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Enhancing sustainability of rural adobe houses of hills by addition of vernacular fiber reinforcement

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Abstract

Adobe is a commonly used building material in rural houses of district Hamirpur of the North Indian state of Himachal Pradesh. Adobe is a sustainable material but has limitations of building smaller room sizes and requires frequent maintenance which is not suitable for modern lifestyle. These become main reasons for rejection of adobe as a building material. Initial investigation comprising of water content analysis, specific gravity analysis, grain size analysis, plastic limit and liquid limit analysis, maximum dry density check reveals that soil is sand clay and its low compressive strength shall be increased for enhancing its sustainability. For this purpose, stabilization with natural fibers of *Pinus roxburghii* and *Grewia optiva* in 0.5%, 1%, 1.5% and 2% proportions is proposed. Total 360 cubical and cylindrical shaped samples of both stabilized and unstabilized compositions were prepared and tested in a laboratory according to Indian standards. Unconfined compressive strength tests and maximum Stress Carrying Capacity tests were conducted after 07 days, 14 days, 28 days, 56 days and 90 days of casting. Results reveal that compressive strength of soil increases by 131–145% with addition of fiber *P. roxburghii* and 225–235% with addition of fiber *G. optiva* for cubical and cylindrical samples respectively. Increased compressive strength also results in a reduced thickness of traditional mud walls thereby increasing internal room size which would suit to changed modern lifestyle requirements. Enhanced properties of adobe will result in wider acceptance of adobe as a building material that will make development of rural housing more sustainable on a wider scale.

Keywords: Earth; Adobe; Compressive strength; Fibers; Sustainable materials

1. Introduction

History of human settlements shows varied forms of human habitat developed as per the needs of people in consideration with climatic factors (Houben and Guillaud, 1994). Different topographical and geographic conditions lead to the development of habitat in many different forms involving use of local materials and techniques however among all, earth has remained a prominently used traditional building construction material (Bui et al., 2009). Earth has several advantages such as easy-to-construct with material, easy availability, thermal conduciveness and low cost maintenance features. Given these advantages, earth has preferentially been used for construction

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purposes especially in rural areas (Taylor and Luther, 2004). Earth is used in many forms as per the geographical and climatic factors of the area such as rammed earth-walls, cob walls, adobe bricks (Bansal and Minke, 1988; Niroumand et al., 2013). Vernacular architecture of the area specifies use of earth in different ways for building purposes. Hilly areas of North Indian state Himachal Pradesh involve the use of earth in the construction of Dhajji wall, Kath-Kuni wall, Dhol-Maide, Doriya and Farque style walls as discussed by Handa (2002) and Kumar and Pushplata (2013a,b) which is different from rammed earth and bamboo walls of houses in parts of North-east India as investigated by Singh et al. (2011).

However use of earth has specific constraints in terms of strength and durability which restrict its use on a wider scale. This traditional material is being widely replaced by stronger and more durable construction materials globally as discussed by Foruzanmehr and Vellinga (2011) and Kairamo (1975).

Earth is used in the form of adobe bricks in construction of rural houses in district Hamirpur of the North Indian state of Himachal Pradesh. However use of adobe has reduced significantly in house construction over the years due to limitation of small sized rooms buildable with adobe and frequent maintenance requirement of adobe walls which is not suitable for modern lifestyle. The present study is focused on addressing the problem of strength aspects of earth thereby improving its compressive strength property by addition of natural and vernacular fibers. In practical sense the increase in compressive strength of wall material results in reducing the thickness of traditional mud walls thereby resulting in an increase in the internal room size. Due to increased compressive strength, improved adobe material can sustain a load of traditional roof truss made up of bamboo, wood or steel of longer spans easily. Both reinforcing fibrous materials being sustainable would produce such construction materials that would also be sustainable and would lead to the development of sustainable rural housing. The research was conducted with objectives to: (1) find the maximum stress carrying capacity of fiber reinforced soil samples (180 cubical samples and 180 cylindrical samples) and (2) investigate unconfined compressive strength of cylindrical soil samples.

Previous studies on enhancement of properties of soil using natural fibers includes use of fibers: jute, sisal, straw, rice-husk, sugarcane bagasse (Ramírez et al., 2012; Khosrow et al., 1999), chopped barley straw (Parisi et al., 2015), processed waste tea (Demir, 2006), vegetal (Achenza and Fenu, 2006), oil palm empty fruit bunches (Kolop et al., 2010), lechuguilla (Juárez et al., 2010), pineapple leaves (Chan, 2011), cassava peel (Villamizar et al., 2012) and *Hibiscus cannabinus* (Millogo et al., 2014). However no study regarding use of fibers of *Pinus roxburghii* and *Grewia optiva* as reinforcement in low compressive soil for enhancement of its mechanical properties has been conducted so far which involves checking of maximum stress carrying capacity and comparative strength assessment of cylindrical and cubical fiber reinforced soil samples.

The paper has been organized into two sections: Sections 2–4 and Section 5–7. In the first half section of the paper, important aspects of traditional material earth relative to its usage in the present context has been discussed which includes building regulation and codes of practice regarding use of earth, benefits of earth in terms of thermal comfort, constraints in terms of mechanical properties of compressive strength and durability and measures to improve the strength and durability properties. The second half section of the paper reports the experimental investigation for improving strength properties of soil of district Hamirpur of state Himachal Pradesh of North India. The investigation results show that compressive strength of soil can be considerably increased by inclusion of natural fibers. This result would be useful to produce fiber mix adobe bricks with improved compressive strength properties. Experimental investigations for checking the durability of same mix specimens have been identified as follow up research.

2. Building regulations for sustainable building material: earth

For propagating use of earth on a large scale for wider acceptability by people; planning, designing and technical guidelines regarding its use are framed in the form of comprehensive codal provisions and legal regulations. In some countries they are mandatory while in others they are advisory guidelines for all construction works with earth (Middleton, 1992; Torgal and Jalali, 2012) as given in Table 1. These regulations give details of usage process of earth in various forms for general construction purposes and for construction in seismic activity areas.

3. Earth: advantages and constraints

Earth walls have proven to be better thermal insulators as compared to brick or cement concrete block walls (Goodhewa and Griffiths, 2005; Binici et al., 2007). Study performed by Shukla et al. (2009) shows that earth has low embodied energy values along with low operational energy and transportation energy values as compared to modern construction materials. Studies by Mohammed (2004) and (Tiwari et al., 1996) further show the effectiveness of earth in maintaining comfortable indoor thermal environment of houses in relation to outdoor environment. However, earth as a building material suffers from some drawbacks in mechanical properties. Limitation in the form of low compressive strength and durability against weathering agents restricts its use on large scale (Alfred and Ngowi, 1997). This limitation coupled with problems of frequent and tedious maintenance of earth structures forms the reasons for replacement of use of this material