TEST REPORT

Tests on Pultruded GFRP Post and Rail Safety Barriers

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Summary

The report describes several static load tests carried out on two types of pultruded glass fibre reinforced polymer (GFRP) post and rail safety barriers. The posts and hand/knee rails of the first type of safety barrier (Type 1, considered to be a modular barrier system) were fabricated from circular cross-section tubes. The posts were connected to the foundation by means of bolted sheet moulded compound (SMC) bases. Joints between the posts and rails were formed by bolted, two-part, two, three and four-way SMC connectors. The posts of the second type of safety barrier (Type 2) were square cross-section tubes with bolted SMC bases. A C-section custom profile, riveted to the tops of the posts, formed the handrail and a circular cross-section tube provided the knee rail.

Single- and two-bay Type 1 barriers with bay spans of 2.4 m and 1.25 m respectively were tested by applying incremental dead-weight loading normal to the plane of the barrier at the centre of the handrail of each bay. The maximum load applied was equivalent to the General Duty load (0.36 kN/m) specified in the latest draft of BS 4592 – 0 [1]. One two-bay Type 2 barrier with bay spans of 1.25 m was tested twice. In the first test it was loaded incrementally up to the maximum General Duty load. It was subsequently re-tested up to the maximum Heavy Duty Load (0.74 kN/m). During the Type 1 and 2 barrier load tests deflections were recorded at the loading point(s) and the junctions of the posts with the handrail. Both types of safety barrier were able to support the General Duty loads without suffering any obvious damage. The Type 2 barrier was also able to support the Heavy Duty load without damage. As expected, the single-bay Type 1 barrier was the most flexible and the two-bay Type 2 barrier was the stiffest. Under General Duty loading the maximum deflections, recorded at the centre(s) of the bay(s) ranged from approximately 30 to 80 mm, whereas, for Heavy Duty loading on the two-bay Type 2 barrier the maximum deflection was nearly 60 mm. After unloading each barrier, the residual deflections were generally less than 7 mm.

Disclaimer

The work described in this report has been carried out, as far as possible, in accordance with the descriptions given in the Engineering Department's Job initiation and Contract Form and the Client's purchase order.

The results contained in the report relate solely to the components and materials supplied by the Client for testing. The authors, the Engineering Department and the University are not responsible for any damage or loss arising from subsequent use, by the Client or third parties, of the results contained in the report.

The opinions and comments expressed in the report relate solely to the particular components and materials supplied by the Client for the tests carried out in the Engineering Department's Structures Laboratory. They do not apply to any other similar components and materials supplied by the Client to others. Furthermore, no endorsement of the components and materials, supplied by the Client for testing, is implied by the opinions and comments expressed in the report.

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1. Introduction and Objectives

Traditionally safety barriers are fabricated from tubular steel components. They are used to prevent people from falling off balconies, staircases, walkways etc and sustaining severe injury or even death.

Safety barriers fabricated from pultruded glass fibre reinforced polymer (GFRP) composite components are significantly lighter and potentially cheaper than their steel/aluminium counterparts. Moreover, their low self-weight facilitates rapid on/off-site assembly and also reduces transportation costs. Furthermore, they may be supplied as a modular system or tailored to required dimensions on site by cutting to length and assembling using simple hand tools. A significant application of these lightweight materials is anticipated to be rapid-assembly, temporary safety barriers on construction sites. Figure 1 shows an example of a two-bay pultruded GFRP post and rail safety barrier.

Figure 1: A three-post, two-rail pultruded GFRP safety barrier (modular system)

The objective of the test work described herein is to demonstrate, by means of static load testing, that pultruded GFRP post and rail safety barriers have sufficient structural integrity to satisfy the General Duty and Heavy Duty load capacity requirements defined in the draft BS 4592-0 [1]. The test configurations and procedures adopted for the safety barrier tests have taken account of the limited guidance given in [1], but differ in a number of respects. These differences are explained at the relevant locations within the report.

2. Materials and Components

The Client supplied the composite material components and fasteners to enable the post and rail safety barriers to be fabricated for testing.

Two types of composite material components were used in the safety barriers. The main structural components (posts and rails) were circular and square cross-section pultruded GFRP tubes and custom C-sections. Two sizes of circular cross-section tube were used, namely 50 x 5 mm and 38 x 3 mm (outer diameter x wall thickness. The square cross-section tubes were 51 x 6.4 mm (side length x wall thickness).

The components which formed the joints between the posts and rails and the bases which connect the posts to the foundation were, according to the Client, made of short fibre glass reinforced sheet moulding compound (SMC). Figures 2 (a) and 2(b) show the bases for the circular and square cross-section posts, respectively. The holes in the flanges of the bases for the holding down bolts are 12 mm in diameter. Four external, triangular, composite gussets stiffen the sockets of the bases.

(a)  (b) 

Figure 2: SMC post bases: (a) for a circular cross-section post and (b) for a square cross-section post

Three types of two-part SMC connector were used to join the posts and rails formed by the larger circular cross-section tubes. *Two-way* connectors were used to form the joints between the end posts and the upper rail (handrail). *Three-way* connectors joined the interior post to the handrail and the end post to the lower rail (knee rail). *Four-way* connectors were used to form the joint between the interior post and the knee rails on opposite sides thereof. Figure 3 shows the three types of bolted joint made with the two-part connectors.

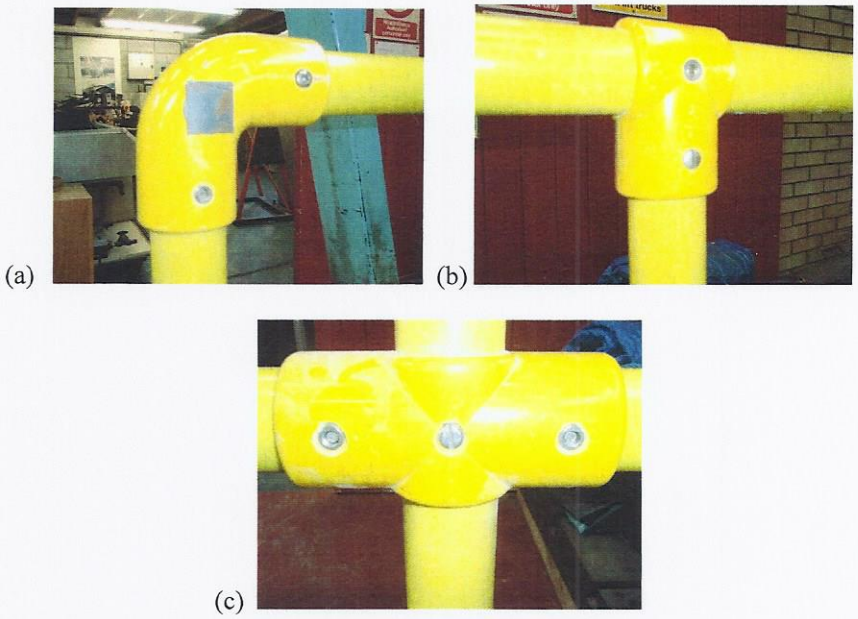


Figure 3: Two-part connectors used to form orthogonal joints between the circular cross-section pultruded GFRP posts and rails: (a) two-way, (b) three-way and (c) four-way bolted joints

3. Pultruded GFRP Post and Rail Safety Barriers – Basic Details

Two types of pultruded GFRP post and rail safety barrier were tested in this investigation. The first type – Type 1 – the modular barrier - used the SMC circular post bases and two-part connectors and the larger pultruded GFRP circular cross-section tubes for the posts and hand/knee rails. The second type of barrier structure – Type 2 – used the SMC square post bases. The C-section handrail was push-fitted over the tops of the posts and was connected to them by a rivet on each side, as shown in Figure 4. The knee rail, formed by the 38 x 3 mm circular cross-section tube, passed through holes drilled in opposite walls of the interior post (see Figure 5) and holes drilled through the inside wall of each end post. Hence, the knee rails were not rigidly connected to the posts.

Figure 4: C-section handrail connected to the top of the square cross-section post by a rivet through each side (Type 2 safety barrier)

Figure 5: Knee rail tube passed through holes drilled in opposite walls of an interior square post (Type 2 safety barrier)

In accordance with the Client's instructions three safety barriers were fabricated to be tested for compliance with both the General and Heavy Duty loads specified in [1]. Two were Type 1 (modular) barriers and the third was a Type 2 barrier. The dimensions of the barriers are given in Table 1.

Table 1

Dimensions of the three safety barriers fabricated for static load testing

Safety Barrier Type	Number of Bays	Bay Length [m]	Handrail Height [m]	Knee Rail Height [m]	Post Section [mm]	Handrail Section [mm]	Knee Rail Section [mm]
1	1	2.4	1.1	0.55	50 x 5 (C)	50 x 5 (C)	50 x 5 (C)
1	2	1.25			50 x 5 (C)	50 x 5 (C)	50 x 5 (C)
2	2	1.25			51 x 6.4 (S)	C-section	32 x 3 (C)

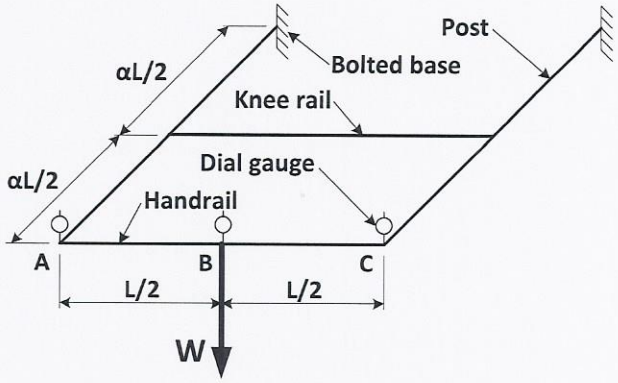
Note: (C) and (S) denote circular and square cross-section pultruded GFRP tubes, respectively. The first dimension denotes the outer diameter or side length and the second the wall thickness. The dimensions of the C-section are not given, though the gap between its flanges must be 51 mm to satisfy the push-fit requirement.

4. Experimental Setup for Barrier Tests and Test Procedure

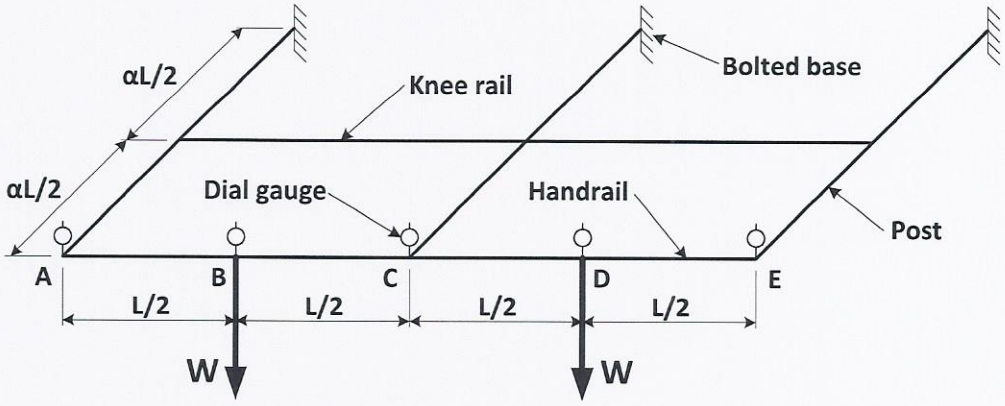
The current draft of BS 4592-0 [1] only specifies the load that has to be applied at the level of the handrail. No guidance is given about the test setup to be used. Therefore, with the agreement of the Client, it was decided that, it would be preferable to test two-bay safety barriers. This configuration would provide structural continuity across bays and was deemed to be more representative of how a safety barrier would perform in service. Nevertheless, a single-bay safety barrier was also tested because one of the Client's customers had requested such a test.

Again, with the Client's agreement it was decided to set up the safety barriers for testing in the horizontal plane by bolting their post bases to a vertical steel frame, formed from giant meccano sections, anchored to the laboratory strong floor. This allowed the handrails to be loaded incrementally and normal to the plane of the barrier by slotted steel dead weights on steel hangers.

According to [1], for General and Heavy Duty applications the handrails have to be capable of supporting uniformly distributed loads of 0.36 and 0.74 kN/m, respectively. However, because of the relatively short spans of the bays and the shapes and small sizes of the handrails, it was deemed impractical to apply the required loading uniformly to the handrails. Consequently, with the Client's agreement, it was decided, instead, to apply the total uniformly distributed load per bay as a concentrated load at the centre of the handrail. This decision meant that the handrails were subjected to more onerous loading than that specified in [1]. Consequently, if the barrier was able to support the concentrated load, it would also be able to support the specified uniformly distributed load.
Schematic diagrams of the test setup for the single and two-bay barrier tests are shown in Figures 6(a) and 6(b) respectively.



(a)



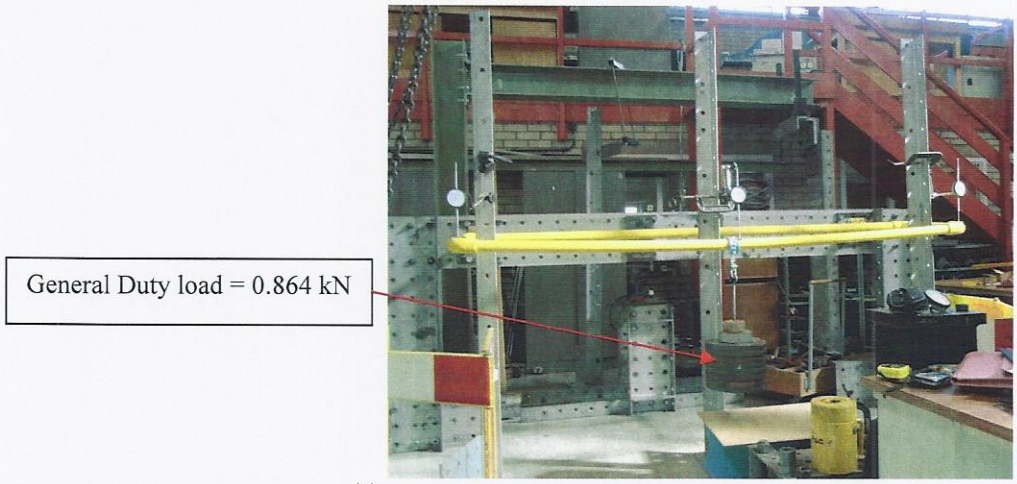
(b)

Figure 6: Schematic diagrams of the test setups for the safety barriers: (a) two-post, two-rail, single-bay barrier and (b) three-post, two-rail, two-bay barrier

In Figure 6 generalised frame dimensions and loading are shown (to enable the development of a generalised grillage analysis for predicting the load – deformation response of the safety barriers). The overall dimensions of the two Type 1 and the Type 2 safety barriers are given in Table 1.

Dial gauges with travels of the order of 50+ mm were placed in contact with the joints between the top of the posts and the handrail, i.e at Points A, C and/or E in Figure 6. In addition, dial gauges were positioned close the mid-bay load point(s), i.e. at B and/or D. For practical reasons the latter gauges had to be offset by between 25 and 35 mm from the load point(s) on the handrail, depending on the particular barrier being tested. This departure from the ideal situation did not make a significant difference to the recorded values of deflections.

A similar loading procedure was used in all of the tests, i.e the load was increased in approximately 10 kN increments (except for the first and last load increment) up to the maximum load. There was a short dwell time (typically 5 minutes) at the maximum load in order to allow photographs to be taken. Thereafter, the load was decreased in similar decrements to zero. After each load increment/decrement the dial gauge readings were recorded. Images of the two Type 1 safety barriers supporting the General Duty load given in [1] are shown in Figure 7. Likewise, Figure 8 shows the Type 2 safety barrier supporting both the General Duty and Heavy Duty loads.



(a)

(b)

Figure 7: Type 1 safety barriers (modular system) supporting the General Duty loading specified in [1]: a single-bay (2.4 m bay) and (b) two-bay (1.25 m bays)

(a)

(b)

Figure 8: Type 2 safety barrier subjected to maximum loads specified in [1]: (a) General Duty load and (b) Heavy Duty load (1.25 m bays)

5. ***Test Results and Discussion***

It is convenient to present the test results for, and comments on, the Type 1 and 2 safety barriers separately as follows:-

5(a) Type 1 – Two-Post, Single-Bay Barrier (2.4 m bay)

This barrier was tested under General Duty loading. It was loaded incrementally up to the maximum load of 0.864 kN and then unloaded. At each stage of loading/unloading the deflections at A – C (see Figure 6(a)) were recorded. Unfortunately, the travel of the dial gauge at B was exceeded during the application of the last load increment, so that the maximum deflection could not be recorded. The dial gauge at B was reset the barrier was unloaded and deflections were recorded after the removal of each load decrement.

In order to determine the maximum mid-span deflection at B under the General Duty load, the barrier was re-tested by applying the total load in one increment. Figure 9 shows the deflections recorded at A, B and C as the load was increased. It is evident that the deflections increase linearly with increasing load. The deflections at A and C should, in theory, be identical and they are reasonably similar, especially at the lower levels of loading. At the General Duty load the deflection at B (mid-span) is nearly twice that at A and C. From the *straight line fit* to the load – deflection data for point B, it is evident that the transverse stiffness of the handrail is only about 10.5 N/mm.

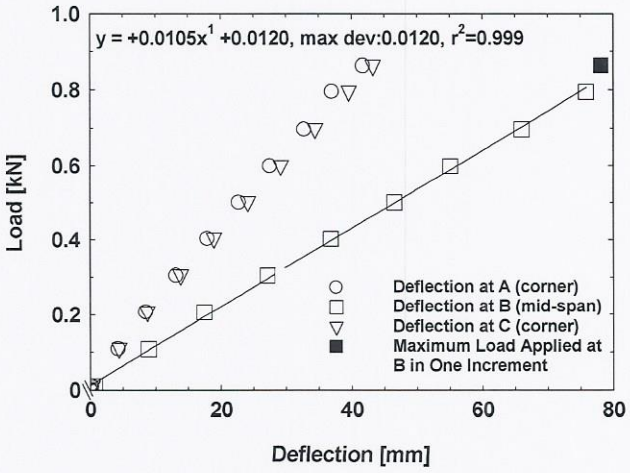


Figure 9: Load – deflection response of the Type 1 single-bay barrier (2.4 m bay)

The maximum and residual deflections recorded for this safety barrier at A, B and C are given in Table 2. It is evident that the maximum deflection at C is approximately 3.6% greater than that at B and the maximum deflection at B is between 87% and 81% greater than those at A and C, respectively. Moreover, the residual deflections of the barrier's handrail range from 4 mm to 5.4 mm

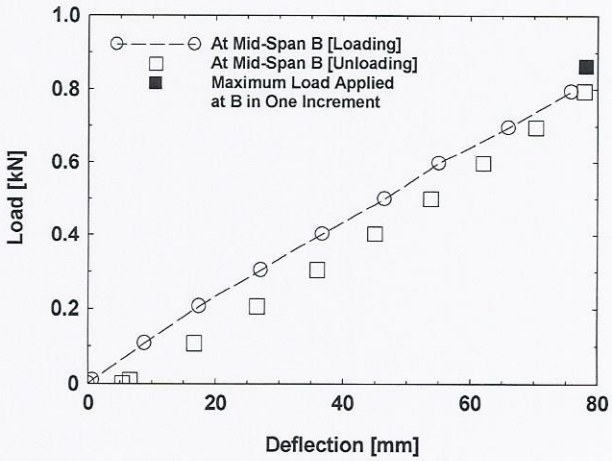
Table 2

Deflections at maximum load and after unloading of the single-bay two-post modular handrail system

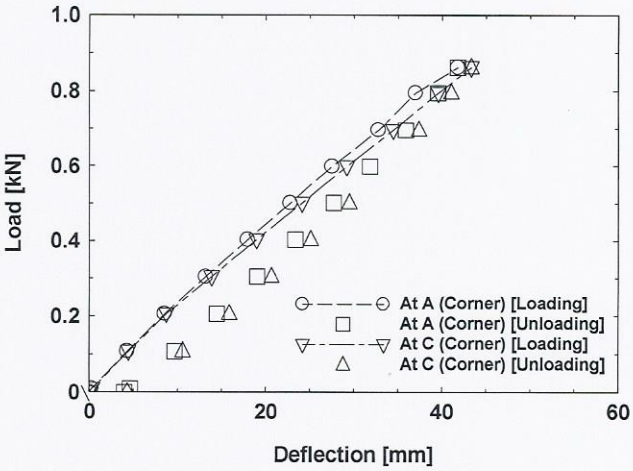
Point Load at Mid-Span of Bay [kN]	Span of Bay [m]	Deflection at A [mm]	Deflection at B [mm]	Deflection at C [mm]
0.864	2.4	41.8	78.2**	43.3
0.0 (unloading)		4.0	5.4	4.3

**Deflection measured with total load applied in one increment because dial gauge ran out of travel during the application of the last load increment (0.0491kN) of the incremental load test. Furthermore, the deflection was measured at a point 30 mm to the right of B (see Figure 6(a).

The differences between the load/unload – deflection responses of the barrier are shown in Figures 10(a) for point B and 10(b) for points A and C, respectively. It is evident that there is a small measure of hysteresis in the responses.



(a)



(b)

Figure 10: Load/unload – deflection responses of the Type 1 single-bay barrier: (a) Point B and (b) Points A and C (2.4 m bay)

5(b) Type 1 – Three-Post, Two-Bay Barrier (1.25 m bays)

The load – deflection responses up to the General Duty load are shown for points A – E (see Figure 6(b)) in Figure 11. It is evident that there is a greater difference between points A and E than was observed between A and C for the single-bay barrier. However, there is not much difference between the deflections at B, C and D.

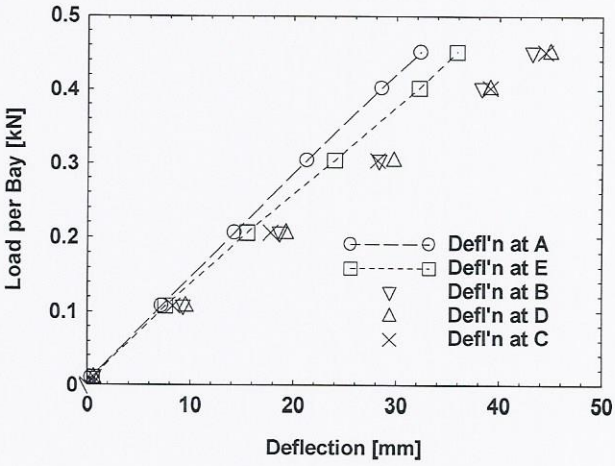


Figure 11: Load – deflection response of a Type 1 two-bay barrier (1.25 m bays)

The maximum and residual deflections at A – E are summarised in Table 3. It is evident that the maximum deflection at E is 11% greater than that at A. However, the maximum deflection at D is only 4.2% greater than that at B. Of course, in theory, deflections A and E should be equal, as also should B and D. Furthermore, the deflections B, C and D are, for practical purposes, approximately equal.

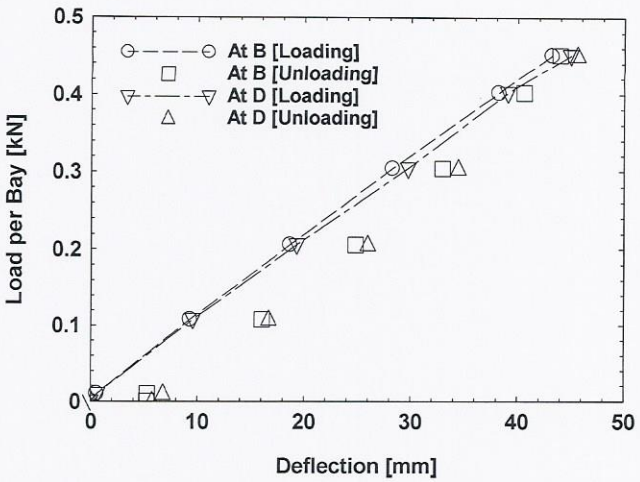
Table 3

Deflections at maximum load of the two-bay three-post safety barrier (modular system)

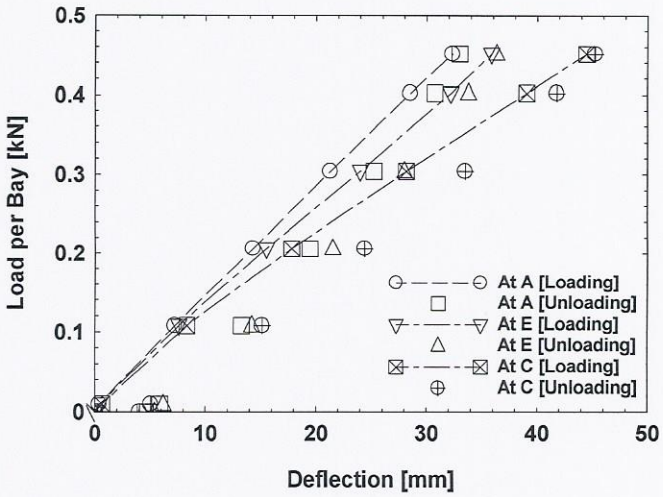
Point Load at Mid-Span of Each Bay [kN]	Span of Each Bay [m]	Deflection at A [mm]	Deflection at B [mm]	Deflection at C [mm]	Deflection at D [mm]	Deflection at E [mm]
0.451	1.25	32.3	43.2*	44.5	45.0*	35.9
0 (unloading)		4.6	5.2	4.1	5.8	5.4

*Deflections were measured at 30 and 32 mm to the right and left of B and D respectively.

The loading and unloading responses for points B and D and for points A, C and E are shown in Figures 12(a) and 12(b), respectively. The former figure shows clearly the good similarity between the loading and unloading paths of points B and D, whereas latter figure shows that the difference between the corresponding paths of points A and E is much larger. Both figures show that there is a significant difference between the loading and unloading paths for all points, i.e. there is significant hysteresis in the responses.



(a)



(b)

Figure 12: Load/unload – deflection responses of the Type 1 two-bay barrier: (a) Points B and D and (b) Points A, C and E (1.25 m bays)

5(c) Type 2 – Three-Post, Two-Bay Barrier (1.25 m bays)

This safety barrier with the C-section handrail was first tested under General Duty loading. The load – deflection responses for points A – E are shown in Figure 13. It is evident that this barrier is stiffer transversely than the corresponding Type 1 barrier. For this barrier too, the difference between the responses of points A and E appears to be greater than that between B and D. A similar situation was observed with the corresponding Type 1 barrier.

The maximum and residual deflections for points A – E are given in Table 4. The mid-bay maximum deflections (points B and D) differ by 6.5%, whereas the difference between the corresponding end post deflections at A and E is approximately 17%. Moreover, the mid-bay deflections for General Duty loading are only 71% to 73% of the corresponding deflections of the Type 1 two-bay frame for the same loading. Furthermore, the residual deflections are between 67% and 78% of the corresponding values for the Type 1 barrier.

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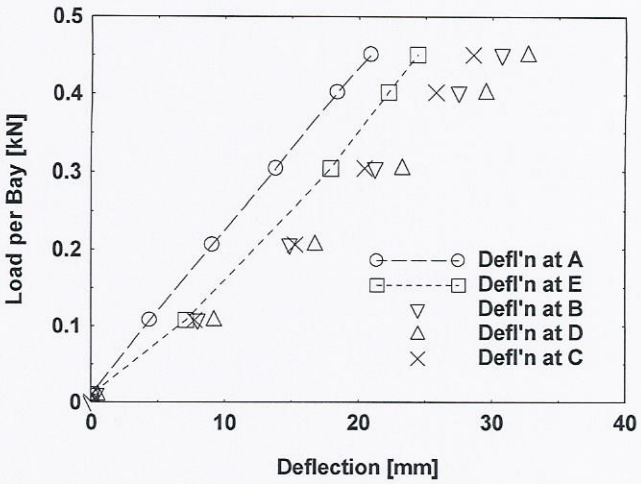

Figure 13: Load – deflection response of a Type 2 two-bay barrier (1.25 m bays)

Table 4

Maximum and residual deflections of the Type 2 safety barrier (General Duty Load Test)

Point Load at Mid-Span of Each Bay [kN]	Span of Each Bay [m]	Deflection at A [mm]	Deflection at B [mm]	Deflection at C [mm]	Deflection at D [mm]	Deflection at E [mm]
0.451	1.25	20.9	30.7*	28.6	32.7*	24.4
0 (unloading)		1.8	3.5*	4.9	4.5*	3.9

*Deflections were measured at 25 mm to the right of B and D.

In the interests of brevity the loading – unloading plots, which correspond to Figure 12, are not presented for this Type 2 barrier as they do not exhibit any particularly noteworthy features.

5(d) Type 2 – Three-Post, Two-Bay Barrier (1.25 m bays) [Heavy Duty Loading]

As this Type 2 barrier had supported the General Duty load without showing any obvious signs of damage, the client requested that it should be re-tested in order to establish whether or not it could support the Heavy Duty loading. Accordingly, the barrier was re-tested.

The load – deflection responses obtained for points A – E are shown in Figure 14 It is evident that the dial gauge at point D was misread when the load was about 0.63kN. In addition, problems were experienced with the dial gauges during the application of the last two load increments. The gauge at C ran out of travel and the gauges at A and E slipped off the rivets, with which they were originally in contact. The latter was attributed to effective shortening of the cantilevered end posts due to significant bending. Consequently, the maximum deflections at these locations may not be accurate. Likewise, because these gauges had to be reset prior to unloading the barrier, the residual deflections at these points may also be inaccurate. Nevertheless, there were no problems with the dial gauges at points B and D, where the largest deflections would be expected. Hence, these maximum and residual deflections may be regarded as accurate. The maximum and residual deflections obtained from the Heavy Duty load test on this Type 2 barrier are given in Table 5.

Given that there were problems with several of the dial gauges during the Heavy Duty load test on the Type 2 barrier, it is not particularly sensible to present load – unload responses for each of the points A – C, as in the other sub-sections of Section 5. Instead a load/unload – deflection plot is presented for point B under General and Heavy Duty loading. This is shown in Figure 15.

There were no obvious signs of damage to the Type 2 safety barrier after the Heavy Duty load test and the barrier was able to support the required load.

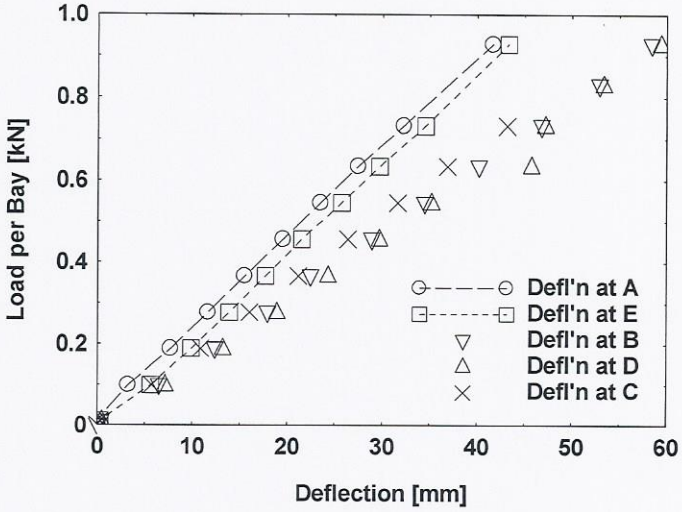

Figure 14: Load – deflection response of Heavy Duty load test the Type 2 barrier (1.25 m bays)

Table 5

Maximum and residual deflections of the Type 2 safety barrier (Heavy Duty load test)

Point Load at Mid-Span of Each Bay [kN]	Span of Each Bay [m]	Deflection at A [mm]	Deflection at B [mm]	Deflection at C [mm]	Deflection at D [mm]	Deflection at E [mm]
0.928	1.25	41.65**	58.4*	43.2***	59.4*	43.3**
0 (unloading)		2.5	3.9*	6.5	4.5*	3.4

Note: *Deflections were measured 25 mm to the right of B and D.
** Dial gauges slipped off the rivet head during the penultimate load increment.
*** Corresponds to load of 0.73 kN – dial gauge out of contact for the remaining two load increments.

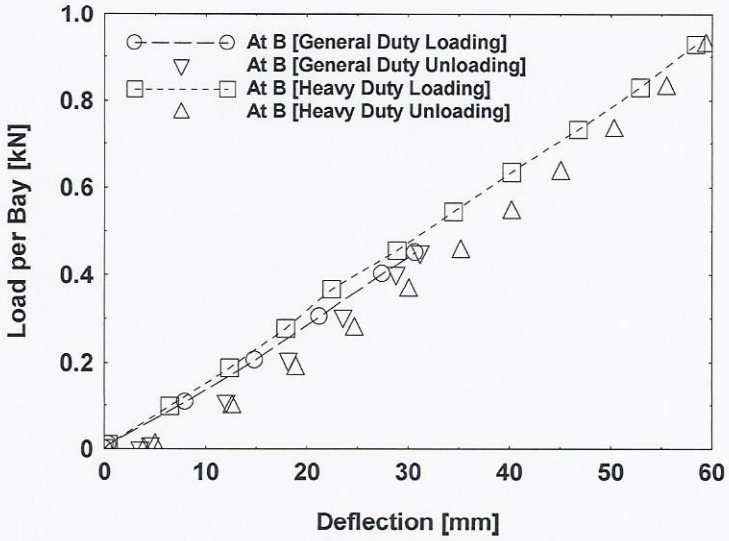

Figure 15: Comparison of load/unload – deflection response for point B of the Type 2 barrier obtained from the General and Heavy Duty load tests (1.25 m bays)

6. Concluding Remarks

Three pultruded GFRP safety barriers were fabricated from pultruded GFRP tubes, two-part multi-way SMC connectors and SMC bases. Bolts and rivets were used to join the tubular posts and rails of the barriers and bolts were used to fasten their bases to the foundations.

Two Type 1 (modular) barriers used only circular cross-section tubes for the posts and rails and all of the joints were bolted. One of the Type 1 barriers was single-bay and the other was two-bay. The third barrier – Type 2 – used square cross-section tubes for the posts and a C-section for the handrail. A smaller circular cross-section tube was used for the knee rail. The C-section was riveted to the tops of the posts.

The Type 1 and Type 2 barriers were tested under incremental/decremental static concentrated loading applied to the handrail at mid-bay. The maximum load (General Duty load) was equivalent to 0.36 kN/m. During loading and unloading deflections were recorded at the mid-bay points of the handrail and at the junctions of the posts with the handrail.

Both of the Type 1 and the Type 2 barriers were able to support the General Duty load without any obvious or clearly visible damage.

The Type 2 barrier was re-tested under increased concentrated incremental/decremental loading applied at the mid-bay points on the handrail. During the loading and unloading phases of the test deflections were recorded at the mid-bay points on the handrail and the joints between the posts and the handrail. The maximum load (Heavy Duty load) was equivalent to 0.74 kN/m. The barrier was able to support the increased load without any obvious or clearly visible signs of damage.

Graphs of the load – deflection responses for selected points (post – handrail joints and mid-bay points on the handrail) have been presented together with images of the fully loaded barriers, their joints and bases. In all cases, the load – deflection responses were linear or very mildly nonlinear (softening). Furthermore, the loading and unloading responses differed, indicating the presence of some hysteresis.

As concentrated loading is a more onerous form of loading than uniformly distributed loading, it is concluded that the Type 1 and 2 barriers are able to support the General Duty loading specified in [1]. Moreover, the Type 2 barrier is also able to support the Heavy Duty loading specified in [1].

7. References

1. Anon., *BS 4592-0: Flooring, stair treads and handrails for industrial use – Part 0: Common design requirements and recommendations for installation*, British Standards Institute, Draft dated: 11-6-2012.