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CONSTRUCTION OF AN IMPROVED RADIATION SHIELDING WALL FOR DIAGNOSTIC RADIOLOGY

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Abstract

The need for an improved alternative radiation shielding protection in hospital radiation environment is increasing on daily basis. Different types of materials had been used as radiation shielding materials for medical radiation facilities such as diagnostic radiology, nuclear medicine and radiotherapy rooms. The cost of production of this radiation shielding materials and their effectiveness is of a major concern to the stakeholders in radiation protections services and health care services. To this effect effort was put in place to look into construction of an improved radiation shielding wall for a radiation diagnostic environment. The paper focuses on Mortar-less Technology (MT) for radiation shielding. The radiation shielding wall was constructed using interlocking stabilized-soil-barium bricks. Further analysis was undertaken with respect to resource-use implications (cement, water, soil) of employing mortar-less technology. The study concludes that the flexibility requirements on mortar-less technology for wall construction can be fully met, which will further boost market opportunities of interlock bricks. The self-aligning characteristic of interlock bricks eases brick-laying, encourage the use of less skilled manpower and realizing higher productivity. Apart from savings of material, mortar-less technology saves time due to higher productivity resulting in an ultimate cost saving of around 50%.

Keywords: *Construction, radiation, shielding wall, radiation shielding, concrete, brick, mortar-less technology, hospital.*

1. Introduction

The need to obtain a clinical image of sufficient quality to provide the relevant diagnostic information is of paramount importance. Justification is achieved by providing clinical practitioners with information about the potential health detriment from each medical exposure based on an assessment of dose and risk that can be weighed against the medical benefit. Optimization is accomplished by ensuring that those who carry out the exposure know how the techniques and equipment factors that they select affect the quality of the clinical image and the dose received by the patient. Periodic assessments of patient doses are undertaken to ensure that the levels are appropriate, taking account of possible implication for image quality. Also, there has been tremendous increase radiation leakages in diagnostic radiology arising from high costs of improvement of the existing medical facilities. Also during the construction of radiation room, old methods are still being used, the methods are expensive and time consuming meaning with small funds such construction designs are hard to complete in time hence leading to a delay in radiation medication exercise which can lead to delay and poor radiation doze given hence death of patients in the long run. This calls for the need for appropriate radiation shielding wall.

Traditionally, various types of concretes as primary shielding materials are in use for medical radiation facilities such as diagnostic radiology, nuclear medicine and radiotherapy rooms (Mansouri et al., 2020; Tekin et al., 2019). The cost and use difficulties as well as being opaque to visible light that is quite impossible to look through a concrete-based radiation shield can also be said to be another disadvantage. In theory, it can be said that any material with a certain material density and thickness can reduce the radiation. Therefore, different types of alternative materials namely building materials, bricks, polymers, steel, resins, composites and alloys have been investigated by different researchers for their possible radiation shielding applications (Sayyed et al., 2018). Another alternative radiation shielding material is glass. Due to several significant advantages such as cheap cost, optical transparency for visible light, ease of production in different sizes and forms with no variation in their composition and density with external fields makes glasses attractive and in recent years, are of interested to investigate them by many researchers as encouraging materials for ionizing radiations such as X-ray, gamma and neutron radiation shielding (Elmahroug et al., 2018; Obaid et al., 2018; Kumar et al., 2018).

The range of materials which may be used to provide radiation shielding include:

1. Lead sheet and lead fabricated products (lead plywood, lead plasterboard).
2. Concrete, concrete blocks and concrete products.
3. Barium plaster.
4. Various types of brick.
5. Gypsum wallboard.
6. Lead glass.
7. Lead acrylic.
8. Other materials (e.g. steel and wood for low energy/mammography trailers).

The choice of material depends on several factors, including the level of shielding to be achieved, the cost, and the practicalities of installation.

Mortar-less technology using interlocking stabilized-soil-barium bricks reduces cost of construction of radiation shielding walls. It also saves time and the materials are locally available. It is important to note that the results obtained from the study will improve decisions made by planners for better future solutions as far as radiation safety for workers and patients both inside and around the health facilities in Uganda are concerned.

2. Method and Materials

2.1 Cement

Cement is a vital component for soil-stabilized bricks, enhancing both strength and durability. Cement, an expensive element, can be kept down to the range of 3 to 10 % of the mix without compromising performance. From Ugandan experience, a ratio of 1:20:3 (cement to soil to sand) can produce an average of 120 Stabilized Soil Barium Brick from one 50kg bag of cement mixture. This is equivalent to 480 litre of wall volume. By contrast Conventional Bricks (CB) with cement-to-sand ratio of typically 1:8 can only produce 20 blocks per 50 kg bag of cement (equivalent to 310 litres of wall volume). Therefore, ISSB yields 35.4 % more wall volume than CB.

2.2 Soil

Although site planning is a well-known subject in the building industry, the full utilization of available resources at the individual sites (plots) is rarely achieved. What is required here is to test the soil available on site first before going anywhere else. Proper soil selection for stabilization is required. Soil is a major raw material for stabilized brick; it requires only labour for its preparation and therefore in a low-wage country is the cheapest material for brick production.

2.3 Barium

Barium may be used in combination with bricks. Its absorption properties with respect to X-rays are greatly enhanced by the presence of a K absorption edge in barium. A thickness of up to 25 mm can be applied to a surface (BIR, 2000; Rezin & Kumlanmış, 2021). Applying barium plaster so that it will be well finished to the thickness required.

2.4 Water

The importance of water in construction and in building material production is well known, but the quantity needed is normally not clearly assessed, nor its availability checked nor did its significant cost realize. It is assumed to be readily available and cheaply obtained when needed. The cost of water for brick-making is sometimes higher than the cost of soil when the latter is obtained in the vicinity of the site. Many African rural districts, villages, and even suburbs of towns have no permanent source of water (pipe water) and thus the quality is not guaranteed.

Water cost varies from one location to another depending on source and labour. Here we meet a major obstacle of least developed countries; scarcity of quality water that makes such water expensive. However, the production of ISSB doesn’t have requirements for water quality differing from other concrete works as recommended by (British Standards Institution, 2000; British Standards Institution, 2006). Water suitable for making concrete should be free from impurities and harmful ingredients (chlorides and sulfates, alkalis, organic and suspended solids). It is generalized that water fit for drinking is the suitable one (British Standards Institution, 1997; British Standards Institution, 2005).

Water requirements depend on the following factors:

i. Production-water consumption depends on water-to-cement and soil-to-cement ratios
ii. Curing-depends on duration in days (minimum 7days). The potential strength of any Ordinary Portland Cement (OPC) product will be maximized by curing under moist conditions. The highest rate of reaction (hydration) between cement and water takes place in the first three to seven days, which therefore require proper curing/attention (British Standards Institution, 1997; British Standards Institution, 2005).
iii. Cleaning-depends on number of labourers and tool.

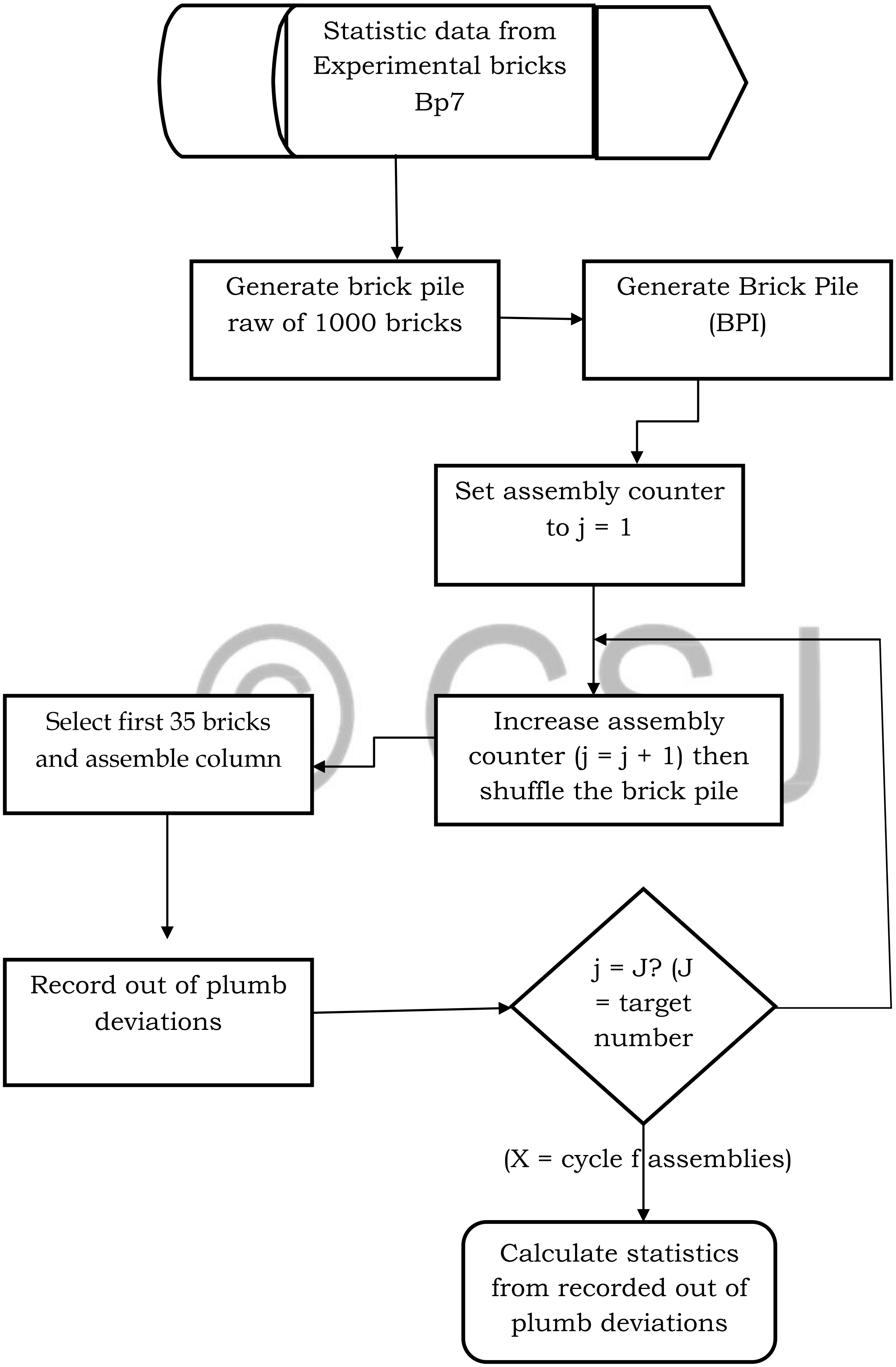
The following is a simple example of estimating the volume of water for production and curing, based on author’s practical experience with stabilized-soil brick production. Knowing the average ratio of cement to soil (1:20) and assuming a water/cement ratio of 0.5:1, one bag of cement (50 kg) requires on average three buckets of water (60 litres) to produce 120 bricks. With one brick press, three labourers can comfortably produce 500 bricks a day, namely a batch, and to cure one batch we require two buckets (40 litres of water) per day for 7 days. Washing of three labourers and tools requires five buckets of water (100 litres) per batch.

2.5 Flow chart model

The design flow chart is presented as follows;

- Get the statistical data from the experiment bricks (Bp7)
- Continue down to generate brick pile rate 1000 bricks
- Hence generating 1st brick pile called BI
- Further continue to set assembly count to the first brick i.e. j = 1
- Continue by increasing the assembly counter (j = J +1) then shuffle the brick pile
- Then select the first 35 bricks and assert column because it makes up the first smallest unit of barrier wall (shielding) which is 1sq i.e. ($1m^2$ = 35 bricks)
- It makes it possible to record the out plumb deviations i.e., (x_5, x_{10} and $-x_{20}$)
- Continue up to the target number J with x assemblies

Figure 1: Flow Chart Model for Shielding Wall Assembly and Construction Strategy



3. Results

3.1 Wall Construction Stages

The wall construction process includes the cost of materials and only four stages are considered: Bricklaying (BL), Pointing/jointing (P/J), Rendering/plastering (R/P), and Wall-strengthening (WS). The interlocking bricks are assumed perfectly produced and in good condition, likewise the sand-cement blocks. The bricks are built in the following wall construction stages;

1. Bricklaying [costs per piece include materials (brick) and bricklaying labour per piece].
2. Jointing (cost is based on cement, sand and water per cubic meter (m^3) of mortar).
3. Pointing of interlocking bricks (externally only); (unit cost includes mortar and labour per m^2).
4. Rendering/Plastering (a standardized construction cost per square meter (m^2) that includes mortar and labour). Some saving could be realized here by rendering soil-stabilized walls with a stabilized-soil plaster that matches the lean mix used for the bricks themselves; such lean plaster cannot be used on conventional blocks because it will not adhere properly.

This option is not generally considered, but it should be in practice. Because of the machined MT brick quality, their external surfaces do not require rendering; only pointing to prevent insects breeding and moisture penetration. By contrast CB is usually given an external render to improve their appearance.

5. Strengthening interlocking brick walls by pouring grout through vertical holes. Hollow/ Perforated interlocking brick walls optionally require strengthening by pouring grout (soil/sand-cement slurry) into the vertical holes through the wall (Kintingu, 2003), forming 50mm diameter cores at 300mm centres throughout the wall.

This task (grouting) is normally done after completion of wall erection, while preparing the wall to receive a ring beam. Before doing so, we insert all conduit pipes in the required positions and any reinforcement if required. Placement of grout can be accomplished in one lift for single-story walls less than 8.5ft (2.60m) high.

Grout lifts must be consolidated with an internal vibrator with a head size less than 25 mm NCMA TEK 14-22 (2003). The Hydro-form solid interlocking block wall is by contrast strengthened by laying the first two to three courses and the four last/top courses with mortar like a conventional wall. Thus about a quarter of all courses are mortared and the remaining three-quarter is un-mortared.

6. Plastering with Barium. The mixture of Varnish formed and Barium sulphate reduces the cost of lead and increase radiation protection.

Instead of using the shielding requirement for lead as 2.36mm lead which is costly barium enhanced plaster is used on both sides of the wall that is to say inside and outside to achieve the same required thickness purpose.

3.2 Cost Benefit Analysis

3.2.1 Cement Reduction

Interlocking Stabilized-Soil Bricks (ISSB) can save cement in both brick production and bricklaying compared to Conventional Blocks (CB). In conventional walling mortar is compulsory. The density of OP cement mortar is 2162 kg/m3 = 2.162 kg/litre. If the mortar ratio is 1:4 (cement to sand) the cement content will be (1/5 = 0.2) of the total volume. In practice volume batching is normally used, which increases the weight of cement because cement has a higher density than sand. And due to the fact that mortar require more workability and hence more water, a cement content of up to 0.5kg per litre mortar may be employed (increased from 2.162 x 0.2 = 0.4324kg/ litre).

One CB-1 plus its joint mortar occupies 460 x 240mm of a wall surface area, of which the block occupies 94% and mortar joint (10mm) occupies 6%. The total cement consumption for block and mortar will be: 94% is block @ 0.161kg cement per unit volume (litre) of block 6% is mortar @ 0.5kg cement per litre of mortar, Giving: (0.94 x 0.161) + (0.06 x 0.5) = 0.151 + 0.03 = 0.181 kg/ litre of wall. Therefore {(0.181-0.111)/0.181 = 0.39} CB-1 consumes 39% more cement than ISSBB in a wall unit volume. But through Uganda experience the ratios most time were 95% and 5% hence yielding 42% of more cement consumed by these ordinary bricks.

3.2.2 Cost of MT Walls

We compare the cost of MT walls using 30 variants of dry-stacked ISSB (Hydraform-ISSB-SA, Tanzania-ISSB-T and Uganda-ISSBB-U) with walls made using conventional (mortared solid-sand-cement) Blocks (B) which are most commonly used in Uganda in radiation shielding and protection in hospitals.

Using CBS we can construct a 150mm thick wall by laying bricks (CB-I) as stretchers on their front face or 230mm thick using CB-2 as stretchers on their bottom face. Comparison of these bricks are summarized in Table 3.1 in each aspect assume one square metre of walling is to be produced by a brick maker who knows the right quantities.

Table 1: Characteristics of walls compared

S/N	**System**	**Brick type**	**Brick volume (litres)**	**Mortared wall**	**Un-mortared wall**	**Wall thickness (mm)**	**No. of bricks per m²**
1.	MT	ISSBB-U 266 x 140 x 100mm	3.724 or 4			140	35
2	MT	Perforated ISSB-T 300 x 150 x 100mm	4.5		Optionally grouted	150	33
3.	MT	Solid ISSB-SA 230 x 220 x 115mm	5.8	¼ of courses are mortared	¾ of courses un-mortared	230	40
4.	CB-1	Solid CB-1 450 x 230 x 150mm	15.5	Laid on its front face		150	9
5.	CB-2	Solid CB-2 450 x 230 x 150mm	15.5	Laid on its bottom face		230	14

Key: MT – Mortar-less Technology, CB – Conventional Block

4. Discussion

The construction of wall shielding from radiation in a medical facilities or hospital makes use of the existing resources, which has great cost and radiation protection consequences. Interlocking Stabilized-Soil Bricks (ISSB), whose use is known as Mortar-less Technology (MT), are produced from the following natural resources. Soil, water, cement, equipment and using energy. If we compare them to the existing or currently used (conventional) it;

- Reduces use of limited resources
- Reduces costs
- Reduces radiation levels
- Converses the environment
- Increase performance (productivity, durability)
- Saves time

5. Conclusion

The construction of wall shielding from radiation in a medical facilities or hospital can make a step forward to protect the environment by making the revolutionary choice of using alternative walling materials (dry-stacked stabilized-soil bricks) to replace conventional (sand-cement-blocks) that consumes more cement. The use of dry-stacked stabilized-soil bricks realized more than 50% cement saving, thus a reduction of up to 40% of CO^2 released by cement production.

The study identified the importance of water in the quality control of material using cement, showing a simple method for estimating the water quantity needed for production and curing.
It estimated that water cost equaled 7% of brick value (selling price), equivalent to the normal net profit margin. So omitting water costs in estimating production expenditure can result in losses and ultimately the extinction of brick-production projects.

Finally, we compared the cost of wall construction using mortar-less and conventional technologies. Using this method is cheaper so it will enable other hospitals with no radiology department to build one. MT shows a potential serving of more than 50%, this may make a substantial contribution to making wall shielding affordability to the low income people. We can conclude that the flexibility requirements on MT for wall construction can be fully met, which will further boost market opportunities of interlock bricks. The self-aligning characteristic of interlock bricks eases brick-laying, encourage the use of less skilled manpower and realizing higher productivity. Apart from savings of material, MT saves time due to higher productivity resulting in an ultimate cost saving of around 50% (Whelan, 1985; Hines, 1993; Anand & Ramamurthy, 2003).

6. Recommendation

1. A feasibility study to be performed for practical implementation of the research findings, to extend and perfect the construction flexibility performance described in this paper.

2. A long term study for interlock wall strength following lifetime disturbances to be performed on the local movements: of foundations, mechanical shocks (due to door slamming) and major shocks (caused by earthquakes).

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