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Design, Construction and Evaluation of a Twin-Block Making Machine for Farm Structures

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Abstract: The design and construction of a twin-block making machine was carried out as an improvement on the manual production of single block locally with a lot of ergonomic problems resulting from frontal loading and back straining. Material mix is fed into the machine, compressed and cranked up to remove the blocks from the mould. The machine is powered manually by a chain operated lever arm. The machine is capable of producing two standard size blocks, 457.2×127×228.6 and 457.2×152×4×228.6 mm^3 per operation. The calculated work (input) required to lift the two-block load of 529.5 N through a height of 0.279 m by the machine has been determined to be 147.73 J with an effort arm of 99.15 N. The output of the machine in terms of production capacity indicated that the machine has a throughput of 800 blocks h^{-1} compare to hand mould with 432 blocks h^{-1}, one moulder/operator and a helper. The efficiency of the machine was found to be 92.4%.

Key words: Compression, couple, brick, kinematics, stress, crank

INTRODUCTION

There are many methods of making bricks and blocks, several of which are suitable for local production since they are labour intensive but do not require skilled labour. The decision on which method of block or brick making to employ depends on several factors, such as the raw materials available, the characteristics of the soil, raw material and production costs, the requisite standards of stability, compressibility factor such as strength, water resistance, the existing facilities for the maintenance of production tools and machines, the needed productivity etc. (Lennart and Whitaker, 1988).

Blocks may be solid, cellular or hollow. Cellular blocks have cavities with one end closed, while in hollow blocks the cavities pass through. Concrete block Technology offers a speedier, cost effective, environmentally sound alternative to conventional walling materials.

As is known, a block-making machine generally comprises a form which is divided into moulds and is filled with a moist mixture of concrete aggregate and other inert materials and which is fixed to the vibrator plate and subjected to vibration to compact the mixture. It is based on the principle of densification of a lean concrete mix to make a regular shaped, uniform, high performance masonry unit. The mixture is then subjected to a pressure by means of a press and at the same time, is subjected to vibrations such as to compress the mixture to form compact blocks, which after suitable curing can be used as building construction materials for example, perforated or solid blocks, hollow building tiles, kerbed stones car paving. The specifications and the characteristics of a concrete block depend on the machine used to manufacture concrete blocks. The most common size of solid concrete blocks is 300×200×150 mm. The basic raw material is cement, fine aggregate and coarse aggregate. Very little water is used.

This is possible only with mechanized compaction and vibration and gives the block high quality in spite of the lean mix, which uses very little cement. Weight of a concrete block is about 18-19 kg. Concrete blocks can be surface engineered by using pieces of stone or ceramic waste on their face. Another common type is hollow concrete blocks. They are made with a richer mix, but offer a number of advantages, such as lighter weight, easier handling and facility for conducting or reinforcement through the hollows.

Concrete blocks are usually produced using a semi-mechanized stationary type machine. The other production systems are manual moulds that require hand tamping, a mobile semi-mechanized egg-laying machine and fully mechanized system that combines compression and vibration. These requirements are of fundamental importance since the homogeneity of the product, its surface finish and its mechanical strength depend directly upon these parameters.

Considerable efforts have been made at designing and construction of hollow block making machine by the local industries in recent years for the benefit of reducing

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cost of imported products such as Vibrobloc, model V.5-p (Rosacometta, 1997). Other models are capable of producing two hollow blocks per operation but such machines need special skills and are often powered by diesel fueled engines, which is becoming more expensive by the day (Field Survey, 2007).

Traditionally, bricks are produced without holes and their strength properties have been confirmed more useful in soils prone to irregular expansions because of their mass and solidity. Clay bricks are locally produced with wooden moulds on a flat platform or floor, while cement blocks (masonry) are manually produced with steel moulds. Constrains such as fatigue stress, high energy input in compaction, transporting and laying on the ground in one continuous operation has led to increased interest in quest for developing alternative to traditional molding practice.

This study therefore, presents a prototype design of a twin-block (2 in 1 operation) moulding machine capable of producing two blocks in one operation and also able to produce two sizes of blocks 5 (457.2×127.228.6) and 6 (457.2×228.6×228.6) mm, respectively. This study is set to produce a simple machine with improved efficiency over manual moulds, produced two sizes of standard solid blocks in one operation and reduce the cost of procuring a commercial vibrobloc, which is not by any means greater than the cost of the equivalent hand labour.

MATERIALS AND METHODS

Materials selection was based on the results of preliminary design considerations, force analysis and calculations.

Power shaft design: The load bearing shaft is subjected to two types of loading; vertical loading and horizontal loading. The vertical loads constitute the bending load, while the horizontal loads constitute the torsional load. The shaft considered for satisfactory performance is to be rigid enough, while transmitting load under various operating conditions.

To achieve this, a solid circular shaft was considered for analysis of combined torsional and bending stresses (Ndaliman, 2006). The shaft diameter that will withstand the vertical load (529.5 N) was determined from the maximum shear stress theory and evaluated by the combine stress equation expressed by Ademosun and Olukunle (2003).

$$\pi d_s^3 = \frac{\left[T^2_{max} + Mb^2_{max}\right]}{S_{all}} \quad (1)$$

Where:

T_{max} = Maximum torsional twisting moment (K_tM_t)

$M_{b\,max}$ = Maximum bending moment (K_bM_b)

K_b = Combined shock and fatigue applied to bending moment (1.5)

K_t = Combine shock and fatigue applied to torsional moment (1.0)

S_{all} = Allowable combined shear stress for bending and torsion for steel shaft without keyway is 3.799×10^7 N M^{-2}

d_s = Shaft diameter to be determined. Assuming a safety factor of 1.6, the designed diameter is $1.6*d_s$

The strength in shaft is determined to know the limit to which bending in shaft is prevented. This is determined by the bending stress, τ equation given by:

$$\tau = \frac{\text{Bending load}}{\text{Area of x-section of shaft}} \quad (2)$$

The Bending stress, τ for steel is 700 kg m^{-2} (10,000 psi). The diameter was calculated and found to be 17.4 mm and a shaft of 20 mm was used in order to have a higher factor of safety. The designed shaft was checked for deflection, torsional and critical speed criteria and found to satisfy the limiting design criteria.

Crank kinematics: The path traced out by crank arm, OB is given by XB, when the link bar ZB travel a vertical distance equal to one stroke, which is the required block width (Fig. 1). The displacement S, when the crank has

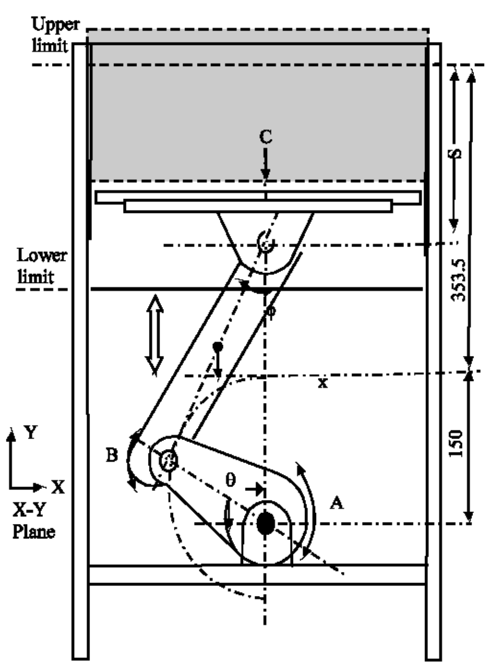

Fig. 1: Lift arm link mechanism

turned θ^0 from the upper or lower limits is given by (Liljedah and Turnquist, 1989).

$$S = r + 1 - r\cos\theta - 1\ \cos\varphi \quad (3)$$

where, r and l are crank radius and the connecting rod length, respectively. For any given value of r, 1 l and z, the value of θ can be evaluated from:

$$S = r[(1-\text{Cos}\theta) + r/4\,1\ (1-\cos 2\theta)] \quad (4)$$

Dynamics of the link mechanism: Taking the origin O at the center of the shaft and x and y coordinates as shown in Fig. 1, the upper part of the link arm experience rotary motion and produced an inertia force along Ox.

Link BZ perform reciprocating motion in the direction Oy. Point B executes a rotary motion about a fixed axis from O. Considering the inertia forces due to the masses of the entire system, the center of gravity of the crank pin, crank arm and the shaft, the concept of equivalent mass expressed by Liljedah and Turnquist (1989) is used to determine the inertia force components X_B and Y_B due to the dynamic components from the equations:

Horizontal component:

$$X_B = X_e + X_r = M_B\ W^2 r\cos\theta \quad (5)$$

Vertical component:

$$Y_B = Y_e + Y_r = M_B\ \omega^2 r\cos\theta \quad (6)$$

Where:

M_B = Total mass of crank and crank pin and equivalent mass of rotating members

Point O perform rotary motion, point C is fixed along the vertical axis and performs a reciprocating motion. The inertia force produced in that direction is given by:

$$X_A = M_A\,\omega^2 r\,(\cos\theta + (r/l)\cos 2\theta) \quad (7)$$

The vertical component $Y_A = 0$

$$M_A = M_P + M_C$$

Where:

M_P = Equivalent mass of block, pallet and plate

M_C = Mass of upper link arm and pin

The various weights acting on each link and shaft as determined through calculations are shown in Table 1.

Table 1:Weight distribution of components

Components/parts	Weight of component (kg)
Plate and pin hinge	3.69 (36.20 N)
Linkage bar	2.83 (27.76 N)
Crank arm	3.42 (33.55 N)
Crank	4.12 (40.37 N)
Shaft	4.10 (40.22 N)

Results of design calculations and specifications normat

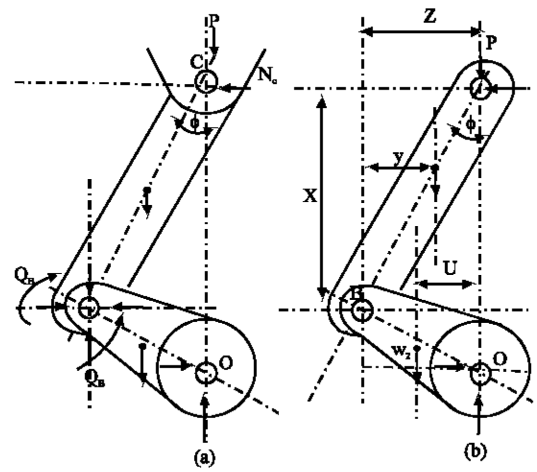

Fig. 2: Forces in linkage mechanism

Kinematic relations and force system: In solving the problem of the forces acting on the pins and links, the unknown forces are resolved into x and y-axis coordinates and force and moment equations written for each link. P is a known force (weight of block) acting vertically downward at point C (Fig. 2). N_C is an unknown force reacting on the wall and resisting the collapse of the system due to W_1 and P.B_1 and B_2 are reactions on the pin at B.Q_B (Nm) is the unknown limiting friction couple in the pin. The direction of the limiting couple is determined by assuming that load P acting is in equilibrium (Harrison and Nettleton, 1979).

At the point of overcoming P and thus, moving against gravity, link AB impact an anticlockwise couple on BC causing AB to experience a clockwise couple (Fig. 2b). The two approaches used by Harrison and Nettleton (1979) were adopted in the determination of the unknown forces N_C and couple Q_B. writing equation for one moment and two force equations for each link, thus resulting in equations with six unknown, which can be solved simultaneously, or taking moments about B for link BC only and obtaining a relationship between P and the unknown for N_C.

Hence, N_C can be found by taking moments about A for the two connected links. Taking moments about point B in Fig. 2a:

$$\sum B = 0 \Rightarrow Q_B = xN_c + yW_I + Z_p$$

For the entire system and taking moment about O,

$$\sum M_o = 0 \Rightarrow \frac{Nc = (yW_I + uW_2)}{x}$$

Free body moments: The Free Body Diagrams (FBD) for the links BC and BO are shown in Fig. 2b with the force components at B on AB equal and opposite to those at B, on BC, which is equal and opposite to those at B on BO (Newton's third law), the directions of the forces otherwise being chosen arbitrarily (an axis perpendicular to the xy-plane).

At equilibrium, the following conditions were identified:

$$\Sigma F_x = 0,\ \sum F_y = 0,\ \sum M_o = 0$$

Therefore, for link BC Fig. 2b,

$$\Sigma F_x = 0 \Rightarrow B_2 - Nc = 0$$

$$\Sigma F_y = 0 \Rightarrow B_I - N_I - P = 0$$

$$\Sigma M_B = 0 \Rightarrow Q_B = xNc + yW_I + zP$$

For link BO Fig. 2b,

$$\Sigma F_x = 0 \Rightarrow H_A - B_2 = 0$$

$$\Sigma F y_y = 0 \Rightarrow B_A = B_I + W_2$$

$$\Sigma M_A = 0 \Rightarrow Q_B = zB + vB_2 + uW_2$$

For the entire system Fig. 2b,

$$\Sigma F_x = 0 \Rightarrow H_A - N_c = 0$$

$$\Sigma F_y = 0 \Rightarrow w_I + w_2 + P - B_A = 0$$

$$\Sigma m_A = 0 \Rightarrow Nc = (yw_I + uw_2)/x$$

These equations were substituted for with known forces and the unknown forces were determined as represented in Fig. 3.

The magnitude of the forces in pins A, B and C and Shaft A as determined are as follows:

Shaft O = $2F_O$ = 603.32N
Pin B = F_B = (268.11N)
Pin C = F_c = (231.65N)

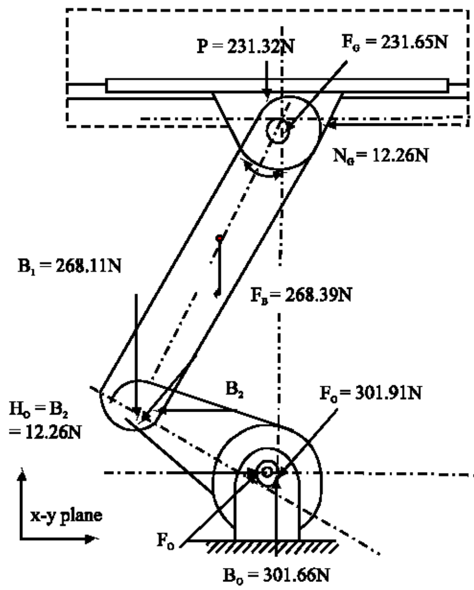

Fig. 3: Forces acting on crank pins

Load distribution on pins: Forces F_O and F_C have the same line of action and are thus collinear implying that F_O and F_C equals the resultant vertical forces acting in the downward direction. F_B is acting opposite to F_O and F_C thus, resisting these forces. The resultant force acting on the system is thus:

$$F_A + F_C - F_B = 264.75N$$

Total force acting downward is 2 x F_O for the entire system. The work done on load is given by load x load distance Therefore, work done on the load through OZ is:

$$W = 2F_O \times OZ$$

The crank arm travels through an angle θ to deliver the load through height OZ, while the effort travel through θ to be able to deliver the load. Taking into consideration average human height (1580 mm) and ease of operation to the length of effort arm determined is (800 mm).

Effort required to lift the load is given by
Effort = load x effort distance = 99.15N

Useful work done is given by;

Useful work = work input-work done against friction

Machine description: Using locally available materials, all component parts were fabricated from first principles in

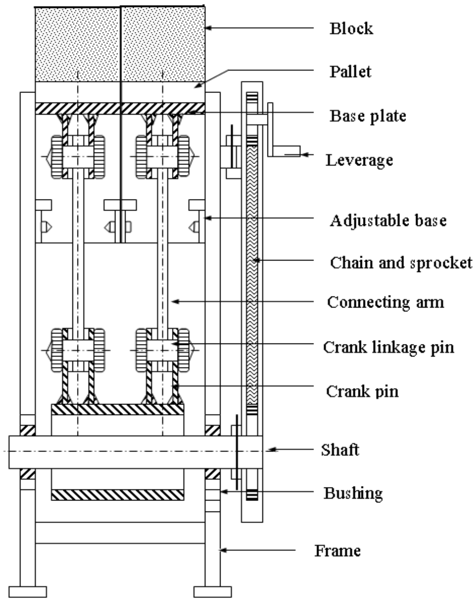

Fig. 4: A sectional view of the machine

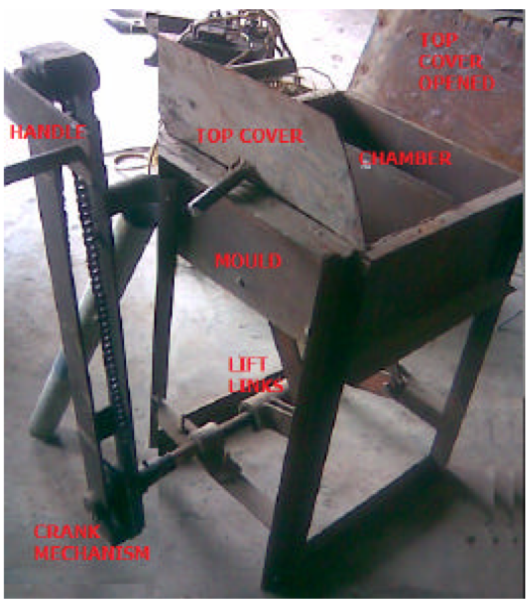

Fig. 5: Twin block making machine

agreement with the operating criteria. The sectional view of the machine is shown in Fig. 4 and 5. The major components of the machine comprises of the lift arm, which provides required force to compress the materials and lift the moulded material out of the mould. There is a base plate with pallets mounted on linkage bars supported by the crank and crank pins.

The entire system is mounted on a shaft supported by two bushings (locally fabricated). The mould/form is a box that produces the required block sizes. It comprises of metal plates formed into two rectangular box compartments. The lower end of the mould is designed with size adjustment and also to accommodate the base plate support during loading. The base plate rests on angled guides inside the box thus, providing a framework for efficient delivery.

There are two sets of frame supports; one providing support for the mould and the box-cover plates above, the other providing support for the crank mechanism and the lift arm. The main frame provides the needed stability for the entire machine. The material of construction is mild steel angle iron of dimension $(50\times50\times5)$ mm^3.

The lift-mechanism: The lift-mechanism is the engine room of the entire system, which perform two basic functions, compression of mix materials to required density and lifting material out of the mould. The machine is capable of using two forms of lever mechanism: A lever mechanism operating on chain and sprocket with a lever handle to crank the mechanism, which turns the driven shaft. The other is a long lever attached to the shaft directly as found in conventional machines.

The design configuration of the machine is such that the load P compressed in the metal casing is securely guided by a metal plate during compression. With effort E exerted the limiting friction couple, Q_B is easily overcome and the load move up, when the covers were lifted. The result of tests carried out compared favourably with manual operation compression and block delivery.

Performance test: The basic raw materials for the test is cement, fine aggregate and coarse aggregate. The material is measured in proportion and thoroughly mixed with water. 50 kg of cement (one bag) was mixed to normal ratio of soil: cement: water mix. The mix was divided into two equal parts and each parts were moulded using the hand mould and the machine. Two tests were carried out using the machine and manual mould with two operators, respectively.

A measured amount of the mixed material is poured into the two compaction chambers, the lid closed and the crank arm operated. The amount of soil mix fed into the compaction chambers is correct if the cover closes properly. The machine is then operated by cranking the handle. The machine compacts and consolidates the mix so that the blocks attain uniform size.

The lids were then opened and the block is ejected and carried on wooden pallets to the curing site. The inside of the compaction-chamber is cleaned and oiled and a pallet is placed on the feed plate for material reload. Tatal 20 pieces of blocks was produced with the machine, while 18 was obtained using hand mould.

Curing of blocks: The blocks were kept damp on the ground as close together as possible and left to set and cure for two days. They were observed for cracks and other deformities on the third day. Then, the blocks were raised on one edge to further dry for 1 day and carefully stacked in six coaches each for 2 weeks for final curing.

Testing of blocks: Durability was tested by spraying the blocks with water according to a standard procedure and making observations for any erosion or pitting. Simple weather resistance test was carried out at the end of the curing period; three blocks were selected from each set, immersed in a tank, all night and dried in the sun all day. This wetting and drying is repeated for seven days. The surfaces were examined for holes.

RESULTS AND DISCUSSION

The research design is simple, using locally available materials. All component parts were locally fabricated and the layout developed from the first principles in agreement with the above criteria. The vertical load (603.32 N) acting on the shaft as the bearing load and the strength of shaft and shaft diameter were determined in order to select shaft size (31.75 mm), which will give a save limit for shaft bending.

Appropriate shaft section was therefore, selected from steel designers manual. Design configuration of the machine is such that the load P acting on the material in the metal casing is securely guided by a metal plate during compression. The limiting friction couple Q_B is easily overcome by effort arm and the load move up, when the covers were lifted. The vertical load (bearing load, 603.32 N) acting on the shaft, the strength of shaft and shaft diameter were determined in order to select shaft size (31.75 mm), which will give a save limit for shaft bending. Appropriate shaft section was therefore selected from steel designers manual. The fabricated grating machine can be operated both by lever system and chain mechanism. It is therefore, versatile and simple. The total cost of production of a unit is estimated to be about N50,000.00 including both manufacturing and overhead costs as compare to commercially available machines sold for about N100,000.00 a unit. This is affordable for an average entrepreneur.

The performance tests conducted indicated that high values of moulding efficiencies are attainable, when this machine is used than manual operation. This is possible only with mechanized compaction and vibration and gives the block high quality in spite of the lean mix, which uses very little cement. The machine provide high quality vibration in the mix so that the ratio of cement used can be reduced substantially without compromising on the strength of the blocks and attain desired physical properties. It took on average 3 min to load and operate the machine thus, producing two blocks compare to 2.5 min to produce one block with manual mould. On the average 600-800 blocks can be produced by this machine in 8 h of operation by 2 skilled and 6-8 semi-skilled workers per day. The technical specification of the block produced is shown in Table 2.

Table 2: Technical specifications of concrete blocks

Parameters	Description
Typical sizes	(457.2×127.0×228.6 and 457.2×152.0×4×228.6) mm
Average compressive strength at 28 days	50-110 kg sq^{-1} cm
Mix proportion	1:12-14 (1 part cement: 12-14 parts sum graded aggregates)
Water absorption in 24 h	Less than 10% by weight of block

Table 3: Effect of product durability comparing machine and manual mould

Types	No. of visible cracks	No. of edge cut	Sound blocks	Total No. of blocks
Machine mould	3	2	15	20
Hand mould	2	-	16	18

Table 3 shows the result of the observed visible cracks in the blocks from machine mould. This could be associated with the dynamic stress experienced in transit due to the person lifting the blocks out of machine to the ground, while the edge cuts are attributed to mechanical damage.

The output of the machine in terms of production capacity indicated that the machine has a throughput of 800 blocks h^{-1} compare to hand mould with 432 blocks h^{-1}, one moulder/operator and a helper. The result of durability test based on physical examination of surfaces of samples randomly selected indicated that few tiny holes (pits) appeared on the surfaces of the all the sampled blocks on the first day.

This is an indication of loose particles in direct contact with the mould surface peeling off. These holes propagated slowly in the hand mould some of which developed into some form of erosion on the 7th day. Several lines were formed to depths up to 4 mm in some cases.

The machine mould samples showed some resistance to pitting, which is an indication of better compaction than the hand ram. A further sound test carried out on the dry blocks in each sample produced better metallic ring, when tapped with a hammer, showing that they have satisfactory durability and hardness.

CONCLUSION

A block making machine, which is capable of producing twin solid blocks of two different sizes and double blocks in one operation has been designed and fabricated (Fig. 5). This novel machine, which causes significantly less stress and reduced operation time with better quality product and higher performance efficiency is obtained.

The product of this machine contributes to the farm structures development and construction. Furthermore, the machine has improved qualitative performance and requires less maintenance and a smaller number of personnel to operate.

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