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Final Report

On

The Study on Characteristics of Compressed Stabilized Earth Blocks (CSEB) using Chemical Stabilizer

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PREFACE

The Compressed Stabilized Earth Block/Brick (CSEB) represents one of the oldest building materials. With the addition of chemical stabilizer the CSEB with enhanced structural properties could be replacement for the conventional burnt clay bricks and will reign as a green home material with environmentally friendly, affordable, accessible and available material for the construction of buildings. This report presents the results of the tests on the raw materials, the mechanical and physical characteristics of the CSEB (Blocks/Bricks), the compression test results of the brick masonry prisms made of the CSEB bricks in mortar. It also includes the results of the shear test of the brickwork and the compression tests of the cement sand mortar. This report contains all the tasks as envisaged in the TOR for the assignment. It should be noted that the study has been undertaken after a contract of the undersigned with the InnoCSR Nepal Pvt. Limited. It is envisaged that the production and the application of the CSEB will be enhanced by the results of this study. The undersigned would like to acknowledge the kind opportunity provided by the InnoCSR Nepal Pvt. Limited.

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1. INTRODUCTION

1.1 General

The rapid urban development and the economic growth in the last decades have resulted in the considerable growth of the built environment in Nepal and other developing countries. The built environment has been recognized as one of the major sectors having the largest impacts on the environment. In view of the developing nature of the country and the traditional style of living the unreinforced masonry building has been the main type of building construction in the urban and the semi-urban settlements of the country. The conventional style of masonry construction needs to be improved by adopting sustainable or green buildings with an efficient approach of environmentally friendly and energy-efficient but with application of locally available natural materials. In this regard the substitution by the greener materials for the conventional masonry construction has become imperative in Nepal, and hence the affordable, available and acceptable or sustainable materials in Nepal has become urgent more than ever. The system approach of sustainable buildings for Nepal also is intended to ensure the integration of the equitable economic development with responsive environment and the cultural conservation of Nepal.

Nepal has a high risk of natural hazards including earthquakes, floods and landslides. The recent earthquakes of magnitude 7.8 occurred on April 25, 2015 with the following hundreds of aftershocks, have left the country with considerable loss of lives and properties. Hence the sustainable buildings in Nepal also shall duly consider the possible hazards, and the materials of construction shall pave an efficient path for the buildings to withstand safely without damages. Hence resilience is another factor of importance to be addressed in the choice for alternative construction materials, apart from energy efficiency, environmentally friendly and availability in the locality.

The Compressed Stabilized Earth Block (CSEB) is a rectangular brick used in construction. CSEB is made from soil, cement, fine aggregate, crusher dust and water in general, and sometimes with some sort of stabilizer as their ingredients. These blocks have less energy consumption, less carbon emission and provide improved thermal insulation, use local resources, and disseminate appealing aesthetics with elegant profile and uniform size. Due to these advantages CSEB can be used as a construction material. Due to lack of adequate knowledge and publicity on the behavior of CSEB, people are not enthusiastic to use CSEB in load bearing structures. However, the conventional CSEB has been in use with not full confidence on the strength and other mechanical properties of the material. The InnoCSR Nepal Pvt. Nepal has introduced chemical stabilizer (consisting of Mineral salt such as, sodium chloride and magnesium chloride, etc.) in the compressed earth soil block technology as an added additive in conventional system in addition to the use of cement stabilizer. It is believed that the CSEB with the chemical stabilizer will enhance the physical and mechanical properties of the material imparting substantial improvement in the structural performance of the structural system of the buildings made from the type of the CSEB.

This research includes the study of the physical and mechanical characteristics of CSEB units made from soils from different locations with addition of the chemical stabilizer. These blocks (Bricks) were prepared and tested at the Test Center of the InnoCSR Nepal at Bhaktapur. This report presents the results of the CSEB in terms of its physical and mechanical properties, testing of mortar cube tests to determine the compressive strength of the mortar, and the Prisms of the CSEB with the adopted mortar for the compressive strength and the shear strength of the masonry. These shear & prism tests were carried out at the Heavy Laboratory of the Institute of Engineering, Pulchowk Campus.

It is envisaged that the outcome of this study will facilitate the production as well as the application of the CSEB with the chemical stabilizer at par with the conventional burnt clay bricks but with enhanced mechanical properties and with green nature and less expensive.

1.2 Need of the Study

The already existing production and application of the Compressed Stabilized Earth Block (CSEB) is supposed to be performing well provided it was supported by the government agencies and also condescended by the engineering community. It has been well established by now that the conventional unreinforced masonry with the burnt clay bricks are being expensive day by day whereas the quality is deteriorating. At this stage the CSEB with enhanced properties could be the reliable alternative to the burnt clay bricks. This endeavor was carried out by the InnoCSR Nepal by carrying out some preliminary tests on compressive strengths of CSEB blocks using chemical stabilizer in Nepal using local soils. Initial results were found to be encouraging with the tests report giving significant minimum compressive strengths while using controlled soil composition. Samples were tested on InnoCSR Lab established in Thimi, Madhyapur Municipality. The InnoCSR Nepal intends to get approval from the relevant government departments of Nepal for introducing this technology for building construction in Nepal. The InnoCSR Nepal also intends to develop Ready-to-Use Illustrated Guideline for the construction of buildings using CSEB bricks with chemical stabilizer. In this regard, it has been felt necessary to carry out wider range of tests to check the suitability of the chemical stabilizer for different soil composition and to arrive at recommended soil composition to give maximum compressive strength. At the same time, other physical characteristics, such as durability, water absorption, masonry strengths, etc. are also to be investigated to comply with the code requirement available for ordinary CSEB with cement stabilizer. This study will result in development of detailed specification of CSEB block using chemical stabilizer in Nepalese context which will then be used for getting compliance certificate from the Government of Nepal.

1.3 Scope of the Study

According to the Terms of Reference for the study, presented in Annex 1, the study on Characteristics of the Compresses Stabilized Earth Block (CSEB) using Chemical Stabilizer is carried out broadly in three areas.

These are:

(i) Tests related to the soil composition

(ii) Tests related to physical and mechanical properties

(iii) Tests related to the Strength of the masonry

1.3.1 Tests related to the soil composition

The tests on the soil composition have been carried out as per the Indian Standard Code IS 1782: 1982 (reaffirmed 2002). Different soil samples were tested for soil composition with Grain Size distribution to determine the relative content of clay, sand and silt and also for Plasticity Indices (Liquid Limit, Plastic Limit etc.).

1.3.2 Tests related to physical and mechanical properties

The soil samples with a fixed value of cement and the chemical stabilizer were tested for the following properties of the CSEB:

a) Compressive Strength - The blocks to be tested in accordance with the procedure laid down in IS: 3495 (Part I)-1976
b) Water Absorption - The block to be tested in accordance with the procedure laid down in IS: 3495 (Part II)-1976
c) Weathering Test - When tested in accordance with IS 1782: 1982 Appendix A.
d) Possibility of efflorescence problem when using chemical stabilizer
e) Sampling and criteria for conformity of the blocks shall be done in accordance with the procedure laid down in IS: 5454-1978
f) Requirement of Curing to achieve higher compressive strength.
g) Density of Brick with standard composition
h) Influence of brick dust in the compressive strength of the CSEB.

1.3.3 Tests related to the Strength of the masonry

Under this group of tests, the compressive strength of the mortar (cement sand mortar with 1:6 composition) was investigated by testing the cube strength of the mortar at the outset. The masonry prisms of the CESB with the cement sand mortar were made and cured before testing in the Heavy Laboratory of the Institute of Engineering at Pulchowk. Different prism specimen was made of CSEB prepared from the soils from different locations and tested separately to know the effect of origin of the raw materials on the CSEB masonry strengths. Three samples from each location were tested and the average value of the strength was determined. The samples made were related to Kapilvastu, Chovar, GCB bricks, Surya Binayak and Nawalparashi. The tests were carried out and the compressive strength of the masonry was determined as specified in IS 1905: 1987. The compressive strength test was followed by the Bed Joint Sliding Test as per IS 1905: 1987 for the shear strength of the masonry.

2. OBJECTIVE OF THE STUDY

The main objective of the study is to:

1. Determine the percentage of clay in relation to the silt and sand components for the optimum compressive strength of the CSEB blocks/bricks.
2. Determine the mechanical properties of the CSEB including compressive strength, water absorption, weathering test, and density.
3. Determination of compressive strength of the masonry with CSEB and the mortar selected.

3. CONSTITUENTS OF THE RAW MATERIALS FOR CSEB

Earth has long been the oldest building material known. The environmental and ecological issues in the world have substantially increased the use of earth as a building material. The compressed stabilized earth block/brick has been a logical representation of earth as the building material, satisfying the general requirements of the people. It is distinguished with the conventional fired clay bricks through its raw materials and the production process. The raw materials for the CSEB are not the discarded soil of any kind or without regard to the contents of the important ingredients. The CSEB block/brick requires compaction and stabilizer to enhance the mechanical properties. The raw materials hence shall be suitable to impart necessary characteristics like strength, durability, water absorption, weathering resistance and other related characteristics.

A soil, in general, for the purpose of making CSEB, contains mainly four components: gravel, sand, silt and clay. The tentative portions of each of the main components are as presented in Fig. 1. As is accepted the good soil for CSEB is more sandy than clayey.

Fig. 1 Constituents of the good soil for CSEB production

The investigation for the constituents of the soil is normally carried out by the sedimentation jar test. As shown in Fig. 2. The soil to be tested is passed through a sieve with 5 or 6 millimeter. The sieved soil is filled in a straight sided clear glass jar and filled

one-third full. Water is added in the jar until it is full. The glass jar is shaken for one or two minutes. The jar is placed on a flat surface. After about half an hour the soil is settled, and after checking the jar is then shaken it up again well. The jar is left to settle overnight. It is helpful to add a little salt (¾ or 1 teaspoon) to the jar because this helps to separate the clay from the sand.

Fig. 2 Sedimentation jar test

The soil separates out into layers as shown in the figure above. The height of the different layers are measured and the results are written down. From the measurements, the approximate proportions of the different parts of the soil are determined in terms of percentage.

The clay content in the soil for CSEB production is decisive in obtaining the positive characteristics of the CSEB, such as strength, shrinkage and durability. It is normally believed that the clay content should not be more than 20%, irrespective of the percentage of silt and sand. It also has been a common practice to add sand or silt in the soil with higher portion of clay to control the shrinkage and reduction in compressive strength of the CSEB. It has been found that the lower percentage of clay, say, less than 10 % is favorable for the better strength of the CSEB if it is stabilized with the cement.

Cement is another important constituent material which is required for stabilization of the soil. However, its content also is equally important. As the strength of the CSEB block/brick depends upon the cement-content, types of soil (plasticity index), compaction pressure and types of compaction, the optimum cement content for the stabilization is in the range of 5% to 10% where addition above 10% will affect the strength of the bricks in a negative way. In this regard, it is praiseworthy that the InnoCSR has selected the content of cement for the CSEB as 9.8%. There was no need of adjustment of the cement content.

4. CHEMICAL STABILIZER

The chemical stabilizer is supplied by the InnoCSR from Korea. The product name of the chemical stabilizer is GBSS-01. Its general feature is powder mixture of chemicals and non-metallic mineral, and it is used as cement additives for soil stabilizing.

The Composition/Information on Ingredients of the chemical stabilizer provided is as presented in Table 1.

Table 1 Composition/Information on Ingredients

No.	Chemical name	Other names	Molecular formula	Density	CAS No.	Contents (%)	UNIT
1	Sodium chloride	Common salt; Halite; Table salt; Rock salt	NaCl.	2.165	7647-14-5	16~35	kg
2	Calcium Chloride, Hydrated	Magnesium dichloride	$CaCl_2 H_2O$	1.850	10035-04-8	15~34	kg
3	Calcium chloride	Calcium(II) chloride, Calcium dichloride, E509	$CaCl_2$	2.150	10043-52-4	15~28	kg
4	Sodium triphosphate	Sodium tripolyphosphate, Polygon, Pentasodium triphosphate	$Na_5P_3O_{10}$	2.520	7758-29-4	15~18	kg
5	Sodium sulfate	Thenardite	Na_2SO_4	2.664	7757-82-6	18~25	kg

		(mineral), Sal mirabilis (decahydrate), Glauber's salt (decahydrate), Mirabilite (decahydrate)					
6	Sodium Lignosulfonate	Sulfonated lignin sodium salt, Vanicell, Polyfon, Lignosol	$C_{20}H_{24}Na_2O_{10}S_2$	0.5	8061-51-6	16~35	kg
7	Sodium bicarbonate	Baking soda, Sodium hydrogencarbonate	Na_2HCO_3	2.20	144-55-8	5~27	kg

5. TESTS FOR THE CHARACTERISTICS OF CSEB

The most important properties of the CSEB influencing the performance of the CSEB structures are briefly described as follows:

Strength

Apparently, the compressive strength is the most universally accepted value for determining the quality of the CSEB bricks/blocks. The strength is intensely related with the soil types and stabilizer content. Factors affecting the CSEB brick/block strength are cement-content, types of soil (plasticity index), compaction pressure and the types of compaction. Optimum cement content for the stabilization is in the range of 5% to 10% where addition above 10% will affect the strength of the bricks in negative way. Plasticity index of the clay soil is usually in the range of 15 to 25.

Density

Commonly, most researchers found that the density of compressed stabilized earth bricks is within the range of 1500 to 2000 kg /m3. Density of the compressed earth brick/block is consistently related to its compressive strength and compaction force applied during production.

Water Absorption and Moisture Content

Water absorption is a function of clay and cement content and usually related with the strength and durability of earth bricks/ and therefore it is important to determine the rate of water absorption of earth bricks/blocks. As observed by Walker, P. J. (1997), water

absorption, as well as porosity, increases with clay content and decreasing cement content. Sand content in the mixes apparently can reduce water absorption and weight loss even though does not affect the compressive strength significantly as suggested by Guettala, A. (2002). Moisture contents affect strength development and durability of the material and have a significant influence on the long term performance of stabilized soil material especially has an effect on bonding with mortars at the time of construction.

Shrinkage

Drying shrinkage of the bricks was primarily governed by the plasticity index and cement content. Water-loss also contributes to the shrink of the clay fraction. For low clay mineral content (index plasticity below 20%), drying shrinkage showed steady increase with the increase of clay content, but for plasticity index beyond 25% – 30% drying shrinkage increased rapidly as the clay content also increased. Soil with plasticity index <20 is good for cement stabilization with cement content 10%.

Durability

The basic principle of the stabilization is to prevent water attacks and it could be achieved if a durable material can be obtained with limited loss in mechanical strength in a wet state. From several experiments, durability associated with the stabilizer content, clay content and compacting stress. Basically, durable stabilized clay material building can be achieved as long as they are not saturated. The problems arise when the materials are subjected to the long term saturation and exposed to various climatic conditions. Also it is observed that the presence of un-stabilized material was likely to be particularly detrimental to the durability.

BASIC DATA ON CSEB

PROPERTIES	SYMBOL	UNIT	CLASS A	CLASS B
28 day dry compressive strength (+20% after 1 year)	σ_d	Mpa	5 -7	2 - 5
28 day wet compressive strength (after 24 hours immersion)	σ_w	Mpa	2 - 3	1 - 2
28 day dry tensile strength (on a core)	τ	Mpa	1 - 2	0.5 - 1
28 day dry bending strength	β	Mpa	1 - 2	0.5 - 1
28 day dry shear strength	S	Mpa	1 - 2	0.5 - 1
Poisson's ratio	μ	-	0.15 - 0.35	0.35 - 0.50
Young's Modulus	E	Mpa	700 - 1000	-
Apparent bulk density	γ	Kg/m3	1900-2200	1700-2000
Coefficient of thermal expansion	-	mm/m^{o}C	0.010-0.015	-
Swell after saturation (24 hours immersion)	-	mm/m	0.5 - 1	1 - 2
Shrinkage (due to natural air drying)	-	mm/m	0.2 - 1	1 - 2
Permeability		mm/sec	1.10-5	-
Total water absorption	-	% weight	5 - 10	10 - 20
Specific heat	C	KJ/Kg	~ 0.85	0.65 - 0.85
Coefficient of conductivity	λ	W/m^{o}C	0.46 – 0.81	0.81 – 0.93
Damping coefficient	m	%	5 - 10	10 - 30
Lag time (for 40 cm thick wall)	d	h	10 - 12	5 - 10
Coefficient of acoustic attenuation (for 40 cm thick wall at 500 Hz)	-	dB	50	40
Fire resistance *	-	-	Good	Average
Flammability *	-	-	Poor	Average

5.1 Tests of CSEB on major characteristics

Different soils collected from various locations were brought to the Test Center of the InnoCSR Nepal at Madhyapur Thimi of Bhaktapur District and the samples of CSEB were produced, seasoned and cured for some time. After an ample time of setting/hardening these CSEB samples were tested in the compressive testing machine in the Test Center for compressive strength and recorded.

The summary of the results updated on March 16, 2020 are presented in Table 2 Summary of the Test results.

Research test result-16th March 20:

Table 2 Summary of Test results

Summary :Research Work results

1. Standard Composition (Soil-90%, Cement-9.8%, Soil Stabilizer-0.2%)

S.No	Location	Compressive Strength (MPA)				Water Absorption	Efflorescense test	Weathering test	Soil composition (Jar Test)		
		7 days	14 days	21 days	28 days						
		Standard Composition (Soil-90%, Cement-9.8%, Soil Stabilizer-0.2%)							Clay	Silt	Sand
1	Chovar	7.23	8.70	13.34	13.48	10.80%	Pass	Pass	8.75%	30%	61.25%
2	Bhaktapur	**	5.97	6.52	5.81	15.55%	Pass	Pass	3%	Unable to separate layer	
3	Nawalparashi	**	12.90	16.06	16.71	9.38%	Pass	Pass	12.50%	50%	37.50%
4	Kapilbastu	**	7.52	7.94	8.57	13.11%	Pass	Pass	couldn't separate layer on jar		
5	GCB Bricks	**	8.10	9.40	10.00	11.00%	Pass	Pass	8.55%	30%	61.45%

** - Didnt perform CST of 7th day as suggested by Researcher
Note : CST results showed in the table are on MPA (N/mm2)

2. With 1%,2% & 3% use of Brick Dust & reducing same percentage of cement on brick composition								
S.No	Location	1% BD	2% BD	3% BD	Soil composition (Jar Test)			Remarks
With use of Brick Dust		Compressive test (MPA)			Clay	Silt	Sand	
1	Chovar	9.60	9.36	8.64	8.75%	30%	61.25%	
2	Bhaktapur	3.84	3.31	3.00	3%	-	-	
3	Kapilbastu	4.03	3.73	3.32	Unable to separate layer			
4	Surya Binayak	9.00	9.06	7.55	17.33%	36%	46.67%	

3. Brick composition without use of soil stabilizer			
S.No	Location	Soil-90% , Cement-10%	Remarks
Without use of Soil stabilizer		Compressive test (MPA)	
1	Chovar	3.25	
2	Bhaktapur	NA	Tried to make bricks but broke down due to low bonding .
3	Kapilbastu	NA	No soil remaining
4	Surya Binayak	3.91	

As it is clear from the Table 2 containing the Summary of the Test Results, the number of locations for the soil collection is 4 in numbers: Chovar, Bhaktapur, Nawalparasi and Kapilvastu. It is also clear that the cement added in each case is **9.8%** and the chemical stabilizer added is limited to **0.2%. The maximum percentage of clay content is 12.5% (Nawalparashi) yielding the maximum compressive strength of 16.71 MPA** on the 28th day of testing, which is very encouraging. The compressive strength on the 7th day, 14thday and 21st day are also shown in the first of the Table 2.

The CSEB blocks/bricks also were produced and tested with addition of different percent, namely, 1%, 2% and 3% of brick dust. For this purpose the soils were collected from Chovar, Bhaktapur, Kapilvastu and Surya Binayak. From the second table of Table 2 it is evident that the CSEB with 1% brick dust results into the highest compressive strength, and as the brick dust is increased, the compressive strength reduces. From the third of Table 2 rightly shows the poor result value of the compressive strength without the soil stabilizer.

The details of the test results for the soils from individual locations including the dates of production and testing and test results for strength, size of the blocks/bricks, water absorption etc. are presented in excel sheets separately.

6. Conclusion on the Tests of Raw Materials of CSEB Blocks/Bricks and the Characteristics of the CSEB Blocks/Bricks

From the various tests carried out and the results obtained and in reference with the available literature the following major conclusions can be drawn:

1. The location from which the soil sample is taken may not be important but the contents of clay, silt and sand mainly matters. The clay content shall be not more than 20% irrespective of the contents of silt and sand. If the clay content is limited to 10 to 20% it will not only increase the compressive strength of the CSEB, it will also result into better properties like water absorption, durability and weathering resistance.
2. The cement content shall be limited to 10% maximum. More than 10% will be the reason for decrease in strength of the CSEB. In this regard the 9.8 % of cement content fixed by the InnoCSR is optimum.
3. As per test performed, 0.2 % of soil stabilizer is found as the best composition percentage & is recommended to use. By the performed tests, it is evident that the chemical stabilizer does its work properly on the compressed soil brick and is an essential ingredient to achieve the better strength. If the soil with clay component less than 20% is used along with 9.8% of cement & 0.2% of soil stabilizer, the resulting CSEB gives compressive strength of at least 8MPA in 28 days.
4. As per the tests carried out on the CSEB produced without the SS/chemical stabilizer from Chovar and Surya Binayak, it gave low strength results. Sample making attempt with Bhaktapur soil turned out as unsuccessful without use of SS. If the clay content is limited to less than 20% and SS of 0.2% & cement is added with less than 10% ,the CSEB on 28^{th} day shall give minimum 8MPa at least. It is evident from researches carried out in the IOE.
5. We performed test of CSEB with composition of 1%, 2% and 3% of brick dust with assumption that it will reduce the brick production cost and will reduce the cement percentage(if 1 % Brick dust is used , 1 % of cement will be decreased on brick composition). From the test results it is clear that the use of 1% brick dust addition can be done but above more than 1% leads to decrease in brick strength.
6. The 28^{th} day compressive strength of 16.71 MPa of the CSEB from the Nawalparasi is excellent. It should be recorded that the clay content in the soil is 12.50%. The water absorption test results of samples also were observed to be good results.

7. Tests related with the structural Strength of the CSEB masonry

7.1 Compressive strength of the cement sand mortar (1:6)

At the outset, the cubes of cement mortar with a composition of 1:6 cement sand were made and kept for curing. Three samples of the cubes of size 100 mm x 100 mm x 100 mm were tested in a compressive strength test machine and breaking load in compression for each cube is noted. The results of the mortar cube tests are presented in Table 1 below.

Table 1 Compressive Strength of Cement Sand Mortar in N/mm^2

S. No.	Ratio	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6)	8.64	8.13	8.13	**8.30**

The compressive strength of the mortar cube obtained from the test is good & fulfills the requirement. In general, the compressive strength of the mortar (cement sand 1: 6) should be 5.0 – 7.5 N/mm^2 on the 28th day, as per Table 1 Grade of Masonry Mortars (IS 2250 – 1981 *Indian Standard* CODE OF PRACTICE FOR PREPARATION AND USE OF MASONRY MORTARS *(First Revision)* Page 12*.*

7.2 Compressive strength of the CSEB masonry prism

In order to determine the compressive strength of the CSEB masonry in cement sand mortar (1:6), various samples of the CSEB masonry prisms were made for the soils from different locations, with approximately of 240mm x 240 mm x 110 mm sizes, and kept for curing in the Heavy Laboratory of the Institute of Engineering, Pulchowk Campus. Three samples for each origin of samples were tested and the average value of the compressive strength was determined. The test results for the compressive strength of the CSEB prisms for the soils of Kapilvastu, Chovar, GCB bricks, Surya Binayak, and Nawalparashi are respectively presented in Table 2 to 6 respectively.

Table 2 Compressive Strength of CSEB Masonry in N/mm^2 (Kapilvastu)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	3.27	2.83	3.27	**3.12**

Table 3 Compressive Strength of CSEB Masonry in N/mm^2 (Chovar)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	4.27	4.06	4.12	**4.15**

Table 4 Compressive Strength of CSEB Masonry in N/mm^2 (GCB)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	3.06	3.06	3.38	**3.16**

Table 5 Compressive Strength of CSEB Masonry in N/mm^2 (Surya Binayak)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	3.69	4.11	4.25	**4.08**

Table 6 Compressive Strength of CSEB Masonry in N/mm^2 (Nawalparashi)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	4.27	3.48	4.27	**4.00**

It is seen from the results that the compressive strength of all the prisms from all the source are relatively high and comparable with the compressive strengths of brick or other masonry prisms. It is evident from the fact that the minimum compressive strength of the masonry on the 28th day with M2 mortar (cement sand 1:6 ratio) will have 3 N/mm^2 as per TABLE 1 MIX PROPORTION AND STRENGTH OF MORTARS FOR MASONRY (Page 6) of the INDIAN STANDARD CODE OF PRACTICE FOR STRUCTURAL USE OF UNREINFORCED MASONRY IS 1905:1987. TABLE 8 BASIC COMPRESSIVE STRESSES FOR MASONRY (after 28 days) page 16 of the same Standard indicates that the masonry units of compressive strength of 20 N/mm^2 with a cement sand mortar M2 (cement-sand ratio 1:6) will give 1.17 N/mm^2 compressive strength of the masonry. This situation indicates that the compressive strength of the masonry units (CSEB in this case) is very high, which is true from the results of the CSEB compressive strength tests results.

7.3 Shear strength of the CSEB masonry

The shear test of the CSEB was carried out for all the specimens from all the 5 sources, namely Kapilvastu, Chovar, GCB, Surya Binayak and Mata. Two layers of half bricks were made as the specimen and the horizontal shearing force is applied to determine the shear strength of the CSEB masonry. A vertical force of 2.5kN was applied as the vertical dead load. The results of the tests are presented in Tables 7 – 11.

Table 7 Shear Strength of CSEB Masonry in N/mm^2 (Kapilvastu)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	0.59	0.65	0.62	**0.62**

Table 8 Shear Strength of CSEB Masonry in N/mm^2 (Chovar)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	0.65	0.59	0.67	**0.63**

Table 9 Shear Strength of CSEB Masonry in N/mm^2 (GCB)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	0.76	0.73	0.94	**0.81**

Table 10 Shear Strength of CSEB Masonry in N/mm^2 (Surya Binayak)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	1.04	1.20	1.26	**1.16**

Table 11 Shear Strength of CSEB Masonry in N/mm^2 (Mata- Nawalparashi)

S. No.	Mortar	Sample 1	Sample 2	Sample 3	Average Strength
1	(1:6) Cement: Sand	0.88	0.93	0.82	**0.87**

The shear strength of the CSEB masonry is found as good results. As per the criteria, the shear test should result value from 0.5-2 N/mm2.The minimum shear value achieved is 0.62 N/mm2 of Kapilvastu. The highest shear test result obtained is 1.16 N/mm2 of Surya Binayak Soil, which is very impressive result.

8. Cost Comparison of Good Bricks with fired bricks & normal type CSEB bricks:

Many types of bricks are available these days in the market which is used for construction purposes. Different type of bricks has its own properties. The price comparison is shown below to check through the economic aspect. The number of bricks requirement is calculated below for 1 cubic meter.

S.No.	Sample	Description	Sample type	Size in cm (l*b*h)	Volume with 1cm mortar	Approx number of bricks	Price per piece (NPR)	Total Price (NPR)	Remarks
1		Good Bricks(GCB Bricks)	Non-fired Solid rectangular bricks	23*11.0*6.0	2016	500	15	**7500**	
2		Normal Fired Bricks (Bhaktapur)	Fired rectangular bricks	22*10*5.5	1644.5	610	15	**9150**	
3		CSEB bricks	Hollow Interlocking bricks	30*15*10	5456	185	55	**10175**	

9. Conclusion on the Structural Tests of the CSEB masonry

The tests related with the structural properties of the CSEB masonry, namely, the compressive strength and the shear strength tests were carried out on the masonry specimen prepared from 5 locations as the sources of soil raw materials. These locations are Kapilvastu, Chovar, GCB, Surya Binayak and Nawalparasi. The compressive strength of the CSEB masonry in cement mortar (cement sand 1:6) for the 5 sources, in general, is good and encouraging. As a rule, the compressive and the shear strengths of the masonry largely depend upon the compressive strengths of the CSEB elements and the mortar. The 28 day compressive strengths of the CSEB elements tested in March 2020 are available for the sources: Chovar, GCB bricks, Surya Binayak, Nawalparasi and Kapilvastu. These values are respectively 13.48, 10, 5.81, 16.71 and 8.57 N/mm^2 respectively. Nawalparasi had highest compressive strength of 16.71 MPA and also had CSEB masonry compressive strength as 4 N/mm2. The largest compressive strength is 4.15 N/mm^2 for the location of Chovar. The largest shear strength is 1.16 N/mm^2 for the location of Surya Binayak.

The Test Statements for the compressive strength tests of mortar, compressive strength and shear strength tests of the CSEB masonry are presented in Annex 2 of this report.

It can be concluded that the CSEB elements with the addition of the chemical stabilizer have considerably enhanced the compressive strengths of the CSEB elements, and hence shall give a very high structural (compressive as well as shear strength) properties of the CSEB masonry.

The CSEB With the addition of the chemical stabilizer, as is seen from the tests on physical, mechanical and structural properties of the materials as well as the masonry with the CSEB elements, are highly favorable for use in the construction of the masonry buildings and seems to have a high scope of use, and hence shall be encouraged for production and use in the construction works in Nepal.

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ANNEX 1

Terms-of-Reference for

The Study on Characteristics of Compressed Stabilized Earth Blocks (CSEB) using Chemical Stabilizer

1. Introduction:

InnoCSR was a Sustainability strategy company which started in Shanghai, China in 2008. By consulting Fortune 500 companies in different countries, InnoCSR has accumulated a heavy global network and business insights. InnoCSR now operates in Korea, China, Philippines, Malaysia and Nepal. InnoCSR's Impact Technology Business uses these resources to help companies that have proven Green Technologies to reach out to developing countries to do good and do well.

With the aim of promoting green technology in Nepal, InnoCSR has established InnoCSR Nepal Office in Kathmandu, Nepal. It has introduced the use of chemical stabilizer (consisting of Mineral salt such as, sodium chloride and magnesium chloride, etc.) in the compressed earth soil block technology as an added additive in conventional system in addition to the use of cement stabilizer. It enhances the compressive strength of CSEB blocks with lesser addition of the chemical stabilizer but with reduction in the proportion of cement stabilizer. Since it is a green technology, promotion of CSEB blocks with this chemical stabilizer will contribute towards less carbon emission and will give alternatives to the production of conventional burnt clay bricks. It is expected that bricks manufactured using this technology will relatively be cheaper and stronger as compared to the burnt-clay bricks.

2. Need for the Study on Characteristics of CSEB Blocks using Chemical Stabilizer:

InnoCSR Nepal has done some preliminary tests on compressive strengths of CSEB blocks using chemical stabilizer in Nepal using local soils. Initial results are found to be encouraging with the tests report giving minimum compressive strengths of 9-11 MPa while using controlled soil composition. Samples were tested on InnoCSR Lab established in Thimi, Madhyapur Municipality using higher percentage of clay percentage.

InnoCSR intends to get approval from the relevant government departments of Nepal for introducing this technology for building construction in Nepal. To facilitate house owners the construction of one-two storied buildings without carrying out structural design through engineers, InnoCSR also will develop Ready-to-Use Illustrated Guideline for the construction of buildings using CSEB bricks with chemical stabilizer. In this regard, it has been felt necessary to carry out wider range of tests to check the suitability of the chemical stabilizer for different soil composition and to arrive at recommended soil composition to give maximum compressive strength. At the same time, other physical characteristics, such as durability, water absorption,

masonry strengths, etc. are also to be investigated to comply with the code requirement available for ordinary CSEB with cement stabilizer. This study will result in development of detailed specification of CSEB block using chemical stabilizer in Nepalese context which will then be used for getting compliance certificate from GoN and ultimately share with brick manufacturers and house owners.

3. Scope of the Study on CSEB Bricks using Chemical Stabilizer:

Studies carried out elsewhere regarding the composition of soil for ordinary CSEB bricks using cement stabilizer has shown that higher percentage of silt and sand as compared to clay will result in higher compressive strength and good durability whereas preliminary test reports of InnoCSR shows that higher clay content will give higher compressive strengths when chemical stabilizer is used. Hence, primary focus of the study will be to study the effect of variation of clay, silt and sand content on the compressive strength of CSEB bricks using chemical stabilizer. At the same time, bricks so produced have to meet other code requirements (durability, water absorption, etc.) as well. Following tests as recommended by BIS Code IS 1782: 1982 (reaffirmed 2002) -Specifications for Soil Based Blocks used in General Building Construction will be carried out on the recommendation and supervision of the Consultant:

i) Tests to determine the Soil Composition for Different Samples:

a) Grain Size distribution to determine the relative content of clay, sand and silt.
b) Plasticity Indices (Liquid Limit, Plastic Limit, etc.)

ii) Tests to determine the effect of soil composition on desirable properties of blocks:

Parametric study on the following properties of bricks manufactured with different types of soil to assess the effect of proportion of clay/silt/sand content, percentage of cement and chemical stabilizer:

a) Compressive Strength - The blocks to be tested in accordance with the procedure laid down in IS: 3495 (Part I)-1976
b) Water Absorption - The block to be tested in accordance with the procedure laid down in IS: 3495 (Part II)-1976
c) Weathering Test - When tested in accordance with IS 1782: 1982 Appendix A.
d) Possibility of efflorescence problem when using chemical stabilizer
e) Sampling and criteria for conformity of the blocks shall be done in accordance with the procedure laid down in IS: 5454-1978
f) Requirement of Curing to achieve higher compressive strength. Prepare a chart of "Strength vs. Curing in number of days"
g) Density of Brick with standard composition

iii) Tests to assess the Masonry Strength

a) Prism tests on masonry wallets as per IS 1905: 1987
b) Bed Joint Sliding Test as per IS 1905: 1987

iv) Tests with use of Brick Dusts

a) Need to test the compatibility of brick using Brick dust.
b) Suggest the best percentage of Brick dust to be used (having higher strength & workability)
c) Check on % reduction of cement by use of brick dust.

On the basis of the above-mentioned tests, the Consultant shall prepare a report with recommendation on the following matters:

a) Suitability of the Technology in the Nepalese Context
b) Recommended composition of soil for the manufacture of CSEB block using chemical stabilizer.
c) Relative Economy as compared to burnt-clay brick or ordinary CSEB block as analyzed for a sample building in Nepal.

4. Logistic Support for Carrying Out the study:

InnoCSR Nepal will take responsibility on the following:

a) Procurement, transportation and delivery of the soil samples and preparation of bricks, brick wallet, mortar, etc. at the designated laboratory
b) Availability and testing of the samples in in-house lab at Thimi, wherever applicable
c) Arrangement of the laboratory and testing of the samples in IOE or other labs, wherever applicable.

The Consultant shall, take the responsibility for the following:

a) Recommend the type of tests, number of samples for soil, bricks and brick wallet for the commencement of the tests.
b) Recommend which tests can be carried out in-house and which ones to be done elsewhere.
c) Closely monitor sample preparation and testing of the samples.
d) Share the detailed test results ,report & catalog of the performed tests
e) Share the details on required time frame for each tests & tentative cost related to it.
f) Analyze & submit research paper on the study with conclusion & recommendations as stipulated in the scope-of-study.

5. Time Frame for the Study:

The Consultant need to complete the study within a time frame of 2 months after the date of signing of contract. The report shall be submitted to InnoCSR Nepal Office at New Baneshwor, Kathmandu, Nepal.

6. Remuneration to the Consultant:

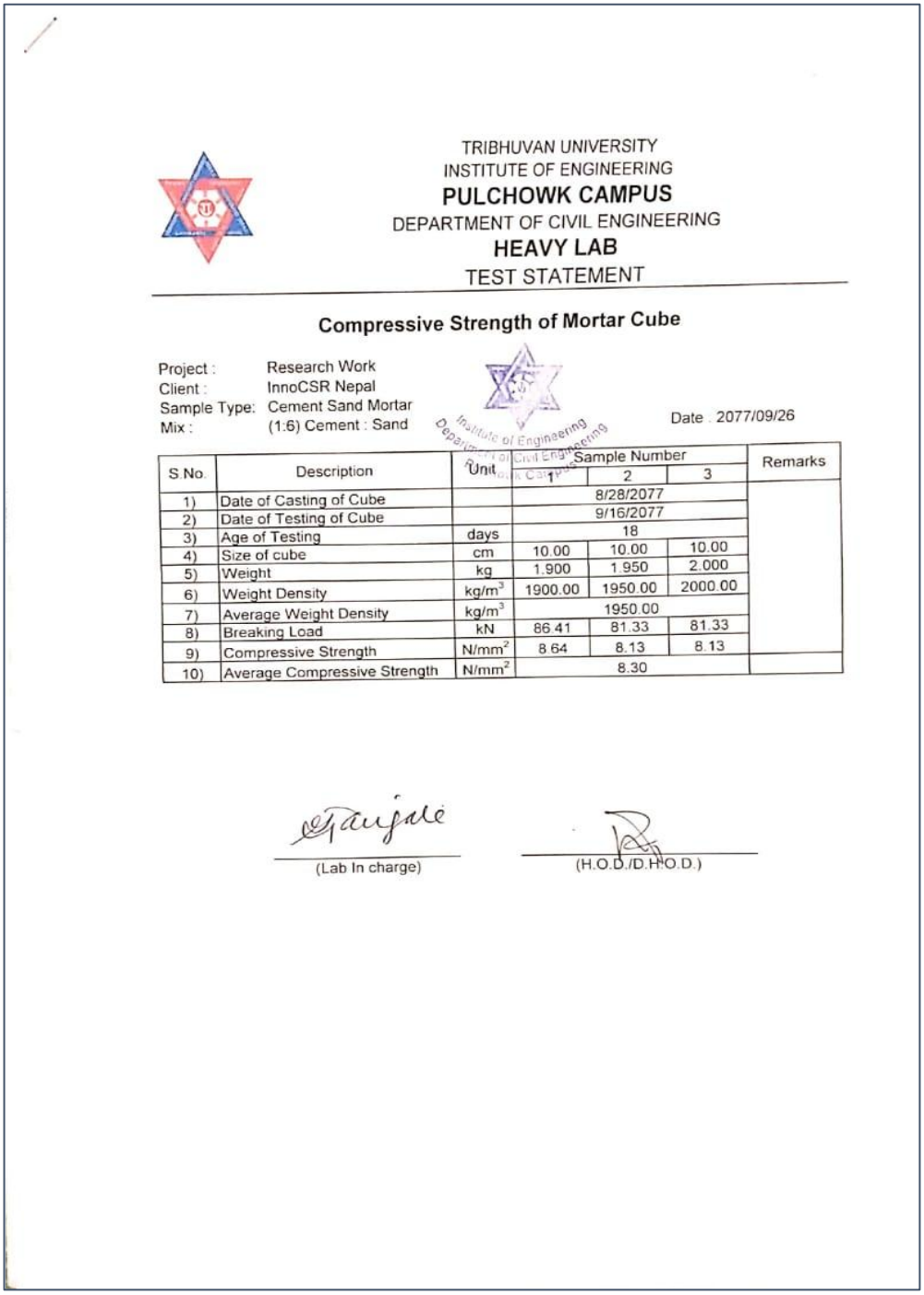
InnoCSR Nepal will provide a remuneration of NRs ……. towards the cost of Consultant's expertise on completion of study and submission of the study report.

ANNEX 2

TEST STATEMENT

Compressed Strength of Mortar Cubes and CSEB Masonry Prisms

1. Compressive strength of Mortar Cubes



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TEST STATEMENT

Compressive Strength of Mortar Cube

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Cement Sand Mortar
Mix : (1:6) Cement : Sand

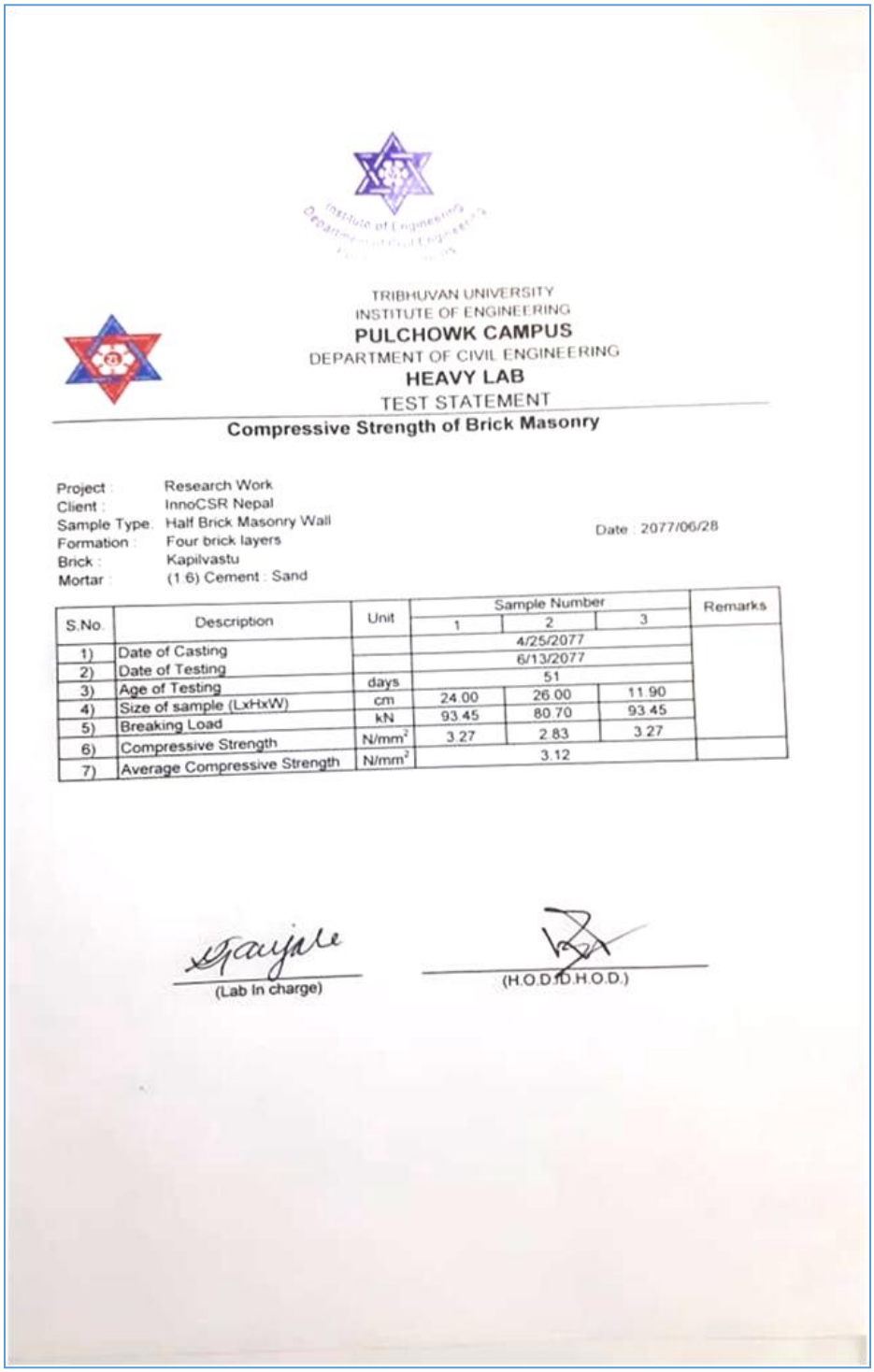
Date : 2077/09/26

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting of Cube		8/28/2077			
2)	Date of Testing of Cube		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of cube	cm	10.00	10.00	10.00	
5)	Weight	kg	1.900	1.950	2.000	
6)	Weight Density	kg/m^3	1900.00	1950.00	2000.00	
7)	Average Weight Density	kg/m^3	1950.00			
8)	Breaking Load	kN	86.41	81.33	81.33	
9)	Compressive Strength	N/mm^2	8.64	8.13	8.13	
10)	Average Compressive Strength	N/mm^2	8.30			

(Lab In charge)

(H.O.D./D.H.O.D.)

2. Compressive strength of CSEB Prism (Kapilvastu)



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TEST STATEMENT

Compressive Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type : Half Brick Masonry Wall
Formation : Four brick layers
Brick : Kapilvastu
Mortar : (1:6) Cement : Sand

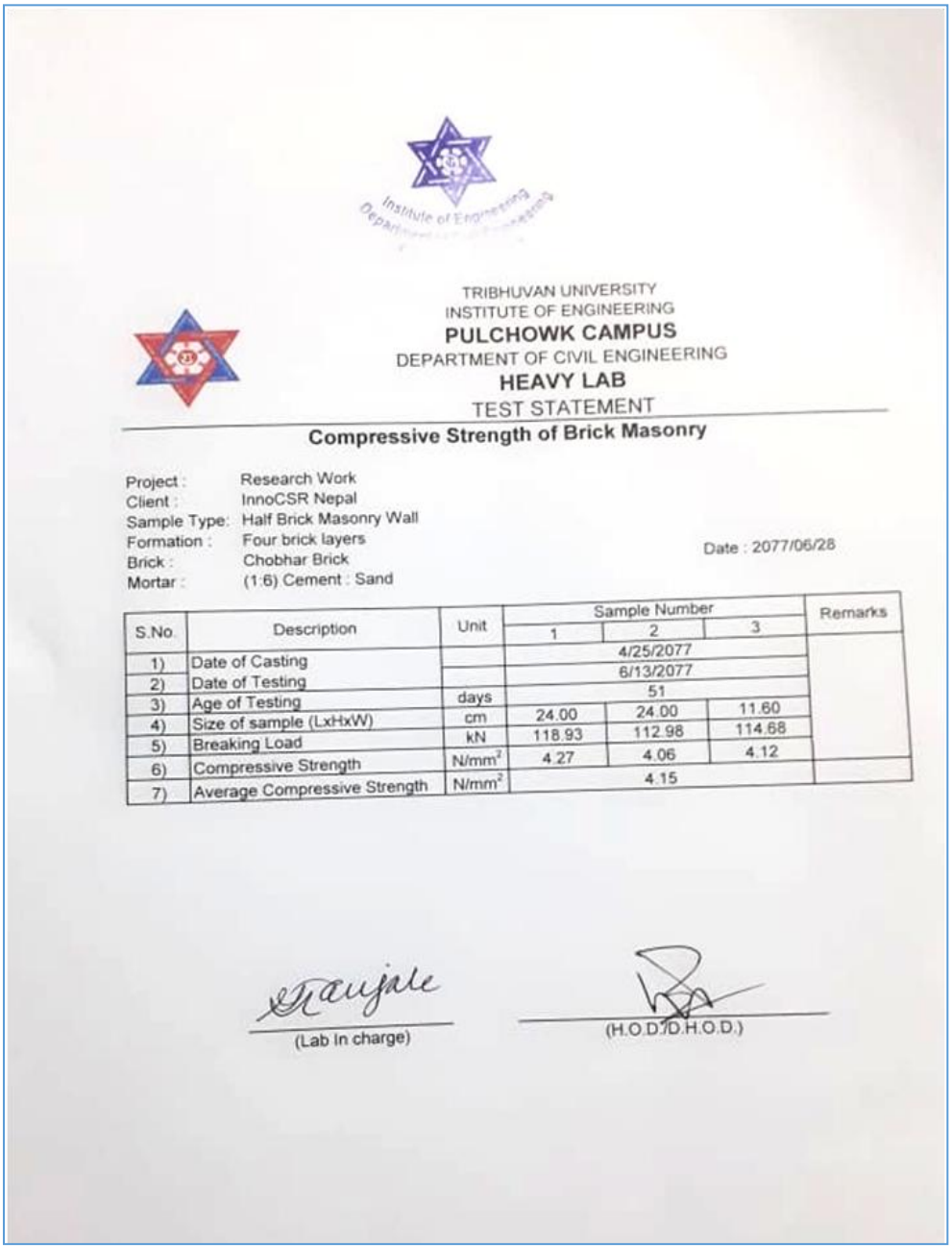
Date : 2077/06/28

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		4/25/2077			
2)	Date of Testing		6/13/2077			
3)	Age of Testing	days	51			
4)	Size of sample (LxHxW)	cm	24.00	26.00	11.90	
5)	Breaking Load	kN	93.45	80.70	93.45	
6)	Compressive Strength	N/mm^2	3.27	2.83	3.27	
7)	Average Compressive Strength	N/mm^2	3.12			

(Lab In charge)

(H.O.D./D.H.O.D.)

3. Compressive strength of CSEB Prism (Chovar)



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Compressive Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Four brick layers
Brick : Chobhar Brick
Mortar : (1:6) Cement : Sand

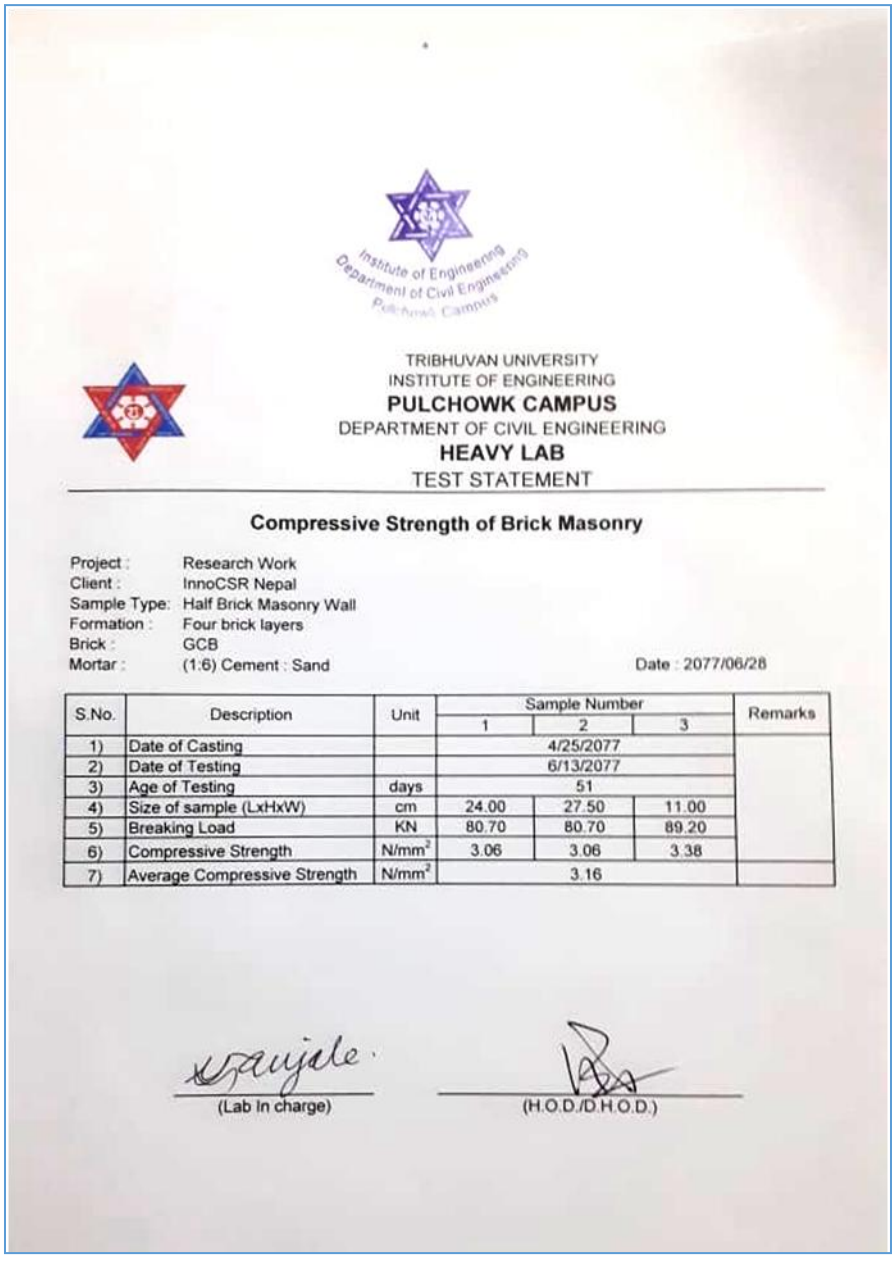
Date : 2077/06/28

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		4/25/2077			
2)	Date of Testing		6/13/2077			
3)	Age of Testing	days	51			
4)	Size of sample (LxHxW)	cm	24.00	24.00	11.60	
5)	Breaking Load	kN	118.93	112.98	114.68	
6)	Compressive Strength	N/mm^2	4.27	4.06	4.12	
7)	Average Compressive Strength	N/mm^2	4.15			

(Lab In charge)

(H.O.D./D.H.O.D.)

4. Compressive strength of CSEB Prism (GCB bricks)



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Compressive Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Four brick layers
Brick : GCB
Mortar : (1:6) Cement : Sand

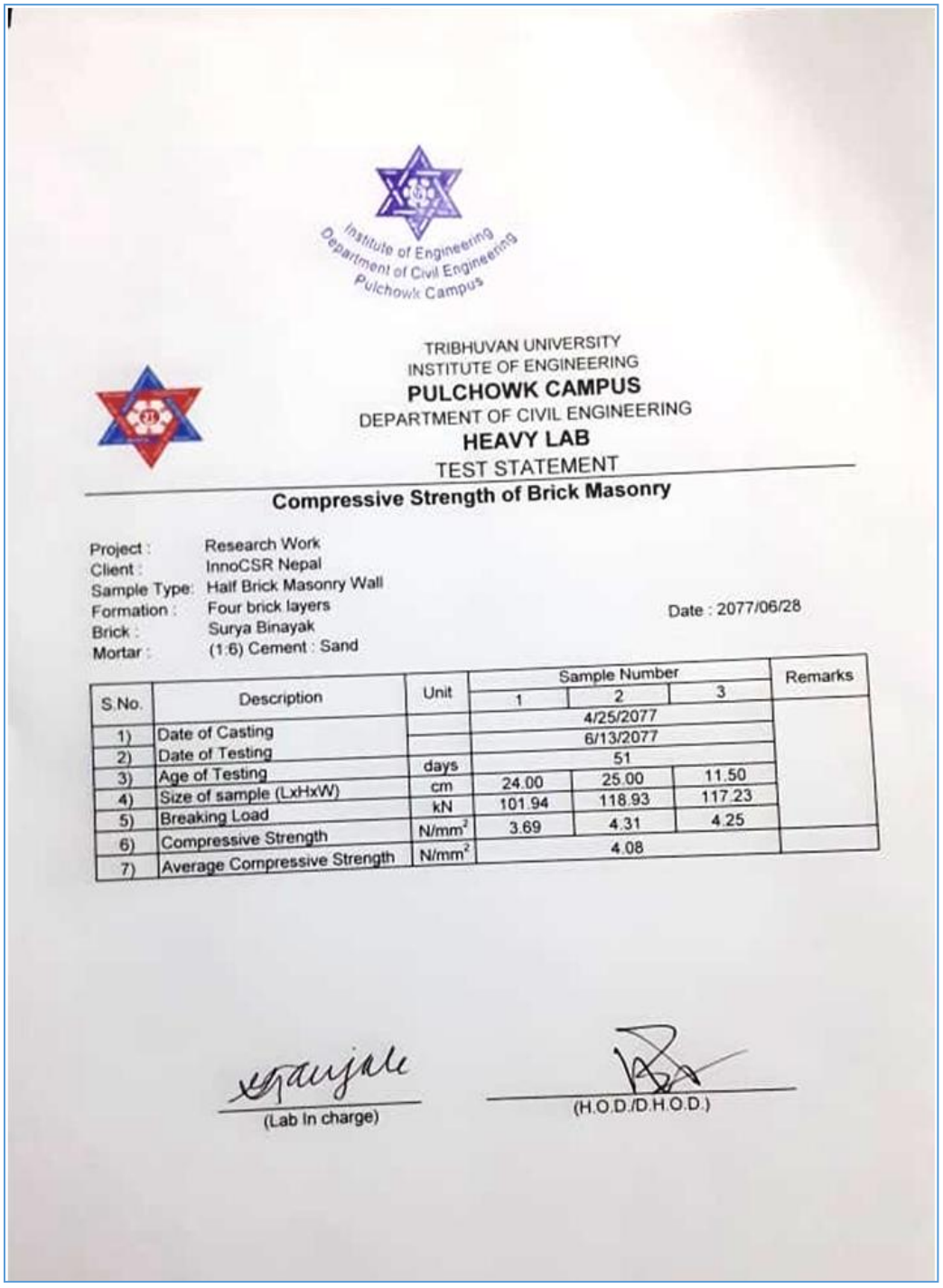
Date : 2077/06/28

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		4/25/2077			
2)	Date of Testing		6/13/2077			
3)	Age of Testing	days	51			
4)	Size of sample (LxHxW)	cm	24.00	27.50	11.00	
5)	Breaking Load	KN	80.70	80.70	89.20	
6)	Compressive Strength	N/mm^2	3.06	3.06	3.38	
7)	Average Compressive Strength	N/mm^2	3.16			

(Lab In charge)

(H.O.D./D.H.O.D.)

5. Compressive strength of CSEB Prism (Surya Binayak)



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Compressive Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Four brick layers
Brick : Surya Binayak
Mortar : (1:6) Cement : Sand

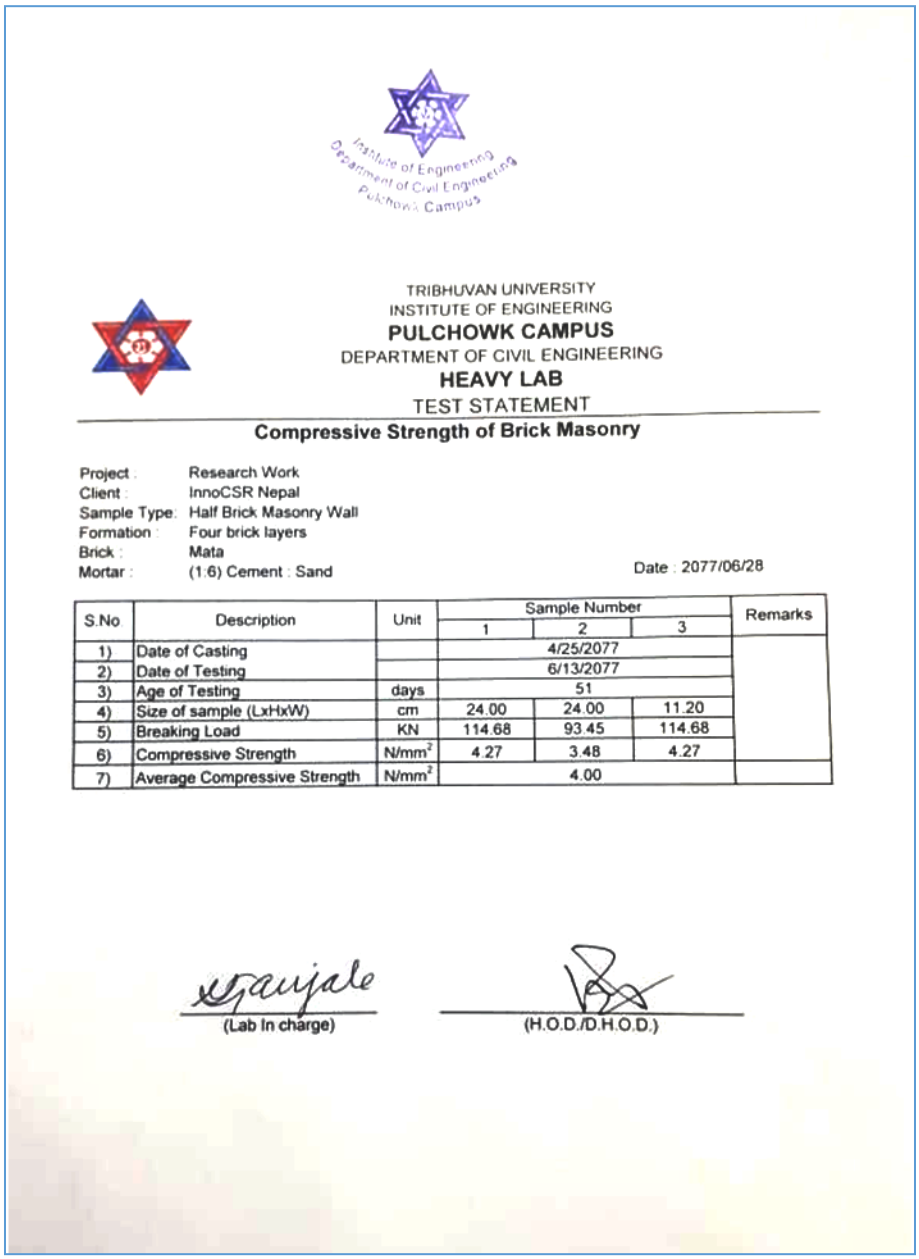
Date : 2077/06/28

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		4/25/2077			
2)	Date of Testing		6/13/2077			
3)	Age of Testing	days	51			
4)	Size of sample (LxHxW)	cm	24.00	25.00	11.50	
5)	Breaking Load	kN	101.94	118.93	117.23	
6)	Compressive Strength	N/mm^2	3.69	4.31	4.25	
7)	Average Compressive Strength	N/mm^2	4.08			

(Lab In charge)

(H.O.D./D.H.O.D.)

6. Compressive strength of CSEB Prism (Mata-Nawalparashi)



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Compressive Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type : Half Brick Masonry Wall
Formation : Four brick layers
Brick : Mata
Mortar : (1:6) Cement : Sand

Date : 2077/06/28

S.No	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		4/25/2077			
2)	Date of Testing		6/13/2077			
3)	Age of Testing	days	51			
4)	Size of sample (LxHxW)	cm	24.00	24.00	11.20	
5)	Breaking Load	KN	114.68	93.45	114.68	
6)	Compressive Strength	N/mm^2	4.27	3.48	4.27	
7)	Average Compressive Strength	N/mm^2	4.00			

(Lab In charge)

(H.O.D./D.H.O.D.)

7. Shear strength of CSEB Masonry (Kapilvastu)

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Shear Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Two Brick Layers
Brick Type : Kapilvastu
Mortar : (1:6) Cement : Sand

Date : 2077/09/26

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		8/28/2077			
2)	Date of Testing		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of sample (LxHxW)	cm	23.70	10.00	11.50	
5)	Vertical Load	kN	2.500	2.500	2.500	
6)	Actual Horizontal Load	kN	16.01	17.58	16.80	
7)	Shear Strength	N/mm^2	0.59	0.65	0.62	

Note: Horizontal Shear Load is applied at given vertical pressure.

(Lab In charge)

(H.O.D./D.H.O.D.)

8. Shear strength of CSEB Masonry (Chovar)

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Shear Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Two Brick Layers
Brick Type : Chovar
Mortar : (1:6) Cement : Sand

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S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		8/28/2077			
2)	Date of Testing		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of sample (LxHxW)	cm	23.70	10.50	11.50	
5)	Vertical Load	kg	2.500	2.500	2.500	
6)	Actual Horizontal Load	kN	17.58	16.01	18.37	
7)	Shear Strength	N/mm^2	0.65	0.59	0.67	

Note: Horizontal Shear Load is applied at given vertical pressure.

(Lab In charge)

(H.O.D./D.H.O.D.)

9. Shear strength of CSEB Masonry (GCB)

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Shear Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Two Brick Layers
Brick Type : GCB
Mortar : (1:6) Cement : Sand

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S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		8/28/2077			
2)	Date of Testing		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of sample (LxHxW)	cm	23.00	11.50	11.00	
5)	Vertical Load	kN	2.500	2.500	2.500	
6)	Actual Horizontal Load	kN	19.15	18.37	23.75	
7)	Shear Strength	N/mm^2	0.76	0.73	0.94	

Note: Horizontal Shear Load is applied at given vertical pressure.

(Lab In charge)

(H.O.D./D.H.O.D.)

10. Shear strength of CSEB Masonry (Surya Binayak)

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Shear Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Two Brick Layers
Brick Type : Suryabinayak
Mortar : (1:6) Cement : Sand

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Date : 2077/09/26

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		8/28/2077			
2)	Date of Testing		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of sample (LxHxW)	cm	24.00	10.50	11.50	
5)	Vertical Load	kN	2.500	2.500	2.500	
6)	Actual Horizontal Load	kN	28.57	33.23	34.75	
7)	Shear Strength	N/mm^2	1.04	1.20	1.26	

Note: Horizontal Shear Load is applied at given vertical pressure.

(Lab In charge)

(H.O.D./D.H.O.D.)

11. Shear strength of CSEB Masonry (Mata-Nawalparashi)

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Shear Strength of Brick Masonry

Project : Research Work
Client : InnoCSR Nepal
Sample Type: Half Brick Masonry Wall
Formation : Two Brick Layers
Brick Type : Nawalparashi
Mortar : (1:6) Cement : Sand

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Date : 2077/09/26

S.No.	Description	Unit	Sample Number			Remarks
			1	2	3	
1)	Date of Casting		8/28/2077			
2)	Date of Testing		9/16/2077			
3)	Age of Testing	days	18			
4)	Size of sample (LxHxW)	cm	23.70	9.80	11.50	
5)	Vertical Load	kN	2.500	2.500	2.500	
6)	Actual Horizontal Load	kN	23.86	25.43	22.29	
7)	Shear Strength	N/mm^2	0.88	0.93	0.82	

Note: Horizontal Shear Load is applied at given vertical pressure.

Result:

(Lab In charge)

(H.O.D./D.H.O.D.)