EVALUATION OF THE RESPONSE OF SHEAR CRITICAL WALLS USING A THREE-PARAMETER KINEMATIC THEORY

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Abstract

This paper discusses a newly developed three-parameter kinematic theory (3PKT) for shear critical walls with the help of four wall tests. The 3PKT is used to predict the pre- and post- peak response of the test units. Comparisons are performed with finite element (FE) models and plastic hinge models in combination with a shear degradation model. It is found that the latter underestimate the displacement capacity of the walls while the former do not predict well the post-peak response. The 3PKT with only three degrees of freedom captures the complete response of the walls provided that the size of the critical loading zone (CLZ) of the wall is well predicted.

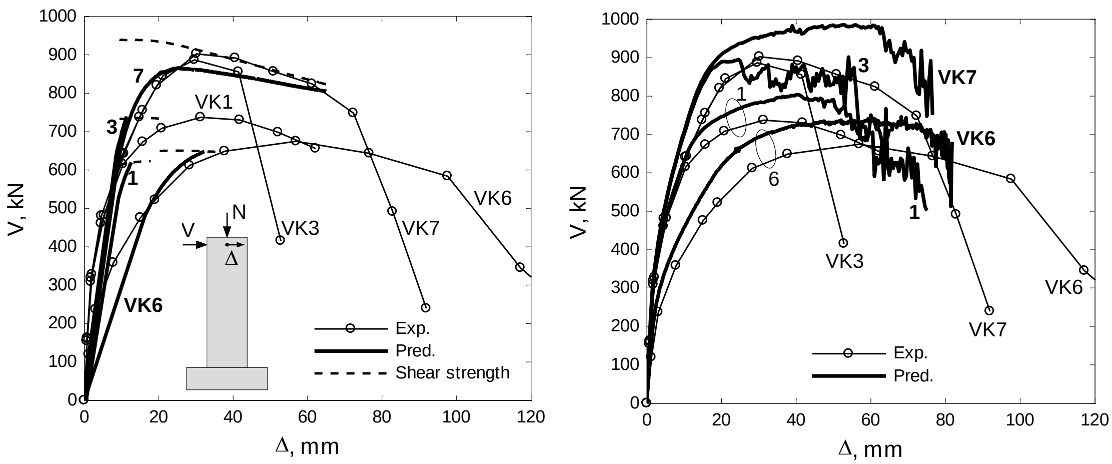
Keywords: shear walls, shear failure, kinematic model, plastic hinge, displacement capacity

1 Introduction

Modern guidelines for the design of earthquake resistant reinforced concrete wall structures require the response of the walls to be governed by flexure. To ensure ductile flexural failures, the shear capacity of the walls is designed to meet capacity design requirements. However, in existing buildings or bridges it is common that the walls are susceptible to diagonal shear failures. Such failures may occur in a very brittle manner prior to yielding of the flexural reinforcement or in a more ductile manner following significant plastic rotations at the base of the wall. The ability to accurately predict the displacement ductility at which shear failure would occur is therefore the key to a realistic evaluation of existing wall structures in earthquake-prone areas. This paper discusses a newly developed three-parameter kinematic theory (3PKT) (Mihaylov et al. 2013a) for the complete pre- and post- peak behaviour of cantilever walls susceptible to shear failures. The 3PKT stems from a two-parameter kinematic theory for deep beams (Mihaylov et al. 2013b).

2 Models for shear critical walls

Figure 1 compares the predictions of two very different approaches for modelling the load-deformation response of shear critical walls: a simple plastic hinge model (Priestley et al. 2007, Bohl and Adebar 2011), Fig. 1a, and a complex non-linear FE model (program VecTor2, Vecchio 2000), Fig. 1b. These models are applied to four wall tests reported by Bimschas 2010 (test unites VK1 and VK3) and Hannewald et al. 2013a (VK6 and VK7). Test unit VK7 failed in flexure while walls VK1 and VK3 failed in shear after the yielding of the longitudinal reinforcement. The last wall, VK6, exhibited a mixed flexure-shear failure mode. The plastic hinge approach, which was originally developed for flexure-controlled members, is combined with a shear strength degradation model to capture premature shear failures along diagonal cracks (Biskinis et al. 2004). It can be seen from Fig. 2 that this approach significantly underestimates the deformation capacity of three of the test units while the FE model does not capture well the steep degradation of lateral load resistance. In shear critical walls this degradation is associated with downward sliding of the top intact part of the wall along the critical diagonal crack. Apart from difficulties in predicting this effect, the FE approach also has the inherent disadvantage of requiring significant time for modelling and computation, as well as demanding significant expertise to ensure a safe use.

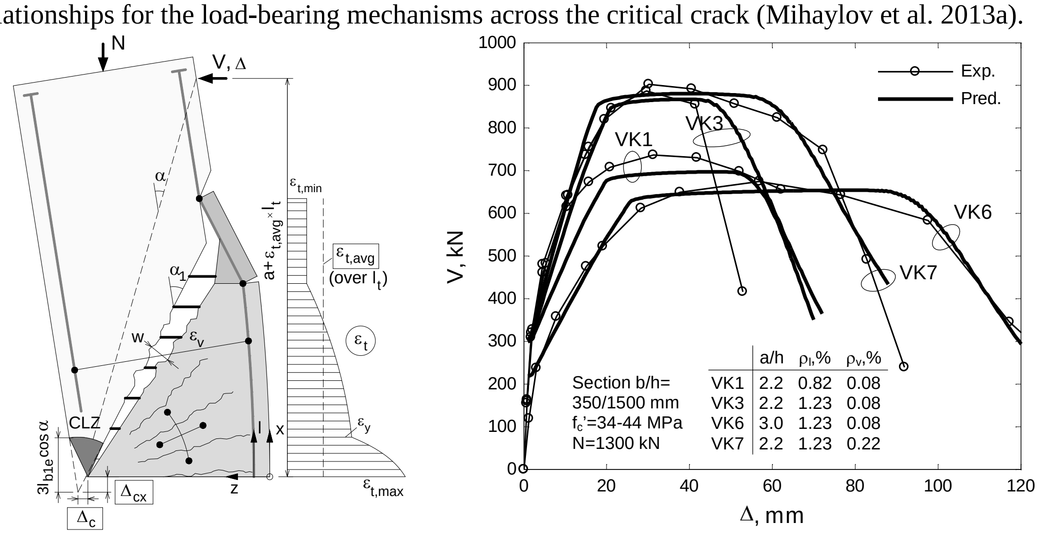


(a) Plastic hinge model with shear degradation model (b) FE model predictions – program VecTor2

Fig. 1 Load-displacement response of shear critical walls – experimental results and predictions

3 Three-parameter kinematic theory (3PKT)

The 3PKT is based on a kinematic model which describes the deformed shape of diagonally-cracked walls with the help of only three degrees of freedom (DOFs), Fig. 2a. In this model the wall is separated into two by the critical diagonal crack. The portion of the wall above the critical crack is represented by a rigid block while the zone below the crack is modelled as a fan of radial struts. The motion of the rigid block is described by DOFs $\varepsilon_{t,avg}$, Δ_c, and Δ_{cx} which represent the average strain in the flexural reinforcement, the horizontal displacement at the critical loading zone (CLZ), and the vertical displacement at the CLZ, respectively. These DOFs are predicted by combining the equations of the kinematic model with equilibrium conditions and constitutive relationships for the load-bearing mechanisms across the critical crack (Mihaylov et al. 2013a).



(a) 3DOFs kinematic model (b) Predicted load-displacement responses

Fig. 2 Three-parameter kinematic theory (3PKT)

Fig. 2b shows results from the 3PKT approach applied to the four test units. It can be seen that the 3PKT provides excellent predictions for the complete response of the VK series, including the steep degradation of lateral resistance following the plastic plateau. The end points of the 3PKT curves correspond to the lateral displacement at which the walls lose their capacity to support the vertical load. Since the 3PKT uses only three degrees of freedom, it takes only several minutes to generate the plots in Fig. 2b. The predictions in Fig. 2b were obtained with a characteristic length l_{b1e} of the critical loading zone of 320 mm or 21.3% of the depth of the section *h*. This quantity is the only open parameter in the 3PKT. A detailed discussion on the size of the CLZ as well as a simple preliminary expression for l_{b1e} can be found elsewhere (Hannewald et al. 2013b).

4 Conclusions

This paper presented a validation of a three-parameter kinematic theory (3PKT) for predicting the response of shear critical cantilever walls. When applied to four large scale tests of walls, the kinematic approach produced excellent predictions of the pre- and post- peak load-displacement response. In comparison, plastic hinge modelling of the walls in combination with a shear degradation model resulted in very conservative predictions of displacement capacity, while non-linear FE analyses did not capture the strength degradation of the walls. The 3PKT analyses were performed with an appropriately selected size of the critical loading zone of the walls while further research is needed to develop an accurate expression for this important parameter.

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