Experimental investigation on compressed stabilized earth block

M. Harikumar, Firozemon,N.P.Raseena, S.Rithika, S Nipin, T.S Shayifa, K.M Jini

Abstract—In the growing concern of awareness regarding sustainable building material and environmental issues, Compressed Stabilized Earth Block(CSEBs) which gives the view of energy efficient, cost effective and environmental friendly building material. CSEBs are ecofriendly and as these blocks are unburnt blocks, during production no coal or burning material is needed, so it doesn't produce any harmful gases during the production phase.CSEBs are manufactured using stabilizers to provide adequate compressive strength and durability, so as to make them suitable as building blocks. Though cement is a popular stabilizer used in manufacture of CSEBs, not a relevant study has been reported utilizing lime, ash and fiber in combination with cement as partially replacing stabilizers. In this study an attempt is made to stabilize CSEBs which is casted using locally available soil&clay with lime, ash along with cement with varying proportion of coconut husk fiber and hair fiber. The variation in properties like compressive strength and water absorption of the blocks are studied and compared. It will be helpful for optimize the quantity of stabilizers used, to reduce the cost of blocks. The main objective of the project is to analyze the various engineering properties of CSEBs using lime, ash and fiber as stabilizers along with cement so as to establish the potential of these blocks as an alternative to traditional bricks , hence this would be a good contribution towards sustainable development.

Keywords—Cement, Compressive strength,Fiber,Lime, Stabilization, Sustainability, Water absorption, Wood ash.

———————————— ◆ ————————————

1 INTRODUCTION

The construction practices of today heavily depend on materials like burnt bricks, cement, and other metals like steel, aluminum etc.These are energy intensive materials which consume a lot of energy and thus the production of these building blocks has a negative impact on environment.Since these materials can be produced only in particular areas there is a need to transport to the site to be used and again resulting in consumption of energy, so it is evident that these materials contain lot of embodied energy in them.

Hence it is important to produce alternative building materials which consume less energy and can be used for construction.Earth has been the most widely known and abundantly available material for human society to use it in construction.Even though building with earth once fell out of popularity when the modern building materials and methods were discovered, but then it gains its revival time following the energy crisis. Local availability of mud makes its use leads to energy efficient building material, cost effective and it is a very reliable material for any building in general and low cost buildings in particular.

Traditional earth construction technology has undergone a considerable change that enhancesearth's durability and quality as a construction material for low-cost buildings. Such methods include rammed earth and machine compressed stabilized earth blocks.The technique to enhance natural durability and strength of soil defined as soil stabilization.The mainadvantage of manufacturing unfired bricks is that itrequires lesser energy than fired bricks, and hence therelease of carbon dioxide into the atmosphere is 80% lessthan fired bricks.Compressive strength of the block hasbecome a basic and universally acceptable unit of measurementto specify the quality of masonry units, as this is anindirect measure of durability of the blocks.

2 LITERATURE REVIEW

Stabilization is considered to be an important step in the manufacture of CSEBs, and is aimed at improving the performance of a soil as a construction material. As a guideline, the best possible combination of ingredients would

ISSN 2229-5518

be70% of sand and gravel, and 10% to 20% clay for obtaining good wet compressive strength of blocks (Olivier and Mesbah, 1987 Houben and Guillaud, 1994, V.Reddy and Jagadish, 1995 etal).Amongst the variety of soil stabilizers used, cement has been the most popular stabilizer in the manufacture of CSEBs. Attempts have been made by various researchers in the past to document the role of cement as a stabilizer in CSEBs (Spence, 1975; V.Reddyand Jagadish, 1989; V.Reddy, 1991; Houbenand Guillaud, 1994; Walker and Stace, 1997; Kerali,2001; V.Reddy and Walker, 2005). It has been reported the optimum content of cement to get wet compressive strength of 3–5 MPa for compressed stabilized mud blocks made out of soils having kaolinite as the principal clay mineral proportion with about 70% sand and 20% fines [silt and clay] is 8%(V.Reddy and Jagadish, 1989, V.Reddy, 1991, Kerali, 2001 etal).Lime has been used in stabilizing clayey soils, and has been found to impart long-term strength gain as reported in the literature (Bell and Coulthard, 1990, Little, 1995, Mallela et al., 2004, Amu et al., 2011, Herrier et al., 2012). However, compared to cement, utilization of lime as a stabilizer in the preparation of CSEBs has not found popularity. Veryrecently an attempt have been made to utilize lime in combinationwith cement as a stabilizer to achieve desirable propertiesof CSEBs byH.B. Nagaraj, 2014 etal have reported that combination of cementand lime has been found to be mutually very beneficial inimparting strength to the blocks in a much better way,because cement has taken care of stabilizing the sand portionwith hydration products obtained from cement andlime to stabilize clay fraction present in the mix. As lime isknown to impart strength in the long term, its utilizationin some proportion as a replacement to cement may be beneficial. There exit many research works based on utilization of ash and fiber to improve the properties of soil. Soil blocks with 15% and 20% corn husk ash had their required compressive strengths(Yalley and E.Asiedu,2013) The ecological evaluation of wood ash as a soil stabilizer resulted in the increase of bearing strength of road constructed using it(K.Supancic and I.Obernberger.,2011). For maximum improvement in strength, soil stabilization using 10% RHA content with 6% cement is recommended as optimum amount for practical purposes (Aparna Roy, 2014). Fiber size of 2.5cm was chosen as it was found best option for mixing and compressive strength point of view (Kabiraj.K & Mandal.U.K,2011). The determined strengths of coir reinforced laterite blocks are higher than those for ordinary laterite blocks (Aguwa J. I , 2013). Several investigations have been carried out on the addition of coconut and sisal fibre, which have shown very promising results. The addition of 4% of fibres (weight ratio), reduced significantly the occurrence of visible cracks and gave high ductility in soil blocks (Ghavami et al.1999, Galan-Marin et al. 2010). This paper reports the attempts made to understandthe role of lime,wood ash,fibers in combination with cement as a stabilizer inimproving the properties of CSEBs, optimize theuse of stabilizers and maximize the strength of the blocks.Any effort to optimize the quantity of stabilizers used incombination would help in reducing the cost of the blocks.This work is thus aimed at contributing towards improvisingthe existing technology of manufacture of unfired earthblocks. This would be a good contribution towards sustainabledevelopment.

3 MATERIALS

In the present study locally available red earth, wood ash, ordinary Portland cement and lime were used for preparation of CSEBs.

3.1SOILS:

It was ensured that the selected soilwas air dried, pulverized to break the clods and sieved.

3.1.1RED EARTH:

The soil used was sourced from the campus locality of college of engineering Vadakara. The

ISSN 2229-5518

best possible combination of ingredients would be 70% of sand and gravel, and 10% to 30% clay for obtaining good wet compressive strength of blocks (Houben and Guillaud, 1994).The selected soil was characterized for its physical properties namely; liquid limit, plastic limit, optimum moisture content, particle size distribution, maximum dry density and specific gravity using the standardprocedures as specified by Bureau of Indian Standards(BIS) (SP: 36-Part1, 1987) and the results are summarizedin Table 1.

TABLE1

Properties of the red earth soil.

Property	***Value***	
Specific gravity	2.4%	
Liquid limit	30%	
Plastic limit	-	
Grain size distribution	Gravel	22.33%
	Sand	76.55%
	silt	1.07%
	clay	0.05%
OMC	8.33%	
MDD	1.733g/cc	
Plasticity index	30	

3.1.2BENTONITE:

Bentonite was sourcedfrom Bangalore. Bentonite is essentially highly plastic clay containing not less than 85% clay mineral, montmorillonite.Sodium bentonite is usually referred to as bentonite.The commercial importance of bentonite depends more on its physico-chemical properties rather than its chemical composition.Excellent plasticity and lubricity, high dry-bonding strength, high shear and compressive strength, low permeability and low compressibility make bentonite commercially viable. The engineering and index properties of bentonite are given in Table 2.

TABLE 2

Properties of bentonite

Property	***Value***
Specific gravity	1.67
Liquid limit	350
Plastic limit	66.67
OMC	19 %
MDD	1.34 g/cc
Plasticity index	283.3

3.2WOOD ASH:

The wood ash used was sourced from campus canteen and neighboring houses.Wood ash consist of 50% CaO and 8% MgO . This was sieved through a 0.075 mm sieve. The specific gravity was obtained as 2.16.

3.3LIME:

Lime used for the study was obtained locally. Lime has the capacity to stabilize clayey soils through pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. It provides an economical way of soil stabilization. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction in presence of water.

3.4CEMENT

Bharathi cements, OPC 53 grade was used in the study. Ordinary Portland cement was used in the study conformed to requirements of Bureau of Indian Standard (IS: 8112, 1989).

ISSN 2229-5518

3.5.FIBRES

3.5.1. COCONUT FIBER

Fiber was sourced from Payyoli coir production unit.There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean.

3.5.2HAIR FIBER

Human hair was collected from saloons in the locality. It was washed with acetone to decontaminate it. Hair strands posses a high tensile strength which is equivalent to that of a copper wire with comparable width. As a non-degradable matter the environmental issue caused by it can be minimize by utilization as a fiber reinforcing material. It is additionally accessible in wealth and with ease. It reinforces the mix and keeps it from spalling.

3.4METHODOLOGY:

The required laboratory tests are performed over materials. The density of the blocks was maintained at 2 g/cc. The required quantities of the ingredients namely, soil, sand, and the stabilizers (lime, fibers and cement) as obtained from the calculations depending on the series were weighed and initially mixed in a dry condition.

TABLE-3.1
Proportions of stabilizers used in the preparation of different series of CSEBs.

Series	Reconstituted soil, (%)	Cement, (%)	Lime, (%)
S-1	92	8	0
S-2	92	7	1
S-3	92	4	4

TABLE-3.2
Proportions of stabilizers used in the preparation of different series of CSEBs.

Series	Reconstituted soil, (%)	Cement, (%)	Lime, (%)	Ash
S-3-A	92	4	4	30% of lime

TABLE-3.3
Proportions of stabilizers used in the preparation of different series of CSEBs.

Series	Reconstituted soil, (%)	Cement, (%)	Lime, (%)	Ash	Coir-fiber
S-3-A-1	92	4	4	30% of lime	2% by volume of soil
S-3-A-2	92	4	4	30% of lime	5% by volume of soil
S-3-A-3	92	4	4	30% of lime	8% by volume of soil

TABLE-3.4
Proportions of stabilizers used in the preparation of different series of CSEBs.

Series	Reconstituted soil, (%)	Cement, (%)	Lime, (%)	Ash	Fiber	
					Coir	hair
S-3-A-2-1	92	4	4	30% of lime	4% by volume of soil	1% by volume of soil
S-3-A-2-2	92	4	4	30% of lime	2.5% by volume of soil	2.5% by volume of soil
S-3-A-2-3	92	4	4	30% of lime	2% by volume of soil	3% by volume of soil

Based on initial trials, the optimum water content needed to mould the blocks and eject them successively as one unit was determined by mixing the dry mix of the ingredients with minimum water that is sufficient to obtain a good intact ball without sticking to the hand. For making soil blocks, the proportioned dry mix was spread on big tray, and the calculated quantity of water was sprinkled to the mix and thoroughly worked with hand to have uniform distribution of moisture. Manual mixing of stabilizers of various proportions for each of the block combinations with required water content (OMC) was completed within 2-3 minutes after addition of water. Care was taken to use hand gloves while remoulding the mix. Then the wet mix was transferred to the mould, placed in position on the pressing machine. The wet mix was remoulded in the mould using a wooden mallet to give proper placement. The lid of the mould was closed and properly locked at the top. Using the toggle lever mechanism, the mix was pressed to give the designed compactive effort. The soil block was ejected from the mould by opening the top lid. The ejected block was weighed and serially labeled with date of preparation, date of testing and a suitable identification number (for the series adopted) for ease of future from the date of preparation as per the prescribed procedures of Bureau of Indian Standards. The size of the blocks prepared using MARDINI block making machine was 23X19X9 cm. 5 bricks will be prepared for each proportions & tested. Curing and drying are completed before 28th day. 7th day and 28th day dry compressive strength and water absorption tests are conducted. The results in this study are an average of test conducted on blocks at each period of ageing.

Compressive strength of the CSEBs was determined by one day drying under atmospheric temperature of cured blocks. Tested for their compressive strength using Universal Testing Machine (UTM). The load was applied at the rate of 2 N/mm2/min. Sheet of 3 mm thick was placed on either faces of the block before the application of load.

Water absorption on CSEBs was done as per Bureau of Indian standards (IS: 1725, 1982). The blocks were dried completely in the oven and their mass was recorded accurately. The blocks were then immersed in water for 24 h. Later, the blocks were weighed again, and the increased mass was noted to determine their water absorption.

4RESULTS AND DISCUSSION

4.1WET COMPRESSIVE STRENGTH

4.1.1OPTIMUM PROPORTION OF CEMENT: LIME

Fig. 1 represents the plot of wet compressive strength of CSEBs for the three proportions versus curing period of 7days (Table-4). Further, it can be observed that, the blocks prepared with cement alone (Series S-1) have shown to have marginally more wet compressive strength compared to that of blocks prepared with lime and cement (Series S-2 and S-3). The relatively more strength of blocks prepared with cement alone at the initial stages of ageing may be due to quick hydration of cement, which helps formation of cementitious compounds in the blocks. For S-2 series CSEBs, in which 1% lime has been replaced for cement as a stabilizer, it has been observed that strength of these blocks are lower than for the S-1 series. This may be due to the reduction of cement in the blocks. Additionally, though lime is available in the mix, the quantity may not be sufficient to increase the pH of the system to release silica and make it available for producing cementitious gel needed for stabilizing the clay fraction. It has been reported by Bell (1996) that when lime is added to the clay soil, first it is adsorbed by the clay mineral until the affinity of the soil for lime is achieved. This quantity of lime is known as lime fixation and normally the amount is between 1% and 3% lime by weight of soil. Any amount of lime added in excess of the lime fixation contributes to the pozzolanic reaction and thereby create hydrated cementitious gel. This may be the probable reason for blocks of S-2 to have lower strength as compared to the blocks S1-series. With increased period of ageing, the blocks prepared with 4% lime and 4% cement (Series S-3) have shown to have strength values more than for cement alone (Series S-1) or with 7% cement and 1% lime (Series S-2). The optimum combination of cement and lime has been found to be mutually very beneficial in imparting strength to the blocks in a much better way, because the cement undergoes self-hydration in presence of water, producing hydration products that bind the sand particles. It is the binding of sand particles, and the products of the self hydration of the cement that contribute to the early strength of the blocks. Hence using a combination of cement and lime in an optimum combination would help in reducing the amount of stabilizer used in the preparation of the blocks. This would lead to the reduced cost of the blocks and also a better green rating.

TABLE-4

OPTIMUM PROPORTION OF CEMENT: LIME

PROPORTIONS	**COMPRESSIVE STRENGTH**	
	7th DAY	28th DAY
	Average	Average
8% Cement	2.4	3.2
7% Cement + 1% Lime	0.457	1.2
4%Cement + 4% Lime	2	3.64

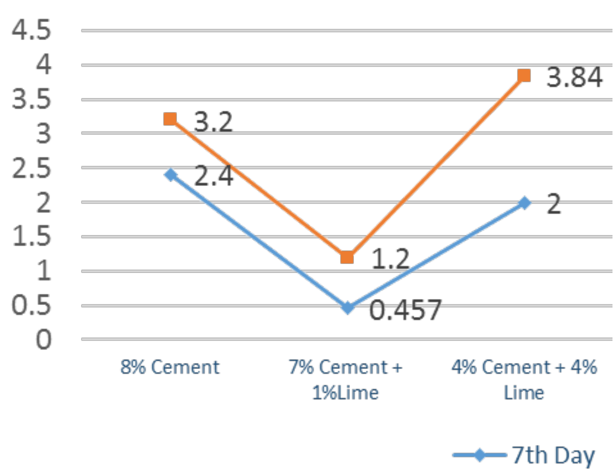

Fig.1. compressive strength v/s proportions

4.1.2 ADDITION OF ASH IN TO THE OPTIMUM PROPORTION OF CEMENT: LIME

Fig. 2 represents the plot of wet compressive strength of CSEBs with the addition of wood ash versus curing period of 7days (Table-5). Stabilisation of soil with wood ash significantly improved the compressive strength of soil blocks produced. It was found that wood ash taken as 30% of lime in the soil blocks improved the compressive strengths as there is an increase in the formation of compounds possessing cementitious properties that binds with the particles together. This according to earlier studies (Ogunbode etal ,2012) occurs predominately due to the presence of silica and other crucial compounds present in the completely burnt wood ash and the natural soil confirming studies conducted on Pozzolanic and stabilising materials.

TABLE-5

ADDITION OF ASH IN TO THE OPTIMUM PROPORTION OF CEMENT: LIME

PROPORTIONS		**DRY COMPRESSIVE STRENGTH(N/mm²)**	
		7th DAY	**28th DAY**
1	4% Cement+4% Lime	2	3.64
2	4% Cement + 4% Lime +Ash(30% of lime)	2.74	3.88

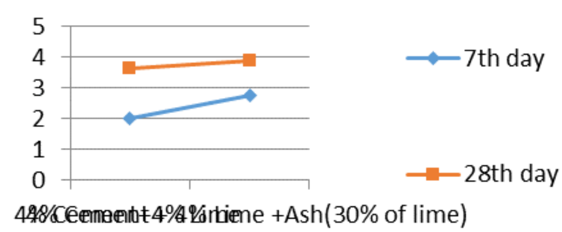

Fig.2. compressive strength v/s proportions

ISSN 2229-5518

4.1.3ADDITION OF COIR IN TO THE OPTIMUM PROPORTION OF CEMENT: LIME: ASH.

Fig.3 represents the plot of wet compressive strength of CSEBs with the addition of coir fiber versus curing period of 7days(Table -6). Adding coir fiber to the blended soil increased compressive strength as well as ductility. The compressive strengths of the samples increased steadily to a peak of 2.97MPa for 5%addition of coir fiber content, after which it began to drop. Also the densities reduced slightly with increase in the fiber-content of the mix. The increase in the compressive strength is due to the increases cohesive strength between the soil particles and the fibers. Hence, when compressive axial load is imposed on the sample, an internal tensile stress is reduced which tries to prevent the sample from splitting/failing. However at higher replacement levels of the fiber, the density reduces and the cohesion between soil particles is impaired and hence the compressive strength drops.

TABLE-6

ADDITION OF COIR IN TO THE OPTIMUM PROPORTION OF CEMENT: LIME: ASH.

PROPORTION	COMPRESSIVE STRENGTH (N/mm²)	
	7th DAY	28th DAY
4%Cement + 4% Lime + Ash 30% of lime+2% Coir	2.93	4.688
4%Cement + 4% Lime +Ash 30% of lime+ 5% Coir	2.97	4.752
4%Cement + 4% Lime+ Ash 30% of lime+ 8% Coir	2.86	4.576

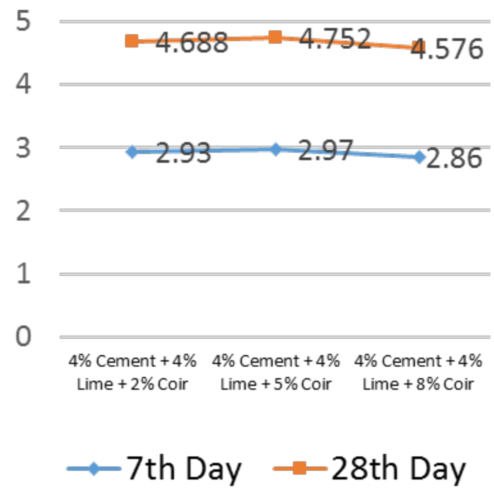

Fig.3. compressive strength v/s proportions

4.1.4 PARTIALLY REPLACING COIR WITH HAIR FIBER IN THE OPTIMUM PROPORTION OF CEMENT: LIME: ASH: COIR

Fig. 4 gives the variation of compressive strength by partially replacing coir fiber with hair fiber in the optimum proportion of cement: lime: ash: coir

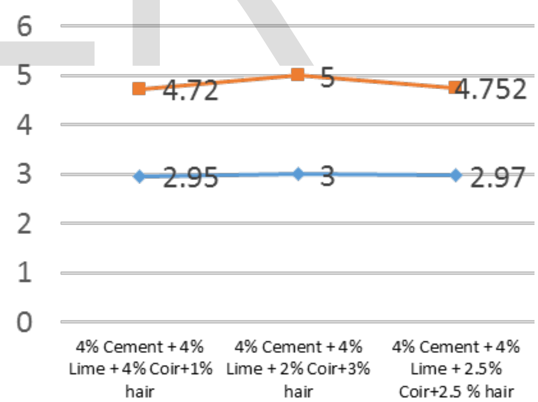

Fig.4. compressive strength v/s proportions

TABLE-7

ADDITION OF HAIR IN TO THE OPTIMUM PROPORTION OF CEMENT: LIME: ASH: COIR.

PROPORTION	COMPRESSIVE STRENGTH (N/mm^2)	
	7^{th} DAY	28^{th} DAY
4%Cement + 4% Lime + Ash 30% of lime+2% Coir	2.95	4.72
4%Cement + 4% Lime +Ash 30% of lime+ 5% Coir	3	5
4%Cement + 4% Lime+ Ash 30% of lime+ 8% Coir	2.97	4.752

2% coir and 3% hair contribute the maximum compressive strength of 5MPa from the tested series.

4.2 WATER ABSORPTION

The block with more than 15% by weight of water absorption values will draw moisture from the mortar and reduce its effectiveness(as per IS). The decrease in permeability is as a result of the reduction of pore spaces as the finer particles of the lime, cement, clay content and wood ash content fill the voids thereby drastically reducing the flow of water within the soil blocks or could be attributed to the increase in the pH value of the moulding water as a result of the partial dissociation of the calcium hydroxide (Okunade 2008). These calcium ions (Ca+) combine with the reactive silica or alumina or at worst both, present in the soil to form insoluble calcium silicates or aluminates or both which inhibits the passage of water through the soil blocks.

TABLE 9

WATER ABSORPTION(%) AT 28 DAYS MATURITY AGE

Series	Average water absorption(%) at 28 days maturity age	Remarks
S-3-A-2-3	10.45	Below 15% as per IS

4.3 COST ANALYSIS

TABLE 8

CALCULATED DRY WEIGHT AND COST PER KILO-GRAM OF COMPONENTS

Component	Calculated dry weight of component per block in kg SERIES(S-3-A-2-3)	Cost per kg in Rupees as per schedule of rates(2012)	Cost of component per block in Rupees
soil	4.298	0.00	0.00
clay	1.842	.153	0.283
cement	.266	8.50	2.261
Lime	.266	2.60	0.69
Ash	.0798	0.00	0.00
Coir fiber	.1228	0.00	0.00
Hair fiber	.1842	0.00	0.00
		Total	3.234

The cost analysis of blocks with series S-3-A-2-3 suggests that they are about 49.65 percent cheaper than the burnt clay bricks of size 19x9x9cm.

5 CONCLUSIONS

- It can be observed that, the blocks prepared with cement alone (Series S-1) have shown to have marginally more wet compressive strength compared to that of blocks prepared with lime and cement (Series S-2 and S-3)
- The optimum proportion of cement:lime to give maximum compressive strength is 4%cement + 4% lime.
- Addition of wood ash increases the compressive strength.
- 5% by volume content of coir fiber is taken as the optimum.
- 2% coir and 3% hair contribute the maximum compressive strength of 5MPa from the tested series.

- The cost analysis of blocks with series S-3-A-2-3 suggests that they are about 49.65 percent cheaper than the burnt clay bricks of size 19x9x9cm.

REFERENCES:

[1] Bureau of Indian standards IS: 3495-1, 1976. Methods of Tests of Burnt Clay Building Bricks: Part 1 Determination of Compressive Strength. Bureau of Indian Standards, New Delhi, India.

[2] Bureau of Indian standards IS: 1725, 1982. Specification for Soil Based Blocks Used in General Building Construction. Bureau of Indian Standards, New Delhi, India.

[3] Bureau of Indian standards IS: 712, 1984. Specification for Building Limes. Bureau of Indian Standards, New Delhi, India.

[4] Bureau of Indian standards IS: 8112, 1989. 43 Grade Ordinary Portland Cement – Specification. Bureau of Indian Standards, New Delhi, India.

[5] Olivier, M., Mesbah, A., 1987. Influence of different parameters on the resistance of earth, used as a building material. In: Int. Conf. on Mud Architecture, Trivandrum, India.

[6] Reddy, B.V., Jagadish, K.S., 1989. Properties of soil cement blocks masonry. Masonry Int. 3 (2), 80–84.

[7] Bell, F.G., Coulthard, J.M., 1990. Stabilization of glacial deposits of the Middlesbrough area with cementitious material. In: Price, D.G. (Ed.), Proc. 6th Intl. Congress, International Association of Eng. Geology, Amsterdam, Rotterdam, 3, pp. 797–807.

[8] Venkatarama Reddy, B.V., 1991. Studies on static soil compaction and compacted soil cement blocks for walls (Ph.D. thesis). Department of Civil Engineering, IISc, Bangalore.

[9] Houben, H., Guillaud, H., 1994. Earth Construction – A Comprehensive Guide. Intermediate Technology Publications, London.

[10] Venkatarama Reddy, B.V., Jagadish, K., 1995. Influence of soil composition on the strength and durability of soil cement blocks. Indian Concr. J. 69 (9), 517–524.

[11] Kerali, A.G., 2001. Durability of Compressed and Cement-Stabilized Building Blocks (Ph.D. thesis). University of Warwick.

[12] Mallela, J., Quintus, P.E., Smith, K.L., 2004. Consideration of limestabilized layers in mechanistic-empirical pavement design. Retrieved from http://www.training.ce (accessed on 24.01.2006

[13] Amu, O.O., Bamisaye, O.F., Komolafe, I.A., 2011. The suitability and lime stabilization requirement of some lateritic soil samples as pavement. Int. J. Pure Appl. Sci. Technol. 2 (1), 29–46.

[14] Herrier, G., Berger, E., Bonelli, S., 2012. The Friant-Kern canal: a forgotten example of lime-treated structure in hydraulic conditions. In: 6th International Conf. on Scour and Erosion, Paris, France, pp. 1527–1534.