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Assessment of economic feasibility of LDPE-sand composite block for construction

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ABSTRACT

Construction industry is looking for materials and methods that can be used to enhance the sustainability aspects. One approach is the use of industrial/agricultural waste products in construction. Plastic bricks are emerging as a new trend in construction due to its lightweight, durability and high strength properties. The current paper explores the economic viability of LDPE-sand composite blocks as a construction material. The composite was manufactured from waste plastic and is meant to replace traditional bricks that are generated in an unsustainable manner. In the study, a G+9 building model was chosen, and an analysis was performed using standard bricks available on the market. The results are compared with the similar model with LDPE-sand composite bricks. It has been noticed that the low weight of LDPE-sand brick leads to an economic gain by decreasing the overall infrastructure material requirements in terms of concrete and steel, resulting in a 12% cost reduction. As a result, the waste plastic will have extra value and it will encourage the society to recycle waste plastic for use in the building sector.

1. Introduction

The expansion in the built environment, which includes structures and infrastructure has been considered as a significant component for a country's economic and social progress. Construction materials play a crucial role in this regard. Concrete is a composite material made up of many ingredients including binding materials, water, aggregates and admixtures [1]. It is required for all types of construction operations. Concrete's adaptability as a large-scale construction material stems from its great strength, minimal maintenance cost, resistance to weathering, cost-effectiveness over other construction materials, and outstanding structural performance. Furthermore, the rapid expansion in the rate of industrialization and urbanisation as a result of the current development in the economy and population has resulted in the usage of concrete as the most non-sustainable material, consuming the greatest quantity of natural resources. Because of its high-volume consumption concrete plays a critical part in a country's economic growth. Every year, it consumes around 20 billion tons of raw materials (coarse aggregate) [2]. Concrete is being used at a rate of around 20 billion metric tons per year. In 2010, an industry average of 0.719 tonnes of CO_2 was released in India for every tonne of cement produced. More than half of the CO_2 released comes from the calcination of limestone, with the remainder coming from the use of fossil fuels to heat the rotary kiln. The emissions involved with powering up the additional gear and transporting cement from the plant to supply points add to the environmental load. In reality, transportation accounts for around 10% of total cement sector emissions.

Brick is an essential material in the construction industry. The traditional way of producing bricks has kept this vital material at a standstill. Copious amounts of construction materials will be required for infrastructures such as buildings for housing and industry, as well as systems for handling water and sewage. Because of the increased demand for building materials, particularly in the recent decade, there is a mismatch between demand

Abbreviations: LDPE, Low-density polyethylene.
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and supply management for these materials. As a result, in order to fulfil the ever-increasing demand, researchers are working to discover and create sustainable alternatives for construction materials [3]. As per a survey conducted by the Central Pollution Control Board in 60 Indian cities, 59 cities create more than 15,000 tonnes of plastic garbage every day, with around 60 percent of waste recycled [4]. A substantial portion of the plastic trash produced ends up in landfill, water bodies or is not collected at all. Plastic debris is ingested into the food chain by aquatic living organs and animals. A solution has been developed to address the shortage of building materials and fulfil rising demand by creating construction materials such as interlocking bricks utilising waste LDPE plastic waste (primarily available in the market as single-use plastic) as a bonding medium instead of cement. There have been attempts to utilise plastic garbage in the construction business. Numerous studies have been undertaken to substitute fillers like gravel and sand with plastic waste. Here, cement is replaced with plastic as a bonding agent and characterized and evaluated the resultant composite using common building materials. This causes a fundamental change in the concept of substituting cement with plastic waste as a bonding agent, increasing the value addition of the plastic waste while lowering carbon emissions from cement manufacturing [5,6,12].

A preliminary experimental investigation was carried out in order to validate the materials and characterize them in relation to the building material [5–7]. The economic feasibility of the developed blocks is validated by carrying out an analysis and design of a G+9 building. Buildings with conventional clay bricks and the one with plastic bricks are analysed and the results are compared in terms of cost saving, deformation and strength characteristics. The study mainly focused on assessing the economic feasibility as it is critical to demonstrate the effectiveness of the developed block to convince the society to adapt such modern technology deployments.

2. Materials and methods

2.1. Materials

a.Low-density polyethylene (LDPE).

The fundamental material is recycled Low-density polyethylene (LDPE) recovered from waste that has been shredded using an agglomerator and reduced to a granular size of less than 5 mm [7].

b.River sand.

The study employed naturally occurring river sand from the South Indian states of Kerala and Tamil Nadu, with a specific gravity of 2.69, bulk density of 0.87 kg/l, and water absorption of 2.5 percent. To lower the moisture level, it was dried in an oven for 20 min.

2.2. Methods

STAAD.Pro stands for Structural Analysis and Planning Program [13]. It was developed by Analysis Engineers International (REL) at Yorba Linda, California in 1997. Today, STAAD professional is one amongst the popular and widely used software for structural analysis across the world by Civil engineers. It supports all sorts of assorted materials like steel, concrete, and timber etc. It ensures on-time and budget-friendly completion of structures and styles associated with steel, concrete, timber, aluminium, and cold-formed steel, unsuitable to the complexities. STAAD.pro helps structural engineers to automatize their tasks by removing the tedious and long procedures of the manual ways. It permits civil engineers to investigate and analyse varied types of structures on virtual platforms. Structural engineering companies, consultancies, various departments of construction corporations, and government companies use STAAD.pro extensively.

The analysis and design of the G+9 building is carried out in two cases.

Case 1. *With standard brick of density* 19.2 kN/m^3.

In India, standard bricks are of size 190 mm × 90 mm × 90 mm and are normally made of clay by burning in a kiln. These bricks with mortar of 10 mm thickness will be 200 mm × 100 mm × 100 mm in size. They are arranged in a single layer to form a wall of thickness 115 mm along with mortar and in 2 layers to form a wall of thickness 230 mm. The compressive strength of first-class standard clay brick shall not be less than 10 N/mm^2. The water absorption of this brick, when immersed in water for 24 hrs shall not exceed 15%. There shall not be any efflorescence [10].

Case 2. *With LDPE brick of density* 12 kN/m^3.

Bricks made from LDPE were measured at 200 × 100 × 100 mm. There is no need to use mortar for cementing LDPE bricks together as these are interlocking in nature. Additionally, this brick contains recycled plastic and sand and is environmentally friendly.

The G+9 storey building model has been developed [9], analysed, and designed using STAAD.Pro software [13]. The building has an area of 648 m^2. IS 456–2000[8] was taken into consideration in STAAD.Pro to design the model. The building model was developed for two different wall loads. The plan and model of the building are shown in Figs. 1 and 2.

The various loads are assigned as per IS 875–1987 provisions [11]. As per codal recommendations, the following loads were assigned in the analysis.

Dead loads (IS 875–1987 part 1).

The following dead loads were taken during the analysis of the structure.

a. Floor finish load – 1.5 kN/m^2
b. Ceiling load – 0.5 kN/m^2
c. Waterproofing load – 2 kN/m^2
d. Wall load (case 1) – 11.71 kN/m
e. Wall load (case 2) – 7.6 kN/m

Live loads (IS 875–1987 part 2). [11].

The following live loads were taken during the analysis of the structure.

a. Load 1–2 kN/m^2
b. Load 2–3 kN/m^2

The G+9 high-rise building height is 30 m above ground level. The beams, columns, and slabs are designed using M25 concrete. For main bars, Fe 550 has been selected because it is the most common grade used for high-rise buildings. Particularly, Fe 415 was used for ties and stirrups since they must be bent, which is relatively easy to do with lower-grade steel. In this case, all stirrups are two-legged stirrups.

3. Results and discussion

The sizes of the structural members are determined through trial and error. There is a 19% reduction in the cross-sectional area of structural members using LDPE brick and is presented in Table 1. The reduction in the cross-sectional area is due to the wall load in Case 2 which is lesser than that of in Case 1. This can ensure lesser

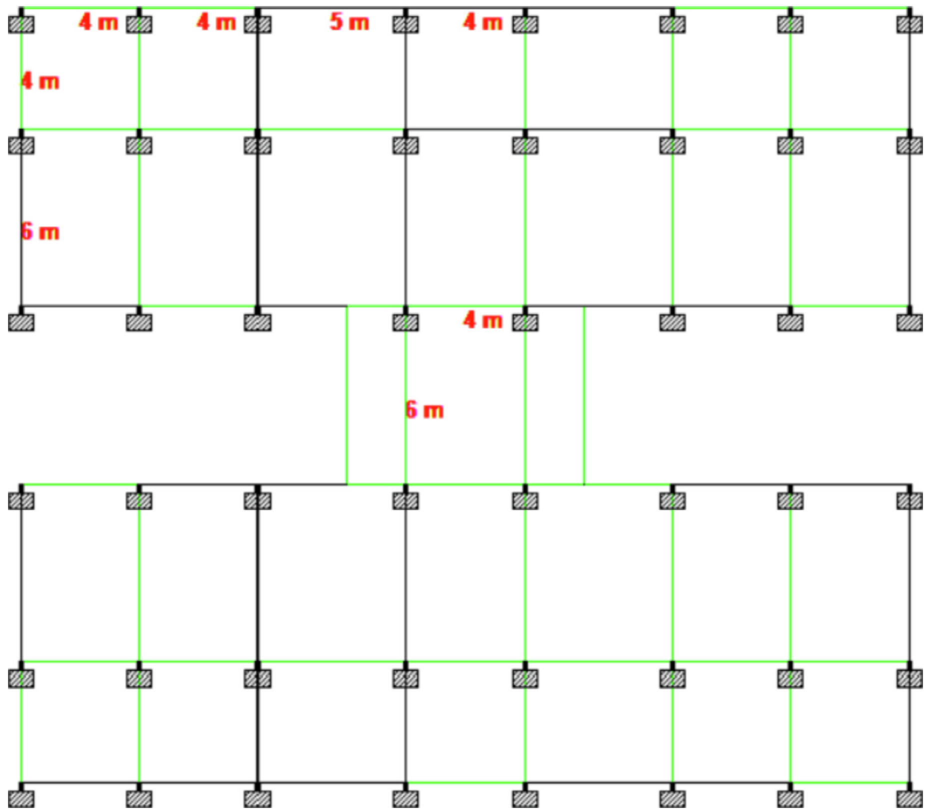

Fig. 1. Structural plan of the building.

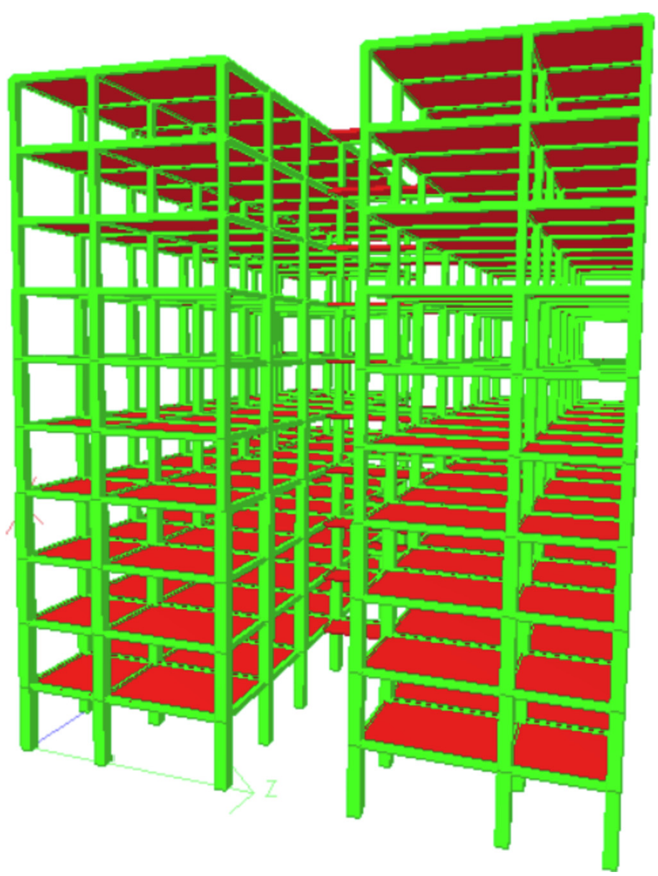

Fig. 2. 3D model of the building.

Table 1
Sizes of members.

Member	Type	Case 1	Case 2
		Size (m)	Size (m)
Column	1	0.5 × 0.5	0.45 × 0.45
	2	0.4 × 0.4	0.36 × 0.36
	3	0.3 × 0.3	0.27 × 0.27
Beam	1	0.23 × 0.27	0.23 × 0.27
Slab	1	0.15 thick	0.15 thick

usage of concrete during construction. In both cases, quantity estimation and cost estimation have been carried out.

From the results of the analysis, it can be inferred that there is a difference in the total material cost of the building. Due to the change in wall load, there is a 19% reduction in the cross-sectional area of all three assorted sizes of columns. There is no decrease in the cross-sectional area of beams since loads on slabs are the same in both Case 1 and Case 2.

As shown in Table 2, the wall length of one floor is calculated with the help of the plan of the building. The building is assumed to have the same plan throughout. Based on the assumption made, total wall length of the G+9 building was calculated. Wall openings

Table 2
Details of wall.

Detail	Result
Total wall length for 1 floor	406
Total wall length for 9 floors	3654
Thickness of wall	0.23
Depth of wall	2.73
The total volume of wall	2294
Total bricks required	11,47,173

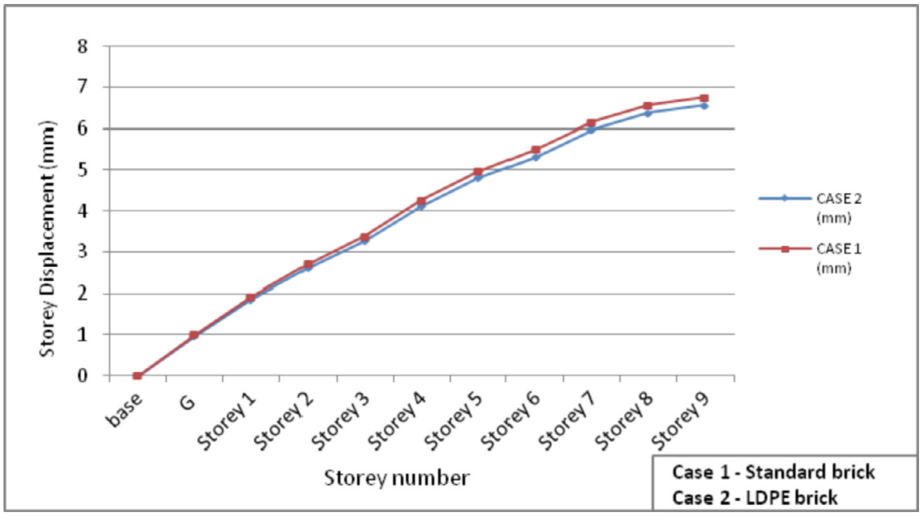

Fig. 3. Comparison of displacement at each floor.

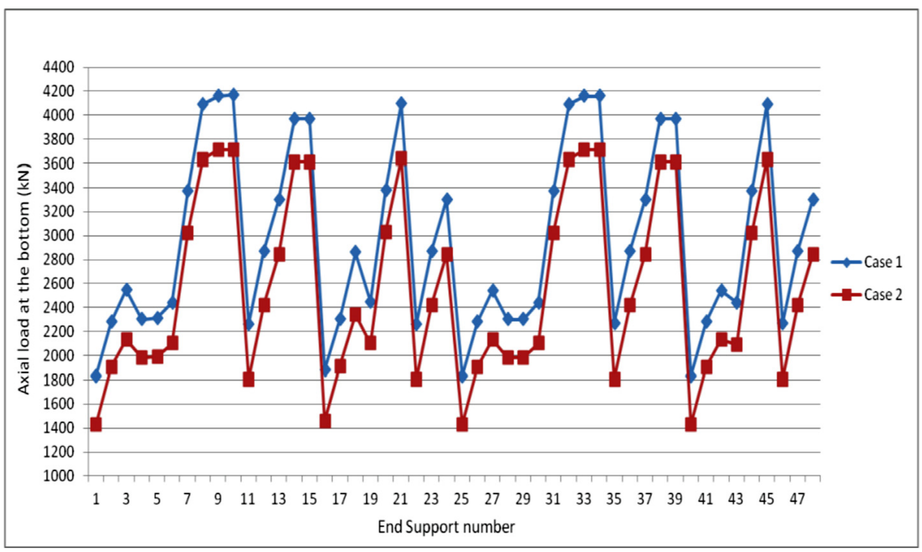

Fig. 4. Comparison of vertical reactions at the base.

Table 3
Cost Analysis.

Comparison of results		
	With standard brick	With LDPE brick
Size of Brick	20 cm*10 cm*10 cm with mortar	20 cm*10 cm*10 cm without mortar
Density of the Brick	19.2 KN/m^3	12 KN/m^3
Approx. No of bricks required	11,50,000.00	11,50,000.00
Cost of single brick	□ 9.00	□ 8.00
Total cost of bricks	□ 1,03,50,000	□ 92,00,000
Total quantity of Fe550 grade Steel in kg without considering foundation	72,945.00	61,910.00
Cost of steel per ton	□ 48,000.00	□ 48,000.00
Total cost of steel	□ 35,01,360.00	□ 29,71,680.00
Total quantity of concrete in m3 without foundation	469.4	420.5
Cost of M25 concrete per ton	□ 4,000.00	□ 4,000.00
Total cost of concrete	□ 18,77,600.00	□ 16,82,000.00
TOTAL MATERIAL COST	□ **1,57,28,960.00**	□ **1,38,53,680.00**

were not taken into consideration as it is constant in both the cases. Depth of the beam is 0.27 m and it is the same for all the beams. Excluding the depth of the beam, the depth of the wall is calculated as the floor height is known. With basic calculations, total volume of the wall and number of bricks required were found and are listed in Table 2.

It is estimated that for every 1 m^3, 500 standard bricks are required along with mortar. Therefore, as per the plan of the building, total wall volume is calculated to find the approximate number of bricks required for the construction of the building. This is estimated to give a total number of 11,50,000 bricks. The total quantity of concrete and steel has been taken from the results of STAAD.Pro software and the values are shown in the Table3.

4. Conclusions

The economic feasibility of using LDPE-sand composite for construction in comparison with conventional bricks is evaluated in the present work. The study elaborated the design economical analysis and its structural performance between conventional bricks and developed LDPE retrieved from waste - sand bricks. Based on the study the following conclusions are arrived at.

- A significant 19% reduction in column cross-sectional area. resulting in less consumption of concrete and thus less CO_2 emissions is obtained.
- The performance of LDPE sand compost bricks are almost same as traditional bricks in terms of lateral displacement at each storey as shown in the Fig. 3.
- Based on this study, it was found that the axial load at the base of end supports reduced to 9.1% to 22.4% when using LDPE sand composite bricks as per the Fig. 4. This automatically reduces the foundation requirement, thus resulting in less consumption of construction materials and a drastic reduction in the total cost of building.
- The study has demonstrated a 12 % reduction in total construction cost in superstructure due to the deployment of the developed LDPE-sand bricks.

Based on the above test results and conclusions, it can be observed that the use of plastic bricks is a viable, sustainable and cost effective solution in the construction sector without compromising the structural performance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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