Development of a Windbreak Fence of New Material

To reduce the effect of high wind on operation, we have been proceeding with installation of windbreak fences in sections in the greater Tokyo area to which many operation control commands due to wind are issued. As such fences are installed over a long distance, cost reduction needs to be studied. In light of the situation, we have addressed development of a windbreak fence made of FRP that would be lighter and easier to erect with all-in-one components. FRP has attracted attention in recent applications such as railings. Upon producing prototypes (railing-integrated type, barrier-mounted type), we carried out static loading tests and field test installation. Behavior measurement after the test installation proved that no problems occurred in terms of bearing force, displacement and fatigue. With the barrier-mounted type, further improvement taking workability into account has achieved weight reduction by 47% from the weight of the initial type. In viaduct sections, we expect that using the windbreak fence developed this time will reduce costs by more than 20% compared to that of existing windbreak fences.

Keywords: Windbreak fence, GFRP, Static loading test, Measurement of vibration, Measurement of stress

1 Introduction

As countermeasures against operation disruption due to high wind, we have introduced a wind warning system and windbreak fences. Still, wind considerably affects operation. In order to reduce such effects, we are proceeding with installation of windbreak fences to weaken the wind force on rolling stock in sections in the greater Tokyo area to which many operation control commands due to wind are issued. Cost reduction, though, needs to be studied as such fences are installed over a long distance. In light of the situation, we have addressed development of a windbreak fence that would be lighter and easier to erect with integrated components. In this article, we will report the results of static loading tests, field test installation and behavior measurement after installation of the developed prototypes (railing-integrated type, barrier-mounted type). The article will further cover improvement of the barrier-mounted type based on the results of static loading tests and test installation.

2 Overview of the New Windbreak Fence

2.1 Material Used

Materials of reinforced fiber such as carbon fiber and glass fiber fixed with resin is called fiber reinforced plastics (FRP). Taking into account of the bearing force and cost requirements for windbreak fences, we have decided to adopt glass fiber reinforced plastics (GFRP). Compared to steel used for existing windbreak fences, FRP has higher corrosion resistance, and it is resilient against salt damage and acids as well. The windbreak fence developed this time has a protective layer called gelcoat applied that is approx. 300 to 500 μm thick, so, it has sufficient durability against ultraviolet light. FRP is increasingly being adopted, including adoption for the railing of the new viaduct near Nagamachi station on the Tohoku main line.

Fig. 1 Shape of the New Windbreak Fence

2.2 Shape

In this development, we have produced two prototypes for viaduct sections. One is a railing-integrated type that is to be installed after removing the existing railing, and the other is a barrier-mounted type that is to be installed on top of existing railing (Fig. 1). The upper part of each is the windbreak fence, which has perforations to meet the solidity ratio requirement of 60% (area of the part of the windbreak fence that blocks wind/total area of the windbreak fence). That is the same as with existing windbreak fences. The lower part of the railing-integrated type is railing of a hollow box structure. This can reduce weight of the railing and improve installation workability thanks to its all-in-one structure. Existing windbreak fences have foldable plates with holes that have to be attached between steel H-beam supports installed in advance (Fig. 2).
3 Static Loading Test

We have set the following two performance requirements for GFRP windbreak fences: ① Bending moment and shear force within the allowable values when 3.0 kN/m² wind load acts on the fence (with no train on the viaduct), and ② Displacement within the target values when 1.5 kN/m² wind load acts on the fence (with a train on the viaduct). After checking in the design phase, ① and ② are to be confirmed by loading tests using a full-size windbreak fence. The target horizontal displacement is to be around 1/100 of the height, the value at which the formation is not affected. We also confirmed that the stress occurring at the location of cross section change is less than the fatigue limit when the 1.0 kN/m² pressure variation that is used in designing sound barriers acts on the fence. Reference document 1 reports that FRP has no defined fatigue limit. However, based on reference document 3, we have here assumed a 106 N/mm² (= 140 N/mm²÷1.32) fatigue limit. That takes into account the bending fatigue strength (double amplitude) at 2 x 10⁶ bends of GFRP.

3.1 Testing Method
In the check of the displacement and the bearing force of the mounting bracket and the frame, a concentrated load was applied via the steel H-beam using a hydraulic jack, so wind load acts evenly on the windbreak fence (Fig. 3). To check the bearing force of the plate with perforations, a concentrated load equal to the wind load that acts on the windbreak fence as a whole was applied to the center of the plate using a jig. Displacement was measured at the top where displacement of the windbreak fence would be the largest, and strain was measured around the perforations as the weak point and on the border between the perforated plate and the frame. There were three test samples.

3.2 Test Results
Fig. 4 shows the relationship between the displacement and the load applied from the track side in the check of the displacement and the bearing force at the mounting bracket of the railing-integrated type. At loading equivalent to 1.5 kN/m² wind load, the displacement was approx. 18 mm or less, less than the target (26 mm). When loading up to three times the 3.0 kN/m² wind load to observe the breakage mode, we confirmed that the amount of displacement was more than 60 mm, significantly over the target. Even so, the test sample did not reach the breakage point. The frame was not broken in the bearing force check either. Similarly, we confirmed that the barrier-mounted type had no problems in the check of displacement and bearing force at the mounting bracket.

Fig. 5 shows the load and the stress around holes where the largest stress occurred when loading on the perforated plate of the railing-integrated type from the track side. When applying the load equivalent to 1.0 kN/m², the occurring stress was around 20 N/mm² or less. It was just around 1/5 of the fatigue limit of 106 N/mm², so we judged that there would be no particular problems in terms of fatigue.

4 Field Measurements
After checking required performance in static loading tests, we test installed windbreak fences on the Keiyo Line. The purpose was to check ease of installation and to evaluate effects on existing structures. The installed prototype windbreak fence is shown in Fig. 6. The weight of the railing-integrated type windbreak fence was approx. 80 kg/m and that of the barrier-mounted type was approx. 30 kg/m.

Meanwhile, we were concerned that vibration of structures at train passing might change and increase in amplitude after installing the windbreak fence, and we were concerned that would affect the bearing force of existing structures. We thus decided to measure vibration of structures and the windbreak fence at train...
passing after completion of test installation to confirm that no amplitude increment or resonance of the structures would occur. Vibration of structures (overhanging slab, railing) was measured before installation, so we also decided to compare the results with values after installation to study the effect of the windbreak fence on structures. Furthermore, we decided to confirm that stress generated would be less than the fatigue limit by measuring stress at the windbreak fence body as trains pass.

4.1 Vibration
For measurement of vibration, we used “U Doppler”, a non-contact vibration measurement system. Actual vibration measuring is shown in Fig. 7. Fig. 8 shows the displacement time history of the structure and the windbreak fence at train passing at the point installed with the railing-integrated type, and Fig. 9 shows the same with the barrier-mounted type. Here, overhanging slab expresses perpendicular vibration at the edge of the overhanging slab and body expresses horizontal vibration at the top of the railing or the windbreak fence.

Fig. 8 (a) shows that vibration amplitude of the body at the installation point with the railing-integrated type was larger by approx. 0.1 mm with the GFRP windbreak fence. With GFRP, free vibration was also found after train passing. Those are probably because damping with GFRP is smaller since the GFRP windbreak fence is lighter and has lower rigidity than the railing (PC plate). As shown in Fig. 8 (b), free vibration after passing of a train was found in the vibration of the overhanging slab installed with the fence. This would be the effect of free vibration of the GFRP windbreak fence. We have decided that would not be an issue because the variation of amplitude was less than 0.1 mm before and after installation, representing almost no variation.

In Fig. 9 (a), vibration amplitude of the body at the installation point with the barrier-mounted type reached approx. 1 mm with the GFRP windbreak fence, showing free vibration. This also could be because the GFRP fence was lighter and has lower rigidity than the railing (cast-in-place concrete). Still, there was no variation of vibration of the overhanging slab in terms of amplitude and wave shape, so we have decided there would be no problems.

At all measured train speeds, we found no resonance where amplitude shows peculiar increase. Based on those results, we have decided that installing windbreak fences would not affect existing structures much.

4.2 Stress
We measured strain that occurs as a train passes by attaching strain gauges to the points where strain was detected in static loading tests. That strain was measured multiple times. Fig. 10 shows the stress time history around the holes of the barrier-mounted type when a series 205 train passed at 109 km/h. Occurring strain reached its peak at that instance. Stress amplitude was less than 10 N/mm². Since the occurring stress was smaller than 1/10 the bending fatigue strength of 106 N/mm², we have decided that fatigue would not be a problem.
We considered ease of installation of the barrier-mounted type based on the results of laboratory tests and the test installation, and we made improvements for further weight reduction. The main improvements are ① change of mounting bracket (decreasing four holes to two, changing the circular hole shape to oval and eliminating embedded nuts, decreasing the area of mounting brackets), ② making the frame slimmer and ③ changing the shape of the perforation part (circular to square). With those, we can expect a variety of effects. Those include improvement of installation workability thanks to avoidance of reinforcing bars of existing railings in installation of windbreak fences, weight and cost reduction by material reduction and simplified production of fences with easier fiber placement. Fig. 11 shows a comparison of the shape before and after improvement. The weight after improvement is approx. 16 kg/m, demonstrating successful reduction of weight by 47% from that of the initial model.

We have confirmed that there would be no problems in terms of displacement, bearing force and fatigue by carrying out tests of the improved windbreak fence in the methods as explained in section 3. Fig. 12 shows the relationship between load from the track side and displacement in checks of displacement and bearing force of the mounting bracket. As rigidity was lowered compared to with the initial model, the displacement became larger. Yet displacement at a load equivalent to 1.5 kN/m² wind load was less than the target (9.5 mm). To check the breakage mode, we applied loads up to three times the 3.0 kN/m² wind load and confirmed that the windbreak fence did not reach the breakage point. Fig. 13 shows the relationship between stress around the holes of the perforated plate loaded from the track side and load. The occurring stress was smaller than that of the initial model because the content rate of glass fiber was increased to approx. 1.5 times that of the initial model due to the slit shape change. The occurring stress at a load equal to 1.0 kN/m² was less than approx. 10 N/mm², just around 1/10 the fatigue limit of 106 N/mm², so we have determined that fatigue would not be a problem.

We made prototypes windbreak fences using GFRP and confirmed required performance such as displacement and bearing force through static loading tests. Through on-site measurement, we decided that there would be no problems in terms of both vibration of the structures and stress of the windbreak fence at train passing. Furthermore, improvement of the barrier-mounted type achieved further weight reduction. The windbreak fence developed this time is to be introduced to the Keiyo Line, to which we planned to introduce windbreak fences in viaduct sections. We expect that the total cost there can be reduced by more than 20% compared to installing existing fence by adopting this windbreak fence.

5 Further Improvement of the New Windbreak Fence

We considered ease of installation of the barrier-mounted type based on the results of laboratory tests and the test installation, and we made improvements for further weight reduction. The main improvements are ① change of mounting bracket (decreasing four holes to two, changing the circular hole shape to oval and eliminating embedded nuts, decreasing the area of mounting brackets), ② making the frame slimmer and ③ changing the shape of the perforation part (circular to square). With those, we can expect a variety of effects. Those include improvement of installation workability thanks to avoidance of reinforcing bars of existing railings in installation of windbreak fences, weight and cost reduction by material reduction and simplified production of fences with easier fiber placement. Fig. 11 shows a comparison of the shape before and after improvement. The weight after improvement is approx. 16 kg/m, demonstrating successful reduction of weight by 47% from that of the initial model.

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6 Conclusion

We made prototypes windbreak fences using GFRP and confirmed required performance such as displacement and bearing force through static loading tests. Through on-site measurement, we decided that there would be no problems in terms of both vibration of the structures and stress of the windbreak fence at train passing. Furthermore, improvement of the barrier-mounted type achieved further weight reduction. The windbreak fence developed this time is to be introduced to the Keiyo Line, to which we planned to introduce windbreak fences in viaduct sections. We expect that the total cost there can be reduced by more than 20% compared to installing existing fence by adopting this windbreak fence.

Reference:
2) "Japan National Railways Design Standards for Railway Structures (Revised) (Steel Railway Bridges, Steel-Concrete Composite Railway Bridges)“, April 1983 (in Japanese)