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Numerical Investigation of Composite Steel and Precast Reinforced Concrete Transom for Sydney Harbour Bridge under Static Loading

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Abstract

The Sydney Harbour Bridge requires the replacement of the timber transoms that currently reside in the railway system. Composite steel and precast reinforced concrete transoms have been proposed as the replacement for the current timber counterparts. In existing studies, it is found that there is little investigation into the effect of derailment loading on reinforced concrete transoms. This paper provides a continuation on a previous study of static loading on reinforced concrete transoms and investigates the failure behaviour through means of finite element analysis. The FEA commercial software known as ABAQUS was used to investigate the effect of static loading on the composite concrete transoms. The FE data accuracy was verified by comparing the existing experimental results. The experimental study and numerical investigation, transoms using AJAX bolts was shown to perform better than the welded headed shear studs. Additionally, the FE models produced in this study were validated by the results of the experimental study; however, further investigation into the damage properties is required before proper evaluation of the failure behaviour is determined.

Keywords: Railway, Static, Failure, Finite element analysis, Concrete

1. INTRODUCTION

Through history, railway systems have incorporated large amounts of timber into the construction of various components. The most common component that utilises timber is the transom; mostly due to the availability of timber and simplicity with regards to construction and transportation. However, timber is susceptible to environmental and climate conditions, often leading to a low service life. For instance, the Sydney Harbour Bridge's railway network currently used timber transoms that require a high level of maintenance, hence, a more durable material is being sought after to replace the current transoms. To create a more consistent railway track in terms of quality and comfort for the passengers, and to provide the long-term functionality required, an alternative material must be found. In the modern era, railway locomotive speeds have been increasing as detailed by González-Nicieza et al. (2008) where it is stated that improvements in transom design is mainly focused upon increasing the durability of the sleeper around the loading produced by higher speeds of the locomotive. In recent studies, it is found that there is a lack of investigations with regards to numerical static railway loading scenarios on reinforced concrete. The purpose of this numerical investigation is to provide a detailed analysis of the performance of reinforced concrete transoms under static railway loading. This study provides a continuation on an existing experimental study conducted by Zaher (2016). This study aimed to explore the ultimate load capacity of conventionally reinforced composite concrete transoms. Experimental testing was conducted on two conventionally reinforced specimens using AJAX and welded headed shear studs. The experimental loading setup is illustrated in Figure 1. Since the numerical investigation herein simulated half the experimental specimen, the loading point used is the leftmost point of loading presented in Figure 1 with Point A. The loading of the transom consisted several stages; firstly, repeated increasing loads of 100 kN, 150 kN, 240 kN and 360 kN was applied to the transom at service load. Finally, a load of 900 kN was applied to determine the ultimate capacity of the transom. The failure behaviour is illustrated in Figure 2. From the results, it was concluded that the AJAX bolts perform better than the welded shear studs. Similarly, in a numerical and experimental investigation conducted by Johnston (2016), the same transom was analysed but being made of a glass fibre composite material. With the loading conditions being identical, it was also shown that the AJAX bolts outperformed the alternative shear connector.

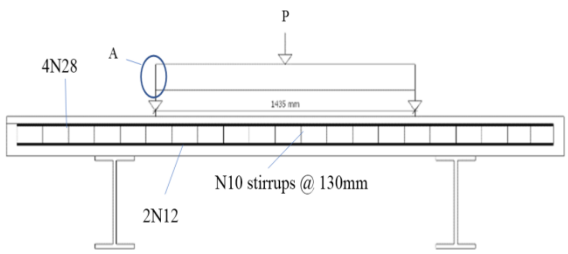

Figure 1. Numerical and experimental loading

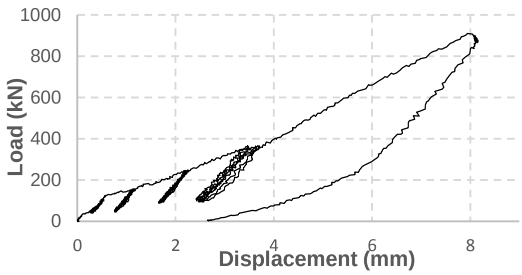

Figure 2. Experimental failure behaviour

2. FINITE ELEMENT MODEL

2.1. Element Type, Mesh and Contact Interactions

The elements used for the nodes in this investigation are the C3D8R element. As stated by Mirza (2008), this is derived from the five aspects of their behaviour; the family, degrees of freedom, number of nodes, formulation and integration. For the element utilised as stated above, the ‘C’ refers to the solid continuum family, the ‘3D’ refers to the three degrees of translational freedom at each node, the ‘8’ refers to the number of node for which the degrees of freedom are calculated and the ‘R’ refers to the reduced integration method for calculation purposes. The C3D8R element is used for all parts except for the conventional reinforcement where the truss element, T3D2 is used. Meshing, an important aspect in finite element analysis requires a mesh sizing to be applied to each part instance, this greatly induces the simulation time and accuracy of the results. Meshing is based upon a sensitivity analysis conducted by Griffin (2013) due to the similarity of FE models. For consistency, the same mesh size is used across all specimens presented herein.

The importance of contact interaction is greatly increased when the composite structure is considered since the load-bearing capacity of the structure is dependent upon the interaction between one or more elements. Surface to surface contacts are used for connecting the concrete to prestress tendons and Bondek II as well as connecting the Bondek II to the stringer beam. Complex interactions regarding the connection of the shear studs used the tie interaction to reduce simulation times.

2.2. Boundary Condition and Model Setup

The FE model consists of four specimens: Conventionally reinforced concrete transom with welded shear studs (CS-Welded), conventionally reinforced concrete transom with AJAX bolts (CS-AJAX), prestressed concrete transom with welded shear studs (PS-Welded) and prestressed concrete transom with AJAX bolts (PS-AJAX). All specimens are 2100 mm in length, 180 mm in depth with stiffened 610UB125 steel beams spaced 991 mm from the centre section of the transom.

3. RESULTS AND DISCUSSION

3.1. General

To keep results consistent, only the elasto-plastic region of the experimental and numerical results was considered. This is due to the concrete damage properties not yet being defined in the FE models. Hence, the presentation of the graphs was limited to 2 mm of displacement for clarity purposes. For deformation stress contour plots of the FE model, stress is limited to 10 percent of the characteristic strength of the concrete to observe the cracking failure of the concrete.

3.2. Conventionally Reinforced Transom with Welded Shear Stud (CSWelded)

To verify the numerical analysis, the results of the numerical static analysis were compared to the experimental results produced by Zaher (2016). Figure 3 shows the comparison of the experimental and numerical load versus displacement results. The graph shows a similar behaviour to experimental data and the discrepancy is with 10%. The failure behaviour of concrete is illustrated in Figure 4 through a deformation stress contour plot of the FE model.

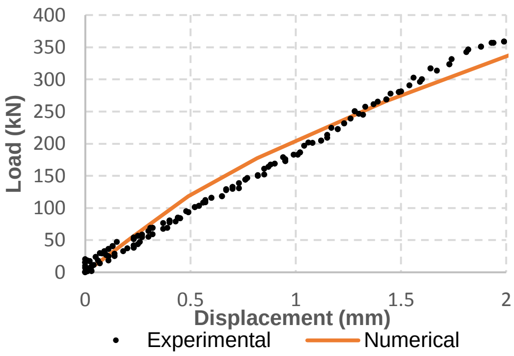

Figure 3: Comparison of numerical and experimental results for CSWelded

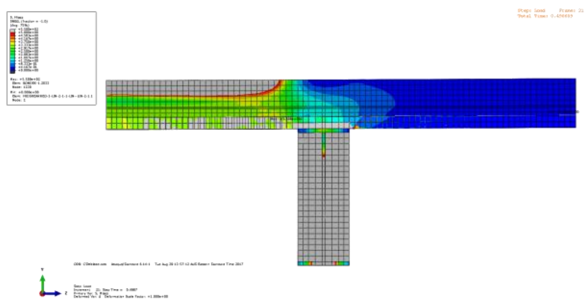

Figure 4: Stress contour plot of specimen CSWelded

From the numerical and experimental results, the loading produced to develop 2 mm of displacement was 336 kN and 360 kN respectively, corresponding to a 7% difference. Stiffness was also calculated to be 168 kN/mm for numerical analysis and 180 kN/mm for the experimental testing. These results are summarised in Table 4. From Figure 6, the cracking failure of the concrete is visualised through the red section of the stress contours. Cone shaped stress can also be observed around the support.

3.3. Conventionally Reinforced Transom with AJAX Bolts (CSAJAX)

Figure 5 shows the comparison of the experimental and numerical load versus displacement results. The failure behaviour of concrete is illustrated in Figure 6.

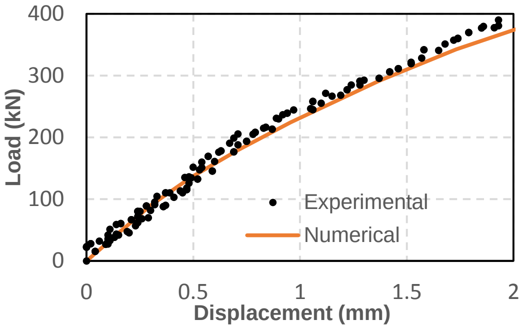

Figure 5: Comparison of numerical and experimental results for CSAJAX

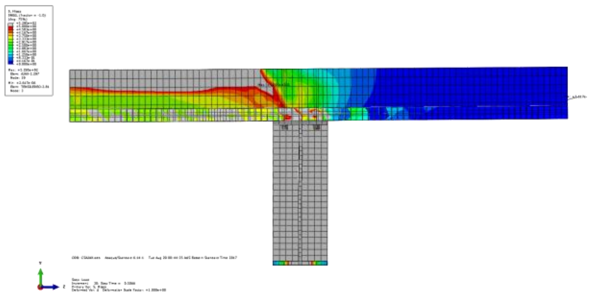

Figure 6: Stress contour plot of specimen CSAJAX

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From the numerical and experimental results, the loading produced to develop 2 mm of displacement was 374 kN and 390 kN respectively, corresponding to a 4.3% increase. Stiffness was also calculated to be 187 kN/mm for numerical analysis and 195 kN/mm for the experimental testing. These results are summarised in Table 4. From Figure 8, the cracking failure of the concrete is visualised through the red section of the stress contours. Increased cone shaped stress can also be observed around the support when compared to the previous conventionally reinforced transom.

3.4. Prestressed Transom with Welded Shear Stud (PSWelded)

From the results of the comparison between the numerical and experimental investigation, the FE model can be assumed to be verified due to the minimal difference between the two sets of results. Hence, the numerical analysis of the conventionally reinforced transoms can be used as a baseline to evaluate the performance of the prestressed transoms. Figure 7 compares the performance of prestressed transom specimen with welded shear studs with its conventionally reinforced counterpart. Figure 8 also illustrates the failure behaviour of the PSWelded.

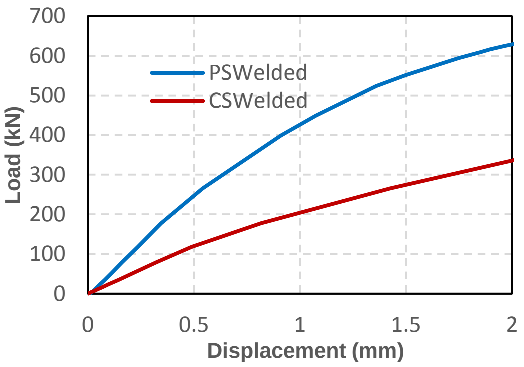

Figure 7: Comparison of specimens PSWelded and CSWelded

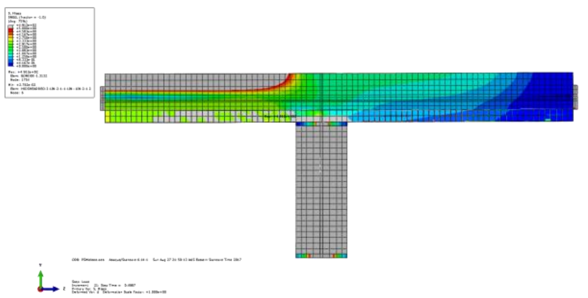

Figure 8: Stress contour plot of specimen PSWelded

From the results presented above, the loading at 2 mm of displacement was 628 kN for the prestressed transom comparing to 336 kN of loading at the same displacement resulting in an 87% increase in strength. The stiffness can also be calculated to be 314 kN/mm for the prestressed specimen. Table 4 also displays the results of the numerical investigation for specimen PSWelded. From Figure 10, the cracking failure of the concrete is visualised through the red section of the stress contours. Like the conventional specimens, cone stress distribution can be seen around the support. However, the stress around the support is noticeably less than the conventional counterpart.

3.5. Prestressed Transom with AJAX Bolts (PSAJAX)

Figure 9 compares the performance of the prestressed transom specimen with AJAX bolts with its conventionally reinforced counterpart. Figure 10 also illustrates the failure behaviour of the PSAJAX specimen.

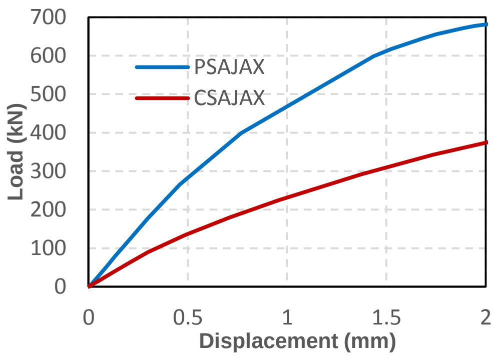

Figure 9: Comparison of specimens PSAJAX and CSAJAX

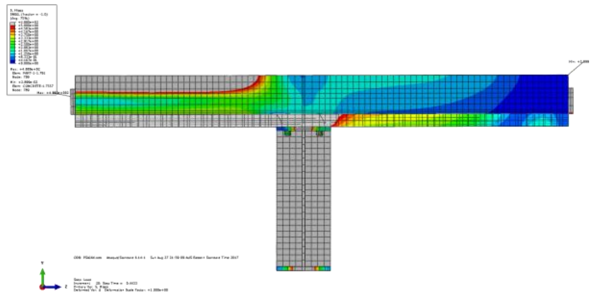

Figure 10: Stress contour plot of specimen PSAJAX

From the results presented above, the loading at 2 mm of displacement was 681 kN for the prestressed transom comparing to 374 kN of loading at the same displacement resulting in an 82% increase in strength. The stiffness can also be calculated to be 341 kN/mm for the prestressed specimen. Table 4 also presents the results obtained for specimen PSAJAX. From Figure 12, the cracking failure of the concrete is visualised through the red section of the stress contours. Also, visibly less cone stress distribution can be seen around the support when compared to the previous prestress section.

3.6. Result Comparisons

From the results, the existing experimental results produced by Zaher (2016) were compared to the numerical counterparts with the objective of validating these models. Once validated, they were then used as a baseline for which to compare the prestress specimens. Table 4 summarises all the results obtained from experimental and numerical investigation herein. The percentage difference was calculated between the results for welded shear studs and AJAX bolts. Throughout the results, transoms using the AJAX bolts perform better than transoms using the welded shear studs with an average percentage increase of 9.2%.

Table 4: Summary of experimental and numerical results

Experimental Results			
Specimen	**Loading at 2 mm displacement (kN)**	**Stiffness (kN/mm)**	**% Difference**
Conventional Welded Shear Stud	360	180	8.3
Conventional AJAX Bolt	390	195	
Numerical Results			
Specimen	**Loading at 2 mm displacement (kN)**	**Stiffness (kN/mm)**	**% Difference**
CSWelded	336	168	11
CSAJAX	373	187	
PSWelded	628	314	8.4
PSAJAX	681	341	

4. CONCLUSIONS

The research illustrates the validation of FE model and an understanding of the failure behaviour was made. The research concludes that: The discrepancies between the numerical and experimental results were less than 10%. Therefore, the FE models are reasonable accurate. The performance of these models will be able to be used as a baseline and provide the foundation for future numerical analysis on the same specimens. It was found that the prestressed models performed significantly better over the conventional models in terms of stiffness by an average of 84.7% as well as a higher resistance to cracking.

5. ACKNOWLEDGEMENTS

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