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Minimizing cutting wastes of reinforcing steel bars through optimizing lap splicing within reinforced concrete elements

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HIGHLIGHTS

- A mathematical model to optimise lap splicing in steel reinforcement is proposed.
- Proposed model takes advantage of flexibility in selecting location of lap splices.
- Demonstration is conducted on concrete columns and shear walls.
- Case study indicates significant reductions in the amount of cutting waste.

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ABSTRACT

A major waste stream in construction of concrete structures is the steel reinforcement waste generated during cutting of steel rebar to their final required lengths. The amount of steel waste generated during the cutting process can be affected considerably by the cutting patterns specified to steel providers after structural design of reinforced concrete elements. This paper proposes a novel approach for minimizing the cutting waste from reinforcing bars by taking advantage of a slight flexibility in selecting the location of lap splices of reinforcing bars within reinforced concrete members as specified by design codes. The focus is placed on identifying the lap splicing patterns for steel reinforcement used in concrete columns and shear walls. A framework to implement the proposed approach is presented and applied to a case study involving the construction of columns and shear walls for an actual 6 storey building. The estimated waste produced after adoption of optimal lap splicing patterns obtained using the allowable flexibility for the lap splices location is compared with the waste generated when cutting patterns are optimized based on fixed lengths, with no flexibility, according to conventional cutting waste minimization methods. The results show a decrease of 50.7% and 55.7% in terms of steel waste generated, and a reduction of 7.7% and 11.8% in steel reinforcement consumption for columns and shear walls, respectively, due to optimizing the lap splicing patterns by the framework.

1. Introduction

Minimizing the material waste generated during construction is one of the major objectives of sustainable construction, given the associated economic and environmental benefits that can result [1]. Examples of economic benefits include reductions in material procurement and waste management costs, while environmental benefits include the reduced need for natural resources and a reduction in the carbon emissions and energy use associated with waste processing [2,3,20]. A major material waste stream in construction of concrete structures is related to the reinforcing steel bars embedded within the structural elements, accounting for up to 5% and 8% of the total waste in public and private residential construction, respectively [4]. The common bar sizes used in structural elements such as N20, N24, etc. cannot be provided in coil and are produced in standard lengths. The reinforcing bar waste is generated mostly during the cutting of steel bars by either steel suppliers or concrete contractors, from standard lengths provided by manufacturers to required lengths requested by clients [5–7].

The amount of waste generated during cutting of steel bars can be affected considerably by the selected cutting patterns and thus

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may be minimized by selection of optimal cutting patterns. Cutting patterns are a combination of various steel bar lengths. Any change in the required lengths will directly affect cutting patterns and hence the final amount of steel waste produced [6–8]. The current practice for identifying cutting patterns in a way that waste is minimized involves manual comparison of various viable options identified based on engineer's best judgment, and is known to be both tedious and laborsome [6,7]. To overcome this challenge, a number of attempts has been made in previous studies to develop optimisation models for the rebar cutting problem. Chen and Yang developed a framework to generate an optimum rebar arrangement that minimizes cutting waste from concrete beams' reinforcement, where reinforcing bars can either be lapped or not within the beam span [6]. Furthermore, Porwal and Hewage presented a framework for integrating building information modelling (BIM) with optimization techniques to minimize trim losses at the design stage [7]. In line with this, considerable effort has been also made in terms of optimization methodology by categorizing rebar's cutting loss minimization problem as a one-dimensional cutting stock problem (1D-CSP) [9,10]. The common approaches used to solve 1D-CSP include Linear Programming (LP) [9,10], Integer Programming (IP) [11], Heuristics [12–14] and Genetic Algorithm (GA) [5].

A common assumption in the above studies is however that the required length of the reinforcing bar is given with no flexibility in terms of slight variations in the length. This assumption however overlooks the fact that design codes usually specify an allowable interval for location of the lap splice, rather than a single point [15]. The flexibility in selecting location of the lap splice within this specified range in turn leads to some degree of flexibility in terms of rebar length for structural reinforced concrete elements.

This paper proposes a novel approach to minimize the cutting waste from reinforcing bars by taking advantage of the above-mentioned flexibility in location of lap splice in the structural reinforced concrete elements. Accordingly, an optimization framework is proposed to i) identify all potential cutting patterns for the reinforcing bars required in a particular project, by considering the flexibility in location of center of lap splices and ii) identify the optimal pattern which minimizes the cutting waste. The proposed method is presented by placing the focus on steel bars used in concrete columns and shear walls as representative reinforced concrete elements for which the proposed concept is most applicable. The framework is applied to a case project involving the construction of a 6 storey building. The estimated waste produced after adoption of optimal lap splicing patterns obtained using the allowable flexibility for the lap splices location is compared with the waste generated when cutting patterns are optimized based on fixed lengths, with no flexibility, according to conventional cutting waste minimization methods.

The paper is organized as follows: in Section 2, a methodology, highlighting the main components and modules of the framework, including the optimization problem, is presented. Section 3 presents the findings from the application of the framework to a case study. Finally concluding remarks along with limitations and future work prospects are presented.

2. Methodology

The proposed framework is comprised of four main modules (Fig. 1), i.e. Data Collection, Splicing Pattern Generation, Cutting Pattern Generation and Trim Loss Optimization Module. Data Collection Module acts as a data entry interface for gathering all the required information needed to calculate the bar lengths. Splicing Pattern Generation Module identifies all the possible lap splice positions within the permitted intervals specified by design codes. Cutting Pattern Generation Module is responsible for generating all the possible cutting patterns, based on an enumeration pattern generation algorithm. An enumeration algorithm is one that solve an enumeration problem, where all feasible solutions of the problem are listed and examined [1]. Finally, Trim Loss Optimization Module incorporates a Linear Integer Programming model that

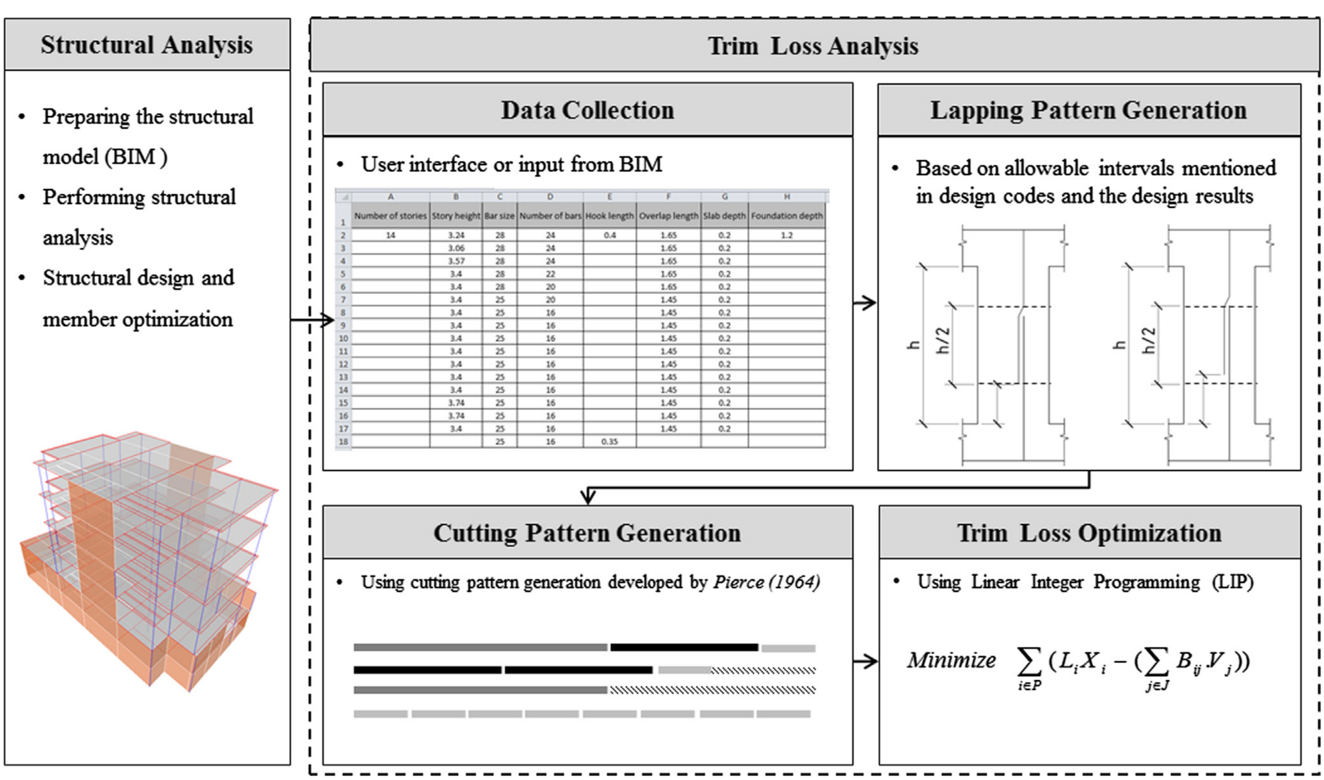

Fig. 1. Framework for trim loss optimization of concrete elements.