

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 load capacity requirements defined in the 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.

The main structural components (posts and rails) were circular cross-section pultruded GFRP. 50 x 5 mm (outer diameter 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) show the base for the circular posts,. 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.



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

Three types of two-part SMC connector were used to join the posts and rails formed by the 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.

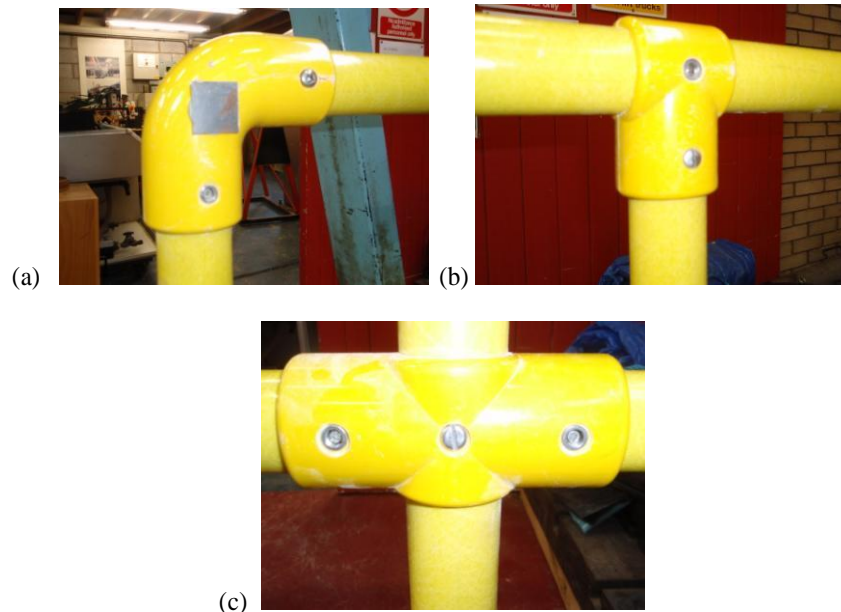


Figure 3: Two-part connectors used to form orthogonal joints between the circular cross-section pultruded GFRP posts and rails: (a) two-way, (b) three-way and (c) four-way bolted joints

In accordance with the Client's instructions the safety barrier was fabricated to be tested for compliance with the General Duty load specified in [1]. The dimensions of the barriers are given in Table 1.

Table 1

Dimensions of the the safety barrier 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	2	1.25	1.1	0.55	50 x 5	50 x 5	50 x 5

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 a two-bay safety barrier. This configuration would provide structural continuity across bays and was deemed to be more representative of how a safety barrier would perform in service.

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 Duty applications the handrails have to be capable of supporting uniformly distributed loads of 0.36 kN/m. 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.

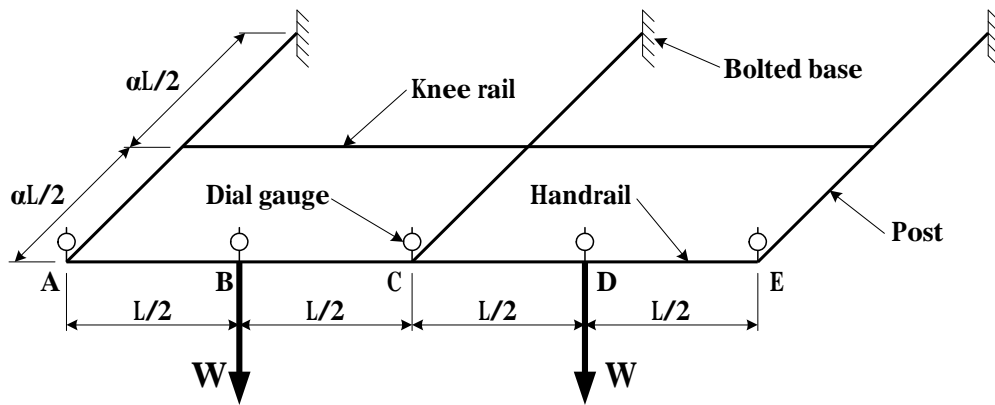


Figure 6: Schematic diagrams of the test setups for the safety barriers three-post, two-rail, two-bay barrier

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 safety barrier is 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.

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 safety barrier supporting the General Duty load given in [1] are shown in Figure 7.



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)

5. Test Results and Discussion

5 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.

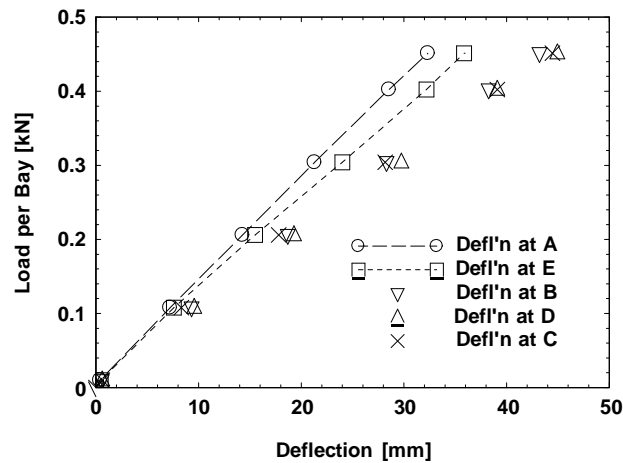


Figure 11: Load – deflection response of a two-bay barrier (1.25 m bays)

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.

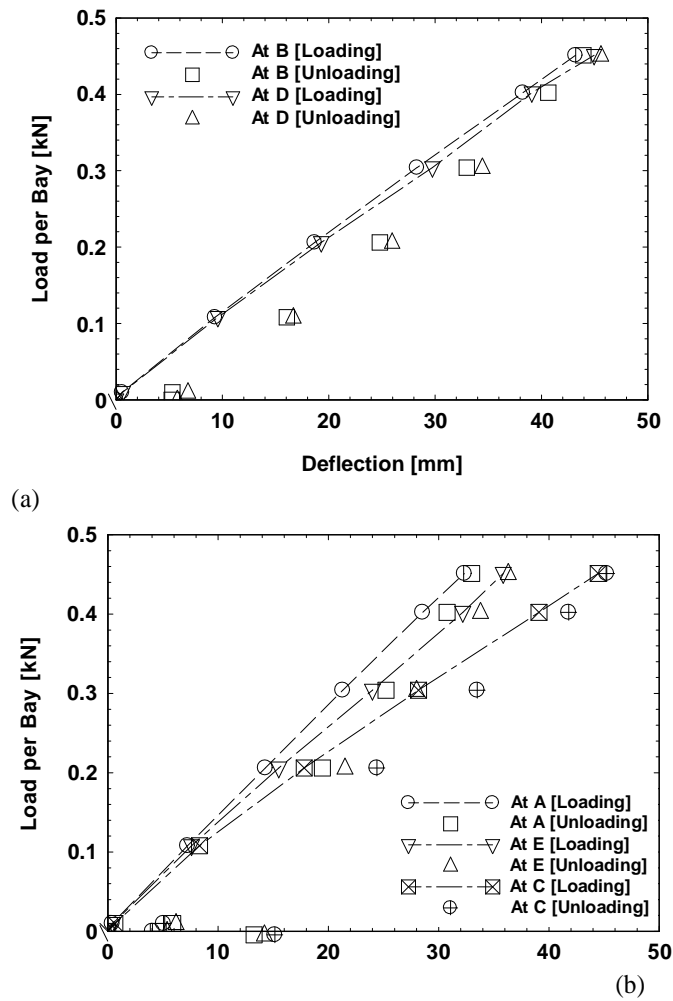


Figure 12: Load/unload – deflection responses of the two-bay barrier: (a) Points B and D and (b) Points

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6. Concluding Remarks

A pultruded GFRP safety barrier was 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.

The modular barrier used circular cross-section tubes for the posts and rails and all of the joints were bolted.

The barrier was 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.

The safety barrier was able to support the General Duty load without any obvious or clearly visible 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 barrier is able to support the General 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.