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EVALUATION OF STRENGTH AND STIFFNESS OF A FRP SANDWICH BRIDGE DECK

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1. INTRODUCTION

Bridge decks are one of the most promising fields of fibre reinforced polymers (FRP) structural application in construction nowadays [1]. Some of the favourable characteristics of these decks involve high strength-to-weight ratio, high durability (particularly large tolerance for de-icing salt), short installation time as well as possible increase of the carrying capacity of existing bridges due to replacement of the heavy concrete decks into the lightweight FRP decks. Many different FRP deck systems have been already developed, but these two main structural forms can be identified: decks made of pultruded structural shapes glued together and sandwich slabs with different face/core structures [1].

Only the latter type could be considered in the R&D project presented herein, due to current possibilities of the Polish composite manufacturers. The sandwich deck was proposed and implemented in the construction of the first Polish road bridge fully made of FRP composites [2]. The all-composite bridge superstructure is formed by four FRP composite girders with an overlying 130 mm thick FRP sandwich deck slab. The FRP deck slab is bonded to the top flanges of the girders with epoxy adhesive.

The stiffness of the proposed sandwich deck system and its resistance to wheel loads were investigated within a research project presented in this paper. Further aims were to structurally optimize the deck system according to Eurocode loads and to assess the global safety coefficients for future applications.

2. SANDWICH DECK CONFIGURATION

According to previous authors' experience [3], the best structural solution that takes both structural as well as manufacturing aspects into account, seemed to be the sandwich plate made of GFRP faces and foam core stiffened with the internal vertical GFRP ribs. The total thickness of the deck panel (130 mm) and the division between faces and core were determined by the initial composite plate analysis. As a result, the sandwich bridge deck panel consists of two 12 mm thick GFRP faces and 105 mm thick PUR foam core. To obtain the high bearing resistance to patch loading, the core is stiffened with the 2-3 mm thick vertical GFRP ribs spaced at 25 mm (Fig.1). In order to find the most economical solution of the deck, two structural parameters have been changed during this research: foam density and thickness of vertical ribs, i.e. architecture of fabrics used to fabricate the deck.

The reinforcement of panels' composites consists of two types of glass fabrics:

- bi-directional braided fabric B-E 0/90 with the grammage g=800 g/m^2;
- bi-directional knitted fabric X-E ±45 with the grammage g=600 g/m^2.

The fabric architecture in the faces and ribs are as follows:

- faces: total of 15 fabrics, [0/90$_3$, ±45, 0/90$_3$, ±45, 0/90$_3$, ±45, 0/90$_3$];
- internal vertical ribs: panel A and C – 2 fabrics, [0/90, ±45], panel B - 1 fabric, [0/90].

The core is made of PUR foam and usability of two foam's densities have been checked in this research: ρ=30 kg/m^3 and ρ=105 kg/m^3. Considering the manufacturer's experience, the VARTM technology that uses the epoxy resin as a matrix, has been chosen to fabricate the FRP sandwich deck (Fig.1).

Fig. 1: Sandwich panel configuration (left) and panel prepared for VARTM.

The different structural parameters of tested panels are shown in Table 1. Three deck panel specimens (A-C) with the overall dimensions of 130 x 1200 x 2750 mm were manufactured to find the best structural solution in terms of stiffness and strength of the FRP sandwich deck. Bending, shear and bearing tests were performed for each panel type. The plate behavior of the specimens was ensured by applying the span length of 2.4 m during bending tests.

Table 1: Structural parameters of the tested panels.

Panel	Foam density (kg/m^3)	Ribs reinforcement
A	105	2 fabrics [0/90; ±45]
B	105	1 fabric [0/90]
C	30	2 fabrics [0/90; ±45]

3. DECK PANELS TESTING

Loading Schemes

Four loading schemes were applied for each panel type to evaluate panel behavior under bending, shear and bearing, namely (Fig.2):

- scheme 1 – four point bending according to LM-1 Eurocode model;
- scheme 2 – three point bending according to LM-2 Eurocode model;
- scheme 3 – shear loading (short beam);
- scheme 4 – bearing on the load path 0.4 x 0.4 m according to Eurocode models.

Panels' displacements and strains in several points of the top and bottom faces were measured during static tests.

Fig. 2: Loading schemes of panel specimens: scheme 1 to scheme 4 from left to right.

Panel Behavior

The behavior of all specimens under loading was very similar, regardless the panel structure (A, B, C). Both "load-displacement" and "load-strain" plots were almost linear until failure (Fig.3). The initial plot curvature is due to support adjustment in the first loading phase. However, in some cases a small "knee" effect was also observed.

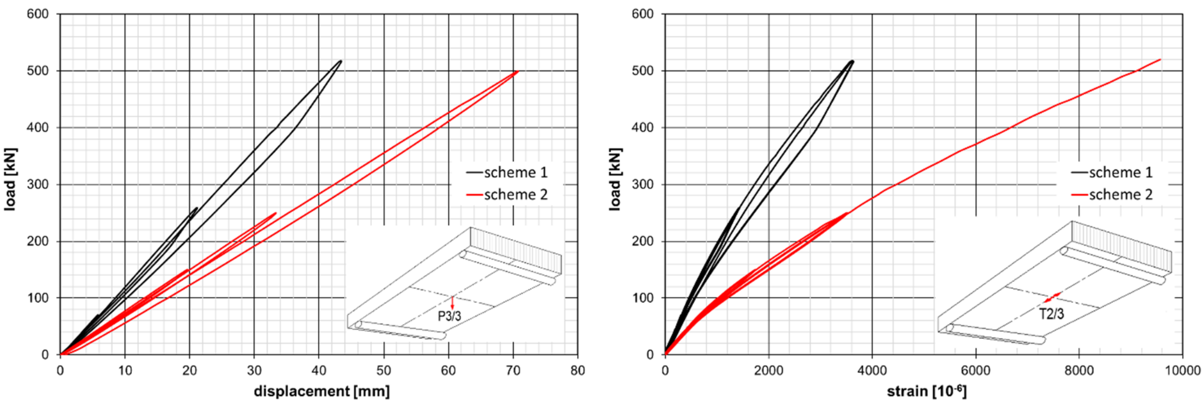

Fig. 3: Exemplary "load- displacement" (left) and "load- strain" (right) plots for scheme 1 and 2.

Failure Modes

Failure mode for each panel depended strongly on the loading scheme, i.e. the decisive inner force. For bending schemes (1 and 2), the failure in the middle of the panel was observed in the form of top face delamination along with crushing of the core foam beneath (Fig.4(a-b)). The delamination between top face and foam core at the support was observed as a shear failure mode in the scheme 3 (Fig.4(c)). Total crushing of the core, both foam and ribs, was the obvious failure mode in the scheme 4 under bearing path load (Fig.4(d)). The failures of all panels (except in scheme 4) occurred suddenly, without any warning, with loud sound of delamination. No earlier damages, neither in faces nor in core, were observed before final failure took place. In the scheme 4, slow but incremental damage of the core proceeded, until the loading was stopped. For all loading schemes, the failure mode was independent on the panel structure, i.e. foam density and rib thickness in the core. However, the panel structure has considerable influence on the total carrying capacity as well as global safety coefficient of various panel types, which is discussed below.

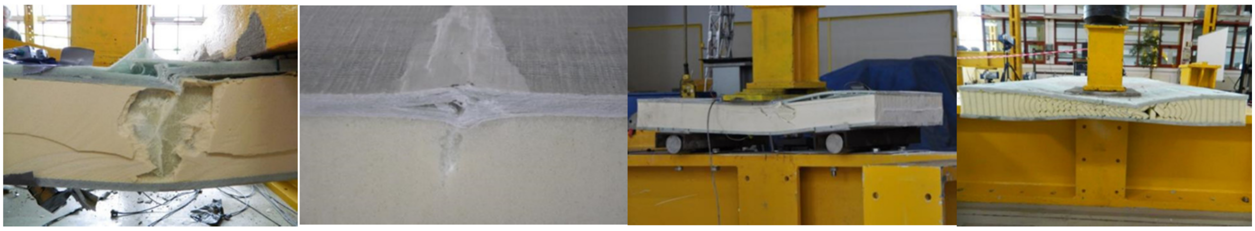

Fig. 4: Failure modes in particular loading schemes: scheme 1 to scheme 4 from left to right.

4. DISCUSSION OF RESULTS

Strength & Global Safety Coefficients

Experimentally determined strength of each panel was assumed as equal to the relevant inner force (bending moment, shear force, bearing load), calculated for the failure load of each panel under particular loading scheme. This experimental strength was divided by the characteristic inner force, calculated in the panel design under the LM-1 load model (as applied in the bridge design). The result represents the global safety coefficient of the panel in each type/loading scheme. The results for all cases under consideration are summarized in Table 3.

Table 2: Global safety coefficients of the tested panels for relevant strength cases.

Strength	Panel A	Panel B	Panel C
Bending	22.86	10.07*)	17.75
Shear	10.33	3.32	3.82*)
Bearing	5.18	3.97	2.74

*) minimum value, panel was not damaged

Taking the partial safety factors and conversion factors applied in FRP bridge design according to new European rules [4] into account, the minimum value of global safety coefficient should be greater than 3.375. Thus, only the A panel may be considered in this particular design circumstances and no material savings are allowed in the sandwich deck for the all-FRP composite bridge.

Stiffness

To compare the resultant A deck panel to another FRP sandwich decks, the approximate stiffness of the deck was assessed, basing on mid-span displacements measured in the tests of scheme I and II. No shear deformation was taken into account in this initial assessment. The plate stiffness was calculated for the panel width of 1.2 m. The stiffness calculation for the panel A is shown in Table 3.

Table 3: FRP sandwich deck stiffness calculation according to measurements (panel A).

Scheme	Max. load	Max. displacement	Stiffness	Average stiffness
	[kN]	[mm]	[Nm^2/m]x10^6	[Nm^2/m]x10^6
I	517	43,52	7,105	4,406
II	500	70,26	1,708	

The obtained plate stiffness of the tested panel is similar to another FRP sandwich decks [5]. However, the tested sandwich deck is only 130 mm deep, what means its stiffness is relatively higher than the others, considerably deeper (180 – 250 mm). Moreover, its mid-span deflection under service design load is only L/633, which is more than two times less than the allowable value assumed in design (L/300).

5. CONCLUSIONS

The tests carried out on the novel FRP sandwich deck panel confirmed its satisfying strength, stiffness and global safety coefficient to be implemented on site in the first Polish all-composite bridge. However, to obtain this good structural performance, no material savings in core may be allowed, comparing to the originally designed structure (panel A). The novel sandwich deck is also relatively stiffer than the others, implemented on various bridges worldwide.

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