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Experimental and Numerical Study of Connection Subjected to Bending in Airfield Pavement

Introduction

Polymer Flexible Joint (PFJ) is a technology that can be used as a mechanical connection between concrete slabs in pavements, especially located on the airports, where high concreted forces occur [1]. PFJ design in practical applications requires precise prediction of its mechanical behavior. Stresses and deformations are one of the most important parameters that should be calculated at design stage. This work presents a set of experimental and numerical tests’ results concerning PFJ connection subjected to bending.

Bending occurs in many types of elements connected by PFJ. Due to its hyperelasticity, PFJ’s behavior may be strongly nonlinear. The designer in particular case has to decide what PFJ dimensions should be applied in order to obtain required deformations and stresses. This work is an analysis of PFJ’s dimensions (height, width and thickness) influence on mechanical behavior of concrete elements connected by PFJ.

Research methodology

This work examines couple of geometrical variants of concrete elements connected by PFJ with PM type polymer usage. Examined specimens are subjected to four-point bending and has been developed according to code [2]. General scheme of tested specimens consists of two cuboid-shaped plane concrete elements connected by polymer layer, as shown in Fig. 1. The aim of experimental laboratory tests is to determine how connection stiffness and carrying capacity is influenced by connection:

- thickness
- width
- height

The tests were performed on seven geometrical variants of specimens listed in Table 1. Firstly a series of experimental laboratory tests has been done, after that a set numerical models have been developed. The aim of this part was to show the convergence between values calculated and measured, which potentially could lead to further large size connections’ design subjected to bending.

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Table 1. List of specimens variants with a variable geometry

<table>
<thead>
<tr>
<th>Variant symbol</th>
<th>polymer thickness [mm]</th>
<th>width [mm]</th>
<th>height [mm]</th>
<th>span [mm]</th>
<th>height/span [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10x40x40</td>
<td>10</td>
<td>40</td>
<td>40</td>
<td>120</td>
<td>1/3</td>
</tr>
<tr>
<td>20x40x40</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>120</td>
<td>1/3</td>
</tr>
<tr>
<td>30x40x40</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>120</td>
<td>1/3</td>
</tr>
<tr>
<td>10x80x40</td>
<td>10</td>
<td>80</td>
<td>40</td>
<td>120</td>
<td>1/3</td>
</tr>
<tr>
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<td>40</td>
<td>120</td>
<td>1/3</td>
</tr>
<tr>
<td>10x40x80</td>
<td>10</td>
<td>40</td>
<td>80</td>
<td>240</td>
<td>1/3</td>
</tr>
<tr>
<td>10x40x160</td>
<td>10</td>
<td>40</td>
<td>160</td>
<td>480</td>
<td>1/3</td>
</tr>
</tbody>
</table>

Experimental laboratory tests

Experimental laboratory tests have been performed with usage ZWICK 1455 test machine with maximum force of 20 kN and precision of 0.1 N. There was used a mechanical extensometer with 0.005 mm precision. The speed of loading was assumed to be 100% per minute in bottom fibers of the connection [3]. In order to meet the condition the following loading speeds have been applied:

- 5 mm/min for specimens with connection thickness of 10 mm
- 10 mm/min for specimens with connection thickness of 20 mm
- 15 mm/min for specimens with connection thickness of 30 mm.

All rigid elements were made of plane low-grade concrete. The polymer has been applied only to surfaces which were obtained by concrete cutting, thereby polymer has not been glued do cement slurry, but to aggregate. The glued surfaces has been primed after accurate dust removal [4]. After that a polyurethane mass type PM has been applied. The precision of specimens realization has been assumed to 1 mm. Mechanical testing has been performed after 9 days from specimen preparation. As a result force-displacement dependence has been obtained as well as total carrying capacity.

Each test series consists of 6 specimens due to statistic requirements. Besides one test all results has been classified as correct. Adhesive destruction between polymer and concrete was the most commonly observed failure mode. A total of 42 tests were performed. Sample photographs showing the testing have been presented in Fig. 1–3.

![Sample bending test of specimen variant 10x160x40](image-url)
Numerical modelling

All numerical models were developed in Abaqus 6.12 basing on Finite Elements Method. Three-dimensional 8-node elements were used to model concrete (C3D8R) and polymer (C3D8H). Due to regular shape in all variants regular fit type mesh has been performed with mesh concentration in polymer zone. Polymer was modelled as Mooney-Rivlin hyperelastic material with parameters according to [5]. All models were reduced to quarters, assuming longitudinal and transverse symmetry. Summary number of nodes ranges from 23 247 for 10x40x40 variant to 89 667 for 10x160x40 variant.

All analyses has been performed as geometrically nonlinear due to big deformations occurring in polymer. Contact boundary condition has been modelled between rigid cylinders and tested specimens in order to precisely model actual support conditions [6]. Numerical models’ visualization for all variants have been shown in Fig. 4.
Fig. 4. Numerical models’ visualization for various variants

Results

As a result several force-displacement relations for various variants have been obtained for both experimental and numerical method. Fig. 5 presents results of laboratory testing for all the series. Graphs show results for all the specimens with computed arithmetic average.
Fig. 6. presents a summary of average results for all the variants. By analyzing resultant graphs there can be noticed that the biggest carrying capacity have been obtained for specimens with the biggest width. The smallest capacity was observed for specimens with the smallest cross-section surface. The highest deformability is noticed in specimen with the biggest polymer layer thickness.

Stress maps for numerical models have been presented in Fig. 4. All the maps are shown in the same scale. Deformation scale factor at all visualizations is equal to 1. Those photos have been made for state in which maximum stress in polymer is equal to about 3 MPa.

A summary of results obtained in numerical method have been presented on a graph in Fig. 7. When comparing to Fig. 6 there can be noticed a good qualitative convergence. Comparison of force-displacement graphs obtained by experimental and numerical method is shown in Fig. 8–10 and may lead to conclusion, that PFJ behavior in numerical models is less stiff than in reality. All numerical results are presented at displacement range similar to experimental tests results with an accuracy of one calculation increment.
Fig. 5. Experimental laboratory tests’ results for different geometrical variants

Fig. 6. A summary of results obtained by experimental method for all geometrical variants
Fig. 7. A summary of results obtained by numerical method for all geometrical variants

Fig. 8. Comparison of results obtained by experimental and numerical method for different polymer layer’s thickness
Fig. 9. Comparison of results obtained by experimental and numerical method for different specimens’ width

Fig. 10. Comparison of results obtained by experimental and numerical method for different specimens’ height
Conclusions

Preliminary conclusions concerning PFJ under bending load have been presented below. The conclusions should be verified by large-size laboratory experiments. Analyzing this work’s results there can be noticed, that:

- The increase of PFJ thickness leads to bigger deformability, though its carrying capacity remains at the same level. PFJ stiffness is decreased by thicker polymer layer. The dependence of PFJ’s stiffness on PFJ thickness seems to be approximately linear in analyzed example.
- The increase of PFJ width leads to higher connection stiffness, increasing PFJ carrying capacity and its deformability. The dependence of PFJ’s stiffness on PFJ width seems to have nonlinear tendency with smaller growth for successive specimen width increase.
- The increase of PFJ height leads to higher connection stiffness, the dependence of PFJ’s stiffness on PFJ height seems to have nonlinear tendency with smaller growth for successive specimen height increase. Higher PFJ results in better carrying capacity, however specimens height increase does not influence maximum deformation that can be applied to connection.
- Maximum deflection relative to specimen’s span does not depend on PFJ width and decreases for higher specimens. Deformability of connection can be increased by thicker polymer layer.
- The direction of bending does not have a big influence on connection stiffness in rectangular shaped cross-section specimens. There can be noticed in Fig. 6 that connection stiffness is similar in tests 10x40x160 – 10x160x40 as well as in 10x80x40 – 10x40x80. The same phenomenon can be observed in Fig. 7 presenting numerical results. There could be drawn a conclusion that connection’s stiffness depends mainly on connection’s cross-section to PFJ side area ratio, what has been shown in other works [7].
- Relation between force and displacement in small deformations range is approximately linear.
- Numerical model with hyperplastic Mooney-Rivlin material form gain a good qualitative convergence. In qualitative sense all the numerical models get stiffer results of about 120–150%. This may be related to incorrect hyperelastic model identification that bases only at dumbbell tensile test. Also it may result from rheology effect omission in numerical models. The comparison indicates the need of hyperelastic model’s improvement.

This research will be continued for a number of further laboratory and numerical tests. As a final result there should be obtained a simplified relation for PFJ stiffness made of PM type polymer, depending on shape and other parameters. This will lead to higher precision of PFJ and airfield concrete pavements design.

Abstract

This paper presents results of analysis of Polymer Flexible Joint (PFJ) connection between concrete elements subjected to bending. Airfield concrete pavements are often subjected to high bending moments coming from plane loads. In order to properly design the pavements there is a necessity of testing elements constructed with PFJ. This paper presents both laboratory experimental and numerical results of specimens under bending load. There is shown PFJ stiffness, capacity and deformability values depending on type of specimen geometry. All tests concern PFJ made by PM type polymer. Several test results are presented and conclusions are drawn.

Keywords: bending tests, concrete beam, flexible joint, polymer
EKSPERIMENTALNA I NUMERYCZNA ANALIZA POŁĄCZENIA PODDANEGO ZGINANIU STOSOWANEGO W NAWIERZCHNIACH LOTNISKOWYCH

Streszczenie


Słowa kluczowe: polimer, belka betonowa, Polimerowe Złącze Podatne

References


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