Engineering Structures 130 (2017) 83–98

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Simplified reliability analysis of punching in reinforced concrete flat slab buildings under accidental actions

P. Olmati [a,1], J. Sagaseta [b,*], D. Cormie [c], A.E.K. Jones [c]

[a] University of Surrey, UK[2]
[b] Department of Civil and Environmental Engineering, University of Surrey, Guildford GU2 7XH, UK
[c] Arup, London W1T 4BQ, UK

ARTICLE INFO

Article history:
Received 13 January 2016
Revised 10 June 2016
Accepted 27 September 2016
Available online 17 October 2016

Keywords:
Punching
Flat slabs
Reliability analysis
Progressive collapse
Dynamic amplification factor
Finite element analysis
Column failure
Floor impact
Explosion load

ABSTRACT

Flat slab concrete buildings are widely found in infrastructure such as office and residential buildings or industrial facilities. The susceptibility of progressive collapse of such structures due to accidental loads is highly dependent on the structural performance of the slab-column connections. This paper presents a framework for a simplified reliability analysis and derivation of safety factors for computing the probability of punching of flat slab concrete buildings subjected to accidental loads such as column removal, slab falling from above or blast load. The main advantage of the proposed approach is that it considers in a simple manner, the uncertainty in the gravity load applied in the slab before the accidental event, which affects the inertial effects and demand/capacity ratio in the slab-column connections. Eurocode 2 and the Critical Shear Crack Theory for punching are used and extended to dynamic cases for the assessment of the demand/capacity ratio using computer-based time history finite element simulations. The proposed reliability method is applied to a case study of an existing building showing that the column removal situation is not always critical whereas the slab falling from above is much more detrimental.
Crown Copyright © 2016 Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

1.1. Progressive collapse of flat slab buildings

Concrete flat slab structures is a common form of structural reinforced concrete (RC) construction in buildings, especially in medium-rise offices due to their efficient span/depth ratios and the economies gained by reducing the storey heights. A governing aspect in the design of RC flat slabs is the detailing of the slab-column connections in order to provide sufficient deformation and punching shear capacity of the slab at the connection. Structural failures of flat slab buildings due to punching have been reported in the past in America, Asia and Europe; some examples are the Skyline Plaza Complex collapse in Virginia (1973), the Harbour Cay building in Florida (1981), the Sampoong Department Store collapse in South Korea (1995) and the Gretzenbach underground parking garage collapse in Switzerland (2004). The reasons behind these failures include deficiencies in design, errors during execution and unforeseen actions; some of the causes mentioned are not unique to flat slab construction.

The main concern with flat slabs is that unless special measures are adopted, the shear capacity at the column-slab connection is low after punching failure which can contribute to a horizontal propagation of failure and subsequently the slab can fall onto the next lower floor [1]. Moreover, the propagation of failure (horizontally and vertically) is influenced by dynamic effects which can significantly increase the shear demand in the slab-column connections. As pointed out by Vlassis et al. [2], modelling the connection behaviour accurately is critical towards providing alternative load paths and achieving continuity and ductility in the structure.

1.2. Design considerations

Commercial and residential buildings are generally not designed to withstand extreme loads since the occurrence of such extreme events does not concern the life-cycle of the building due to the low probability of occurrence. However, exceptional loads due to extreme events could lead to severe consequences in terms of structural integrity and socio-economic impact on the community [3]. The term "disproportionate collapse" is often used to refer

* Corresponding author at: Faculty of Engineering and Physical Sciences, Civil Engineering C5, Guildford, Surrey GU2 7XH, UK.
E-mail address: j.sagaseta@surrey.ac.uk (J. Sagaseta).
[1] Current address: Tokyo Polytechnic University, Kanagawa, Japan.
[2] Formerly postdoc.

http://dx.doi.org/10.1016/j.engstruct.2016.09.061
0141-0296/Crown Copyright © 2016 Published by Elsevier Ltd.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

to the disproportion between the scale of the event and the severity of the consequences, although this term is subjective and it has several definitions [4]. Extreme events can be caused by natural hazards (hurricanes, tsunamis, flooding, earthquakes), accidents (vehicle impact, event during construction, industrial accident and unexpected local failure due to fire or poor design) and malicious actions (terrorist attack).

The perception from the general public and stakeholders of the risk of having disproportional collapse of buildings has increased significantly over the last two decades [5] and therefore robustness (insensitivity of the structure to local failure) must be verified in practice according to most designing codes (e.g. CEN [6]; DoD [7]; GSA [8]); guidelines are also available for example Ellingwood et al. [9], FEMA [10] or HSE [11]. In order to design against progressive collapse, prescriptive rules (indirect approaches) have been available since soon after the Ronan Point failure in 1968. Direct approaches are becoming more easily accessible to designers although the behaviour of buildings subjected to exceptional loads is still an under-researched area in structural engineering [12]. The alternate load path method as described in DoD [7] is widely used in practice to design buildings to withstand accidental loads. However, the applicability of this approach depends on the form of construction used affecting the behaviour of the connections, alternative load path mechanisms and energy dissipation of the system.

1.3. Literature review and research significance

Different progressive collapse analyses have been suggested in the past for steel frame buildings covering column removal and falling debris cases (e.g. Vlassis et al. [2]; Szyniszewski and Krauthammer [13]). Similarly, research on RC structures has been carried out predominately looking at beam-column frame structures [14,15] under column removal and impact scenarios. Beam-column-slab concrete buildings were also investigated numerically and experimentally by Helmy et al. [16] showing that the slab needs to be considered in the analysis to obtain accurate results.

Research on progressive collapse of flat slab buildings (without beams) is rather limited (e.g. Mitchell and Cook [17]; Utagawa et al. [18]; Qian and Bing [19]; Liu et al. [20,21]). Flat slabs provide enhanced structural continuity compared to frame structures. Moreover, the slabs are effective in providing alternative load paths due to the two-way bending and membrane actions [17,22–24]. However, flat slabs are prone to punching which is a brittle type of failure that should be controlled to arrest the progressive collapse of the structure. Relevant studies of the residual shear strength of the connection after failure (post-punching behaviour) were carried out by Melo and Regan [25] and Fernández Ruiz et al. [26] amongst others. The residual strength of the slab-column connection can vary between 25% and 50% [1] and the results are influenced by many factors such as anchorage or the presence of integrity reinforcement in the compressive zone.

The progressive collapse of flat slab buildings is highly influenced by the inertial effects of the slab. This paper presents a simple reliability approach for flat slab buildings which takes into account the inertial effects and considers the uncertainty in the gravity load applied in the slab and the dynamic response of the slab-column connection. The proposed approach requires computer-based dynamic structural analyses (time history analysis for punching) to estimate the variation of punching demand and capacity at the connections. The punching capacity is estimated based on EN 1992 [27] and the Critical Shear Crack Theory (CSCT) by Muttoni [28] and Fernández Ruiz and Muttoni [29], with special considerations for dynamic loading (see Section 2). Three extreme events are investigated in a case study, viz. column removal, falling slab from above and blast load. The proposed approach focuses on the prediction of failure of the connections during extreme events. The analysis of the propagation of the collapse is outside the scope of this paper; in such cases, system-based analyses are generally required considering the mechanisms that develop before and after punching (e.g. [20,21,24]).

2. Punching shear time history analysis

In this work, time history analyses are carried out for the assessment of punching shear in flat slab buildings subjected to different damage scenarios. In these analyses, the punching shear demand around the column is calculated numerically by means of finite element (FE) models (non-linear dynamic). Both punching shear demand and capacity are estimated at different time steps using design formulae for punching in EN 1992 [27] and the CSCT [28] which is the basis of the Model Code 2010 formulae for punching [30]. The main difference between the two approaches in dynamic situations is that the former assumes that the capacity is constant with time whereas the latter assumes that the capacity is a function of the slab rotation outside the column region $\psi(t)$ which varies with time. In both approaches, the punching shear demand $V_D(t)$ varies with time due to variations in the axial forces and moments developed in the columns and slab during the forced and free vibration phases.

2.1. Dynamic punching shear demand

Local damage in flat slab buildings can result in an increase in the moment transfer in the column-slab connections (increase in eccentricity of the reaction at the column). An increase in moment transfer will result in a higher concentration of shear forces in certain segments of the control perimeter adopted in the punching shear calculations which in turn results in a higher shear demand. This is taken into account in EN 1992 [27] by means of the eccentricity coefficient $\beta(t)$ given by Eqs. (1) and (2) for internal and edge/corner columns respectively.

$$\beta(t) = 1 + 1.8\sqrt{\left(\frac{e_y(t)}{b_x}\right)^2 + \left(\frac{e_x(t)}{b_y}\right)^2} \tag{1}$$

$$\beta(t) = \frac{u}{u_{red}} + k_a \frac{u}{W_1} e_{par}(t) \tag{2}$$

where u is the basic control perimeter defined in EN 1992 [27] at a distance $2d$ from the column face, $e_x(t)$ and $e_y(t)$ are the eccentricities in the two orthogonal directions of the slab, b_x and b_y are the dimensions of the control perimeter corresponding to each direction. Eq. (2) is for edge columns and it is reduced to its first term in case of corner columns; u_{red} is the reduced control perimeter according to geometric conditions given in [27], k_a and W_1 are coefficients which depend on the dimensions of the column and of the effective depth of the slab, and $e_{par}(t)$ is the eccentricity with respect to the bending of the slab along the edge. The punching shear stress demand $v_D(t)$ according to EN 1992 [27] is given by Eq. (3).

$$v_D(t) = \beta(t)\frac{V_D(t)}{ud} \tag{3}$$

In the CSCT, the eccentricity effect is taken into account similarly using a reduction factor $k_e(t)$ given by Eq. (4) which multiples the basic control perimeter b_0 to calculate the punching shear stress in Eq. (5). The basic control perimeter b_0 in the CSCT is taken at a distance equal to $0.5d$ from the column face.

$$k_e(t) = \frac{1}{1 + e_u(t)/b_u} \tag{4}$$

Download English Version:

https://daneshyari.com/en/article/4920554

Download Persian Version:

https://daneshyari.com/article/4920554

Daneshyari.com