Samarawickrama, Sumanthri, et al (eds), 2018, "Sustainability for people - *envisaging multi disciplinary solution": Proceedings of the 11th International Conference of Faculty of Architecture Research Unit (FARU), University of Moratuwa, Sri Lanka, December 08, 2018 Galle* pp. 346–353. ©

EXPERIMENTAL INVESTIGATION ON THE OPTIMAL LIFTING HEIGHT OF A SELF-COMPACTING IN-SITU CAST MUD-CONCRETE LOAD-BEARING WALL SEGMENT

F.R. AROOZ[1], K.L.T.H. PERERA[2], MADUJITH SAGARA CHANDRA[3] & R.U. HALWATURA[4]
Department of Civil Engineering, Faculty of Engineering, University of Moratuwa, Sri Lanka
[1]rizznaz@gmail.com, [2]tharinduharshika@gmail.com, [3]madujithsagara123@gmail.com, [4]rangikauh@gmail.com

Abstract

Initial objective of this research is investigating the optimum lifting height of a wall segment of self-compacting in-situ cast Mud-Concrete load bearing walls. It is a novel walling technique which has been developed through series of research process in Sri Lanka. Thus, identifying the possible construction height of a Mud- Concrete wall without reducing the strength is very important when introducing a novel material to industry and popularizing the technique among public. A questionnaire survey was conducted among 400 construction workers to identify the comfortable pouring height of an in-situ cast wall segment prior to design the formwork and it was found as 1200mm height. Using the results, 1200mm x 1200mm (height x width) and 150 mm thick of Mud-Concrete wall was casted and drilled after 28 days to test the compressive strength of cored samples along four different heights of the wall. According to the results obtained, increasing the height of the Mud-Concrete wall does not reduce the compressive strength of the wall. Therefore, study concludes that, there is no height restriction in construction of a Mud-Concrete wall. However, 1200mm of comfortable lifting height is consider as the optimum lifting height of a wall segment and used the results in modular formwork fabrication.

Keywords: *Optimum lifting height, In-situ cast load bearing walls, Mud-Concrete, Self-compaction, Compressive Strength, Cored samples*

1. Introduction

The earthen building technologies have been used worldwide for thousands years because of the simple construction technologies, local environmental friendly material usage (Ma et al., 2016),(Van Damme and Houben, 2017),(Fay et al., 2001), economic affordability (Omar Sore et al., 2018), (Arrigoni et al., 2017), thermal comfortability (Allinson and Hall, 2010), (Allinson and Hall, 2012), (Hall and Allinson, 2009) and low embodied energy consumption (Morel et al., 2001), (Christoforou et al., 2016), (Galán-Marín et al., 2015). Most importantly use of local materials and in-situ constructions are resulting to eliminate the transportation cost and associated CO_2 emissions in earthen technologies. Though earthen architecture is popular due to its sustainable norms and using as building material in low cost residential development projects the popularity is limited due to the lack of scientific base in earthen construction comparing to the other prevailing construction technologies which are exist (Bernat Masó et al., 2016). Thus proper scientific base and corresponding standards must develop to popularize the earthen technologies to use confidently and compete with other contemporary construction materials.

Mud-Concrete (MC) is such a novel and sustainable construction technology which introduced through series of research process recently (Arooz et al., 2017b), (Halwatura, 2016). The concept of MC is to develop a composite material similar to concrete out of soil (Arooz and Halwatura, 2017). There are two types of masonry units could develop through MC technology. First one is Mud-Concrete Block (MCB) (Halwatura, 2016), (Arooz and Halwatura, 2017) and the second one is in-situ cast Mud-Concrete load bearing wall (MCW) (Arooz and Halwatura, 2016), (Arooz et al., 2017a), (Bandara et al., 2016). In this research our focus is to discuss about the self-compacting in-situ cast Mud-Concrete load-bearing walls (MCW). MC is self-compacting material which develop with 20% optimum water of the total dry mix (Arooz and Halwatura, 2017). The best mix design of MCW was found as 45% gravel (4.75mm <gravel < 31.5mm), 50% sand (0.425mm <sand <4.75mm) and 5% fine (fine < 0.425mm) with minimum 4% cement (Arooz et al., 2017a). After identifying the mix design, it is important to identify the optimum construction technology for newly developed material. Thus, identifying the optimum construction height of a wall segment is most important to enhance the workmanship and standardize the construction technology.

The optimum construction height of an in-situ cast wall can be affected by different factors such as segregation of material when increasing the wall height, the workmanship available at the site, the techniques use for handling and fixing formwork/mould of the wall, etc. Whilst introducing a new in-situ cast load-bearing walling material, it is important to check the strength variation with the height of the wall. Similarly, this optimum construction height of the wall will govern the speed of the construction process. As recorded in literature, the testing of optimum lifting height of Stabilized Rammed Earth (SRE) wall was done in two (02) methods (Lombillo et al., 2014),(Ciancio and Gibbings, 2012). First one is moulding sample from the same mixture of casted wall and testing the compressive strength variations of the block or cylinder moulds. Second one is core the casted wall and get the cored sample to check the compressive strength variations. Recorded results depict that moulded samples are almost two times stronger than the cored samples of SRE. Horizontally cored samples are slightly stronger than the vertically cored samples of SRE. Ciancio and Gibbings assume this difference may be occurred due to the intersection of coring samples with ramming lines (Ciancio and Gibbings, 2012). However, the main objectives in this research is to investigate comfortable, optimum lifting height of MCW. Thus, the two main methods (qualitative and quantitative) were adopted to achieve the said objectives in the study.

2. Materials and methods

2.1. METHOD 01: QUESTIONNAIRE SURVEY

A questionnaire survey has been conducted among the 400 sampling of construction workers (especially concrete workers in different sites) to identify mainly the comfortable lifting height of pouring concrete to a wall or a column. Simultaneously, the questionnaire was focused to identify the issues in placing the concrete to a wall or a column and the practical issues occurred in assembling and dissembling the formwork systems.

2.2. METHOD 02: CORE SAMPLE TESTING

a. Finding the existing particle size distribution of used sub-soil samples

Gravelly laterite soil was used to commence the investigations. Soil samples were obtained from a homogeneous layer; 600mm-900mm below the top of the soil to get the good composition of soil and to avoid the organic particles in the soil samples. Three (03) random air-dried soil samples were used to conduct the sieve analysis tests to understand the existing particle size distribution of the soil while minimizing the errors. Liquid limit, plastic limit and plastic index were obtained by conducting Atterberg limit tests (Table 1). The average values of gravel 40.85%, sand 47.49% and fine 1.66% was available in existing soil samples (Figure 1). Then the soil was developed up to the achieved best mix design of MCW.

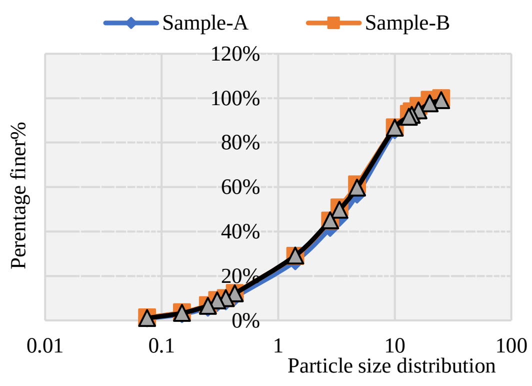

Figure 41, Particle size distribution of

Table 1, Physical properties of selected virgin soil

Properties	Values
Liquid limit	35.99%
Plastic limit	21.78%
Plasticity index	14.95%
Dry density (soil gravel)	1600 -1800 kg/m3
Wet density (soil gravel)	1800 - 2100 kg/m3

b. Developing the soil and casting the wall specimen

The sieve analysis results were used to develop the virgin soil up to the achieved best mix by adding needed gravel and sand while keeping the 5% fine content in the total mix. Four (4%) percent minimum cement quantity was used in geo-polymerization of MCW. Wall specimens were cast in optimum segment size (obtained results of the questionnaire survey were used) of 1200mm height, 1200mm width and 150mm thickness for the purpose of core testing. Table 2 shows the needed total soil quantity and the added gravel and sand to cast a single wall segment.

Table 2, Needed soil quantities for one wall segment and developing the soil according to the best mix of Mud-Concrete wall

Total weight of the mix to cast a one wall segment – size 150mm(thick), 1200mm(width), 1200mm(height) (To keep 5% fine from the total weight of the mix)							641.3 kg
Added cement (4% of the total weight of the mix)							25.65 kg
Sample No: (ex.)	Sample weight of the soil (kg)	Existing proportions and weight			Proposed proportions and weight		
W1	275	Gravel	Sand	Fine	Gravel	Sand	Fine
		40.85%	47.49%	11.66%	45%	50%	5%
		112.34kg	130.59kg		288.58kg	320.65kg	32.07kg
Added gravel to keep the 5% fine in the mix (kg)							176.25 kg
Added sand to keep the 5% fine in the mix (kg)							190.05 kg

Formwork was removed after 24 hours and curing procedure was started soon after formwork dismantling. Wall specimen was cured for 14 days using wet gunny bags at room temperature (± 25 ^{o}C Temperature, ± 75% Relative humidity).

c. Core cutting and compressive strength testing of cored samples

Wall specimen was cored using a core cutter machine to check the compressive strength of cored samples after 28 days (Figure 2 and Figure 3). The diameter of core specimen should be at least 94mm to determine the compressive strength in load bearing structural members (ASTM, 2004). Because the preferred minimum core diameter is three (03) times the nominal maximum size of the coarse aggregate (ASTM, 2004). The core locations were marked on the wall in different heights prior to take the samples (Figure 2). The blade of the core cutter machine kept perpendicular to the wall surface while obtaining cored samples from the MC wall in different heights (Figure 3). The faces of some samples were damaged due to the practical issues occurred while drilling the MC wall (Figure 4). Therefore, a capping had to be applied on each faces of the cored samples to make the faces even and flat (Figure 6).

Obtained core samples were stored in separate plastic bags (seal to prevent moisture loss) and kept at ambient temperature and protected from without exposing to direct sunlight. A 5mm thick capping was applied to maintain flat surface from both ends (ASTM, 2004). Cores were crushed using an electronic load testing machine (Figure 5). Calculate the compressive strength of each specimen using the computed cross-sectional area based on the average diameter of the specimen. Then compressive strength of the cored samples extracted in different heights along the MCW was plotted to see the compressive strength variation. The preferred length of the capped or ground specimen should between 1.9 and 2.1 times the diameter. If the ratio of the length to the diameter (L/D) of the core exceeds 2.1, reduce the length of the core so that the ratio of the capped or ground specimen is between 1.9 and 2.1. Core specimens with length-diameter ratios equal to or less than 1.75 require corrections to the measured compressive strength (Table 3). A strength correction factor is not required for L/D greater than 1.75. A core having a maximum length of less than 95 % of its diameter before capping or a length less than its diameter after capping or end grinding shall not be tested (ASTM, 2004).

Table 3, Correction factors for L/D Values

Ratio of Length to Diameter (L/D)	**Strength correction factor**
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

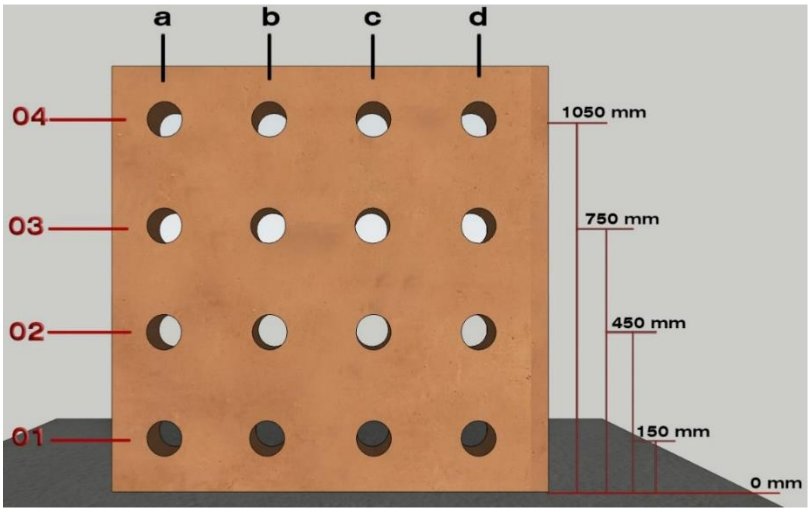

Figure 42, Cored locations along the MC wall

Figure 4, MC core samples

Figure 3, Obtaining MC core samples

Figure 5, Applied capping on both side of MC sample

Figure 6, Checking the compressive strength of MC sample *d. Compressive strength testing of moulded samples*

Same MC mix (which is used to cast the MC wall) was used to cast the 150mm x 150mm x 150mm MC blocks to check the dry compressive strength of moulded samples. Six (06) similar samples were cast and cured for 14 days using wet gunny bags at room temperature (± 25 ºC Temperature, ± 75% Relative humidity). Dry compressive strength of the blocks were tested after strength gain in 28 days.

3. Results and discussion

3.1. QUESTIONNAIRE SURVEY

According to the results analyzed of survey conducted among construction workers at different construction sites (Figure 7), it was found that 90% of workers are comfortable with 1200mm (4'-0") of concrete pouring height to a wall or a column (Figure 8). Further, 5% of the workers are comfortable with 1500mm (5'-0") pouring height and the rest of 5% of the workers are comfortable with 900mm (3'-0") pouring height. Thus, it was understood the correct physical ergonomics are more important to optimize the construction methodologies and introduce labour free methodologies effectively.

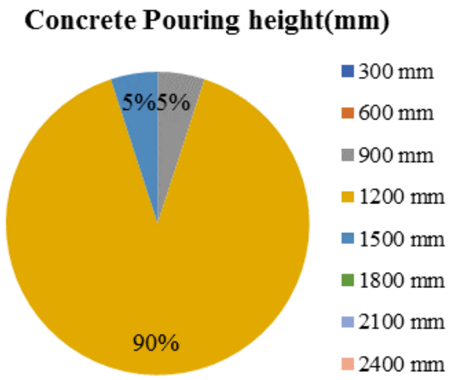

Figure 7, Worker's preferences on concrete pouring height

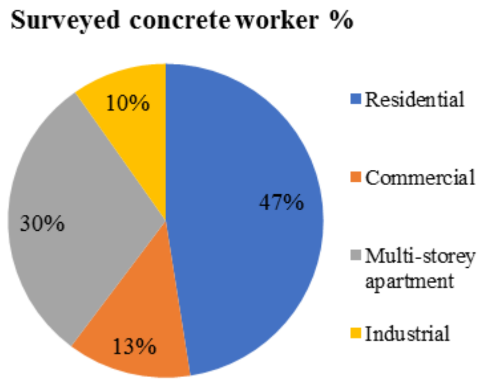

Figure 8, Survey carried on different construction sites and surveyed percentage of workers

Though, the comfortable height was found as 1200mm (4'-0"), it was doubtable whether the needed strength could achieve within this 1200mm height in MCW segment. Therefore, it was urging to fill this gap between the comfortableness & the structural capability in practical aspects. Maximum construction height of a wall segment should not reduce the strength of the wall in total construction process. Hence the core testing was conducted to check the behaviour of compressive strength of core samples extracted along MC wall to identify the most optimum lifting height of a MCW segment.

3.2. CORE SAMPLE TESTING

Table 4, Obtained compressive strength values for cored samples taken from different heights through Mud-Concrete load bearing wall

Core Number	wall height(mm)	Compressive strength(N/mm²)
01/a	150	1.38
01/b	150	1.50
01/c	150	-
01/d	150	1.45
02/a	450	1.38
02/b	450	-
02/c	450	1.59
02/d	450	1.44
03/a	750	1.45
03/b	750	1.53
03/c	750	1.40

03/d	750	-
04/a	1050	1.35
04/b	1050	1.55
04/c	1050	1.36
04/d	1050	1.50

Results show that increasing the height of the wall does not reduce the compressive strength of the MCW (Figure 9 and Table 4). Therefore, there is no height restriction for constructing a MC wall segment. Thus, the required total wall height can cast once, since there is no height restriction in achieving the strength of the wall. But considering the comfort of the workers, the size of optimum size of a MC wall segment was finalised as 1200mm (4'-0") in construction. Correspondingly this data was forwarded to use the formwork fabrication and optimisation in the next level of the research.

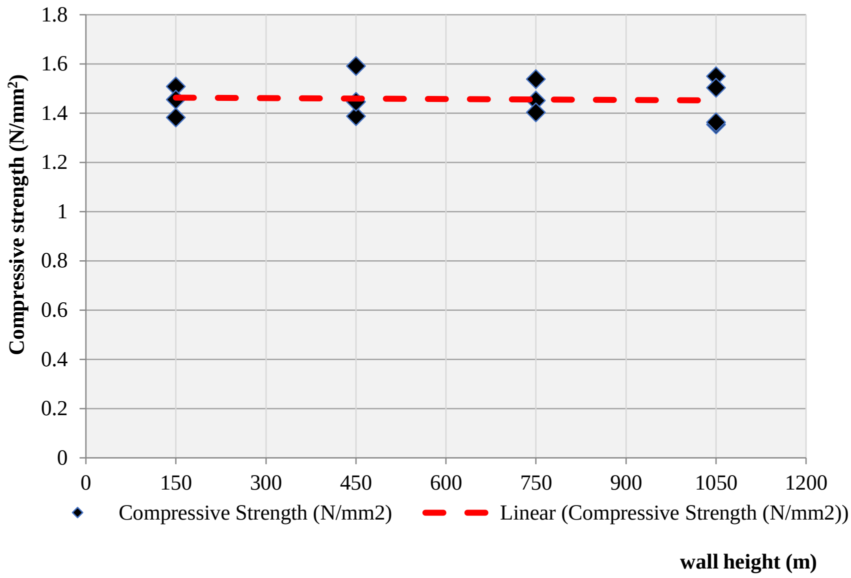

Figure 9, Behavior of the compressive strength variation along the height of the Mud-Concrete load bearing wall

3.2. MOULDED SAMPLE TESTING

Table 5, Average dry compressive strength values of moulded samples and comparison of average values of cored samples

Dry Compressive Strength (N/mm²) of MC with 4% cement							
S:01	S:02	S:03	S:04	S:05	S:06	Average Values of moulded samples	Average values of cored samples
3.05	3.10	3.02	3.0	3.15	3.03	3.05	1.45

Table 5 shows the average compressive strength values of MC moulded samples. The values depict that compressive strength of moulded samples are always greater than the compressive strength of cored samples. Further the results confirmed that MC moulded samples are stronger than MC cored samples more than two times. MC cored samples are giving less compressive strength, because bonding between the gravel particles are getting weaker due to cutting and vibration in coring process.

4. Conclusion

Identifying the optimum height of a MCW segment is important to reduce the repercussion in construction. Because this optimum construction height of the wall will govern the speed of the construction of the wall and quality of the overall work presented at the end. The optimum construction height of a wall can be affected by different factors such as segregation of material by increasing the wall height, the workmanship available at the site, the techniques use for handling and fixing formwork/mould of the wall and etc.

The experiment results confirmed that moulded MC samples are stronger than the cored MC samples. Further, the results demonstrated that increasing the height of the MCW does not reduce the compressive strength of the wall. Therefore, there is no height restriction for constructing an in-situ cast MC wall segment. But then again the comfortable height of pouring concrete to formwork was found as 1200mm (approx.4'-0") through the questionnaire survey conducted among 400 construction workers in different construction sites. Therefore, the formwork to cast a one wall segment was optimized up to 1200mm height. Since there is no height restriction, the total wall height (1200mm – height of a one wall segment) can be casted at once without proposing any joints.

5. References

Allinson, D., Hall, M., 2012. Humidity buffering using stabilised rammed earth materials. Proc. Inst. Civ. Eng. - Constr. Mater. 165, 335–344. https://doi.org/10.1680/coma.11.00023

Allinson, D., Hall, M., 2010. Hygrothermal analysis of a stabilised rammed earth test building in the UK. Energy Build. 42, 845–852. https://doi.org/10.1016/j.enbuild.2009.12.005

Arooz, F.R., Babilegedara, T.D., Halwatura, R.U., 2017a. Effect of Aggregate Percentage on Compressive Strength of Self-Compacting In-Situ Cast Mud - Concrete Load Bearing Walls, in: CFP17B72-PRT. Presented at the 3rd International MERCon 2017, IEEE, University of Moratuwa,Sri Lanka, p. 48.

Arooz, F.R., Halwatura, R.U., 2017. Mud-Concrete Block (MCB): Mix design & Durability characteristics. Case Stud. Constr. Mater.

Arooz, F.R., Halwatura, R.U., 2016. Self-Compacting in-situ cast Mud-Concrete load bearing wall system. 18762.

Arooz, F.R., Udawattha, C., Halwatura, R.U., 2017b. Community empowerment through Mud-Concrete technology Sustainable building techniques to revitalise the war victim communities in Batticaloa, Sri Lanka, in: World Sustainable Built Environment Conference 2017, Hong Kong. Presented at the World Sustainable Built Environment Conference 2017, Hong Kong, Construction Industry Council and Hong Kong Green Building Council Limited, Hong Kong.

Arrigoni, A., Beckett, C., Ciancio, D., Dotelli, G., 2017. Life cycle analysis of environmental impact vs. durability of stabilised rammed earth. Constr. Build. Mater. 142, 128–136. https://doi.org/10.1016/j.conbuildmat.2017.03.066

ASTM, I., 2004. ASTM C42/C42M-04-Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete1.

Bandara, D.M.H.., Arooz, F.R., Halwatura, R.U., 2016. Effect of Gravel size on strength of Mud-Concrete, in: Civil Engineering Research Symposium-2016. Presented at the CERS-2016, Faculty of Engineering, University of Mortuwa, pp. 62–65.

Bernat Masó, E., Gil Espert, L., Escrig Pérez, C., 2016. Textile-reinforced rammed earth : experimental characterisation of flexural strength and thoughness. Constr. Build. Mater. 106, 470–479. https://doi.org/10.1016/j.conbuildmat.2015.12.139

Christoforou, E., Kylili, A., Fokaides, P.A., Ioannou, I., 2016. Cradle to site Life Cycle Assessment (LCA) of adobe bricks. J. Clean. Prod. 112, 443–452. https://doi.org/10.1016/j.jclepro.2015.09.016

Ciancio, D., Gibbings, J., 2012. Experimental Investigation on the Compressive Strength of Cored and Molded Cement-Stabilized Rammed Earth Samples. Constr. Build. Mater.

Fay, R., Owen, C., Treloar, G.J., 2001. Environmental assessment of rammed earth construction systems. Struct. Surv. 19, 99–106. https://doi.org/10.1108/02630800110393680

Galán-Marín, C., Rivera-Gómez, C., García-Martínez, A., 2015. Embodied energy of conventional load-bearing walls versus natural stabilized earth blocks. Energy Build. 97, 146–154. https://doi.org/10.1016/j.enbuild.2015.03.054

Hall, M., Allinson, D., 2009. Analysis of the hygrothermal functional properties of stabilised rammed earth materials. Build. Environ. 44, 1935–1942. https://doi.org/10.1016/j.buildenv.2009.01.007

Halwatura, R.U., 2016. Mud Concrete Block. 17616, E04C 1/100, B28B, B28C.

Lombillo, I., Villegas, L., Fodde, E., Thomas, C., 2014. In situ mechanical investigation of rammed earth: Calibration of minor destructive testing. Constr. Build. Mater. 51, 451–460. https://doi.org/10.1016/j.conbuildmat.2013.10.090

Ma, C., Chen, B., Chen, L., 2016. Variables controlling strength development of self-compacting earth-based construction. Constr. Build. Mater. 123, 336–345. https://doi.org/10.1016/j.conbuildmat.2016.07.017

Morel, J.C., Mesbah, A., Oggero, M., Walker, P., 2001. Building houses with local materials: means to drastically reduce the environmental impact of construction. Build. Environ. 36, 1119–1126. https://doi.org/10.1016/S0360-1323(00)00054-8

Omar Sore, S., Messan, A., Prud'homme, E., Escadeillas, G., Tsobnang, F., 2018. Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. Constr. Build. Mater. 165, 333–345. https://doi.org/10.1016/j.conbuildmat.2018.01.051

Van Damme, H., Houben, H., 2017. Earth concrete. Stabilization revisited. Cem. Concr. Res. https://doi.org/10.1016/j.cemconres.2017.02.035