Verification of Nondimensional Energy Spectrum-Based Blast Design for Reinforced Concrete Members through Actual Blast Tests

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Abstract: A method has been developed for the design of reinforced concrete (RC) members when subjected to blast loadings based on the nondimensional energy spectrum. Numerical analyzes showed good agreement between the approximate responses of RC members designed to their respective levels of target response. This paper further verifies this method through the actual response of a RC column and beam subjected an actual detonation of explosives at a short standoff. When subjected to blast loading from a short standoff distance, the cantilever column behaved predominantly in direct shear. Thus, ways to mitigate the damage of a cantilever column should draw focus on the robustness. The developed design procedure provides a feasible method for the blast resistant design of members, subjected to blast loads at a short standoff distance.

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Introduction

From observations of buildings subjected to deliberate or accidental blast loads at a short standoff distance, it can be seen that the collapse of the structural systems are due mainly to the failure of one or more critical structural members (Longinow and Mnizsweki 1996; Li et al. 2009; Luccioni et al. 2004). The result of the failure of a critical structural member is the redistribution of the internal forces within the structural system. If the increased demand resulting from the redistribution exceeds the capacity of the remaining members, subsequent failure of the remaining members may arise. This may result in an eventual failure of the structural system. Known cases of failure of structural systems include the Ronan Point Building and the Murrah Federal Building (Corley et al. 1998; Hinman and Hammond 1997; Milakar et al. 1998; Hayes et al. 2005).

In recent years, a number of methods have been proposed for blast resistant design of reinforced concrete (RC) members (ASCE 1985; Allgood and Swihart 1970; Biggs 1964; TM5-855-1, United States Department of Army 1965; May and Smith 1995). These are based on the performance of the RC members with an explicit consideration of the behavior of the member beyond its elastic region of response. The focus of these design methods ensures that the performance of the designed members contributes toward the safety of the structure. In a performance-based design framework for structures subjected to blast loads, it is common to select appropriate response parameters as performance indicators of the members. Using these selected parameters, the expected performance level can be established and applied to the design in limiting the extent of the response and the damage level of the member. Currently, two performance indicators which are commonly used are: (a) the target support rotation of the member (TM5-1300, United States Department of Army 1990; May and Smith 1995) or (b) the target displacement ductility factor expected of the member (TM5-855-1, United States Department of Army 1965; Biggs 1964; Manual 42, ASCE 1985). The target support rotation refers to the rotation at the support of an equivalent single-degree-of-freedom system, which represents the structure. Given a target support rotation $\gamma_t$, or a target displacement ductility ratio $\mu_t$, for a critical location along the span of the member to be designed (e.g., the midspan of a simply supported member or the free end of a cantilever member), the blast design can then be carried out.

However, research pointed out that neither $\gamma_t$ (i.e., target support rotation) nor $\mu_t$ (i.e., a target displacement ductility ratio) alone could provide a complete definition of the performance of a structural member under blast loads (Rong and Li 2008). In other words, design for blast resistance should in effect consider both the target support rotation and the target displacement ductility. Such a method for the design of RC members for blast resistance has been developed, which is based on nondimensional energy spectrum (NES). Numerical analyses show good agreements between the approximate responses of RC members designed to their respective levels of target responses. This was demonstrated using equivalent single-degree-of-freedom systems. While the approximate responses of the RC members were shown to be lower than the target levels of response, this difference is considered to be conservative and leaves a buffer for additional response of the structural system. The result $y_t$ is used in determining the expected performance of the member.

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