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Nonlinear Behavior of Flat Slabs with Openings in Column Strip

BY

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STATEMENT

This thesis is submitted to Ain Shams University, Cairo, Egypt, on April 2017 for the degree of Master of Science in Civil Engineering (Structural).

The work included in this thesis was carried out by the author in the Department of Civil Engineering (Structural Division), Ain Shams University, from April 2013 to April 2017.

No part of this thesis has been submitted for a degree or qualification at any other University or Institute.

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Abstract

In the last few decades, greater effort has been given to explicitly evaluate how reinforced concrete buildings are likely to perform during earthquakes. As being one of the special reinforced concrete structural forms flat slabs-columns systems, it needs further attention about its adequacy to resist the earthquake, especially if constructed with large opening in the columns strip.

This study presents through three-dimensional simulations, a nonlinear static analysis to assess the seismic performance of this kind of buildings. The target buildings are assumed to be located in Cairo and designed according to Egyptian code seismic standards. The nonlinear static pushover analysis is performed following the Applied Technology Council procedures (ATC) in assessing the performance of these buildings under moderate earthquake motion.

The results of the study conclude that at the performance point, the point at which the demand made on the structure by seismic load is exactly equal to the capacity of the structure; the performance of the structure is assessed by the structure state at this point and this can be achieve by studying the plastic hinges status that formed at different locations in the structure when the structure reaches its performance point. It is observed that hinges form beyond Collapse Prevention (CP) is zero and hinges were in Life Safety to Collapse Prevention range (LS-CP), overall performance of the studied buildings acts like life safety to collapse prevention and in this event, significant yielding occurred in the slabs-columns connections of the lower stories causing decrease in the structure rigidity and original strength. However before collapse would occur, a substantial margin remains for additional lateral deformation. The structure should be possible to repair; however, for economic reasons this may not be practical. According to ATC categories, these buildings perform well under seismic loads and it is capable of sustaining moderate earthquake if properly designed according to the Egyptian code seismic standards.

NOTATIONS

W_u	Factored load per unit area
Vg	Direct shear force due to gravity load only
α	Effective width factor
β	Factor representing cracking effects (0.33 to 0.5)
l_e	Elastic effective beam width,
β	Stiffness reduction factor due to cracking,
ξ	Time - dependent factor
Lsup	Superimposed Load
Lsus	Sustained Load
∑ Kc	Refers to the sum the flexural stiffness of the columns above and below the slab
Ic	Moment of inertia of the columns
Θt, avg	A rotation for a unit moment
Kt	The torsional stiffness
C	Modulus of rigidity
E	Modulus of elasticity of concrete
b_w	The span between two supports in the direction being considered
b_0	The perimeter along the critical section
f_c	Concrete compressive strength
v_u	The factored shear stress
φ	The stress reduction factor for shear
V_n	The nominal shear stress
V_u	The factored shear force acting at the centroid of the critical section
M_u	The factored unbalanced bending moment
J	Property of the critical section analogues to the polar moment of inertia
v_c	The nominal shear stress resistance
VR	The shear ratio
α_1	Mass coefficient factor
PF1	Participation factor
φi	Roof level amplitude
λ	Factor (it also called K-factor in ATC-40) (See table 3-1 and figure 3-1)
βo	Hysteretic damping
ED	Energy dissipated
Eso	Maximum strain energy

TABLE OF CONTENTS

Chapter 4: Results and Discussions

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1

INTRODUCTION

1.1 General

Nowadays, flat slabs-columns buildings have become widespread in Egypt and the presence of diaphragm opening in these buildings are often unavoidable; it's frequently required to provide accessibility such as elevators, stairs and air condition ducts. Usually, in Egypt, the designers are using the linear-elastic method during the design process for these types of buildings following the Egyptian code seismic standards but this method cannot give clear vision about the seismic adequacy for these buildings. Thus in the last few decades, the structural engineer community moved away from simplified linear elastic methods and start using a nonlinear technique such as pushover analysis and nonlinear dynamic methods in assessing buildings damage vulnerability.

This study presents through three-dimensional simulations, pushover analysis to assess seismic performance of flat slab-columns buildings with/without diaphragm opening. ETABS program is used for implementing buildings models and performing the inelastic static analysis. The nonlinear static pushover analysis is performed following the applied technology council procedures ATC-40 in assessing the performance of these buildings under moderate earthquake.

In this research, six buildings with common configurations and with different parametric studies were investigated. The target buildings are assumed to be located in Cairo and designed according to Egyptian code seismic standards as a flat slab-columns system. Buildings used in the study are a four-story and eight-story flat slab buildings representing low and medium-rise flat slab buildings that can be constructed without shear walls.

1.2 Objective of the study

1. Studying the nonlinear behavior for flat slab-columns buildings with/without large diaphragm opening which designed according to the Egyptian seismic standards.
2. Assess the performance of this type of buildings under earthquake motions following the applied technology council procedures ATC-40.

1.3 Thesis scope

This thesis consists of five chapters, which are briefly outlined as follows:

Chapter (1): Presents the introduction and the objective of this study,

Chapter (2): Presents the available previous literature related to this study,

Chapter (3): Presents pushover technique, the evaluation procedures, geometry and design of the studied buildings and also present the method that used for the nonlinear modeling,

Chapter (4): Presents the nonlinear analyses results, the evaluation according to the applied technology council procedures ATC-40 and the discussions,

Chapter (5): Presents the important conclusions and the future works. Finally, a list of references is given.

CHAPTER-2

LITERATURE REVIEW

2.1 General

The flat slab structure consists of a solid beamless slab with uniform thickness supported on the columns. The easy of construction and economy of flat slab buildings lead to its widespread throughout the world. The flat-slab structure is generally used for lightly loaded structures such as apartments, hotels, and office. Buildings with long spans or heavier loads, the designer use column head or drop panels to decrease punching shear stresses.

2.2 Flat slab design under gravity loading

Flat slabs can be designed by any procedure that satisfies the required strength and serviceability conditions. Generally, some of the methods employed for the design are;

a. Direct design method,
b. Equivalent frame method,
c. The yield-line method,
d. The finite element method.

ACI [4], BS [7] and EC [9] indicate that if the columns are located on straight lines with a difference not more than 10%, the designer can use the empirical method or the equivalent frame method. The strip method and equivalent frame method are the most common methods for calculating flexure in the flat slab. The equivalent frame method means that, the structure is considered to be divided into frames while the strip method means that the slab panels must be divided into column and field strips.