COST OPTIMISATION OF RC BEAMS USING A META HEURISTIC TECHNIQUE

Sukhwinder Singh[1], Jagbir Singh[2]

1. GNDEC, Ludhiana, India
2. GNDEC, Ludhiana, India

ABSTRACT. Optimisation in structural designing has become indispensable with the ever-increasing cost of building materials, but maintaining the economy of a structural design is a tough row to hoe. The present research work has been carried out to generate minimum cost design of RC beams. Various softwares like SAP2000, MS-Excel and MATLAB have been integrated for the purpose of automation, while using their individual strengths for getting faster results. The versatility lies in the fact that the beam models that are optimised come from SAP2000, which is widely used by structural designers. The technique implied for optimisation is Improved Ray Optimisation (IRO) which is a meta-heuristic technique based on Fermat's principle. The effectiveness of this technique has been verified by considering various beam models that are actually part of a larger RC frame model. The results obtained thereby are found to be motivating. Further, the reinforcement details are also reported corresponding to optimum beam designs.

Keywords: Automated structural detailing, Improved ray optimisation, RC beams, SAP2000.

Sukhwinder Singh, M.Tech. research scholar, Department of Civil Engineering, Guru Nanak Dev Engineering College, Ludhiana, India. His research interest includes structural designing and optimisation.

Dr. Jagbir Singh, Professor, Department Civil Engineering, Guru Nanak Dev Engineering College, Ludhiana, India. His research interest includes concrete technology and structural optimisation.

INTRODUCTION

Optimising cost of concrete structures using different approaches and techniques have been going on from long time but till date structures that are optimised in field are based on accumulated wisdom of the structural designer. In the research, optimisation has been applied on beams present in a RC frame. The technique adopted to carry out optimisation is a recently developed meta-heuristic technique called Improved Ray Optimisation (IRO). The objective function of the cost optimisation algorithm takes into consideration the cost of concrete, cost of steel and cost of formwork for beams. The optimisation program has been developed using three software applications, SAP2000, EXCEL and MATLAB. The purpose of behind using these applications is to achieve automation so that the optimisation can take place swiftly and it requires least input from the user. An important aspect has been covered while preparing this optimisation program that the cost minimized by the program doesn’t compromises with the safety of a structure.

The RC structure that user needs to optimise shall be modeled in SAP2000 software. The analysis result of the structure is extracted from the software using a macro written in the EXCEL application. The EXCEL file created is utilized by MATLAB to perform optimisation and design calculations. The number of analysis to be performed by optimisation program, i.e. number of agents and number of iterations, is to be entered by the user. The user has an access to control the sizes of the optimised sections because the search space in which the optimisation algorithm finds its optimal solution is entered by the user. The design code followed during optimisation of beams is IS 456:2000. Both type of rectangular beams, singly as well as doubly are optimised. The optimisation program after completing the optimisation on beams declares the optimum sizes for the sections that if replaced with original sections will reduce the cost.

Among various RC frames optimised during the research, a case study of a 3 storey RC frame from a literature published by A. Kaveh and O. Sabzi [11] has been discussed here. The sections of the beams used in the literature are fed into the optimisation algorithm and optimised sections are obtained. A comparative study is conducted on the cost of beams coming from the literature versus that from optimisation algorithm.

OPTIMISATION TECHNIQUE

Improved Ray Optimisation technique applied is the present study is a meta-heuristic technique developed by A. Kaveh et al. [9]. It is an improved version of a technique called Ray Optimisation (RO) technique [10]. The principle behind both the techniques is same, Fermat’s Principle of light rays. IRO is better than the RO in two aspects. Firstly, RO can’t handle more three variables at a time, though it can handle any number of variables but the variables need to be break into the set of three or two variables. For example, if an objective function is dependent on five variables then, for finding optimal solution, the function needs to break-up in such a way that at a time it depends on two variables or at the most three variables. Therefore, in this example, it is broken into set of three and two variables. The results of the objective functions are linked together to obtain optimal solution for the main objective. But, there is no such breaking and joining process in IRO method. It doesn’t need to break the variables and can handle all at a time. Secondly, IRO can search ‘n’- dimensional space which RO cannot and thus, gives more accurate results than RO. The working of IRO based algorithm is shown in Figure 1.

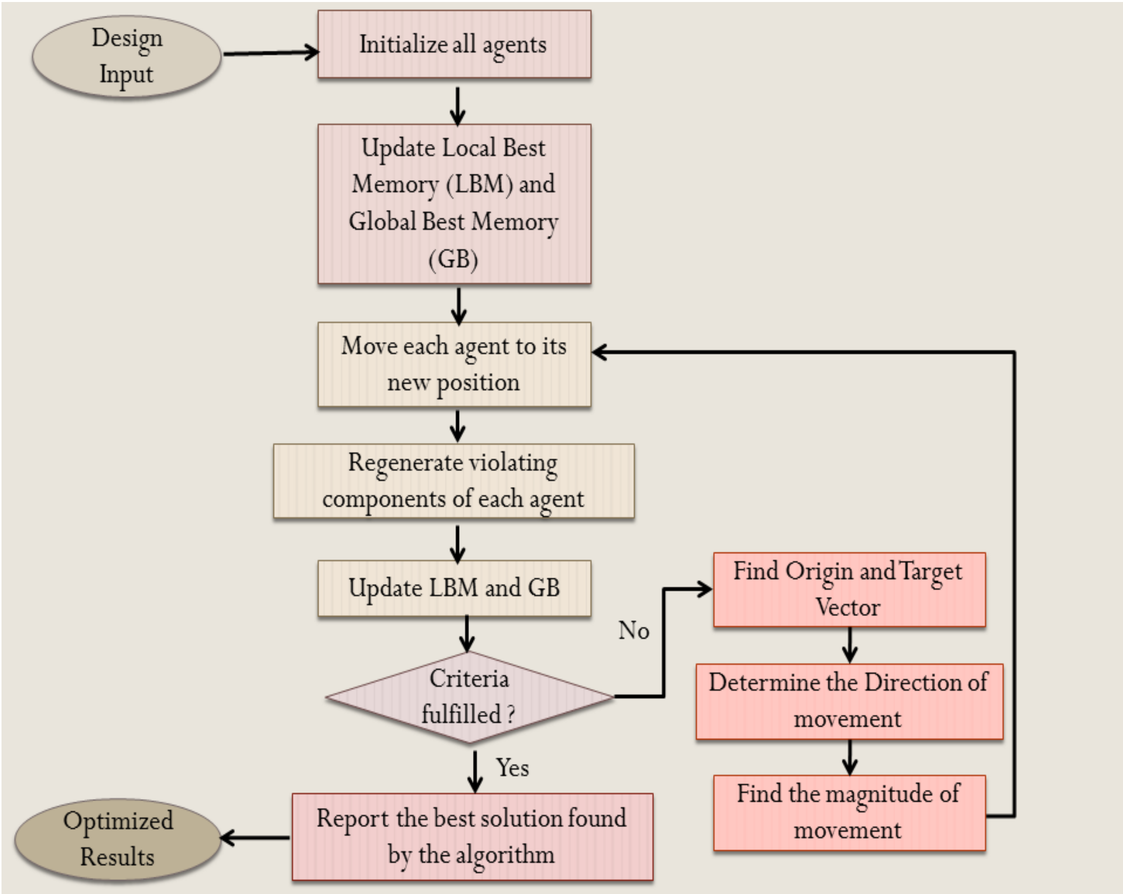

Figure 1   Flow-chart showing the working of IRO

CASE STUDY

A 3-storey RC Frame is taken from a literature published by Kaveh A. et al. [12] modeled in SAP2000. The geometrical dimensions and section properties assigned are given in the following figures.

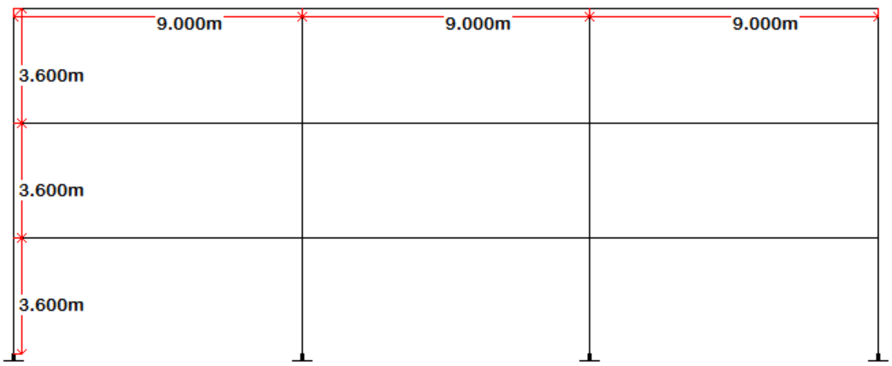

Figure 2   Dimensions of 3-Storey Frame

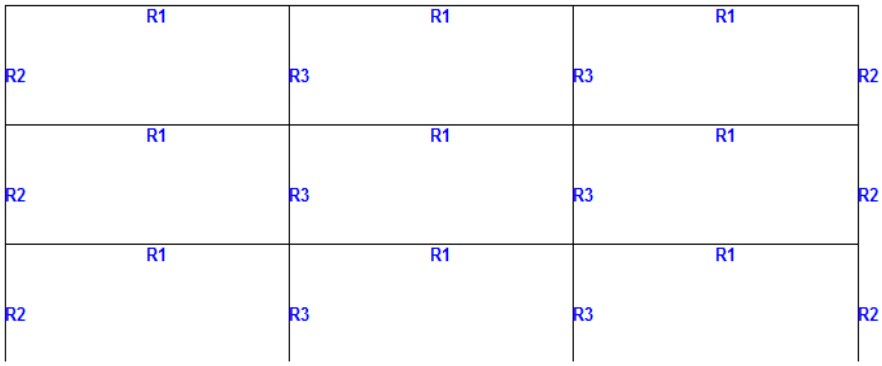

Figure 3 Section Properties of 3-Storey Frame

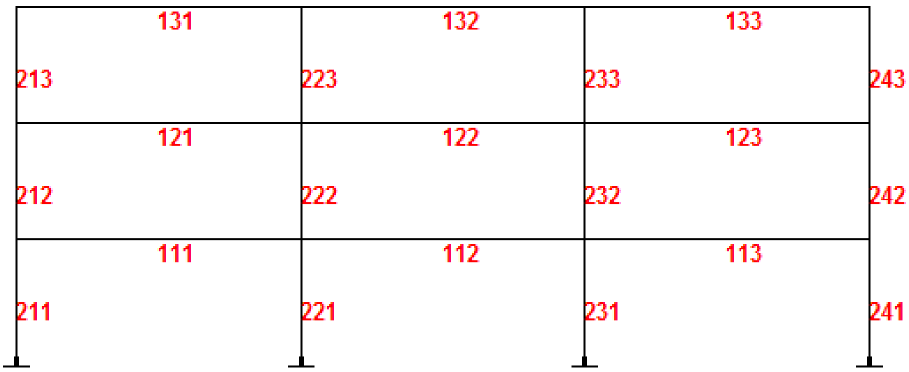

Figure 4 Member Numbers of 3-Storey Frame

- The loads are applied in the same manner on the RC frame as given in literature. A uniform dead load of 16.5 kN/m and uniform live load of 7.2 kN/m is acting on all the beams. The load combinations used for analysis purpose are as per ACI. The strength of concrete and steel provided are as cited in the literature. The sections of beams and columns used by the literature are shown in

Table 1 Dimensions of Sections for 3-Storey Frame
Table 1. The costs of different quantities involved are considered as given in literature, i.e.

- Cost of Concrete = 54 $\$/m^3$ (₹ 3500 per m^3) where, 1$ = ₹ 65
- Cost of Steel = 0.55 $/kg (₹ 35.75 per kg)
- Cost of Formwork (For Beams) = 50.5 $\$/m^2$ (₹ 3283 per m^2)

Table 1 Dimensions of Sections for 3-Storey Frame

S.No.	Section Name	Depth D (mm)	Width b (mm)
1	R1	500	300
2	R2	350	350

3	R3	300	300

RESULTS AND DISCUSSION

The optimal sections reported by the optimisation program corresponding to the minimum cost are mentioned and compared with the literature in Table 2 and
Table 3.

Table 2 Comparison of Optimised Sections with STAAD and literature for 3-Storey Frame

Section Name	**Kaveh (2012)** Depth x Width in mm	**Present Study** Depth x Width in mm
R1	500 x 300	450 x 270
R2	350 x 350	350 x 325
R3	300 x 300	275 x 275
Total Cost ($)	**6505**	**6053**

The minimum cost reported by the IRO technique is $ 6053. It may be noted that the cost of the 3-storey RC frame is decreased by 7 % when compared with Kaveh A. et al. literature's cost. The number of analysis performed by the optimisation algorithm to find minimum cost is 50. The detailing given the optimisation program is for three sections in a beam, i.e. Left, Middle and Right section.

Table 3 Comparison of detailing of beams with literature for 3-Storey Frame

Member	STAAD				IRO			
	Dxb (mm)	Rebars (Number-Diameter)			Dxb (mm)	Rebars (Number-Diameter)		
		Left	Centre	Right		Left	Centre	Right
111	500 x 300	3-25	2-25	4-25	450 x 270	5-20	2-20	5-20 + 2-16
		2-25	3-25	3-25		2-16	3-16 + 4-12	4-16
112	500 x 300	6-20	2-20	6-20	450 x 270	5-20 + 2-16	2-20	5-20 + 2-16
		3-12	7-12	3-12		4-16	2-16 + 5-12	4-16
113	500 x 300	4-25	2-25	3-25	450 x 270	5-20 + 2-16	2-20	5-20
		3-25	3-25	2-25		4-16	3-16 + 4-12	2-16
121	500 x 300	5-20	2-20	6-20	450 x 270	5-16 + 5-12	2-16	9-16
		3-12	8-12	3-12		3-12	9-12	6-12
122	500 x 300	9-16	2-16	9-16	450 x 270	9-16	2-16	9-16
		3-12	7-12	3-12		6-12	8-12	6-12
123	500 x 300	6-20	2-20	5-20	450 x 270	9-16	2-16	5-16 + 5-12
		3-12	8-12	3-12		6-12	9-12	3-12
131	500 x 300	3-25	2-25	4-25	450 x 270	4-20	2-20	3-20 + 6-16
		3-12	10-12	3-12		2-16	3-16 + 6-12	4-16

132	500 x 300	6-20	2-20	6-20	450 x 270	3-20 + 6-16	2-20	3-20 + 6-16
		3-12	7-12	3-12		4-16	3-16 + 2-12	4-16
133	500 x 300	4-25	2-25	3-25	450 x 270	3-20 + 6-16	2-20	4-20
		3-12	10-12	3-12		4-16	3-16 + 6-12	2-16

CONCLUSION

The optimisation program developed shows that Improved Ray Optimisation technique is a successful technique in terms of its ability in optimising (minimising) the cost of beams present in RC frame. The cost of the beams is reduced by 8% for a small structure shows that great savings can be made when this optimisation technique is applied on bigger structures. The detailing provided by the optimisation program is continuous for continuous beams.

REFRENCES

1. A. AGA ABOBAKR & ADAM FATELRAHMAN (2015), “Design Optimisation of Reinforced Concrete Frames”, Open Journal of Civil Engineering, vol. 5, Issue 1, March 2015, pp: 74-83.
2. CAMP CHARLES, PEZESHK SHAHRAM & KAN HANSSON HÅ. (2003), “Flexural Design of Reinforced Concrete Frames using a Genetic Algorithm”, Journal of Structural Engineering, American Society of Civil Engineers (ASCE), vol. 129, Issue 1, January 2003, pp: 105-115.
3. CHUTANI SONIA AND SINGH JAGBIR (2018), “Optimal Design of RC Frames using a Modified Hybrid PSOGSA Algorithm”, Achieves of Civil Engineering, vol. LXIII, Issue 4, pp: 123-134.
4. ESFANDIARI M.J., URGESSA GIRUM, SHEIKHOLAREFIN SAEID AND DEHGHAN MANSHADI S. (2018), “Optimum Design of 3-D Reinforced Concrete Frames using DMPSO Algorithm”, Advances in Engineering Software, vol. 115, January 2018, pp: 149–160.
5. IS 456:2000 PLAIN AND REINFORCED CONCRETE - Code of Practice is an Indian Standard code of practice for general structural use of plain and reinforced concrete.
6. JIHONG SHEN, LI JIALIAN AND WEI BIN (2012), “Optimal Search Mechanism Analysis of Light Ray Optimisation Algorithm", Journal of Mathematical Research with Applications, Sept. 2012, vol. 32, No. 5, pp: 530-542.
7. KAN WANG AND JIHONG SHEN (2012), “Multi-Objective Light Ray Optimisation”, Proceedings of the 2012 5th International Joint Conference on Computational Sciences and Optimisation, August 2012, pp: 822-825.
8. KARGAHI MOHSEN AND C. ANDERSON JAMES (2006), “Structural Weight Optimisation of Frames Using Tabu Search. II: Evaluation and Seismic Performance”, Journal of Structural Engineering, American Society of Civil Engineers (ASCE), December 2006, vol. 132, Issue 12, pp: 1869-1879.
9. KAVEH A., GHAZAAN M., AND BAKHSHPOORI T. (2013), “An Improved Ray Optimisation Algorithm for Design of Truss Structures”, Periodica Polytechnica, vol. 57, Issue 2, September 2013, pp: 97-112.

10. KAVEH A. AND KHAYATAZAD M. (2012), “A New Meta-Heuristic Method: Ray Optimisation”, Computers and Structures, vol. 112-113, October 2012, pp: 283-294.
11. KAVEH A. AND SABZI O. (2012), “Optimal Design of Reinforced Concrete Frames using Big Bang-Big Crunch Algorithm”, International Journal of Civil Engineering, Vol. 10, Issue 3, September 2012, pp: 189-200.
12. KWAK HYO-GYOUNG AND KIM JIEUN (2008), “Optimum Design Of Reinforced Concrete Plane Frames Based On Predetermined Section Database”, Computer-Aided Design, vol. 40, Issue 3, March 2008, pp: 396-408.
13. SAINI B & SEHGAL VIJAY AND L. GAMBHIR M. (2006), “Genetically Optimised Artificial Neural Network Based Optimum Design of Singly and Doubly Reinforced Concrete Beams”, Asian Journal of Civil Engineering, vol. 7, Issue 6, December 2006, pp: 603-619.
14. SHEN JIHONG & LI JIALIAN (2010), “The Principle Analysis of Light Ray Optimisation Algorithm”, 2010-Second International Conference on Computational Intelligence and Natural Computing (CINC), pp: 154-157.
15. R. KULKARNI ASHWINI & BHUSARE VIJAYKUMAR (2016), “Structural Optimisation of Reinforced Concrete Structures”, International Journal of Engineering Research & Technology (IJERT), vol. 5, Issue 7, July 2016, pp: 123-127.
16. SANCHEZ-OLIVARES GREGORIO, TOMAS ANTONIO, A. MARTÍNEZ (2017), “An Improved Firefly Algorithm for Optimisation of Reinforced Concrete Sections”, Fourth International Conference on Mechanical Models in Structural Engineering, Dec 2017, pp: 1-21.
17. SP 16 DESIGN AIDS FOR REINFORCED CONCRETE TO IS 456:1978.
18. YOUSIF SALIM AND M. NAJEM RABI. (2013), "Optimum cost design of reinforced concrete continuous beams using Genetic Algorithms", International Journal of Applied Sciences and Engineering Research, vol. 2, Issue 1, April 2013, pp: 79-92.