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Ultrasonic Pulse Velocity Testing of Gadhi Soil Adobe Bricks

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Abstract: **-- The earth or mud is being used for building houses all over the world since ancient times. Earthen construction has gained a significant interest and beneficial edge due to its 'environment-friendly' and 'sustainable' properties and also due to the heritage value of numerous historic buildings. In the Maharashtra State of India, a stabilized soil; locally known as 'Gadhi Soil' (GS) had been traditionally used for the construction of rural houses since many generations. These houses have provided excellent seasonal comfort, strength, and durability. In the local construction of these houses, people have been using GS for constructing load bearing cob walls of about 300-450 mm thickness for their houses since several generations. From the physical properties of GS, it is classified as inorganic silts of medium to high plasticity. The compressive strength of the earthen blocks of GS is about 1 MPa and a successful attempt was made to improve its strength by preparing adobe bricks of modified mix adding local quarry sand (QS), cement (C) and fly ash(FA); mix optimized by proportioning the ingredients using Modified Fuller Parabola. Adobe is a sun-dried mud brick and the traditional adobe is made with soil composed of a homogeneous mixture of clay, sand, and silt. There had been a few attempts to use Non-Destructive Testing (NDT) on earthen blocks The methodology included the casting of adobe bricks and carrying out ultrasonic tests using Ultrasonic Pulse Analyzer by the direct method of wave propagation. The ultrasonic pulse velocity (V) through the brick samples was determined and an attempt is made to correlate the UPV with the density and the compressive strength of adobe bricks. Those have shown better relationships with the increasing cement contents and also with variations in fly ash contents. A better relationship is observed within the groups made as per their type of mixes. It shows that the adobes can also be standardized by using NDT method viz. ultrasonic pulse velocity measurements and indicates the promising further use of this method in the cracks determination, maintenance, and rehabilitation of earthen walls.**

Index Terms: **- Adobe, Compressive strength, Gadhi Soil, Ultrasonic Pulse Velocity.**

I. INTRODUCTION

A. Earthen Houses

The earthen houses have been used by people since many generations all over the world and our ancestors have practiced the earth, as a construction material in India and also throughout the world [1, 2]. The earthen houses have many advantages [2] viz. it is cost effective, it balances air humidity and improves indoor climate. It is reusable and never becomes a waste material harming the environment. The energy consumption and pollution emission is comparatively very much less than wire cut and country fired bricks [3]. It stores heat acting as a passive material and are thermally very effective [4, 5].

B. Gadhi and Gadhi Soil

In the Maharashtra state of India, there exists an ancient historical mud fortress, called as a "Gadhi" [6] in almost every village. It is a heap of soil of almost a small hill-size. They are in existence as long as public memory goes back and the youngest of them is reportedly about 150 years old. Those have been used in Maharashtra as safe dwellings during wars for protection purpose of village people. 'Gadhi' is a colloquial name given to this kind of dwelling / fortress [7]. Those have been used as soil mines and this soil is being named as 'Gadhi Soil' (GS). It is also locally named as 'gadhichi / pandhari mati' in Marathi language [8]. The photograph of a typical Gadhi existing in a village is shown in Fig.1. The elderly villagers told that GS is not a naturally available soil but is a properly stabilized soil with certain traditional processes well known then.

Fig. 1. Gadhi in a village Kherda, Dist- Buldhana

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The various physical properties of Gadhi Soil are listed in Table 1 and based on those it is classified as 'inorganic silts of medium to high plasticity' [9].

Table 1. Physical properties of Gadhi Soil

Sl. No.	Physical Property	
1	Grain Size Analysis: Gravel (%)	23.62
	Sand (%)	19.78
	Silt (%)	46.75
	Clay (%)	9.85
2	Plasticity Index (%)	10.8
3	Specific Gravity	2.626
4	Optimum Moisture Content (%)	25.0
5	Maximum Dry Density (gm/cc)	1.36

C. Rural houses built using Gadhi Soil

The village people are using this soil for construction of their houses since many generations. These houses have even stood for 3-4 generations. The houses are more than 200 years old. This soil is termite proof. It does not slip with rains indicating its good cohesive strength. It can be reused as many times as possible for construction. The photograph of houses constructed by using GS is shown in Fig. 2. They are warm in winter and cool in summer. In today's context, it is an environment friendly construction material.

Fig. 2. Houses made of 'Gadhi Soil'

II. NON-DESTRUCTIVE TESTING OF EARTHEN BLOCKS

Non-destructive testing (NDT) methods have a role in the evaluation and testing of civil engineering structures. NDT methods may be divided into conventional and nonconventional. The commonly used conventional NDT methods are like visual or optical inspection, liquid penetrant testing, magnetic particle testing, eddy current testing, radiographic testing and ultrasonic testing. Nonconventional NDT methods are used only for specialized applications like neutron radiography, acoustic emission, infrared testing, microwave techniques, leak testing, holography etc. [10, 11].

A few researchers have attempted to use the Non-Destructive Testing (NDT) techniques on earthen blocks and stones etc. Galan-Martin et al. [12] studied natural fibre reinforced, polymer – stabilized earth blocks and their ultrasonic, molecular and mechanical testing. They evaluated the influence of utilizing natural polymers as a form of soil stabilization, in order to assess their potential for use in building applications. Ultrasonic wave propagation was found to be a useful technique for assisting in the determination of soil shrinkage characteristics and fibre-soil adherence capacity and UPV results correlated well with the measured mechanical properties. Concu et al. [13] evaluated ultrasonic P-wave velocity as a feature for predicting some physical and mechanical properties that describe the behavior of local building limestone. The ultrasonic testing and compressive tests were carried out on several limestone specimens and statistical correlation between ultrasonic velocity and density, compressive strength, and modulus of elasticity was studied. The effectiveness of ultrasonic velocity was evaluated by regression and the mathematical expressions of the correlations were found which showed strong relations between ultrasonic velocity and limestone properties indicating that these parameters can be reasonably estimated by means of this nondestructive parameter.

III. METHODOLOGY

A. Casting of adobe bricks

Adobe is a sun-dried mud brick and the traditional adobe is made with soil composed of a homogeneous mixture of clay, sand, and silt. Many researchers had used various sizes of compacted soil bricks or blocks. For this study, the adobe bricks of size (219 mm x 100 mm x 80 mm) were casted. The grain size analysis of Gadhi Soil and Quarry Sand (QS)

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were done as per IS 2720: Part 4 (1980). For optimization of proportions of GS and QS, an approach given by 'Modified Fuller Parabola', was used as the reference grain size distribution curve of the desired mix [14]. The adobe bricks were manually prepared in the mould of selected size using various proportions of ingredients given in Table 2 and the casted adobe bricks are shown in Fig. 3.

Table 2. Proportions of the ingredients for preparation of adobe bricks

Group	GS (%)	QS (%)	Cement (%)	Fly Ash (%)
G1	100	0	0	0
G2	40	60	2	0, 5, 7, 10
G3	40	60	5	0, 5, 7, 10
G4	40	60	7	0, 5, 7, 10

The dimensions and weights were recorded and the adobe bricks were tested for compressive strength after 28 days using a compression testing machine at loading rate of 0.23 MPa per second and sensitivity of 0.4 kN. Three samples of each composition were tested and the average test results are presented in this study.

Fig. 3. GS adobe bricks

Non-destructive testing (NDT) of Adobe bricks

Ultrasonic tests were carried out with the Ultrasonic Pulse Analyzer of make Controls. This equipment gives the time from when a wave leaves the transmitting transducer and is received by the receiving transducer and displays it in microseconds (T). The ultrasonic pulse velocity (V) through a sample is then calculated using equation (1).

$$V = \frac{L}{T} \quad (1)$$

where L is the length dimension along which the wave travels / propagates. All the UPV tests were carried out on the prismatic adobe brick specimens as per the guidelines of IS 13311(Part 1): 1992 [15]. The petroleum gel was used as a coupling agent who facilitated an airtight bond between surface and transducers. Ultrasonic stress (compression or shear) waves are produced by electro acoustic transducers made up of piezoelectric material. Transducers convert electric energy to the mechanical energy in form of stress wave which may be surface, compressive or shear waves. In this study, direct method of wave propagation is used as shown in Fig. 4.

Fig. 4. Ultrasonic Pulse Velocity testing of adobe bricks

IV. RESULTS AND DISCUSSIONS

The results of the UPV testing on the different GS adobe bricks are represented in the graphs shown in Figures 5 to 8. The Ultrasonic Pulse Velocity given here is an average of the three adobe bricks from each mix proportion.

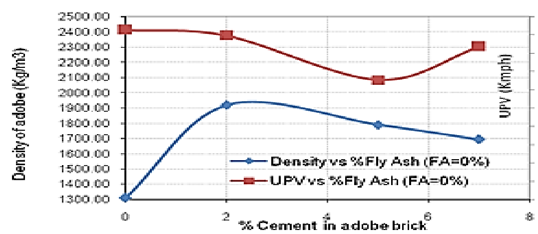

Fig. 5. Variation of density and corresponding UPV of adobe bricks with varying cement content and Fly Ash=0%

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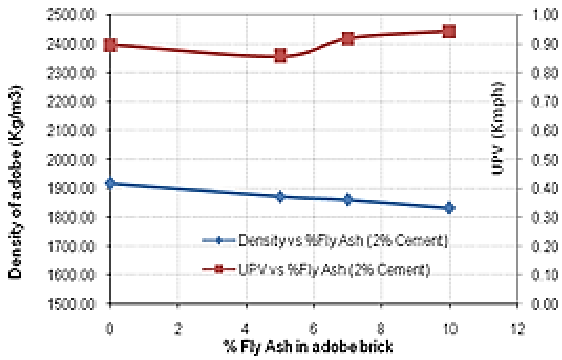

Fig. 6. Variation of density and corresponding UPV of adobe bricks with varying fly ash content and cement=2%

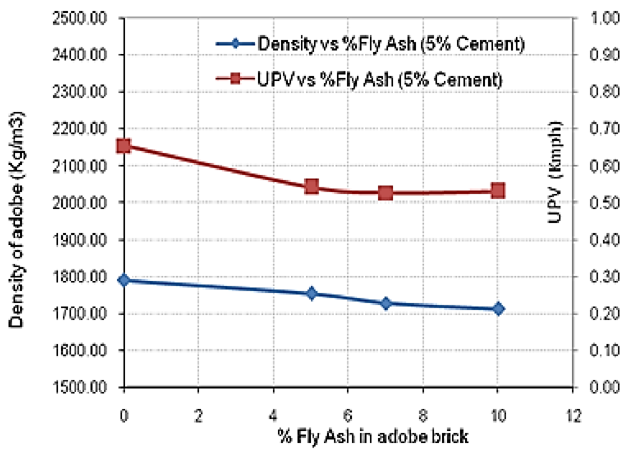

Fig. 7. Variation of density and corresponding UPV of adobe bricks with varying fly ash content and cement=5%

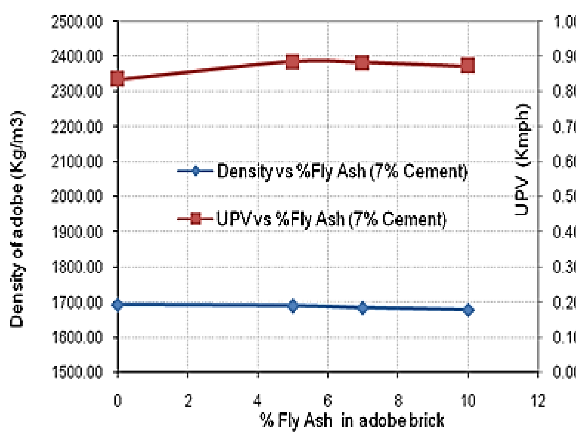

Fig. 8. Variation of density and corresponding UPV of adobe bricks with varying fly ash content and cement=7%

From the graphs in Fig. 5 to 8, it is observed that the ultrasonic velocity in GS adobes is related not only to the density but also to its cement content. Up to 5% cement content, the pulse velocity has reduced as the density reduced, but the velocity increased further after up to 7% cement even though the density reduced. And as contents of fly ash increased, the density had reduced and so the pulse velocity has also reduced.

V. CORRELATION OF DENSITY OF ADOBE BRICKS WITH UPV

From the results, an attempt is made to correlate the UPV with the density of the adobe bricks. The graphs shown in Fig. 9 to 13 show their variations and correlations. From Graph shown in Fig. 9, when all the different types of adobe bricks are grouped together and only density as the criterion for the UPV variation, the R2=0.085 value indicates their poor relationship.

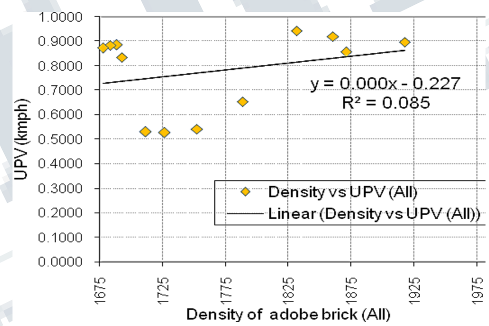

Fig. 9. Variation of density and corresponding UPV of adobe bricks (all mix proportions)

As seen a poor relationship from Fig. 9, it is observed that the adobes cannot be grouped on the basis of their density alone. So, a relationship is found by grouping them separately as per the type of mix and those are shown in Figures 10 to 13. It is observed that the relationship is improved by grouping them separately as per the proportioning of ingredients in that particular group.

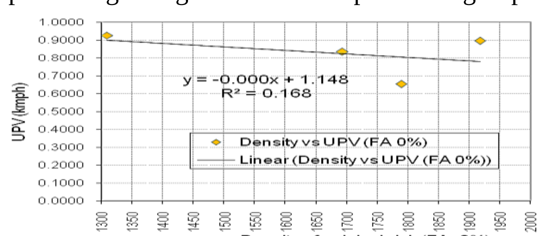

Fig. 10. Variation of density and corresponding UPV of adobe bricks (FA=0%, C=0 to 7%)

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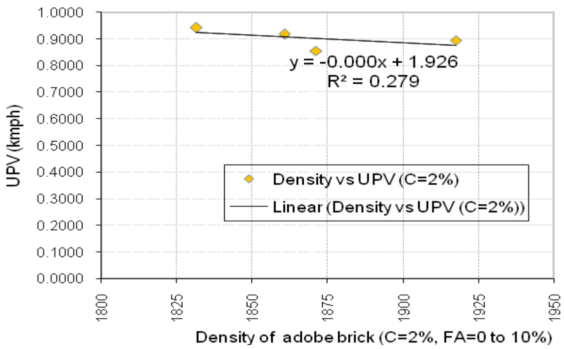

Fig. 11. Variation of density and corresponding UPV of adobe bricks (C=2%, FA=0 to 10%)

It is observed that the ultrasonic velocity in the GS adobes is related to the density. A better relationship is seen with the increasing cement contents and also with variations in fly ash contents. It shows that the adobes can also be standardized by using NDT method viz. ultrasonic pulse velocity measurements by grouping them as per their type of mix.

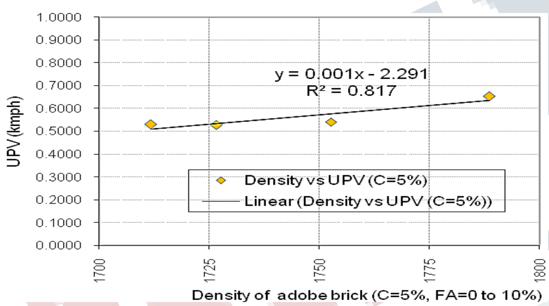

Fig. 12. Variation of density and corresponding UPV of adobe bricks (C=5%, FA=0 to 10%)

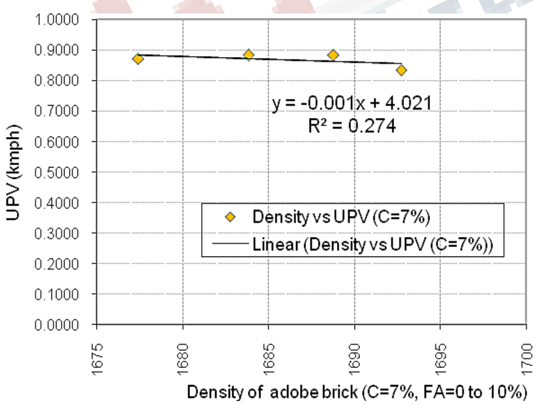

Fig. 13. Variation of density and corresponding UPV of adobe bricks (C=7%, FA=0 to 10%)

VI. CORRELATION OF COMPRESSIVE STRENGTH OF ADOBE BRICKS WITH UPV

The correlation of compressive strength and corresponding UPV is plotted in Fig. 14 by grouping all the types of mixes. The relationship is poor with R2= 0.063.

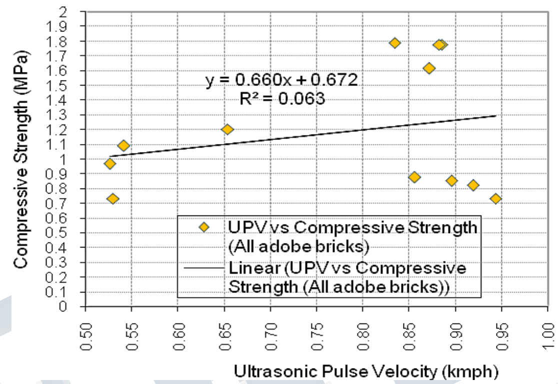

Fig. 14. Variation of compressive strength and corresponding UPV of adobe bricks (all mix proportions)

The plots are drawn as per their mix groups as shown in Fig. 15 to 18. It is found that their relationship is improved in the similar way as correlation of density with UPV.

The ultrasonic velocity in the GS adobes is also related to the compressive strength. The figures 15 to 18 below show the graphs of ultrasonic velocity with compressive strength of adobe bricks. When all the groups are formed together, the relation is poor with R2=0.063. But it improved when the results were compared within the groups as per their mixes.

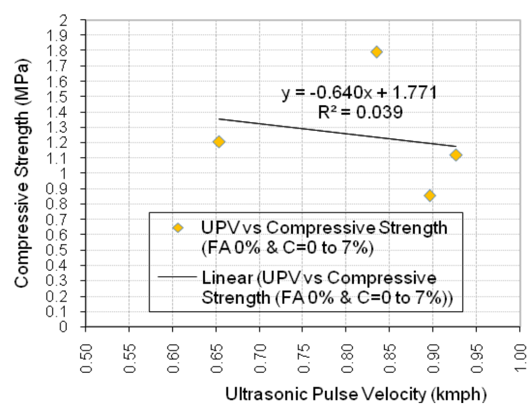

Fig. 15. Variation of compressive strength and corresponding UPV of adobe bricks (FA=0%, C=0 to 7%)

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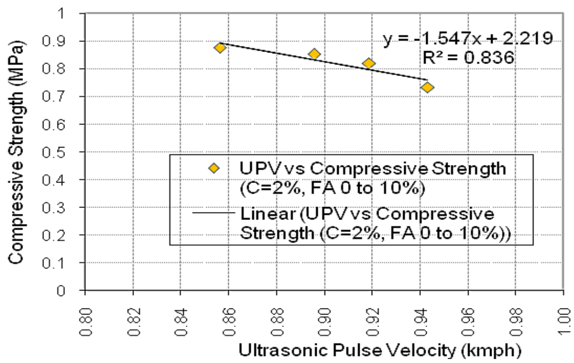

Fig. 16. Variation of compressive strength and corresponding UPV of adobe bricks (C=2%, FA=0 to 10%)

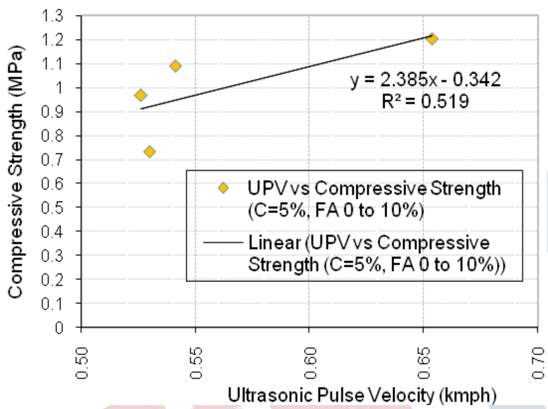

Fig. 17. Variation of compressive strength and corresponding UPV of adobe bricks (C=5%, FA=0 to 10%)

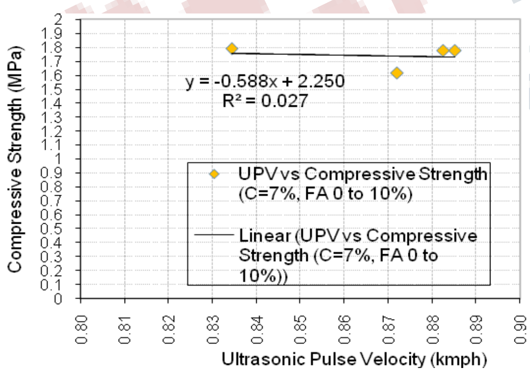

Fig. 18. Variation of compressive strength and corresponding UPV of adobe bricks (C=7%, FA=0 to 10%)

VII. CONCLUDING REMARKS

The adobe bricks are prepared manually and are not standardized as concrete. Hence, it was thought that its correlation with NDT testing shall help in understanding the strength properties of adobe bricks. This attempt to utilize the Ultrasonic Pulse Velocity Testing of adobe bricks and correlate its strength properties is encouraging. The results show that the adobes can also be standardized by using NDT method viz. ultrasonic pulse velocity measurements with respect to its density and compressive strength. Further it can also be used in detection of cracks, maintenance and rehabilitation of earthen walls.

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