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What is more stable for RC and masonry: a single nonlinear analysis or a sequence of thousand linear analyses?

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Cracks in concrete and masonry structures occur in a discontinuous manner, both discontinuous in space and in time. The discontinuity in space requires special techniques like interface models, regularized smeared crack models or embedded discrete crack lines. Here, much research efforts have been spent over the past years and also DIANA offers a number of possibilities. The discontinuity in time, however, has received less attention. Cracks are known to occur suddenly, in a brittle manner. In reinforced concrete, the cracking process involves stress redistributions accompanied by little peaks, valleys and subsequent recoveries in the load-displacement response. In large scale masonry structures, cracks often emerge in a very brittle or even explosive fashion, accompanied by sharp peaks and snap-backs in the load-displacement response.

Numerically speaking, this peaky and spiky response is difficult to trace. The incremental-iterative Newton-Raphson scheme for the nonlinear analysis may fail. A reason behind this is that we use softening stress-strain relations of negative slope, involving negative stiffness. Also, the Newton-Raphson scheme has been meant originally for “smooth” problems, but it seems to be less suited for problems with sharp peaks, snaps and jumps. Remedies like arc-length techniques certainly help, but cannot stabilize all cases.

This contribution presents an alternative method: a sequentially linear saw-tooth softening model. Rather than a single nonlinear analysis, a series of linear analyses is performed keeping memory of local stiffness reduction. The softening curve of negative slope is replaced by a saw-tooth diagram of positive slopes, while the incremental-iterative procedure is replaced by a scaled sequentially linear procedure. Advantages of the model are numerical robustness, automatic detection of peaks and snap-backs and avoidance of bifurcations. The approach fits engineer’s thinking. RC practitioners often globally reduce concrete stiffness at areas of anticipated cracking. The present approach does the same, but then locally and automatically, at finite element level.

A previous version of the model was presented at the DIANA User’s meeting in Nijmegen in 2005. In the present contribution, the progress since then is reported. A new saw-tooth approximation of the stress-strain laws, using a “ripple curve” on top of a softening base curve has been developed. Plastic stress-strain relations have been included, also for reinforcing steel. New structural examples have been elaborated for reinforced concrete and masonry. Also, current limitations of the model and required future extensions will be discussed.

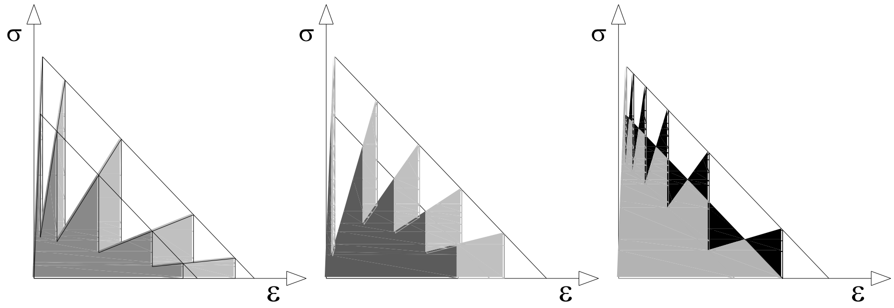

Fig. 1. Saw-tooth approximations of a softening stress-strain curve.

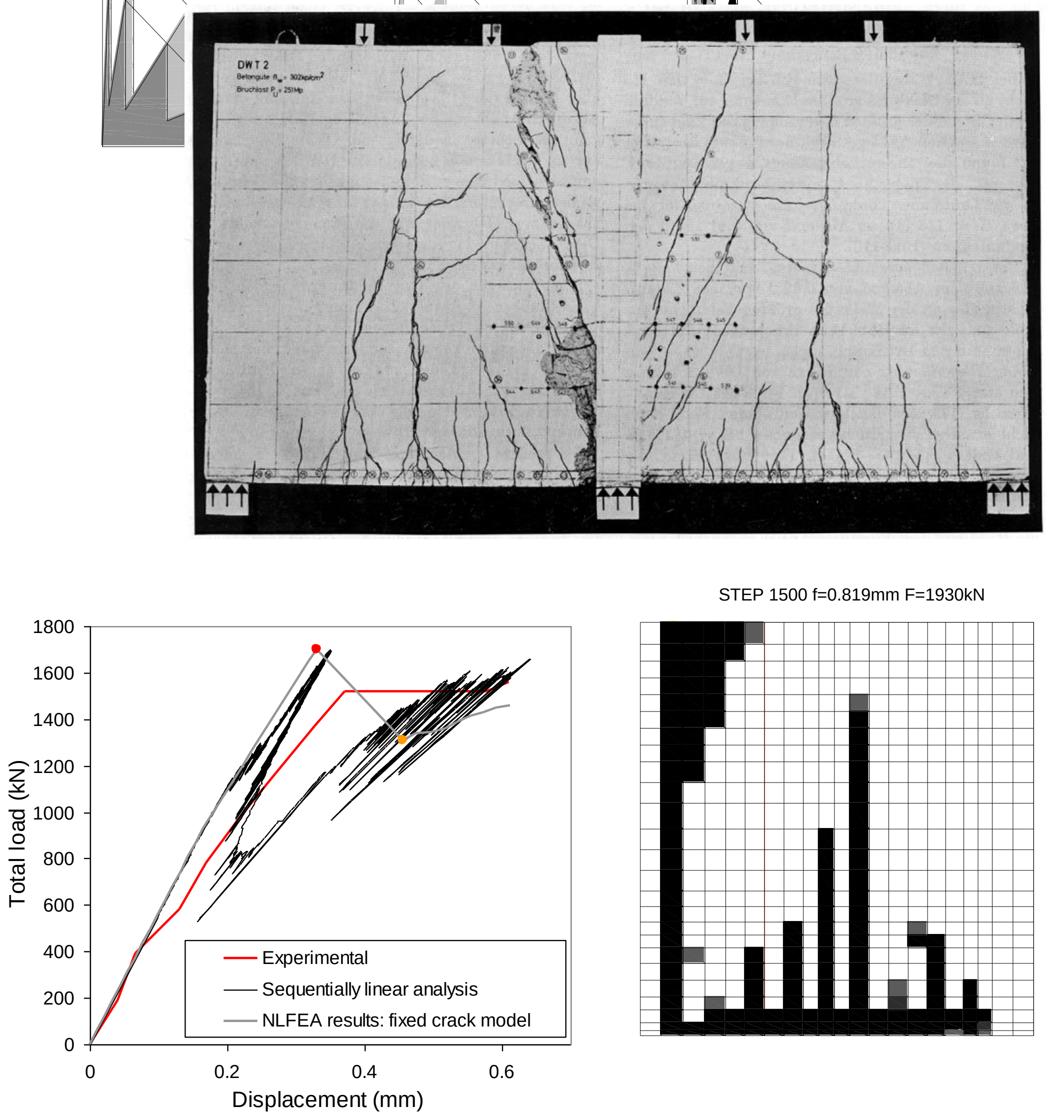

Fig. 2. Example of reinforced concrete deep beam.
Top: experimental result.
Bottom-left: load-displacement response revealing snap-back.
Bottom-right: cracked elements for sequentially linear analysis.