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Comparison of Three Concrete Structural System Using AHP Method

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Abstract

For selecting the appropriate structural concrete prefabricated system, construction managers have to identify and extract the most important and most effective features. This paper addresses how the best system can be selected using Analytic Hierarchy Process (AHP) method. This method has been utilized for selecting the appropriate structural system among three pre-fabricated concrete construction system, including Large Panels, 3D Panels and Insulating Concrete Formwork (ICF). These systems considered to examine the importance of the criteria of efficient construction including cost and time, technical specifications and performance facilities. In this paper expert choice program has been used to approach the best system.

The result of this study shows that the cost of production the pre-construction percentage, and the weight of elements and moreover the less need for heavy machinery and modularity of components have the maximum rank among the performance criteria. In addition, 3D Panel has been selected as the most appropriate structural system, and then ICF system and Large Panel have been selected as the second and third choice, respectively.

Keywords: construction materials, structural system, Large Panel, 3D Panel, ICF, AHP method.

1. Introduction

The construction industry has adopted a number of new building materials over the past years. These materials are designed to achieve enriched strength and durability characteristics at ambient conditions [1]. The performance of modern construction materials from cost, time and technical specifications points of view is steel not identified completely. Quality control and safety represent increasingly important concerns for project managers. Choosing the best materials which impact significantly on projects is a key ingredient of the overall strategy [2]. In this research, determination of the most effective criteria in selecting a pre-fabricated concrete system, using hierarchical analysis method (AHP), is considered. In AHP method every pair of alternative (criterion) must be compared with each other with respect to the common alternative at their higher level [3]. The importance of the criteria and sub-criteria, including economic factors, cost and time, technical specifications and performance facilities of the three pre-fabricated concrete construction systems is evaluated. These structural systems include the large panel, the 3D panels, and the Insulating Concrete Formwork (ICF) which are very well-known for building engineers.

Large panel structures are prefabricated elements of buildings and structures made from large factory-produced slab elements that are assembled on-site. Panel structures are one of the most progressive industrial types of structural elements.

3D panel is a wire mesh products. It is double layer welded wire panel, using welding method joining two pieces of welded wire panel together, mainly used in wall constructions. It's high tensile and is easy to install and these features make 3D wire mesh panels very popular by construction customers.

ICF includes permanent formworks used for concrete work and making reinforced concrete walls. Once concrete work is done, the formwork forms a part of walls. ICFs are usually made of expanded polystyrene which should be protected by the exterior and interior envelopes and finishes [4].

For selecting the optimum concrete prefabricated system, one has to identify and extract the most important and most effective criteria. The results of the previous studies resulted in 36 effective factors

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for selecting the prioritization and comparison of the mentioned systems, as described in Table 1.

Table1
The primary Criteria for choosing the best prefabricated system

	criteria		criteria
1	Low cost of construction	19	No need for heavy machinery
2	Increase productivity	20	The rigidity of the ceiling
3	Safety	21	Low execution stages
4	Low building time	22	project management
5	Ease of supply of materials in the interior	23	Diversity in architectural design
6	Low maintenance costs	24	Compatible with modular design
7	Time needed to return investment	25	Existence of executive regulations
8	Recycling of materials	26	Quality considerations
9	Possibility to make next changes	27	Management Considerations
10	Stability of the elements	28	Required Resources
11	quality control	29	Energy consumption
12	Fire safety	30	Reducing environment
13	Compatibility with non-structural elements	31	Adapting to the climatic conditions
14	The need for skilled workforce	32	Impact on the labor market
15	Prefabricated percentage	33	No traffic jams during construction
16	Executive seasonal constraints	34	Provide workers' health and safety
17	Sound insulation	35	Compatibility with Iranian culture
18	Thermal insulation	36	Providing visual aesthetic

Reliability of decisions made through AHP method highly depends on the quality of the questionnaires and the accuracy of the information provided by the experts involved in the decision making process [4]. The three selected structural systems have been ranked based on the criteria which presented in Table 1. Then it was provided and yielded to statistical population which included 120 experts. The experts choose their priority and ranked all of the above mentioned criteria. Finally 15 major and important factors were extracted from the expert’s answer and these factors were categorized to four main group listed below and presented in Table 2. These four groups include 1- Construction cost, 2- Construction time, 3- Technical Specifications and 4- Executive features.

Table 2
Final criteria selection

criteria		Sub- criteria	
1	Construction cost	1	Cost of production
		2	Transportation costs
		3	Assembly cost
2	Construction time	4	Runtime limits in different Season of the year
		5	Time to Loading and transportation
		6	Pre-fabrication percentage and consequently reduced construction time
		7	The duration of the operation in the Place of construction
3	Technical Specifications	8	Adaptation with technical regulations
		9	Lightweight components and weight loss of building
		10	Sustainability against earthquake
		11	Environmental friendly
4	Executive features	12	Variety of parts and adaptation to architectural design
		13	Least need for heavy machinery
		14	Least need for expert human resources
		15	Modularity of parts

2. Analytic Hierarchy Process (AHP Method)

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Thomas L. Saaty [5]. It has particular application in group decision making [5, 6] and is used around the world in a wide variety of decision situations [6-8]. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.
Users of the AHP decompose their decision problem into a hierarchy of more easily comprehended sub-problems which can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to each other with respect to their impact on an upper level element in the hierarchy. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational

and consistent way. This capability distinguishes the AHP from other decision making techniques [9 -12]. Then it can be said that the AHP method are based on building a decision tree hierarchy. The first step is the decision tree hierarchy, in this first-level tree representing the target and the down level representing rival options and intermediate levels of decision-making factors and factors, including criteria and sub-criteria [13, 14]. One of the advantages of the hierarchical analysis process is the possibility of examining the consistency of judgments [15]. Moreover the advantages of AHP over other multi criteria methods are its flexibility, intuitive appeal to the decision makers and its ability to check inconsistencies [16]. Generally, users find the pairwise comparison form of data input straightforward and convenient. Additionally, the AHP method has the distinct advantage that it decomposes a decision problem into its constituent parts and builds hierarchies of criteria [17] In this study, the expert choice software is used for analysis and make decision tree hierarchy.

3. Compatibility in Cognition and Decision

Pairwise comparison matrix is a reliable base for calculations only if it is consistent. Consistency means a condition in which ratios assigned for comparing criteria and options in a matrix (based on the pairwise connection between criteria) are mutually consistent [4]. Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. Then some inconsistency is expected and permitted in AHP analysis [15].
Saaty provides the calculated RI value for matrices of different sizes [18]. In AHP, the consistency ratio is defined as CR where CR = CI/RI. Saaty has shown that a consistency ratio (CR) of 0.10 or less is acceptable to continue the AHP analysis. If the consistency ratio is greater than 0.10, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it [14].

4. Inconsistency rate of pair comparisons

The existence of the right judgments of the decision maker has an important role in creating the pairwise comparison matrix in Analytical Hierarchy Process. If the judgment matrix does not have an acceptable level of consistency, the results are not reliable [3]. To verifying the results, inconsistency rate of all of analyses is presented here. All of the calculation of the consistency ratio is easily performed by computer program and presented in Table.3. Since these values of inconsistency are less than 0.10, we can assume that our judgments matrix is reasonably consistent so we can continue the process of decision-making using AHP.

Table 3
Inconsistency rates for paired comparisons

Pair Comparison Title	inconsistency ratio
Comparison the main criteria	0.02
Comparison of construction cost sub-criteria	0.00
Comparison of Construction time sub-criteria	0.04
Comparison of Technical Specifications sub-criteria	0.00298
Comparison of executable abilities sub-criteria	0.00
Comparison options for lower product price	0.03
Comparison options for less shipping	0.06
Comparison of options in terms of less installation and assembly costs	0.06
Comparing options in terms of prefabrication percentage and thus reducing runtime	0.08
Comparing options in terms of less loading time and carrying Pre-fabricated parts	0.08
Comparison of options in terms of less runtime in different seasons of the year	0.03
Comparing the options in terms of less time for the operation in the workshop	0.03
Comparison of options in terms of compliance with the technical regulations	0.00
Comparison of options for maximum stability against earthquake	0.00
Compare the options for the most environmentally friendly	0.04
Comparison of options in terms of lighter parts and weight loss	0.08
Comparison of options in terms of prefabricated parts variation and adaptation to architectural design	0.06
Comparison of options in terms of minimum requirements for heavy machinery	0.07
Comparison of options in terms of minimum requirements for specialized staffing	0.00
Comparison of options in terms of modularity of parts	0.00352

5. Results and Discussion

Introduction of new structural systems into construction industry has created a competitive situation wherein selecting the most appropriate structural system has become increasingly difficult. Some structural systems have priority over others due to their unique features, as well as the special requirements of various construction projects [4]. The outputs of questionnaires in this study have been used to develop pairwise comparison tables. Details of modeling and AHP chart have been presented in Table 4.

Table 4
The chart of criteria, sub-criteria and research options

Goal	Criteria	sub criteria	Options
select the best construction system	Construction cost	Cost of production(C1)	
		Transportation costs(C2)	
		Assembly cost(C3)	large panel(A1)
	Construction time	Runtime limits in different Season of the year(T1)	
		Time to Loading and transportation(T2)	
		Pre-fabrication percentage and consequently reduced construction time(T3)	
		The duration of the operation in the Place of construction(T4)	3D panel(A2)
	Technical Specifications	Adaptation with technical regulations(TF1)	
		Lightweight components and weight loss of building(TF2)	
		Sustainability against earthquake force(TF3)	
		Environmentally friendly(TF4)	ICF(A3)
	executable abilities	Variety of Parts and Adaptation to Architectural Design(E1)	
		At least the need for heavy machinery(E2)	
		At least the need for expert human resources(E3)	
		Modularity of parts(E4)	

Note: C1,C2,... are used to define the sub criteria and options for Expert choice software.

Table 4 shows the models created in Expert choice program for comparison of three mentioned construction system as well as criteria and sub-criteria. Results of general comparisons of the main criteria with respect to the research goal are illustrated in Fig. 1. The construction cost criterion with the relative weight of 0.560 has the highest value and is preferred, the construction time criterion with a relative weight of 0.249 is in the second place, and the technical specifications and Executive features with a relative weight of 0.095 are in the third and fourth place.

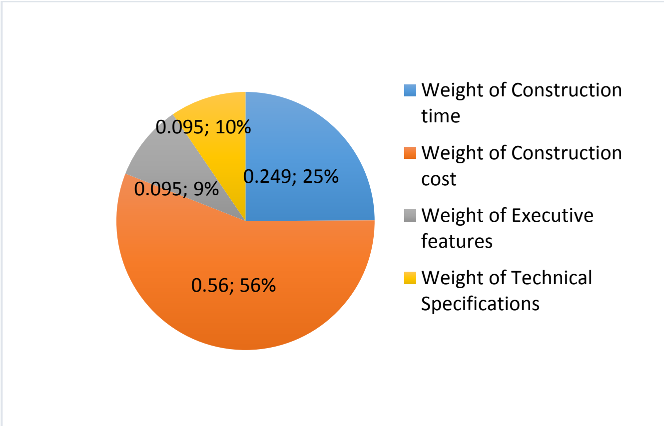

Fig.1. The relative weight of the main criteria relative to the goal

Evaluation of the construction cost as shown in the Fig. 2, Shows that the production cost is the most important feature in controlling cost of construction.

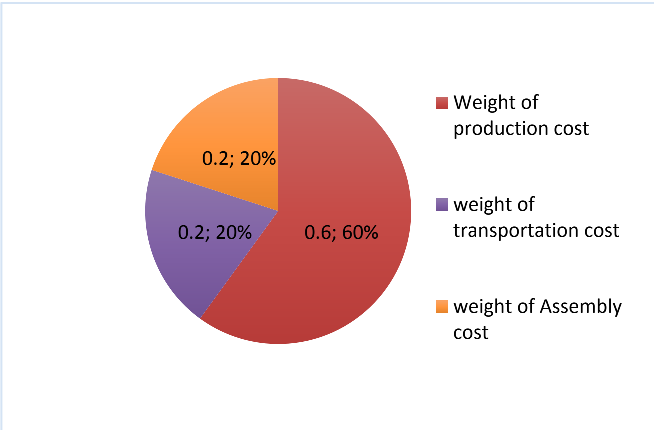

Fig.2. The relative weight of the sub-criteria in evaluating the cost of construction

Evaluation of the parameters of construction time, as shown in the Fig. 3, shows that the percentage of pre-fabrication has the primary importance in controlling time of construction. And then time of loading and transportation has the second place. Then the duration of the operation and finally runtime limits in different seasons have the less importance.

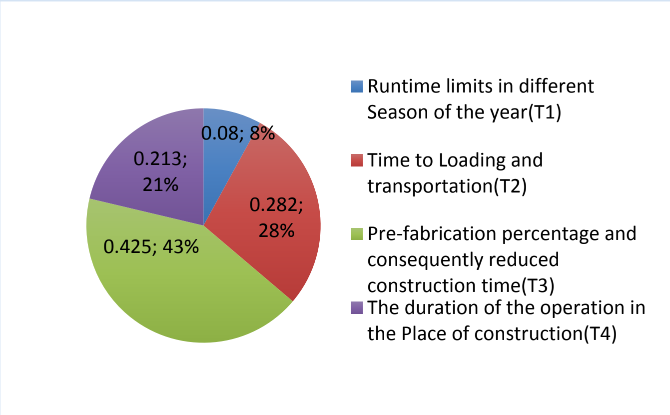

Fig.3. The relative weight of the sub-criteria in evaluating the construction time

Technical specifications analyses are shown in Fig.4. According to the results of the analyses, it is clear that the environmental friendly materials are in the top priority.

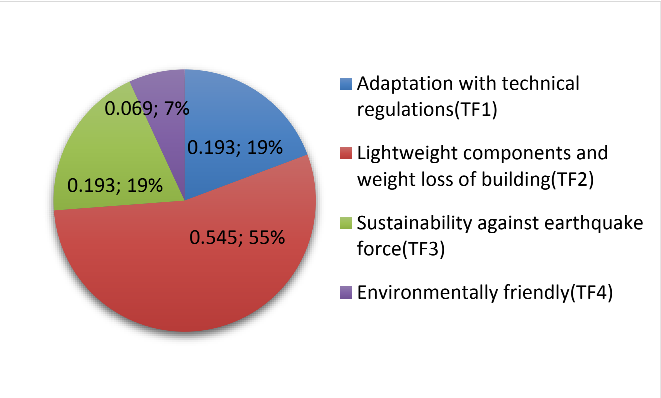

Fig.4. The relative weight of the sub-criteria in evaluating the technical specifications

The analyses of executive features of methods are shown in Fig. 5. According to the results, the least need for machines and the modularity of components are of the highest priority. Modular construction, when optimized and capably delivered, can demonstrate a series of benefits over traditional construction for appropriate projects

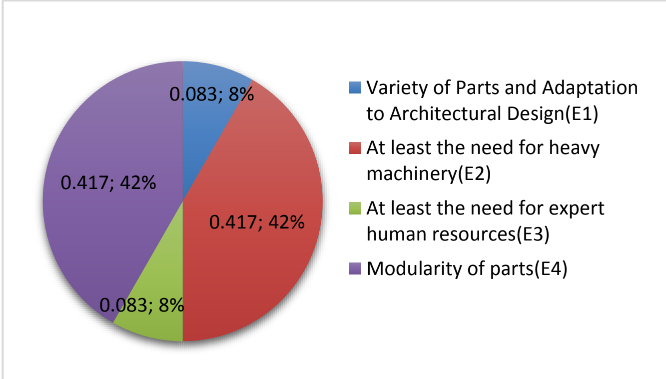

Fig.5. The relative weight of the sub-criteria in evaluating the executive features

And finally evaluation of structural systems results is shown in Fig. 6. According to the scores and ranking shown in this figure, the best choice has been 3D Panel. Then ICF is preferred and large panel system was determined as the worst alternative according to the AHP ranking.

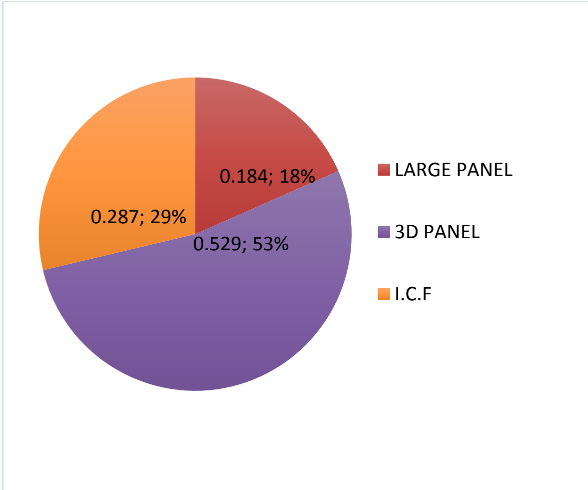

Fig.6. The relative weight of three structural system

6. Conclusion

Application of new methods and structural systems can promote the construction techniques. Selecting the appropriate structural system has a significant influence in projects success. AHP method is well-known decision making technique but using it in the selection of proper structural systems is a new application in construction industry. Identification of criteria can also be an important issue in such a selection process and the case of this research can provide a recommendation for other researchers. The decision matrix was used to calculate the criteria weights. Relevant criteria were compared against each other and the following criteria have achieved the highest importance:

1. Cost of production, has a degree of importance of 62% compared to other sub-criteria in evaluating the construction costs.
2. In the analyzing the construction time, pre-fabrication percentage the construction time has the degree of importance of 42.5% compared to other sub-criteria.
3. Weight of parts, has the degree of importance of 54.5% compared to other sub-criteria in evaluating technical specifications of all methods.
4. Minimum requirements of heavy machinery and modularity of components from executive features, has the degree of importance of 41.7% compared to other sub-criteria.

And finally the analyses showed that considering all of the economic conditions and construction technologies in Iran, the 3D panel structural system is the best option, and then the ICF structural system is the second and the large panel structural system is third option.

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