An approximate resizing system for the preliminary design of reinforced concrete frames

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Abstract Techniques for the preliminary design of a multi-storey-multibay, moment-resisting reinforced concrete frames are investigated. Two-level optimization patterns are constructed in this paper. The objective function at the system level is to minimize the total volume of reinforcing steel. The relationship between the area of longitudinal reinforcement and the fully plastic moments of cross-sections will be approximated by a quadratic expression. Once the optimum plastic moments result at the system level, and the member sizes and reinforcement at critical sections within the span of each member will be selected at component level to complete the automatic resizing system. Two examples of reinforced concrete frames are presented to illustrate the features of the proposed method.

1 Introduction

The central purpose of structural analysis is to predict the behaviour of trial designs. The results of structural analysis are used to assess the adequacy and relative merits of alternative trial designs with respect to established design criteria. Historically, the desire to reduce structural weight without unduly compromising structural integrity has been a strong driving force behind the development of structural optimization methods. Someday, the possibility of building large structures in space may place a new and challenging set of demands on our ability to analyse and design structural systems (Hagler 1976).

Since the process of designing a reinforced concrete frame in civil engineering basically is a trial and error operation. Most engineers dedicate themselves to explore a design method for solving reinforced concrete frames quickly. Numerical optimization techniques is a method that can achieve this problem effectively.

At many practical optimum design instances of reinforced concrete frames, designers focus on the optimization of cross-sectional dimensions and reinforcing steel of structural members (Brown 1975; Cohn and Macrè 1984; Erbatur et al. 1992). The study of an entire structure has not appeared frequently, since such a study must consider the theory of structural mechanics and the method of optimum design at the same time. A design tool that can deal with the entire structural analysis and seek optimum solutions with an optimum design method simultaneously is still the emphasis of study of designers. Recent studies of optimum design of reinforced concrete frames have been investigated by Gerlein and Beaufait (1980), Erbatur and Alhussainy (1992), Dinno and Mekha (1993), etc., and deal only with the optimum strength design rather than detailed cross-sectional sizes of members. Another type of optimization problem concerns the optimum design of the dimensions of reinforced concrete members (Surahman and Rojiani 1983; Moharrami and Grierson 1993). However, it does not consider the structural analysis of reinforced concrete frames. According to the above explanations, a computer program is developed here for the optimum preliminary design of a multistorey-multibay reinforced concrete frame. In this paper, both the optimum strength arrangements and the optimum design of the sizes and reinforcing steel of each reinforced concrete member are constructed.

Two-level optimization patterns are performed in this paper. At the system level the optimum strength arrangements are considered. The shape and geometry of the structure and the layout of the longitudinal reinforcement are given and the areas of reinforcement are design variables. The objective function is the minimum requirement of longitudinal reinforcement under the strong column and weak beam criterion. A dual quadratic programming problem is used to obtain a minimum amount of reinforcing steel. The relationship between the area of longitudinal reinforcement and the fully plastic moments of cross-sections will be approximated by a quadratic expression. Once the optimum plastic moments result at the system level, the member sizes and reinforcement at critical sections within the span of each member will be selected at the component level to complete the automatic resizing system. Two examples of reinforced concrete frames are presented to illustrate the features of the proposed method.

2 Problem formulation at system level

At the system level of present work, the structural analysis is based on the plastic hinge theory and a strong column-weak beam design criterion of general reinforced concrete frames. The following assumptions of system-level optimization are utilized to simplify the course of designing a reinforced concrete frame.

- A plastic hinge can be developed in a reinforced concrete member and the plastic moment capacity is equal to the ultimate moment capacity (Mattock et al. 1961).
• The $P$-$\Delta$ effects of the frame and the effects of axial deformation of all columns are neglected.

• The floor loads are uniformly allocated over the entire span of a beam and lateral loads are concentrated at the floor levels.

• The inflection point of each column is at midheight of the corresponding storey.

• The reinforcement at the ends of the beams framing a column are equal.

• The moment capacity within the span of each beam is positive.

2.1 Constraint equations

A multistorey-multibay reinforced concrete frame is the main object of interest in this paper. The structure can be broken down into a series of subassemblies. A typical subassemblage that consists of the floor beam of a given storey and the columns that connect with the beam is shown in Fig. 1. Here $w_i$ is the gravity load, $L_i$ is the clear span, $V_i$ is the lateral load for span $i$ and $\sum V_a$ is the effective storey shear of the floor above the subassemblage being studied; $h_t$ and $h_b$ are the height of columns above and below the floor beam, respectively. According to the aforementioned assumptions, the possible moment capacities of the $i$-th span are shown in Fig. 2. The moments causing tension in the top fiber of the beam are displayed above the beam and the moments causing tension in the bottom are identified below the beam.

\[ \sum V_a \]

![Fig. 1. A typical subassemblage of a given storey](image)

For each subassemblage, a series of collapse mechanisms can be identified. This includes the basic mechanisms (Gerlein and Beaufait 1980) of the $i$-th span shown in Fig. 3: a beam mechanism for gravity loads, a panel mechanism for lateral loads, and a combined mechanism for both lateral and gravity loads. Each span of a subassemblage may fail in one of these three modes. Because the number of possible failure mechanisms is so large, a procedure has been devised (Bas-sam and Powell 1974) where a reduced set of mechanisms are used in obtaining a design. These can be summarized as follows.

\[ W_E \leq W_I \]  

(1)

for each possible collapse mechanism. Here $W_E$ is the external work by all loads, $W_I$ the internal work done by the plastic moments. For a beam mechanism, as shown in Fig. 3a, the kinematic consideration must satisfy the form

\[ MP_{,3i-2} + 2MP_{,3i} + MP_{,3i+1} \geq w_{ui} \frac{L_i^2}{4}, \]  

(2)

in which the plastic moments are described in Fig. 2. For a panel mechanism, as depicted in Fig. 3b, the kinematic constraints are

\[ MP_{,3i-2} + MP_{,3i+2} \geq \sum V_a \left( \frac{h_t}{2} + \frac{h_b}{2} \right) + V_i \frac{h_b}{2}, \]  

(3)

when the mechanism sways to the right and

\[ MP_{,3i-2} + MP_{,3i+2} \geq \sum V_a \left( \frac{h_t}{2} + \frac{h_b}{2} \right) + V_i \frac{h_b}{2}, \]  

(4)

when the mechanism sways to the left. The kinematic constraint of a combined mechanism which identified in Fig. 3c, assuming sway to the right is

\[ 2MP_{,3i-2} + 2MP_{,3i+1} \geq w_{ui} \frac{L_i^2}{4} + \]