Dr. Lepakshi Raju

Phone: (+91) 9886633893, (+91) 8970019061
Email: lepr2508@gmail.com
Address: **No. 6, Mounika Espancia, Banjara Layout, Horamavu Agara Main Road, Bengaluru - 560043.**

EDUCATION

September 2020

Post Doctoral Fellow, Indian Institute of Science, Bengaluru, Karnataka
"Lakes of Bengaluru as drivers of an enriched blue-green cityscape"
(September 2018 – September 2020)

Graduated, April 2018

Ph.D., Civil Engineering, Indian Institute of Science, Bangalore, Karnataka.
"Studies on characteristics of cement stabilised rammed earth and Flexural behavior of plain and reinforced rammed earth" (Direct Ph.D.)
(Aug 2009 – Nov 2017)

Graduated, May 2008

B.E., Civil Engineering, BMS College of Engineering
(Visveshwaraiah Technological University), Bangalore, Karnataka
(Aug 2004- May 2008)

RESEARCH EXPERIENCE

Title:
Influence of layer thickness and plasticisers on characteristics of cement stabilised rammed earth

Advisor:
Prof. B. V. Venkatarama Reddy

A detailed experimentation was conducted on cement stabilised rammed earth (CSRE) cylinders with varying compacted layer thickness to study the influence of compacted layer thickness on the CSRE compressive strength. The strength behaviour in wet and dry condition was investigated. The study examined and derived CSRE cylinders for its optimum layer thickness and compaction energy.
The latter part deals in understanding the effect of super-plasticiser on the compaction energy and compressive strength of CSRE. Its effect on stress strain properties of CSRE was also examined. Different dosages of super-plasticiser between 0.07 to 2% of fines were considered and compared with test CSRE specimens. The optimum compacted layer thickness of CSRE that achieves maximum strength and the optimum dosage of super-plasticiser to reduce the compaction energy to achieve maximum strength. The practical significance of controlling the compacted layer thickness to its optimum and addition of optimum dosage of super-plasticiser is discussed.

Title:
Experimental and analytical studies on the stress-strain behaviour of cement stabilised rammed earth

Advisor:
Prof. B. V. Venkatarama Reddy

Stress-strain relationships and elastic properties of CSRE being essential for the analysis and design of CSRE structural components, extensive investigations were conducted on CSRE specimens. The compressive strength of CSRE depends upon the dry density, soil composition, cement content and the moisture content during testing. In this study three parameters were considered as variables by considering the generally used field values for dry density, cement content and clay content. About 250 CSRE cylindrical specimens were cast and tested under uni-axial compression. Experimental stress strain relationships, strength and stiffness relationships and elastic properties for CSRE in dry and wet conditions were determined.

An analytical model was developed to predict the stress-strain response. The empirical relationships for strength of CSRE and strain at peak stress for CSRE in terms of density and cement content were established. The curve fit factors for each series of stress strain relationships of CSRE were established. The proposed analytical model was validated for all the experimentally obtained stress strain relationships and for a couple of studies by others.

Title:
Shear strength parameters and Mohr-Coulomb failure envelope for cement stabilised rammed earth

Advisor:
Prof. B. V. Venkatarama Reddy

The study focused on determining the shear strength; shear strength parameters and Mohr-Coulomb failure envelopes for CSRE specimens through tri-axial compression tests. Its significance can be directly related in determining in-plane shear strength of CSRE walls, modelling of CSRE failures under different types of loading condition and many more. The CSRE cylindrical specimens were cast with optimum soil composition and constant dry density with cement content being the variable. The rammed earth specimens were tested under four confining pressures. The influence of cement content and confining pressure on the shear strength of CSRE and the practical significance of using failure envelopes are discussed.

Title:
Bond strength of rebars in cement stabilised rammed earth

Advisor:
Prof. B. V. Venkatarama Reddy

CSRE walls are subjected to in-plane and out-of-plane bending due to wind or seismic loads. The most effective method to improve the flexural strength of CSRE is by providing reinforcement. The flexural behaviour of reinforced CSRE greatly depends upon the bond strength between the rebars and the CSRE matrix.

Standard pullout tests were performed to assess the bond strength between rebars and the CSRE matrix. Cement content, dry density and type of rebar were the variables considered for the experimental protocol.The bond force – slip relationships for CSRE with different types of rebars were generated and presented. The influence of type of reinforcement on the bond strength of CSRE and the failure mode of CSRE specimens with different rebars are discussed.

Title:
Flexural behaviour of plain and reinforced CSRE beams

Advisor:
Prof. B. V. Venkatarama Reddy

This experimental protocol investigated the behaviour of plain and steel reinforced cement stabilised rammed earth beams under flexure. The study included the development of stress block and stress block parameters for CSRE followed by arriving at design calculations for reinforced CSRE beams. The flexural strength of CSRE in the two orthogonal directions was investigated and presented. The moment-curvature relationships, load deflection relationships and displacement profiles for plain and reinforced CSRE beams were established. The failure modes of plain and reinforced CSRE beams with flexural stresses parallel and perpendicular to the compacted layers were assessed

POST-DOCTORAL EXPERIENCE

Title: *Lakes of Bengaluru as drivers of an enriched blue-green cityscape*

Advisor: *Prof. Monto Mani*

- Conducted field studies to identify the factors influencing the lake water quality
- Participated in organizing the citizen science programs that creates a platform to interact with the general public, environmental enthusiasts and volunteers by sharing the knowledge from our investigations on Bengaluru lakes.
- A methodological survey was conducted to study the nature of relationship (and ownership) of the fringe communities around the lake and the lake water quality
- Developed a forecasting model to test various community dynamics in the fringes and their possible role and effectiveness in the lakes revival.

JOURNAL PUBLICATIONS

- Raju, L. and Reddy, B. V. V., "Influence of layer thickness and plasticisers on the characteristics of cement stabilised rammed earth", DOI: 10.1061/(ASCE)MT.1943-5533.0002539, Journal of Materials in Civil Engineering, ASCE, 2017.

- Lepakshi, R., Venkatarama Reddy B.V., "Shear Strength Parameters and Mohr–Coulomb Failure Envelopes for Cement-Stabilised Rammed Earth", DOI: https://doi.org/10.1016/j.conbuildmat.2020.118708, Journal of Construction & Building Materials, 249, 2020.

- Lepakshi, R., Venkatarama Reddy B.V., "Bond Strength of Rebars in Cement-Stabilised Rammed Earth", DOI: https://doi.org/10.1016/j.conbuildmat.2020.119405, Journal of Construction & Building Materials, 255,2020.

CONFERENCE PUBLICATIONS

- Raju, L. and Reddy, B. V. V., "Analytical model for predicting the stress-strain behaviour of cement stabilised rammed earth", Rammed Earth Construction: Cutting-Edge Research on Traditional and Modern Rammed Earth, p. 133, 2015.

- Lepakshi R., Venkatarama Reddy B.V. (2019) Shear Strength Parameters and Mohr–Coulomb Failure Envelopes for Cement-Stabilised Rammed Earth. In: Reddy B., Mani M., Walker P. (eds) Earthen Dwellings and Structures. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore

- Lepakshi R., Venkatarama Reddy B.V. (2019) Bond Strength of Rebars in Cement-Stabilised Rammed Earth. In: Reddy B., Mani M., Walker P. (eds) Earthen Dwellings and Structures. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore

CONFERENCES, SYMPOSIUMS AND WORKSHOPS

- International symposium on earthen structures, "Shear strength and Mohr-Coulomb failure envelopes for cement stabilised rammed earth", 2018 (Presented the paper)
- International symposium on earthen structures, " Bond strength of rebars in cement stabilised rammed earth", 2018 (Presented the paper)
- Rammed Earth Construction: Cutting-Edge Research on Traditional and Modern Rammed Earth, "Analytical model for predicting the stress-strain behaviour of cement stabilised rammed earth", 2015 (Presented the paper)
- Fourth annual student symposium, Dept. of Civil Engineering, IISc, Bangalore 2011(Chaired a session)
- Attended the Energy efficient buildings workshop series on "Low carbon materials and building systems" 2014.

COURSES

- Solid Mechanics (score obtained: 6/8)
- Fracture Mechanics (score obtained: 6/8)
- Numerical Methods (score obtained: 6/8)
- Design of Reinforced concrete and masonry structures (score obtained: 6/8)
- Advanced Concrete design (score obtained: 6/8)
- Technology and Sustainable development (score obtained: 8/8)

SOFT SKILLS

- Teamwork
- Communication
- Problem solving
- Creativity
- Emotional Intelligence

LANGUAGES

- Kannada
- Tamil
- English

PERSONAL DETAILS

Father's Name:	Mr. Kantha Raju	Marital Status:	Married
Date of birth:	August 25, 1986	Nationality:	Indian
Gender:	Female		

REFEREES

Prof. B. V. Venkatarama Reddy
Professor
Department of Civil Engineering,
Indian Institute of Science,
Bangalore 560012,
Phone: +91 080 22933126,
Email: venkat@iisc.ac.in

Prof. Monto Mani
Professor
Centre for sustainable technologies,
Indian Institute of Science,
Bangalore 560012,
Phone: +91 080 22933126,
Email: monto@iisc.ac.in

Prof. Raghu Prasad
Retd. Professor
Department of Civil Engineering,
Indian Institute of Science,
Bangalore 560012,
Phone: +91 9880944749

Prof. K R Suresh
Professor
Department of Civil Engineering,
BMS College of Engineering,
Bangalore 560019,
Phone: +91 9483512589

Prof. Sakey Shamu
Professor
Department of Civil Engineering,
BMS College of Engineering,
Bangalore 560019,
Phone: +91 9902970707

Prof. Sampath Kumar
Professor
Department of Civil Engineering,
BMS College of Engineering,
Bangalore 560019,
Phone: +91 9980941336

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Bond strength of rebars in cement stabilised rammed earth

R. Lepakshi, B.V. Venkatarama Reddy

Department of Civil Engineering, Indian Institute of Science, Bangalore, India

HIGHLIGHTS

- Flexural strength of unreinforced rammed earth (URE) is low. Reinforcing RE structural components improves the same.
- Present study examined the bond between rebar and cement stabilised rammed earth (CSRE).
- Pullout bond strength and bond force-slip relationships were established.
- Dry density of RE, rebar diameter and type of reinforcement greatly influence the pullout bond strength of rebars in CSRE.
- Ribbed rebars develop good bond strength with the CSRE matrix.

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Rebars
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ABSTRACT

Rammed earth construction involves compacting processed soil in progressive layers inside a rigid formwork. Rammed earth structural elements experience bending stresses under lateral loads such as wind and earthquake loads. The flexural strength of cement stabilised rammed earth (CSRE) walls is low. Reinforcing the rammed earth will improve the flexural strength of rammed earth to resist lateral loads. There is hardly any information on the bond strength of rebars embedded in CSRE matrix. There is a need to examine the bond developed between rebar and CSRE matrix. This paper focuses on determining the bond strength between rebar and CSRE; establish bond force – slip relationships for reinforced CSRE. The variables considered in the study included two dry densities (1800 and 1900 kg/m^3), two cement contents (7% and 10%) and three types of rebars. The CSRE cubes embedded with different types of rebars were tested for pullout loading under two testing conditions (dry and wet). The bond strength of rebars in CSRE matrix was found to be greatly influenced by the dry density of the CSRE and the type of reinforcement. The bond strength of deformed rebars is higher than the plain rebars irrespective of the specimen density.

1. Introduction

Cement stabilised rammed earth (CSRE) wall is constructed by compacting partially saturated loose soil in a rigid formwork. These walls are generally 200–400 mm thick. Structural walls can be constructed using CSRE. The behaviour of CSRE under gravity loads is widely examined by several researchers in the past [5,10–13,18,19,25]. The CSRE walls are subjected to in-plane and out-of-plane bending during the action of lateral loads arising due to the wind and seismic loads. The flexural resistance of CSRE walls under out-of-plane lateral bending is poor, especially when the bending is in the vertical direction. Reinforcing CSRE with rebars can improve the flexural strength. Plain as well as deformed rebars can be used as reinforcement. The bond between rebars and CSRE matrix is essential for better flexural behaviour of CSRE walls. Therefore, there is a need to understand the bond development and the bond strength between rebars and CSRE matrix.

Bond strength of rebars in concrete has been elaborately investigated [1,3,14,21,26]. Standard test procedures are available to assess the bond strength of rebars in reinforced concrete [8,20]). Generally pullout testing procedure is adapted to quantify the rebar bond strength in concrete [1,2,15,17,22,26].

There are limited studies on the bond strength of rebars and flexural strength of CSRE. A brief review of previous investigations contributing to the bond strength of CSRE is provided here. Investigations on the bond strength of steel reinforcement in CSRE was examined by Walker and Dobson [23] through rebar pullout tests. The pullout test procedure specified in RILEM [20] was used in this study. The variables considered include soil type, cement content, type of rebar and the embedment length. The pullout specimens were cylindrical in shape with 150 mm diameter and varying

E-mail addresses: lepakshi_raju@yahoo.com (R. Lepakshi), venkat@iisc.ac.in (B.V. Venkatarama Reddy)

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Shear strength parameters and Mohr-Coulomb failure envelopes for cement stabilised rammed earth

R. Lepakshi *, B.V. Venkatarama Reddy

Department of Civil Engineering, Indian Institute of Science, Bangalore, India

HIGHLIGHTS

- Shear strength of rammed earth is inadequately explored.
- Examined the shear behaviour of cement stabilised rammed earth (CSRE) under tri-axial state of stress.
- Shear strength parameters and Mohr-Coulomb failure envelopes were generated.
- Cement content influenced the shear strength and cohesion of CSRE in both dry and wet conditions.

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Rammed earth
Tri-axial shear test
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Cohesion
Cement stabilised rammed earth

ABSTRACT

Cement stabilised rammed earth (CSRE) is a stratified layered construction. The technology is predominantly used in the construction of structural walls in buildings, retaining walls, foundations etc. across the world. There is inadequacy in the study on the shear strength parameters of CSRE and there is hardly any information on Mohr-Coulomb failure envelopes for CSRE. Determining the shear strength parameters of CSRE assumes importance in the analysis of CSRE behaviour under compression and in determining the in-plane shear strength walls. The paper presents the experimental studies on characterising the shear strength parameters and generating the Mohr-Coulomb failure envelopes for CSRE. Triaxial compression tests were performed and the shear strength parameters, cohesion and angle of internal friction were determined in dry and wet conditions. Cohesion of CSRE was found to be a function of cement content. Mohr-Coulomb failure envelopes of the form $\tau_{csre} = c + \sigma \tan\phi$ were generated.

1. Introduction

Rammed earth is a monolithic construction material. The rammed earth has been explored for the construction of walls across the world [2,10,11,14,15,16,22,23,29]. Two types of rammed earth structures can be recognised: unstabilised and stabilised. The unstabilised rammed earth structures were common in the past, where pure earth and gravel are mixed, and rammed earth walls are constructed. Generally, unstabilised rammed earth walls are thicker (>450 mm), even though this type of construction has been used for low-rise buildings. The unstabilised rammed earth structures have good thermal performance but are prone for damage due moisture ingress and rain impact. Hence, unstabilised rammed earth buildings need good protection against moisture damage. The durability of unstabilised rammed earth can be drastically enhanced by the use of inorganic additives such as cement and lime. Cement stabilised rammed earth (CSRE) is being widely used for the construction of load bearing walls since several decades [7,9,11,25,28,29]. The CSRE walls are thinner (150–300 mm) and possess good durability characteristics, especially against vagaries of moisture induced damage.

The CSRE structures under axial compression, are observed to fail ultimately in shear [2,14,15,22,23,29]. Fig. 1 shows typical shear failures of a CSRE cylinder, a wallette and a wall. The shear failures observed in the CSRE elements can be attributed to its monolithic nature of construction. The shear strength parameters are essential in the analysis of (1) behaviour under compression, (2) in predicting the strength, (3) establishing the failure envelopes and (4) in modelling the failures under different types of loading. The investigations on modelling and analysis of stabilised rammed earth structural elements are limited, and there are limited studies on the shear strength parameters and Mohr-Coulomb failure envelopes of CSRE. The present investigation focuses on determining the shear strength parameters such as cohesion and angle of

* Corresponding author.
E-mail addresses: lepakshi_raju@yahoo.com (R. Lepakshi), venkat@iisc.ac.in (B.V. Venkatarama Reddy).

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Influence of Layer Thickness and Plasticizers on the Characteristics of Cement-Stabilized Rammed Earth

Lepakshi Raju[1] and B. V. Venkatarama Reddy, Ph.D.[2]

Abstract: Cement-stabilized rammed earth (CSRE) is used for load-bearing walls. CSRE is a monolithic construction that is constructed by compaction of processed soil in a rigid formwork. The compacted layer thickness varies between 100 and 150 mm. Generally, a dry density in excess of 1,800 kg/m^3 is achieved for CSRE through compaction. Apart from the need for very rigid/stiff formwork, a considerable amount of compaction energy is expended in achieving such high dry densities. The paper (1) examines the influence of layer thickness on characteristics of CSRE; and (2) explores use of superplasticizers for reducing the compaction energy. Considering four different layer thicknesses, the strength and stress–strain characteristics of CSRE were experimentally determined. The compaction energy and characteristics of CSRE were monitored by using different dosages of superplasticizer additive. The major findings of the investigations are (1) optimum compacted layer thickness giving maximum compressive strength for CSRE is 90–100 mm; and (2) the compaction energy reduces by half with the use of 0.65% of superplasticizer with enhanced strength and modulus for CSRE. **DOI: 10.1061/(ASCE)MT.1943-5533.0002539.** © *2018 American Society of Civil Engineers.*

Introduction

Rammed earth is a monolithic construction. Cement-stabilized rammed earth (CSRE) has been used for load-bearing walls in the last six to seven decades, and such constructions can be found across the world. Rammed-earth construction basically involves compaction of partially saturated processed soil mixed with cement in a rigid formwork in layers. Generally, a rammed-earth construction is an in situ operation. There are some recent developments and examples of some precast rammed-earth components such as precast stabilized rammed earth (SRE) wall sections and precast SRE panels in construction (Hall et al. 2012). Hall and Djerbib (2004), Walker et al. (2005), Kotak (2007), Easton (2008), Reddy et al. (2014), and many others have given information on the cement content, density, and soil grading for rammed-earth construction. CSRE structural walls are cast with (1) soils containing optimum clay content, and sometimes containing gravel and coarse aggregates; (2) generally, 6%–10% (by mass) portland cement; (3) rammed earth with a density that varies between 1,800 and 2,200 kg/m^3; and (4) a compacted layer thickness that falls in the range of 100–150 mm. There is a need for understanding the role of layer thickness on the characteristics of CSRE. Hardly any studies have been conducted on this topic.

Rigid formwork is essential to achieve a dry density $>1,700\ kg/m^3$. The traditional formwork consists of stiffened wooden planks held together by wooden ties. Varieties of formwork have been developed for rammed-earth construction (Walker et al. 2005; Hall et al. 2012). Stiffened steel, aluminium, or wooden planks form the major part of a modern formwork with proper fasteners. Simple short-length formwork consists of steel or wooden planks with fasteners, and the formwork length varies between 0.6 and 1.0 m (Fig. 1). Use of this type of formwork creates a big block of rammed earth with vertical joints, filled with a similar mix as used for rammed earth. Lengthy and stiffened wooden planks or steel plates are used for the construction of long rammed-earth walls (Walker et al. 2005; Easton 2008; Hall et al. 2012). Fig. 2 shows a long stiffened wooden formwork (Reddy et al. 2014). Very sophisticated formworks that can be easily dismantled and reused are also used. Such formworks are expensive and cover entire height of the wall in one stretch.

The density achieved is a function of the compaction energy. The strength of CSRE increases with increases in density (Reddy and Kumar 2011b). There is a need for reducing the compaction energy without sacrificing the characteristics of CSRE. Reduction in compaction energy can improve packing density and results in achieving higher density and strength.

Process of Rammed-Earth Compaction and Rammers for Compaction

The processed soil is poured into the rigid formwork and then compacted using a rammer for achieving the desired layer thickness. Generally, the compacted layer thickness is in the range 100–150 mm. The density of the compacted layer can be controlled by taking a known quantity of processed soil in each layer (of known compacted volume). Two types of rammers are used in the rammed-earth compaction process, namely manual rammers and pneumatic rammers. Manual rammers are usually 3–6 kg in mass and consist of a flat bottom with a handle (1.0–1.2 m). Pneumatic rammers need a power-driven compressor.

Compaction Energy in Rammed Earth

The compaction energy required in rammed-earth construction depends upon (1) dry density, (2) molding moisture content, and (3) soil composition/grading. The compaction characteristics of

[1]Research Scholar, Dept. of Civil Engineering, Indian Institute of Science, Bangalore, Karnataka 560012, India. Email: lepakshi_raju@yahoo.com

[2]Professor, Dept. of Civil Engineering, Indian Institute of Science, Bangalore, Karnataka 560012, India (corresponding author). ORCID: https://orcid.org/0000-0003-0936-5594. Email: venkat@iisc.ac.in

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