Optimal Design of Intermediate Reinforced Concrete Moment Resisting Frames with Shear Walls for Different Arrangements of Columns

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Abstract—Today, reinforced concrete (RC) structures are the most common structural system in Iran and in the world. Due to good performance in the construction of concrete walls, dual system of RC moment resisting frame with shear walls is one of the common structural systems in the structural engineering. Given the possibility of structural and environmental conditions, soil type, and owner needs, it should be mentioned that between dual systems the system such as intermediate RC moment resisting frame and intermediate RC shear walls have the most application in construction engineering. Determining the appropriate system including optimal span length and compressive strength of concrete for a specific number of floors is one of the important issues in designing in terms of economical design. In this paper, the effect of these parameters has been investigated in the structural construction cost by analysis and design of the many structural models. Generally, it can be concluded that in RC structures including intermediate RC moment resisting frame and intermediate concrete shear walls, increasing span length will lead to the rise in the structural construction cost, and increasing the strength of concrete will increase of structural construction cost despite decreasing the relative weight of structures.

Keyword-Optimal Span, Moment Resisting Frame, Shear Wall, Concrete Compressive Strength, Intermediate Ductility

I. INTRODUCTION

A structural system based on the national Iranian regulations that is highly applicable for the reinforced concrete (RC) structures can be referred to dual system of moment resisting frame with shear walls. Dual system in which structural frames and shear walls tolerate the gravity loads and resist against lateral loads are provided with a series of shear walls and with a set of moment resisting frames. Dual systems have a vast usage in Iran. Because of good performance of the RC shear walls in the concrete structures, dual system (moment resisting frame and shear wall) have been considered as typical issues in structural engineering.

Based on the Iranian national standard [1], linear analysis is limited to the height of 50 meters of a building with this system. Many residential complexes in Iran have height less than this limit, so the result of this study and optimization of the system will be useful for designers, engineers and owners.

Regarding optimization of RC concrete buildings, many studies have been performed. The effect of ductility levels of ordinary, intermediate, and special for RC frame structures studied by Babaei [2]. Sanaei and Babaei [3-4] have studied optimization of continuum structures using cellular automata (CA) method and they applied the method to optimize the weight of these structures.

Babaei et al. [5-6] studied multi-objective optimal design of steel frames with outrigger-belt truss system for buildings with 20 to 50 story numbers, and proposed optimum number and locations for trusses. Other studies on multi-objective optimization of steel structures have been performed in the literature [7].

Fadayi and Grierson in 1996 [8], studied the optimization of 3D RC structures using optimality criteria (OC) method. Cam et al. studied flexural design of RC frames using genetic algorithm (GA) [9]. Many other studies have been performed in the field of optimal design structures [10-12].

The main purpose of this paper is to propose the best economical layout for dual system of RC frames with shear walls, satisfying architectural requirements such as providing parking area for cars. Therefore, many models are defined so that to cover different story numbers, usual soil types, and different arrangements for columns. Similar studies have been performed for other steel and RC structural systems [13-21] and the building models are according to these references to compare the results.

II. METHOD

To investigate the effect of number of floors, span length, concrete strength and soil type on the total structural cost in RC moment resisting frames with shear walls 54 building models with different story numbers, different arrangements for columns and different strength for concrete selected. Buildings with 5, 10, and 14 floors, and with span length of 5.6, 7.5, and 11.2 meter, based on parking area needed by architectural requirements, are defined.

In Iran, soil is classified into five types and only two types of them, type II and II, are usual. So, only these two types are considered for the models. Compressive strength for concrete of 30, 40, and 50MPa are considered for the models. Analysis and design of building models are performed according to the ACI [22] and Iranian codes [23-25]. Story heights are assumed to be 3.5 meter. Figures 1 to 3 illustrate plan of the models and shear wall locations for different arrangements of columns.

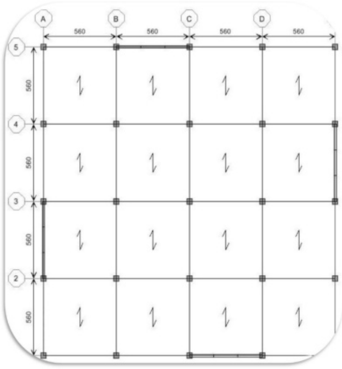

Fig.1: Building plan with span length of 5.6m

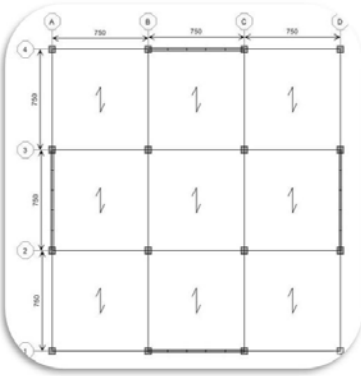

Fig. 2: Building plan with span length of 7.5m

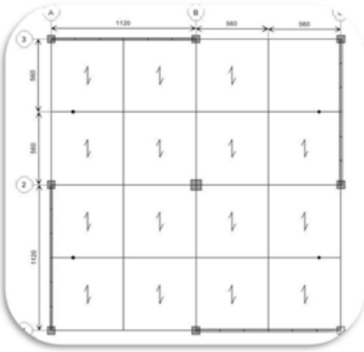

Fig. 3: Building plan with span length of 11.2m

III. Results

According to the analysis and design of the building models, the following results are obtained.

A. Five-story building group

In this group, the results show that the construction cost rises with increasing of span length, and weight of the reinforcement bars and required concrete volume will increase. Increasing the concrete strength is one of the textures of concrete weight reinforcement and can decrease the volume of concrete to some extent. But considering the high cost of concrete, totally the cost of construction will be incensed Reinforcement material weight, formwork, and concrete volume in soil type III will increase as equal as soil type II. The comparison of reinforcement material weight, formwork, concrete volume and construction cost of structures in 5-storey building group are provided in Figures 4 to 7 that they confirm the above – mentioned points in this group.

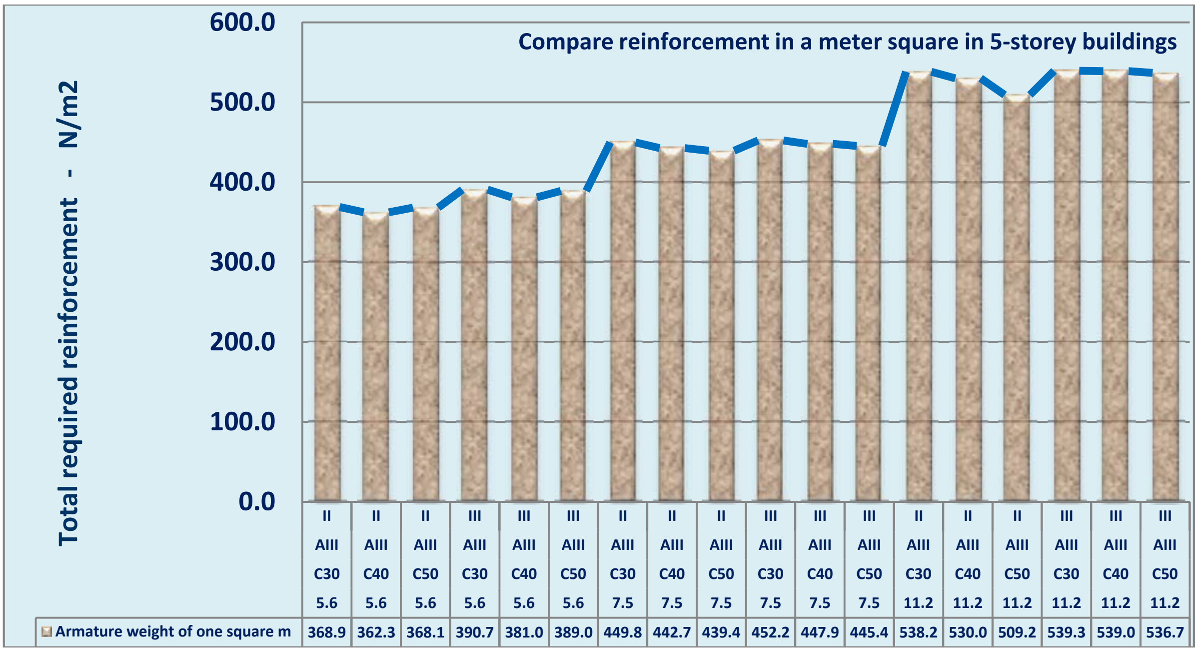

Fig. 4: The comparison of required reinforcement material weight in 5-storey building

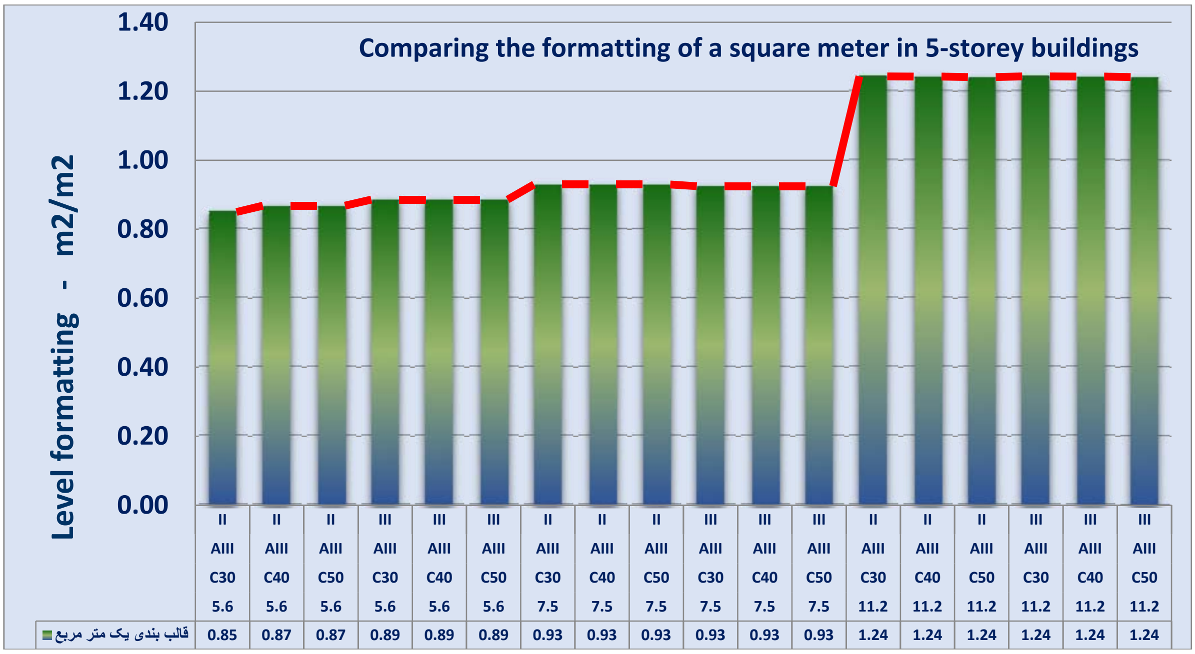

Fig. 5: The comparison of formwork in 5-floor buildings

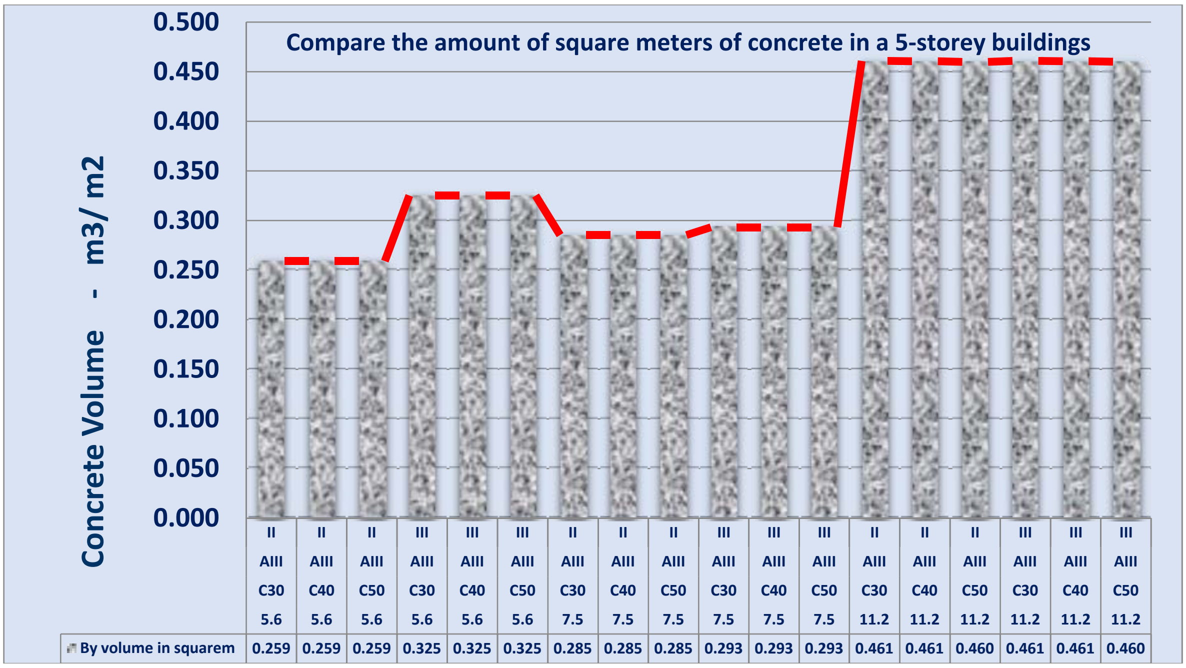

Fig. 6: The comparison of required concrete volumes in 5-storey building

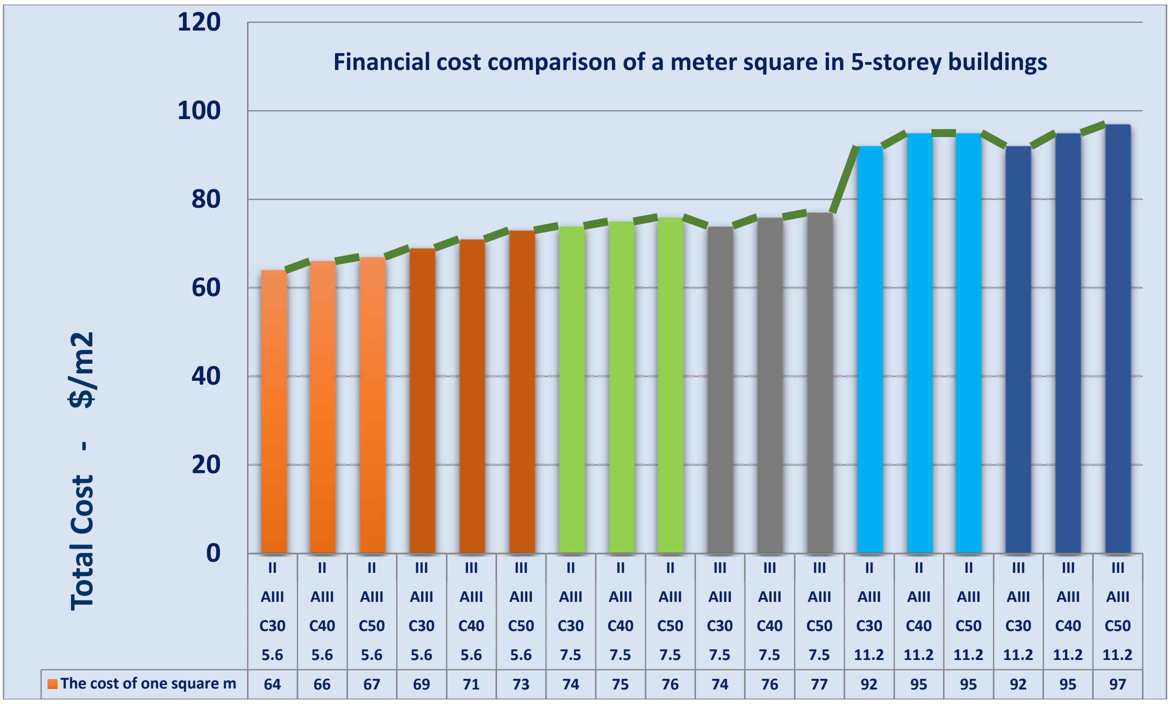

Fig. 7: The comparison of construction cost of structures in 5-storey building

B. Ten-storey building group

Construction cost rises with increasing span length and also the weight of reinforcement for concrete structures and concrete volume will increase. The increase of concrete strength is one of the features of concrete weight reinforcement and can decrease the volume of concrete to some extent. But considering the high cost of concrete, totally the cost of construction will be increased. Reinforcement material weight, for matting, and concrete volume in soil type III will increase as equal as soil type II. The comparison of reinforcement material weight, formwork, concrete volume, and construction cost of structures in 10-storey building groups are provided in Figures 8 to 11 that they confirm the above – mentioned points in this group.

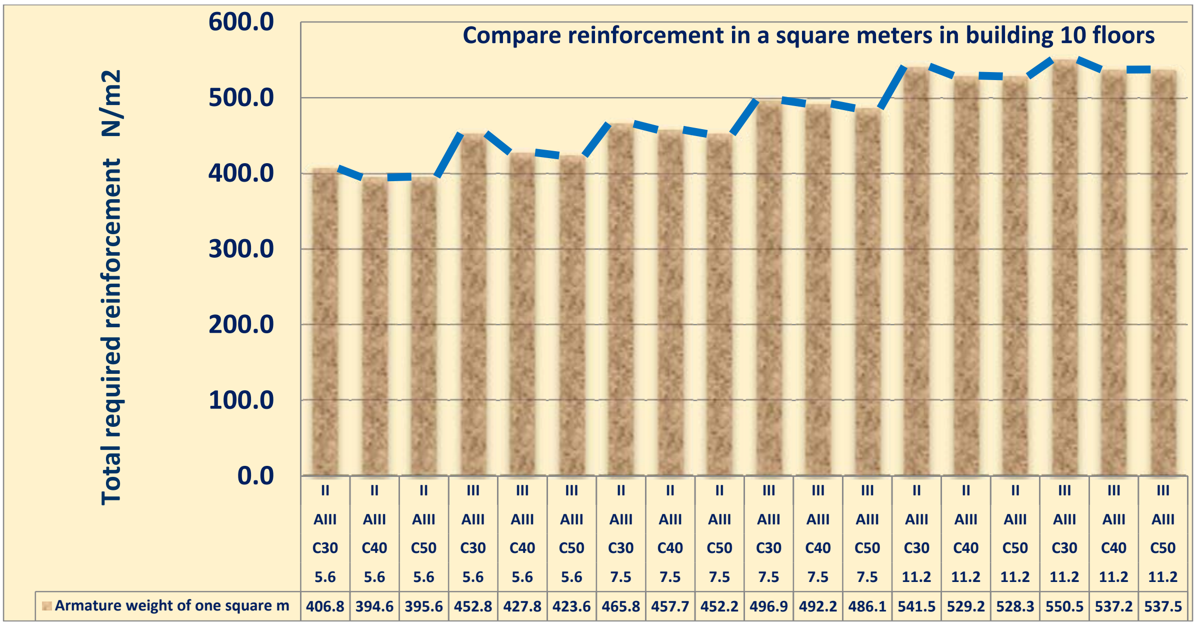

Fig. 8: The comparison of required reinforcement material in 10-storey buildings.

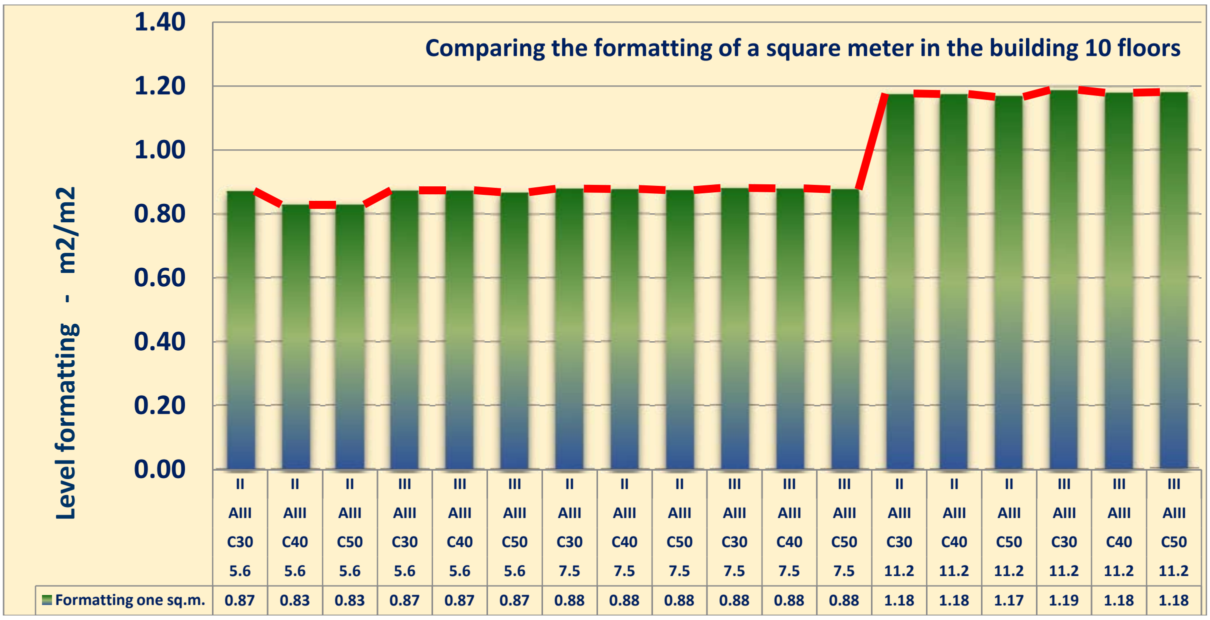

Fig. 9: The comparison of formwork in 10-storey buildings

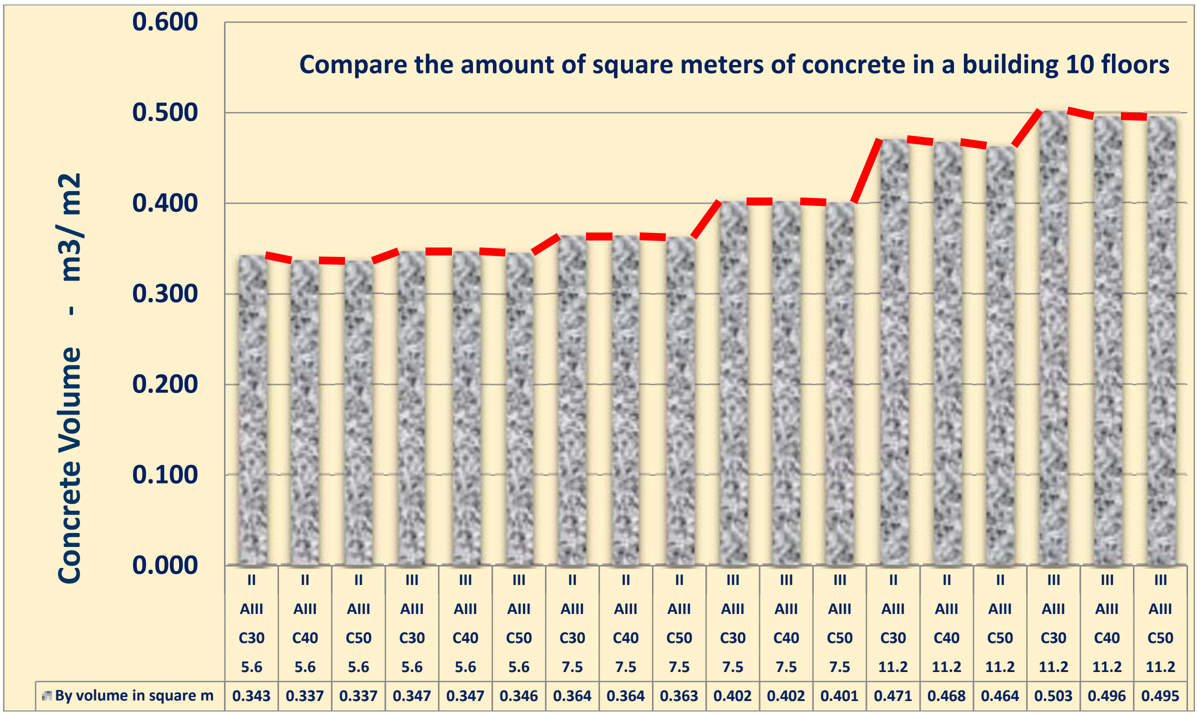

Fig. 10: The comparison of concrete volume in 10-storey buildings

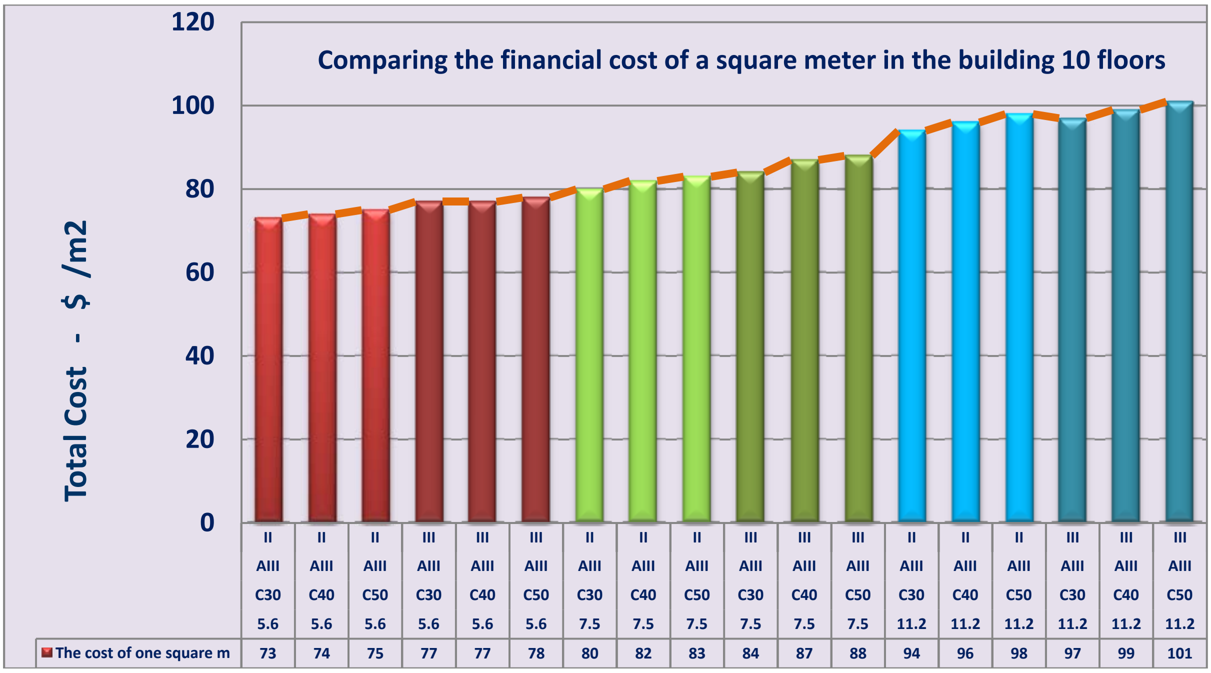

Fig. 11: The comparison of construction cost of structures in 10-storey buildings

C. Fourteen-storey building group

Construction cost rises with increasing span length and also the weight of reinforcement for concrete structures and concrete volume will increase. The increase of concrete strength is one of the features of concrete weight reinforcement and can decrease the volume of concrete to some extent. But considering the high cost of concrete, totally the cost of construction will be increased. Reinforcement material weight, formwork, and concrete volume in soil type III will increase as equal as soil type II. The comparison of reinforcement material weight, formwork, concrete volume, and construction cost of structures in 14-storey building groups are provided in Figures 12 to 15 that they confirm the above – mentioned points in this group.

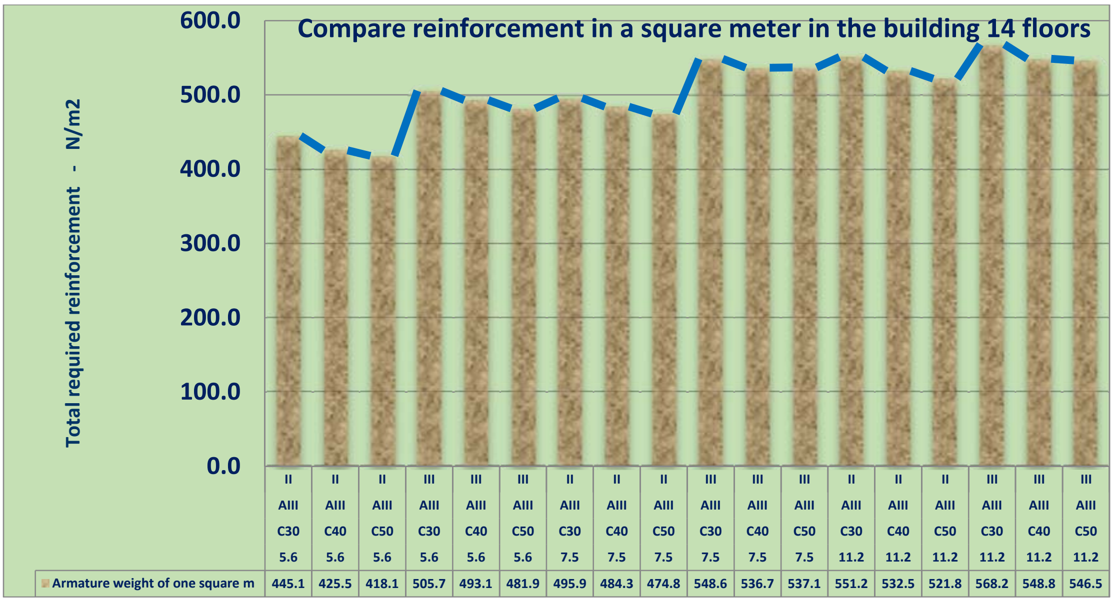

Fig. 12: The comparison of required weight of reinforcement material in 14-storey buildings

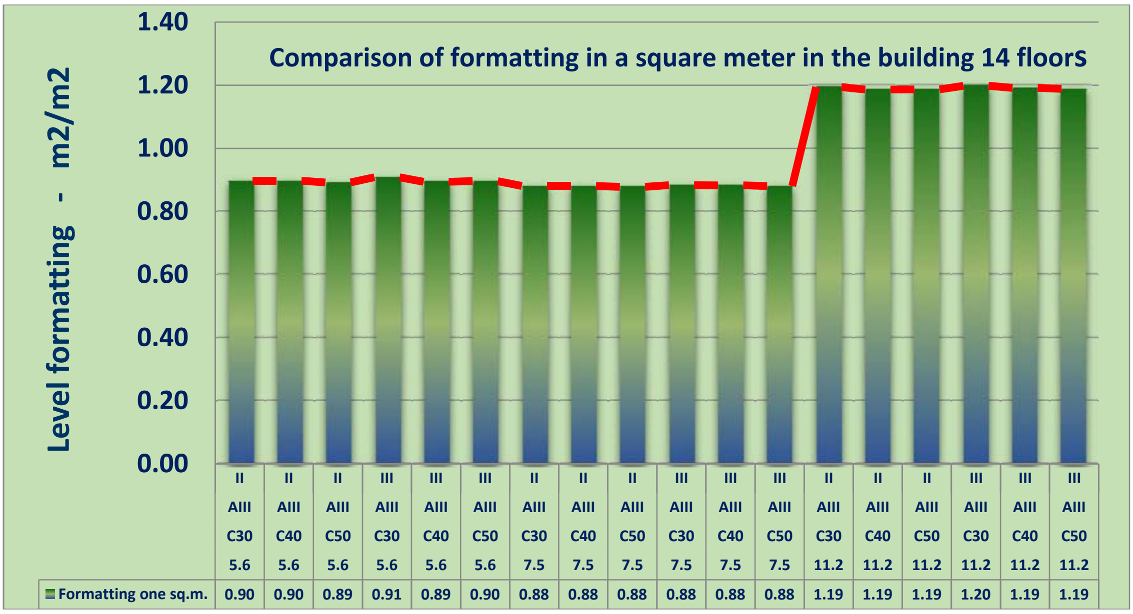

Fig. 13: The comparison of level formwork in 14-storey buildings.

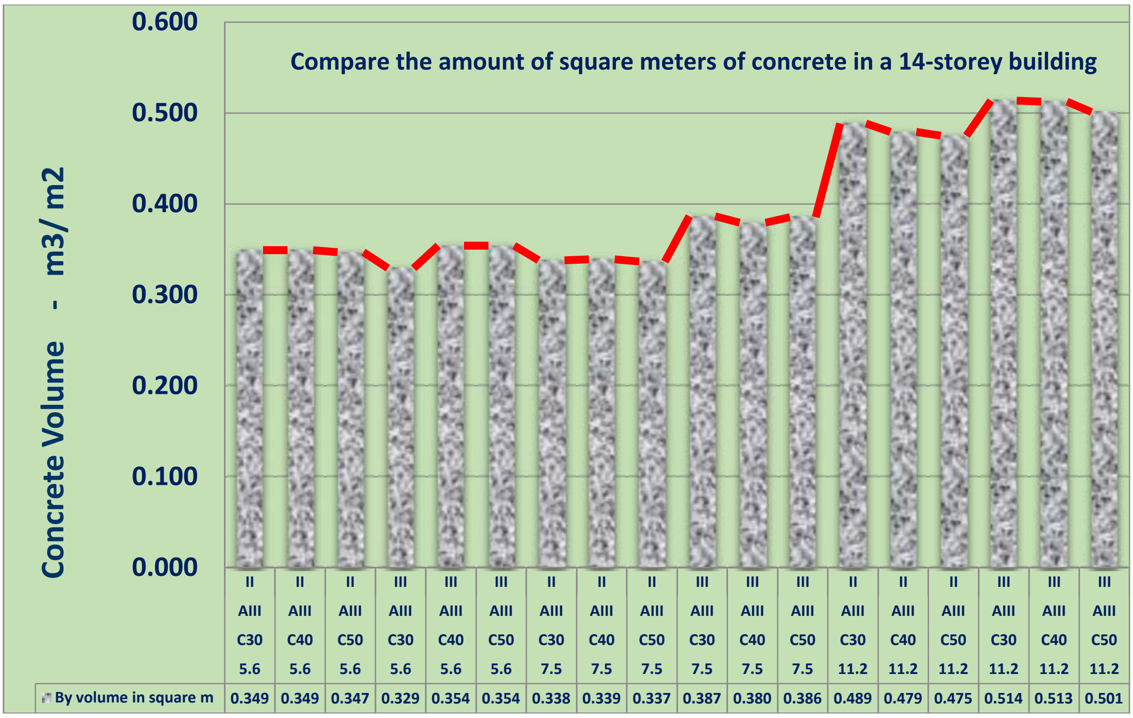

Fig. 14: The comparison of required concrete volume in 14-storey buildings

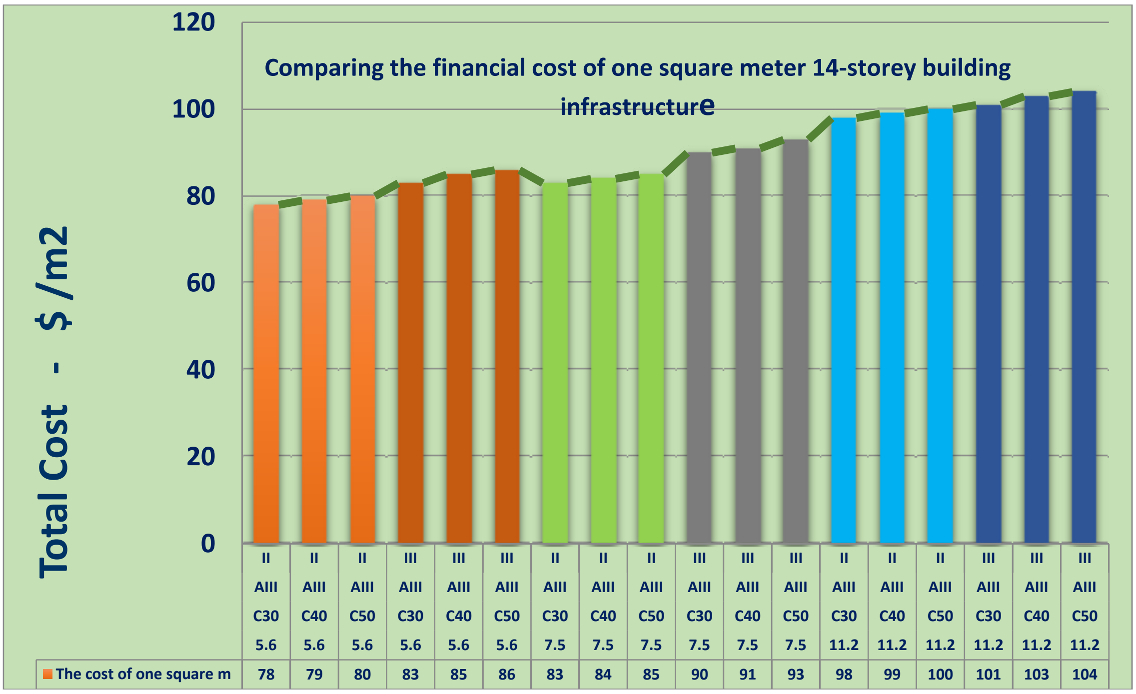

Fig. 15: The comparison of construction cost structures in 14-storey buildings

D. Comparison of 5, 10, and 14-storey buildings

With the increase of floor numbers, the cost of structure construction will increase non-linearly and the weight of required reinforcement material, formwork, and the concrete volume will increase too. The comparison of a typical type of reinforcement material weight, formwork, and construction structure cost in 5, 10, and 14-storey buildings are presented respectively in the Figures 16 to 19 that confirm the above- mentioned issues. The cost of 14-storey is bigger that of 10 and 5-storey building.

With the investigation of figures in the entire stories, the increase in all of construction cost of structures and required reinforcement material, formwork, concrete volume and also the span length can increase too. The cost of 11.2m span Is bigger than 7.5m and 5.6m span. In all of the -stories, the increase of compressive strength with the weight of reinforcement can decrease formwork and concrete volume but with the consideration of high cost of concrete, the total cost of structure will increase. In all of the floors, the weight of reinforcement material, formwork, and volume of concrete in soil type III is more than soil type II.

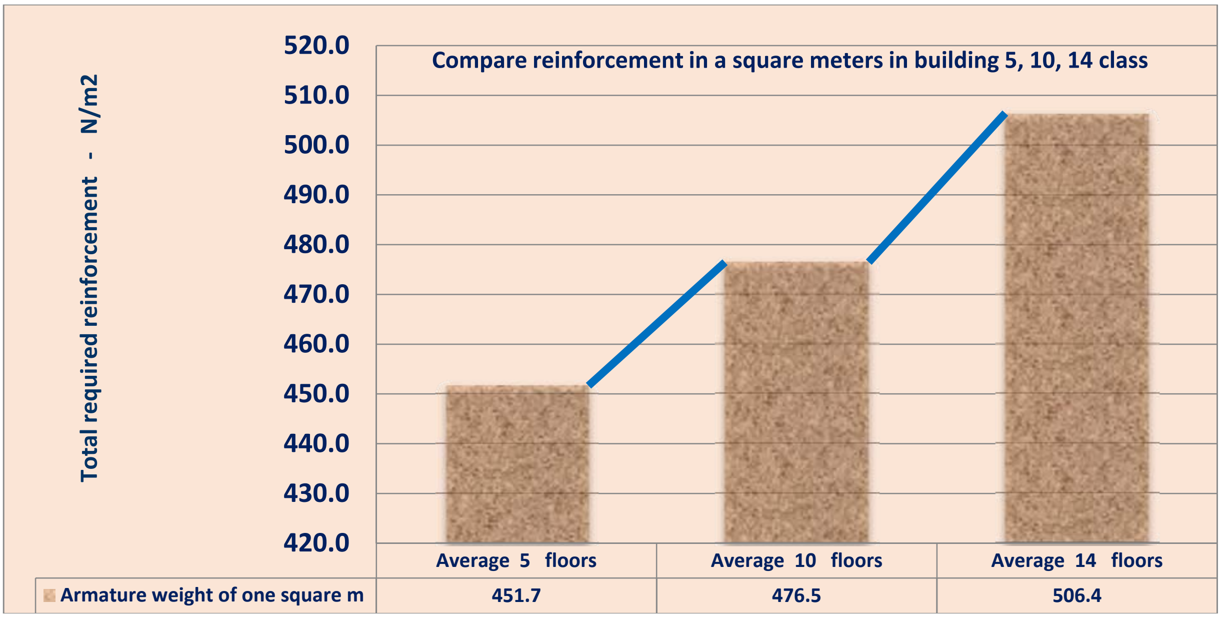

Figure 16: The comparison of required concrete in 5-storey, 10-storey, and 14-storey buildings

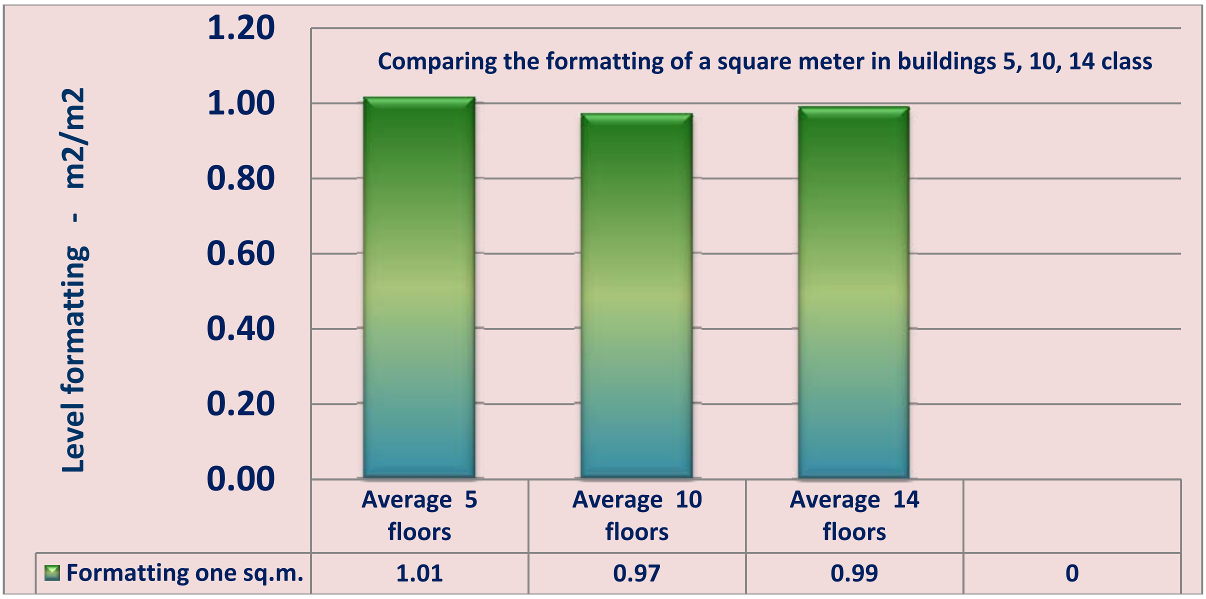

Fig. 17: The comparison of medium level formwork in 5-storey, 10-storey, and 14-storey buildings

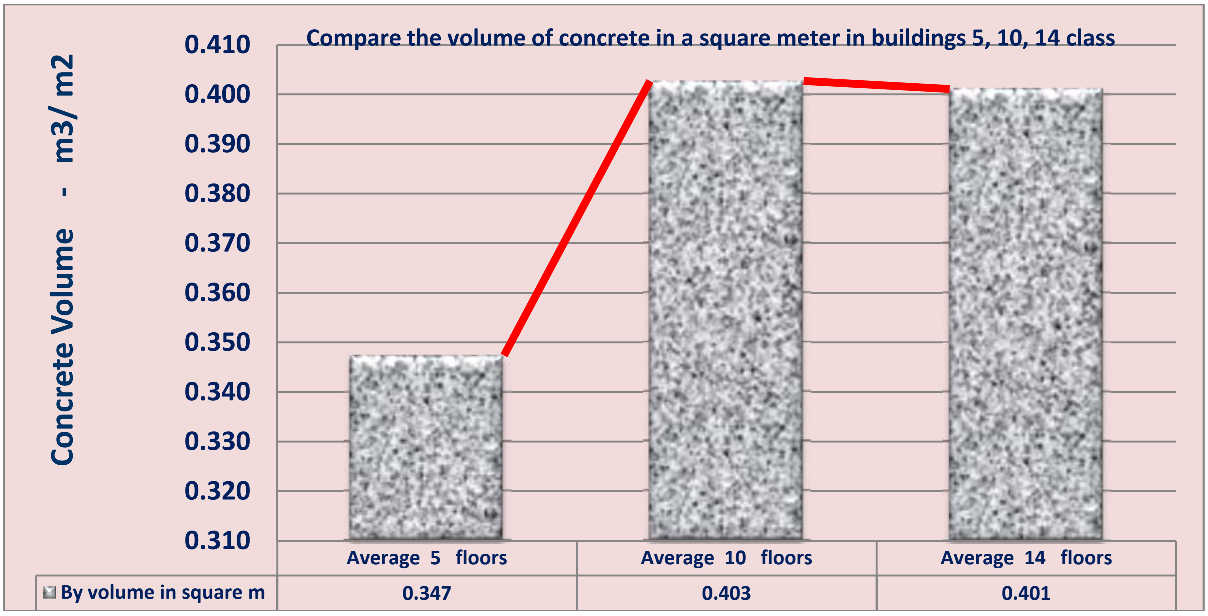

Figure 18: The comparison of medium concrete volume in the groups of 5, 10, and 14-storey

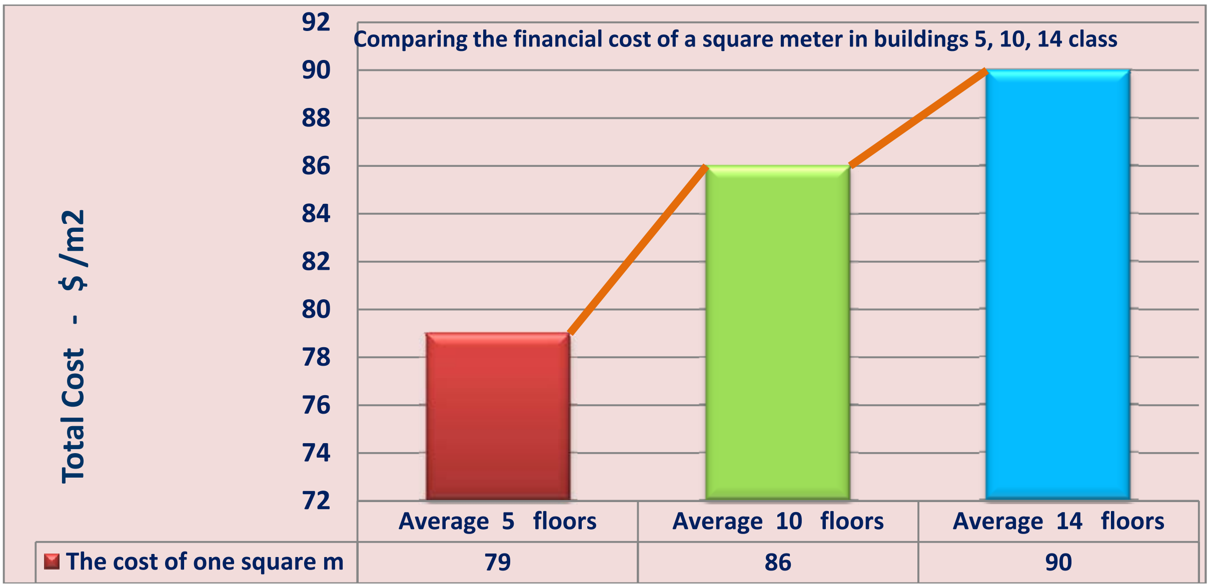

Figure 19: The comparison of medium concrete volume in the groups of 5, 10, and 14-storey.

E. Optimized structure in 5, 10, and 14-storey floors

Based on the conducted research and comparisons and also the mentioned Figures in all of the floors, the number of floors, span length, and soil type were all considered in the costs of intermediate reinforced concrete moment resisting frames and intermediate concrete shear walls with joist block with span length of 5/6 and compressive strength of concrete is 30MPa which is considered as optimal type. In soil type II and in 5-storey buildings, the financial cost of construction will be optimal.

Buildings with span length of 7/5 meter can be considered as optimal. However, due to high costs or making use of double joist block in the ceiling, the cost of structure cost is higher than the length span of 5/6 meters. To evaluate, the number of storey, span length, concrete strength, and soil type were all considered in the construction cost of intermediate reinforced concrete moment resisting frames with intermediate shear walls and with joist blocks of 45 structure models and in 5, 14, and 10-storey were designed their span lengths were 5.6, 7.5 M, and 11.2 meters respectively and their compressive strength in concreters of 30, 40, and 50 mega Pascal have been analysed and designed.

IV. Discussion and Conclusion

After analysis and design of structures with different spans, floors and soil types, generally it can be concluded that in the intermediate reinforced concrete moment resisting frames and intermediate shear walls with joists block beam the factors such as the increase of the floors, the increase of span length and poor soil will lead to increase of structural cost, and increase of concrete strength even with relative decrease of structural weight will lead to increase of structural construction cost. It is economically more efficient to consider the minimum span for short buildings and the lower compressive strength for concrete in strong soil.

References

[1] Standard No. 2800-05, (2005). Iranian Code of Practice for Seismic Resistant Design of Buildings.

[2] Babaei M. (2015). The Economical Effect of Ductility Levels on Reinforced Concrete Frames Design. American Journal of Civil and Structural Engineering, 2(1), 1-6.

[3] Sanaei E., & Babaei M., (2012). Topology Optimization of Structures using Cellular Automata with Constant Strain Triangles. International Journal of Civil Engineering, 10(3), 179-188

[4] Sanaei E., & Babaei M., (2011). Cellular Automata in Topology Optimization of Continuum Structures. International Journal of Engineering, Science and Technology, 3(4), 27-41

[5] Babaei M. Multi-Objective Optimal Number and Location for Steel Outrigger-Belt Truss System. under review

[6] Babaei M., Asemani R., & Kazemi F. (2015). Exploring for Optimal Number and Location of Trusses in Core and Outrigger Belt Truss System. 1st International & 5th National Conference of Steel and Structure, Iranian Association of Steel Structures, Iran.

[7] Babaei M., Sanaei E. Multi-objective Optimal Design of Braced Frames using Hybrid Genetic and Ant Colony Optimization Algorithm. under review

[8] Fadaee, M. J. and Grierson, D. E. (1996). Design optimization of 3D reinforced concrete structures. Structural Optimization, 12(2-3): 127-134.

[9] Camp C., Pezeshk S, Handerson H. (2003). Flexural Design of Reinforced Concrete Frames Using a Genetic Algorithm", Journal of Structural Engineering, 129(1): 105-115.

[10] Lindt J. W., Dao T. N. (2007). Evolutionary Algorithm for Performance-Based Shear Wall Placement in Buildings Subjected to Multiple Load Types. Journal of Structural Engineering, 133(8): 1156-1167

[11] Ketkukah T. S., Abubakar I. and Ejeh S. P., "Optimum desing sensitivity of reinforced concrete frames", International Journal of Advanced Engineering Research and Technology, 2(5), (2014), 144-158.

[12] Sharafi, P., Hadi, M. N. and Teh, L. H., (2013) "A methodology for cost optimization of the layout design of multi-span reinforced concrete beams", Proceedings of the Fourteenth International Conference on Civil, Structural and Environmental Engineering Computing (p. 124). United Kingdom: Civil-Comp Press.

[13] Babaei M. (2015). Exploring Practical Optimal Topology for Reinforced Concrete Moment Resisting Frame Structures. American Journal of Civil Engineering, 3(4): 102-106.

[14] Babaei M., Mousavi S Said. (2015). Economic Effects of Beam Spans, Number of Stories and Soil Type on Special Steel Moment Resisting Frames with X-Bracings. International Journal of Science and technology, 4(8): 420-426

[15] Babaei M., J. Dadash Amiri. Determining the Optimal Topology for Intermediate Steel Moment Resisting Frames with Eccentric Braces in Hybrid System. under review

[16] Babaei M., Taherkhani S. (2015). Optimal topology design of intermediate steel moment resisting frames with reinforced concrete shear walls. International Journal of Applied Engineering Research, 10(17), 37909-37916

[17] Babaei M., Mousavi A. R. Cost Evaluation of Columns Arrangements in Special Steel Moment Resisting Frames with Special Chevron Braces. under review

[18] Babaei M., Omidi F. (2015). Determining the optimum spans for special steel moment resisting frames with special eccentric braces. Research Journal of Applied Sciences, 10(9): 474-478

[19] Babaei M., Memarian A. Topological evaluation of simple steel frames with special eccentric braces. (in press)

[20] Babaei M., Jabbar M. Evaluation of Special Moment Resisting Frame Structures with Different Spans and Story Numbers. under review

[21] Babaei M., Yousefi M. Optimal Layout for Intermediate Steel Moment Resisting Frames with Special Chevron Braces. under review

[22] American Concrete Institute (2011). Building code requirements for reinforced concrete, ACI 318-14

[23] Iranian National Building Code. (2011). Part 6: Loadings.

[24] Iranian National Building Code (2011). Part 9: Design and construct of reinforced concrete structures

[25] Iranian National Building Code (2011). Part 10: Design and construct of steel structures.