PROBLEM OF STRESS CONCENTRATION AND DEFORMATION IN THE USE OF MULTILAYER GFRP (GLASS FIBRE REINFORCED POLYMER) IN BEARING STRUCTURES

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Abstract

The paper analyses a problem concerning concentrated stress in the use of multilayer GFRP carriers. Due to concentration of stress excessive deformation and local collapse occurs much sooner than the material stress peak is achieved. The paper shows the testing of the material samples and the carriers with two different spans. Also the linear and nonlinear numerical analysis was conducted. In the end the comparison of the results and a proposal for the design calculation is shown. Also the material improvement on the critical concentration places is proposed.

1. Introduction

Through progress in production of civil engineering materials every new day the market introduces more new, improved, advanced and better materials. Engineering structures demand a vast amount of specific characteristics of a material in order to fulfil the basic demands which the structures, constructive and non constructive elements, are demanding. The basic advantages that glass fibre composite that is reinforced polymer has are small specific weight, resistance to corrosion or different kind of material deteriorating due to atmospheric influence on the unprotected structure. This is a common problem with civil engineering structures made from traditional materials. GFRP (glass fibre reinforced polymer) is already well implemented into civil engineering constructions through primal or secondary bearing structures in bridges or different plateaus and as different sandwich plate like systems [1,2,3]. Besides independently GFRP is being used in combination with other materials, commonly traditional building materials in order to improve some of their poorer characteristics [4,5].

2. The analysed GFRP carrier

The material that the GFRP carriers were made of was tested on samples (figure 1.) and the results are shown in the diagram (figure 2.)

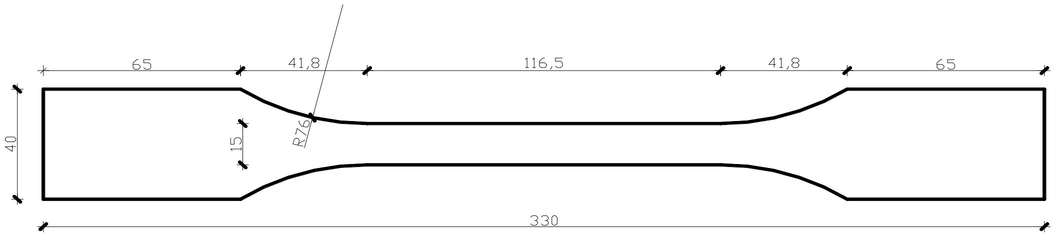

Figure 1. Dimensions of the testing sample [mm].

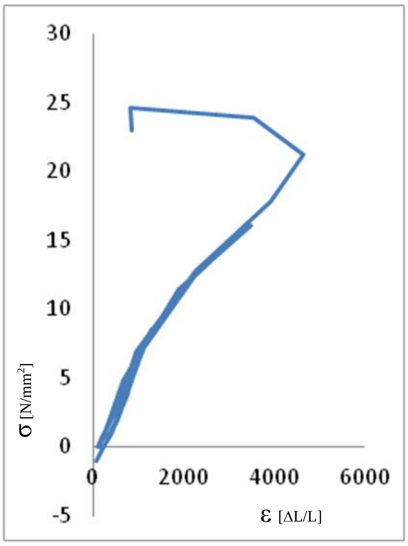

Figure 2. Diagram σ/ε of the GFRP.

Analysed and tested carriers (figure 3.) are made from plates of multilayered glass fibre reinforced polymer (GFRP) and are intended to replace carriers traditionally used and made from traditional materials used in constructions. Trapezoidal shape, thickness of plates and orientation of the carriers were chosen in order to better coincide with the most commonly used carriers as floor and/or roof carriers [6]. The plates of the cross section were produced in two types which was conditional from the production capabilities. With better production capabilities this segment practically has no boundaries in the sense of the amount of layers and different types of layers and of course the amount of the used fibres in a layer and in the composite in general. With no doubt the larger use of this material has a good influence in production terms so the proposition is to use and/or produce the new carriers as similar as possible, material and shape like.

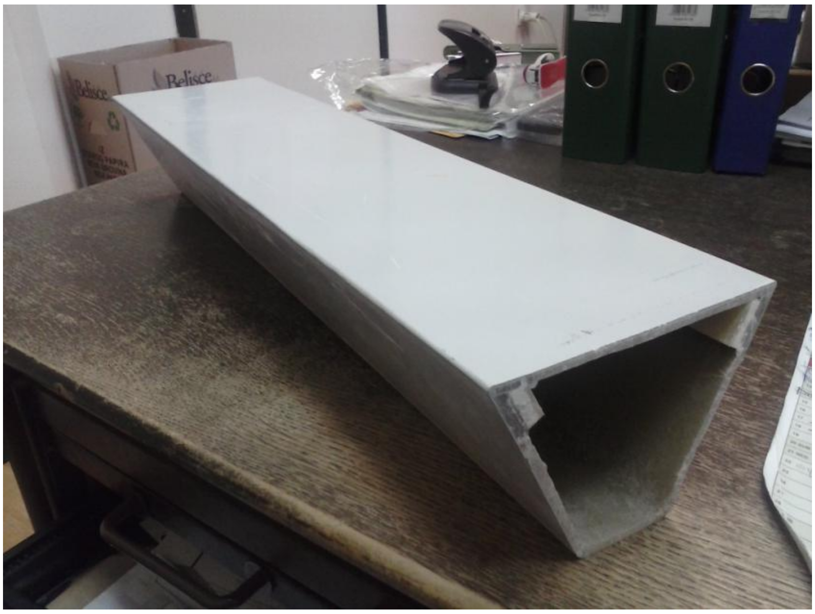

Figure 3. Glass fibre reinforced (GFRP) carrier.

3. The testing and the calculation

The carriers were tested with four-point-bending-test (4PBT, figure 4.) with two different orientation (50-W wide upper flange, 50-N narrow upper flange), with two different plate thickness (90-W-3 three layer thickness, 90-W-4 four layer thickness) and with two different spans (50-W-3 50 cm span, 90-W-3 90 cm span). It was expected that the more compact cross sections will endure more larger forces but it was noticed that for some combination of orientation, plate thickness and span the collapse was caused by a smaller force and it produced a different shape of the deformed carrier that the expected one.

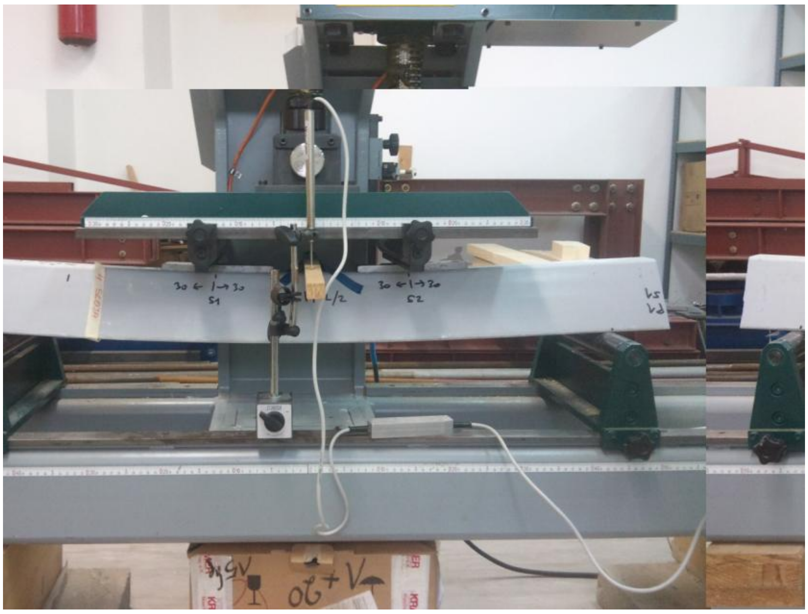

Figure 4. The testing of the GFRP carrier – four-point-bending-test – 4PBT.

The cause of this behaviour was the stress concentration which occurred on the expected points in the structure, the point of force implementation and the point of the supports. But besides these points the stress concentration also appeared on the joint of the web and the flanges, both the wide and the narrow ones. The carriers also collapsed due to the achievement of maximum tensile and/or compressive stress of a part of the cross section but also through geometrical instability of the cross section and then consequently of the whole carrier. Due to the production processes the carriers have points of breaking of the skin that is the point that required the use of glue. These points represent a weak point in the structure and at the same time the points of failure origin of the cross section and consequently of the whole carrier. Due to the cross section shape some points of geometrical illogicality were inevitably produced. Such point is the point of the joining of the web and the flanges and vice versa. These points also produce some unusual stress and deformation concentrations. This problem does not appear only on these carriers and material but is a constantly present problem in practical application in constructions. These problems were observed through the failure before achieving of the maximum stress and some of the illogicality can be seen on the diagram force/deformation (figure 5.)

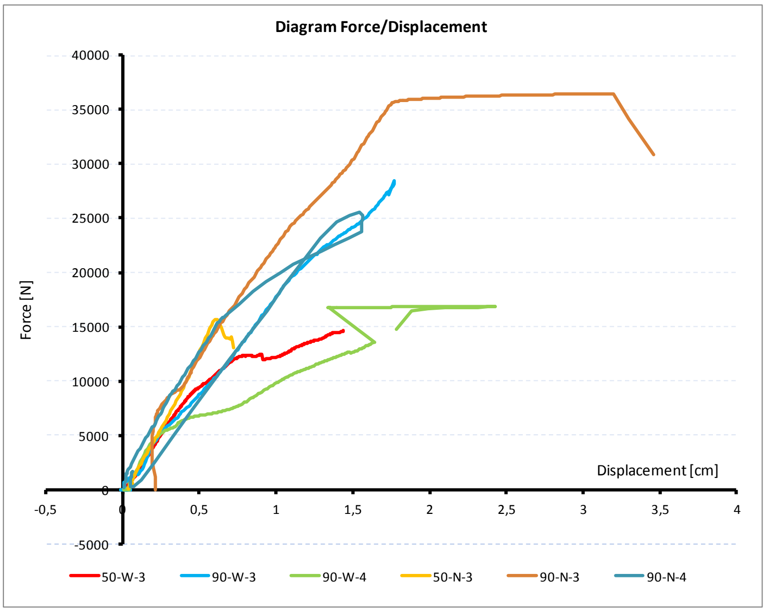

Figure 5. Diagram Force/Displacement.

Beside mentioned problems the concentration of stress that exceeds the bearing capacity of the material was present at points of the force application and at the points of the supports. As the carriers are constituted from thin plates it's expected that the problem would be local breaches through the plates at the points of stress concentration that is points of force application and points of the supports. This problem showed to be second in line concerning the overall performance of the carriers. Even if the stress does not achieve breaking values at the point of the stress concentration the material begins to collapse locally. This collapse occurs as high local deformation through denting of the plates by the testing equipment elements which eventually causes a breach through the plate and/or a whole side of the carrier and consequently the collapse of the whole carrier (figure 6. and 7.). This kind of failure is inevitable when force is applied to its maximum but can appear even at lower intensities. The next noticed problem is also caused by slenderness of the parts and the whole cross section. The problem is deformation of the cross section that is the deformation within the cross section that greatly influences the overall deformation properties of the whole carrier and does not exhibit the idealised deformed form as we usually calculate through the design procedures. Overall the “soft cross section problem” results with unplanned stress peaks through the cross section and is definitely a constant negative side of such cross section carriers.

Figure 6. Failure of the carrier at the support.

Figure 7. Failure of the carrier at the point of the force input.

In both linear and nonlinear finite element analysis [6,7,8,9] stress and deformation concentration appears at the expected points in the carrier. The difference in the nonlinear from linear analysis is noticed through a slightly higher local concentration of stress while that phenomenon is lessening in the linear analysis (figure 8.) Certain deviations between the linear and nonlinear models can be observed at the deformation analysis of the carrier and its cross section parts (figure 9.) but also in the meaning of more localisation of the nonlinear opposed to the linear analysis.

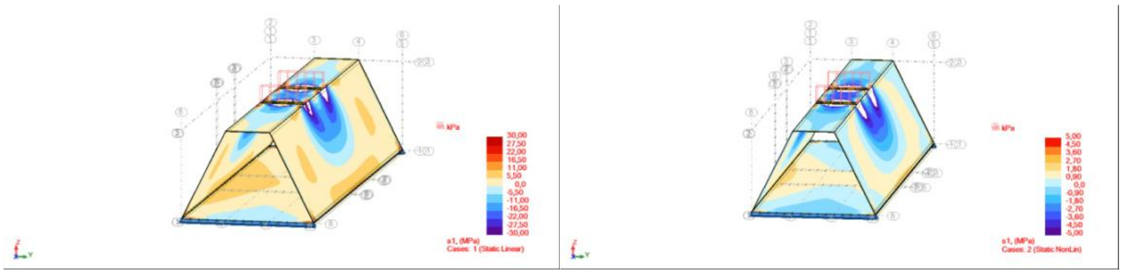

Figure 8. Linear and nonlinear model for normal stress of the 50-N-3 model.

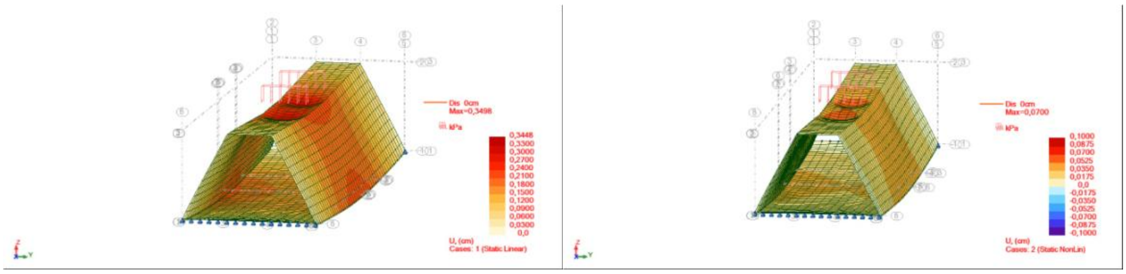

Figure 9. Linear and nonlinear model for the deformations of the 50-N-3 model.

4. Conclusion

The aim of this research is to warn for possible problems of stress and deformation concentrations at the points of concentrated force application on hollow carriers made from glass fibre reinforced polymer (GFRP). As the carriers are made from relatively thin and slander plates that then form also a slander cross section we propose constructing a more robust cross section in order to avoid this problem. The down side of this proposition is that such carriers demand a larger consumption of material and at the same time have a larger building price. To compensate this problem we propose to achieve a robust cross section through only local increase of cross section parts and only in positions of force introduction and/or at supports. In doing so we would achieve a lower material consumption and thus a lower building cost and at the same time soften the influence of the stress and deformation concentration by distributing it to a larger area of the carrier. It is also proposed to avoid places where glue is required that is to construct a cross section out of one piece. Because there is a large number of variations' concerning this problem it would be better to consider more examples before proposing a design procedure. Until that the obvious solution is the restriction of stress to the case with the fully distributed load and support areas.

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