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Modeling floor systems for collapse analysis

Chen Wan, Charlie Audi, Mehrdad Sasani *

400 SN, Dept. of Civil and Environmental Engineering, Northeastern University, Boston, MA 02115, United States

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ABSTRACT

Gravity load redistribution and collapse resistance of structures following loss of load bearing elements due to natural and manmade hazards significantly depend on the floor response. Effects of floor system modeling on collapse resistance of damaged structures are studied in this paper. In particular, axial and flexural constraints imposed by the floor slab on joists and beams of RC structures is evaluated and characterized. The axial constraint imposed by the slab leads to additional compressive force, enhancing flexural response and in turn load carrying capacity of beams and joists. The flexural constraint can be captured by proper modeling approaches and can help improve the response of floor joists and beams. It is shown that the method by which the floor system is modeled has considerable effects on the floor response following loss of load bearing elements. The effects of modeling techniques on the structural response are also evaluated from an energy point of view. The effects of flexural-axial, as well as torsional cracking of the floor slab are evaluated and characterized.

1. Introduction

Progressive collapse is defined as the spread of an initial local failure from element to element, eventually resulting in collapse of the entire structure, or a portion of the structure disproportionate to the initial damage [3]. Allen and Schriever [2] defined progressive collapse as a situation where local failure of a primary structural component(s) leads to the collapse of adjoining members which in turn leads to additional collapse. Thus, the extent of collapse is disproportionate to the initial damage. One approach often used to evaluate collapse resistance and integrity of structures (direct design, [3]) is to suddenly remove a column of the structure and study the building response. This study utilizes the aforementioned approach.

Compressive membrane action (particularly in slabs), also known as arch action, has been studied by several researchers [15,7,5,9,14]. Park [9] and Park and Gamble [10] proposed different formulations to capture arch action. Bazan [4] and Sasani and Kropelnicki [12] have demonstrated this action can be captured through Bernoulli beam theory, making its utilization more effective. That is, in order to account for arch action, the special formulations mentioned above would not be needed and the same beam theory used to model axial-flexural interaction of beam elements can capture arch action as well. The compressive membrane action develops as a result of constrained tendency of RC beams to grow in length as their sections crack and yield in flexure [12]. The constraint is primarily provided by the floor system, which leads to the development of axial compressive force in beams as they deform following structural damage. In this paper, the effects of modeling floor systems on such response is evaluated. In particular, the effects of relative elevation of the slab with respect to the beam centerline is studied.

Sagiroglu and Sasani [11] studied the effects of including the elevation difference between the center lines of beams and floor slabs in analytical modeling. It was reported axial compressive force and flexural resistance increased at the supports of beams bridging over the lost columns. Kazemi and Sasani [6] studied a structure with deep beams and observed similar effects. The main objective of this paper is to identify and characterize the underlying effects of the slab elevation (with respect to beam and joist centerlines) on building response in damaged reinforced concrete (RC) structures. The response of two finite element modeling techniques that simulate progressive collapse resistance of two RC frame structures following initial local failure is evaluated. In model A, the floor is modeled conventionally, i.e. all structural nodes are in the same plane. In model B (with raised slab), however, using rigid elements, the vertical elevation of the slab is increased, such that the slab is placed at its actual height relative to the beams and joists. Behavior of each model following sudden loss of an exterior first floor column is evaluated.

* Corresponding author.
E-mail address: sasani@neu.edu (M. Sasani).

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2. Characteristics of structures

Each structure is a seven-story building designed as an ordinary moment frame structure with a longitudinal span of 26′ (7.93 m) and transverse span of 30′ (9.14 m). The height of the first floor is 12′–8″ (3.86 m) and that of floors above is 11′–6″ (3.51 m). A floor live load of 50 lb/ft^2 (2.39 kN/m^2) and 100 lb/ft (1.46 kN/m) wall weight on spandrel beams are applied. Note the floor dead load of each building is different because they are dependent on the dimensions of floor system elements. Each building is assumed to be located at a site class C with a 1-s spectral acceleration of 0.1 g and seismic response coefficient of 0.0534 for ordinary frame structures [3]. The concrete is assumed to have a nominal compressive strength of 5 ksi (34 MPa) and unit weight of 150 lb/ft^3 (24 kN/m^3). The reinforcing steel bars have a yield strength of 60 ksi (413 MPa) and modulus of elasticity of 29,000 ksi (20 × 10^5 MPa).

The floor is a one-way joist system in the transverse direction and has a 4 in. (102 mm) thick slab. Fig. 1 shows the building floor plan where sizes of the beam, column, and joist sections are given. Element dimensions are kept the same over the height of the structure. However, the reinforcement details change 3 times over the height of the structure. A floor dead load (excluding beam and column weights) of 100 lb/ft^2 (4.78 kN/m^2) is considered. In the design of spandrel beams and joists, ACI 318 [1] integrity requirements are satisfied. Fig. 2(a) and (b) shows the longitudinal reinforcement in the spandrel beams and joists at the 2nd floor. The reinforcement of the 4 in. (102 mm) thick slab is #3@12 in (D10@305 mm).

The main structural integrity requirements include: (1) for spandrel beams, at least 1/6th of top bars required for negative moment at support, but not less than two bars and at least 1/4th of bottom reinforcement to be continuous; and (2) for joists require to have at least one bottom bar to be continuous or spliced

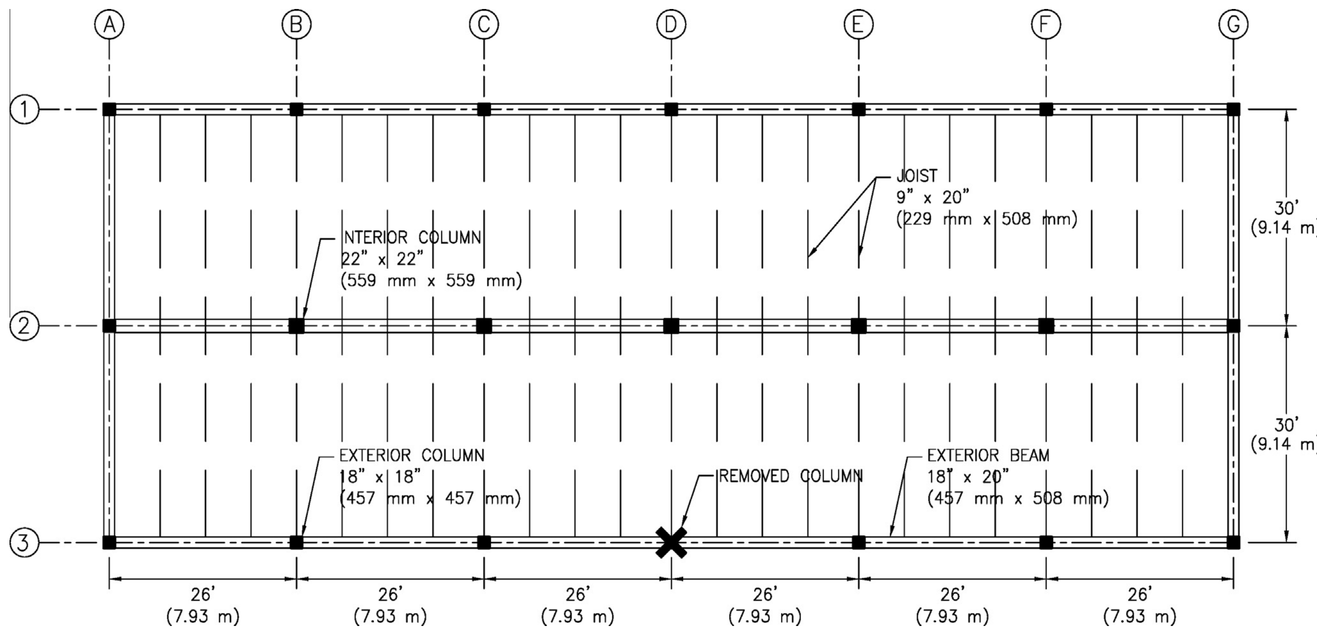

Fig. 1. Typical floor plan for joist floor system.

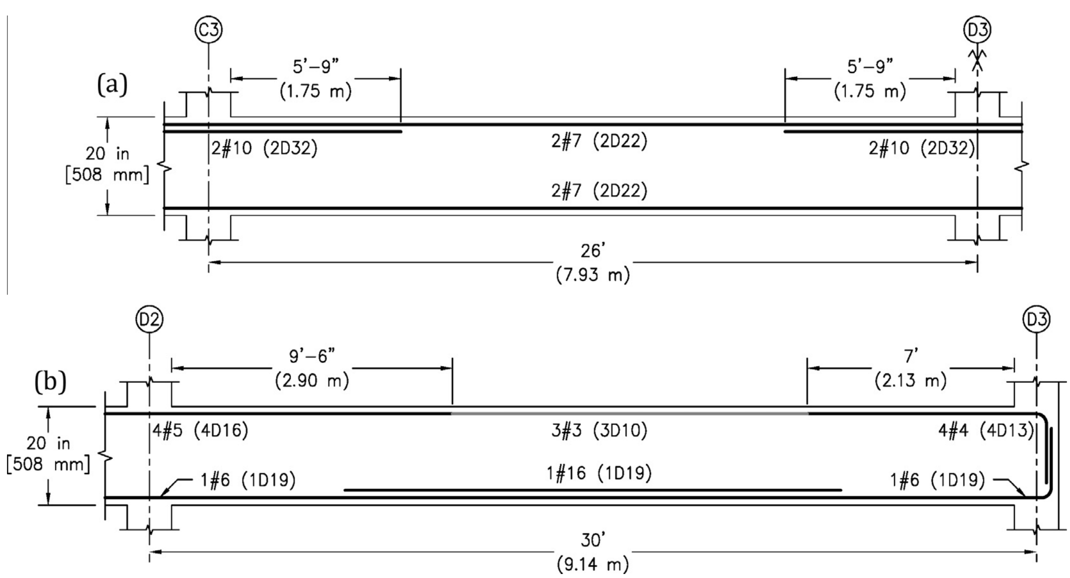

Fig. 2. Reinforcement detail of (a) second floor longitudinal spandrel beam and (b) joist (NTS).