NBRRI

CONSTRUCTION DIGEST No. 1

CORBELLING IN RESIDENTIAL BUILDINGS

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NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE
(FEDERAL MINISTRY OF SCIENCE AND TECHNOLOGY)

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FOREWORD

The quest for shelter, especially affordable housing, has led to the emergence of different innovations and proposals that aim to make houses easily available and more affordable. Corbelling in buildings is simple application of principles of statics in the interactive process of destabilizing and counterbalancing of moments to span over wall openings associated with the utilization of blocks, bricks and masonry for construction.

Traditionally in the application of blockworks, bricks and masonry, openings of various sizes (especially the spans) are encountered. These occur in the forms of doors, windows and other forms to satisfy the form and functional requirements of the structure. In almost every situation, there is usually loading (mostly continuous line loads) imposed upon these spans that do not allow for ordinary non-structural solutions. Hence the use of structural lintel comprising of a reinforced concrete beam or steel element that can counter the flexural stresses arising from the sagging moment that is a maximum at the centre of the span. If the lintel is continuous, then hogging moments and some shear at the edge of the supports must also be countered. Fortunately for framed buildings, the loads are transferred through the primary structural grid and the ultimate resulting loading superimposed upon the lintel is not substantial. Hence, new innovations like *Corbelling technique* can actually be brought in to replace a lintel with an appreciable reduction in cost and time of construction, as it eliminates the needs for formwork and reinforcements and there is no elaborate concreting.

It is therefore hoped that this simple innovation can be appreciated and applied to many brick and masonry openings in buildings. The analysis in this maiden edition of **NBRRI Construction Digest** reveals that this innovation can lead to reduction in construction cost of 2 percent and lead to savings in time resulting in more efficient construction, especially of residential Buildings. It is also viewed as environmentally more friendly through the elimination of undue utilization of timber pieces and avoiding concrete mixing that exudes heat through exothermic hydration reactions.

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CORBELLING IN RESIDENTIAL BUILDINGS

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ABSTRACT

Building construction utilizes a high volume of ordinary Portland cement. The high cost of cement in Nigeria is one of the prohibitive factors in the effort to bridge the housing deficit in Nigeria. This paper dwells on the cost advantage of using the corbel-arch over the conventional reinforced concrete lintel system in buildings. The corbel-arch derives its advantage from the fact that it requires no cement in its production. The environmental friendliness of the use of the corbel-arch is also highlighted in the paper. A case study of a one-bedroom house was presented to illustrate the advantage of the corbel arch with respect to financial viability and environmental sustainability.

Keywords: corbelling, CO_2 emission, cost effectiveness, ordinary Portland cement.

1 INTRODUCTION

1.1 Background to Study

Of the total cost of building construction, building materials make up about 70% of cost in developing countries. Cement accounts for up to 25% of total cost of residential building construction (www.theteamwork.com, retrieved Oct. 01, 2012). Besides these highlighted factors, the adverse effect which the production of cement has on the environment has made it imperative for the adoption of innovations that are environmentally sustainable for the delivery of low cost housing developments. The advantages to be gained include:

I. The reduction of the total cost of construction. This will free-up more funds for the development of more housing units to cater for the housing deficit currently experienced in Nigeria and estimated at between sixteen and eighteen million.

ii. Wider distributions of available cement resource such that more construction activities have access to cement. It is anticipated that this will reduce the need to expand the industrial facilities and processes of cement production that are notorious for degrading the environment.

The construction method that will be considered in this paper is the corbel arch. The corbel arch is defined by Wikipedia as an arch-like construction method that uses the architectural technique of corbelling to span a space or void in a structure, such as an entranceway in a wall or a bridge. The Merriam-Webster dictionary defines corbelling as a structure which spans an opening like an arch by having successive courses of masonry project farther inward as they rise on each side of the gap until they meet, as illustrated in Figure 1.

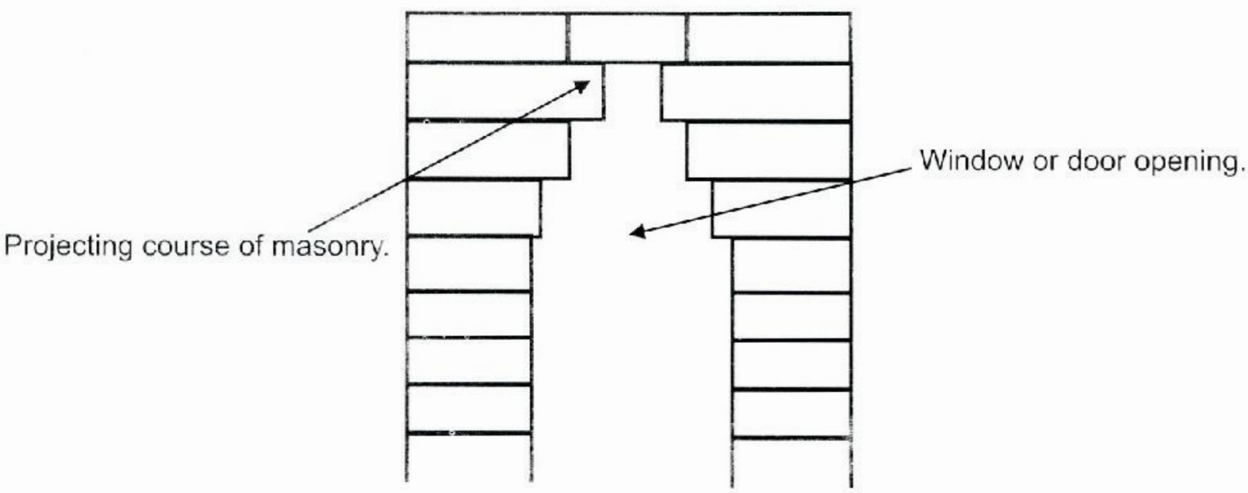

Figure 1: Basic principle of corbelled arch design.

1.2 Statement of Problem

Concrete is amongst the most commonly used construction material in the world with cement as its primary ingredient. The average world carbon intensity of carbon emissions in cement production is 222 kg of CO_2 per tonne of cement (Worrell et al., 2011). Efforts have been made by some manufacturers to reduce CO_2 emissions through improvements in process and efficiency, but further improvements are limited because CO_2 production is inherent to the basic process of calcinating limestone. It is therefore imperative to explore methods of construction that offer a more environmentally and financially sustainable utilization of Ordinary Portland Cement.

The cost of cement in Nigeria is high. These are due to several factors which include the following: a significant proportion of the cement used is imported; haulage cost of cement is high due to poor road infrastructure in Nigeria; and prohibitive tariffs; all of which are subsequently transferred to consumers. This mitigates the efforts of the Government in providing adequate housing for the Nigerian populace (Zenith Economic Quarterly, 2010).

1.3 Aim and Objectives

The aim of this paper is to highlight the advantages of applying construction methods that will eliminate the use of reinforced concrete lintels in residential buildings. The construction method examined is Corbelling. This method of construction shall be applied over door and window openings spanning between 900mm and 1200mm.

1.4 Scope

Corbelling as a method of construction shall be examined considering the various methods that have been applied over time and the rules that have been applied such as the Three-Quarter rule. The cost differential of corbelling and reinforced concrete lintels shall also be examined. This cost evaluation will form part of the basis for the justification of applying corbelling in construction, added to the eco-friendliness that this system of construction is expected to achieve.

2.0 SIGNIFICANCE OF THE STUDY

The cement industry is known to account for up to 5% of global anthropogenic CO_2 emissions (Worrell et al., 2011). To reduce carbon emissions, a reduction in the number of concrete elements is desirable in reducing the high rate of cement consumption. This in turn will reduce the need for the expansion of cement production processes that cause CO_2 emission in a bid to meet demand. These processes include the combustion of fossil fuel at cement manufacturing operations which account for about 40% of the industry's emissions, transport of raw materials about 5%; and combustion of fossil fuel required to produce the electricity consumed by cement manufacturing operations, about 5%. The remaining 50% of cement-related emissions originate from the process that converts limestone ($CaCO_3$) to calcium oxide (CaO), the primary precursor to cement (Bignozzi, 2011), as shown in eqn. 1

$$CaCO_3 \longrightarrow CaO + CO_2 \text{ -----------------------------------}> eqn\ (1)$$

The theory here is that it is anticipated that if there is a reduction in dependence on ordinary portland cement, there will be a reduction in the need to expand cement production processes that lead to the emission of Co_2.

3 DISCUSSION

3.1 Evolution of Spanning in Masonry Construction

The need for spanning over wall openings came about with the utilization of masonry for construction. Masonry construction is the use of stone or brick in the construction of buildings (Microsoft® Encarta®, 2009). This method of construction has been in practice since ancient times and was favored because the masonry elements, that is cut-stone or rubble, cohere through sheer gravity or the use of cementious mortar. The challenge was the spanning over vertical masonry elements such as columns and walls of masonry. The two main methods of spanning that had been used originally were the post-and-lintel construction and arch construction (Coe et al, 1987).

The post-and-lintel option had the spanning element that is lintel or beam, laid horizontally and usually straight. The post-and-lintel construction option can be executed with several materials and before the invention of reinforced concrete in the late nineteenth-century, the predominantly used materials for the spanning element were stone and timber. The limitation of the application of stone is its workability and for timber, it is the fact that it is susceptible to rot.

On the other hand, the arch construction allowed for spanning wide distances because vaulting permits spanning without subjecting the spanning element to bending stresses. Among the earliest improvements to the spanning element are the corbel or masonry arch and the true arch. The true arch is formed with a continuous line of wedge-shaped stones, while a corbel or masonry arch is formed by a series of overlapping stones in which each stone juts out further than the one below. The corbel arch can be traced back to 1500 BC when corbelled brick arches were used in the middle-east to support the walls above doorways (www.makingthemordernworld.org, retrieved 15/01/2012). The illustrations in Figure 2 show a likely method of the arrangement of stone to achieve the spanning needs in construction in earlier times.

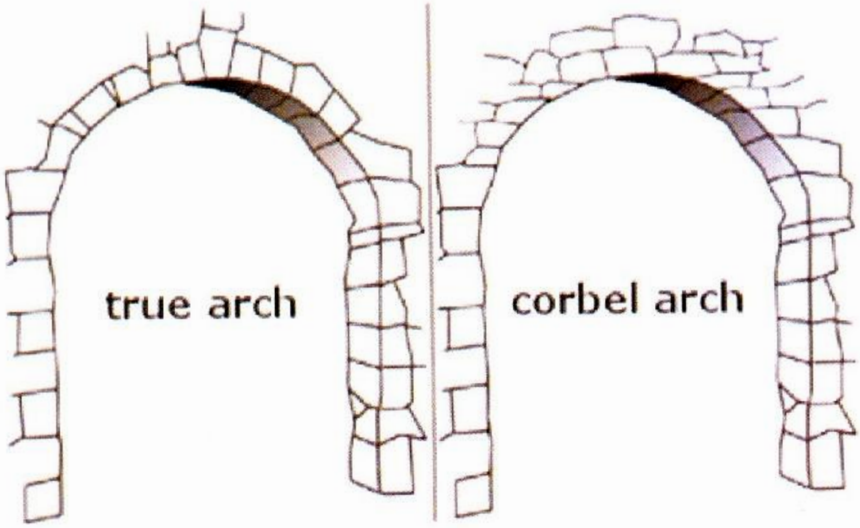

Figure 2: True arch and corbel arch.

An actual application of the corbelled arch using stone can be seen at the tomb of Nasir ud din Mahmud, Ghori in New Delhi as depicted in the Figure 3. The corbelled arch has also been used by the Sumerians to take an aqueduct across a 20 meter wide valley.

Figure 3: A Corbel arch at the tomb of Nasir ud din Mahmud,Ghori, New Delhi.
Source: http://www.merriam-webster.com/the-year-in-words/index.htm

The process of making a corbel arch involves the neat stacking of blocks or bricks such that a bit of the block above extend over the preceding block beneath it as illustrated in Figure 4.

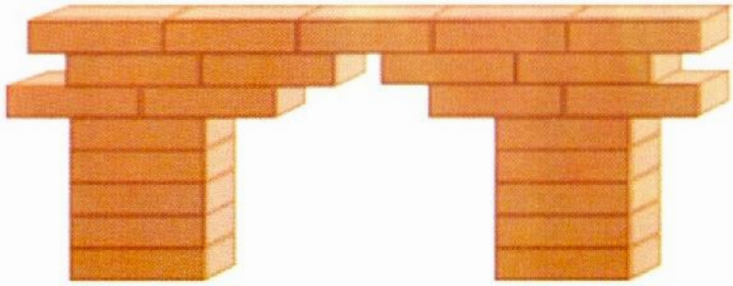

Figure 4: Corbel arch using brick

3.2 Methods of Corbelling

Corbelling has many applications in construction. It has been used for bridges, door and window openings and also for regulating masonry work for sub-structural works such as manhole construction. The rules of corbelling will be discussed in the context of the appropriate extent in terms of dimension at which a brick is cantilevered so that it is still stable and does not overturn after loading.

In works concerning manholes and regulating masonry when using 225mm (9") bricks as headers, the over-sail or cantilever is kept to a maximum of 50mm and half of 50mm (25mm) when bricks are laid as stretchers (www.pavingexperts.com, retrieved 3/12/2012). The dimensional limit for this method of corbelling can be attributed to the fact that there will be a greater turning moment as the length of the cantilevered end of the brick increases. This is illustrated in the free body diagram and equation given in Figure 5.

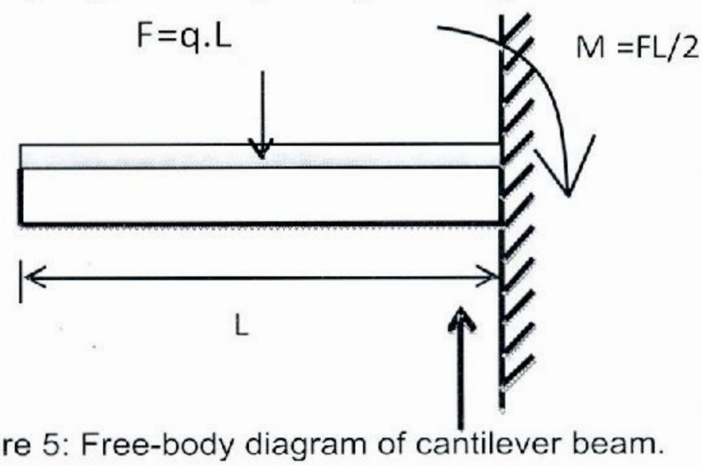

Figure 5: Free-body diagram of cantilever beam.

Turning Moment is given by

$M=FL/2$

$F=q.L$

Where:

M= turning moment
q= uniformly distributed load (total load)
L= length of cantilever

Thus, the turning moment of a cantilever beam bearing a uniformly distributed load is given by:

$M=qL^2/2$

Using the NBRRI brick, with length 225mm and weight of 10kg, the turning moment of the brick at half its length, at two thirds its lengths and cantilevered at 50mm will be analysed in scenarios 1,2 and 3 presented in the next page.

SCENARIO 1: CANTILEVERED AT HALF BRICK LENGTH

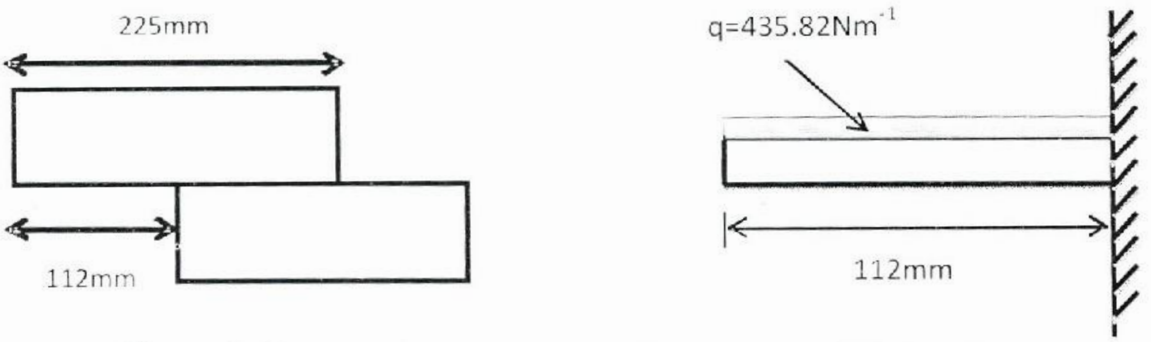

Figure 6: Figures showing brick cantilevered at half its length.

For scenario 1,

$M = qL^2/2$

$L = 0.225m$

$q = (10x9.806)/0.225 = 435.82Nm^{-1}$

$M = [0.43582\ KNm^{-1}(0.112^2)]/2$

$M = 2.73Nm$

SCENARIO 2: CANTILEVERED AT TWO THIRDS BRICK LENGTH

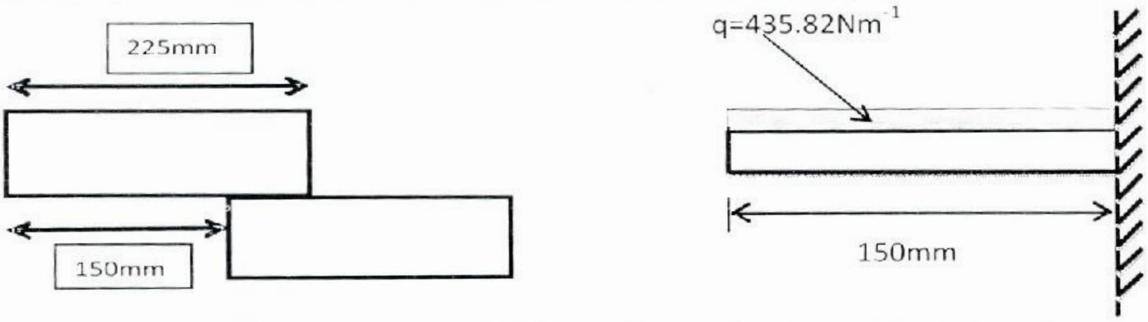

Figure 7: Figures showing brick cantilevered at two thirds its length.

For scenario 2,

$M = qL^2/2$

$L = 0.150m$

$q = (10x9.806)/0.225 = 435.82Nm^{-1}$

$M = [0.43582KNm^{-1}(0.150^2)]/2$

$M = 4.90\ Nm$

SCENARIO 3: CANTILEVERED BY 50mm

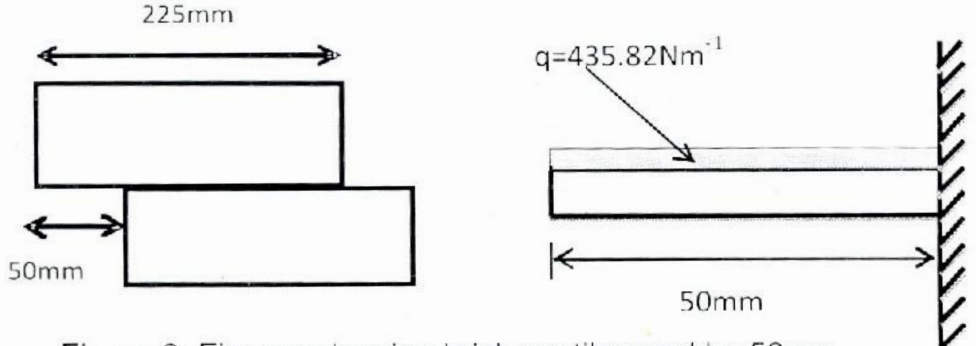

Figure 8: Figures showing brick cantilevered by 50mm.

For scenario 3,

$M = qL^2/2$

$L = 0.05m$

$q = (10x9.806)/0.225 = 435.82Nm^{-1}$

$M = [0.43582KNm^{-1}(0.05^2)]/2$

$M = 0.55Nm$

A summary of the analysis carried out is tabulated below.

Table 1: Turning Moments at varied cantilever lengths (L).

S/No.	Beam span (mm)	Turning moment at support (Nm)
1	150	2.73
2	112	4.90
3	50	0.55

The calculations above illustrate that Corbelled bricks have lesser tendency to turn when the cantilever is limited to less or equal to half the brick length as against when the cantilever exceeds half the length, considering that the turning moment increases as the cantilever increases in length.

In the case of the Corbelling method used for manholes as earlier mentioned, the brick will not overturn; but this method of corbelling for door and window openings will not be functional as the height of the triangular space over the transom of the door or window will be excessive and there will arise the need to produce an infill panel large enough in surface area to close the opening, thereby leading to higher costs that will compete with the cost of the reinforced concrete lintel. This situation is illustrated in Figure 9.

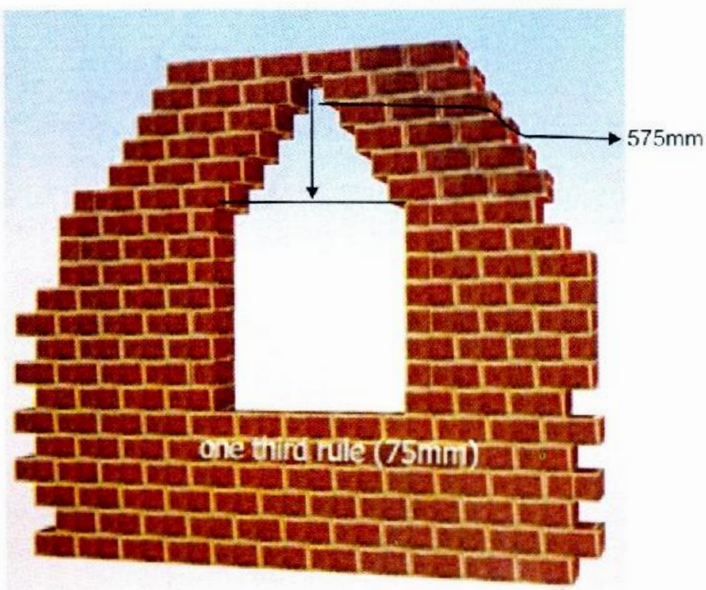

Figure 9: Corbelled brick cantilevered at 75mm (one third of brick length).

Furthermore, it can be postulated that when the masonry bricks have loads laid on them that can counter-balance the up-turning effect of the cantilevered brick, the cantilever can extend up-to but should not exceed half of the brick length, that is, 112.5mm for a 225mm brick length as it is with NBRRI bricks, as illustrated be in Fig 10. This also helps in reducing the height of the triangular space above the transom of the door or window because the number of courses up to which the bricks must rise to before they meet will be less than the number required in the case of the 75mm cantilever distance illustrated in Figure 9.

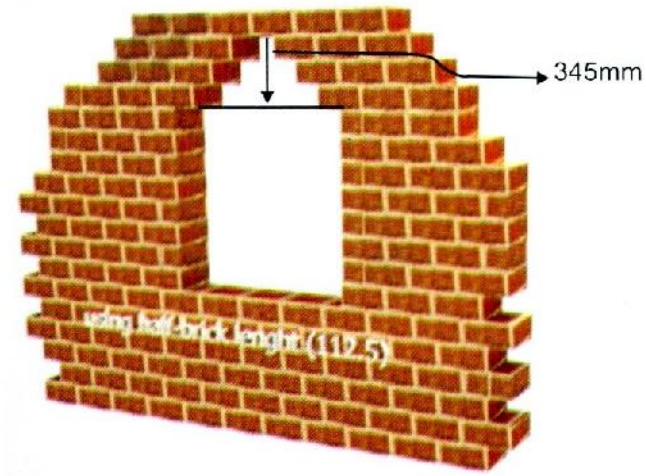

Figure 10: Corbelled brick cantilevered at 112.5mm (half brick length).

An advantage of corbelling over the conventional lintel and post construction in buildings which is worthy of note is its cost-effectiveness in construction. The components and construction processes of the lintel include cement, fine and coarse aggregate, water, reinforcement rods and shuttering for placement of the concrete. These materials have cost units attached to them while corbelling in new construction projects does not require any material besides the brick with or without binding mortar, as the case may be.

3.3 CASE STUDY

For the purpose of clarity, this paper presents a case study of the design of a one-bedroom detached house of the ward-based cluster concept of the Federal Ministry of Science and Technology (FMST). The method of its construction is the dry stacking method using NBRRI interlocking bricks and is designed to illustrate the cost-effectiveness of corbelling over conventional lintels. The floor plan of the one-bedroom prototype building is presented in Figure 11.

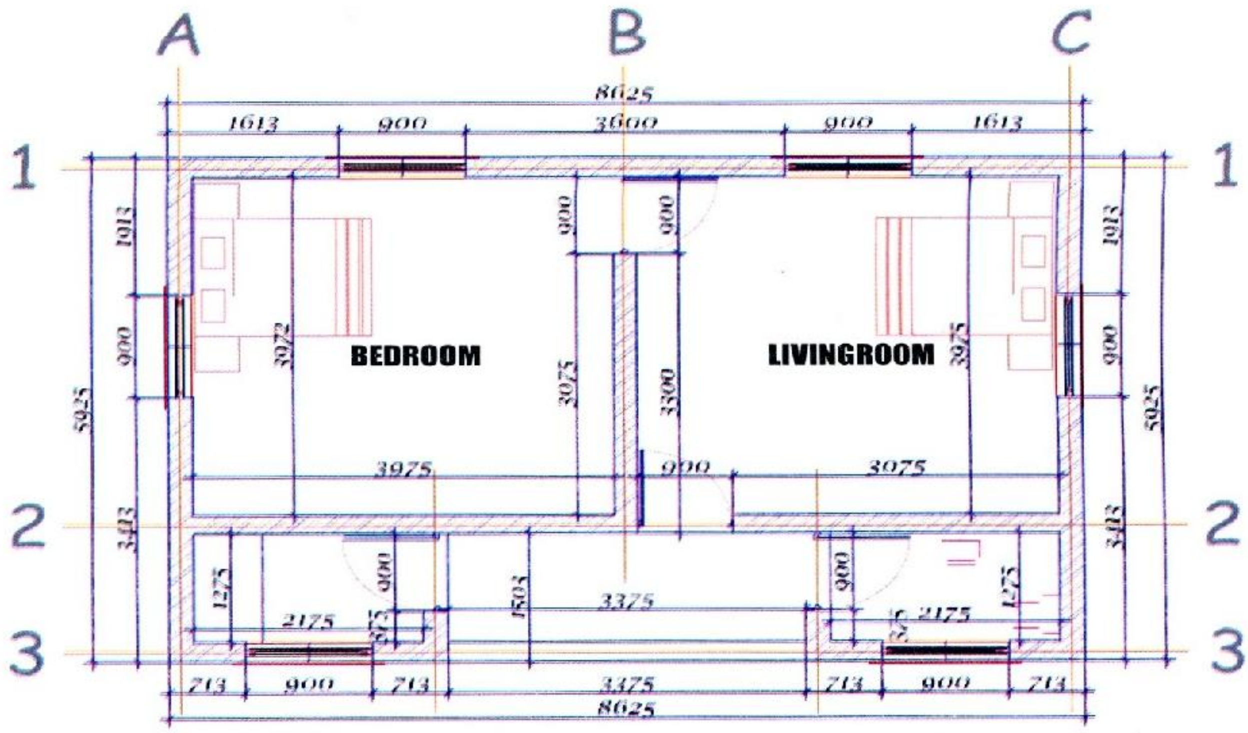

Figure 11: Floor plan of detached one bedroom house.

one bedroom house.

From the floor plan and other working drawings, the total cost of construction was quantified to be two million, three hundred and twelve thousand, three hundred and eighty eight naira, eighty four kobo (N2,312,388.84), assuming the spanning over the openings of the doors and windows are of reinforced concrete lintels. The cost of the construction of a unit of lintel measuring 1500mm x 225mm x 225mm was found to be eight thousand naira only (N8,000.00), factoring all aspects of labor and material with reference to prices published in the *Building Engineering Journal, 2012*

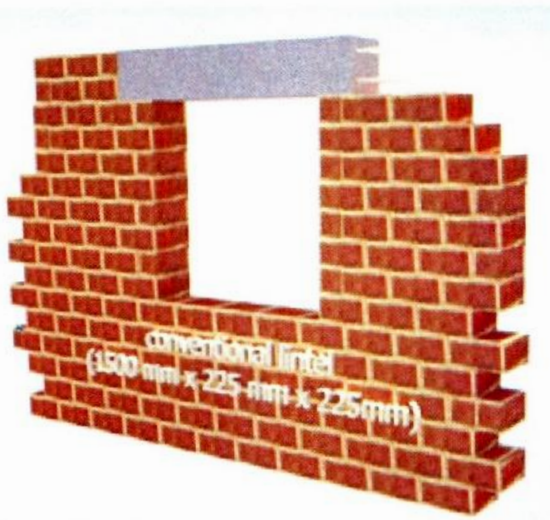

Figure 12: Conventional lintel measuring 1500mm X 225mm X225mm

The cost of erection of the corbel over a 900mm wide opening was found to be three thousand, five hundred naira only (N3,500.00). Going by the floor plan in Fig 11, the number of fenestration openings requiring spanning elements, like lintels and corbels are ten (10) and they add up to a total construction cost of eighty thousand naira only (N80,000.00) if made of reinforced concrete using twelve millimeter diameter (12mm) high yield steel reinforcement rods and measuring 1500mm x 225mm x 225mm. However, the cost of corbelling over the same openings was found to be thirty-five thousand naira (N35,000.00). A summary of these findings is presented in Table 2.

Table 2: Comparative cost analysis between lintels and corbelling over fenestration openings .

Spanning method	Number of openings	Unit cost (₦)	Total Cost (₦)
R.C lintel	10	8,000.00	80,000.00
Corbelling	10	3,500.00	35,000.00

Considering the above, the cost differential on the total cost of construction of the building comparing the two methods of spanning is presented in Table 3.

Table 3: Comparative analysis of total cost of construction between buildings using lintels and corbelling over fenestration openings.

Spanning method	Total Cost of construction (₦)
R.C lintel	₦2,312,388.84
Corbelling	₦2,267,388.84

There is a difference of forty-five thousand naira (N45,000.00) which signifies a two percent (2%) reduction in total construction cost.

With respect to the reduction in quantity of cement used per unit building, it was found that with the replacement of R.C lintels with corbelled arches, the volume of concrete saved was a total of 0.76 m^3. Each lintel measured 1500mm X 225mm X225mm thus having a volume of 0.076 m^3 multiplied by 10 numbers of required lintels will give a total of 0.76m^3.

Dutta (2002) wrote in his book *Estimating and Costing in Civil Engineering,*

1cm^3 of O.P.C =1.44grams (*as per IS: 456; 1liter of O.P.C= 1.44kg*)
i.e. 1m^3 of O.P.C. =1440 kg
Therefore in 1m^3 of cement, there will be 1440/50= 28.8bags
1m^3 of O.P.C =30 bags (for practical purposes)
1 bag of cement (50kg) = 1/30= 0.034m^3

Since 100m^3 of concrete with mix ratio 1:2:4 will require 21m^3 of cement (Dutta, 2002). This translate to 21/0.034= 617.65 bags of cement.

Thus if 100m^3 of concrete requires 617.65 bags, then 1m^3 of concrete will require
617.65/100= 6.1764 bags (or 7 bags of cement approximately- for practical purposes)

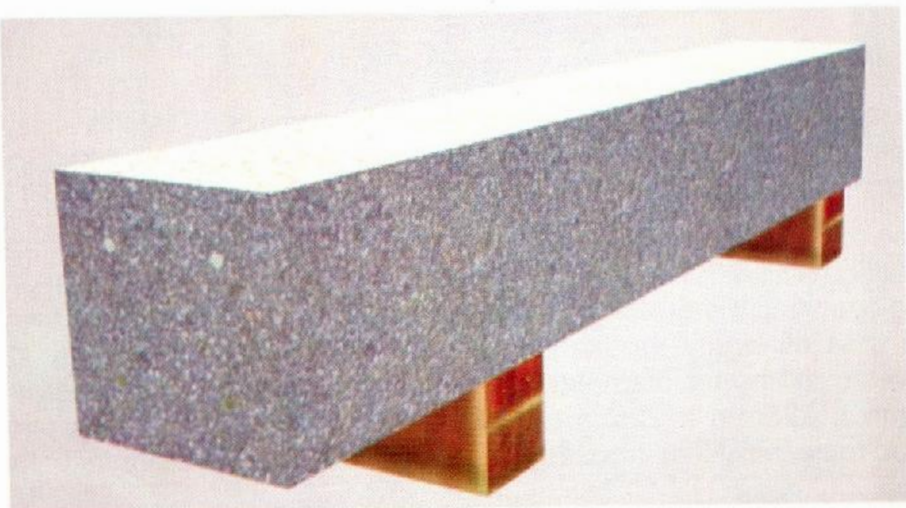

Figure 13: Conventional lintel measuring 1500mm X225 mm X225mm.

Considering that one cubic meter (1m^3) of concrete contains about seven bags of cement, 0.76m^3 which represents the total volume of reinforced concrete lintels in the building, will require:-

7 x 0.76= 5.32 bags.

Therefore, it can be concluded that with corbelling over all the fenestration openings, each one-bedroom unit of the ward based cluster concept building would save 5.32 bags of portland cement.

Aesthetically, the option of corbelling presents a cost effective alternative to the conventional post and beam arrangements over doors and windows. This is illustrated in Figures 14 and 15

Figure 14: Building with conventional lintel.

Figure 15: Building with rendered corbel arches replacing lintels.

4.0 CONCLUSION

It can be observed that with a reduction of 5 to 6 bags of cement in the construction of the one bedroom cluster house and a reduction of two percent (2%) in the total cost of construction, corbelling points one sure way to a more efficient utilization of ordinary Portland cement in residential building construction. This is justified by the fact that it is not only financially prudent to utilize corbelling but it is also environmentally friendly.

It is anticipated that the efficacy of this method of construction will be better appreciated when it is applied on large scale housing projects. The reduction in construction cost of 2% per unit building may seem marginal but on large housing projects, this is quite significant. Furthermore, it could form a part of the measures to reduce overhead expenditures in construction sites such as the cost of transporting certain quantities of cement to site.

5.0 RECOMMENDATION

From the findings above, it is recommended that Corbelling construction should be adopted especially in mass housing delivery in Nigeria for several reasons which include but are not limited to its cost-effectiveness, aesthetics, simplicity in construction, reduction in the use of cement; elimination of formworks and reduced construction period. In addition, adopting the Corbelling construction method will bridge housing deficit in Nigeria on the long run, free up cement resources for more construction and reduce cost of producing housing units.

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