current construction design scenario, viz. low cost, lower CO_2 emmisions and lower energy consumption (Faustino et al. 2012). Many researchers have used agricultural by-products as well as industrial wastes in the development of the production of insulation board, masonry block, lightweight and other value added construction materials. Agricultural by-products such as, coconut coir and its husk, corn cob, rice husk, sugarcane bagasse, sunflower stalk, date palm fibre, hemp, wood shavings, cotton waste, etc. and industrial wastes as papermill waste, construction and demolition waste and other boiler ashes (bio-briquette ash, sugarcane bagasse ash, saw dust, coal and rice husk ash) were used as a supplementary materials in the development of sustainable products. Researchers in their respective research work tried to achieve a low value of density and thermal conductivity in the developed product (Rajput et al. 2012; Madurwar et al. 2015; Sakhare and Ralegaonkar 2015). Ralegaonkar et al. (2017) analysed various design options considering alternative masonry products (Fly ash (FA) against bio-fuel ash CLW (BFA-CLW)) and expanded polystyrene geofoam (EPGF) insulation in the wall and/or roof of the house. Study concludes that considering the energy efficiency of walling material BFA-CLW bricks performs better than FA bricks in view of controlling peak cooling load demand and the cost of the project (Ralegaonkar et al. 2017) as it has low thermal conductivity and lesser density.

Table 1. Details of the considered single storey building

Location	Nagpur ((Latitude: 21°9' 0" N, Longitude: 79°6' 0" E))
Rooms	Bed Room, Living Room, Kitchen, Bath and WC
Height	3 m
Wall thickness	150 mm (external) and 100 mm (internal)
W	1.2 m (Ht.) × 1.0 m (W)
W1	0.5 m (Ht.) × 1.0 m (W)
D	2.1 m (Ht.) × 0.9 m (W)
D1	2.1 m (Ht.) × 0.8 m (W)
Opening (D)	2.1 m (Ht.) × 0.8 m (W)

Using the required information appropriately through Building Information Modelling (BIM), cost of sustainable design can be reduced significantly. BIM has the potential to reduce the delivery time of project by increasing the productivity (Azhar 2008). A virtual model containing defined geometry and related data needed to support the design, procurement and construction work required is digitally built (Eastman and Charles 2008). Project team can be sure of what the output will be before the building is even constructed (Moakher and Pimplikar 2012), which will save money from design changes and energy costs. Action plans or programs that contribute to efficiency are encouraged as well (Turner and Iqbal 2013).

REVIT Architecture is a purpose built tool for information modelling, which is based on parametric building modelling technology. Due to which it delivers its maximum benefits by not only graphically depicting the design, but also captures and uses the data needed for supporting sustainable design. A model created in REVIT will be useful for examination and documentation for different design options. Also, integrating it with other analysis tools will simplify the difficulty in analyzing huge data and will provide proper solutions (Hossein et al. 2015). Peak heating or cooling load is the required amount of heat that needs to be supplied or withdrawn in order to maintain comfortable indoor temperature (Smith B, 2011). With the help of REVIT and EcoTect a simulation tool, a suitable material combination was identified which resulted in the maximum reduction in energy consumption of two level bungalow house (Shoubi 2015). Kim et al., 2016 created 65-design scenarios by altering window dimension, position & orientation and studied its effect on energy load of the building. The Autodesk Green Building Studio was used for energy load estimation of the generated models for each scenario. The above studies validate the use of BIM as a decision-making tool.

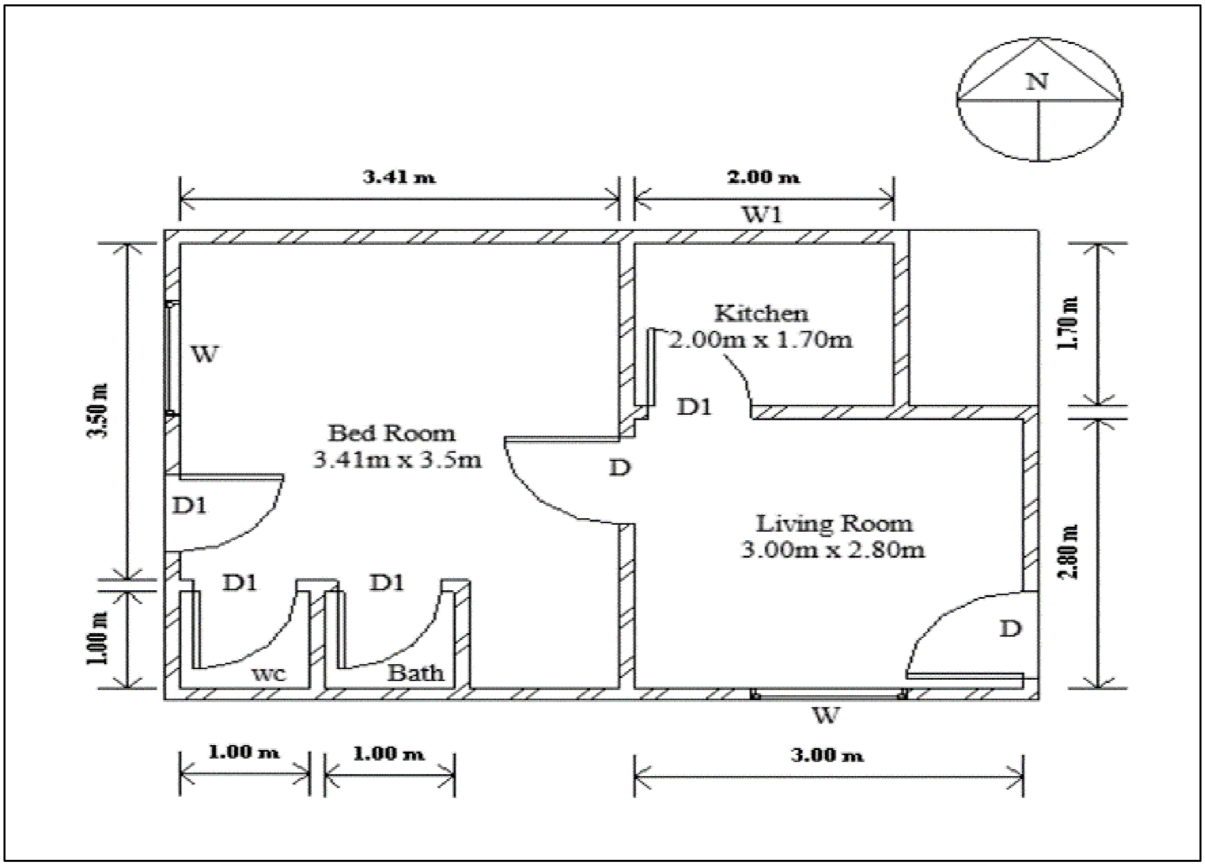

Figure 1. Floor plan (2D view-REVIT model) of building

The present study evaluates the application of co-fired blended ash (CBA) in the development of sustainable and energy efficient walling material. Developed masonry unit was used as an alternative to conventional bricks having better thermal resistance and energy efficiency. Concepts of Building Information Modelling (BIM) were applied and used for detail modelling and estimation of material, cost and energy demand for the considered case.

MATERIALS AND METHODOLOGY

Walling Material

Though fly ash bricks are commonly adopted for wall construction, lightweight and thermally resistant bricks are highly recommended for energy efficient housing. Considering the fact, low thermal conductivity CBA bricks were developed using boiler ash, which was co-fired blended ash (CBA) obtained from an industry Malu Paper Mills Ltd., Nagpur. CBA is a resultant by-product from co-combustion of sawdust and coal in the proportion of 50:50 to achieve 800 °C temperature in the boiler. CBA was used as a partial replacement of sand (5, 15, 25, 35, 45, 55 % weight of sand) in the development of bricks with cement (OPC 53 grade) as a binder. Dry mixes with 10% cement and 90% fine aggregate were cast with 8-9% water percentage and size of 23 cm X 10 cm X 9 cm bricks were molded in an automated brick plant located at VNIT, Nagpur. After demoulding, bricks were left for drying followed by water curing. For each composition 12 samples were cast. Then the developed bricks were tested for the physico-mechanical properties as per the recommendation of Indian Standards IS 3495 (I-III): 1992. The test results were compared with the permissible limits stated in IS 1077: 1992. Followed by this, thermal conductivity of the developed bricks was obatained using Lee's disc apparatus.

Building model

A single storey building, which was approved by the Nagpur Municipal Authority having built area of 27 m^2 is used in the comparative study. Figure 1 presents the plan and orientation of the building. Table 1 provides the details of the considered case.

The building model unit was created as a residential unit having 24-hour usage. The thermal conductivity 'k' value of CBA bricks and FA bricks were given as input to the simulation model (Sakhare and Ralegaonkar 2015). The project information such as location and building definition allows obtaining more accurate heating and cooling information for the project. Spaces (Figure 2) are placed in areas of the building model to determine the volume for each area.

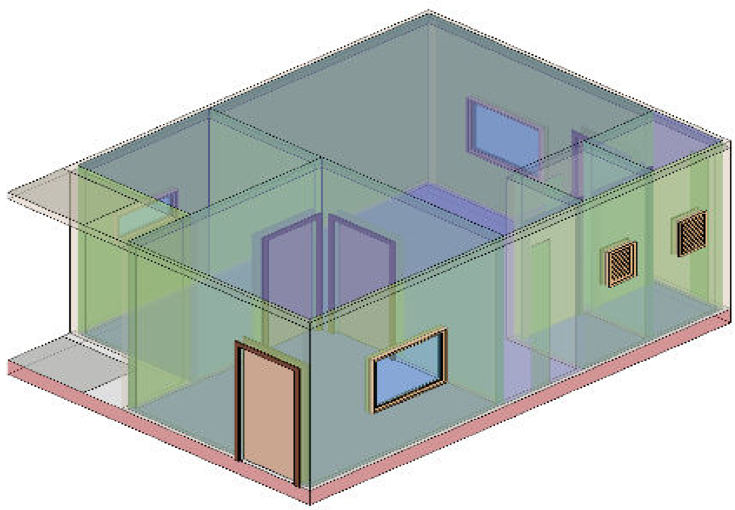

Figure 2. Spaces generated in REVIT Architecture

The thermal and physical properties of building materials have been measured (Table 2).

Table 2. Thermo-physical properties of used construction materials

Material	Particulars	Density	Thermal Conductivity
Masonry Blocks	Fly-Ash Bricks	1800 Kg/m^3	1.05 W/(m-K)
	CBA Bricks	1330 Kg/m^3	0.55 W/(m-K)
Plaster	Cement mortar	1120 Kg/m^3	0.5100 W/(m-K)
Slab	RCC	2500 Kg/m^3	1.0460 W/(m-k)

Once all the data has been assembled, the engine can create schedules of materials, cost and compute the heating and cooling loads. For calculating cooling loads, the engine sums those to compute the total cooling load for each hour and selects the hour of peak load. The engine repeats this process for multiple months to determine the peak load. Figure 3 provides a detailed procedure of Revit Architecture for the cooling load demand valuation. Further, the comparative analysis of the obtained peak cooling load of the model cases was carried out.

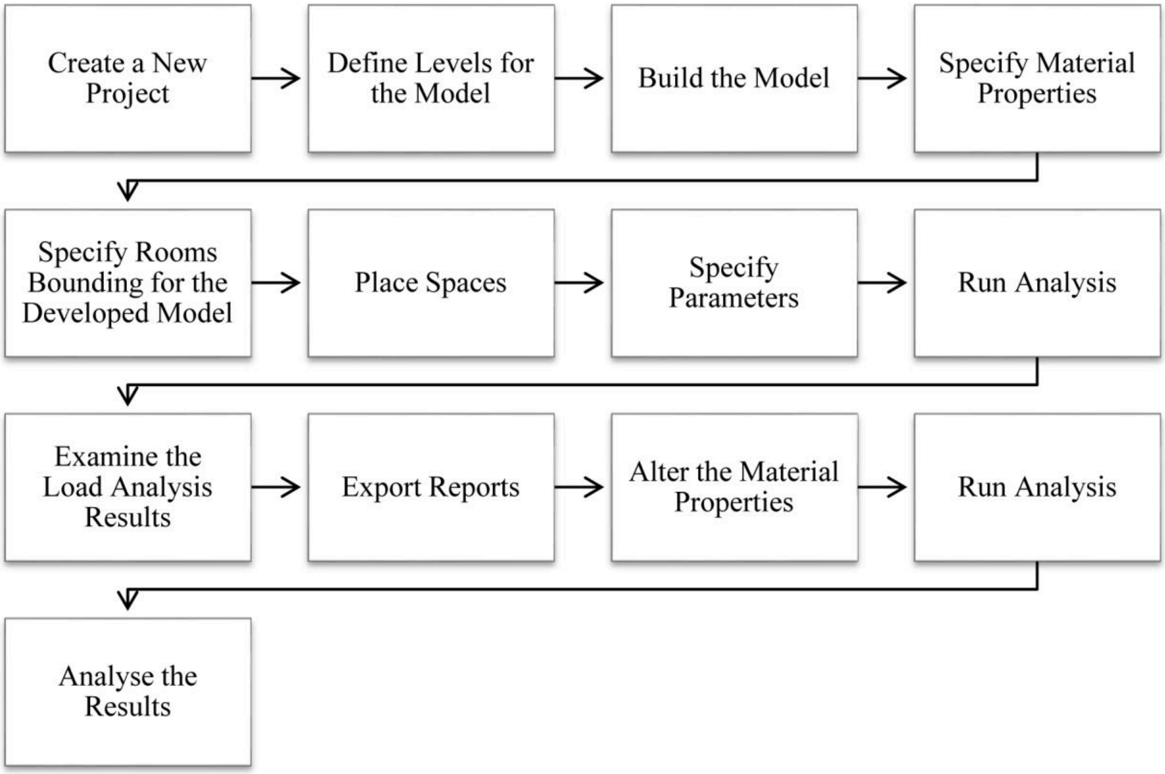

Figure 3. Revit Architecture flow diagram for peak cooling demand estimation

Table 3. Comparative analysis of bricks

Brick Type	Size (In mm^3)	Drying shrinkage	Density (Kg/m^3)	Thermal conductivity (W/m-K)	EE (MJ/ Brick)	Cost/unit (INR)
FA bricks	230× 100×80	-	1800	1.05	2.23	5
CBA bricks	230×100× 90	No shrinkage	1330	0.53	1.71	4.6

RESULTS AND DISCUSSION

As per IS 1077: 1992, bricks up to 35% CBA content were able to accomplish the minimum compressive strength criteria of 3.5 MPa. It was observed that, with the increase in CBA percentage, the compressive strength and dry density tend to decrease and water absorption increased. The water absorption for the CBA bricks (with 25% and 35% CBA content) exceeded the permissible limit of 20%. Still, there is a scope of increment in the CBA content up to 35% in the presence of admixtures. Observed efflorescence in all brick samples was negligible. Table 3 provides the comparative analysis between commercially available fly ash (FA) bricks and the developed CBA bricks. Properties of FA bricks was referred from Madurwar et al., 2015.

As per specifications and architectural drawings, building envelope details were defined as an assembly. Material properties of the assembly, such as thermal conductivity, material density, and material mass were provided as input to simulate the effect of the building envelope on the internal gains of the cooling load. First, peak cooling load was estimated in the primary case (FA Brick) model. Then the walling material was replaced by CBA bricks keeping the roofing material same. Building energy analysis, building massing and cost evaluation was performed using the developed CBA bricks and compared with the primary case model.

The performance analysis results were illustrated in graphical format in Figure 4. The graph provides the peak cooling load estimated for each room on the floor. Use of CBA bricks has reduced the cooling load in all the rooms of the floor in comparison with primary case. CBA bricks can conserve overall 8.3 % of the energy required for the cooling.

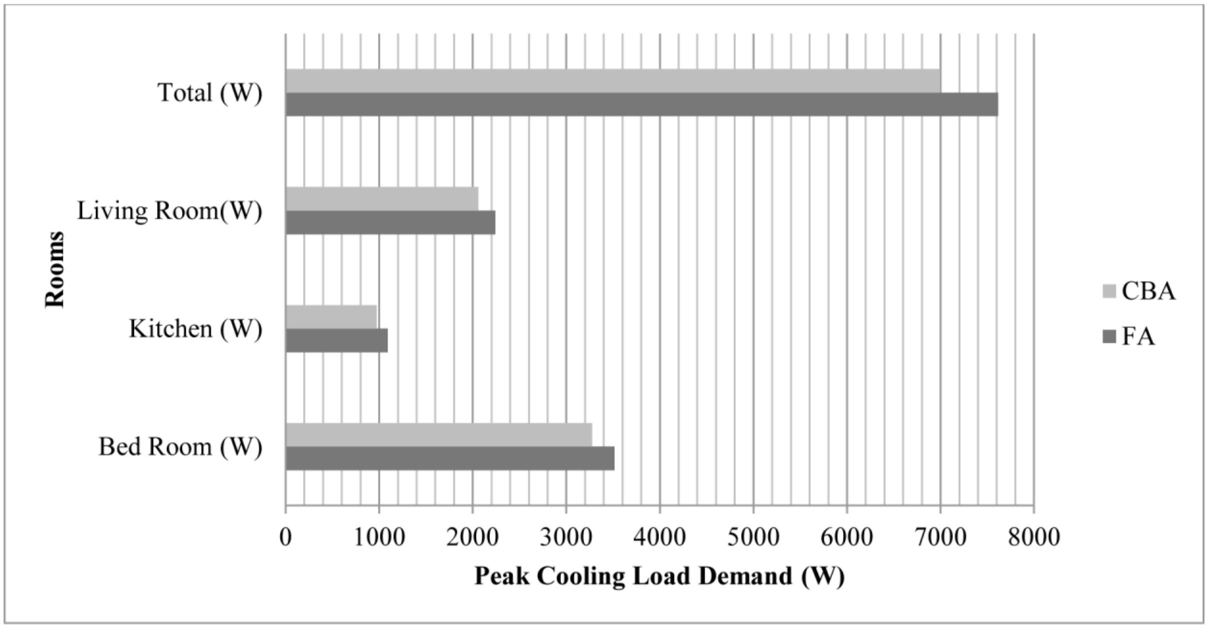

Figure 4. Comparative analysis of peak cooling load of FA bricks and CBA bricks

Total cost of brickwork for fly ash and CBA masonry was estimated at Rs. 39772 /- and Rs. 35071/- results in 11.8 % of cost saving. CBA bricks were found to be 26% lighter in weight with respect to FA bricks, which further caused the reduction in the dead load.

In comparison with the FA bricks, embodied energy (EE/ unit) and thermal conductivity of the developed brick was reduced by 23% and 49.5% respectively. The EE of brickwork for CBA masonry is 6853 MJ, which is 31% of FA masonry having EE as 9890 MJ. Thus, in terms of total cost, EE and cooling load demand, the CBA bricks as a walling material are better compared to FA bricks.

CONCLUSION

This study evaluates the performance of a building when developed CBA bricks were used as an alternate walling material. In the experimental study, CBA brick was developed which has low thermal conductivity, density, EE and low cost as compared to commercially available FA brick and used for the sustainability analysis through a case study. Bricks developed using CBA (up to 15%) were found to comply with the IS standards and found suitable to be used in non-load bearing walls. It is concluded in the case that the use of CBA brick as a possible energy efficient walling material seems to be an effective solution to gain sustainable, economic, and ecological advantages.

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Experimental Investigation on Durability of Soil Reinforced with Sustainable Fibers Subjected to Wet-Dry Cycles

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ABSTRACT

Sustainable infrastructure plays vital role in overall growth of any country. It includes economical and environmental friendly methods of construction. The intent of the present study is to analyze some geotechnical properties including durability of soil reinforced with locally available fibers. The types of fibers utilized for the present investigation at 1.25% of soil dry weight, are agricultural waste fibers (straw, coir), and industrial waste fibers (shredded tire rubber). Some characterization tests including SPT, UCS, and a wet-dry cycle test, which is simply wet-dry durability test, as adopted from literature were conducted. Results obtained with reinforced samples were much better. It is concluded that after using these fibers peak compressive strength was increased as well as sudden expansive behavior of soil sample was much reduced.

KEYWORDS: Waste fiber; Soil reinforcement; Sustainable construction; Flood resilient; Durability;

INTRODUCTION

Today the world is suffering from some degree of climate change that is causing extreme weather events including frequent flooding. Every year, mostly coastal countries are affected by floods due to heavy rain and sea level rise as they are more vulnerable. In this way considering future aspects there is need to use locally available materials in infrastructure, which should be resilient too. Earthen construction is an eco-friendly, economical and sustainable method of construction. It involves low carbon emission, low first cost, low energy consumption, locally available material and easy construction techniques [1]. The present work is a study of different fibers viz. barley straw, coir, and tire rubber from the waste of agricultural and industrial products as soil reinforcement. The proposed composite could be utilized as a part of low volume road projects, embankments, and as lightweight backfill materials for retaining walls to accomplish the growing demands for new construction materials and potential use of waste fibers in sustainable and environmental friendly approach.

Recently, the demand of “eco-composite” i.e. environmental friendly material, in infrastructure has been increased as landfills are filling up and non-renewable resources are extinguishing [2]. These facts have drawn many researchers attention towards the use of waste material as partial replacement of soil. Barley straw is generally developed and gathered more than once every year in every rustic range in everywhere throughout the developing countries and is guaranteed to be the most financially savvy mulch practice. The incorporation of straw in mud bricks leads not only higher compressive strength but also reduced dead weight and material handling cost [3]. Coir is fibrous material which is outer part of an aged coconut. Coir grids, geo-textiles are nowdays available in various categories, which are economical, and environment friendly [4]. Comparing with synthetic fibers (40.0%) it was observed that coir has shown great improvement (47.50%) in resilient modulus or strength of the soil [5]. Sivakumar Babu and Vasudevan [6] noted an increase in both strength and stiffness of clay reinforced with 1–2% random discrete coir. In another study carried out by Mali and Singh [7], cohesive soil was mixed with 10–30 mm long coir at varying content of 0–2.5%. It was concluded that with incorporation of coir fiber in silty soil, stress-strain behavior of soil was improved and optimum length of fibers was found in between 15–25 mm with optimum fiber content of 1%. Large amount of scrap tires are being produced in industries all over the countries. The problem of disposal of waste tire influenced its use in sustainable construction. Akbulut et al. [8] reported about 1.97 times increment in unconfined compressive strength of tire rubber fiber reinforced clay as compare to unreinforced sample. The optimum fiber length was found 10 mm with optimum fiber content of 2%. A decrease in consistency limits along with compaction characteristics, CBR values, and cohesion was also reported by Sellaf et al. [9], as the tire rubber content increases from 10–50%. Prasad and Raju [10] found that direct shear test and CBR test indicated that for gravel and flyash material reinforced with different content of tire rubber, optimum content of fiber was found 5% and 6%, respectively for flexible pavement.

MATERIAL AND METHODS

Clay, coarse sand, fine sand, gravel, straw, coir fiber and scrap tire fiber were utilized in the present study (Fig. 1).

Figure 1. Materials used in preparation of samples (a. Clay, b. Coarse sand, c. Fine sand, d. Gravel, e. Straw, f. Coir, g. Shredded tire)

For the preparation of samples, basic composition of cob construction was used. For the mixing process all the materials were blended together homogenously. Table 1 and Table 2 show percentage required for different components and the properties of samples prepared, respectively.

Table 1. Properties of materials

Material	Percentage required (% by weight)	Details of preparation
Clay	20.6	Oven dried 105°C- one day
Coarse sand	19.7	Oven dried 105°C- one day
Fine sand	32.5	Oven dried 105°C- one day
Gravel	24.4	–
Fiber (straw/coir/scrap tire)	1.25	15–50 mm
Water	1.55	–

(Source: guidelines from Forster et al. [11])

Table 2. Soil sample properties

Liquid Limit	17.2%
Plastic Limit	13.2%
Plasticity Index	4%
Sp. Gr. (plain/control sample)	2.56
Sp. Gr. (control+ coir)	2.38
Sp. Gr. (Control+ straw)	2.4
Sp. Gr. (Control+ tire fiber)	2.45

Figure 2. Unreinforced and reinforced samples

TESTING PROCEDURES

After some Characterization tests, in second stage compaction tests were performed with the aim of investigating the optimum moisture content for which maximum dry density of different samples (unreinforced, straw reinforced, coir reinforced, and tire fiber reinforced) was achieved. Standard proctor test method was used in investigation in conformity with IS: 2720 (Part VIII)-1983. Further, the optimum moisture content obtained was used in preparation of samples for unconfined compression (Fig. 3) and wet-dry cycle test [12]. For better simulation with field conditions, cylindrical samples (Fig. 2) were prepared using a mould of 75 mm dia. and 150 mm height. The samples were prepared in four equal soil layers. Each layer was rammed with 60 blows as adopted from literature [1].

Figure 3. Set up for unconfined compression test

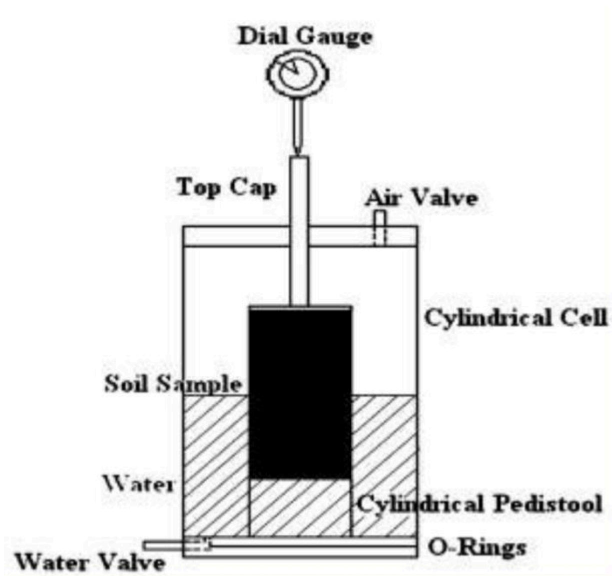

Figure 4. Set up for Wet-Dry cycle test

WET-DRY CYCLE TEST

The test set up was adapted from Forster et al. [11] to explore the response of the specimens under cycles of flooding took after simply drying periods, for the duration of 360 hours (15 days) in 3 cycles. The half portions of the samples were exposed to flooding. Figure 5 demonstrates the format of the mechanical assembly and Table 3 shows durations of wet and dry event for each cycle as adopted from literature. Simply a cylindrical cell of 300mm × 600mm was assembled with water valve and dial gauge for vertical displacement measurement (Fig. 4). The wet-dry cycle test is adopted from the Flooding Simulation Test by Forster et al. [11].