Optimal Design of Reinforced Concrete Frames Considering Seismic Provisions Using Genetic Algorithms with Modified Leader Reproduction

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Summary

This paper discusses the application of Genetic Algorithms (GA) in the design optimization of concrete frames that are resistant against seismic loads. The application of GA to the optimization of concrete frames is discussed. After this, the Concrete Optimization Program (COP) and its 4 main components are discussed briefly. The performance of the COP using different GA constants and improved operators were tested on a 2-storey frame. From the initial results, it can be observed that using simple GA with enhancements is insufficient to provide a practical and efficient means of optimizing a concrete frame. In light of this situation, the modified leader reproduction (MLR) was conceived to improve the overall performance of the COP. The performance of the COP with MLR was tested on both a 2-storey and 4-storey frame. From the results, it was confirmed that using MLR enhanced the efficiency and capability of the COP to yield economical and feasible results.

Keywords: Structural Optimization, Genetic Algorithms, Seismic Design, Concrete Design.

1. Introduction

The global financial crisis has hit the construction industry hard. In the Middle East, several projects dependent on foreign funding have been put on hold and others have been cancelled. In these times, companies are hesitant to invest in new facilities due to lack of funding or the prospect of a gloomy economy ahead. If ever they want to invest, they would demand to get the best value for their money. This means tighter budgets for construction and design fees. To get the best value for their money, structural optimization is needed. But this entails multiple design iterations of the structure which demands a lot of time and resources on the designer’s part. This study aims to achieve a computer program that would aid in the efficient optimization of concrete frames considering relevant seismic provisions of the National Structural Code of the Philippines (NSCP 2001).

Optimization of concrete is not an easy task, to say the least. Unlike steel, concrete does not have a database of sections. Also, the section dimensions in concrete can’t be treated as a continuous variable. Furthermore, designing concrete is not a simple case of finding the amount of reinforcement required. There are dimensional and reinforcement constraints that need to be considered. Applying these constraints to the design of multiple sections for each member would surely tax computer resources which in turn would lead to longer analysis and design times. Integrating this with an optimization algorithm would make things worse as far as computational time is concerned. Given the construction and computational constraints, can an effective and efficient optimization algorithm for concrete be practically achieved?

In this paper, it is proposed that combining an enhanced Genetic Algorithm (GA) with a database of concrete sections would achieve a practical and efficient way of optimizing concrete. The contribution of this study is to show that GA can be practically applied to the design optimization of concrete frames under seismic loading and constraints specified by the NSCP 2001.

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2. The Concrete Optimization Program

The Concrete Optimization Program (COP) is a combination of 4 sub-programs. These programs are: *(1)* Concrete Database Generator (CDG) – The program which creates the database of concrete sections with reinforcement and corresponding capacities. *(2)* FEM Analysis Program (FEMP) – The program which analyzes the structure based on the data contained in the FEM database File. *(3)* Design, Quantity and Fitness Program (DQFP) – The program which gets the design forces produced by the FEM analysis program and designs all structural members and computes the total cost. *(4)* Genetic Algorithm Program (GAP) – The program which integrates the mentioned programs and contains all GA sub-procedures and functions that were used.

3. Testing the Performance of the COP

3.1 Initial Results

The performance of the COP using different operators and constants in optimizing a 2-storey building was tested. Each combination of constants were tested on two aspects: (1) How fast can it improve the fitness of the whole population through 10 generations and (2) How near to the optimal solution are the end results given at maximum generation t=10.

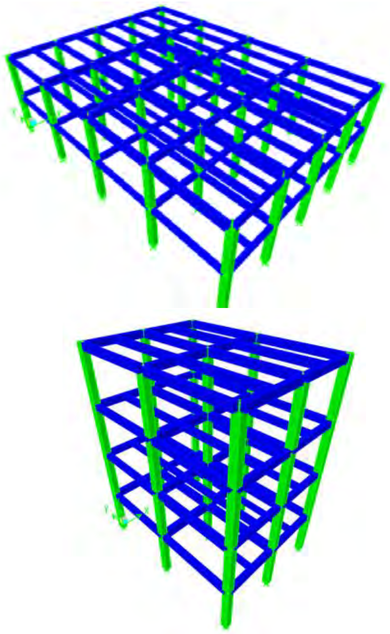

Fig. 1: 2-storey and 4-storey building optimized for the study

After each combination of constants were tested, it was found out that using low mutation rates (0.001), gray coding, a scaling multiplier of 1.5 and leader reproduction (LR) improved the performance of the COP in terms of improving the entire population. A new 25 generation run was conducted using the combination of said operators and constants. However, the sections that resulted at generation t = 25 were deemed impractical. This could be attributed to the tendency of LR to remove the diversity of the population which would eventually lead to premature convergence. To improve the resulting sections from the COP run, the modified leader reproduction was conceived by the author.

3.2 Results using Modified Leader Reproduction

In brief, MLR is a process where a "manufactured" individual/solution is inserted into the population and let its genetic material spread through the population through selection and reproduction processes. The "manufactured" individual/solution contains the minimum sections which pass the maximum forces derived from the whole population.

From the resulting sections at generation t = 20 using MLR, it was apparent that MLR outperformed LR in terms of getting the most economical sections. The MLR was also applied to a 4-storey building and it was seen that the run still gave practical results at the maximum generation.

4. Conclusions

- For any optimization tool that uses GA, low mutation rates and gray coding gives good performance.
- Due to the inefficiency of simple GA, a new type of leader reproduction called modified leader reproduction was proposed. It was found out that this feature improved the effectiveness and efficiency of the concrete optimization algorithm to acquire the optimal values.
- Based on the results of the COP, it could be said that a COP can be practically integrated to a FEM analysis program. The only caveat is the long analysis times consumed by the FEM program. Using the power of parallel computing is a possible solution to reduce analysis times.