Load Carrying Capacity and Remaining Life Assessment: Damage Mechanics Approach

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Summary

Material constitutive laws, defined on the meso-scale, are plugged in a semi-analytical procedure in order to simulate the non-linear mechanical response of a strengthened reinforced concrete beam on the macro-scale. The strain-softening concrete behavior is modeled trough a coupling between elasticity and damage. Keeping track of the damage accumulation enables the accurate evaluation of the level of stiffness degradation of the structural element throughout the loading history. Thus the remaining load-carrying capacity reserve of the strengthened structure is predicted

Keywords: RC beam, CFRP strengthening; damage; crack initiation and propagation; reserves in load-carrying capacity.

1. Aim

The main aim of this work is to investigate the load carrying capacity and the flexural behavior of a reinforced concrete (RC) beam, strengthened by adhesively bonded carbon fiber reinforced polymer (CFRP). The structural element is considered as a multiple component system. The materials composing that hybrid structure: concrete, steel (internal reinforcement), CFRP and adhesive layer are explicitly defined. Constitutive material models and failure criteria are formulated for each of those components.

2. Material models

The non-linear concrete behavior is modeled by elasticity coupled with damage. It is defined on the meso-scale in order to simulate the concrete strain-softening response and local failure. A bilinear kinematic hardening is used for steel. The adhesive is considered as a linear, elastic and isotropic material. The CFRP is considered as a linear, elastic, transversely isotropic material.

3. Semi-analytical procedure

The material constitutive laws are plugged in the post-processing of an incremental semi-analytical procedure. The procedure is written in the ANSYS parametric design language APDL. The structural element mechanical response is reproduced in a sequence of non-linear static analyses. For each step of the semi-analytical procedure the stress and the strain distributions are obtained.

The damage variable is calculated for each finite element and stored in predefined arrays.

For the finite elements, which are affected by damage, the elasticity constants are modified with the damage variable evaluated in the previous step. Before the next step these finite elements are re-meshed with the modified elastic constants. When the damage variable, calculated for a given finite element reaches its experimentally defined critical value, this finite element is deactivated.

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4. Case study

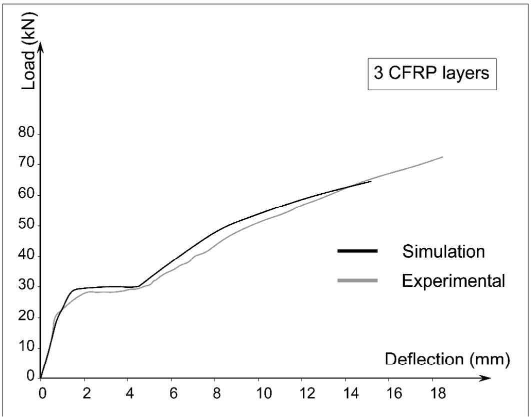

Fig. 1: RC beam strengthened with 3 layers of CFRP: comparison between FE and results

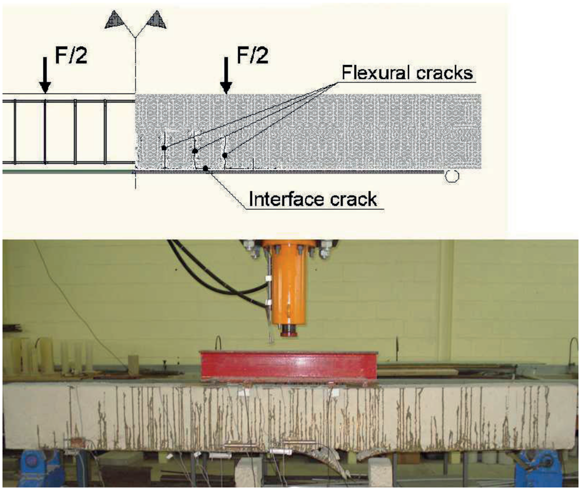

Fig. 2: Crack pattern, obtained by FE simulation and the crack pattern observed in the test

A reinforced concrete beam, subjected to four-point-bending test, is considered.
Comparison between FE simulation results and experimental results for RC beam strengthened with 3 layers of CFRP is shown in *Fig. 1*.

The crack pattern, obtained by FE simulation and the crack pattern observed in the test on a RC beam with the same geometry and reinforcement arrangement are depicted in *Fig. 2*.

It can be seen that the model predicts adequately the load-carrying capacity and reproduces accurately the transition between the different phases of the strengthened element response.

It is assumed here that the transitions between the different phases correspond to the change in the slope which is observed in the load-deflection plot.

By analyzing the load-deflection plots obtained by FE simulation, a remaining life assessment can be done. Thus, at a given moment of the loading history the magnitude of the applied load can be easily compared to the maximum value predicted by the semi-analytical procedure.

5. Conclusion

A reliable semi-analytical procedure, allowing simulating the mechanical response of a reinforced structural element has been presented. The constitutive laws of the materials are defined on the meso scale in order to obtain the structure response on the macro-scale. The non-linear material behavior is taken into consideration. Specifically the strain softening concrete response is obtained by coupling elasticity with damage.

The stress and the strain distributions, the displacement field, as well as the evolution of each of these values at different location can be evaluated. The level of the cumulated mechanical damage can be also rationally evaluated. Thus the remaining load-carrying capacity reserve of the strengthened structure is predicted.

The proposed technique has been validated both qualitatively- by comparing the crack pattern obtained by FE analysis to the failure mechanics observed in the experiments, and quantitatively- by comparing a global characteristic given by the FE simulation and experimental data monitored in the test.