ABSTRACT

Changiz Rezaei, Seyed Hamid, Ph.D., Purdue University, August 2011. Response of RC Elements to High-Velocity Impact Load.

Previous studies showed that RC elements designed to fail in flexure under static load can fail in shear under dynamic loads. An experimental program was conducted to investigate the effect of transverse reinforcement on the resistance of small-scale RC beams to shear forces caused by high-velocity impact loads. A total of 26 beams were tested. Beams subjected to impact had transverse reinforcement ratios of 0.41%, 0.54% and 0.8%, and were proportioned to fail in flexure under static loading. The beams were impacted by water-filled containers moving at velocities ranging from 63 m/s to 104 m/s. It was observed that beams were able to form flexural failure mechanisms and resist nominal shear stresses equal to at least 1.5 times the static shear capacity of comparable specimens which failed in shear.

SDOF models of the test specimens were built based on the following assumptions:

a) The mass of an equivalent SDOF system representing a continuous beam is 0.37 times the total mass of the beam for the elastic range of response and 0.33 times the total mass of the beam for the plastic range of response.
b) The resistance function of the equivalent SDOF model is elasto-plastic. The stiffness and resistance defining this function were means of values extracted from measured load-deflection curves.
d) The loading history was a rectangular pulse with duration equal to the ratio of projectile length to impact velocity and amplitude proportional to the density of the impacting fluid, the area of the projection of the projectile onto the beam, and the square of the impact velocity.
e) Strain-rate effects caused an increase in the unit yield stress of the reinforcing steel of 60%.
f) The damping ratio was 5%.

Using these assumptions, the obtained mean ratio of computed to measured permanent midspan displacement was 1.1 with a standard deviation of 0.38. For detailed FEA (Chapter 4), this ratio was 0.9 and the standard deviation 0.2. The duration of each SDOF analysis was in the order of seconds whereas the duration of each FEA was approximately 2 hours on a machine with a 3-GHz CPU and a 3-GB of RAM.

SDOF models representing columns of the Pentagon building were used to simulate the aircraft impact that took place in 2001. The columns were idealized as SDOF systems using the following assumptions:

a) The columns were impacted at mid height by a prismatic fluid mass with a density of 800 $kg/m^3$.
b) Impact velocity decayed either as a quadratic function or as a linear function of the distance to the façade of the building.
c) Column failure took place when the strain in the longitudinal reinforcement reached 30%.
d) Plastic hinge length was equal to the effective depth of the column.
e) The columns had fixed-end supports and an elasto-plastic resistance function.
f) Strain-rate effects caused an increase in the unit yield stress of the reinforcing steel of 50%.
g) The mass of an equivalent SDOF system representing a continuous column is 0.35 times the total column mass.
h) The loading history was a rectangular pulse with duration equal to the ratio of projectile length to impact velocity and amplitude proportional to the density of the impacting fluid, the area of the projection of the projectile onto the column, and the square of the impact velocity.
i) The damping ratio was 5%.

The quality of the results obtained from nonlinear dynamic analysis of SDOF systems conceived using these assumptions was comparable to the quality of the results obtained from a detailed FEA reported by Hoffmann et al. (2004).