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# Articulated Hollow Concrete Masonry Blocks for Earth-Retaining Structures

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***Abstract*---Earth-retaining structures usually consist of masonry walls or continuous concrete walls. Such structures need to be sufficiently strong and as economical as possible. In this work, both strength and economy issues are addressed. The performance of retaining wall is increased by using articulated concrete masonry blocks to facilitate enhanced mechanical anchorage of the blocks due to interlocking of filling material in their hollow spaces. The blocks are made economical by using fly ash in the concrete. These efficient and economical articulated concrete blocks could be used to construct strong masonry walls to provide better alternatives for various structures like open wells, retaining walls, pitching works in dams, canals, approaches and wing-walls in bridges, road-dividers, protection lining for road-shoulders, compound walls, architectural works in gardens like plain terracing, etc.**

***Keywords---Articulated; hollow concrete block; lining in open wells; earth-retaining structures***

## I. INTRODUCTION

Earth-retaining structures usually consist of masonry walls or continuous concrete walls. Conventionally, in such structures, the masonry walls are constructed using either natural stones, bricks, or hollow concrete blocks. Most of the time, due to certain advantages, the walls are cast in the form of continuous concrete walls. However, such structures should be not only strong enough, but also as economical as possible. Now, where the earth-retaining structural walls are primarily supposed to resist the lateral loads acting on them, the walls made of simple stones/bricks/hollow blocks rely on their strength obtained by virtue of friction that exists amongst various blocks connected to each other. This friction is of course aided by the mortar bond between those masonry blocks. Certainly, there is a way to increase the lateral load resisting capacity of such walls by constructing them using articulated hollow concrete blocks. For this, the walls can be constructed properly using mortar for bonding the various blocks amongst each other. The hollow space in those masonry blocks could be filled by murum particles such that mechanical interlocking takes place amongst the particles while embedding/burying the various arms of the articulated blocks in the filling material. Thus, the lateral earth pressure acting on such walls could be resisted additionally by the derived mechanical interlocking effect.

Consider the example of an open well. The circular shape of open well requires least amount of material for its lining. It allows best use of compressive strength of lining under hoop stress. That is the reason why circular shape of well is prevalent in the world. Now-a-days, brick, stone and timber lining is no more in use due to different limitations. Whereas reinforced cement concrete cast in place as a monolithic ring is presumed to be good enough, it has some constraints which need to be overcome. For example, it consumes excessive material, requires centering and form work, more labour, less infiltration of water without weep holes, requires concrete mixer at site, hazardous construction method, difficult to provide proper steps, and the material once used cannot be reused. Now, the wall of the well is supposed to support the soil behind it while providing enough volume in the well for storage of water coming from springs in it. Therefore, the walls of such wells are supposed to be quite strong to resist the lateral active earth pressure when earth behind the wall is unsaturated/saturated with water. Under such circumstances, it will be structurally very advantageous to derive additional resistance to the lateral earth pressure through mechanical interlocking of murum particles filled in the hollow spaces of the articulated masonry blocks. The efficiency of walls made with articulated concrete blocks is expected to be more than that of made with conventional natural stone/brick/concrete blocks. In order to make it cost-effective, use of fly ash in concrete is proposed.

In this attempt, small handy articulated hollow green concrete blocks, which could be used as building blocks in masonry form of the lining, are proposed. Weight of such typical blocks is kept about 24 kg, with density of concrete 2500 kg/m$^3$. The shape of hollow block is specifically selected to give reasonable unit surface area of the lining. For this many dimensional combinations of articulated hollow blocks are tried to arrive at a stable unit block against overturning, sliding and crushing actions due to pressure from retained material behind such blocks. A most appropriate shape thought over is as shown in the Fig. 1.

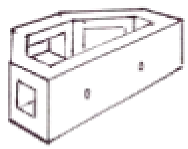

Fig. 1: Isometric view of the block

The articulated blocks are easy for handling by the mason. Besides this, the block is provided with a core which can be filled with the excavated material (murum etc.) so that it provides additional stability to the block through physical interlocking amongst the murum particles. The block has a solid facing plane of 50 mm thickness with two weep holes. The sides and back portion of the block consists of continuous frame-like concrete components having cross-sectional size of 50 x 50 mm, reinforced with 6 mm diameter steel bars. The overall size of the articulated hollow block is 500 x 300 x 200 mm chamfered at corners, provided with the nominal reinforcement. The articulated shape of the block enables it to get an added support of wedging and anchoring actions due to interlocking amongst filled in particles, which contribute to the stability of the lining work. The Fig 2 shows details of the block in plan, elevation and side section.

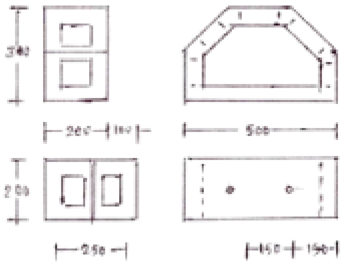

Fig 2: Plan, elevation and two side views of the block

## II. MATERIALS AND METHODS

The material used for making the suggested type of blocks is a fly-ash based green concrete. The Ordinary Portland Cement OPC of grade 53, sand of zone III conforming to IS – 383-1970, and coarse aggregates of size 10 mm with Pozzocrete$^{TM}$ 60 are used in it. In this work, 30% cement is replaced by Pozzocrete$^{60.}$ Nominal reinforcement of 6 mm diameter tor steel bars and chicken mesh are used. The impact value of aggregate used is 9.76 % while its crushing value is 8.95%. The bulk density of fine and coarse aggregate is 1835 and 1948 kg/m3 respectively. The specific gravity of both fine and coarse aggregates was found to be 2.62. The typical chemical composition of the fly ash used is as shown in Table-1.

Table – 1
Chemical Composition [4]

| Constituents of fly ash | % |
|---|---|
| $SiO_2$ | 53.36 |
| $Al_2O_2$ | 26.49 |
| $Fe_2O_3$ | 10.86 |
| CaO | 2.42 |

Other properties of fly ash are mentioned in Table 2.

Table – 2
Typical properties of fly ash [4]

| Properties | Liquid Limit | Plastic Limit | Plastic Index | Specific gravity | Opt. Moisture content | Max. Dry Density | Cohe-sion | Angle of repose | Permeability |
|---|---|---|---|---|---|---|---|---|---|
| Values | 23.9% | 13.14% | 10.76% | 3.26 | 31.2% | 1.2 g/cc | Negli-gible | 35 | $1.3x10^{-4}$ cm/sec. |

Mix proportion design (using 30% fly ash a cement replacement) as per IS-10262-2009 is carried out for M-15 grade concrete. The following quantities of different materials are arrived at:

Table – 3
Material Quantities for M15 Concrete

| Material | Cement (kg) | Fly ash (kg) | Water (lit) | Fine Agg. (kg) | Coarse Aggre-gate 10 mm (kg) | W/C ratio | Total Wt (kg) |
|---|---|---|---|---|---|---|---|
| Per $m^3$ | 260 | 112 | 186 | 718 | 1126 | 0.5 | 2402 |
| Per Test cube (0.0034) | 0.78 | 0.37 | 0.61 | 2.37 | 3.71 | 0.5 | 8.12 |
| Per Hollow block(0.01) | 2.6 | 1.12 | 1.86 | 7.18 | 11.26 | 0.5 | 24.0 |

Since the proposed articulated concrete block consists of jointed thin parts, a nominal reinforcement in the form of 6 mm diameter mild steel rods of required length, and chiken mesh 0.25 $m^2$/block is used in vertical face of the block. For casting the block in required size and shape, 2 mm thick fibre sheet shuttering is used. In order to provide weep holes, two pieces of 20 mm diameter pvc pipe 70 mm long are used on front face of the block.

Using the above mentioned mix proportion, the test cubes and the hollow blocks are cast and cured appropriately. The properties of fresh and hardened concrete are observed as shown in Table 4.

Table – 4
Properties of fresh and hardened concrete

| Slump mm | Density Kg/$m^3$ | Compressive strength | |
|---|---|---|---|
| | | 7 days | 28 days |
| 35 | 2450 | 8.3 | 20.0 |

The hardened articulated hollow concrete blocks are tested in UTM to find their load carrying capacity in direct compression. The average compressive strength observed is 2.60 N/mm$^2$.

*A. Calculation for Depth of Well using Proposed Blocks*

Area of one block in plan = (400 x 50) +5 (150 x 50) = 57500 mm$^2$

Crushing load observed =150000 N

Weight of block with infilled murum = 500 N

No of blocks which can be loaded one over other = 150000/500 = 300

Height of one block = 200 mm

Height covered = 300 x 0.2 = 60 m

With factor of safety 1.5, height of wall that could be constructed= 60 / 1.5 = 40 m

Thus, the compressive strength of block is sufficient for more than 40 m deep well

*B. Mechanical Anchoring of Individual Block*

Due to articulated form of the block, various parts of it get fully embedded in the filling material like murum when they are used in wall of the well. Therefore, it gains additional strength against sliding due to the mechanical anchorage available. Hence all blocks get properly anchored in the wall safely.

*C. Sliding of single block in situ position*

Stability calculations of blocks as a whole in lining position in the earth-retaining structure:

Horizontal pressure intensity due to back filling material of depth *d* would be

$$p = C_a.\gamma.d$$

Total horizontal sliding force for one block

$$P = p \text{ x } l \text{ x } h$$

Hoop compression on the block

$$R = p \text{ x } D \text{ x } h / 2$$

where *D* is diameter of the well.

Hence the force of friction available on each side of block due to hoop action

$$F = \mu_1 R$$

where $\mu_1$ = coefficient of friction between faces of two blocks in contact with each other.

Now, total downward load that could be supported by a block = 150 kN (obtained experimentally in laboratory).

Therefore, the horizontal force of friction available at top and bottom of the block

$$F_{tb} = \mu_2 \text{ x } 150$$

where $\mu_2$ is coefficient of friction for two block contact surfaces which are one below the other.

Thus, the factor of safety against sliding

= Total resisting frictional force / sliding force

$= 2 (F+ F_{tb}) / P$

Thus, for example, taking $\mu_1 = 0.40$, $\mu_2 = 0.35$, $D = 10$ m, $h = 0.2$ m, $p = 0.3 \text{ x } 17 \text{ x } 40 = 204$ kN/m$^2$, and $l = 0.5$ m, the factor of safety against sliding will be 165.14. Therefore, these blocks would be very stable with respect to the sliding action on them.

*D. Adequacy of wall thickness*

Assuming that the outward earth pressure from inner face of the block at 40 m depth would be about 204 kN/m$^2$, the outward force on wall AB of the block would be $H = p.l_1.h$ = 204 x 0.4 x 0.2 = 16.32 kN

Hence, reaction to each end arm of the block =16.32/2 = 8.16 kN

Therefore compressive stress in the arm c/s area = (8.16 x 1000) / (50 x 200) = 8.16 mm$^2$ < 15 N/ mm$^2$. Hence Safe.

These calculations show that the designed block would be quite safe against sliding horizontally for a 40 m deep well with its diameter of 10 m.

## III. RESULTS AND DISCUSSION

The proposed concrete block, to be used in earth-retaining masonry walls, is acted upon by forces from all its six sides when it is submerged in water stored in the well; otherwise in dry condition, forces from five sides will act on it. The calculations shown above prove that it is going to resist all expected loads on it. Being made of strong enough concrete (M15 grade), and articulated form of the block, mechanical interlocking amongst filled-in particles in the hollow space in the block gives additional strength to the earth-retaining structure to withstand all loads coming on it, with reasonable factor of safety. The articulated concrete hollow block, with self-weight of 240 N and additionally a weight of 250 N due to filled-in earth material (murum) into the hollow space in the block, thus the total weight of 490 N and additional benefits of block form, circular shape of well, the wedging and anchoring actions will suffice the loading configurations with desired performance of the block in the structure. The use of M-15 grade green concrete with nominal reinforcement is sufficient enough to take care of crushing action on the blocks.

## IV. CONCLUSION

With 30% replacement of cement by fly ash, M-15 grade green concrete articulated blocks can be a better replacement of conventional cast-in-situ reinforced concrete lining ring, with a material saving of 35% and cement saving 30% without loosing the strength, stability and gaining extra durability, finish, performance, speedy and easy construction with minimum labour force for the lining of open wells.

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