STRUCTURAL ASSESSMENT OF BHUTANESE TRADITIONAL BUILDINGS

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Abstract

Rammed earth construction practice in Bhutan is distinctive with its own architectural necessities and specifications. It cabinets the country's rich culture meanwhile preserves the traditional culture of Bhutan. The construction practice is grounded based upon the past knowledge of the craftsmen and their thumb rules. Hence, a traditionally built structures are very probable to experience unanticipated structural failure during its life time due to non-engineered practice of construction.

Therefore, it is essential to make buildings structurally safe under various unexpected load. This is realized by formulation of design aids to guide the construction of traditional rammed earth buildings. It is necessary to assess the present constructional practice and structural defects of the building and to accomplish this, so seven rammed earth buildings in Wangchang Gewog in Paro Dzongkhag were surveyed. Structural defects and design of each building was recorded from which cracks and uneconomical arrangement of joist was the most prominent drawback found on the buildings.

Numerous probabilities of adapting and refining the present buildingswere carried out with reference to the possible causes of defects and shortfalls composed from several data from different sources and frequent site visits. Based on the collected data and literature reviews, a design charts for joist spacing and rafter was plotted, and a structural stress modelling with several parameters and considerations were conducted.

Key Words :*rammed earth, joist spacing, bearer span*

1) INTRODUCTION

Traditional architecture of Bhutan is one of the most gorgeous expression of the ancient culture of Bhutan. For Bhutan traditional structures and constructions are more than just the appearance and presentation, it forms an essential part of rich cultural heritage and country's unique cultural landscape. The appealing view of traditional building also adds up to tourism fascination. Traditional buildings in Bhutan are uniquely constructed at different province. In the eastern part of Bhutan walls are more often made of stones and in west rammed earth are more frequently adopted.

Bhutan has predominantly followed the Tibetan tradition of Buddhist architecture throughout history. In Bhutan the practice of building traditional houses existed before 7th century of which Jambay Lhakhang in Bumthang and Lhakhang Karpo in Haa are the oldest standing buildings which are constructed around 7th century (Dorji, 2004).

Rammed earth has traditionally been used extensively in Bhutan for the construction of domestic, religious and administrative purposes. Rammed Earth construction technique in Bhutan is unique with its own architectural requirements and specifications. It showcases the country's rich culture and meanwhile it preserves the traditional culture of Bhutan. Bhutanese are proud of their traditions and in particular the 13 traditional arts and crafts of Bhutan, two of which, masonry and woodwork are inherent in the construction of rammed earth building.

However today the lack of standardization appears to be acting as a barrier to the rammed earth construction in urban area. Most of the rammed earth buildings are found with more damages and defects during natural disaster, which puts people into notion that traditional rammed earth buildings were no more suitable. This might eventually lead to the extinction of the cultural landscape of nation. Rammed earth construction practice has traditionally been used extensively in Bhutan, though the practice has seen a steep decline in recent years. Whilst there are a number of explanations for this trend there are also strong economic, environmental and social incentives for the continued use of this highly sustainable technology.

Rammed earth is seen as a highly sustainable building material. The exceptionally low material costs of rammed earth construction give it a significant economic advantage over alternative materials, such as brick, stone and cement, despite the additional costs incurred in using a more labour intensive method. The high thermal mass of rammed earth reduces the energy demand of buildings and the energy input required in production and transportation of the material is inherently low: hence rammed earth is environmentally sustainable.

Despite increasinglabour costs associated with rammed earth, it is invariably the most economic option since the material costs of alternative construction materials are substantial. Stone has been used widely in recent years, however given Bhutan's fragile landscape and unstable topography this trend was unsustainable and traditional construction appears to be declining. There are no proper guidelines for construction of Bhutanese traditional rammed earth building. The current Construction is based on past experience of master craftsman. There is a need for an appropriate code of practice to provide structural guidelines for the rammed earth construction in Bhutan as Bhutanese rammed earth buildings are vulnerable to structural failure.

1.1 Problem Statement

Structural instability in the Traditional Buildings andnon availability of design aids for Bhutanese Traditional Building construction.

1.2 Goals and Objectives

The core aim of this project is to assess the structural stability, study the structural defects and its causes, and formulate a design aids or guidelines for prevailing Bhutanese traditional rammed earth structures. For the fulfilment of the aim various goals and objectives were set at the beginning of this project. They are as follows:

1. Study of the current traditional buildings and its structural defects in Bhutan.
2. Determining new designs for better performance of the traditional buildings under expected load.
3. Formulation of Design Aids for guidance of Bhutanese Traditional buildings.

2) STUDY AND STRUCTURAL ASSESSMENT OF EXISTING TRADITIONAL RAMMED EARTH BUILDING.

In traditional Bhutanese architecture, there is no planning and designing done on papers before a structure is built. Buildings in Bhutan have been built by skilled craftsmen without any plans. These knowledge and expertise are passed on to new generation through practice and experience. Construction of rammed earth buildings essentially consist of foundation, rammed earth walls, timber floors and roofs.

Foundation in Bhutanese context uses strip footing which is made up of random rubble masonry with mud mortar, but of lately cement is used as a liable substitute for mud mortar.

a. Field visits and Assessments

A survey was carried out for several houses located in Paro District to assess the structural detail and the defects of the Bhutanese rammed earth buildings. The survey involved the filling up of the questionnaire through interviews with the owners of the buildingsbesides masons and carpenters. Experienced masons and craftsmen enlightened the survey concerning construction methods and techniques of rammed earth construction. Possible ways to improve the methods of construction were also discussed

b. Assessment of Structural defects and its details

Different types of defects and damagesfound on the rammed earth buildings were brought to spot light through frequent field visits and data collection.

i. Cracks

Various types of cracks on the buildings were the most prominent damages that was noticed. Classification of cracks were done based on its nature and location of its orgin.

Vertical cracks were found at the corners of the rammed earth building as they were not restrained from movement.Most the major cracks were developed from putlog holes.Vertical cracks were the cracks that usually occurs on the wall for releasing stresses which were built up within a structure.

Corner cracks are those cracks that occurred at the corners of traditional rammed earth houses. Corner cracks were found at the intersection of inner wall and outer wall. Corner cracks occurs due to joist movement and improper connection of shear wall.

lintel cracks occurs vertically over windows and doors. The connection between the lintels and walls were found to be weak and it was noticed that the main cause of lintel cracks were due to the poor bonding between wood of lintels and the rammed earth. As the moisture in the timber of the lintel dries up, shrinkage occurs causing cracks on walls.

Horizontal cracksoccurs in the horizontal plane at each lift of rammed earth wall. This type of cracks occur due to poor ramming between lifts of each block. The wall moves along this joint which causes cracks in horizontal plane. It was known that the poor quality of soil and ramming often lead to the horizontal cracks.

ii. Putlog holes

Putlog holes are small holes made in the walls of structure to receive the ends of poles or beams to support a scaffolding. Using putlog holes in the rammed earth construction is still very vibrant all over Bhutan and particularly in rural areas where putlog holes ruled to be the only means to provide proper scaffolding.

It was observed that most of the cracks were either originating or along these putlog holes. Major of the cracks that were occurring in the traditional rammed earth houses was due to the putlog hole

iii. Delamination of walls

The failure where by the splitting of inner layers from outer layers of rammed earth wall is known as the delamination of wall. The main cause of delamination of wall in rammed earth wall is due to weathering. The rainfall erodes the wall as it is exposed to it and thus it reduces the thickness of the wall and wears off the rammed earth wall. Bhutanese rammed earth wall are painted with lime.

3) ANALYSIS AND DESIGN

a. Modelling and Stress Analysis of Rammed Earth Wall

For modelling and stress analysis, STAAD.Pro(software) was used whereby 8-noded solid element was used as a tool for the finite element discretization and analysis of mud house. The solid elements in STAAD have three translational degree of freedom per node. The solid elements enable the structural problems solution involving the general three dimensional stresses. Solid element stresses can be obtained at the center and at the joints of solid element. The stress elements are:

a. Normal stresses: SXX, SYY SZZ
b. Shear stresses: SXY, SYZ, SZX

Two types of materials were used for simulation of rammed earth house model, a) Mud and b) stone(used as base wall at foundation).Their material property and the constant used are given in the table below.

Table 1 Material Properties

PROPERTY	MUD	STONE MASONRY
Young's modulus (E)	45000 kN/m^2	1.65 x 106 kN/m^2
Poisson's ratio	0.22	0.0
Density	19.6kN/m^3	25 kN/m^3

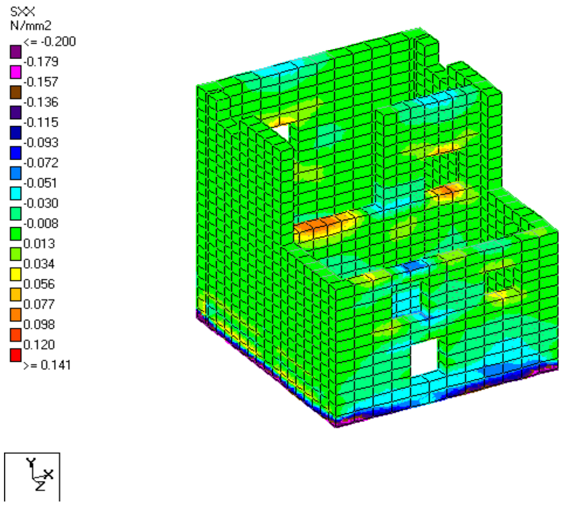

Fig.1 Example of Stress Distribution in STAAD pro

Some of the general conclusions derived from analysis

a. Portions around the openings were found to be highly vulnerable in all load cases.
b. Stresses were found relatively high in regions where floor and the wall meet.
c. The stresses reduce with the increase in the thickness of the rammed earth wall.
d. If the height of rammed earth wall is increased with respect to a constant height, the stresses increases.
e. Stress increases with increased in number of putlog holes.

b. Flooring

The joist and the bearer in timber flooring of the Bhutanese traditional buildings were found with no regular or specific spacing and span. The structural safety of the floors in terms of resistance (Ultimate limit states) and deformation (serviceability Limit States) sought to evaluate the suitability of joist and bearers (beams) to actuating vertical load. Therefore the spacing and span of the beams were designed and determined as per IS 883:1994 Design of timber structure in building.

Floors / Room Area m^2	G+0	G+1	G+2
0	0	0	0
10	500mm	600mm	800mm
15	500mm	600mm	800mm
20	600mm	600mm	800mm

Table 2 Minimum thickness of wall Required

i. Determination of Joist Spacing and maximum bearer span in Floor

Spacing = X (1+Y)
Where
X= spacing obtained from joist spacing graph
Y= correction factor from spacing variation curve

In case of flooring without mud layer (satha), the spacing is to be increased by 25%.

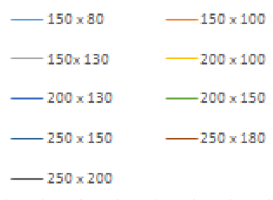

Fig.2 Timber cross section Legends for Charts

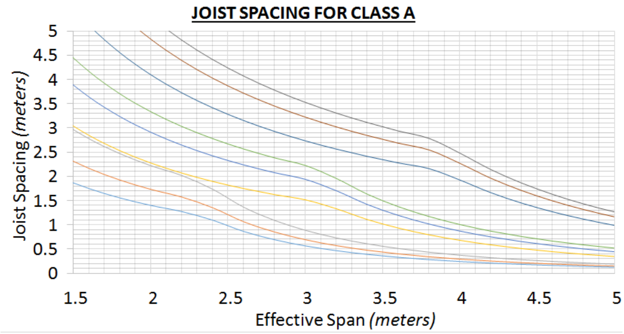

Fig.3 Joist Spacing for Class A Timber

Fig.4 Joist Spacing for Class B Timber

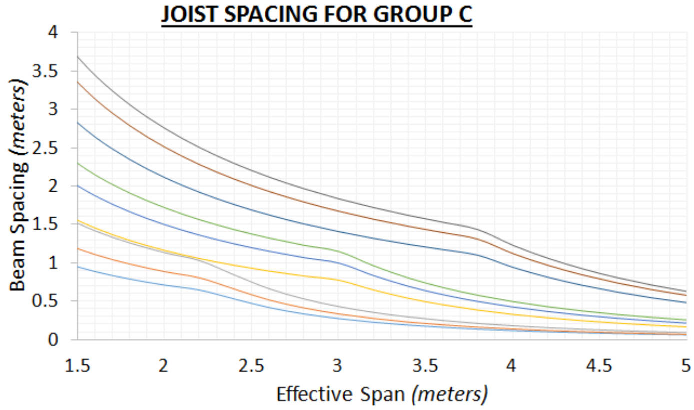

Fig.5 Joist Spacing for Class C Timber

ii. Determination of Maximum Bearer span

Bearer is a timber structure that is stump in the post and supports weight of the flooring and joist. Joist are laid over bearer so that it can carry floor load. It is usually provided if the spacing between the joist is small and dimension of the house is large. The cross section size of the bearers is governed by their span (i.e. the distance between piers) and the spacing and length of the floor joists.

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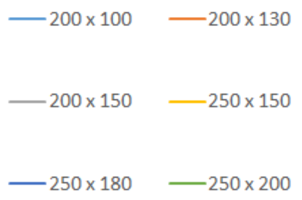

Fig.6 Timber cross section Legends for Charts

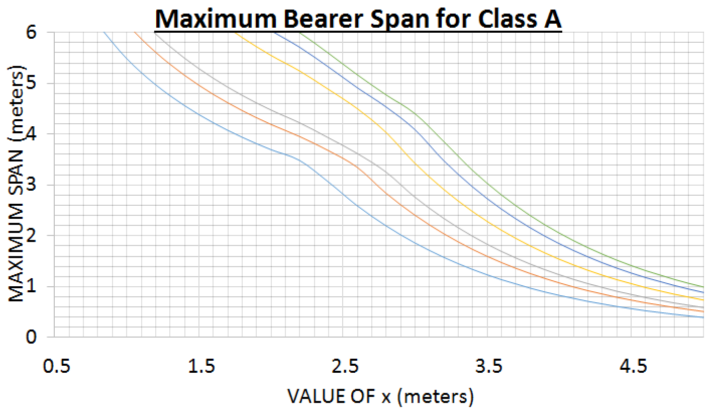

Fig.7 Maximum Bearer Span for Class A Timber

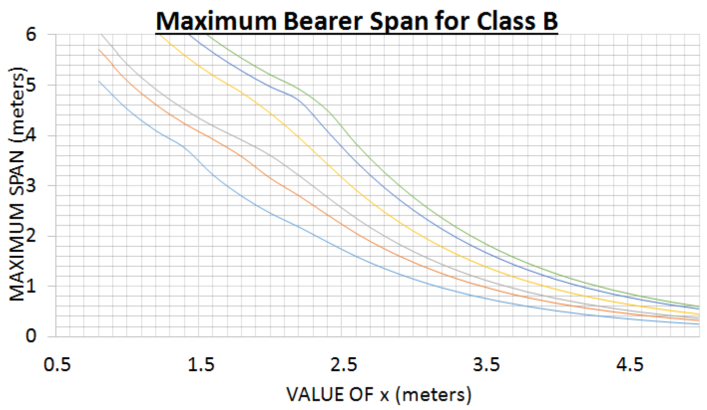

Fig.8 Maximum Bearer Span for Class B Timber

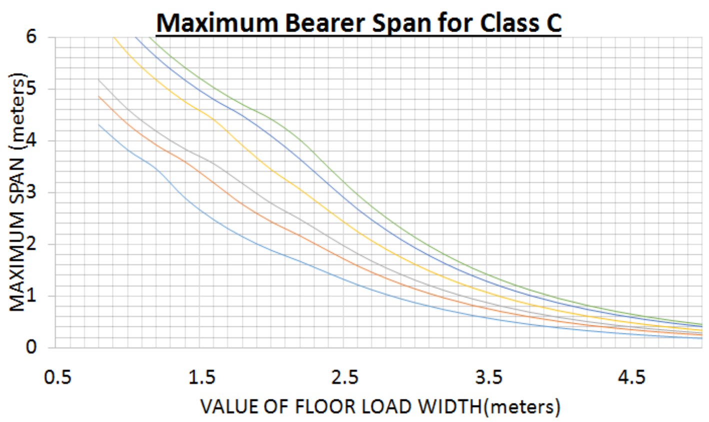

Fig.9 Maximum Bearer Span for Class C Timber

iii. Correction Factor

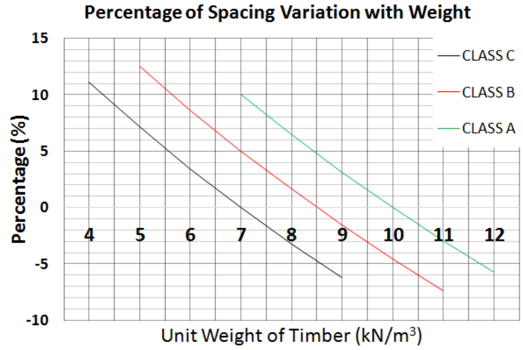

Fig.10 Chart for Correction Factor

a. Roofing

The connections among the truss members of the Bhutanese traditional roof were found weak due to which roofs are easily damaged and blown away during wind storm. Most of the failure was found in the connection between rafter to the tie beam and purlin to the rafter. The roof was found simply supported on the attic floor and there is no connection between support and the floor or wall

i. Determination of rafter spacing

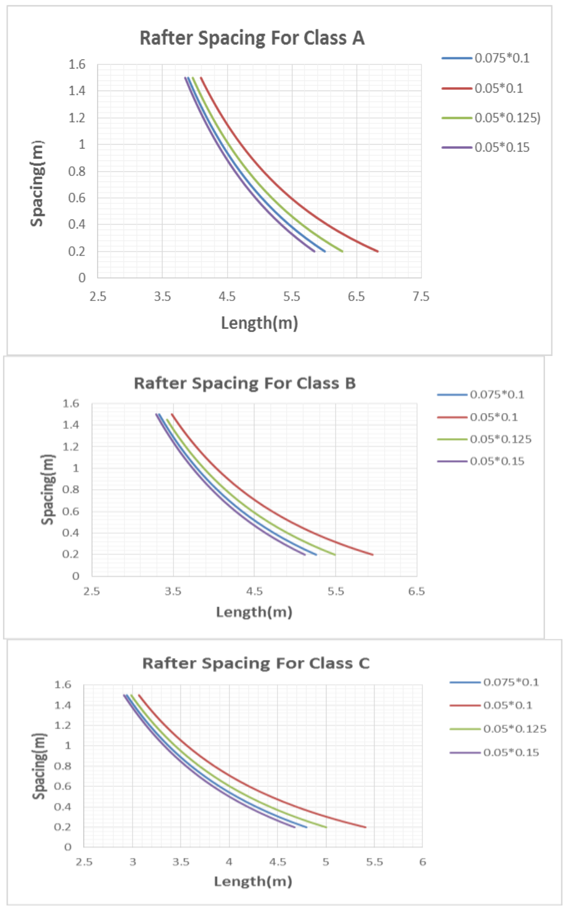

Fig.11 Rafter Spacing Charts

ii. New Connection Design in Bhutanese roof trusses

Some of the methods of connection to be integrated in the Bhutanese timber roof trusses are

Anchorage using steel rod.

Use of angle plates and bolting.

Use of wooden strut.

Gusset plate connection.

Wooden cleat.

Increasing wooden section at base and anchoring base plate

4. Conclusion

Rammed earth has traditionally been used extensively in Bhutan for the construction of domestic, religious and administrative buildings. Traditional rammed earth building show case rich tradition and culture and it is the duty of each and every individual to preserve the tradition which has been passed down from generation to generation. It has been seen that the rammed earth construction in Bhutan is declining over the past few years, with everyone opting for RCC construction now.

Although there is already an existing Bhutan Building Code(BTS-009-2003), it does not specify the use of rammed earth construction. If there is a general guideline for the rammed earth construction in Bhutan, it would facilitate and encourage the continuous use of rammed earth construction. Bhutan has been following a thumb rule based on the master craftsmen, there is no proper aid for the construction and it was found that a proper design aid must be provided for the better performance of the rammed earth building.

Paro and Thimphu was chosen as study area and through the field visits, data collection and literatures, various defects and shortfalls in rammed earth buildings in Bhutan were examined. The defects with the actual existing building along with stress analysis in Staad.pro were validated to get various result which concluded the study of the current traditional buildings and its structural defects in Bhutan.

From countless conceivable causes of structural instability, the most prominent one was the defective constructional practices and poor workmanship implied during the constructional phase of the building. This prominently included overlooking numerous putlog holes, weak and improper formworks which stretches the provisions for future cracks and instability in the structure.

Some components of the Bhutanese traditional building were considered to study the structural stability of the building and produced correlations of stresses with thickness of wall, and timber calculations were done to design charts in possible scenarios such as timber joist spacing, maximum span of bearers, rafter spacing and minimum strut sections. It has been checked and design so that it can be implemented in the rammed earth construction from here onwards.

5. Recommendation

The project could be replicated and carried out in another part of the country where rammed earth construction exists and then carry out the comparative study in construction techniques, structural detail and defects of the buildings for further acceptability of the project.

The joist spacing curve and the maximum bearer span curve contained in the project can be used as a design aids for the determination of spacing while laying the joist and bearer in the real field.

Study and analysis on foundation of the Bhutanese traditional buildings could be done to further determination of the structural behaviour and stability of the buildings.

Construction methodologies and practices needs to be studied properly and corrected since most of the instability in the structure rises from the ill practice and poor workmanship during the construction phase.

Traditional Bhutanese trusses and its timber connection can be studied and modified properly to strengthen the stability of the Bhutanese traditional buildings.

REFERENCES

Om, N., Gyeltshen, K., & Lama, U. (2015). *Retrofitting of traditional rammed earth building in Bhutan*. Retrieved from www.departmentofculture.gov.bt

Sethna, Z. (2008). *A sustainability approach to standards for rammed earth construction in Bhutan*. Retrieved from www.scribd.com

Miyamoto, M., Aoki, T., Tominaga, Y., & Pema. (2014). Pull-down test of the rammed earth walls at Paga Lhakhang in the Kingdom of Bhutan. *International Journal of Sustainable Construction*, 2, 51-59.

Dorji, C. (2004*). Clear exposition of Bhutanese architecture.*

Bhutanese architecture guidelines.. Ministry of Works and Human Settlement: Royal Government of Bhutan.

MoHCA. (n.d.) *General guideline for improved seismic resilient construction techniques for rammed earth structures in Bhutan*. Bhutan: Division for Conservation of Heritage Sites, Department of Culture.

Gupta, R., Miller, T. H., & Dung, D. R. (2004). Practical solution to wood truss assembly design problems. *Practice Periodical on Structural Design and Construction*. 9(12) 54-60.

Ignacia, J. C. (2017, September). Late medieval castles built with rammed earth in Castile, Spain. *Journal of Architectural Engineering*, 23(3).

Jaquin, P. (2011). A history of rammed earth in Asia. *International Workshop on Rammed Earth Materials and Sustainable structures.*

Walker P., & Standard Australia . (n.d.). *The Australian earthbuilding handbook.*Australia: Standard Australia International Limited.

Lotay, Y. (2015). *Wind induced damage to roofs and mitigations: A comparative study on roofs in Bhutan and Japan.*Thimphu: Asian Disaster Reduction Center.

Maniatidis, V., & Walker, P. (2003, May). A Review of Rammed Earth Construction.Paper presented at DTI Project Report, Bath.

Nabouch, R. E., Bui, Q. B., Perrotin, p., &Plassiand , J. P. (2015, June 22-24). Numerical modelling of rammed earth construction: analysis and recommendation . First International Conference on Bio-based Building Material.

Nordenson, G. (2011). Design and construction guidelines for confined masonary housing. New York: Build Change Denver CO.

Policy and Human Resource Development. (n.d.). Study of typology of Bhutanese rammed earth buildings. Retrieved from www.ddm.gov.bt

Rahman, M., Hassan, M. R., &Hossain, M. T. (2013). Seismic performance analysis of mud house. International Journal of Scientific & Engineering Research, 1612-1617.