AN EXPERIMENTAL INVESTIGATION ON THE BEHAVIOUR OF MOULDED FRP GRATINGS

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ABSTRACT

The popularity of fibre reinforced polymer (FRP) grating is slowly gaining momentum as they offer numerous advantages over customary materials for use in platforms and walkways, particularly within harsh and corrosive environments. However, there are still no detailed guidelines relating to the design and use of FRP gratings, making this material at a disadvantage when considered against traditional construction materials. In this paper, an experimental investigation was conducted using full-size moulded FRP gratings to have an understanding on their behaviour under three different loading conditions, i.e. line loading at midspan, and concentrated loading applied at midspan and near the support. It was found that the concentrated load regardless of the location of the load application is more critical than the line loading. The FRP gratings under line loading failed at an applied load of around 56 kN while the gratings under the concentrated load failed at an applied load of only around 30 kN. The two concentrated loading cases showed very similar failure behaviour on which the loading block sank into the grid and crushed the grid under the loading area. On the other hand, the failure of the FRP gratings under a line loading was a major flexural tensile cracking at midspan. From this study, a better understanding on the behavior of moulded FRP gratings is gained for their widespread use and application in civil infrastructure particularly in platforms and walkways.

1 INTRODUCTION

For a very long time within the engineering and construction industries, steel, concrete and timber are the commonly used materials in the construction of platforms and walkways. These traditional materials have posed various problems due to dilapidation and deterioration over time. In offshore application, steel platform is always exposed to harsh marine environments and enhancement of corrosion resistance is required to prevent failure [1]. Similarly, the corrosion of steel reinforcement is reported as the most frequent cause of failure of offshore concrete platforms [2]. For timber, the risk for biological deterioration should be considered when the structure is exposed to high moisture conditions to avoid catastrophic failure [3]. Given the issues of these traditional engineering materials, there has been an urgent need for a more sustainable materials and technologies that will assist in increasing the longevity and lifespan of structures in corrosive and wet environments.

Fibre reinforced polymer (FRP) grating demonstrates numerous advantages over customary materials for use in platforms and walkways, particularly within harsh and corrosive environments where traditional materials have proven to suffer. The popularity of fibre composite gratings is slowly gaining momentum as they offer a number of attractive benefits such as light weight, high corrosion resistance, electrical insulation, and non-magnetic properties [4]. In fact, the Queensland Government [5] has identified walkways and drainage grating as some of the many applications of composite gratings in the mining, minerals and chemical processing plants due to its highly corrosion resistance. Currently, there are two types of composite gratings available, i.e. pultruded and moulded gratings.
Pultruded grating are arrays of parallel I-beams wherein the composite fibres are longitudinally aligned and are transversely spaced and connected by transverse dowels [6]. On the other hand, moulded grating is a lattice of connected beams and is manufactured by systematic laying of continuous fibres in both longitudinal and transverse directions [7]. Due to this feature, moulded composite grating is used mostly in the oil and gas industry especially in areas where openings and complex shapes are required as it offers bi-axial strength and stiffness. Biddah [8] also indicated that composite grating can be used to build walkways in corrosive conditions. However, Gibson et al. [9] indicated that there are still no detailed guidelines relating to the design and use of composite gratings, making this material at a disadvantage when considered against traditional construction materials.

Some research works have been conducted using pultruded composite gratings but very limited work has been reported for moulded gratings. Biddah [8] used GFRP pultruded grating as reinforcement for concrete slabs and suggested that it is possible to achieve a significant increase in the capacity by reinforcing the slabs with fiberglass grating. Burrel et al. [4] conducted a preliminary fire testing of pultruded composite offshore pedestrian gratings and concluded that the composite gratings successfully met the post-loaded test criteria for structural fire integrity for use in open deck areas. Most recently, Mangire and Srinivasan [6] investigated the mechanical behavior of GFRP pultruded composite gratings under three point bending test. They found that the pultruded gratings behaved linear elastic up to failure with the mode of failure is predominantly fibre fracture. In the case of moulded gratings, the work is limited to the analysis conducted by Shokreih and Heidari-Rarani [10] wherein they have proposed a closed form solution to predict the load-deflection behavior in the elastic range of the simply supported composite moulded grating. This clearly indicates that there is limited information and knowledge on the structural behavior of these composite technologies.

This paper presents an experimental investigation on the behaviour of moulded composite gratings under different loading conditions. The investigation focused on the behavior under centrally applied line load representing a uniformly distributed dead or live weight, and centred/non-centred point loading representing a concentrated load acting on the grating. From this study, a better understanding on the behavior of moulded FRP gratings is gained for their widespread use and application in civil infrastructure particularly in platforms and walkways.

2 EXPERIMENTAL PROGRAM

2.1 Materials

The composite grating investigated is made up of continuous E-glass fibres in both horizontal directions and isophthalic polyester resin supplied by Nepean Building and Infrastructure. The size of the square mesh is 38 mm x 38 mm (web spacing centers) and 38 mm deep with 6 mm thick web. Coupon specimens were cut directly from the full-scale gratings and tested to establish the material properties of the moulded FRP gratings including fibre volume, flexural and compressive properties.

The density of the composite grating is around 1950 kg/m³. The burn out test conducted following ISO 1172 [11] indicated that the fibre content by weight of the composite gratings is around 52%. Similarly, this test confirmed that the amount of the unidirectional fibers in the longitudinal and transverse directions is the same with no fibers oriented in the thickness direction of the grid. On the other hand, the compressive strength measured using 2x2 and 3x3 grids is around 38 MPa while the average bending stress is 230 MPa and the flexural modulus is 10.5 GPa.

2.2 Test set-up and instrumentation

The behavior of full scale composite moulded grating was evaluated by testing an 836 mm x 836 mm grating (22 x 22 grids) under line loading and a concentrated load applied on the centre and near the support following the test procedures described in AS 1657 – 2013 [12]. While the concentrated load directly represents a point load acting on the grating, the line loading was implemented instead of uniformly distributed load representing dead or live load. Three replicates were tested for each specimen type. The line loading was achieved through a rectangular hollow metal bar positioned directly in the midspan of the moulded grating as shown in Figure 1. On the other hand, the concentrated load was achieved using a solid steel (100 mm x 100 mm square) welded to a base plate.
which is bolted to a 220 kN load cell. For the centred loading case, the load block was positioned directly in the centre of the test panel, both longitudinally and transversely. However, the off-centred load was positioned at a distance of 200 mm from the support or span/4. Laser displacement transducer was positioned directly under the centre of the applied load to measure the deflection. Uniaxial strain gauges were attached on the webs along the longitudinal and transverse directions. For the grating tested under point load, a uniaxial strain gauge was attached to measure the compressive strain under the load application. The load was applied using a 200 kN hydraulic jack. All specimens were tested up to failure to observe the failure mechanism.

Figure 1. Test set-up and instrumentation for line loading (left) and under point load (right)

3 RESULTS AND DISCUSSION

3.1 Behavior of FRP gratings under line loading

Figure 2 shows the load and midspan deflection and the load-strain behaviour of the composite gratings under line loading. An almost linear elastic load-deflection behavior up to failure was exhibited by the 3 samples. Under line loading, the gratings failed at an applied load ranging from 53 to 56 kN (stress of 350 to 370 MPa) with the midspan deflection between 60 and 64 mm. The strain measurements also indicated the almost linear elastic response of the gratings. In the graph, the strain reading in the transverse direction is designated by (T) while the strain in the longitudinal direction is designated by (L). As expected, only the grids in the longitudinal direction resisted the applied load as indicated by the high level of strain measured in this direction. This is due to the gratings simply supported only at the longitudinal direction. As an inspection observation taken during the testing, the physical failure is described as major tensile cracking and delamination on the bottom face of the grating at midspan followed by transverse shear failure. This caused the grating to lose its capacity to carry load and failed immediately. In contrast to the test of coupons, the longer length of the gratings prevented the transverse shear failure occurring first resulting in the effective utilization of the high tensile strength of the fibres. In fact, the full-scale gratings failed at an average flexural strength of 364 MPa, which is 58% stronger than the strength determine from test of coupons. This result is encouraging as Biddah [8] reported that the full-potential of pultruded fiberglass grating is not realized due to the buckling of the compressive flange of the longitudinal I-beams as the transverse dowels connecting them have significantly lower stiffness than the I-beams. This type of failure is prevented in the moulded gratings as the grid in the transverse direction provided rigidity and stabilized the longitudinal direction until reaching its maximum strength. The load strain behavior has also shown that some loads were transferred to the grid in the transverse direction when the failure was initiated as indicated by the increase in the strain levels in (T). As indicated by Meng and Lo [7], these bidirectional strength properties make moulded grating a more suitable material for platform and walkways than the pultruded mouldings.
3.2 Behavior of FRP gratings under concentrated load at centre

Figure 4 shows the load and midspan deflection and the load-strain behaviour of the composite gratings under concentrated load applied at the centre of the grating. An almost linear elastic load-deflection behavior was observed up to failure. Similar behavior was observed for the 3 samples with the gratings failed at an average load of 33.5 kN and deflected under the point load of around 50 mm. It is believed that the grating can still resist the same level of the load but with a higher deflection when the test was terminated due to the maximum stroke of the hydraulic cylinder was already reached. In addition to the strain gauges attached to the transverse (T) and longitudinal (L) directions, strain gauge was provided in the vertical direction to measure the compressive strain through the depth of the grid and was designated with (V). As expected, a higher level (75% higher) of strain was measured in (L) than in (T) due to the gratings simply supported only at the longitudinal direction. Similar to the deflection observed for the line loading, the load and deflection curve is relatively linear up to failure. However, the magnitude of deformation is higher than the line loading as the deflection is resisted only by the longitudinal grids under the loading point with the grid in the transverse direction redistributed some of the loads to other longitudinal grids to assist in carrying the total applied load.

The failure of the grating is due to the compressive failure of the grids within the immediate surrounds of the loading block with the block appearing to ‘sink’ into the test panels. This is due to the crushing of the fibers, interface decohesion and matrix plastic deformation in the through thickness direction as was also observed in the compressive test of coupons. When the applied load was removed, the area which the load block sunk into the grating rebounded back with only approximately 2 to 3mm of permanent depression as most of the horizontal and transverse fibres did not fail in flexure.
3.3 Behavior of FRP gratings under concentrated load near the support

Figure 5 shows that the grating under off centre concentrated load deflected almost linearly up to an applied load of around 30 kN. After this load, there is no significant increase in the load but a significant increase in the deflection due to loading block sunk into the grating as the fibres crushed in compression in the through the thickness direction. It is interesting to note that this level of failure load is almost similar to the failure load when the point load was applied at midspan. While a lower strain is measured in the longitudinal (L) direction compared when the load was applied at midspan, an almost similar strain in the transverse (T) and vertical (V) directions was observed for both gratings loaded at midspan and near the support. The measured strain in (T) is almost 55% in (L). This indicates that transverse grids effectively redistributed the load to the entire grating and results in compression failure. This also shows that there is sufficient width to carry the applied load before shear failure occurred as shown in Figure 3. However, compared to the grating under line load, the failure load is lower when subjected to concentrated load as this creates stress concentration and results in the compression failure in the transverse direction of the FRP composites.
4 CONCLUSIONS

Investigation on the behaviour of moulded FRP gratings was conducted using full-scale specimens and loaded under line loading at midspan and point loading at midspan and near the support. Based on the results, the following are the conclusions are drawn:

- The full-scale moulded grating under line load at midspan exhibited 58% higher flexural strength than the coupon specimens. Failure is initiated by tensile cracking at midspan followed by transverse shear failure.
- The moulded gratings under concentrated load applied at midspan and near the support failed at almost the same level of load. This is due to similar failure behaviour, which is compressive failure in the through thickness direction of the gratings under the loading application.
- Under point load, the strain measured in the transverse direction is about 55-75% of the strain in the longitudinal direction indicating that the transverse grids effectively redistributed the load to the entire grating. The transverse grids also provide resistance against the deflection of the grid.
- The moulded FRP grating is more critical under concentrated load than under line loading as this loading condition creates stress concentration and results in the compression failure in the weaker direction of fibre composites.

REFERENCES