"Comparative Analysis of RC Frame Building by Using Various Infill Wall Materials Based on the Structural Performance & Project Cost of the Building in Bhutan"

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Abstract: The constant increase in the cost of building material has led to consider a cost saving alternative which can make the cost of construction affordable for the respective stakeholders. With government economic policy inclined towards the use of locally available materials in construction sectors, the need to substitute conventional infill wall materials like red clay brick, which is largely imported, with concrete bricks and AAC blocks has made the stakeholders indecisive due to its indefinite financial impact on the project cost and the variance in structural performance of the building. This paper investigates potential economy achieved by using different infill wall materials of mandatory thickness on a specified building and studies the influence of the infill wall on the structural performance of the building by comparing the structural parameters like the story drift, displacement, base shear, story shear, building moment & shear force.

Keywords: Cost saving, Structural load, infill wall material, Red clay brick, Solid Concrete brick, AAC block.

Introduction:

Cost benefit analysis is a systematic approach to estimating the strengths and weakness of alternatives used to determine options which provide the best approach to achieving benefits while preserving savings. It is important that we select the best building infill wall materials since it has significant impact on the overall cost of the project with additional factors like cost effectiveness, labor requirements, technical skills, weathering actions, environmental issues and energy efficiency playing a part in the selection of the building infill wall material.

With the rapid growth in technology and continuous innovations, many new building wall materials have come up, ranging from traditional and naturally available materials to artificially manufactured materials. The wall materials taken into considerations for the study are red clay brick, autoclaved aerated concrete (AAC) blocks and solid concrete block. The reason for choosing the aforementioned materials for this study is because these materials are being commonly used in Bhutan and are readily available in the market. Red brick is the most common, one of the oldest and popular walls building material used in Bhutan.

Red bricks are made of clay which is eco-friendly and doesn't catch fire easily. Red brick walls are heavy and quite expensive. Concrete blocks are very strong and durable. They don't require maintenance too often and installation of concrete block wall is not much labour intensive. Autoclaved aerated concrete is an eco-friendly and certified green building material which is lightweight, load-bearing, high-insulating, durable building block.

Objective

1) Design and analyse the same building structure using three different wall materials.
2) Study the impact of the wall materials on the different component of the building.
3) Evaluate the cost difference incurred by the different wall materials.
4) Evaluate the structural performance of the building, using different wall material by comparing different response parameters such as the base shear, storey drift, displacement contour, building moment & shear force.

Literature Review:

Infill walls are termed as the non-structural element hence no design standards are in place. However, the infill walls do play a part in the seismic behavior of the building in the case of lateral loading (A Ahmed, 2018) carried out a research that concluded that the masonry infill walls may have significant effects on the seismic response of the reinforced concrete frame structures, therefore, infill walls need to be considered during the design and analysis of the building.

The experimental research carried out by (Nayakar, 2018) have shown that the AAC blocks infilled RC frame exhibits better performance subjected to lateral loads than that of conventional bricks infilled frames. The low strength and stiffness of AAC infill results in improved load sharing between infill and frame, which help to develop yield mechanism in the frame earlier for better energy dissipation (Supratik Bose, 2014).

The usage of AAC Block reduces the cost of construction up to 25% as reduction of dead load of wall on beam makes it comparatively lighter members. The use of AAC block also reduces the requirement of material such as cement and sand up to 55% (Alim Shaikh, 2013). AAC block reduces operation cost by 30% -40%, reduces the overall construction cost by 2.5% as it requires less jointing and reduces the need for cement and steel. AAC reduces construction time by 20%. The productivity of mason with AAC block increases up to 3 times due to a smaller number of joints (Shukla, 2014).

Methodology:

For this study, the building taken into consideration is a typical residential G+4, Category III quarter for the proposed affordable housing project to be constructed by NHDCL with the support of ADB. Separate analysis was carried out for the specified building with different infill wall material. Design optimization were carried out as per the obtained analysis results from the Midas Gen software for the structural components of the building like their beam, column and footing sizes. The design coefficient of 0.8 were kept constant for all the design. The reinforcements were distributed as per the optimized design and the cost comparative analysis were carried out by using BSR 2020.

The design and analysis for the G+4 Structure was carried out using the design software MIDAS GEN, 2019. The reinforcement values for the beams were calculated considering the area of steel values from the software. For the column, capacity design was used to obtain the reinforcement values as per IS 13920, 2002. In the case of footing design, the critical reaction value was obtained from the software and further design was carried out using IS 456, 2000.

For the estimation and costing, BSR Civil 2021 was used to find the rates for specific items and when the rates for items are not included in the BSR Civil 2021, we used the combination of LMC Civil 2021 and BSR Civil 2021 from which we find the Labour/Material Coefficients and Basic Material/Labour Rates respectively, and also the prevailing market rate to do the Rate Analysis. The prevailing Market Rates are used when the rates are not included in Basic Material and Labour Rates in BSR Civil 2021.

Result Analysis and Interpretation:

This research includes findings in terms of structural performance of the building & cost benefit analysis for the different building wall material:

Structural Performance of the building

After carrying out the seismic design & analysis for the building with the three infill wall materials, the structural performance of the building is compared among the three using the structural parameters such as the base shear, story displacement, beam moment and the stiffness irregularity check.

1) Base Shear

   Base shear is an estimate of the maximum projected lateral force on the base of the structure due to seismic activity.

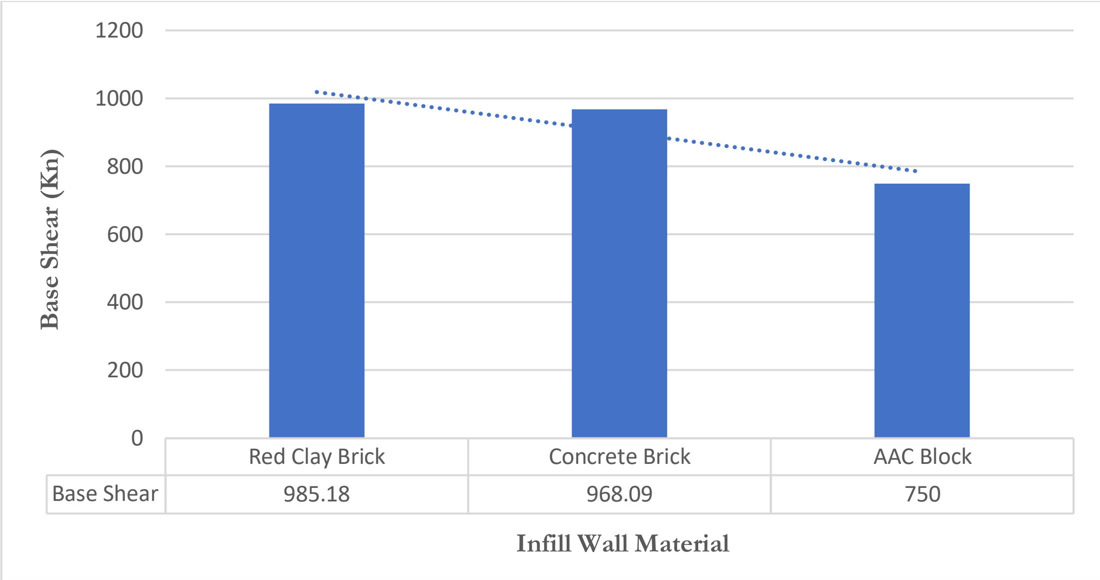


Figure 1. Base Shear of Building with different infill wall materials

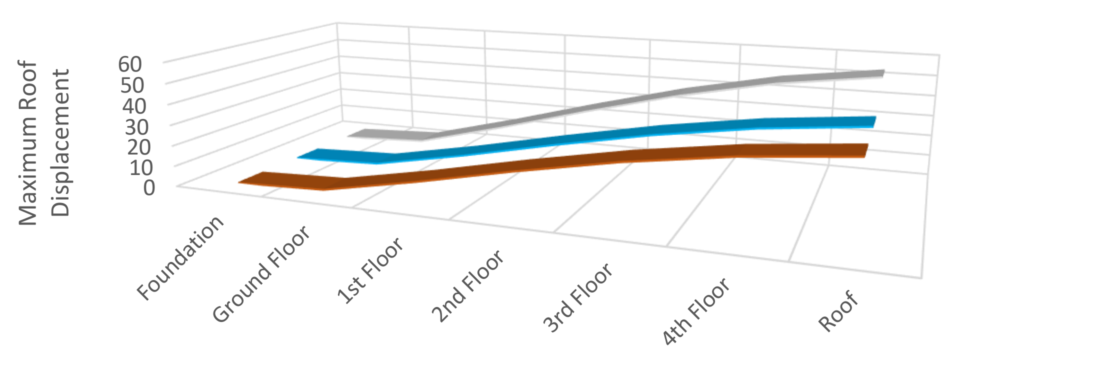
The base shear of the building with AAC block masonry is less compared to the other two. There is a decrease in the base shear of the AAC infilled wall building by 23.87% compared to the conventional red clay brick and 22.53% compared to Solid concrete block. This is because of the light weight of the AAC block contributing to the dead load of the building. Due to the reduction in the base shear, member forces are also reduced which leads to the reduction in the percentage of steel & sectional sizes of the structural components of the building.

2) Story Displacement

Story displacement is the lateral displacement of the story relative to the base. The lateral force-resisting system can limit the excessive lateral displacement of the building. The story drift is the relative displacement of one-story relative to the other. The importance of the story drift is in the design of partitions and curtain walls.

The role of the infilled wall material contributes to the stiffness of the building which is normally determined by the designing through equivalent diagonal strut modelling of the infill wall. However, in our study & going by the common practices of building structural design in Bhutan, we don't design the infilled wall material through the equivalent diagonal strut method. Our common practice is to apply the weight of the wall on the external & internal beam which doesn't consider the infill wall as a part of the lateral force resisting system. As per the study by (A Ahmed, 2018), it is concluded that building analysis and design with infill walls can economize the cost of structures as the in-fill walls contribute towards lateral stiffness due to braced frame action.

The maximum displacement obtained for the red clay and concrete brick masonry building is 40.36 mm and 41.00 mm in the lateral Y direction. In the case of the AAC block masonry building, the maximum value 53.55 mm in the lateral Y direction. Since our scope of study does not consider the lateral stiffness contributed by the infill wall in the building, the story displacement is only due to the structural loading of the building. Owing to the lighter building material in the case of AAC masonry building, the story displacement is found to be the highest among the three buildings. The stiffness contributed by the overall weight of the building which helps to resist the lateral forces is highest for the red clay brick masonry building resulting into the least displacement among the three.



	Foundation	Ground Floor	1st Floor	2nd Floor	3rd Floor	4th Floor	Roof
Red Clay Brick	0	1.65	10.42	20.15	29	35.9	40.36
Concrete Brick	0	1.63	10.32	20.06	29.09	36.27	41
AAC Block	0	1.94	13.61	26.2	37.89	47.36	53.55

Figure 2. Maximum roof displacement of building with different infill wall materials

3) Bending Moment

The most common structural element that is subjected to bending moment is the beam, which may bend when loaded at any point along its length. The stiffer the building, higher the moments are developed in the structural element of the building to resist the lateral forces thus requiring higher sectional member sizes and high percentage of reinforcement. Consequently, the building with the red clay brick which had higher stiffness values was observed to have developed higher moments in the structural elements eventually resulting into higher reinforcement values. The lower bending moment values observed in the AAC infilled walled building results to the economy in the reinforcement quantity.

Table 1. Critical Hogging & Sagging bending moments

Storey	Beam Hogging Moments (KN-m)			Beam Sagging Moments (KN-m)		
	Red Clay Brick	AAC block	Solid Concrete Block	Red Clay Brick	AAC block	Solid Concrete Block
6	-71.5	-77	-73.5	28.09	33.4	28.1
5	-123.9	-112.8	-122.5	44.81	43.6	48.8
4	-148.8	-134.8	-146.6	67.41	65.7	73.1
3	-162.9	-145.7	-159.1	81.09	76.3	85.1
2	-161.7	-145.6	-156.3	80.47	76	82.8
1	-79.8	-73.7	-80.3	44.70	47.2	43.2

Cost Comparative Analysis

1) Infill wall saving

After carrying out the detailed study and estimation of G+4 building using three different infill wall material, total project cost savings is determined in terms of infill wall saving, plaster saving, maintenance cost saving, labour cost saving and reinforcement saving.

Table 2. Estimated cost for 1 cum of infill wall

Sl. No.	Material	Unit Cost (Nu.)	Quantity per cum	Total Cost (Nu.)
1.	Red Clay Brick	13.00	650.00	8,450.00
2.	Solid Concrete Block	8.15	18,800.00	153,163.60
3.	AAC Block	12.00	504.00	6,049.15

Table 3. Cost savings in AAC block for 1 cum of infill wall

Description	Saving comparted to Red Clay Brick	Saving compared to Solid Concrete Block
Cost savings in AAC Block Infill wall	43%	21%

2) Plaster Saving

AAC Blocks have uniform shape and texture, which gives even surface to the walls. The AAC Block when built has both faces as fair faces as compared to brick work which has only one fair face and has undulations at the same time. Hence, the thickness of plaster for AAC block is much less compared to conventional bricks.

The thickness of plaster used in this estimation is 6mm for both internal and external walls for AAC Blocks as infill material in compliance with BSR 2021. For Red Clay Bricks & Solid Concrete Blocks, the plaster thickness considered is 12mm for internal wall and 15 mm for external wall. There is 21% saving in plaster while using AAC Block as infill wall material.

Table 4. Cost difference in plaster works.

Description	**Red Clay Brick**	**Solid Concrete Block**	**AAC Block**	**Cost Saving**
Cost of Plastering (Nu)	828,836.60	828,836.60	656,663.30	21% saving in AAC block as infill material

3) Maintenance saving

For maintenance cost saving, considering the life expectancy of a building to be 50 years and keeping the maintenance requirement of the infill wall constant for a periodic cycle 10 years the use of AAC Block reduces the operating and maintenance cost in terms of plaster by 21% as AAC comes in precise and accurate dimensions unlike Red Clay Bricks and so the AAC blocks after laying offers a uniform surface without any undulation.

So, a thin layer of plaster is also sufficient to plaster the wall. Wall painting and plaster last longer as there is minimal efflorescence effect on AAC. Moreover, AAC Blocks are characterized by micro pores. Micro pores are small air bubbles evenly distributed throughout the material which restricts the entry of water molecules. As such, absorption of water into the AAC material is minimum. This translates to lower maintenance cost for AAC blocks and increased durability.

4) Labour cost saving

Table 5. Estimation of labour cost for 1 cum of infill wall

Infill Wall Materials	**Mason Gd.1 Days**			**Mason Gd.2 Days**			**Labour Days**			**Labour Cost**	**Cost Saving**
	Days	**Rate (Nu/ Day)**	**Total Cost (Nu)**	**Days**	**Rate (Nu/ Day)**	**Total Cost (Nu)**	**Days**	**Rate (Nu/ Day)**	**Total Cost (Nu)**		
Red Clay Brick	0.763	632.5	482.5	0.763	575	438.7	2.792	460	1078.2	1,999.542	51% in AAC compared to the conventional brick.
Solid Concrete Block	0.763	632.5	482.5	0.763	575	438.7	2.792	460	1078.2	1,999.542	
AAC Block	0.431	632.5	272.3	0.431	575	247.6	1.019	460	468.5	988.506	

LMC 2021 and BSR 2021 were used for the calculation of labour days and rate respectively. Using the LMC 2021, the labour days for the construction of the building were calculated by multiplying the coefficient of specific workers with the total volume of the infill wall materials required. The labour days were then multiplied with the rates from BSR 2021 to find the total cost of specific workers. There is up to 51% saving in cost of labour in terms of AAC Block as infill wall material due to bigger size and lighter weight of AAC Block which translates to a smaller number of blocks in wall work. The lesser joints in AAC also contributes to 3 times reduction in time required to lay the blocks.

5) Reinforcement saving

Due to the changes made in the building wall material, changes were observed in the values of the reinforcements in Beam, Column and the footing. The steel take-off in structure with AAC block reduced by 32.86% compared to Red clay brick and 30.14% compared to Solid Concrete Block. The steel take-off in the beams for AAC Block structure is lower compared to Solid Concrete Block by 45.8% and 44.13% compared to Red Clay Brick.

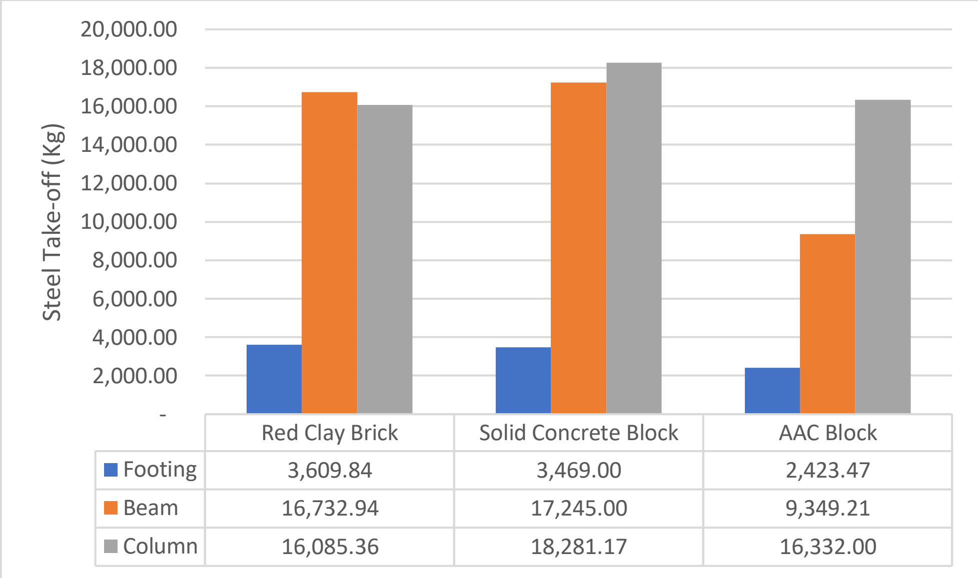


Figure 3. Steel quantity take-off for structural members

Total Project Cost Comparison

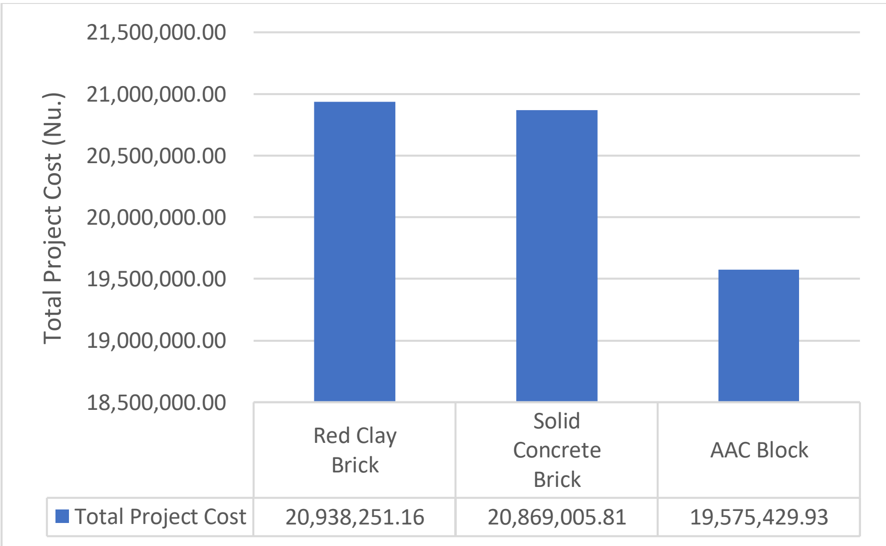


Figure 4. Total project cost of the building

AAC Blocks are more cost efficient than Red Clay Brick and Solid Concrete Blocks. There is reduction in overall construction costs by 5.6-6.2% as compared to Red Clay Brick and Solid Concrete Block respectively, as it requires less jointing, lesser excavation for foundation and reduces need for cement, sand and steel. The thickness of plaster is also reduced up to 50% which further reduces the cost of construction. The micro pores characterized in AAC block restricts the entry of moisture which keeps detoriation and maintenance minimum in wall plaster hence reducing maintenance cost as well.

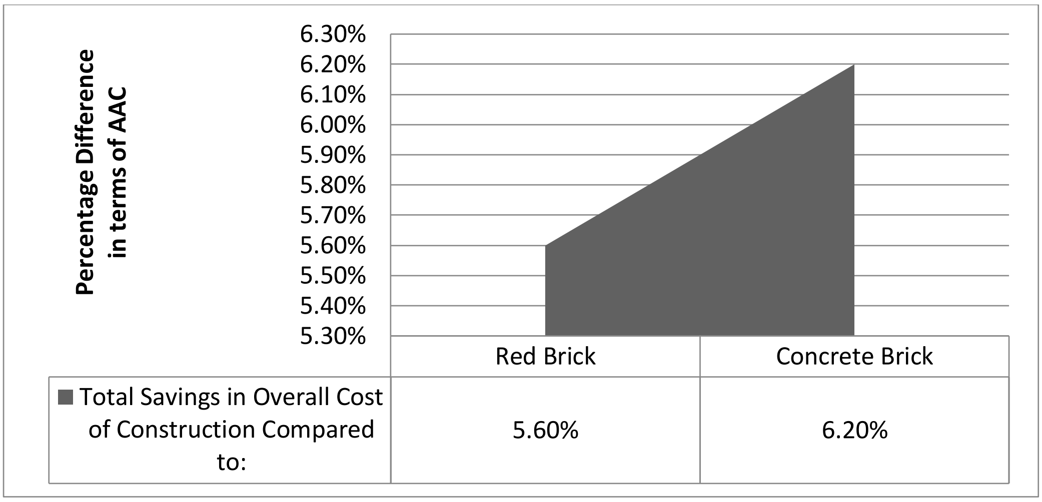


Figure 5. Percentage cost saving for the overall project cost

Conclusion and Recommendation:

In our study, an effort has been made to understand the difference in the building's structural behavior and the cost incurred by the use of three different types of infill wall (i.e., red clay brick, solid concrete brick & aac block) materials available in Bhutan. From the results obtained from our study, it can be concluded as follows:

The lightweight nature of the aac block has significant impact on reducing the building dead load, resulting into the reduction of the structural members section size and reinforcement percentage used. The reduced base shear and moment benefits the structure to perform better during seismic loading. As a common building design practice in Bhutan, infill wall is considered as a non-structural member which does not play the role of lateral load resisting member. Thereby the study of our research is limited to the understand the actual behavior of the building contributed by the type of infill wall used in the building and the limiting subject will be the future scope of study.

The overall cost savings achieved from our study by comparing aac block with conventional red clay brick and solid concrete brick was 5.60% and 6.20% respectively. The result obtained was based on the study performed for building project site in Thimphu and the rate was obtained as per BSR 2021. The building components affected by the type of infill wall, was studied based on their altering cost of materials. The alteration caused by the infill wall types on the plastering cost, labour cost, maintenance cost and reinforcement cost, favored more saving in the aac infill wall as compared to conventional infill wall. The varying demand and availability of the infill wall material significantly influences the rate and maybe subjected to change against our study.

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Conflict of interest: The authors declare no conflict of interest.

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