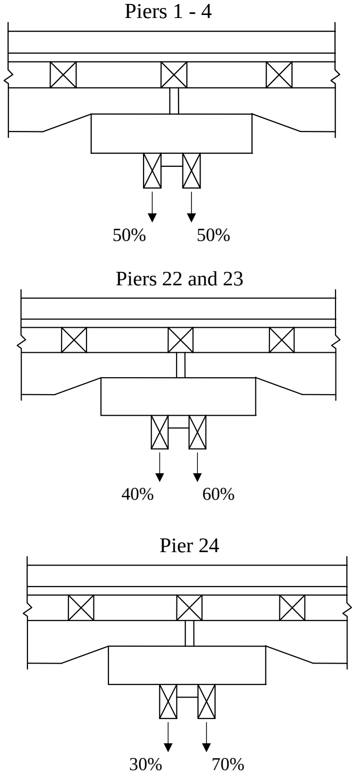


Fig. (20). Load sharing between the half-caps for pier.

HALF-CAP LOAD SHARING APPROXIMATION FOR GOOMALLING END PIER 21

Due to the unreliable load cell readings at pier 21 during the Goomalling end testing, corbels 1 and 2 were excluded from the analysis. As a result, the total half-cap load sharing percentages could not be determined for this pier. This section deals with approximation of the load sharing between the eastern and western half-cap at pier 21, by using the valid load cell measurements, recorded at corbels 3 and 4. This was achieved by summing the loads at these two corbels separately for the eastern and western sides. It should be noted that from previous results, obtained for other piers, the local half-cap load sharing at the corbels was sometimes different from the total pier half-cap load sharing. As the loads, recorded at corbels 3 and 4, are the only valid data for pier 21 during the Goomalling end testing, they will be used to determine an approximate load sharing for the pier.

Fig. (**21**) shows the average and range of expected distributions for the half-cap load sharing at pier 21. The values, shown in this figure, are approximations based on the load sharing, obtained from corbels 3 and 4. Comparison of Figs. (**20** and **21**) shows that the approximated half-cap load sharing percentages for pier 21 were very different, compared to those, obtained for piers 22, 23 and 24. Piers 22, 23 and 24 had a greater percentage of the load, supported by the eastern half-cap, whereas for pier 21 the western half-cap supported the majority of the load.

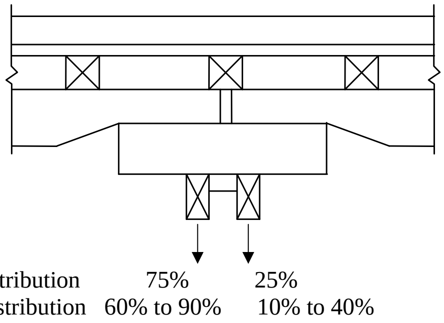


Fig. (21). Approximate half-cap load sharing for pier 21.

As explained previously, inspection of the bridge members after testing revealed a large crack, running down the underside of the eastern half-cap at pier 21. The damage to the eastern half-cap affected the local load sharing at corbels 3 and 4, with more load being distributed to the stiffer westdern half-cap. As the total pier half-cap load sharing was determined using the valid load cell readings at corbels 3 and 4, the approximated load distribution for pier 21 will also reflect this damage. Hence, it is likely that only 25% of the load would be distributed to the eastern half-cap as a result of the large crack.

Another possible reason for the western half-cap, supporting the majority of the load, may be due to the slope of the bridge deck as a result of local jacking. At both piers 21 and 24 the slope of the bridge deck changed due to the local jacking at the piers. In both cases it was found that the majority of the load was supported by the half-caps on the outer side. The eastern half-cap at pier 24 supported the greatest percentage of load, and the western half-cap at pier 21 supported the majority of the load, which may be due to the slope of the bridge at these locations.

CONCLUSIONS

The load sharing capabilities for timber half-caps on Toodyay Bridge 631 were investigated. The half-cap load sharing was examined for north and south loading of the bridge deck at the pier and span positions. The findings of the analysis for only the bridge deck's north loading case at pier position are summarized. Investigation of these load cases will give more insight into the load sharing of the half-caps on Bridge 631.

The purpose of this investigation was to continue the research on the load sharing capabilities of timber half-caps on Toodyay Bridge 631. It was found that the typical half-cap load distribution under pier loading at northern side varied just by about 5%. Under centre loading of the bridge the half-cap load sharing ratio for pier loads of 45% - 55% was determined. As Toodyay Bride 631 is a typical timber bridge in western Australia, the findings of the current research can be applied to the remaining bridges to estimate the working life of the existing timber bridges and to help prolong their lifetime.

As there is a large quantity of data, obtained from the testing, there is still much to be learnt about the load sharing capabilities of the timber half-caps. This would include the analysis of the south loading of the bridge deck at both the pier and span positions.

The research work presented in this paper offers significant benefits to the community, including local government, road users, the road freight industry and tertiary institutions. However, further analysis of the test data particular for the south loading case is required and the finite element model needs to be applied to both the north and south loading cases in order to verify the consistency of the analysis with the observed behavior.

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