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Insulated Concrete Formwork Systems (ICFs) from the Perspective of Project Management

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Abstract: Affordable industrial housing is possible due to the high efficiency of production factors, repetition of production process, low cost and economically efficient housing and providing detailed financial and executive plans. Industrial housing mass production requires efficient management to benefit from modern technologies on the one hand and domestic capabilities on the other hand. Insulated Concrete Formwork system (ICF) is of new structural systems that is widely used in many developed countries such as America and Canada. This system consisting of a wall filling with concrete that has permanent formworks where it is considered as a part of wall after concreting and acts as a thermal insulation. According to the studies conducted, we can say in this study that compared with today's traditional and conventional systems as well as new structural systems that have emerged over the past few years, ICF system has had an acceptable performance and perhaps the most important weakness of such system is the need for skilled manpower and relatively high cost raw materials which considering other parameters involved is not a big weakness for the whole system. Also, given the reduced project duration with this system compared to other systems and high levels of energy saving in projects that use this method in the construction, economic benefits can be considered as one of the main features of this system. In this study, after a brief introduction of ICF features, this system will be examined from the perspective of project management and according to three parameters, cost, time and human resources.

Key words: Insulating Concrete Formworks (ICF), modern structural systems, project management, Canada, America

INTRODUCTION

Rapid population growth and thus increased demand for housing as well as issues affecting the quality and price of the buildings have caused a change in construction methods. Meanwhile, one of the ways to improve this situation is to industrialize building production. This reduces a lot of cost and speeds up the construction process. Building industrialization systems include all activities related to design, technologies and construction methods and manufacturing building pieces and components. In this method, building components are manufactured in factories under the industrial system and then tested in different aspects of quality and transmitted to the workshop. Thus, few building operations will be done in the workshop and the production will be increased (Saba and Qolizadeh, 2012). The most important purposes of using this method are improving quality and speed of construction and cost reduction whose results can be summarized as follows (Hemati and Nazer, 2012):

- Building earthquake resistance and strengthening
- Lightweight construction
- Reduced materials waste
- Energy efficiency
- Reducing the volume of construction operations in the workshop and increased production in the factory

Given that three elements of land prices, construction costs and profit from construction determine the final price of housing as in our country, land price comprises 40-50% of the final price of housing, it can be stated that increasing the share of land prices in building construction increases the initial investment which leads to the reduction of liquidity during the project. Hence, lack of preparation of an accurate financial plan and liquidity control during this period affects the whole project so badly. Also reducing the share of land prices per production unit and proper executive planning by reduction of unhelpful spaces and saving shared spaces, further possibility for taking advantages from pre-built technology, decrease in the cost of heating and cooling installations per production unit are all some of factors reducing the cost price of each square meter of the area over the process of industrialization. Among other influential factors, reduction of construction period by m^2, improvement of the building quality, innovation, efficient use of urban infrastructure, etc., can be mentioned. So, it is undeniably necessary to move towards industrial construction of buildings. In fact, building industrial production is a process including every construction phase from financing to obtaining the necessary licenses and permits, selection and application of construction technology, sales and marketing, after-sales services, utilization management. Some of properties of the industrialization are quality improvement, more speed, faster return of capital and therefore more economical projects, raising the skills of manpower and variation in the composition.

MATERIALS AND METHODS

ICF system, structural properties and behavior

Specifications and features: ICF system stands for insulating concrete formwork which is a type of construction system composed of Reinforced Concrete (RC) and Expanded Polystyrene Panels (EPS) where RC acts as a load-bearing component and polystyrene panels function as concrete formwork and thermal and acoustic insulation (Hemati and Nazer, 2012). This system was invented in Germany during 1970s and 80s and developed with an impressive speed in North America as a basic structure. This system is designed and developed by different methods all of which consist of two layers of insulation foam usually made of EPS are parallel to each other in different distances and become a part of the wall after concreting. The two layers are connected to each other by armed elements which are installed between them (Fig. 1).

Joining components are mostly made of plastic or straps made of galvanized sheets (Golabchi and Mazaherian, 2010). Formworks are mainly made of expanded polystyrene but other materials such as composite polystyrene, cement or polyurethane foam are also used. These formworks are different from each other in terms of size, geometrical shape of holes and type of components and are divided into three types of block and vertical and panel in terms of shape and size. Blocks are smaller in size compared to the other types and are normally made in 120×30 cm dimensions. Board or strip forms are usually larger up to 240×30 cm which are transferred to the building location in two separate boards with 5 cm thickness and then they are adjoined to each other using plastic connectors.

Panels are so diverse in size and dimensions and are normally made up to 120×360 cm (Kari and Jahromi, 2008). Some of the features and benefits of ICF system include (Hemati and Nazer, 2012):

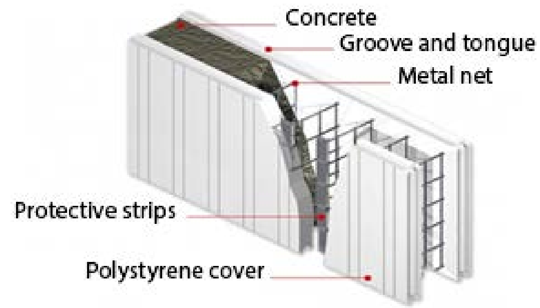

Fig. 1: Layers of insulation foam

- Complying with national building regulations (Section 11)
- Possible to be integrated with other construction systems
- Easy transport and shipping and fast implementation
- The possibility of embedding openings in the walls with different dimensions
- Flexible design and creating various forms
- High quality especially in concreting
- Suitable for a variety of building facades
- Reduced materials waste
- No need to implement the formworks in concreting
- Increasing building resistance and strength, building protection against environmental conditions
- Reducing the weight of the building
- Thermal, cooling and acoustic insulation
- The possibility of passing and installation through walls and ceiling

Seismic behavior of ICF system: Load-bearing walls (shear walls) and thermal insulated roof joists or ICF slabs are the main load-bearing elements of building constructed through this method. What is of great importance in such buildings is the role of structural walls as the main elements resisting lateral loads as well as key members (in combination with ceiling slab) to withstand and transfer vertical loads due to lack of beams and columns. In this system, gravity and lateral loads are uniformly transferred to the foundation by wall and slab system. To avoid local stress and concentration and to minimize the effect of torsion, the bond in the structural shear walls must be preserved throughout the building height.

The bond created in the wall and ceiling by in-situ concrete leads to a good seismic performance and horizontal and vertical bond of the structural components and delay in the formation of plastic zones and in members and critical points of the structure such as wall-ceiling connections or around the walls openings and thus this building system will demonstrate an appropriate seismic performance. The greater the number of structural members participating in load-bearing with more independent performance is the more suitable and better the system will be. If structural walls are sufficed in terms of number, there will be many uncertainties in the system and like in parallel systems we expect to witness an acceptable seismic behavior from the system. One of the seismic features of such systems is low fundamental period of the structure due to the plurality of load bearing walls of reinforced concrete in the main line of the building and this will lead to a considerable attraction of the acceleration and earthquake force which may remarkably damage non-structural components and the equipment inside the building. That's why the amount of load-bearing walls in plan should not be more than building structural needs and to reduce the dead load of the building and system's additional stiffness and proper use of the infrastructure to build walls of blade, it is recommended that other common and valid systems be used (Kari and Jahromi, 2008).

RESULTS AND DISCUSSION

Evaluation of the system from the perspective of project management considering three parameters: cost, time and human resources

ICF system operating costs: Cost estimation is one of the most important steps of the project management. In other words, cost estimation determines the main path of expenses in various stages of developing the project. The costs of implementing a construction project is so important that specifies whether it is feasible to be operated or not. To manage the project so properly, it is of high importance to determine the minimum costs which includes: direct expenses including material, labor and equipment, office costs and general spending, other operating expenses.

Sawhane and Mund (2008) conducted a study on executive costs of new structural systems. A part of this research is shown in Table 1 about a comparison between equipment and labor costs as well as material prices per square foot of ICF system in dollar and AAC (Autoclaved Aerated Concrete) and SIP (Structural Insulated Panels) systems.

As shown in Table 1 and according to research done by Stroh (2001) one of the weaknesses of the ICF system is its high initial costs. According to the Department of American Energy, the initial costs of implementing ICF system on average is 4% higher than common timber-frame structures (wood frame) which are used in developed countries (US Department of Energy, 2003). Figure 2 represents the comparison between operating costs of each square foot of the three systems including

Table 1: A comparison between material and equipment costs and labor expenses per square foot in three structural systems

Items	AAC	ICF	SIP
Material costs	~\$2.95/ft²	~\$3.25/ft²	~\$3.20/ft²
Equipment and labor costs	~\$2.25/ft²	~\$2.00/ft²	~\$1.25/ft²

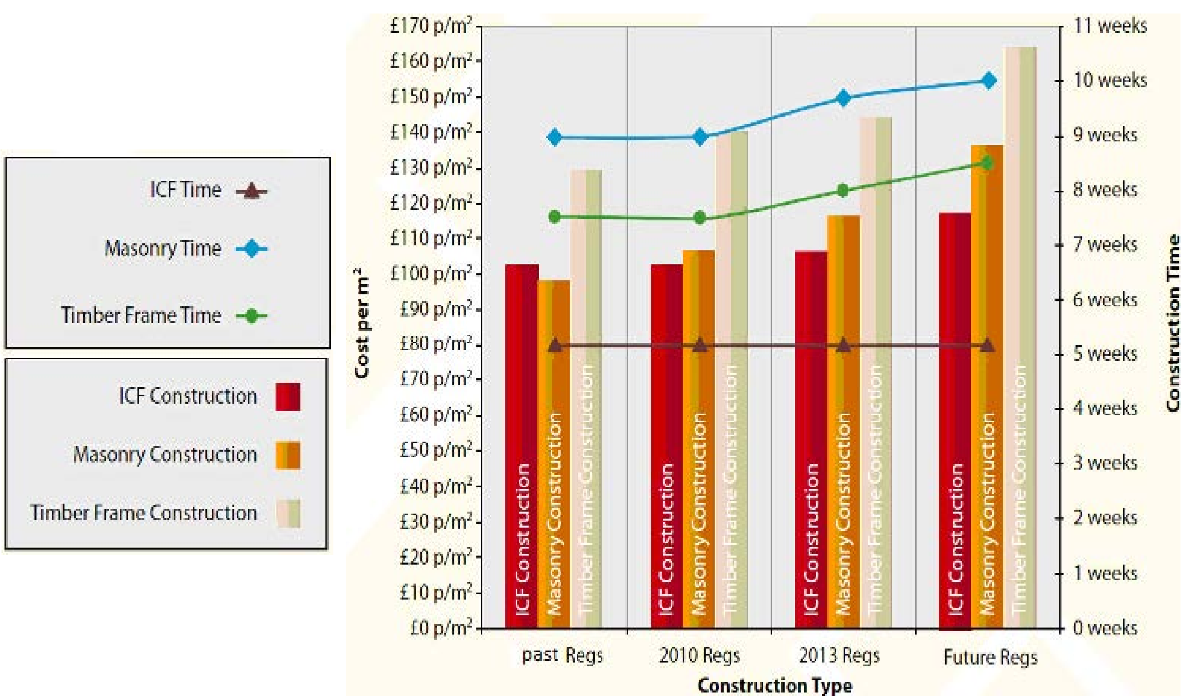

Fig. 2: A comparison between costs and time of the construction of three structural systems

Table 2: A comparison between costs of constructing a building skeleton with ICF system and ordinary concrete moment frame system (Rashidian and Mahdavi Adeli, 2013)

			Concrete structure		ICF structure	
Item description	Unit	Unit price	Amount	Total cost (Rial)	Amount	Total cost (Rial)
Providing ribbed rebar in every diameter	Kg	19500	23587.58	459957810	14246.27	277802265
Providing concrete grade of 300 kg/m^3	M^3	850000	130.77	111154500	152.63	129735500
Providing concrete piles with transferring	M^2	159650	625.95	99932920	625.95	99932920
First grade styrofoam in 1×0.5 m	Number	16500	451	76219000	462	78078000
Providing clay bricks in 20×20×15 cm with transferring and unloading	Number	3050	12243	37341150	-	-
Wage of building brick walls	M^2	48000	489.72	23506560	-	-
Providing cement bags type 2	Ton	1370000	48.58	66554600	37.15	50895500
Providing sand with transferring it to brick wall building	Ton	140000	57.76	7226400	-	-
Wage of formatting, rebar binding, concreting with all equipment and devices	M^2	370000	625.95	231601500	-	-
Wage of operating ICF formwork and rebar binding, concreting with all equipment and devices	M^2	350000	-	-	625.95	219082500
Providing insulated formwork with transferring	M^2	400000	-	-	490	196000000
Plaster and soil coating with 2.5 cm thickness	M^2	42760	489.72	20940427	-	-
Water insulation with pitch and one layer of sack on the wall	M^2	127220	18	2290000	-	-
Providing rebar binding wire	Kg	40000	80	3200000	75	3000000
Cost of concrete pump for concreting	M^2	63330	625.95	39641413	625.93	39641413
Total (Rial)				1.180.566.280	1.094.168.098	

ICF, masonry building and timber-frame structures and the time required to perform each system during changes in executive regulations in different years. This chart has been prepared by an English contractor under the Eurozone. As is clear in figure, it is anticipated that changes in regulations will lead to the significant reduction of ICF system operating costs and time within the eurozone compared to the timber frame systems and masonry constructions.

Comparing ICF structural system and modern systems it can be concluded that costs of material equipment and implementation of the system is higher than other new systems. But according to the comparison between ICF costs and traditional and conventional systems which are currently used in our country, operating this system cost far less than abovementioned systems. In Table 2, costs associated with construction of a building skeleton with fixed dimensions in ICF system and ordinary concrete moment frame are demonstrated. As seen in the table, the cost price of building a skeleton in new ICF system is reduced by removing several steps of the project such as building a brick wall, insulation, etc.

Also to avoid waste of energy in each structure, some rules must be observed. Implementation of existing standards in the country in order to prevent energy waste in construction of a building costs 35000 Tomans per m as a result the cost price in only increased by 10% but this figure accounts for only 1% of the commercial property price. Although, the implementation of Article 19 of National Building Regulations is now mandatory in the constructions but it is only monitored in the industrialization process. Meanwhile, if these regulations are strictly operated, 211 million barrels of crude oil equivalent will be saved yearly. Integration of material type to avoid energy losses is addressed extensively in scientific discussions (Shilei *et al*., 2007). Soil, rock, sand, plaster, etc. are materials that prevent energy waste at an intermediate level (Kuznik *et al*., 2008; Dincer and Rosen, 2011; Farid *et al*., 2004). Figure 3 shows the heat flux per day for exterior surface of timber frame, masonry construction and ICF system. As you can see, ICF changed temperature during 24 h was fixed which reflexes the strength of this system in insulation shown in Fig. 4.

Operating time in ICF system: If a construction project does not come into use in a certain time, it'll lead to losses and amortization and the investment will remain useless. So, project execution time is important in particular thus timing must be considered and controlled so accurately in planning the projects. To do this, we need to have the exact information about volumes and costs. The time required to complete and implement a construction project depends on several factors must be considered in estimating it. Selective structural system in a construction project is one of the main factors that has a great impact on the time required to complete the whole project. Table 3 represents time and cost needed to complete a construction project with their properties (Fig. 5) in an area of 2180 sq. ft. with timber frame construction, sandwich panel, ICF, SIP and AAC systems.

As it can be observed in Table 3, among systems including timber frame construction, sandwich panel, SIP, ICF and AAC, ICF structure system takes the third rank in

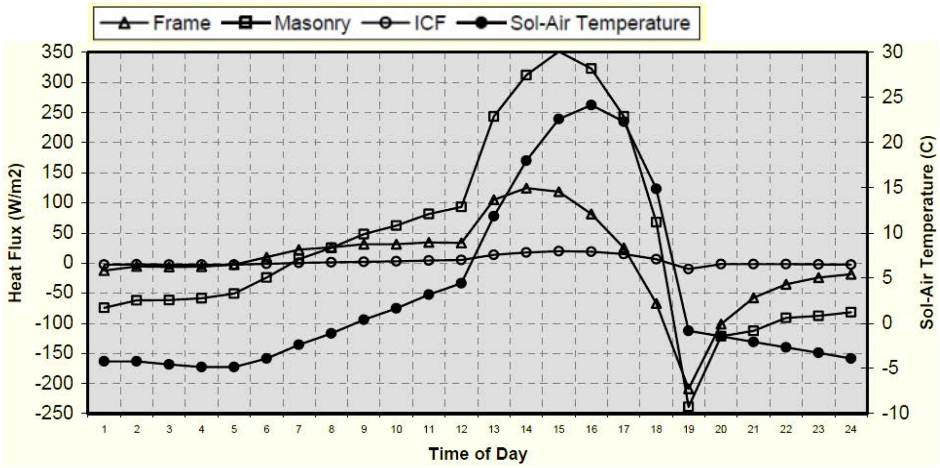

Fig. 3: Heat flux per day for exterior surface of timber frame, masonry construction and ICF system (Arthur and Ribando, 2004)

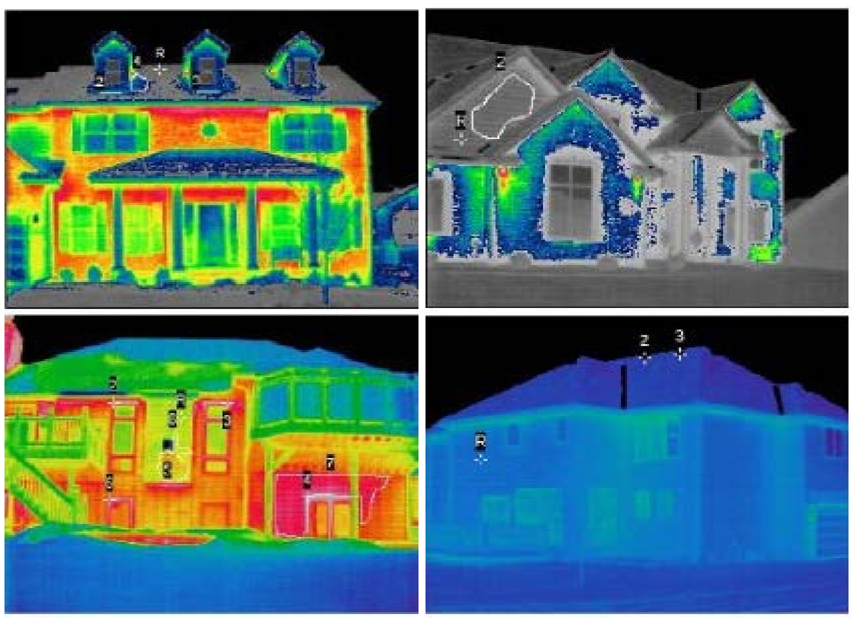

Fig. 4: The amount of energy waste in ICF system (right) and timber frame construction (left) (Arthur and Ribando, 2004)

Table 3: Operating time and costs (dollar) of the structure of Fig. 5 with different structure systems (Bloustein, 2014)

Variables	Time on site	Cost
Wood frame wall	Complete in 3-4 months (erected 2-3 days)	$4.24
Precast concrete sandwich panel	Complete in 2-3 months (erected in a few days)	$41.11
Insulated Concrete Forms (ICFs)	Complete in approx. 2 months (erected in a few days)	$27.47
SIPs	Complete in 2-4 weeks	$17.01
AAC	4 min a block/less than a month	$10.10

time and the second in terms of costs. A small tem is able to finish building up the foundation and skeleton of an ICF structure system with typical dimensions in less than a week and the remaining time is generally spent on full completion of the project in this system. Complexity of the project, location and the climate of the region the project is operated in are also very important factors which must be calculated in determining the implementation time.

Comparing with systems used in single building projects, the competitive advantage of this product is the speed of executing its forming part. But in mass produced housing, this system is slower than some in-situ concrete systems such as tunnel system. In addition, the components are insulated thermally to high extent which

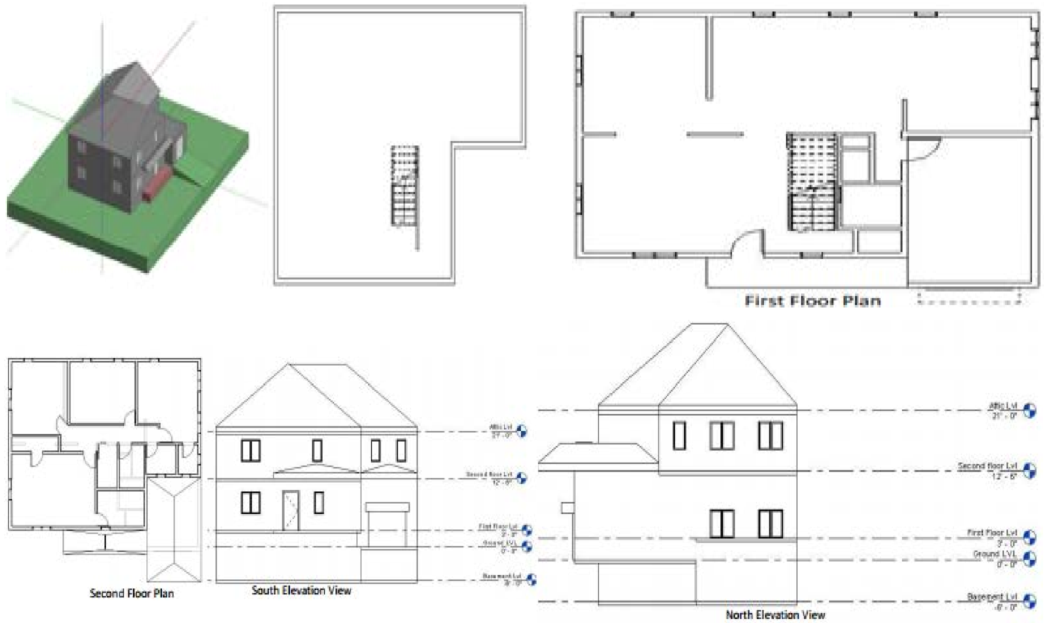

Fig. 5: Plan model of the structure studied (Bloustein, 2014)

Table 4: Labor skills necessary to work in different new structure systems (Maloney, 1997)

Variable	Wood frame wall	Precast concrete sandwich panel	Insulated Concrete Forms (ICFs)	SIPs	AAC
Labor needed	No specialized expertise required	Repeated use of materials can reduce cost	Expertise needed	Expertise needed	Trained labor

achieving the expectations set out in the National Building Code is so easy. Besides, given the fact that there is no restriction on the form in this system, parallel actions in various parts of the project and creating the necessary overlaps between different executive activities will reduce the project time.

It is also essential to note that since thermal insulation forms are used in this system, it is possible to concrete in different temperature conditions and in most seasons. And considering the point that thermal insulation is done at the same time with building the wall in this system, thus performing the elaborated work inside and on the façade can also be done more easily and rapidly (Kari and Jahromi, 2008).

Human resources needed in ICF system: Human resources play and important and key role in companies operating in the construction industry and urban mass produced housing. These companies won't be able to achieve their business goals without regarding various needs and circumstances of human resources. Given that diverse human resources are working in this industry, it is so difficult and challenging to manage and control them. Table 4 shows the human resources skills necessary to work in different new structure systems. Mehrian has done a comprehensive investigation on rationale of the crack growth in concrete and related response under thermal shocks (Nowruzpour Mehrian and Naei, 2013; Vaziri *et al*., 2015; Nowruzpour Mehrian *et al*., 2013; Mehrian and Mehrian, 2015; Nowruzpour Mehrian *et al*., 2014; Mehrian *et al*., 2016). As seen in the above table, the specialized labor forces are not required in wood frame structure system and low-skilled labor can be used in the project. In sandwich panel though, in case that human resources have experiences of working with materials, the level of productivity of labor force will be raised and thus the costs will be reduced. In SIP and ICF systems on the other hand, the specialized expertise are used in the project who must have passed high level courses before stating to work. In AAC system, the labor needs to be trained on intermediate level to begin their job.

As mentioned before, to implement the ICF system, highly specialized human resources is required. But at the same time it should be noted that since formworks are low weight and light in this system, they can be easily transferred and thus easily moved in the workshop so the labor force won't need to put a lot of energy on that. While more people are needed to move forms in conventional systems and since the formworks are so heavy, more manpower, more time and eventually more money are needed. The last point is that relatively fewer human resources are needed to implement this system than other systems (Kari and Jahromi, 2008).

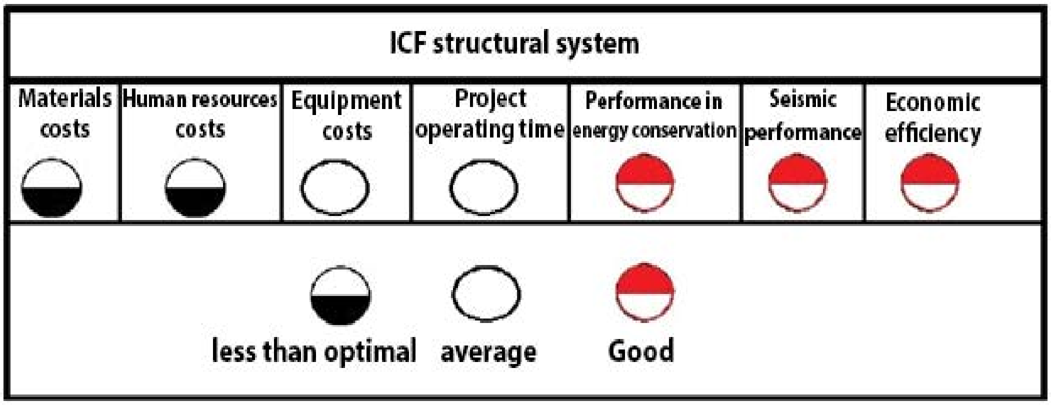

Fig. 6: Summary of ICF system performance

CONCLUSION

In this study, the performance of Insulated Concrete Formwork (ICF) was examined from the perspective of project management considering three parameters, time, cost and human resources. According to the studies conducted it can be stated that the performance of this system in various aspects is acceptable and it has the potential to be replaced with many traditional construction systems in the country. So with high approximation we can conclude that this structural system is better than conventional systems in all directions and aspects that many steps in the traditional systems are eliminated in this system which is resulted in creating a more resistant and more integrated structure. Furthermore, ICF system has a better seismic performance than traditional structures in the country.

Perhaps, the major problem with this structural system is that it requires skilled and specialized employees besides the raw materials needed here are relatively costly. But, it takes less time to operate the projects using this system than other new structure systems and it is one of the best structures among others in terms of performance in energy and economy efficiency. Figure 6 summarizes the multilateral information on this system.

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