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RESEARCH ARTICLE

MECHANICAL PROPERTIES FOR SURKHI BONDED KATHMANDU WORLD HERITAGE BUILDINGS

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ABSTRACT

Kathmandu World heritage buildings have suffered heavy damage in past earthquakes both in 2034 and 2015. It has lost millions of rupees earning from tourism. Saving heritage is not just saving a buildings but also saving tradition, values and states income. To ensure importance of those properties, reconstruction, renovation, retrofitting and strengthening of heritage structures require traditional material. It is been a challenging job since less investigation have been done due less priority given in this area and how high level of seismic safety is maintained using those materials is a big question. Thus, in this investigation, tests have been done in order to find out various mechanical properties require for numerical simulation, evaluation of strength and design. Three kinds of test - shear, compression and combined loadings on the wallets made from bricks collected from old buildings. Various test specimen were prepared and tested in the laboratory to find the properties of brick elements and walls made from lime Surkhi mortar bonding such as density, modulus of elasticity, Poisson's ratio, shear modulus, shear wave velocity, compressive and tensile strengths.

INTRODUCTION

Kathmandu World Heritages lies in the city of Himalayan city of Kathmandu which one of the sever seismic sources of trans alpine belt. It has the recorded history (Pant, 2000) strong earthquakes occurred since 1223AD. At least one third of the populations were killed and most of the houses were damaged severely in 1223 and 1255. A great earthquake occurred in 1934 (Rana, 1935) which killed ten thousand people and damaged most of the residential houses, temples and royal palaces. Big earthquake occurred on 25th April 2015 which killed 8900 peoples, twenty two thousands were injured and seven billion rupees lost in damages of various sectors (PDNA, PDRF 2015). Severe damages are observed in the heritage structures. All together 753 structures in heritage area have been damages. Some of them are collapsed and other are severely damaged (Fig 1). In the 2015 earthquake severe damages in heritage buildings because of low seismic capacity of brick masonry structures. All heritage buildings are made of brick with mud or lime Surkhi mortar. They are very weak in seismic forces. Thus, sever damages were found in heritage properties. Kathmandu World Heritage was inscribed on the List of World Heritage in 1979, as a single site comprising of seven best monuments and Durbars. They are Durbar Squares (Patan, Kathmandu and Bhaktapur) and the monuments Pashupatinath, Swoyembhunath, Bouddhanath and Changu Narayan. Durbar Square comprises ensembles of Durbars and residential buildings and monuments.

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They were made from los strength masonry (LSM) using mud and Surkhi mortar and have performed very weak in 1934 earthquake (Rana, 1935) and 2015 earthquake (Parajuli 2015). LSM have become the prime cause of death and destructions in earthquakes.Investigation of mechanical properties of mud bonded structures are described in Parajuli 2012. This paper is aimed at finding the properties and strength of Surkhi bonded structures which is necessary for numerical modelling and evaluation of strength. In Kathmandu, the Dharahara collapse killing 180 people inside. Several pagodas and temples on Kathmandu Durbar Square, one of the World Heritage Site, collapsed. Several temples, including Kasthamandap, Panchtale temple, and the top levels of the nine-story Basantapur Durbar, the DasaAvtar temple and two dewals located behind the Shiva Parvati temple were flattened. Some other monuments including the TalejuBhawani Temple partially collapsed. The famous hindu temple Pashupatinath, swyambhunath, Boudhanath Stupa, RatnaMandir, inside Rani Pokhari also have moderately damaged. In Patan, the pati inside Patan Durbar Square, the Taleju Temple, the Hari Shankar, Uma Maheshwar Temple and the Machhindranath Temple in Bungamati were destroyed. In Tripureshwar, the KalMochanGhat was completely destroyed and the nearby Tripura Sundari also suffered major damage. In Bhaktapur, most of the monuments such as the Fasi Deva temple, the Chardham temple and the 17th century VatsalaDurga Temple were sustained moderate damages. Degree of damages can also been understood from the Fig 2. Aside damages in the Kathmandu World Heritage, the PalanchokBhagwati, in Kabhrepalanchok District, the Rani Mahal in Palpa District, the Churiyamai in Makwanpur District, the Dolakha Bhimsensthan in Dolakha District, and the Nuwakot Durbar, also have experienced cracks.

a. Hanumandhoka Durbar square b. Patan Durbar Square c. Dharahara (Bhimsen Stambha)

Figure 1. Damages in Heritage Heritage buildings before and after the 2015 Gorkha earthquake

The Manakamana Temple in Gorkha, the Gorkha Durbar has sustained very sever damages. The Manakamana Temple in Gorkha, previously damaged in an earlier quake, tilted further. Most of the monuments had been designated as World Heritage Sites in Kathmandu, Bhaktapur and Lalitpur District, were either completed collapse or damaged severely. They cannot be restored to their original states. All the heritage structures were built by low strength masonry and done by the earthquake Looking at the extensive damages in heritage structures both in 2034 and 2015 earthquake, if not strengthened, restored and preserved properly, we loss not only the physical structures but also the heritage, cultural values and the earnings through tourisms. So, preserving heritages in earthquake is a most important task. One of the key requirement of numerical calculation for evaluating seismic capacity is mechanical properties. So, an investigation for finding out mechanical properties of the Surkhi bonded world heritage brick masonry buildings have been done. Thus, a research project was done in Thapathali Campus, Institute of Engineering (IOE), Tribhuvan University, Nepal. Three tests – compression, shear and combined loadings in walls and bricks were carried out.

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MATERIALS AND METHODS

In order to prepare masonry unit for the testing purpose, the following materials were used from the damaged sites from 2015 Barpak - Gorkha earthquake

Brick: About 200 years old bricks from damaged buildings of Hanuman Dhoka Palace and Patan Durbar Square were collected. They consist of different shape, size, types and ages.
Surkhi: Surkhi is a fine dust made out of bricks, which is used as a substitute for sand for concrete and mortar, and has almost the same function as of sand but it also, imparts some strength and hydraulicity. Surkhi for purpose of making the mortar was collected from the Patan Durbar Square.

Lime: Lime is a white caustic alkaline substance consisting of calcium oxide, which is obtained by heating limestone and which combines with water with the production of much heat. The local name for the lime is Chuna.

Sand: Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt.

Chicken wire mesh (as reinforcement): It is made of thin, flexible galvanized steel wire, with hexagonal gaps. Available in 1 inch (about 2.5 cm) diameter, 2 inch (about 5 cm) and 1/2 inch (about 1.3 cm), chicken wire is available in various wire gauges usually 19 gauge (about 1 mm wire) to 22 gauge (about 0.7 mm wire). It is easily available in the market. Nowadays, it is increasingly used in the retrofitting of masonry wall.

Preparation of test specimen: Constituent material for mortar was of lime, Surkhi and sand mixed in the proportion of 1:1:3. The mortar was mixed manually.

Figure 2. Preparation of Surkhi mortar

Table 1. Normal and shear strength relationship

S.N.	Normal Stress σ N/mm^2		Shear Stress τ N/mm^2		Remarks	
	Unreinforced	Reinforced	Unreinforced	Reinforced	Unreinforced	Reinforced
1	0.50	0.80	0.39	0.44	Equivalent	Equivalent
2	0.70	1.00	0.38	0.67	Coulomb's	Coulomb's
3	0.90	1.50	0.59	0.82	parameters C =	parameters C =
4	1.10	1.80	0.61	0.95	0.1308&tanφ =	0.128&tanφ =
5	1.30		0.67		0.4622	0.4423
6	1.50		0.73			
7	1.70		0.86			
8	1.90		1.04			

First, lime in powder form, fine Surkhi and dry sand is mixed thoroughly till the mix appeared uniform color. The water was then added as shown in Fig. 2and shoveled or hoed thoroughly until the mortar was easily workable and the ingredients were thoroughly distributed. Fifty percent of total weight of lime was mixed in powdered dry form with other ingredients of mortar and the remaining was mixed with water and left for two days so as to allow for full reaction. The lime solution was then added to the dry mix to make mortar workable.

Fabrication fortest specimens

Once the mortar was ready, a large number of test specimens were prepared. Two, three and four bricks were bonded by mortar face to face for the compression, shear and tensile test respectively. The thickness of the mortar in the joint is 10 mm. So far as specimen with reinforcement is considered, after one week of the fabrication, a few numbers of specimens were reinforced with wire mesh in both the sides of the specimen for each test. For this wire mesh were cut into required size and then attached to sides of the specimen and covered with Surkhi mortar again. A sufficient bonding is ensured by proper anchorage. Meanwhile, cubes of mortar of size 70.6 x 70.6 x 70.6 mm were prepared to investigate the compression strength of mortar applied in the specimens.

Description of tests

Shear Test

The specimens for shear test are made of three bricks joined together by Surkhi mortar face to face. In the shear testing machine, the samples are first given a constant normal load, and then direct shear force is gradually increased until failure. The shear strength of the masonry joints has been calculated dividing the ultimate shear load by the shear area of the horizontal joint.

The results are shown in the Table 1 for the unreinforced and reinforced specimens respectively. Regression lines were obtained from the graphic plotted with reference to average shear strength with respect to the correspondent average normal stress as shown in Fig. 3.

The joint shear strength was expressed as a Mohr-Coulomb type of failure criterion shear stress (□) as follows:

For unreinforced specimens:

$\tau_1 = 0.4423\sigma + 0.128$

For reinforced specimens:

$\tau_2 = 0.4622\sigma + 0.1308$

In the first relation corresponding to unreinforced specimens, coefficient 0.4423 indicated the coefficient of friction between mortar and masonry unit which correspond to a friction angle of 24^0 and coefficient 0.128 indicates the cohesion or shear bond strength at initial compression equal to zero. The similar description holds for the second relation corresponding to reinforced specimen. Comparison of the respective coefficients for the reinforced and unreinforced specimens indicated both cohesion and friction coefficient is slightly higher for the reinforced specimen.

Compression Test

Compressive strength test ofreinforced and unreinforced masonry specimens consisting of two bricks with and without mortar were tested in compression testing machine (Fig 2). The least count of the machine was 7.5 kN. In order to obtain the mechanical properties of the brick and mortar, dial gauges were fitted in the vertical and lateral direction which measured the normal and lateral deformation of the specimen.

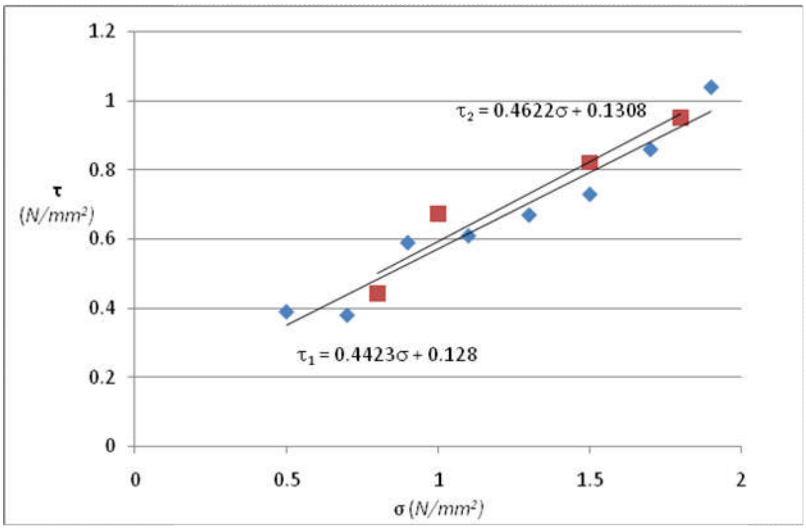

Fig. 3. Shear stress and normal stress Surkhi mortar

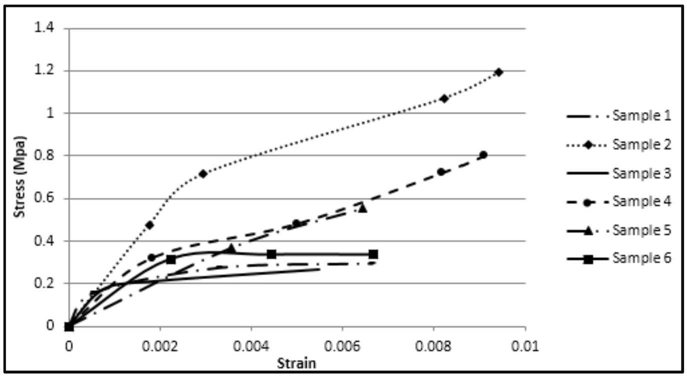

Fig. 4. Stress-strain relationship for brick masonry without mortar

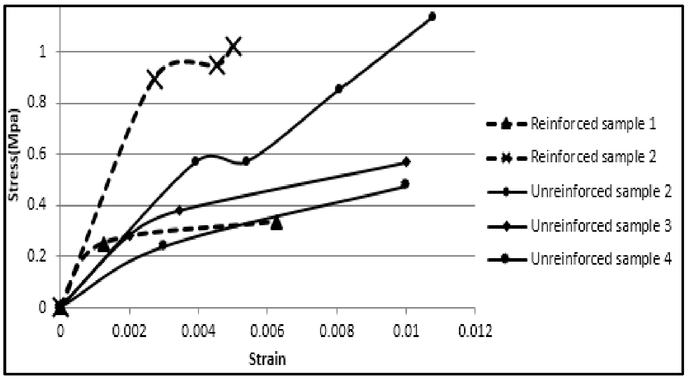

Fig. 5. Stress-strain relationship for brick masonry with mortar and reinforcement

Table 2. Mechanical Properties and Compression Strength of Specimens w/o and w/ mortar

S. N	Initial stress		Initial strain		Young's modulus		Poisson's ratio		Compressive strength		Density	
	σ N/mm^2		ε_n		E N/mm^2		υ		σ_{max} N/mm^2		ρ kg/m^3	
	w/o mortar	w/ mortar	w/o mortar	w/ mortar	w/o mortar	w/ mortar	w/o mortar	w/ mortar	w/o mortar	w/ mortar	w/o mortar	w/ mortar
1	0.159	-	0.0006	-	286	-	0.60	-	6.94	1.19	1640	1522
2	0.476	0.568	0.0018	0.0039	270	144.83	0.19	0.21	11.90	1.14	2011	1646
3	0.179	0.284	0.0008	0.0020	223	142.05	0.38	0.27	6.25	3.98	1786	1488
4	0.321	0.238	0.0018	0.0030	176	79.37	0.10	0.37	5.61	3.33	1487	1746
5	0.370	-	0.0036	-	104	-	0.05	-	7.77	0.66	1269	1852
6	0.316		0.0022		142		0.07		7.58		1731	
				mean	200	122	0.23	0.25	7.68	2.06	1654	1651
				SD	72	37	0.22	0.032	2.22	1.49	256	152
				median	200		0.15		7.26		1686	

Normal strain was obtained dividing normal deformation with the original height of the specimen whereas lateral strain was obtained dividing the increase in length as measured by dial gauge by the original length of the specimen. The least count of the dial gauge used for the measurement of vertical deformation in the direction of compression loading was 0.01 while that of the lateral deformation measuring gauge was only 0.002.Compressive loads were applied on the test specimens and the loads versus deformations were recorded at various intervals of loadings. Stress – strain relationship for the brick specimens without mortar are shown in the Fig.4 and that for the specimens with mortar and reinforcement are shown in the Fig.5.

Elastic Properties: Young's modulus of elasticity was obtained as the stress-strain relationship from the compressive strength test of specimen. But as seen from the Fig. 4-5, stress-strain relation is nonlinearly varying. As such the ratio of initial stress to initial strain was considered as the value of Young Modulus. From the stress-strain curve, it is found that the modulus is higher at the beginning and decreases at some point as we increase the load, which implies the formation of cracking at the mortar. However, increase in slope again on further loading indicates that the bricks start to take the load. The values of Young's modulus obtained from the compression test of prisms of two bricks only, two bricks with mortar and two bricks with mortar and reinforcement are given in Table 2, and Table 3.

Table 3. Mechanical properties and compression strength of specimens w/ mortar & reinforcement

S. N.	Initial stress	Initial strain	Young's modulus	Poisson's ratio	Compressive strength	Density
	σ N/mm^2	ε_n	E N/mm^2	υ	σ_{max} N/mm^2	ρ kg/m^3
1	0.251	0.00125	201	0.25	2.34	1728
2	0.895	0.0027	328	0.22	2.51	1674
		mean	264	0.24	2.42	1701
		SD	90	0.02	0.12	38

Fig. 6. Compression testing

Table 4. Compression strength of mortar (1:1:3)

S. No.	Size of cube	Volume	Weight	Density	σ_{max}
	mm	*mm^3*	*gm*	*Kg/m^3*	*N/mm^2*
1	70.6 x 70.6 x 70.6	351896	439	1248	1.50
2	70.6 x 70.6 x 70.6	351896	510	1449	1.2
3	70.6 x 70.6 x 70.6	351896	480	1364	2.4
			Mean =	1354	1.70

Table 5. Young's Modulus, Poisson ratio and Compressive Strength of mortar

S. No.	σ	ε_n	E	υ	σ_{max}	ρ
	N/mm^2		*N/mm^2*		*N/mm^2*	*Kg/m^3*
1	0.20	0.00142	142	0.23	1.70	1354

Table 6. Summary of all the tests

S. N.	Cases	Description	Density	Young's modulus	Poisson's ratio	Shear Modulus	Compressive strength
		Symbol	ρ	E	υ	G	σ_{max}
		Unit	*kg/m^3*	*N/mm^2*		*N/mm^2*	*N/mm^2*
1	Bricks + mortar	Unreinforced	1651	122	0.25	49	2.06
2		Reinforced	1701	264	0.24	107	2.42
3	Bricks only	Unreinforced	1654	200	0.23	81	7.68
4	Mortar cube (1:1:3)		1354	142	0.23	54	1.70

The average values of Young's modulus for these three types of specimens are 200 MPa, 122 MPa and 264 MPa respectively. The modulus is found to be higher for the specimen joined by mortar and strengthened with wire mesh reinforcement. The Poisson's ratio of masonry was evaluated by the ratio of unit lateral expansion and unit axial deformation within the elastic limit. The average lateral strains obtained by dividing the total measured lateral deformations by the corresponding length of the prismatic-masonry specimen. The average axial strains obtained by dividing the total measured axial deformation by the corresponding height of the specimen. The high deviation in the Poisson's ratio value was obtained which may be due to non-uniform surface and uneven shape. The average value of Poisson's ratio for bricks only specimen, bricks with mortar specimen, and bricks with mortar and reinforcement are respectively found as 0.23, 0.25 and 0.24.

Compression test on mortar cube

The cubes of mortar were tested after two months in the compression machine with the similar procedure adopted above specimens. The values of density, Young's modulus, Poisson's ratio and compressive strength are given in Table 2 and 3.

Tensile Test

For the tensile strength test, four bricks were bonded together face to face by Surkhi mortar and then tested after two months. The ends of the specimens were rested horizontally at two supports and two points loading is given from the compression testing machine. Though it was expected to fail in tensile with flexural cracks at the middle mortar joint, all the specimens got shear failure which may be attributed due to short span between the supports. So, it was unable to harvest the tensile strength values of mortar from this experimental research, and hence no tensile strength is virtually zero.

RESULTS AND CONCLUSION

The test results obtained from experiments are presented in the table 6. It is useful for analysis and retrofitting of masonry structures. Despite limited resources and budget, experimental research on the mechanical properties of brick masonry with reinforcement measures were successfully carried out. Except for the tensile strength of mortar, all the engineering parameters required for the finite element analysis of masonry buildings such as density, Young's modulus, Poisson's ratio, Shear modulus, cohesion, coefficient of friction and compressive strength of bricks, mortar and masonry were determined. These values are useful for numerical and strength evaluation of existing strength**.**

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