

LOCAL RESPONSE OF REINFORCED CONCRETE TO MISSILE IMPACTS*

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SUMMARY

An experimental and computational study was undertaken to obtain the constitutive relations for determining the response of reinforced concrete walls to impacts from postulated tornado-missiles. Impact experiments with rods and pipes were conducted in the laboratory on small reinforced concrete walls to examine the response phenomena. The phenomena observed can be classified into the following categories: crushing, cratering, spalling, radial cracking, and shear failure along the surfaces of a plug or cone of concrete extending through the wall.

From these observations the three primary response mechanisms appear to be: compaction or crush up, shearing, and tensile fracture. Material properties for defining the response mechanisms in the static and high strain-rate range were obtained by static triaxial and dynamic plate impact experiments. Under impact loading, the crush-up and shear strengths are significantly greater than the static strengths and the tensile strength is ten times greater than the static tensile strength.

Computational simulations of the impact and wall response were made with an axisymmetric finite difference wave propagation computer program. The impacting rod and reinforcing steel are described by elastic-plastic work-hardening models. The reinforced concrete target is considered in two parts: regions with plain concrete and regions with concrete and reinforcing steel.

The plain concrete is treated by a CAP model, which describes compaction, shear yielding on a Mohr-Coulomb surface, and tensile separation following an accumulation of tensile strain. Parameters for the CAP model were first evaluated from static data on concrete and this has been termed the static CAP model. A second set of parameters was derived from a series of flat plate-impact experiments conducted to obtain high strain-rate compressive and tensile behavior. This has been termed the dynamic CAP model.

The reinforced region is treated as a mixture of concrete and steel, combining the concrete CAP model with the steel model. In this mixture calculation, the reinforcing is treated as a sheet. The reinforced region has different strengths and moduli parallel and normal to the reinforcing layer.

Two-dimensional computational simulations of a rod impact experiment with threshold cracking attempted, using both static and dynamic parameters. The results based on the static parameters showed the correct location of shear and tensile damage as well as the sequence of cracks. However, the severity of the cracking and penetration was overpredicted. The results based on the dynamic parameters gave good agreement with penetration distance but underpredicted the fracture damage. It appears that an appropriate computational model is one that combines dynamic crush and shear properties with static tensile properties.

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