Analysis and Design of a Pedestrian Bridge with Decommissioned FRP Windblades and Concrete

Raj Suhail[1], Jian-Fei Chen[1], Russell Gentry[2], Benjamin Taristro-Hart[2], Yicong Xue[1,3] and Lawrence C. Bank[4]

[1] *School of Natural and Built Environment, Queen's University Belfast, Northern Ireland, UK*
[2] *School of Architecture, Georgia Institute of Technology, 145 4th Street, NW, Atlanta, GA 30332, USA*
[3] *School of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an, 710055, China*
[4] *The City College of New York, 160 Convent Ave, New York, NY, USA*

Abstract

The rapid increase in the wind energy sector has brought forward a challenging problem of disposing off a huge quantity of non-biodegradable, thermosetting fibre reinforced polymer (FRP) composite materials used in wind turbine blades. Most of the existing solutions are either not sustainable or not economical. This study focuses on re-use options. In this paper a design option for re-using decommissioned wind turbine blades in pedestrian bridges is presented. To demonstrate the concept, an 8.5 m long pedestrian bridge is designed using parts taken from two A29 (modified version of Vestas V27) windblades. A preliminary code-based structural analysis is carried out to assess practicality of the proposed design and to check strength and serviceability requirements given in the prescribed codes. The results show that proposed design full-fills the strength criteria and serviceability requirements recommended in the Eurocodes. The maximum strength utilisation of the blade components is found about 61% and deflection is limited to span/303.

Keywords: Windblade, FRP reuse, FRP pedestrian bridge

Corresponding author's email: j.chen@qub.ac.uk

Introduction

The recently published data [1] by Global Wind Energy Council (GWEC) shows that the total wind power capacity installed globally has already crossed the 500 GW mark in 2017. The predicted moderate growth scenarios from GWEC for future wind power installations shows that the total installed capacity would reach nearly 3983 GW in 2050 [2]. Assuming an average turbine capacity of 2 MW, the number of wind turbines installed by 2050 would reach approximately 2 million. Wind turbines consist of blades which are generally made of non-biodegradable, thermosetting fibre reinforced polymer (FRP) composite materials. A typical 2 MW turbine with three 50m blades has approximately 20 tonnes of FRP material [3]. Assuming 1 MW ~ 10 tonnes of FRP [4], the wind energy sector will have used 39.8 million tonnes of FRP material by 2050. With the lifespan of wind blades ranging only between 20-25 years, a substantial amount of non-biodegradable composite material from the windblades will need to be disposed of in the future.

The three routes that have been identified for handling the end-of-life (EOL) of composite blades are disposal, recovery and reuse [4]. This study focuses on the reuse option. The study forms a part of broader initiative of the multi-disciplinary research project Re-Wind (www.re-wind.info). The project aims to find sustainable solutions to the above discussed problem. The authors of this study previously proposed [4] design options for the reuse of decommissioned blades in affordable housing. In an attempt to expand the reuse options further, in this study, we propose a new idea for using decommissioned FRP wind turbine blades in pedestrian bridges. An 8.5m long pedestrian bridge is designed using windblades as main girders (beams). The conceptual design, along with the results from the preliminary structural analysis carried out to assess the structural applicability of the proposed design are discussed is this paper. A more detailed analysis will be published subsequently.

Pedestrian Bridge Materials and Dimensions

An illustration of the proposed design is presented in Figure 1. The clear span and the minimum clear width of the bridge are assumed to be 8.5m and 1.5m, respectively. The design uses 8.8m length of two14.3m long A29 windblades (a modified version of VESTAS V27 blade), recently acquired by the research team, as main girders to transfer the loads from the deck to supports. The blades are simply supported. To utilise the maximum moment of inertia, the blades are placed with trailing edge (TE) pointing vertically upwards. The deck is assumed to be made of concrete of thickness 100mm. 10mm FRP plates, stiffened internally, are provided at the bottom of deck as stay-in-place form for the concrete deck.
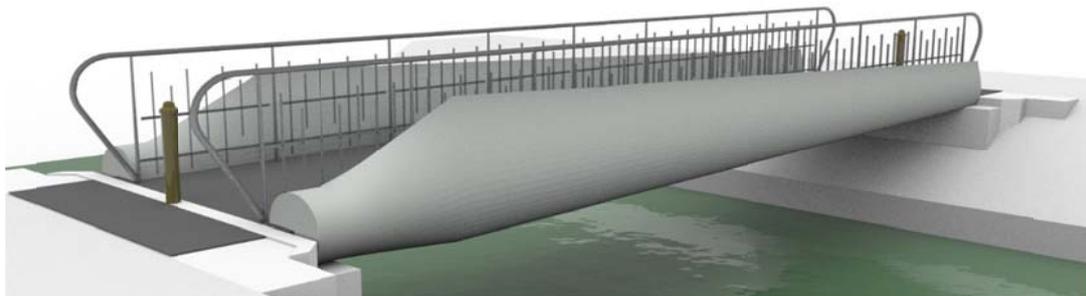
Figure 1: A conceptual design of pedestrian bridge using A29 windblades as main girders.

2

Figures 2 and 3 present the schematics of the longitudinal and cross-section of the bridge. The geometry (airfoils and the chord schedule) and material properties for blade girders are adapted from [5], [6]. Each blade girder is analysed independently as a simply supported beam subjected to a half of the dead and live loads of and on the bridge.
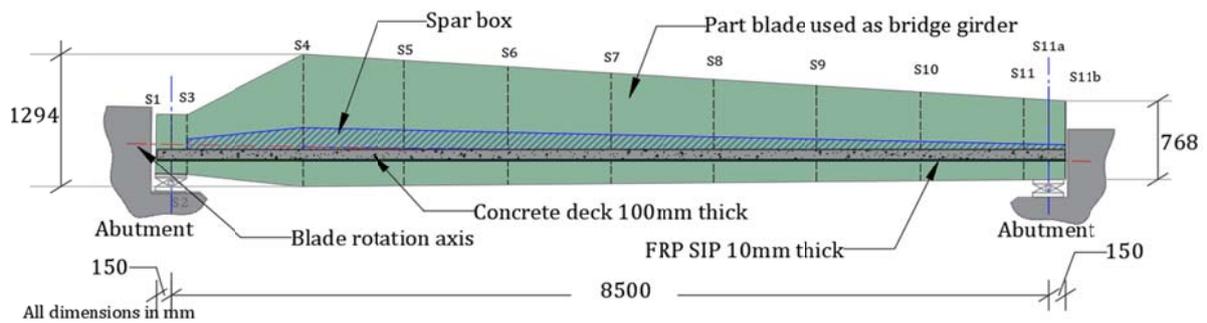

**Figure 2:** Schematics of longitudinal section of the proposed bridge design.

Thickness of skin = 2.788mm; Gelcoat= 0.5mm;
Thickness of spar caps = 14.5mm; Thickness of web plates = 5.92mm;
Foam thickness= varriable
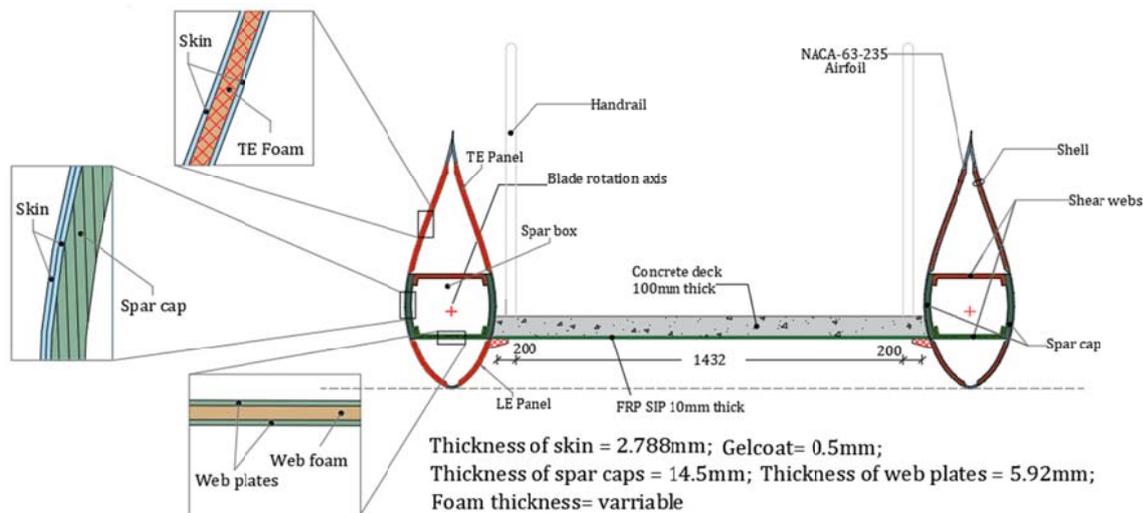
Figure 3: Schematics of cross-section at section S4 (at maximum chord location).

Structural Analysis

Design loads

For the permanent loads, the self-weight of the blade girders, concrete deck, FRP SIP and hand rails are considered in the analysis. For the traffic load, two static cases of vertical loads are considered independently. In the first case, a uniformly distributed load, q_{fk} of 5 kN/m^2 is assumed on the entire deck. In the second case, a concentrated load Q_{fwk} equal to 10 kN is moved along the bridge to take into account the local effects due to, for example, a small equipment for maintenance of the pedestrian bridge. It is assumed that barriers are provided to restrict vehicles from plying on the bridge, no vehicle load is thus considered in the analysis. The

analysis reported here was carried out for the ultimate limit state (ULS) with partial safety factors γ_G = 1.05 for permanent loads and γ_Q = 1.35 for variable loads. The maximum moment M for ULS was found to be 84.4kNm at section S7 (Figure 2).

Stresses due to design loads

A linear elastic analysis was carried out to determine the maximum and minimum stresses in the blade sections. The section properties such as moment of inertia, flexural stiffness EI, etc were obtained first at each section shown in Figure 2. The normal stress at a distance of y from the neutral axis was estimated using the following equation:

$$\sigma_{x,i} = \frac{MyE_i}{\sum_1^n E_i I_i} \tag{1}$$

where:

$\sigma_{x,i}$ = Normal (bending) stress in material i [MPa]
M = Moment at the section being considered [N-mm]
y = Distance from the neutral axis [mm]
E_i = Modulus of elasticity of material i [N/mm^2]
I_i = Moment of inertia of material i about the neutral axis [mm^4]

Figure 4 shows the varriation of the flexural stiffness and the maximum and minimum bending stresses in the blade girder. Also shown in the figure (see inset) is the distance of neutral axis (NA) from the leading edge (LE) and the trailing edge (TE) of the balde. The thickness of the outer shell, spar caps and shear webs was assumed to be constant between S4 to S11b, resulting in linear variations of the distance of NA from the LE and TE within this region. The sandwich core material was neglected in this preliminary alanysis.
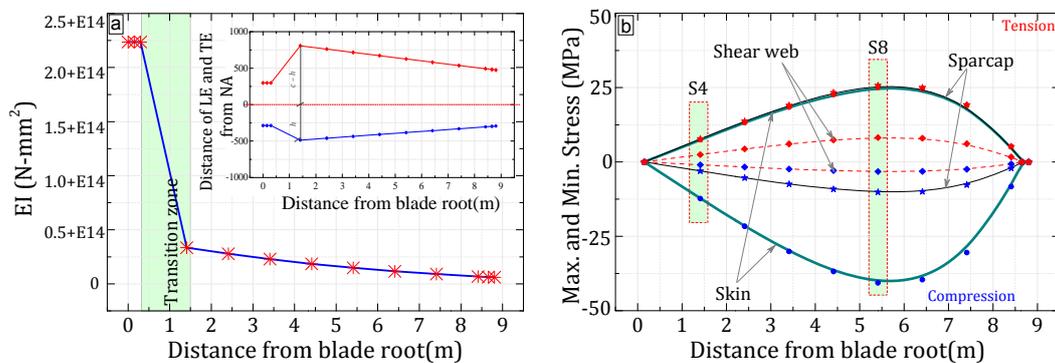

Figure 4: (a) Variation of flexural stiffness, EI (inset: distance of neutral axis (NA) from leading edge (LE) and trailing edge (TE); (b) variation of maximum and minimum bending stresses in the blade components (skin, spar cap and shear webs; core material neglected).

For the ULS, the maximum and minmum stresses are seen at section S8 for all the three materials. The maximum (tension) and the minimum (compresion) stresses in the skin are equal to 25.1 MPa and −40.6 MPa repectively (Figure 4b). The maximum and minimum stress in the spar caps are 25.7 MPa and -10.2 MPa respectively, and those in the shear webs are 8.2 MPa and -3.24 MPa repectively.

Design strength

The strengths of the skin, spar cap and shear webs were estimated by the first ply failure survey method using the maximum strain failure criterion. Dividing these values by the material partial safety factor γ_M (=1.82) gives the design strengths. All the results are shown in Table 1.

Table 1: Estimated design strengths and the maximum applied stresses

Blade component	Design max. tensile stress σ_t (MPa)	Design tensile strength f_t (MPa)	$\frac{\sigma_t}{f_t}$	Design max. comp. stress σ_c (MPa)	Design comp. strength f_c (MPa)	$\frac{\sigma_c}{f_c}$
Skin	25.1	132.9	0.19	-40.6	- 66.1	0.61
Spar cap	25.7	290.9	0.09	-10.2	-143.5	0.07
Shear webs	8.2	78.7	0.10	-3.2	-45.9	0.07

Deflection and natural frequencies

A 1-D beam model of the blade girder was developed in SAP2000. Section properties were defined at 13 locations (at S1-S11b in Figure 2) using *section designer* provided in SAP2000. For the serviceability limit state (SLS) the maximum deflection of 28 mm was obtained at section S7 (at 4.41m form the root end), which falls well below the limit of span/250 recommended in Eurocode 2-1-1. The natural frequency corresponding to the first bending mode of the blade girder in the vertical direction is equal to 5 Hz. This, as per the guidelines given in Eurocode 0/A1, is equal to the limit of 5Hz below which the verification of comfort criteria is required.

Conclusions

The outcome of this study demonstrates that windblades have the good potentials to be used as structural members in pedestrian bridges, providing an alternative and environmentally friendly solution to the disposal of windblades when they are decommissioned. This study paves the way for future studies on structural applications of windbaldes in civil engineering.

ACKNOWLEDGEMENTS

References

[1]   GWEC (Global Wind Energy Council), "Global Wind Report –Annual Market update 2017," Brussels, Belgium, 2017.
[2]   GWEC (Global Wind Energy Council), "Global Wind Energy Outlook 2016," Brussels, Belgium, 2016.
[3]   P. Liu and C. Y. Barlow, "Wind turbine blade waste in 2050," *Waste Manag.*, vol. 62, pp. 229–240, 2017.
[4]   L. C. Bank *et al.*, "Concepts for Reusing Composite Materials from Decommissioned Wind Turbine Blades in Affordable Housing," *Recycling*, vol. 3, no. 1, p. 3, 2018.
[5]   S. M. Petersen, "Wind turbine test Vestas V27-225 kW.," 1990.
[6]   Abdisamed Abdillahi Mohamed, "Modelling of Vestas V27-225kW wind turbine blade," Universitetet i Stavanger, 2011.