Damage caused by accidental loads - assessing of damaged reinforced concrete

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Summary

Accidental loads - for example a vehicle impact or blast and shock waves due to detonations - lead to damages in reinforced concrete structures. These damages are characterized by a central zone, which is visually recognizable and also an obvious invisible damage in the surrounding material caused by shock wave propagation through the concrete. To make a statement concerning the structural behaviour of reinforced concrete structures damaged in such a manner and to predict their residual load bearing capacity in a further step, information on the damage is needed. To assess the size of the total damaged zone consisting of visible and obvious invisible parts, non-destructive tests (NDT) have been carried out. Investigations with the acoustical-based testing method Impact-Echo and the Radar system based on electro-magnetic waves show good applicability for that problem and help to learn more about damages caused by high dynamic loads.

Keywords: Accidental load, high dynamic load, damage, reinforced concrete, non-destructive testing, impact-echo, radar.

1. Introduction and Motivation

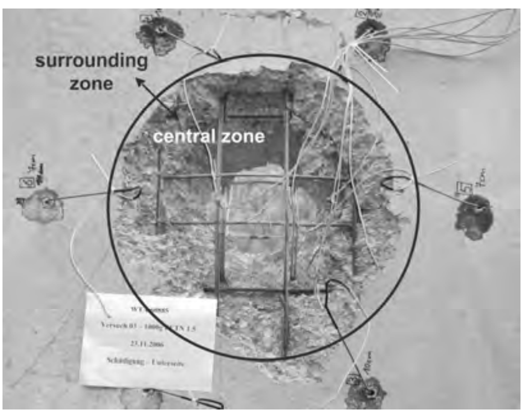

Fig. 1: Zones of damage after accidental load

Accidental loads - for example a vehicle impact or blast and shock waves due to detonations - lead to damages in reinforced concrete structures. These damages are characterized by a central zone, which is visually recognizable and also an obvious invisible damage in the surrounding material caused by shock wave propagation through the concrete (surrounding zone, see figure 1). This damage in the surrounding zone is characterized by a deterioration of the concrete's microstructure as well as bond failure between reinforcement bars and concrete.

https://doi.org/10.2749/222137908796293037
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To make a statement concerning the structural behaviour of reinforced concrete structures damaged in such a manner and to predict their residual load bearing capacity in a further step, information on the damage's intensity and size is needed. One possibility to assess the size of the total damaged zone consisting of visible and obvious invisible parts is non-destructive testing (NDT). The use of the acoustical-based Impact-Echo-method (IE) and the Ground Penetrating Radar system (GPR) based on electro-magnetic waves seem to be appropriate for that particular problem.

2. Experimental investigations

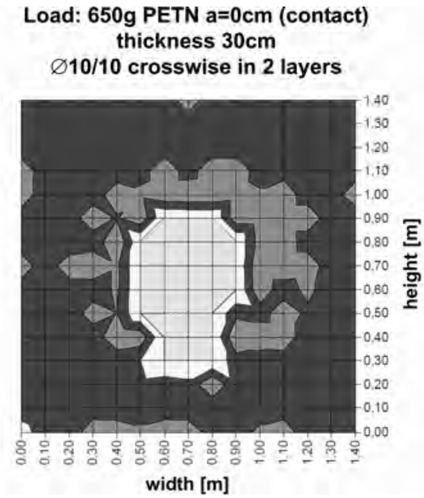

Fig. 2: Exemplarily Impact-Echo test result for a damaged RC-slab

The experimental investigations have been carried out at reinforced concrete slabs (size 300 cm by 400 cm and 200 cm by 200 cm) and thicknesses of 20 and 30 cm. The slabs have been loaded either with a contact or with a near field detonation consisting of different amounts of explosives from 400 g PETN to 2750 g PETN.

Figure 2 shows exemplarily the impact-echo test result at a slab in grid view with coloured zones for different compression wave velocity ranges which indicate deterioration of concrete's microstructure (surrounding zone). The diagram has been generated by linear interpolation between the measured values at single spots

As supposed it can be stated in general that the total damage zone is larger than the visible spalling and scabbing craters. The differential in compression wave velocity for the surrounding zone compared to undamaged zones is explicit. GPR tests show similar results.

3. Conclusions and Acknowledgements

The NDT-tests carried out at RC-slabs preloaded with contact and near field detonations show, that IE and GPR are suitable methods to determine the size of the total damage zone consisting of visible central zone and the obviously invisible surrounding zone. According to the authors' opinion the Impact-Echo method seems to be more appropriate than the Ground Penetrating Radar system for the presented application because of the direct relation between material properties and the p-wave velocity used by IE.

Because of the great number of parameters both on behalf of the action (e.g. kind, amount and stand-off of explosive, size and velocity of impactor) and on behalf of slab resistance (e.g. kind and amount of the reinforcement, anchorage of reinforcement outside the damage zone, size effect and foundation of slab during detonation loading) a quantitative assessment is hard to do. But the NTD-methods can be used to give a qualitative assessment of the damaged zone for each single case.

Additionally to the non-destructive tests presented in this paper destructive tests to gain knowledge about the material properties in the damage zone after accidental load have been carried out. Hereby bond failure between reinforcement bars and concrete in the surrounding zone has additionally been observed. Both the results of the NDT-tests as well as the destructive tests help to learn more about damages caused by high dynamic loads and lead to the development of an empirical based model for damage description after high dynamic loading. Therefore a first approach with modified material properties (young's modulus and compressive strength) and a recommendation for bond behaviour in the surrounding zone (range up to 2 times the crater diameter) has been developed.