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GREEN AND COST-EFFECTIVE SOLUTIONS FOR THE TEMPORARY ACCOMMODATION AND RURAL SETTLEMENT

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In this study, usage of silica fume, fly ash, pozzolan, marble powder, crushed glass, and ceramic as cement additive along with recycled concrete aggregate as concrete aggregate is examined. Savings of this replacement in terms of cost, CO2 emission, and waste production is computed. Concrete mix design formulae obtained by literature review with compressive strength more than 20 MPa are used. A spreadsheet application for the quantity take-off of a typical rural house and barns is prepared. Amount of reduced cement, thus CO2 emission and cost is computed by the application which makes the comparison of different mix designs feasible. Consequently, the most suitable mix design for the structure is determined. Hence buildings in the rural areas can be designed and constructed with the minimum cost and CO2 emission as well as with the maximum usage of waste materials. Similarly temporary accommodation facilities built for disaster management can also be constructed by considering the environmental criterion. This approach will also save significant amount of CO2 emission since thousands of temporary accommodation facilities are constructed after a destructive earthquake.

Keywords: *green building; CO2 emission reduction; cementless concrete*

SOLUCIONES ECOLÓGICAS Y RENTABLES PARA EL ALOJAMIENTO TEMPORAL Y LA SOLUCIÓN RURAL

En este estudio, se examina el uso de humo de sílice, cenizas volantes, puzolana, polvo de mármol, vidrio triturado y cerámica como aditivo de cemento junto con agregado de concreto reciclado como agregado de concreto. Se calcula el ahorro de este reemplazo en términos de costo, emisión de CO2 y producción de desechos. Se prepara una aplicación de hoja de cálculo para el despegue de cantidades de una casa rural típica y graneros. Cantidad de cemento reducido, por lo tanto, la aplicación y la emisión de CO2 se calculan, lo que hace factible la comparación de diferentes diseños de mezcla. En consecuencia, se determina el diseño de mezcla más adecuado para la estructura. Por lo tanto, los edificios en las áreas rurales se pueden diseñar y construir con el costo mínimo y la emisión de CO2, así como con el uso máximo de materiales de desecho. De manera similar, las instalaciones de alojamiento temporal construidas para la gestión de desastres también se pueden construir considerando el criterio ambiental. Este enfoque también ahorrará una cantidad significativa de emisiones de CO2 ya que miles de instalaciones de alojamiento temporal se construyen después de un terremoto destructivo.

Palabras clave: *edificio verde; Reducción de emisiones de CO2; hormigón sin cemento*

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1. Introduction

Throughout the world, millions of people are homeless due to political and economical conflicts and natural disasters. According to the report of United Nations High Commissioner for Refugees (UNHCR) 22.5 million people are refugees. Approximately 55% of the refugees come from Syria, Afghanistan and South Sudan. Top hosting countries are Turkey, Pakistan, Lebanon, Islamic Republic of Iran, Uganda, and Ethiopia with 3.5, 1.4, 1.0, 1.0, 1.0, and 0.8 million refugees respectively. In order to prevent adverse social consequences mass accommodation units are constructed at refugee camps by the corresponding countries.

Besides the refugees, natural disasters also cause significant amount of displaced people. Especially earthquakes lead to mass destruction of buildings and infrastructures. Aftershocks obstruct the retrofit and reconstruction activities for more than four mounts after a destructive earthquake. Therefore victims of earthquakes require temporary accommodation and utility facilities during the recovery period.

Accommodation necessities of both refugees and victims of natural disasters are mainly provided by governments and charities. Temporary houses are constructed in Italy in 1976, in Mexico in 1985, in Greece in 1986, in Japan in 1995, in Turkey and in Columbia in 1999 (Johnson, 2007), and in Turkey in 2011 (Bettemir, 2012). However, costs of temporary facilities are significant expense item even for governments. Construction cost of temporary accommodation facilities for the victims of Van earthquake cost more than half a billion dollar. Operation cost of the facilities was higher than the construction cost. The governmental expense for the victims of Van Earthquake was more than 2 billion dollars.

Besides the high cost, construction and utilization of the temporary accommodation facilities tremendously harm the environment. Usually container type prefabricate structures are preferred since their in situ construction activity requirement is less than the traditional construction methods. However, containers are made of steel and aluminum whose productions consume high energy. In addition to this, containers occupy very high volumes and their transportation to the site requires significant amount of traffic and utilization of trucks and cranes.

Heat insulation is usually omitted or superficially applied for the temporary accommodation facilities. In addition to this, low cost electric heating devices with low efficiency are preferred to reduce construction cost. Therefore, heating of the temporary houses consumes exceptionally high amount of energy (Bettemir, 2016).

Temporary accommodation facilities are dismantled afterwards the construction of permanent houses. The site of the temporary houses becomes contaminated and reuse of the site for another purpose becomes costly (Felix et al., 2013). Moreover, recycling of the construction materials of the temporary facilities is not economically feasible and only metal components are reused (Arslan, 2007; Arslan and Cosgun, 2008). Removal of the temporary accommodation facilities is also an important cost item. Consequently construction of temporary facilities for the refugees and victims of natural disasters is not a proper solution due to its high initial cost, long construction duration, inefficient heating utilities, inadequate comfort, detriment to the environment, high removal cost, and relatively short usage period.

Construction of temporary houses can be avoided by slightly improving the quality of the accommodation facilities. Instead of constructing temporary and permanent houses, the temporary houses can be constructed as permanent house especially in rural areas, slums and refugee camps. This approach will provide the opportunity of obtaining significant amount of savings in terms of construction duration, construction cost, occupied land, and environmental effects. The cost of permanent accommodation facilities can be reduced by using waste materials such as glass, fly-ash, waste marble dust, and grinded waste ceramics. In addition to this usages of grinded rubber tyre, and pumice as aggregate provide heat insulation. Moreover light weight aggregates reduce the weight of concrete and foundation cost as well.

Light-weight concrete with 10MPa compressive strength and heat insulation capability concrete can be obtained. The aimed compressive strength of the concrete is adequate if the walls of the structure are designed as load bearing walls. In this case, the structure would require less reinforcement bars and thick external walls would provide enough heat insulation. Construction cost and workmanship decreases by reduced amount of reinforcement bars and insulation materials. In addition to this, high amount of waste materials would be used for the construction of the facilities which would significantly reduce the area occupied by waste sites.

Low cost accommodation facilities can be used as permanent houses as refugee camps with no additional cost compared with the cost of temporary accommodation facilities. In addition to this, slums of the urban area and the village houses with incapable structural strength can be replaced by the proposed structure. This replacement will significantly improve the life quality of the people and reduce the cost of both aids for the refugees and the emergency management.

The next section of the article explains the concrete mix design with waste materials, structural analysis and cost analysis of the proposed accommodation facility is illustrated in the third section, and the expected benefits by the utilization of the proposed facility is given in the discussion of results section. Finally the findings of the study and further studies are given in the conclusion section.

2. Methodology

Gu and Ozbakkaloglu (2016) states that even though the improvements in the public awareness, ratio of recycled plastic in municipal solid waste to generated plastic had been increased from 0.30% to 8.3% from 1980 to 2012 (EPA 2014). The obtained progress is important but inadequate since land-filling occupies significant amount of area and leads to long-term pollution problems. Besides land-filling wastes can be evaluated by incineration and recycling (Gertsakis and Lewis, 2003). However, incineration causes emission of huge amounts of carbon dioxide and poisonous gases as well as it generates toxic fly as and bottom ash. Therefore incineration of polymers is not a proper choice for the waste management. The third option is the recycling and reuse of the waste materials.

Concrete is very suitable medium for the reuse of waste material as cement additive and concrete aggregate. Thus significantly many studies have been conducted on the reuse of waste materials at concrete structures. Reuse of polymers as concrete aggregate has effects on the physical, thermal, and mechanical properties as well as durability of concrete. Substitution of conventional aggregate with waste polymers decreases the slump thus workability. Polymers have lower density than conventional concrete aggregates and utilization of polymers as aggregate or fiber decreases the density of concrete.

Natural aggregate and polymer aggregates do not uniformly mix in the concrete matrix and this heterogeneity increases the air content and porosity of the concrete (Ravindrarajah, 1999; Tang et al., 2008). Decrease of compressive strength shows almost linear trend with the ratio of substituted polymer as coarse aggregate (Wang and Meyer, 2012). However, utilization of polymers as fiber in small amounts can increase the compressive strength (Han et al., 2005; Song et al., 2005; Hsie et al., 2008). Splitting tensile strength represents similar behavior with compressive strength where substitution of massive amounts of polymers as coarse aggregate decreases the splitting tensile strength of the concrete. On the other hand, adding polymer fibers improves the splitting tensile strength (Gu and Ozbakkaloglu, 2016).

Insertion of waste polymers as aggregate and fibers improves the abrasion resistance of the concrete (Ferreira et al., 2012; Saika and de Brito, 2014). Yesilata et al. (2009) observed up to %18 of improvements at the thermal insulation properties of the concrete by adding %1,7 polyethylene or rubber.

Wang and Meyer (2012) recorded that thermal conductivity reduces to 87%, 69%, and 44% of that the control specimen if 10%, 20% and 50% high impact polystyrene is substituted respectively. The 28 day compressive strength of the 50% HIPS substituted specimen is measured as 14 MPa. Fraternali et al. (2011) obtained approximately 20% of decrease in thermal conductivity by adding 1% of volume fraction of polyethylene and plastic fibers. Mondal et al. obtained 17 MPa of compressive strength with 15% fly-ash and 10% waste plastic. Bulk density of the specimen is measured as 1.66 gr/cm^3 and the thermal conductivity reduced to 0.40 w/(m.K).

Dweik et al. (2008) replaced fine and coarse aggregate with melamine-formaldehyde (MF) and obtained significant improvements on the thermal insulation properties. Sand is replaced with various percentages of MF up to 60% by volume. Thermal conductivity of the specimen reduced to 0.27 w/(m.K) when 60% MF is substituted. Compressive strength of the specimen was measured as 22 MPa which represents that substitution of MF provides good heat insulation without significant decrease in compressive strength.

Substitution of waste polymers improves the heat insulation but reduces the compressive strength of the concrete. If the building is designed as reinforced concrete frame structure, substitution of waste material should not be more that 5% of volume. In this case, loss of strength would be negligible but the improvement of the heat insulation would be inadequate. Therefore application of heat insulation would still be imperative.

Rural settlement, slums, and temporary houses used for disaster management and refugee camps are one-storey without frame structure. Traditionally those houses are constructed with load bearing walls. Compressive strength of 8 MPa is adequate for the load bearing walls of a one storey structure. In this case, coarse aggregate can be replaced by polymers at higher fractions of volume and adequate improvement in thermal conductivity can be obtained. Moreover, load bearing walls should be constructed as thick walls encircling the whole house which provide heat insulation at all portions of the house.

Load bearing walls are usually constructed as one and a half brick wall which has a thickness of 32.7 cm. The proposed concrete structure with high amount of reused waste material can be designed with similar dimensions and the thickness of outside walls can be taken as 35 cm. This approach provides enough space for adequate heat insulation and additional heat insulation requirement would be avoided. However, this requires thermal conductivity of the concrete being less than 0.40 w/(m.K). Literature review showed that the mentioned thermal conductivity can be achieved if the aggregate is substituted at least 25% of volume fraction by melamine-formaldehyde or plastic.

In order to measure the decrease in the compressive strength of the concrete by substituting the aggregate with high amount of waste plastic and light aggregate an experiment is conducted with substitution of 10% of pumice, %8 latex and 13% of waste plastic and 10 MPa compressive strength is obtained at the end of 7 day. The experiment reveals that proper thermal insulation and load bearing capacity can be obtained at the same time by using high amount of waste plastics.

3. Utilization of High Amount of Waste Plastic in Concrete

Experiments have revealed that concrete with more than 10 MPa compressive strength can be obtained even if more than 80% of the aggregate is replaced by polymers. Concrete mix design with 200 kg concrete, 50 kg silica fume, 50 kg recycled and crushed glass, 50 kg fly ash, 250 kg pumice, 50 kg marble powder, 50 kg of ceramic, 300 kg conventional aggregate, 50 kg melamine-formaldehyde, 200 kg water, and 600 kg polymer as fine aggregate, coarse aggregate and fiber can reach 10 MPa characteristic compressive strength.

Density of this mix design is approximately 1.9 ton/m^3 and its average thermal conductivity can be accepted as 0.40 w/(m.K). Outside walls with 35 cm thickness can provide enough heat insulation and no additional heat insulation application would be necessary. Silica fume, crushed glass, marble powder, grinded ceramic, and melamine-formaldehyde have approximately the same unit price with cement when handling, cleaning, and grinding costs are considered. Similarly waste auto tires and polyethylene bottles can be obtained at a very cheap price. However, their handling, cleaning, and grinding costs make them equally priced with conventional aggregate.

One cubic meter of concrete with high amount of waste plastic costs approximately 50$. At first glance, this concrete can be unfeasible due to its weak compressive strength. However, this concrete would not require any heat insulation expense. Furthermore, it will be used as load bearing wall and therefore no reinforcement with reinforcing steel is necessary. As a result, significant saving will be obtained from this two cost items. The total cost of implementation of such a system is computed by a traditional one storey rural house. Architectural plan of the house is shown in Figure 1. The quantity take-off of the house is first performed by considering the fact that it is constructed as reinforced concrete structure. At the second case quantity take-off of the structure is prepared by assuming that it is constructed by concrete with high amount of waste plastic.

Bid of quantities and the construction costs of two houses are compared in Table 1. Alternative 2 is constructed by precast concrete elements and therefore it requires less workmanship. However, Alternative 2 requires lifting equipment for the placement of the precast elements. Savings from the heat insulation, exterior bond wall, reinforced concrete frame, and plastering makes Alternative 2 $9000 cheaper than Alternative 1. Initially the saved amount might be considered as unimportant, but if 35.000 temporary accommodation utility is constructed by this approach $315 million would be saved.

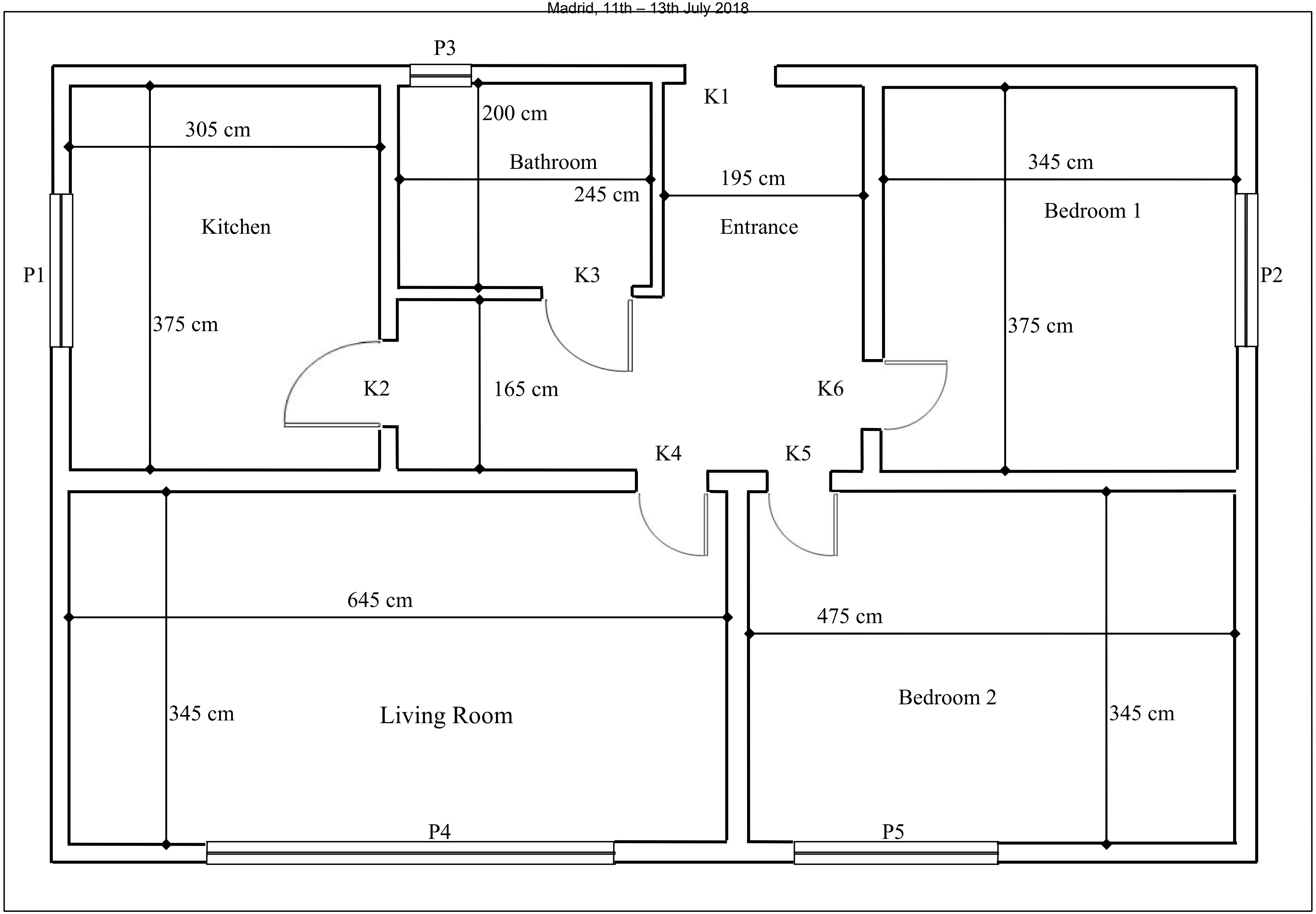

Figure 1. Floor plan of proposed accommodation facility

Table 1. Comparative cost analysis of two construction alternative

	Reinforced Concrete			High Waste Plastic Concrete		
Activity	**Quantity**	**Unit Cost**	**Cost ($)**	**Quantity**	**Unit Cost**	**Cost ($)**
Grading (m^3)	24	1,5	36	25	1,5	37,5
Excavation(m^3)	12	2,5	30	64	2,5	160
Formwork (m^2)	250	12	3000	15	12	180
Concrete (m^3)	28,5	45	1282,5	11	45	495
Reinforcement (ton)	3,2	750	2400	1,6	750	1200
Exterior Wall (m^2)	68	12	816	36 m^3	60	2160
Interior Wall (m^3)	85	9	765	85	10	850
Insulation (m^2)	95	12	1140	0	0	0
Plastering (m^2)	300	10	3000	0	0	0
Painting (m^2)	395	8	3160	110	11	1210
Roof (m^2)	100	15	1500	100	18	1800
			17129,5			**8092,5**

Besides the economic savings, the high waste containing concrete uses significant amount of waste material and prevents pollution. Using precast materials reduces construction waste and construction activity related pollution. In addition to this, construction of temporary houses can be avoided and cost of disaster management can be decreased. Furthermore refugee camps can be constructed by high waste containing concrete.

4. Construction Technique and Plan

Execution of construction activities at a disaster zone is difficult since the excessive fear of the local people, insufficient number of workers and construction machines, and difficulties on the material supply. Therefore, requirement of workers, construction machines and the construction duration must be minimized. In order to minimize the construction cost and duration the accommodation utilities should be constructed by specially designed precast construction elements. The construction technique is suitable for mass construction of accommodation utilities such as a refugee camp.

Excavation for the foundation and the foundation activities have to be executed on site. The excavation can be performed in one day. Then water insulation of the foundation and the foundation itself can be finished in three days. As a result, body work of the accommodation utilities can start at the end of the fourth day.

The exterior walls are formed by 35 cm x 75 cm x 200 cm precast sections. Each section weights approximately one ton. Therefore placement of the sections is performed by mobile cranes. Weight of the precast sections is kept around one tone in order to prevent overturn of the mobile crane. Handling and placement of a precast section takes approximately 10 minutes. One side of the exterior wall of a house can be constructed in 2.5 hours. As a result, exterior walls of the house can be finished in a day. Arrangement of the precast elements is shown in figure 2.

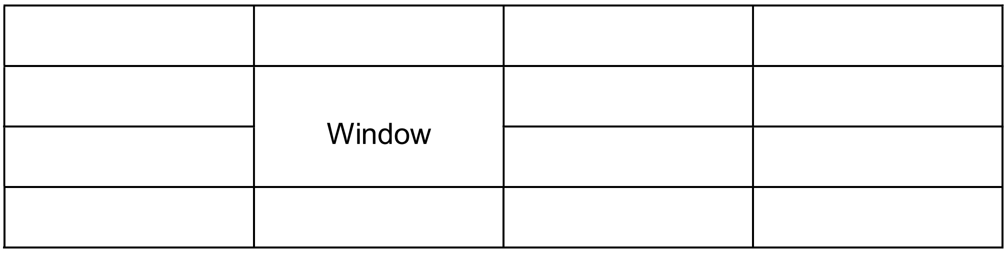

Figure 2. Arrangement of precast elements

Interior walls and the precast ceiling elements can be placed in three days. As a result, one accommodation utility requires four days allocation of a mobile crane. Then, the mobile crane can work on the construction of another accommodation utility. Painting and floor cover of the house can be finished in one day. Door and window frames can also be attached in one day and the total construction of one utility can be finished in ten days.

An accommodation camp with 100 accommodation utility can be constructed in 86 days. An excavator can excavate foundations of five accommodation utilities per day. The excavator can exit the site at the end of the twentieth day. After the excavation of the first five accommodation units construction of the foundation can start. Foundations of the first five accommodation utilities finish at the end of the fourth day. Foundation and water insulation team completes their job at the end of the 61st day.

Placement of the exterior walls of the first five accommodation units starts at the fifth day of the construction and finishes at the end of the 8th day. The placement of precast elements for the whole camp finishes at the end of the 84th day. Door and window frames and painting and floor covering starts at the ninth day and finishes at the end of the tenth day for the first five accommodation utilities. These work items are completed at the end of the 86th day for the whole camp.

Construction of whole camp requires allocation of one excavator, five mobile cranes, and 300 times of hauling of construction materials to the construction site by trucks. Foundation and water insulation team consists of 6 workers, placement of the precast elements is performed by three workers, door and window frames are attached by three workers, painting is performed by two workers and floor covering can be performed by three workers. Therefore the construction site accommodates 100 workers during the most crowded moment.

5. Conclusion

Temporary accommodation facilities constructed for the victims of natural disasters and refugees are very expensive to construct and operate. In this study a new form of concrete with high amount of waste plastic aggregate which can be used as structural element is proposed. Concrete with high waste plastic aggregate has enough thermal resistance and load carrying capacity if is thick enough. Therefore one storey structures can be constructed by using concrete with high plastic aggregate instead of masonry load bearing walls. In addition to this, heat insulation property of waste plastic annihilates the heat insulation requirements and reduces the construction cost.

If precast elements are used, construction duration and cost of the structure significantly decreases. This property can be beneficial for the construction of temporary accommodation facilities built for the refugees and victims of the natural disasters. These facilities can be used for construction of permanent structures at rural areas, slums and refugee camps. Construction of a great number of temporary structures can be avoided and more effort can be made on the recovery of the disaster or civil war zone.

Precast permanent accommodation facilities provide significant savings by voiding temporary accommodation. Analysis on the construction cost and duration show that their construction cost is less than the cost of both traditional reinforced concrete frame structure and temporary accommodation facilities. Duration of construction can be shorter when compared with the duration of construction of temporary accommodation facilities if construction is properly scheduled. Furthermore precast structural elements significantly reduce the requirement of labor. As a result, this approach reduces the cost of disaster management and refugee camps. Besides the construction cost, high amount of plastic wastes would be reused and environmental pollution would be reduced. Consequently, concrete with high amount of waste provides the opportunity of reducing the construction cost and environmental pollution.

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