

Design Parameters Governing Performance of Low Rise Reinforced Concrete Frame Structures Subjected to External Blast Loading

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Abstract

Low rise reinforced concrete (RC) moment frame buildings are designed for dead, live, non coastal wind loads and moderate seismic zones according to 2006 IBC and ACI 318-05 provisions. Pressure-Impulse curves for typical columns in these buildings are generated using a modified TM 5-1300 procedure that uses a fiber hinge model. The curves are used to map damage from scenario blast pressures applied to building faces. Geometric and design parameters influencing redistribution of forces under external blast scenarios are investigated using nonlinear static finite element models.

Introduction

The live loads (based on the occupancy type) and the spans are important parameters governing the preliminary design of a structure. These determine the gross member dimensions and thus the weight and stiffness of the structure, which are important factors in governing the response of the structure to dynamic loadings. The force redistribution capabilities of the structure depend on the joint capacities. The joint capacities depend on the ductility and shear capacity of the joints, which in turn depend on the reinforcement and the area of the joint. The effects of geometric parameters such as column spacing and aspect ratios, on the member and joint capacities are determined.

At the member level, local vulnerabilities need to be identified in order to map the blast damage on the structure. The distribution of blast loading in terms of pressure coefficients on the building face is characterized. Pressure-impulse (P-I) curves corresponding to structural members of low rise RC buildings, designed as per current code for dead, live and seismic loads, are computed, for various aspect ratios. The local damage due to blast and the subsequent loss of members is identified. The consequences of local failure on the surrounding structure, and the subsequent redistribution of loads at the sub-system level are determined, for various changes in the geometric parameters.

Seismic Design

A 3 story regular RC frame building located at Oxford, Mississippi, with 20 ft x 40 ft bays is designed for seismic resistance according to IBC 2006. The most important parameters governing the preliminary design of a structure are the live load and the spans being considered. These govern the gross member dimensions and thus the weight of the structure which is an important factor in governing the response of the structure. The seismic loads are computed based on the equivalent lateral load procedure, where the base shear is computed as in (1). The inertia properties of the structure are inherently included in this equation.

$$V_s = C_s * W \quad \text{Where } C_s = S_d s / (R/I), S_d s = (2/3) * S_m s, S_m s = F_a * S_s \quad (1)$$

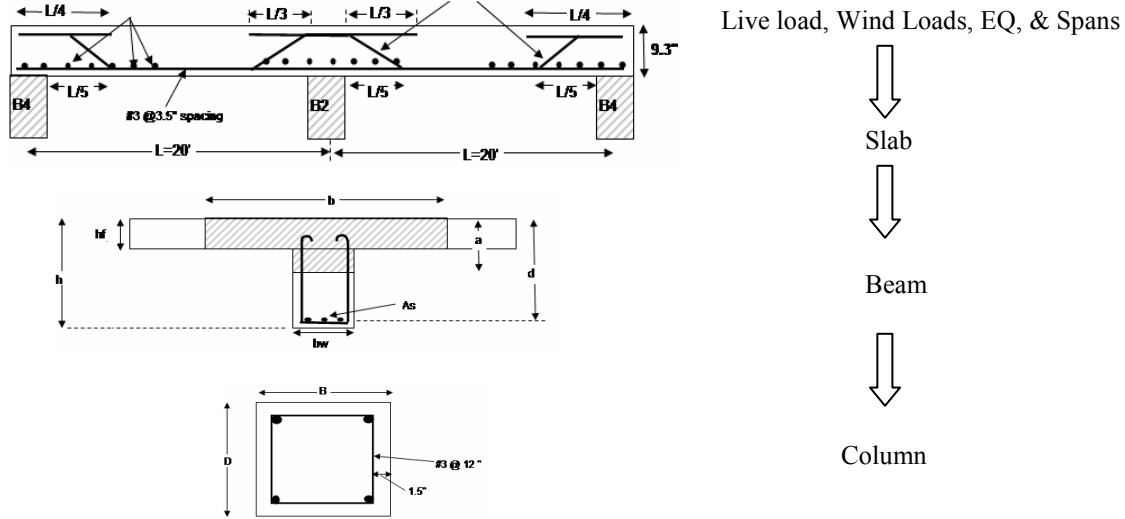


FIGURE 1 Typical reinforced concrete design parameters

The procedure results in equivalent static horizontal loads (Figure 1a) which need to be distributed on the 3 dimensional structure (Figure 1b) based on the relative rigidities of the frames. Once the earthquake forces are determined, linear elastic structural analysis is used to determine the axial forces, bending moments and shear forces on the structure. The P-Delta effects are taken into account by determining the 1st order amplified moments as per IBC 2006. These moments are used to finalize the seismic design of the members. This procedure defines the capacity of the members.

Pressure Impulse Curves

Pressure versus impulse (P-I) curves are used to represent estimated damage levels in components subjected to blast or shock loadings (Fig.5). The procedure and reflected blast pressure versus distance relation follow the TM 5-1300 Joint Forces military guidance. A component (column) is idealized as a single-degree-of-freedom (SDOF) bilinear oscillator per Biggs (1956) where the peak resistance is computed using a SAP2000 fiber hinge model of a fixed-fixed beam-column. The fiber model allows tracking of damage states in the concrete and rebar at points defined on the section (Fig.3a). Four critical damage states corresponding to first tensile cracking of concrete (A), first cracking of outer confined concrete (B), yielding of tensile steel (C), and plastic plateau of steel and rupture of confined tensile concrete (D) have been used to categorize the damage in the columns (Fig.3b). The corresponding displacements at mid column height are used to determine the damage.

The idealized force deflection is chosen such that the area under the curve equals the area under the curve computed by using the fiber model (Fig.4). Peak response is obtained by nonlinear time history analysis (NTHA) of the SDOF system using the implicit generalized Newmark method of time integration in Matlab. A family of P-I curves is obtained by repeating NTHA over a wide range of loads idealized as a triangular impulse and the maximum displacement (y_{max}) is associated with a physically-based damage level: 1) first significant stiffness change 2) peak resistance, and 3) first major post-peak strength degradation (not

collapse). P-I parameters are normalized as follows: $I^* = \frac{I}{R_m \cdot T_0}$ $\mu = \frac{y}{y_0}$ where p_r p_o R_m T_0 y_0 are, respectively, pressure on the exposed column face, peak resistance for the minimum steel ratio case, natural period of SDOF oscillator, and effective yield displacement for SDOF oscillator.

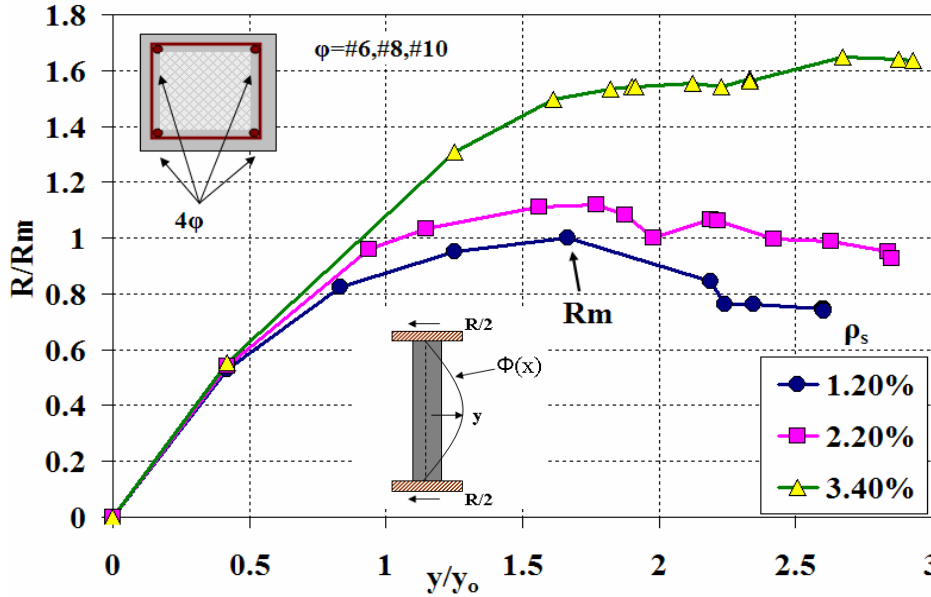
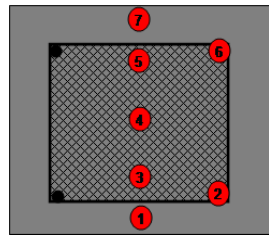
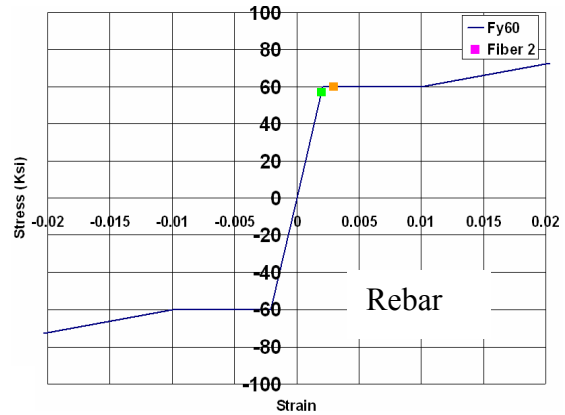
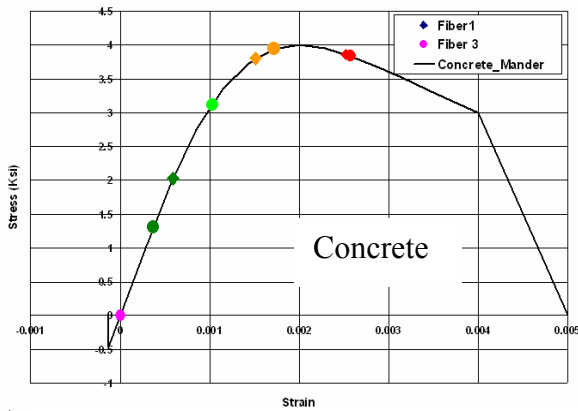


FIGURE 2 Normalized force deflection curves for column (type 1) with various reinforcements



(a)

- (1)- Compression side extreme concrete fiber
- (2)- Compression side extreme steel fiber
- (3)- Compression side Outer confined concrete fiber
- (4)- Inner confined concrete fiber
- (5)- Tension side Outer confined concrete
- (6)- Tension side extreme steel fiber
- (7)- Tension side extreme concrete fiber



(b)

FIGURE 3 Fiber locations used for tracking damage states (a) and points corresponding to the fiber damage states on the material stress-strain curves (b)

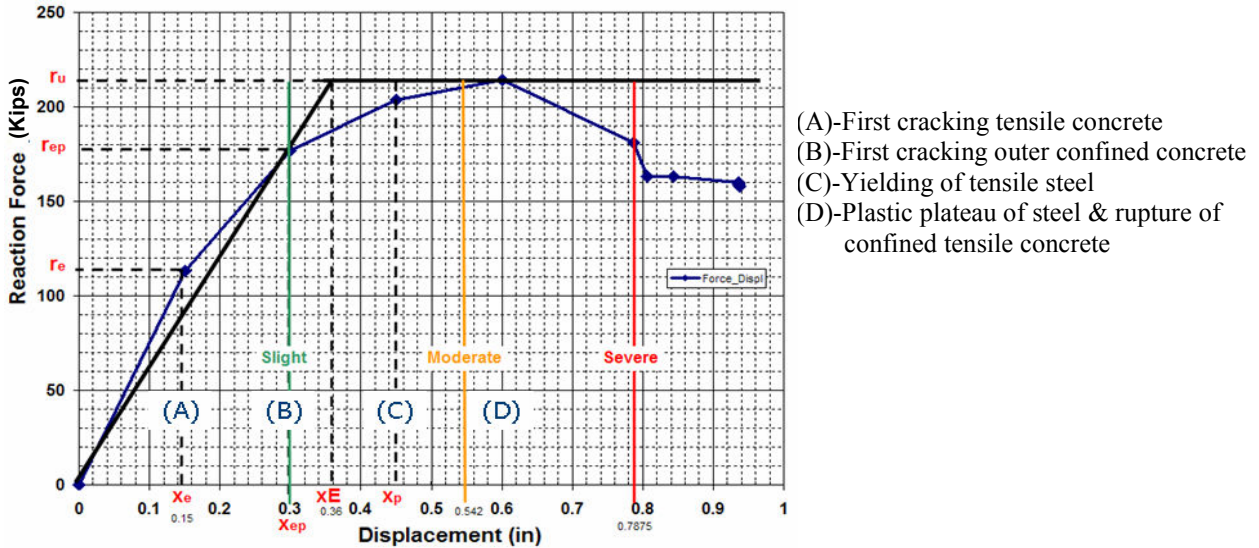


FIGURE 4 Tracking damage at section level

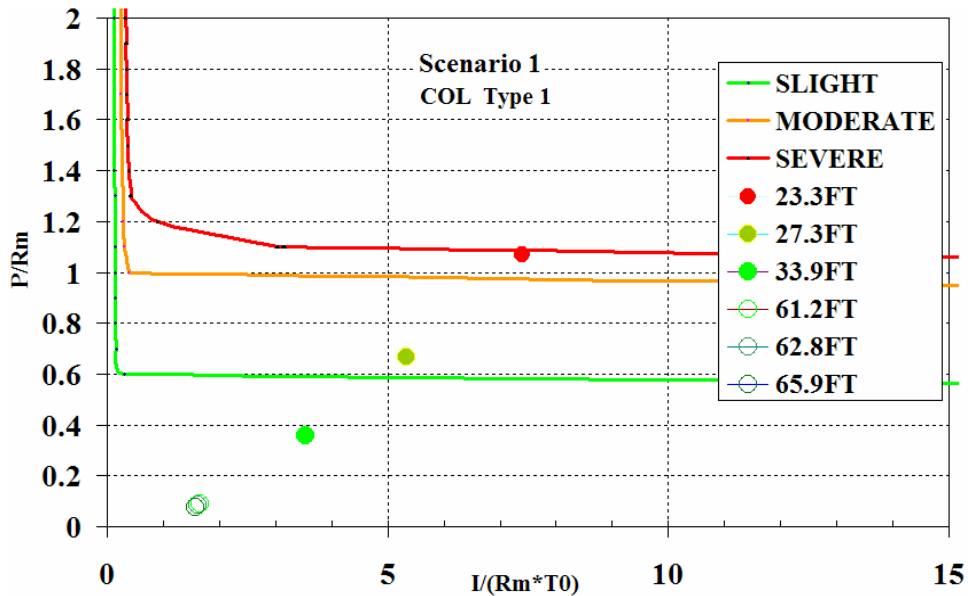


FIGURE 5 Pressure-impulse curves for column (type 1) with 1.2% reinforcement

Blast Damage Mapping

An explosion yield of 100 lb (TNT) corresponding to a portable device is selected. For this yield, an offset of 20ft from the nearest columns is selected. The blast pressure applied to the columns is computed based on the radial distance from the point of explosion to the middle of each column. The damage (slight, moderate or severe) corresponding to the peak pressure and impulse is determined from the P-I curves. An initial displacement corresponding to the damage level is determined from the force deflection curve (Fig.4) and assigned to the columns. This creates strain levels in the columns corresponding to the damage. The fiber model computes the tangent modulus corresponding to the damage state from the stress-strain curves. Thus the reduction in column capacities after the blast is computed and mapped onto the 3D finite element model.

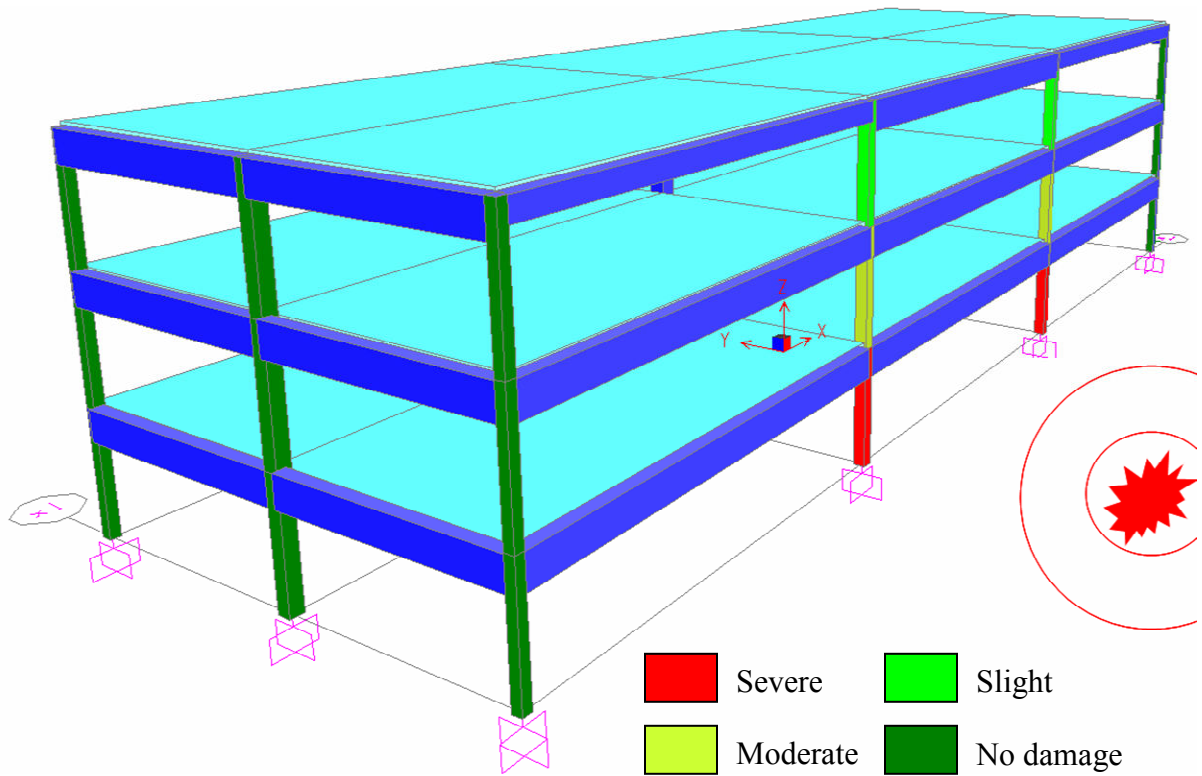


FIGURE 6 Mapping of damage states corresponding to scenario 1 from P-I curves

Collapse Analysis

The collapse resistance of the damaged structure was analyzed by removal of the severely damaged columns along the long axis of the building and studying the nonlinear static response of the structure. It is observed that the tie forces in the columns above the damaged zone do not exceed the tensile axial capacity of the columns. The slab which is monolithic with the beams also contributes considerably to the stiffness. Thus the upper story columns and the slab provide a path for redistribution of forces into the adjacent bays.

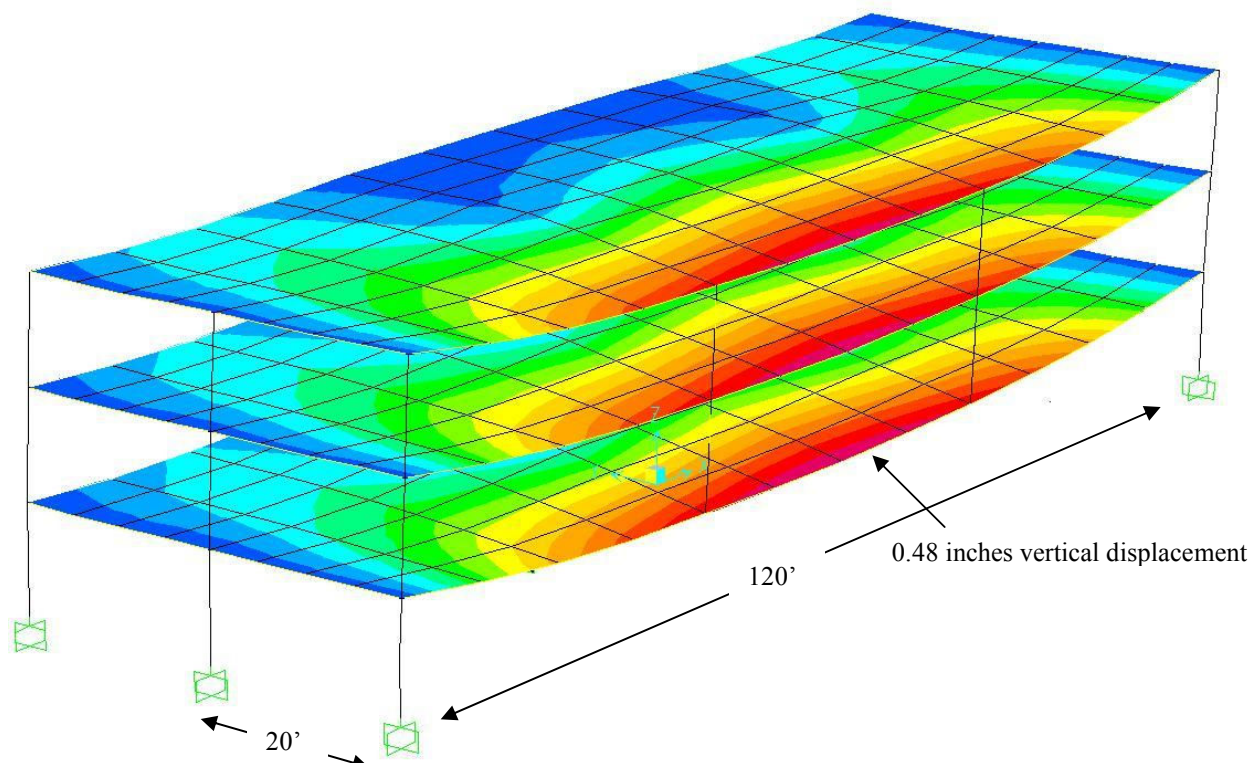


FIGURE 7 Contour of vertical displacements of 3 story buildings due to loss of external columns

Conclusions

P-I curves provide a rapid method of mapping damage due to blast loadings. The fiber model allows precise tracking of damage states in the sections. Low rise RC frame buildings are less prone to collapse since the tie forces do not exceed the joint and capacities vertical members (columns) above the damaged zone.

Acknowledgements

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