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Simple Slab Elements for Environmentally Friendly Construction Technology

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ABSTRACT

Concrete industry poses a great threat to the environment not only by its consumption of natural resources, but also in its role on the global emission of carbon dioxide in the atmosphere from cement industries which in turn results into global warming. In light of these scenarios, serious interventions have to be incorporated in designs to promote sustainable construction and prevent environmental pollution and degradation. In order to minimize the use of cement, a study has been done by developing simple soil arch elements which can be used to support the topping concrete slab of around 30 mm thick. The technique utilizes the semi-prefab technology and therefore eliminates the use of shuttering for slab panel construction. Through this study, it has been shown that the consumption of cement is reduced to 49.32% while the timber formwork is reduced to 60.00%. The technique is recommended for application in upper floor slab casting as it reduces the cost of construction and is environmentally friendly.

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INTRODUCTION

There are numerous construction materials which have been employed for various construction purposes, however; the prominent materials include concrete, steel and timber. The use of concrete materials involve environmental degradation in one way or another be it during materials extraction from their corresponding natural resources, like mining and quarry, and from industrial manufacturing of cement where CO_2 is generated.

Concrete is the most widely used construction material which is obtained by mixing sand, cement, aggregates with a reasonable amount of water. Concrete has become an outstanding material for construction purposes and has extensively been used in construction of various structures including high rise towers, normal buildings, pavement slabs, tunnels and bridges, to mention a few. The versatility of concrete use is mainly attributed by the virtue of concrete's high compressive strength, durability of its structures and readily availability of raw materials used in concrete production.

Construction works involve the utilization of natural resources such as water, land including aggregates, forests and timber. to mention a few. It is in this context of over exploitation of the respective resources and the impacts to the environment by construction activities that has raised demand on adoption of environmentally friendly construction technology (Onyegiri and Ugochukwu, 2016).

Concrete industry poses a threat to the environment by it's over consumption of natural resources such as sand, coarse aggregates, energy, and timber (for formwork). These resources have not only been extremely exploited resulting to reduction and/or extinction of such resources. Also, the manner in which humans have engaged in the exploitation of the resources in the need of raw materials has resulted into environmental problems; such as soil erosion due to limestone mining and excavations in search for sand and rocks blasting in search of coarse aggregates, leaving massive holes on the ground with unstable slopes. Deforestation without planting new trees in need of timber for false work purposes causes distinction of trees.

In addition, another environmental problem posed by concrete construction is its role on the global loading of carbon dioxide in the atmosphere, through manufacture of cement, which in turn results into global warming, that has become an overwhelming global issue nowadays. In light of these scenarios, serious interventions have to be incorporated in designs to promote sustainable construction and prevent environmental degradation.

PROJECT OVERVIEW

The underlying hypothetical formulation in this study is principally reducing the use of cement in concrete constructions particularly slabs while maintaining safety codes requirement of strength. This is achieved through developing a design configuration termed as "simple soil arch elements''. Simplicity of such elements in this case is based on types of materials used, their local availability, labor input and workmanship involved, ease of fabrication and site erection.

The proposed slab design is to be constituted of shallow inverted concrete T-beams and low rising arches made from stabilized soil material built as shown in Figure 1. The arches are to be discontinuous individual pieces bonded in longitudinal direction, the inverted shallow T-beams and arches herein implying the "Simple Slab Technology''.

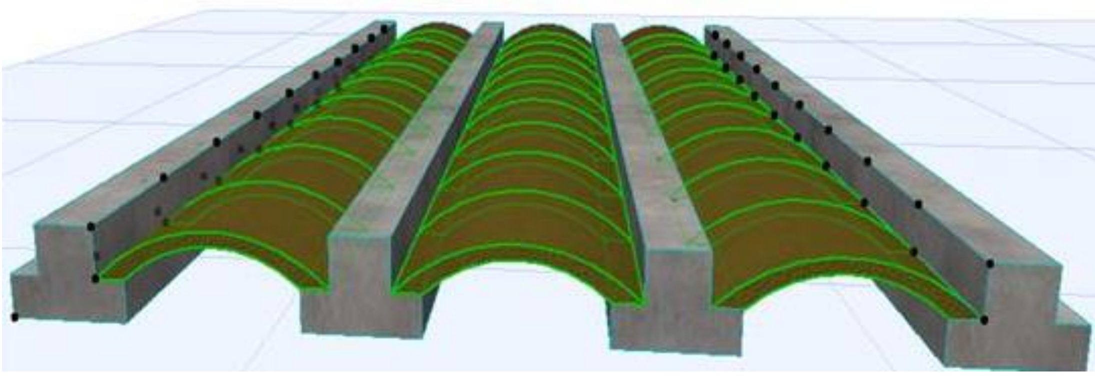

Figure 1: Slab element arches built on and supported by Inverted T- beams.

Concrete shall then be cast on top of the arches up to a level of 30 mm above the inverted T- beams and leveled to form the plane surface of the slab as shown in Figure 2 below. Note that there is a decrease in concrete depth at the apex of arches because of the space created by the arching of the soil slab elements.

It can clearly be observed that the arches are used here to replace the timber formwork for shuttering at the soffit level but also by the virtue of arches curved configuration. Structurally arches are strong in resisting axial forces while the moments become minimum or zero. Since arches are principally acted by axial forces, their incorporation in the design of slabs is an important matter. Such a slab arch soil element is shown in a 3D pictorial view in Figure 3.

Figure 2: 3D view of the proposed slab after concrete is cast.

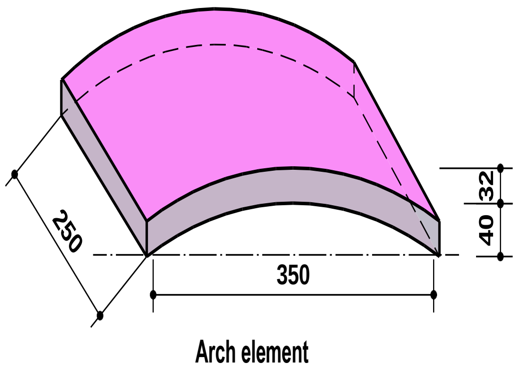

Figure 3: Stabilized soil arch element.

Objectives

The main objective of this study was to develop a slab design that reduces environmental impacts caused by concrete constructions and promotes sustainable use of locally available natural resources. The study focused on minimizing the use of cement and timber in concrete works as part of remedial measures to the current situation posed to the environment as a result of using these two materials in concrete constructions. In order to meet the main objective, the following specific objectives have been adopted.

- To produce a slab design/construction technology which will minimize the use of cement for concreting purposes.
- To reduce the amount of timber used for formwork purposes in concrete slabs constructions.

REVIEW ON CONCRETE SLABS

The current state of building construction is complex in the sense that there is a wide range of construction products and systems which are aimed primarily at different types of buildings. The design process for buildings is systematized and draws upon research formations that study materials properties and performance, code experts who adopt and enforce safety standards, and design professionals who determine the end user needs and design the buildings to meet those needs.

Building materials have been used throughout human history, and archaeology demonstrates that they were also used to some extent in the prehistoric period. It is believed that the earliest humans lived in caves, but eventually they learned on how to use natural substances they found around them to build simple dwellings. Wooden poles, mud and clay were among the first building materials used. The adhesive quality of clay made it easy to work with and form into various shapes. Straw, hay, sticks or other organic fibers were used to help in holding the mud together. Cow dung was added to this mixture to form adobe. Sometimes the earth was compacted or “rammed” together to form walls (Francis and Luna, 2021).

Logs, sticks, thatch, brush and wood were also used for early construction purposes (Dörfler 2020). In addition, uncut rocks and large stones were often used. There are many ancient examples of “cyclopean” architecture consisting of large uncut rocks piled together or stuck together with some form of adhesive.

Concrete as a Construction Material

Concrete is a composite material composed mainly of aggregates, cement and water. Additives and reinforcements are included to achieve the desired physical attributes. Not only is concrete construction among the leading consumer of natural resources, but also a threat to the environment as it involves activities that are responsible for environmental pollution due to carbon dioxide generation.

According to Robbie (2019), industrial production of cement is one among the major activities solely responsible for producing toxic gases to the environment worldwide, the cement industry is responsible for about 2.2 billion tons of CO_2 emission in 2018 which caused the emission of as much Carbon dioxide (CO_2) gas. Also in the year 2000, around 300 million automobiles produced almost 7% of the total world production of CO_2 (Malhotra, 2000). Hence environmental pollution and global warming is increasing continuously and, natural resources and energies are being reduced day by day. Since global warming is known as the most crucial environmental issue at present, time and sustainability is becoming an important issue of economic and political debates (Meyer, 2005). The next developments in the concrete industry will not be the new types of concrete produced with expensive materials and special methods, but low cost and highly durable concrete mixtures containing largest possible amounts of industrial and agricultural waste/byproducts that are suitable for supplementary use of cement. Due to increased effects of global warming and excessive energy consumption, various researches have been going on to find out possible ways to reduce the amount of cement used in concrete structures. The following discussion reviews some of these researches and their outcomes.

Use of Cow Dung Ashes (CDA) as Supplementary Cementitious Material in Concrete

The cow dung ash is obtained from cow excreta which is dried at sunlight and subjected to burning as a result ash is obtained. In many parts of the developing world, caked and dried cow dung is used as fuel. Dung may also be collected and used to produce biogas to generate electricity and heat. Cow dung is also an optional ingredient in the manufacture of adobe mud brick housing depending on the availability of materials at hand. In cold places, cow dung is used to line the walls of rustic houses as a cheap thermal insulator (Rayaprolu, 2012).

By the virtue of its chemical composition, cow dung produces large amounts of ashes. This cow dung ash has cementitious property which is seen as an opportunity to be exploited for partial replacement of cement in concrete. Rayaprolu et al. (2012) conducted an experiment on incorporation of cow dung ash to mortar and concrete by replacing various percentages of cement, the tests of which were done according to IS 456-2000. The average compressive strength for each replacement from test results of the cubes was found to be 23.20 N/mm^2 for 10% replacement, 11.31 N/mm^2 for 20% replacement and 5.72 N/mm^2 for 30% replacement.

DEVELOPMENT OF THE PROPOSED STRUCTURAL ELEMENT

With reference to Figures 3 and 4, the loads acting on arches and support conditions at arch ends can be presented using the statical system in Figure 4. Note that the Loads on slab used in this analysis are in accordance with BS 6399 PART 1, 1996 – Loading for building.

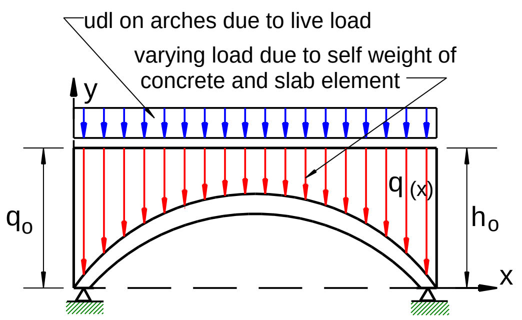

Figure 4: Statical system for arches.

After establishing the appropriate statical system as above, it is important to determine the intensities of the load at various points along the arch. Therefore, it is relevant to establish an equation that will give load intensity $q(x)$ at any point located a distance x from Origin 0 where the intensity is q_o as shown in Figure 5.

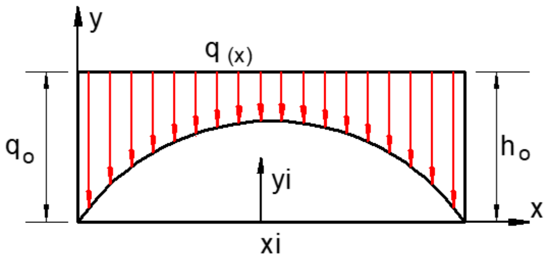

Figure 5: Variation of load intensities along the arch.

$$q_o = \gamma \times h_o \times w\,(kN/m) \qquad (1)$$

$$q_{(x)} = q_o - \gamma \times y \times w(kN/m) \qquad (2)$$

Hence load intensity $q_{(x)}$ at any point x on the arch is given by:

$$q_{(x)} = w(\gamma(h_o - y)) \quad kN/m \qquad (3)$$

Since the arches made from stabilized clay material are weak in enduring stresses resulted from bending moments. It is therefore important to eliminate moments in the arch so that the arch is purely subjected to axial compressive stresses. To eliminate moments in the arch, the sum of moments about any point x should be zero. Consider equilibrium of moments in arch section at a distance x in Figure 6 below.

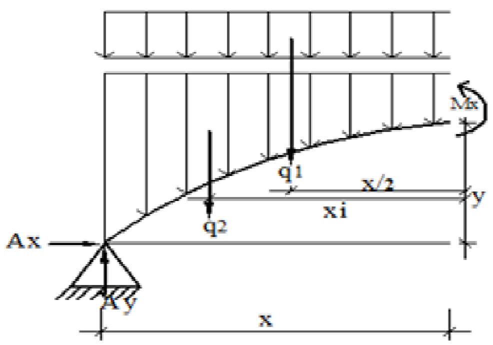

Figure 6: Arch section x m from origin.

$$\Sigma M(x) = 0$$

$$-M_x - q_1\frac{x}{2} - q_2 x_i - A_x y + A_y x = 0 \qquad (4)$$

$$q_1\frac{x}{2} + q_2 x_i + A_x y - A_y x = 0$$

$$q_2 = \int_0^{L/2} w\gamma\left(h_o - y\right)dx \qquad (5)$$

$$q_2 = 0.15\gamma\int_0^{L/2}\left(h_o - y\right)dx \qquad (6)$$

But the Equation for a parabolic arch is given by:

$$y = \frac{4f}{L^2(Lx - x^2)} \qquad (7)$$

If this point is at the center of the arch, then $x = L/2$, and $y = f$.

$$q_{2,mx} = \int_0^{L/2} q_x\left((x)\right)dx \qquad (8)$$

L= 0.35m, x = 0.175m and w = 0.15m. The resulting load q_2 = 0.0168 kN. The factored dead load becomes = 1.4x 0.0168 = 0.02352 kN. The centroid load q_{2mx} is established as follows:

$$q_{2,mx} = 0.15\gamma\int_0^{L/2} x\left(h_0 - \frac{4f}{L^2}\left(xL - x^2\right)\right)dx \qquad (9)$$

From

$$q_1\frac{x}{2} + q_2 x_i - A_x y + A_y x = 0 \qquad (10)$$

At $x = L/2$ = 0.175m, $y = f$, it from Figure 6b: A_y = 0.1075 kN, and A_x = 0.10 kN.

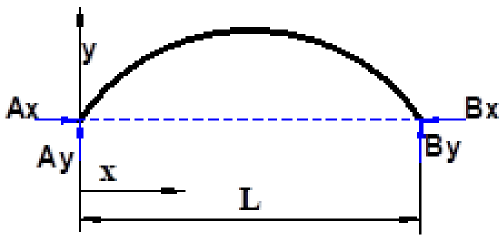

Figure 6b: Resultant axial force on arch section x.

Hence the resultant axial force; $R = \sqrt{0.10^2 + 0.12^2} = 0.16\,kN$

Stress in one arch element is, $\sigma = \frac{R}{A} = \frac{0.16 \times 1000}{40 \times 150} = 0.03N/mm^2$ being the maximum axial compressive stress in the arch, which is very small, and therefore is insignificant.

Structural Analysis and Design of Reinforced Concrete T Beams.

This part includes the design of reinforced concrete T beams to BS 8110 1985 (Part 1). Figure 7 below shows the loads on beams.

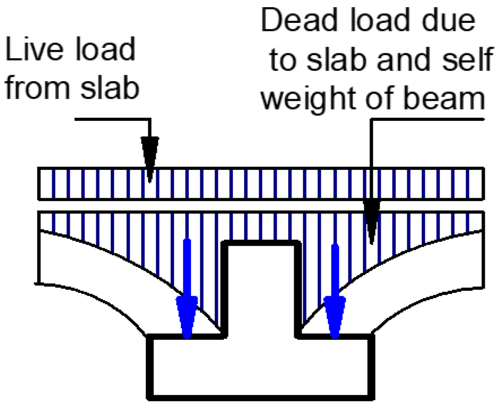

Figure 7: Inverted beam loading configuration.

Note that the middle beams with continuous on either sides have been chosen for the design. these middle beams experience higher loadings than their edge counterparts.

SAMPLES PREPARATION AND LABORATORY TESTING

Fabrication of Arches

The arches as stated earlier in this context, span in between reinforced concrete inverted T-beams. The arches are made from soil with binding properties due to stabilization of the material by addition of small proportion of cement (5%) to enhance the binding properties of soil. Materials and tools and their respective use in making arches are listed in Table 3 below.

Table 1: Polymer samples manufacturing parameters

Materials	Use
Laterite soil from Kunduchi- Dar es Salaam	Used as main material for arches
Portland Cement	To increase binding properties of the soil, hence strength
Tools or Machinery.	
Rectangular brick making machine plus elements for arch formation	To act as a mould for producing arches

Laterite soil was sieved to allow only the appropriate content of the soil to pass. The laterite soil was then mixed with Portland cement at a ratio of 1: 20 (c: s) by volume. The formed soil cement mixture was mixed thoroughly to produce a uniform mix. Water was added and mixed thoroughly again until the mixture was just able to form a soil ball when rolled by hand. This soil mixture was then filled into the brick making machine consisting of timber pieces as part of mould that was to form the final arch shape. The mould machine was used to compact the soil for producing arches as shown in Figure 8 below.

Figure 8: Pack of arches several days after fabrication.

The fabricated arches were left exposed so as to gain initial strength before being covered by moist cloth for curing process to proceed. Figure 8 shows a pack of arches several days after fabrication.

Tests on Compressive Strength of Bricks Made From Mix for Arches

As a means of assessing the compressive strength of the arches made, four samples of rectangular bricks of same composition for the arches were made using the brick making machine and their compressive strength after 21 days was as shown in Table 4.

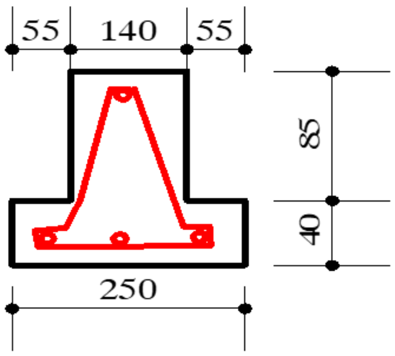

Figure 9: Inverted beam.

Table 4: Strength of bricks at 21 days with a ratio (cement: sand) 1:20 by volume

Sample	Dimensions (mm)	Ultimate compressive load (kN)	Compressive strength. (N/mm^2)
1	300 x 140	143	3.41
2	300 x 140	140	3.33
3	300 x 140	142	3.38
4	300 x 140	158	3.78
Average			3.48

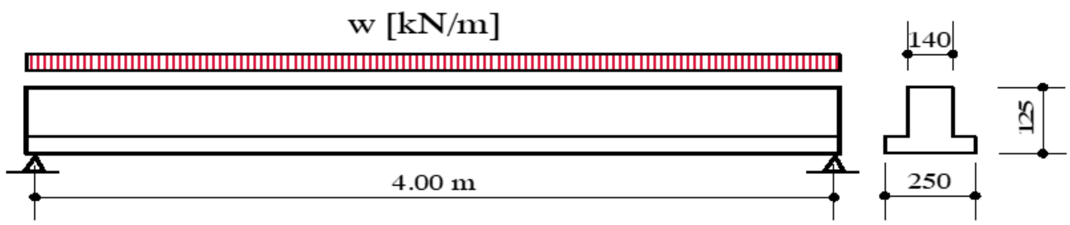

Figure 10: Free body diagram of the beam.

The obtained test results for compressive strength, is at least meeting the specifications for blocks to BS 5628 Part 1of 2.8 N/mm^2

Analysis of Beams, Specimens Preparations and Testing.

Structural Analysis of the Inverted T-Beam

The volume of inverted T-Beam was calculated basing on Figure 9. The span of the room was expected to be 4.00 m center to center of the supporting walls/beams as illustrated in Figure 10.

Loading to the beam

Self-weight of beam: volume x density = 0.68 kN/m, Weight of concrete and arch element was found to be 1.30 kN/m, Finishes: 0.50 kN/m^2 x 0.60 = 0.30 kN/m (the slab strip width for 1 beam is 600mm), Total Dead Load: 0.68 + 1.30 + 0.30 = 2.28 kN/m.

Total imposed load: 2.0 kN/m^2 x 0.6 = 1.20 kN/m. Design load: 2.28 x 1.4 + 1.2 x 1.6 = 5.11 kN/m

Design Moment: M = 5.11 x 4 x 4/8 =10.22kNm. All singly tested epoxy resin specimens' dielectric properties are shown in Figure 5. Excluding the lower and higher frequencies, all ER

From structural analysis and design, the moment of resistance of the beam section was found to be 7.22 kNm being less than the applied moment. Hence, the area for compression steel was found to be 85.81 mm², where a single bar of Y12 (A_{sc} = 113 mm²) was provided. Finally, the tension Steel reinforcement at bottom was established as 2Y12 + 1Y10 (As = 304.5 mm²).

Casting of inverted T-beams

Concrete mix design of grade C25 was established, and the quantities of cement, fine and coarse aggregates were calculated, and water to cement ratio was 0.5. The materials were mixed thoroughly and then cast in the molds. After gaining sufficient strength at 24hrs age, the beams were cured for 21 days. Also, the same concrete was used to prepare cube specimens of 150 x 150 x 150 for testing properties of hardened concrete at 28 days age.

Elements assembly and completion of sample slabs construction

The slab models for testing had to be of the size:1.20m x 1.2m in order to be accommodated by the space available of the testing machine. Timber formworks were prepared to mould the concrete as per dimensions of the proposed specimens size. The soil arch elements were assembled as illustrated in Figure 11, then joined with cement sand mortar of 1:8 ratio. There were 3 beams in total with two rows of soil slab arch elements.

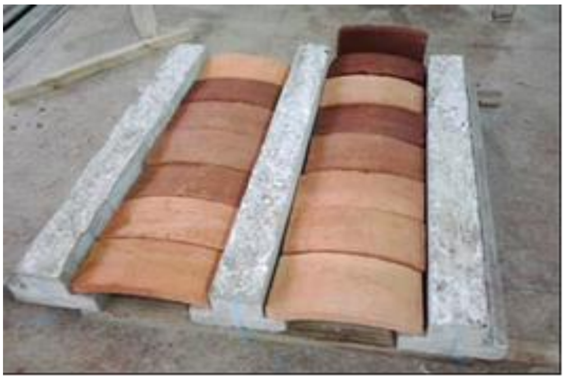

Figure 11: R.C. Inverted T beams and arches assembled.

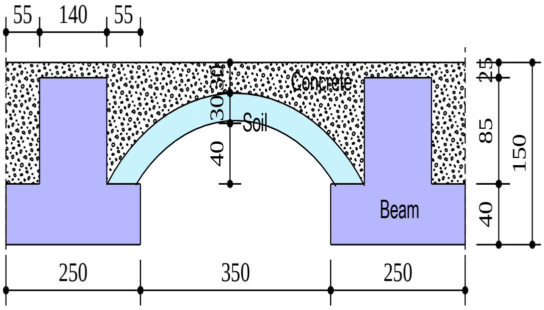

Figure 12: Illustration of part of the completed slab.

The assembly above was followed by casting concrete on top of the arches to produce the concrete topping as per slab details shown in Figure 12. The final appearance of the slabs was as shown in Figure 13. After 24hrs, curing started till the testing age of 28 days.

Tests on compressive strength of concrete cubes

Consequently, as means of assessing the compressive strength of the reinforced concrete slab elements made, samples of concrete cubes of 150 x 150 x 150 mm were prepared from the concrete mix that was cast in beams and slabs. After testing, their average compressive strengths values after 28 days were 25.55 N/mm^2 and 25.40 N//mm^2 for inverted T- beams and Slab Specimen 1 topping concrete respectively. The average values in each case were obtained from 4 individual cube specimens values. For the second sample slab, the average compressive strength was 25.32 N/mm² for beams and 25.20 N/mm² for the topping concrete of the slab.

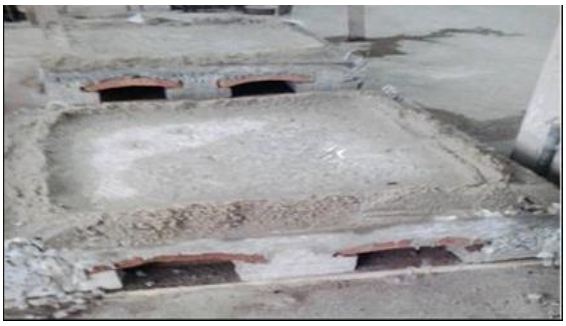

Figure 13: Completed slab samples still in curing process.

Tests for ultimate load carrying capacity of sample slabs

The prepared slab samples were tested to determine the ultimate load carrying capacity of the slabs under conditions that would best simulate the actual loading conditions during the life time of the slab. Each slab sample was lifted using an overhead crane and placed securely in position ready for testing. The slab was supported on two of its edges to simulate the ring beams which shall be constructed at site. The slab was loaded in a direction parallel to inverted concrete T-beams as this loading arrangement would give minimum load at failure which should be the threshold value for safe design.

Table 6: Slab samples test results

Slab sample		Dimensions [m]		Loaded length [m]	Distance between beams [m]	Maximum load at Failure [kN]	Maximum load intensity on T-Beam [kN/m]
		Length	Width				
1		1.2	1.2	1.2	0.6	4.5	6.25
2		1.2	1.2	1.2	0.6	4.3	5.97
	Average						**6.11**

DISCUSSION OF RESULTS

The maximum load intensity endured at failure was 6.25 kN/m and 5.97 kN/m for sample slabs 1 and 2 respectively, with an average value of 6.11kN/m as depicted from the table above. Since the maximum average strength from test results is 6.11 kN/m ≥ total ultimate load intensity of 5.11 kN/m per slab strip, the design is therefore safe.

In order to give a precise evaluation on feasibility of the proposed design, it is important to counter check how the design and construction outcomes meet the objectives set as a primary basis of the assessment as detailed below:

Cement reduction

Assuming a 4.0 m x 4.0 m slab panel, analyzed for normal solid slab and for new slab with inverted T-beams, arch soil elements and topping concrete, using concrete grade C25, the amount of cement was observed to be 49.37 kg/m² in plan and 97.41 kg/m² for normal solid slab. The amount of cement saved using the inverted T-Beam and slab elements is the difference between the two; which is Cement saved = 97.41-49.37 = 48.04 kg/m². This saving in cement when expressed in percentage is 49.32%. Hence there is 49.32% reduction of cement in the proposed slab construction as compared to conventional slabs construction.

Minimization the use of Timber for Formwork

The amount of timber required for the new slab system will be just the formwork for a single inverted T-beam times a half of the number of beams, as the moulds are reusable after 7 days. And assuming that the size of a room is 4 x 4 m, there will be 8 beams. Each beam will have an area of 2.44 m², the required area for 4 beams being 9.76 m². The normal slab with timber shuttering, props of around 3.0 m height, and bracings in both ways of almost 4.0m spaced at 600 mm EW, the total area of timber becomes 40.35 m². Also for the new stab type, the total area including final sides areas is 12.2m²

The saving in the timber requirement is 40.35 – 12.20 = 28.15m², which is 69.76%. Therefore, there is 69.76% minimum saving of surface area of timber for formwork purposes in the proposed slab construction as compared to conventional slab construction.

Cost effectiveness

It can be clearly observed that the cost of constructing the proposed slab is significantly reduced by the reduction of amount of concrete material involved and minimal cost implications incurred for cost of timber for formwork and reinforcement. In addition to that, it can be seen that, due to reduced slab sizes, the total weight of such a building will reduce significantly and hence a subsequent reduction in sizes of other concrete elements such as columns and foundations as a result, lowers the construction costs as well. As the amounts of cement, timber and reinforcement are reduced, it implies also that the cost will diminish since these materials are normally expensive.

Aesthetics

The arches and inverted concrete T beams constitute a combination of elements with pleasing appearance especially when fabrication and placement of these elements is precise and workmanship is good.

CONCLUDING REMARKS

Based on this study, it is concluded that soil arch elements and inverted T-Beams slab system is a suitable technology for slab construction leading to low-cost house system. The construction of the slab is simple, cheaper in cost and is a labour-based construction as it needs no cranes or sophisticated equipment for lifting up the inverted T-Beams. The new slab system is sufficiently strong to bear the slab loads for residential buildings, or where the imposed load does not exceed 2.0kN/m^2, bearing in mind that the imposed loads for residential apartments starts from 1.5 kN/m^2.

From cost analysis summarized in section 5.2 above, it has been found that the cost of this new slab system is at least above 50% in average of the cost of traditional concrete solid slabs. It is therefore recommended that the soil arch elements and inverted T-beams slab system be used in building low cost houses as it is cheaper and will take shorter time to complete the construction of the building as there is no time for making shuttering and steel fixing.

As this technology utilizes less cement and less timber, it enhances good environmental conservation, and keeps the carbon footprint at lower level. Therefore, the construction industry should adopt technological advancements and innovation techniques, such as this new slab system technology. However, as this construction technique is new, dissemination of the technology to the society is needed, so that many people will opt for building two or more stories buildings at relatively cheaper cost.

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