Numerical optimization of a unified specimen for adhesive characterization

I.D. Costa (INEGI, Porto, Portugal), D.S. Correia, E.A.S. Marques, R.J.C. Carbas, A. Akhavan-Safar, L.F.M. da Silva

ADVANCED JOINING PROCESSES UNIT

Introduction

Adhesives are increasingly being employed in industrial applications, which has led to mechanical characterisation techniques that can provide data needed to build advanced numerical models to help design this type of bonded connection. Currently, this involves numerous standards and results in a complex network of specimens and data reduction methods that are exceedingly time-consuming and expensive. This work aims to present a new specimen that combines double cantilever beam (DCB) and end-loaded split (ELS), allowing direct extraction of the fracture energy release rate in modes I and II.

Numerical details

ELS is not a standardised test for adhesive joints that needs further investigation for its application. Therefore, a study will be presented for both specimens, starting with the ELS and then moving to the combined one, numerically computing behaviour changes as a function of the specimens' geometries, as shown in Figure 1. Both load-displacement (P-δ) curves and R-curves, computed using CBBM. [1]

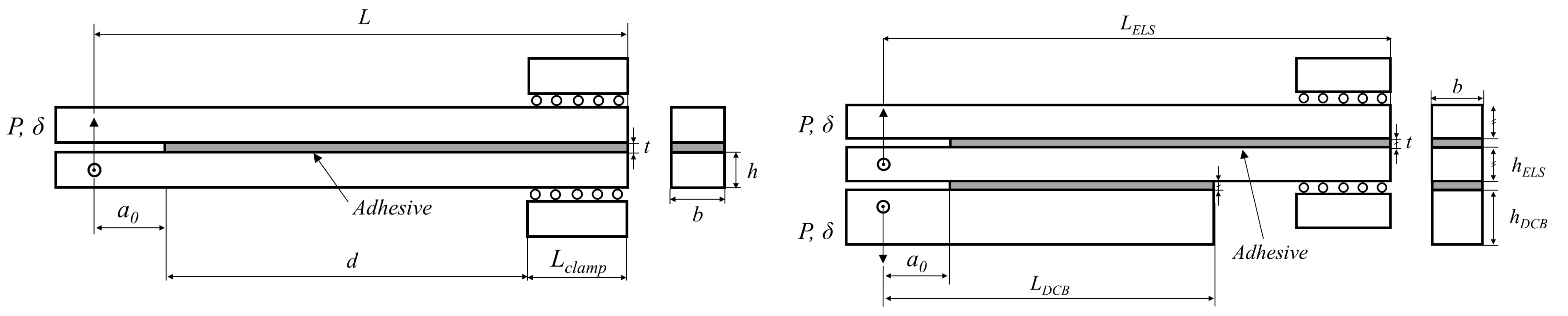

Figure 1 – Relevant dimensions of the ELS specimen (on the left) and of the combined specimen (on the right). Dimensions in mm.

The numerical simulations were run in Abaqus and the load-displacement curves obtained are shown in Figure 2.

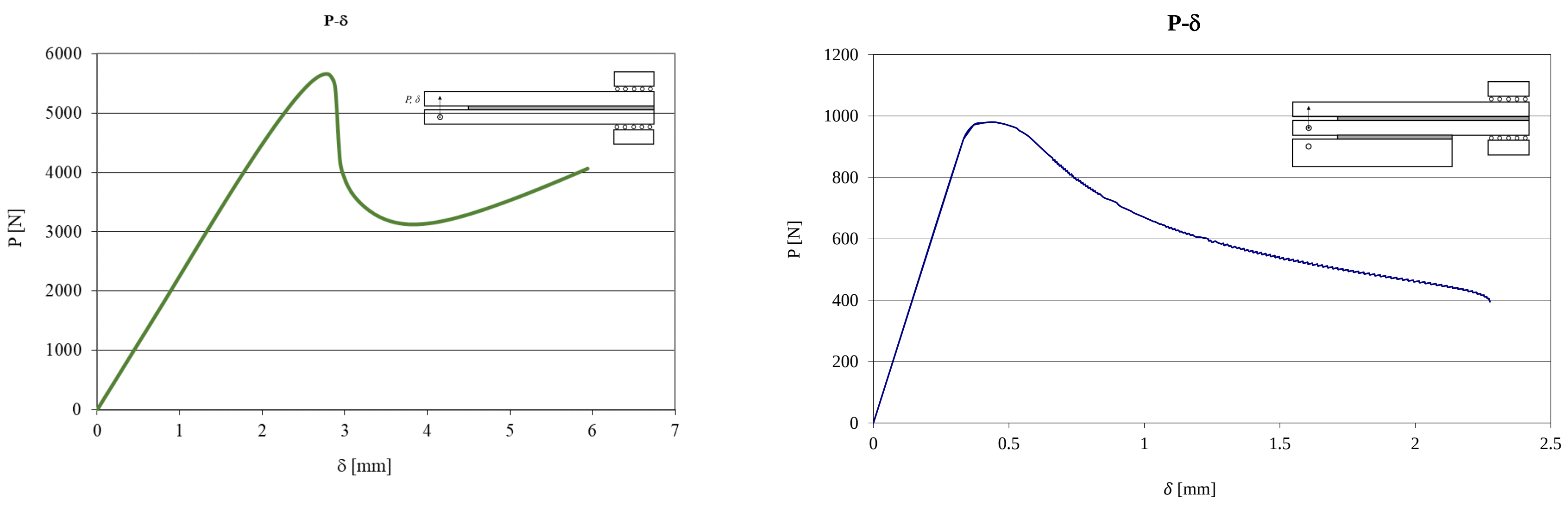

Figure 2 – Relevant dimensions of the ELS specimen (on the left) and of the combined specimen (on the right). Dimensions in mm.

Both numerical models were validated by comparing it with experimental results. The first model intends to estimate the energy release rate in mode I whilst the second model, the combined specimen, aims to estimate the energy release rates of both modes, I and II.

	Numerical	Experimental
ELS specimen	G_{IIc} = 2.30 N/mm	G_{IIc}= 2.35 ± 0.04 N/mm
Combined specimen	G_{Ic} = 0.41 N/mm G_{IIc} = 4.00 N/mm	G_{Ic} = 0.40 ± 0.14 N/mm G_{IIc} = 3.93 ± 0.26 N/mm

Table 1 – Comparison between numerical and experimental results

Experimental results

Firstly, concerning the ELS specimen, changes on the behaviour of the P-δ curves and R-curves were computed by changing the initial crack tip, a_0, and the total length of the specimen, L .

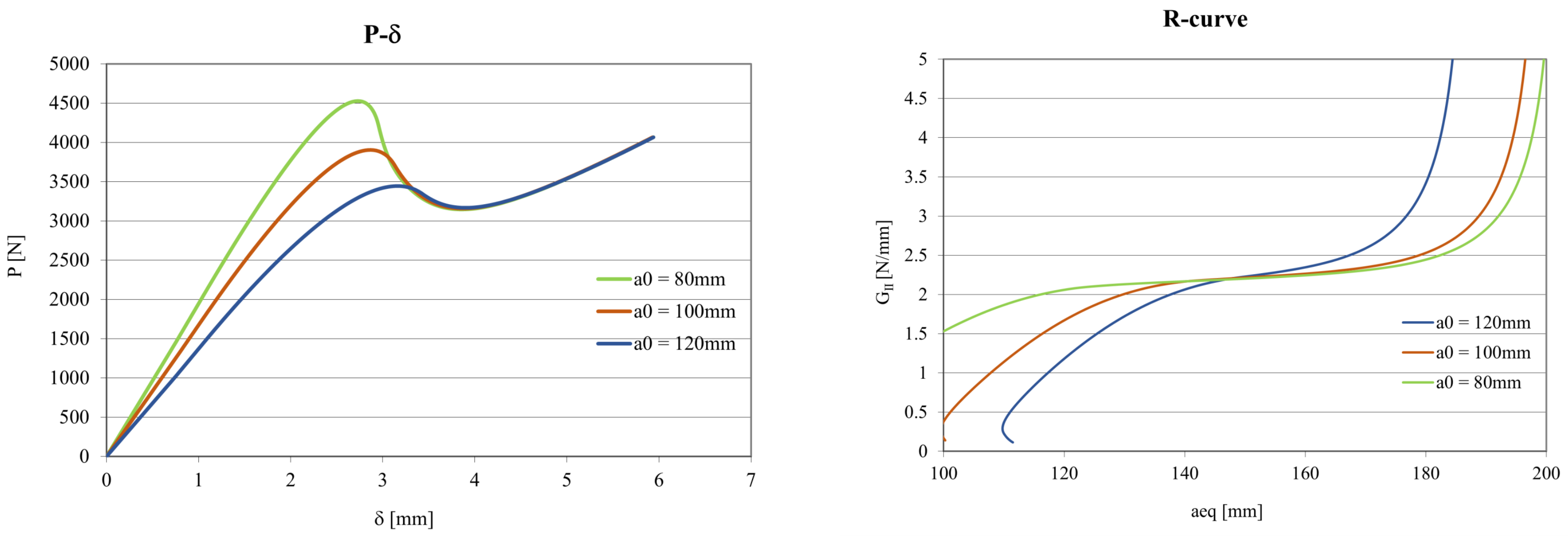

Figure 3 – Study of the influence of a_0 in the behaviour of an ELS specimen for the same L = 290 mm.

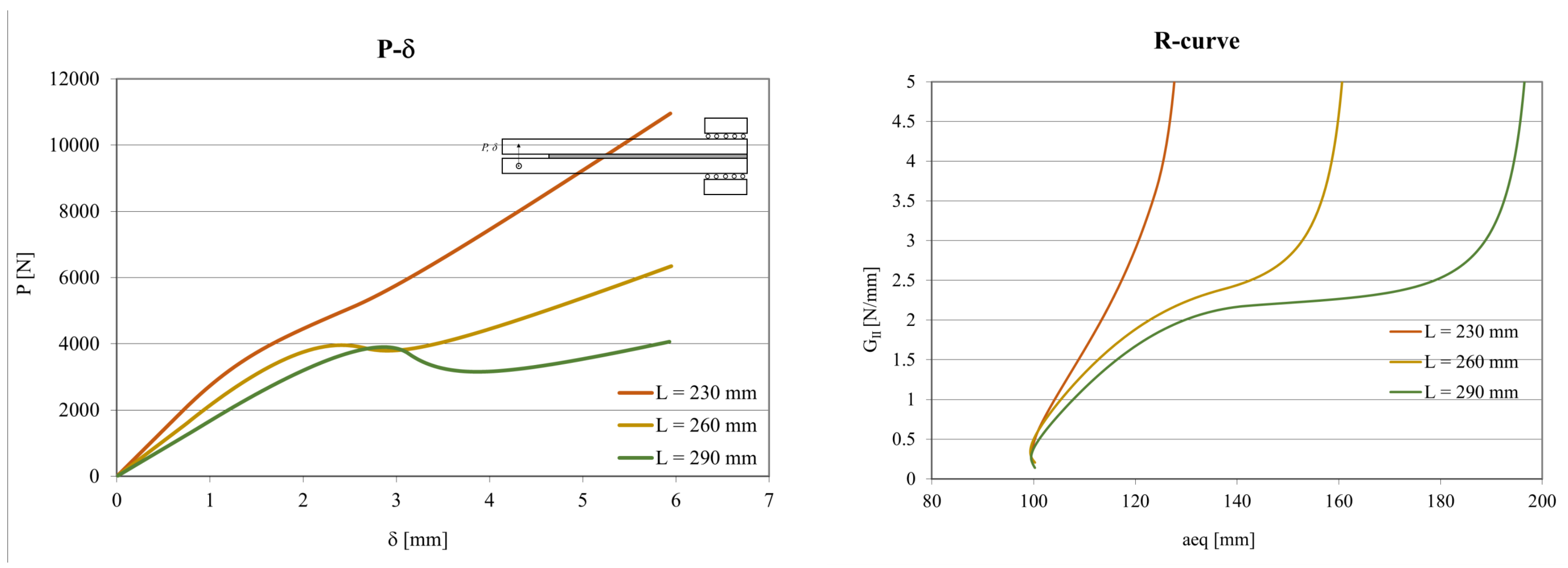

Figure 4 – Study of the influence of L in the behaviour of an ELS specimen for same a_0 = 100 mm.

To compare the difference in influence of changing a_0 or L by keeping the same mid span length of the specimen, d, are presented the following results.

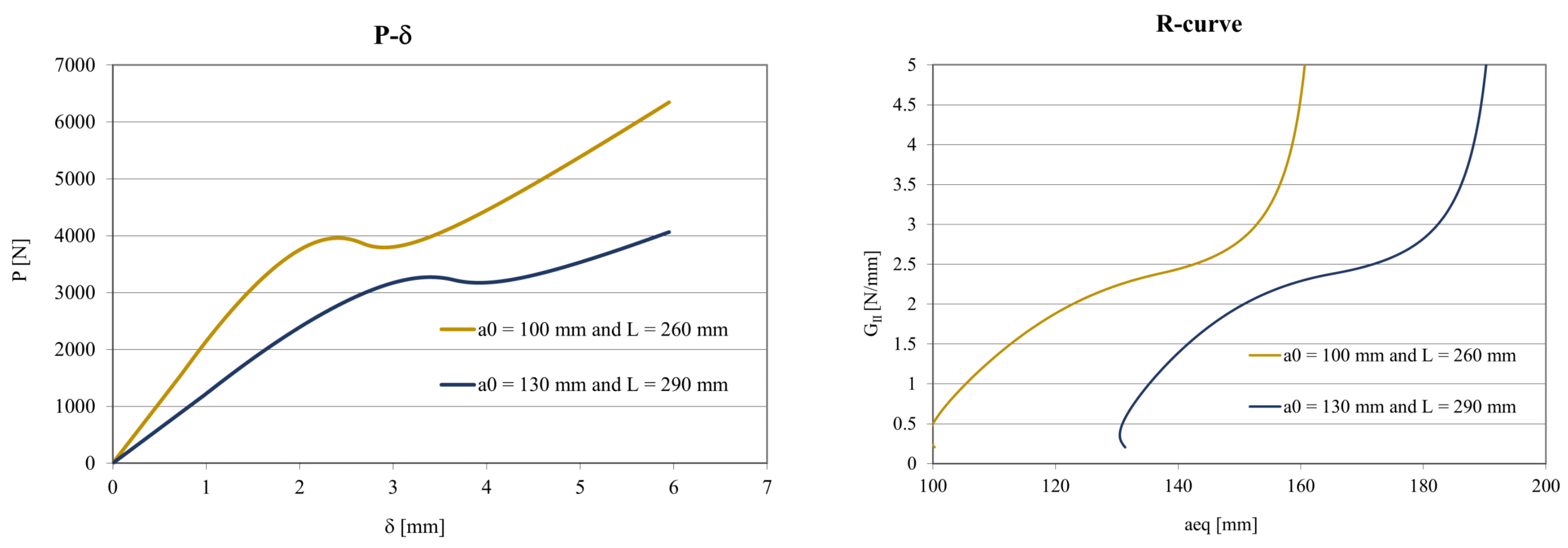

Figure 5 – Study of differences between influence of changing a_0 or L for the same d = 90 mm.

The mid span length, d, can be understood as the available length for crack propagation. To study how the fracture process zone (FPZ), the equivalent crack, a_{eq}, and the crack develops inside of this length, the next Figure plots their evolution in terms of true distance, starting from the initial crack tip, for two different lengths of the specimen.

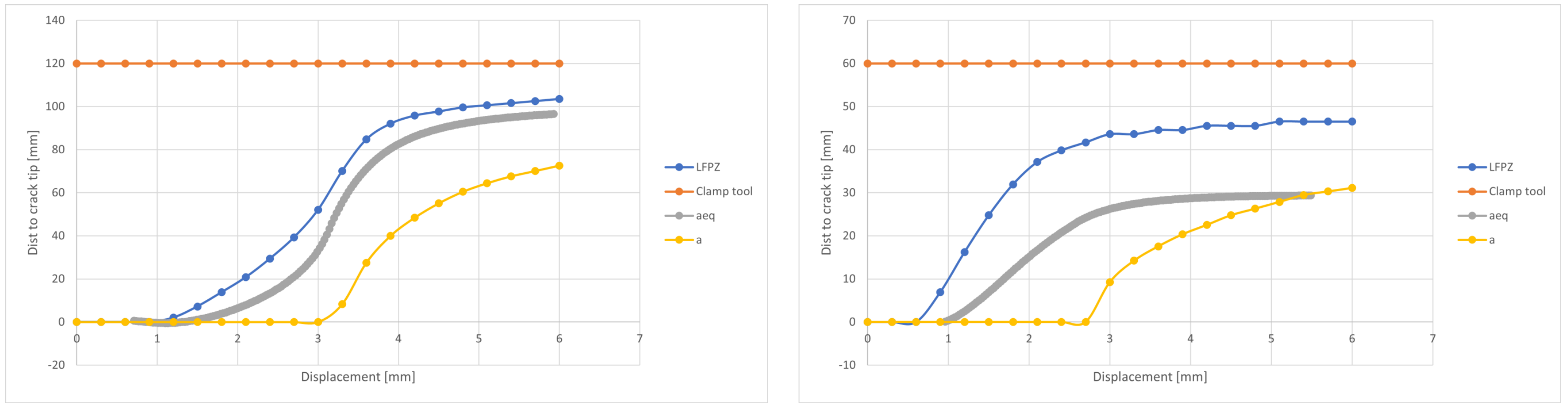

Figure 6 – Study of the evolution of FPZ, a_{eq} and a along the mid span length of the specimen. On the left, L = 260 mm and on the right L = 230 mm.

On the right, in order to understand the influence of changing the height of the lower substrate of the DCB-related part of the combined specimen, h_2, a study where this height was increased is presented.

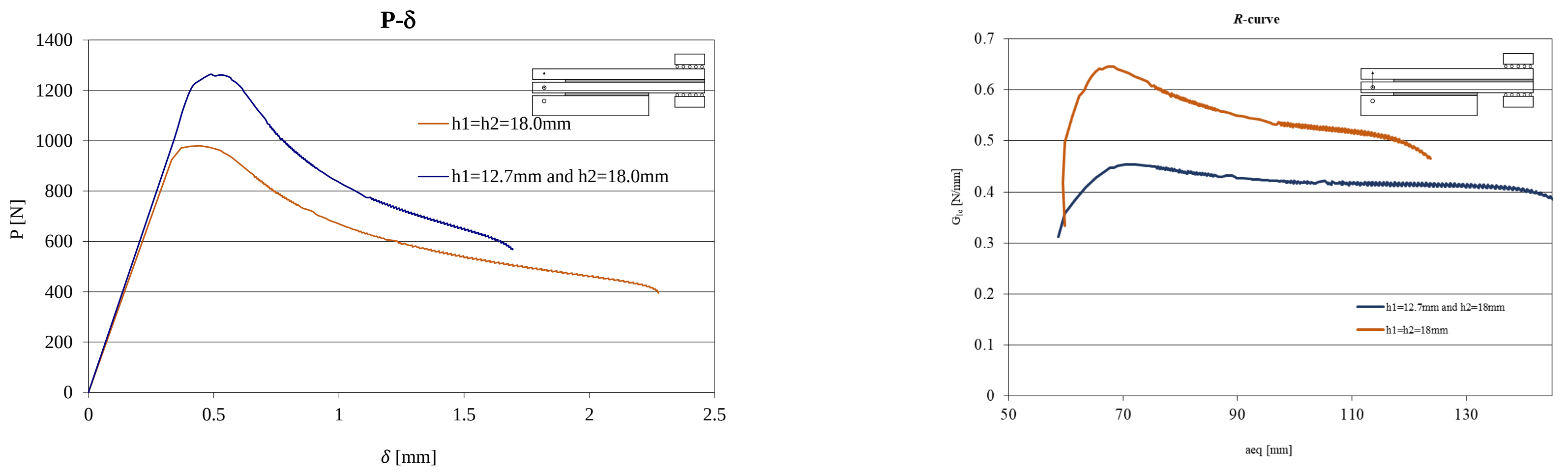

Figure 7 – Study of the influence of height on the DCB-related part of the combined specimen.

Conclusions

By computing various combinations of a_0 and L, an approach that attempts to have the same mid span length, d, finds that decreasing L has a more significant impact on raising the stiffness. However, due to the CBBM formulation, neither affects the R-curves. It must be avoided, though, to select a smaller L. Once the FPZ is close to the clamping tool, the zone's development is halted by compressive stresses. However, in order to have consistent fracture propagation, a minimal FPZ must be developed. The total stiffness of the specimen is unaffected by raising the height of the lower substrate of the DCB-related part of the combined test, but the load it can support is reduced, affecting the G_{Ic} extraction.

References

[1] De Moura et al., Equivalent crack based analyses of ENF and ELS test, Engineering Fracture Mechanics, 75(9): 2584-2596, 2008.