# Structural behaviour of pultruded fibre composites guardrail system under horizontal loading

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| Abstract: | Fibre composite guardrails are increasingly being used to ensure safety of workers from fall-from-height incidents due to its high strength, high corrosion resistance and low maintenance. In this study, the structural behaviour of pultruded glass fibre reinforced polymer (GFRP) guardrail was evaluated following AS1657-1992. GFRP guardrail systems mounted on top and side of a steel beam with different joint connectors are loaded horizontally to top of the guardrail post and to the middle of the guardrail member. The results showed that the guardrail system with joints connected with either polypin or rivets combined with epoxy exhibited 20% higher failure load and almost double the stiffness than those connected using polypin or rivets alone. The side-mounted guardrail failed due to failure of the base connector while the guardrail mounted on top of the beam failed at the joints indicating that the structural behaviour of GFRP guardrail system is affected mainly by the type of joints. |
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Table 1: Description of specimen for test of GFRP guardrail system

| Specimen | Mounting on beam | Location of loading | Connector |
|---|---|---|---|
| GTP-PE | Top | Post | Polypin and epoxy |
| GTP-RE | Top | Post | Rivets and epoxy |
| GTP-P | Top | Post | Polypin |
| GTP-R | Top | Post | Rivet |
| GTM-PE | Top | Member | Polypin and epoxy |
| GTM-RE | Top | Member | Rivets and epoxy |
| GTM-P | Top | Member | Polypin |
| GTM-R | Top | Member | Rivet |
| GSP-PE | Side | Post | Polypin and epoxy |
| GSP-RE | Side | Post | Rivets and epoxy |
| GSP-P | Side | Post | Polypin |
| GSP-R | Side | Post | Rivet |
| GSM-PE | Side | Member | Polypin and epoxy |
| GSM-RE | Side | Member | Rivets and epoxy |
| GSM-P | Side | Member | Polypin |
| GSM-R | Side | Member | Rivet |

Table 2: Failure load (in kN) of the GFRP guardrails

| Type of connector | Top mounted | | Side mounted | |
|---|---|---|---|---|
| | Post | Member | Post | Member |
| Polypin and epoxy | 19.18 | 13.72 | 15.62 | 14.77 |
| Rivets and epoxy | 19.31 | 10.31 | 17.78 | 14.74 |
| Polypin | 12.96 | 13.47 | 9.40 | 13.58 |
| Rivets | 16.77 | 13.21 | 10.04 | 13.72 |

# Structural behaviour of pultruded fibre composites guardrail system under horizontal loading

**Allan Manalo[1] and Mac Pac[2]**

[1]Senior Lecturer, Centre of Excellence in Engineered Fibre Composites (CEEFC), Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba 4350, Australia

[2]Honours student, Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba 4350, Australia



**Abstract**

Fibre composite guardrails are increasingly being used to ensure safety of workers from fall-from-height incidents due to its high strength, high corrosion resistance and low maintenance. In this study, the structural behaviour of pultruded glass fibre reinforced polymer (GFRP) guardrail was evaluated following AS1657-1992. GFRP guardrail systems mounted on top and side of a steel beam with different joint connectors are loaded horizontally to top of the guardrail post and to the middle of the guardrail member. The results showed that the guardrail system with joints connected with either polypin or rivets combined with epoxy exhibited 20% higher failure load and almost double the stiffness than those connected using polypin or rivets alone. The side-mounted guardrail failed due to failure of the base connector while the guardrail mounted on top of the beam failed at the joints indicating that the structural behaviour of GFRP guardrail system is affected mainly by the type of joints.

**Keywords**: Guardrails; Fibre composites; Structural behaviour; Joints; Fasteners.

*Corresponding author, tel. +61 7 4631 2547; fax. +61 7 4631 2110
E-mail addresses: allan.manalo@usq.edu.au (A.C. Manalo), w0101563@umail.usq.edu.au (M. Pac)

## 1. Introduction

The prevention from fall-from-height has long been a popular topic in the field of construction safety. The National Standards in Australia requires for physical protection be provided in a construction site where there is a risk of person falling two meters or more. Min et al.[1] found out that the cardiovascular stress in workers increases when no safety guardrail is available resulting in an increased probability of workers falling from heights. Guardrail system is used to provide protection for unguarded openings and is an effective way to manage the risk of falling from working at heights. Its effectiveness depends on appropriate design and use, and more importantly, the reliability of the connection between its members. However, only a few studies were conducted so far to evaluate the effectiveness of guardrail systems in preventing fall from heights. Bobick et al.[2] evaluated the ultimate strength of a guardrail system made up of quality 38 mm x 89 mm lumber and nail construction. Their results showed that the guardrail system withstood the applied load recommended by the Occupational Safety and Health Administration (OSHA). However, they recommended that reusing old materials is an unsafe practice and should be avoided. Similarly, Lan and Daigle[3] evaluated the effectiveness of temporary wooden guardrails in protecting workers against falls on construction sites. They found out that the current practice of using low-strength timber of 38 mm x 89 mm dimensions, spaced at 1.8 m and nailed to the floor with 89 mm long common nail, were not appropriate for wooden guardrails based on the Quebec Safety Code. Cheung and Chan[4] proposed a rapid demountable platform as an alternative or a supplement to the traditional bamboo scaffold for preventing fall from height accidents. In the field of fibre composite materials, Bank and Gentry[5] investigated the behaviour of a pultruded composite material highway guardrail system. The results of their 10-year research and development program demonstrated that the structural capacity of a composite guardrail is similar to that of steel w-beam highway guardrail. This study suggests the opportunity of using fibre composite materials for guardrail system in a construction site to prevent workers falling from working at heights.

Composite guardrail systems are attractive, strong and low maintenance compared to wood and metals systems[6]. The use of fibre composite guardrails is particularly well suited in moist and demanding environment such as the mining area, offshore platforms and industrial plants where corrosion is a major problem. If a fibre composite guardrail has been used, the fall of a worker from an elevated platform in an underground mine due to the collapsed of the heavily corroded metal guardrail and the serious injuries sustained from the fall[7] could have been prevented. Fibre composite guardrails are now increasingly being used due to its high strength, high corrosion resistance and low maintenance requirements. However, there has been limited study conducted to understand the behavior of fibre composites guardrail system under the applied load. Lan and Daigle[3] indicated that the quickest method of verifying a guardrail compliance with a regulation is to carry out tests by applying forces and evaluate the resistance of the guardrail system against the standard requirements. In this study, the behaviour of pultruded glass fibre reinforced polymer (GFRP) guardrail is determined following AS1657-1992[8] standard. The parameters considered are the anchoring conditions, fasteners between guardrail members and the location of the application of the load. GFRP guardrail systems mounted on top and side of a steel I-beam with different joint connectors and fasteners are loaded horizontally to the top of the middle guardrail post and to the middle of the guardrail member.



## 2. Materials

This section presents the material characteristics of the different components of the guardrail system. All materials are provided by the industry partner, Nepean Building and Infrastructure, Australia.

### *2.1 Pultruded GFRP section*

The main structural component of the guardrail system is a pultruded ribbed GFRP pipe, made up of E-glass fibres and isophthalic polyester resin. The pultruded GFRP section (Figure 1a) has a nominal diameter of 50 mm and wall thickness of 6 mm. The burn-out test revealed that the pultruded GFRP pipe contains 60% fibres by weight, which is mostly in the unidirectional direction with randomly oriented strand glass mats in the outer and inner surfaces as shown in Figure 1b. The mechanical tests of the pultruded GFRP tubes determined from the component material testing shown in Figure 2 indicated that its Young's Modulus, flexural and compressive strength are around 27 GPa, 282 MPa and 350 MPa, respectively.

***2.2 Joints and fasteners***

Different joint connectors were fabricated for easy assembly of the guardrail system. Figure 3 shows the 3-way tee connector, 4-way tee connector and the 90-degree elbow which is made up of the same materials used for the production of the GFRP section. These joint connectors are steel core encapsulated for ultimate strength. They are fabricated wherein they can easily fit to the post and horizontal members of the guardrail and with predrilled holes for easy attachment of the fasteners. Similarly, two types of fasteners to attach the GFRP tube and the joint connector were considered in this study. Stainless steel rivets and polypin with a diameter of 6.35 mm (Figure 4) were used as fasteners to join together the posts and horizontal members of the guardrail system. The effectiveness of providing Techniglue-HP R5 structural epoxy adhesives in combination with rivets and polypin was also evaluated.

The GFRP guardrail is assembled and anchored to the supporting beam using specialized and moulded thermoplastic base connectors. Figure 5 shows the base plate and side-mount bracket connectors for the guardrail assembly. The guardrail post is bolted to the top-mounted connector using 8 mm diameter stainless steel bolts while the post is fixed to the side mounted connector using 2 pcs of 6.35 mm diameter stainless steel rivets.

***2.3 Assembly of the GFRP handrail specimen***

A series of two bays of the GFRP guardrail system was assembled, each with a span of 1.5 m apart. Holes of 6 mm diameter were drilled in the GFRP pipes to accommodate the fasteners. The different joint connectors were then placed and the fasteners were inserted. The connection between the guardrail posts and the base connector for the top mounted specimen was achieved by using 8 mm diameter stainless steel bolts and washers while the side mounted connector is attached to the bottom of the guardrail post by 2 stainless steel rivets. Another set of guardrail system were assembled by gluing the ribbed GFRP pipe to the joint and base connectors before the fasteners were provided.

## 3. Experimental investigation

The static testing of the fibre composite guardrail system assembled using different type of fasteners and horizontally loaded to the post and member is discussed in this section.

### *3.1 Test specimen*

A total of 16 guardrail systems were prepared and tested up to failure. Table 1 summarises the descriptions of the test specimens. In this table, G, T, S, P, and M correspond to the guardrail, top-mounted, side-mounted, post and member, respectively while P, R and E correspond to the different fasteners used such as polypin, rivets and epoxy, respectively.

### *3.2 Test set-up and procedure*

The test assembly consisted of anchoring the GFRP guardrail system on steel I-beam bolted on a strong floor. The guardrail was installed at a height of 1.04 m from the top of the steel I-beam. The base of the guardrail post is secured to the beam by means of 4 pieces - 10 mm diameter full-threaded steel bolts to simulate the industry standard method for connecting the guardrail assembly to a supporting beam. Each guardrail system was subjected to horizontal loading following AS1657-1992[8] standard. The load was applied by means of a 100 kN capacity hydraulic cylinder secured to a test frame with a loading rate of 5 mm/min. A 100 kN load cell was attached at the end of the hydraulic cylinder to measure the applied load while a draw wire displacement transducer was used to measure the deflection of the guardrail. Figure 6 illustrates the test set-up for guardrail loaded directly to the top of the middle post while Figure 7 shows the test set-up for the guardrail loaded to the midspan of a member. Initially, all the guardrail specimens were loaded up to 550N and the load was removed to observe any deformation in the guardrail. All specimens were then tested up to failure to evaluate the ultimate strength and failure mechanism of each guardrail configuration. The applied load and deflection were recorded using a System5000 data acquisition system.

## 4. Experimental results

The load and deflection behaviour and failure mechanisms of the GFRP guardrails loaded horizontally to the post and to the member are reported in the succeeding sections.

### *4.1 Failure load*

All specimens resisted the applied horizontal load of 550N without any signs of failure. There was no measured permanent deformation in the guardrail post and member after the removal of the load. All the specimens were then tested up to failure to determine the maximum load on which the different guardrail system can resist. A summary of the maximum load where the different fibre composite guardrail specimens failed is listed in Table 2. It can be noticed that the guardrail systems mounted on the top of the steel I-beam resisted a higher load than the guardrails mounted on the side of the beam. Moreover, the results showed that the guardrail system loaded to the post failed at a higher load than those loaded to the member. In summary, the guardrail systems considered in this study withstand an applied horizontal force of at least 9.40kN before final failure.

### *4.2 Behaviour of top-mounted guardrail loaded to post*

The load and deflection behaviour of the composite guardrails mounted at the top of the beam and loaded to the middle post is shown in Figure 8. A linear load deflection curve was observed in all specimens at the initial application of the load. For specimens GTP-PE and GTP-RE, a slight decrease in the load was observed due to the initiation of epoxy debonding and sliding of the guardrail members. A significant drop in the load was then observed for both specimens due to the failure in the 4-way tee joint at the middle post. Failure in the 4-way tee joint (Figures 9a and 9b) occurred at a load of 19.18 kN and 19.31 kN in specimens GTP-PE and GTP-RE, respectively. The high deflection after the initial failure is explained by the failure of the 4-way tee joint which separates the top portion of the post, thus reducing the force absorbed by the post. However, the guardrail system continued to carry load as the load was transferred to the top guardrail members but with a significant amount of deflection at the top post due to the progression of failure in the 4-way tee joint. Final failure occurred due to significant damaged on the 4-way tee joint combined with sliding failure on the 3-way tee joint at the top of the post.

For specimens GTP-P and GTP-R, the absence of epoxy adhesive resulted in the joint connectors to rotate and reduced the overall stiffness of the guardrail system. This is expected as the connection between the joints and the GFRP tubes is not fully tight allowing the tube to rotate and lose stiffness resulting in large deformation. For specimens without epoxy adhesive, the continuous splitting of the GFRP tube also contributed to the large amount of deflection observed. The failure in specimen GTP-P occurred due to sliding of the polypin at an applied load of 12.96 kN as shown in Figure 9c. The initial failure of guardrail connected with polypin occurred at a displacement of around 170 mm. This failure of the polypin resulted in a reduction in the applied load but the specimen continued to carry load and deflected more as the load was transferred to the top guardrail members. On the other hand, specimen GTP-R failed due to failure of the GFRP tube at the bottom post (Figure 9d) at an applied load of 16.77 kN. During the spread of the damage, sliding of the 3-way tee joint under the loading nose was observed in all specimens at final failure.

***4.3 Behaviour of top-mounted guardrail loaded to member***

The load deflection behaviour of the top-mounted guardrail loaded to the middle of the horizontal member is shown in Figure 10. For all specimens, it can be observed from the figure that the deflection increased linearly with the applied load up to failure. However, there was an observed drop in the load due to initiation of failure in the guardrail. For specimens GTM-PE and GTM-RE, initial failure occurred due to failure at the 3-way tee joint at the side post (Figures 11a and 11b) at an applied load of 13.7 and 10.3 kN, respectively. Eventhough failure of the 3-way tee joint occurred, the guardrail system still carry load as indicated by the increase in the load capacity as shown in the load-displacement curve. This is due to the load transferred to the guardrail member and post. Final failure of specimens GTM-PE and RE is due to the failure of the GFRP tube at the bottom portion of the middle post as shown in Figures 11b and 12b.

For guardrails without epoxy at the joints, specimens GTM-P and GTM-R, the failure was initiated at 3-way tee joint at the side post (Figure 13) at an applied load of around 13.2 kN. Both specimens continued to carry load with more deformation and finally failed due to the pull-out of the polypin for specimen GTM-P and splitting shear failure of the GFRP tube for specimen GTM-R at the middle post. In specimen GTM-R, the failure of the GFRP tube occurred as only the randomly oriented strand glass mats provide the strength in the transverse direction of the guardrail. However, it can be also seen that the composite guardrail fails progressively with the application of load. The splitting of the tubes occurs without the rupture of the unidirectional glass fibres which preserved some of the strength capacity of the guardrail system. With the continuous application of the load, the splitting and tearing of the composite guardrail progresses resulting in large deformation and total failure of the guardrail system.

***4.4 Behaviour of side-mounted guardrail loaded to post***

The load and deflection behaviour of the guardrail systems mounted on the side of the beam and loaded to post is shown in Figure 14. The figure shows that all specimens behaved linear elastic up to the maximum applied load but a drop in the load was observed due to the failure occurring at the side mounted plate. Based on the results, the specimen GSP-PE and GSP-RE failed at an applied load of 17.7 kN and 15.6 kN, respectively. On the other hand, the specimens GSP-P and GSP-R failed at a load of around 10.0 kN, which is lower than that of the specimens with epoxy at the joints.

All specimens failed due to the failure of the side-mounted plate at the bottom of the middle post as shown in Figure 15a. Except for specimen HSP-RE, failure of the side-mounted plate occurred at a deflection of around 140 mm. However, it can be observed that after a deflection of 140 mm there is a decrease in the stiffness in specimen GSP-RE which indicates that the failure initiated in the guardrails system. The failure of the side mounted connector result in the guardrail losing functionality as indicated by the significant drop in the load. After this point, all specimens showed some resistance to carry load but with significant amount of deflection until the sliding failure of the 3-way tee joint connecting the two guardrail bays at the top post was observed as shown in Figure 15b.

### *4.5 Behaviour of side-mounted guardrail loaded to member*

The load and deflection behaviour of the side-mounted guardrail loaded to member is shown in Figure 16. It can be seen from the figure that all specimens behaved linear elastic up to the maximum applied load. For specimens GSM-RE and GSM-PE, the maximum load recorded was around 14.7 kN while specimens GSM-R and GSM-P resisted an applied load of about 13.5 kN. After which, a drop in the load was observed and the specimen carried some load with significant amount of deformation before the final failure.

Specimens GSM-PE and GSM-RE showed very similar behaviour. Both of them exhibited the same load-deflection behaviour and resisted a maximum applied load of around 14.7 kN when the first failure was observed. Similarly, the failure occurred at a deflection of around 150 mm due to the failure of the 3-way tee joint at the side post as shown in Figure 17a. A drop in the load was then observed after this failure but the guardrail continued to carry load. After failure of the 3-way tee joint, the horizontal guardrail member transferred the load to the middle post which results in the failure of the side mounted plate as shown in Figure 17b.

The specimen GSM-R and GSM-P failed at an applied load of almost 13.5 kN when failure of the GFRP tube at the 3-way tee joint at the side post occurred as shown in Figure 18a.

After the initial failure, the load was transferred to the nearby post (middle post) through the horizontal guardrail member which resulted to the failure of the 4-way tee joint as shown in Figure 18b. This result shows that for joints without epoxy, failure occurs mostly at the joints as there is no continuity of the system and the load is not transferred effectively to the base plate connector.

## 5. Discussion

The effects of the base connectors, fasteners and the application of load on the structural behaviour of the composite guardrail system are discussed in this section. Similarly, an evaluation of the performance of the fibre composite guardrail against the requirements of AS/NZ Standards is presented.

### *5.1 Effects of bottom fixity*

Many guardrail failures reveal the weakest link in the design of guardrail is the attachment of the guardrail post to the deck or the supporting beam. This is because when someone leans against a guardrail, their weight stresses the post connection at the base of the post. Lan and Daigle[3] mentioned that the installation of base connector with a breaking strength of 16 kN or more is always problematic particularly for guardrail system and for temporary structures. In this study, the load test directly provided information on how well the different members of composite guardrail have been connected to each other and acted as a unit to effectively resist the applied load. The results showed that the requirement of 16kN breaking load can be achieved for guardrail system mounted on top of the beam and fastened with epoxy at the joints.

Comparison in Figure 19a showed that the lateral load resistance of the guardrail system loaded to post and with top-mounted connector is greater than that of the side-mounted connector for all types of joint fasteners. This is evident in the results of the testing as the failure of guardrail system mounted on top of the beam occurred either on the joint or the GFRP pipe and not on the base plate connector. This is important as this result showed that the top mounted connector is stronger than guardrail member and joints thereby not collapsing. On the other hand, all side mounted guardrail loaded to top of the central post failed due to tearing of the side mounted plate. When the failure of the side-mounted connector occurred, the guardrails system lost most of its capacity to carry load. This result indicates that the capacity of the side-mounted connector needs to be increased to ensure that failure will not occur at the base connector and leave the guardrail system intact and provide a higher resistance to carry the applied load.

In contrast, the guardrail system mounted on side of the beam connected with either polypin or rivets combined with epoxy and loaded to horizontal member exhibited a higher failure load than the top mounted guardrail system as shown in Figure 19b. This is because the side mounted connector allows the guardrail to deflect more than that of the top mounted guardrails resulting in its capacity to carry a higher load. On the other hand, there is no significant difference on the behaviour between the side-mounted and top mounted guardrail system connected with either polypin or rivets only. The behaviour of these specimens is governed by the joint connectors which resulted in almost the same capacity to carry load.

***5.2 Effects of member fasteners***

Figure 20 shows the comparison of the failure load of the guardrail system connected with different joint fasteners. In general, the results of the test indicated that stainless steel rivet is a more effective fastener than polypin as the guardrail system with rivet connections failed at a higher load. This is because when the rivet is installed in the drilled hole in the joint connector, and the tail is bucked or deformed so that it expands to about 1.5 times the original shaft diameter, holding the rivet in place. On the other hand, the inserted polypin with a constant diameter showed a lower resistance to tension than rivets allowing pullout with relatively a little force. Further, guardrail system connected with rivets indicated that it will absorbed more energy than the specimen connected with polypin. This is evidenced during load testing wherein the specimen continued to carry load but with increasing deformation. This behaviour shows that this type of fastener will provide a significant warning of impending failure of the guardrail.

The results of the test point towards the effectiveness of the epoxy adhesives in increasing the failure load and stiffness of the GFRP guardrail systems. The guardrail system with this type of fasteners exhibited better stiffness than the guardrail system connected with rivets and polypin only. The results showed that the overall displacement of the guardrail system without epoxy is greater than those specimens with epoxy. This lower stiffness of specimen without epoxy can be attributed to the connection between the joints and the GFRP tube not tight fit. On the other hand, the addition of epoxy caused a tight connection between the GFRP profile and the joint which result in a stronger and stiffer guardrail system than the one without epoxy.

The guardrail system with epoxy failed at a higher load than those without. Also, the use of rivets in combination with epoxy results in a stronger guardrail system than the one with polypin. Due to the members connected with epoxy, the guardrail continues to carry load even failure of the 4-way tee joint occurred. That is, the rail post was allowed to shift gradually, transferring load to the guardrail member and remain substantially intact. This results in a progressive failure of the guardrail system and provides an effective warning of impending failure of the system. More importantly, this showed that the epoxy adhesives provided a continuous distribution system to enable the different guardrail components to carry load.

***5.3 Effects of application of loading***

Figure 21 shows the comparison of the failure load of the guardrail system loaded to the post and to the member. The results showed that the guardrail system has a higher capacity to carry load when loaded to post than the member indicating that the design of composite guardrail is more critical when loaded to the member. Except for the side mounted guardrail connected with either polypin or rivets only, the guardrail system loaded to the member failed at an applied load 20% lower than when loaded to the post. The higher failure load of guardrail when loaded to post than those loaded to member is due to the fact that the other side post are contributing in resisting the applied load. On the other hand, the load applied to the guardrail member is resisted only by the side and middle post. Furthermore, the lower failure load of the guardrail loaded to member than that to the post can be explained by mechanisms occurred at the guardrail. As observed in the experimental work, failure of the guardrail loaded to the member occurs mostly due to splitting shear failure of the GFRP tube at the end post. This is expected as the fibres are oriented mostly in the longitudinal direction. Thus, it has high capacity to carry axial forces but low resistance to resist shear forces. As also indicated by Bank and Gentry[5], composite guardrail containing continuous glass fibre reinforcement will likely fail due to shear and not longitudinal rupture of the fibres composite materials.

The specimens loaded on the member deflected more than that loaded on the post. This is expected as the horizontal displacement of the central section was due to bending of the top rail and bending of the post. These results showed the advantage of composite guardrails system. The significant deflection exhibited before final failure indicates that the composite guardrail system can dissipate significant energy due to impact of a falling person.

### *5.4 Comparison with standards*

Guardrail system must be strong enough and secured to prevent them breaking if someone falls against them. Lan and Daigle[3] indicated that the forces on the handrail are static forces, in the order of the worker's weight. In the US, the OSHA regulations require that a force of at least 890N must be supported by the top rail of the guardrail system at any point along the top edge and with a minimum safety factor on loading of 2[2]. On the other hand, AS1657-1992[8] indicated that a guardrail system should resist a load of 550N with no prescribed factor of safety. The results of the test indicate that all composite guardrail system considered in this study resisted the applied horizontal load of 550N without any signs of failure. Also, there was no measured permanent deformation in the guardrail post and member after the removal of the load.

As suggested in Table C1, AS/NZS 1170.0-2002[9], the serviceability limit state criteria for post and rail system of guardrail are height/60 and height/60+span/240, respectively which corresponds to a deflection of 18.33 and 24.58 mm, respectively. This sideway deflection at the top of the post is measured at a load of 2.67kN and 1.12 for FRP handrails with and without epoxy, respectively, while the allowable deflection for rail member is measured at a load of 1.51 and 3.53 kN for handrails with and without epoxy, respectively. These results indicated that the fibre composite is viable for use in guardrail system due to their sufficient stiffness and strength properties and with a reasonable factor of safety against failure.

## 6. Conclusion

The behaviour of GFRP guardrail system mounted on the top and side of a steel beam with different joint connectors are loaded horizontally to the top of the middle guardrail post and middle of the ribbed GFRP member. Based on results, the following are main findings of the study:

- The top mounted connector is a better bottom fixity system for a composite guardrail than a side connector. The lateral load resistance of the guardrail system with top-mounted connector and loaded to the post is at least 10% higher than that of the side-mounted connector for all types of joint fasteners.
- Stainless steel rivet is a more effective fastener than the polypin. The composite guardrail system connected with rivets absorbed more energy than the specimen connected with polypin which shows that this type of fastener will provide a significant warning of impending failure of the guardrail.
- The addition of epoxy adhesives is found effective in increasing the failure load and stiffness of the GFRP guardrail systems. The guardrail system with joints connected with either polypin or rivets combined with epoxy exhibited 20% higher failure load and almost double the stiffness than those connected using polypin or rivets alone.
- The failure behaviour of the composite guardrail system is governed by the joints. For top mounted guardrail, the failure occurred on the 4-way tee joint when loaded to the post while the failure occurred on the 3-way tee joint at the side post when loaded to the

guardrail member. For side mounted guardrail, failure is mostly due to failure of the side mounted plates.

- The design of composite guardrail is more critical when loaded to the member than when loaded to the post. The guardrail system loaded to the member failed at an applied load of 20% lower than when loaded to the post. Moreover, the guardrail system loaded on the member deflected more than that loaded on the post.
- All composite guardrail system resisted the applied horizontal load of 550N with no measured permanent deformation in the guardrail post and member after the removal of the load. Moreover, the GFRP composite guardrail system was found to exceed considerably the strength and serviceability requirements indicating that the material component as well as the joining system can be further optimised for a safe and more cost effective guardrail system.

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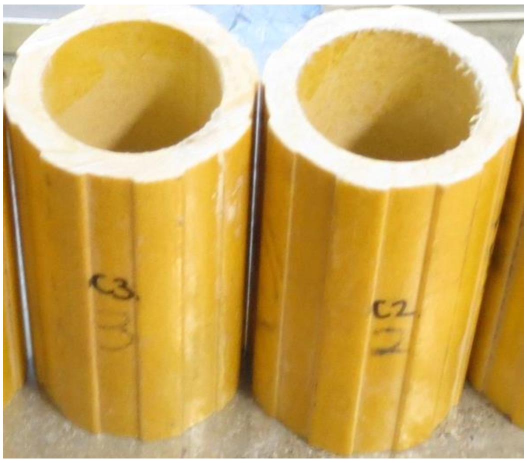
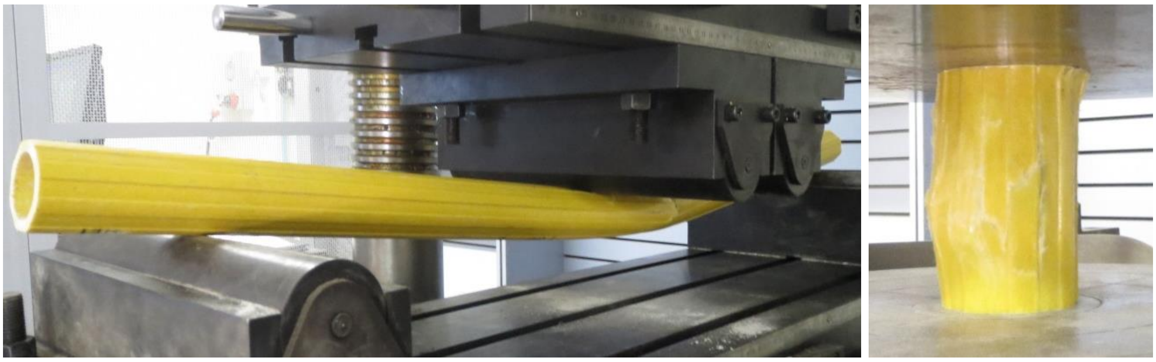


(a) Ribbed GFRP pipe


(b) Details of fibres

Figure 1: Details of the pultruded GFRP pipe



(a) Flexural test (b) Compression test

Figure 2: Material characterisation of the pultruded GFRP pipe

(a) 3-way tee (b) 4-way tee (c) 90-degree elbow

Figure 3: Joint connectors for the composite guardrail

Figure 4: Polypin (left) and rivets (right) fasteners for the composite guardrail

Figure 5: Top mounted (left) and side mounted (right) base connectors


Figure 6: Test of GFRP guardrails loaded to the post (specimen GTP)


Figure 7: Test of GFRP guardrails loaded to the member (specimen GTM)

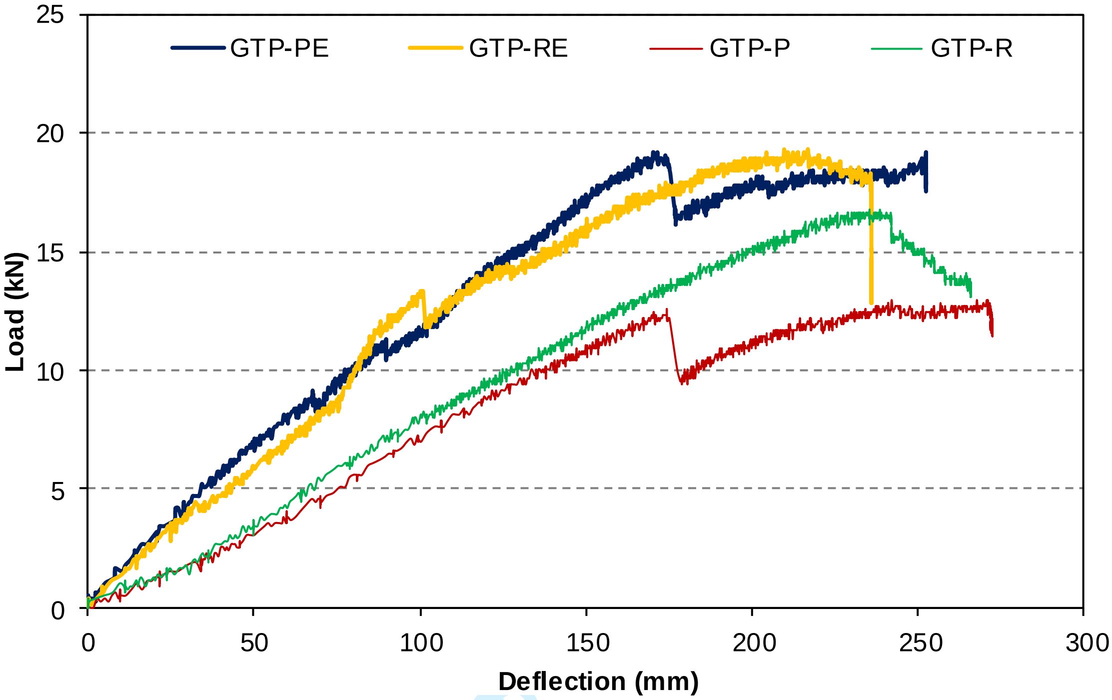
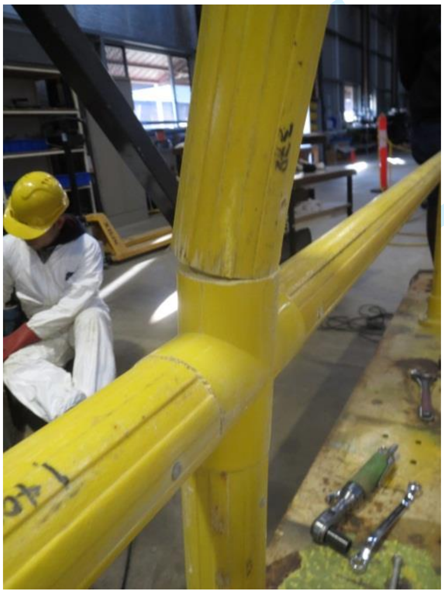



Figure 8: Load-deflection behaviour of top mounted guardrail loaded to middle post

(a)GTP-PE (b) GTP-RE



(c) GTP-P (d) GTP-R

Figure 9: Failure behaviour of top mounted guardrail loaded to post

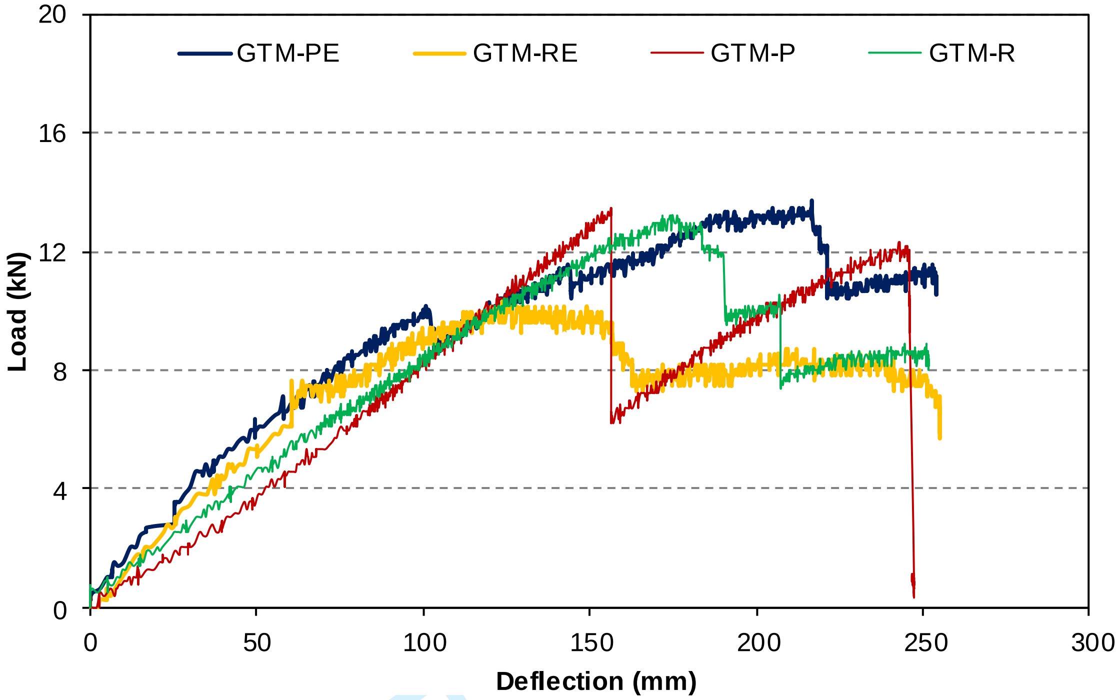



Figure 10: Load-deflection behaviour of top mounted guardrail loaded to member

(a) Failure of FRP profile (side post)

(b) Failure of FRP profile (middle post)

Figure 11: Failure behaviour of specimen GTM-PE

(a) Failure of joint (side post) (b) Failure of FRP profile (middle and end posts)

Figure 12: Failure behaviour of specimen HTM-RE

(a) GTM-P (b) GTM-R

Figure 13: Failure behaviour of specimen GTM

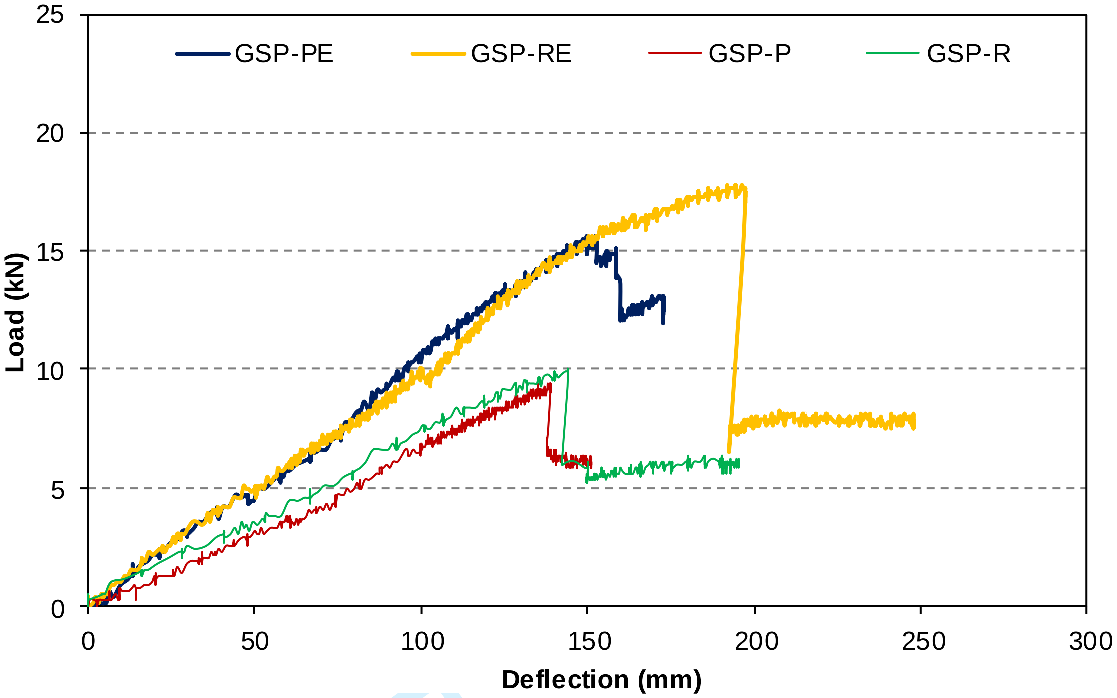



Figure 14: Load-deflection behaviour of side mounted guardrail loaded at middle post.

(a) Failure of the side mount plate (b) Failure of 3-way tee at the top post

Figure 15: Failure behaviour of specimen GSP

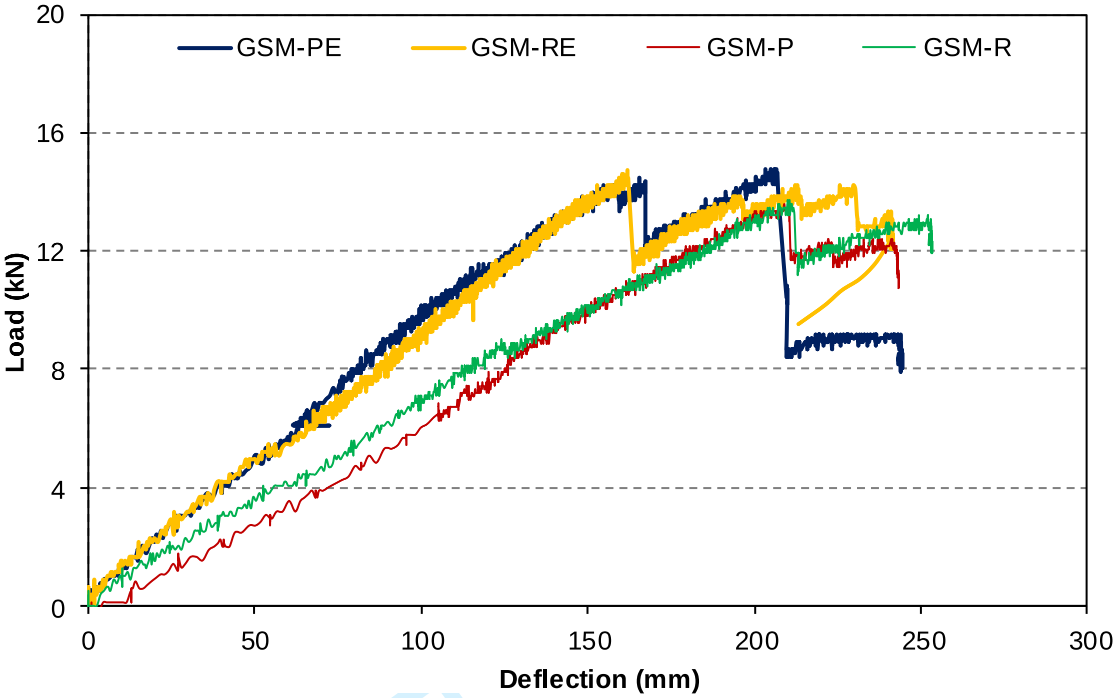
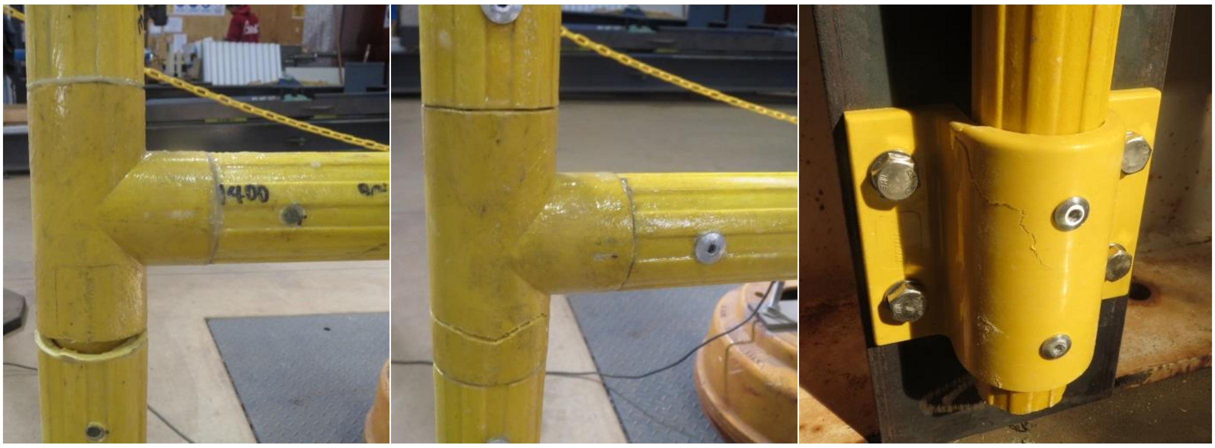



Figure 16: Load-deflection behaviour of side mounted guardrail loaded at member.

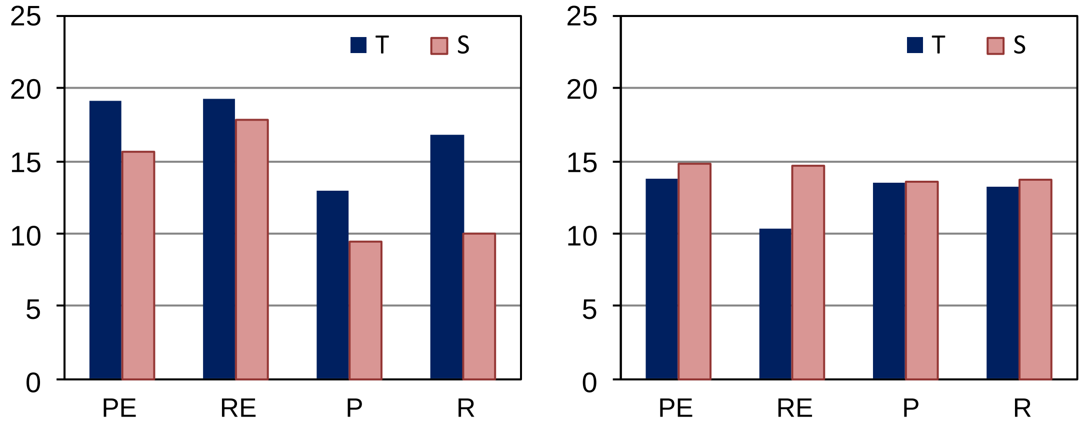


(a) Failure of 3-way tee (GSM-PE, left and GSM-RE, right) (b) Failure of side mount plate

Figure 17: Failure behaviour of specimens GSM-RE and GSM-PE

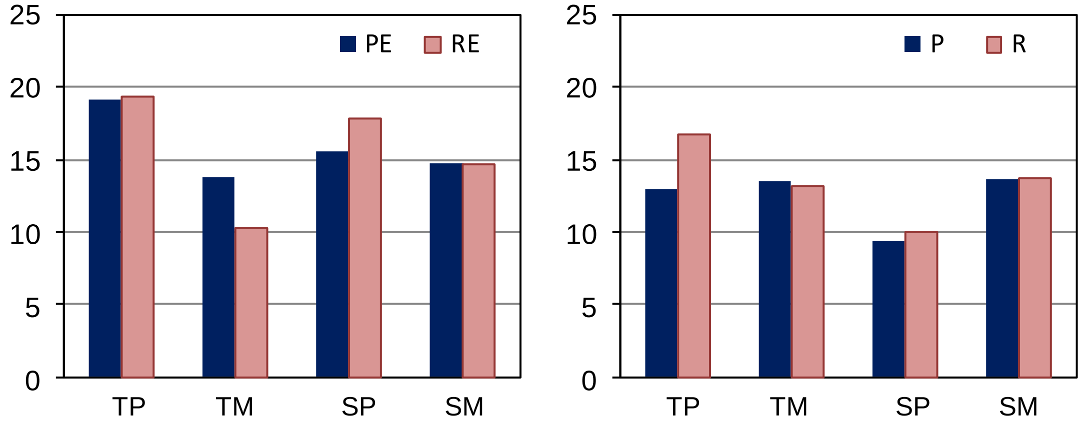
(a) Failure of the GFRP tube at side post (b) Failure of 4-way tee joint

Figure 18: Failure behaviour of specimen GSM-P and GSM-R



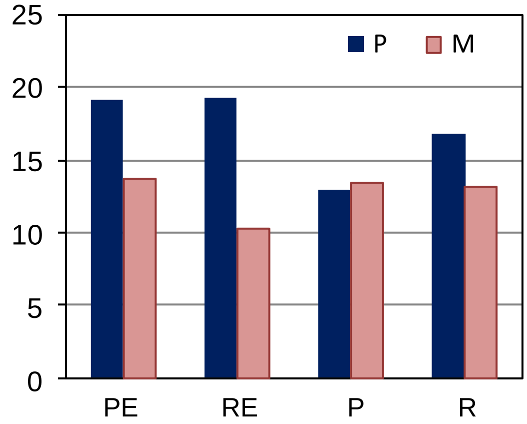

(a) Loaded to post (b) Loaded to member

Figure 19: Failure load of guardrail system with different base connectors

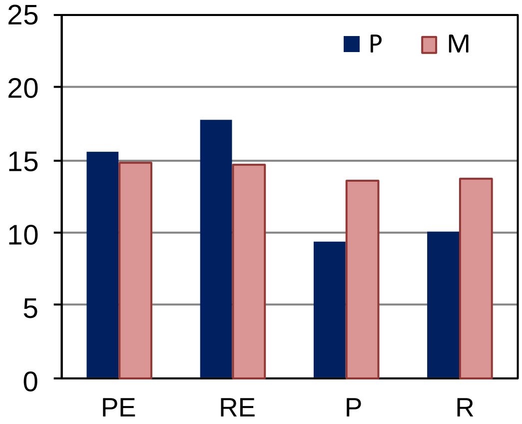



(a) PE and RE (b) P and R

Figure 20: Failure load of guardrail system with different joint fasteners




(a) Top mounted




(b) Side mounted

Figure 21: Failure load of guardrail system with different base connectors