“ENERGY EFFICIENCY AND EFFECT OF REINFORCED CEMENT CONRETE WALL”

A

PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree

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Under the supervision

of

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to

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HIMACHAL PRADESH INDIA

MAY, 2022

DECLARATION

I hereby declare that the work presented in the Project report entitled**"ENERGY EFFICIENCY AND EFFECT OF REINFORCED CEMENT CONRETE WALL** "submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Sugandha Singh.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"ENERGY EFFICIENCY AND EFFECT OF REINFORCED CEMENT CONRETE WALL"**in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat**is an authentic recordof work carried out by **Phub Dorji (181649)and Tshering Gyeltshen (181651)** during a period fromJuly 2019 to November, 2019 under the supervision of **Dr. Sugandha Singh**(Assistant Professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

Most people wish to own a house by the time they retire. However this is easier said than done, since the cost of materials keep rising. Home is considered as an asset when it is actually a liability. The cost of construction kept aside, the cost of running a home is not well perceived. Lots of money is wasted per year just because the structure wasn’t designed for energy efficiency. Now, with the advancement in technology, it enables us to use software that can simulate situations, and check the parameters to help us save energy.

Structural wall is a vertical element of a structure that is designed to resist lateral forces applied parallel to the plane of the structural walls, typically wind and seismic loads. These walls are reinforced and go down till the foundation.

This study will look into the amount of energy that can be saved in an energy efficient building and how much the structural walls help to take the seismic loads.

Key words: seismic, structural walls, energy efficiency.

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CHAPTER 1

INTRODUCTION

1. Background

1. Earthquakes.

Earthquake is the sudden shaking of the earth's surface, resulting from a sudden release of energy that creates seismic waves. An earthquake is caused by a sudden slip on a fault often suddenly releasing strain that has accumulated over a long period.

Earthquakes can be caused by the physical interaction of tectonic plates (Tectonic Earthquake), volcanic activity (Volcanic Earthquake), nuclear/ chemical explosives (Explosion Earthquake), or the tremors felt in caves and mines due to explosion on the surface (Collapse Earthquake).

The damage dealt by earthquakes is not only by the shaking of the ground, but also by rupture of ground, where the earthquakes cause the surface of the earth to break. Seismic forces also cause liquefaction of the soil, which causes heavy damages to structures on the surface due to overturning, differential settlements, etc. Landslides, fires and tsunamis are also sometimes initiated by earthquakes and these effects are known to bring much destruction to infrastructures. Earthquakes have destroyed countless structures and taken countless lives with them.

During an earthquake, the ground oscillates at frequencies ranging from 0.1 to 30 Hz. Since the foundation of a building is rooted in the ground, the superstructure oscillates with the ground. If the structure does not have a regular configuration, a strong foundation and strong columns, the chances of collapse are high.

This study assesses the earthquake resistant design strategies to maintain the structural integrity of a building during a seismic hazard.

1.2 Structural Walls

Number of damages caused by earthquake in the past resulted in elevated interest related to structural dynamics and analysis. And with some advancement in research, structural wall designs were developed in New Zealand. These elements resist the loads that are applied parallel to the plane of the wall.

Types of Structural walls are RC Structural wall, Plywood Structural wall, Midply Structural wall, RC Hollow Concrete Block Masonry Walls, and Steel Plate Structural wall.

Many studies have assessed the effects of structural walls in resisting seismic loads. Structural walls are usually built-in the high rise buildings to provide additional stiffness and strength.

Since the structural walls are connected to the foundation, like columns, they provide stiffness to the building. When seismic waves propagate to the building from the base, the displacement in the superstructure is reduced due to the structural walls. These structural elements resist the loads parallel to the plane of the wall and if placed at appropriate locations, can help the structure resist highly destructive seismic loads.

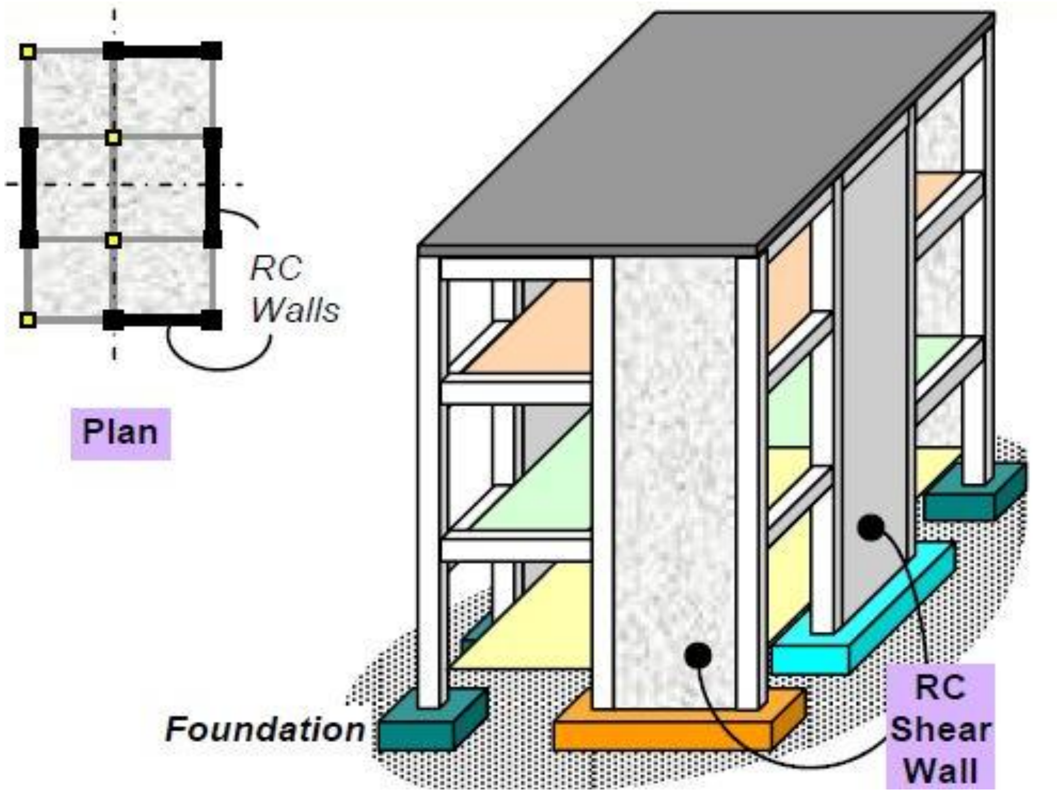

Fig.1 Reinforced Concrete Structural walls

1.3 Energy Consumption in a Building

Home owners rarely take the costs of running a home into consideration. This results in high cost for cooling in summer and heating in winter. By selecting proper materials for the structure, we can save energy over the lifetime of the building. The savings in energy can prove beneficial for the home owners. In olden days, homes were heated by burning wood at very low cost to the home owners. Though wood is very cheap in the unit of money, the price was paid in terms of the health of the occupants as well as that of the ecosystem.However, these days, various building utilities are dependent on electricity, resulting in higher energy consumption, further leading to higher cost of operation.

With the population of the world on the rise, more buildings are constructed to shelter the increasing number of people, and every individual consumes a certain amount of energy. This adds up to increase the total energy consumption of a building.

Around 88% of low voltage consumption was seen to be from the building sectors in Bhutan. And around 52% of the total consumption in the country was thermal energy consumption due to the climate prevalent in the country.(*Bhutan Energy Data Directory 2015*)This verifies that if we can reduce energy consumption of a building, it will be very beneficial to the economy of the country. Energy consumed in a building can be reduced by maximizing the usage of natural sources like sun for heating and wind for cooling.

2. Significance of the Project

Saving energy is becoming a global topic of interest. As a civil engineer, it is our responsibility to help achieve the goal of a greener earth as construction industry contributes the most to global pollution. By making sure that every building saves energy throughout its lifespan, we can save huge amounts of energy, as a whole.

Earthquake has a dark history stained with the lives of many people and therefore, it is a major concern for the structural designers. Structural walls help protect the structure by not allowing the seismic forces to compromise its integrity, saving the lives of its occupants. The construction of buildings keeps getting expensive every year. Hence, as designers and builders, we have to ensure that no weak structures shall come into existence under our supervision.

3. Summary

Earthquake-resistant design is a topic that every civil engineer should know, because earthquakes are unpredictable and therefore, everything in contact with the earth's surface should be designed to withstand appropriate seismic forces. A building should be designed to resist the vibration of the earth's crust mainly to ensure the safety of the residents. Moreover, buildings being a large consumer of energy, it is a necessity to design it for energy efficiency as well.

Bhutan lies in the seismic zones IV and V. Nevertheless, all the buildings are designed for zone V to maximize safety. Although it is a small country, it is seismically very active, because of its geographical location being along the boundary between the Eurasian plate and the Indian plate. Therefore, earthquake-resistant design is of major importance, as the next big disaster could happen anytime. It is necessary for the structures to be properly designed.

Most buildings in Bhutan are not designed for sustainability, due to the lack of proper knowledge and high costs for the special equipments. Energy efficiency is not a commonly practised idea. So far in this project, the basics of energy efficient buildings are understood, and the results show the savings achieved from designing an energy efficient building.

CHAPTER 2

LITERATURE REVIEW

1. General

Energy Efficiency and Sustainable Design are the most important areas that require attention to detail while designing and constructing a structure. These topics are not new in the field of Engineering, as every engineer wants his project to be economic, durable and sustainable.

Now, more than ever, engineers and architects are trying to design energy efficient building and various studies are being conducted on energy models. Previous research show that energy analysis help save considerable amounts of cost throughout a building's lifespan. Theannual energy costs can be minimized by almost 22% during the building life cycle.(*Alothman, Ashour and L. Krishnaraj (2021)*)

This work will look into the effect of parameters like Window Wall Ratio, Roof and Wall Materials, Window Glass Types, Solar Panels and HVAC's on reducing the energy consumption of a building.

2. Structurally Insulated Panels (Sip)

Structurally Insulated Panel is a structural element used for insulation, made by sandwiching rigid insulating foam between two layers of structural boards. They can be used for walls as well as roofs.(*Structural Insulated Panels product guide 2007)*

Fig.2 Structurally Insulated Panel

Providing SIP can save time, labour, money, and produce high-performance green buildings. SIP helps in reducing the cost of homes and can solve housing problems by reducing the cost of construction. Indicating that SIP will be cheaper during construction, and can save energy by its thermal insulating property after construction as well.

3. Window Wall Ratios (WWR)

A study by *Sarah & Meta (2017)* shows that increasing the Window Wall Ratio (WWR) increases the efficiency of the building. Increased window size allows more heat loss, which is optimal for hot places while smaller window size provides better insulation. However, this study was done in Indonesia, which is comparatively hotter and more humid. This means that they do not require much insulation compared to a colder climate like in Thimphu. It is better for cold places to minimize WWR, for better insulation. Hotter places require ventilations, thus the energy efficiency of buildings in warm climate regions is directly proportional to WWR. In this project, we want to hypothesize the opposite, i.e. in cooler climate regions, energy efficiency is inversely proportional to the Window Wall Ratio.

4. Window Shades

Window shades are provided to protect the wooden doors and windows from the rain and also helps reduce the direct glare of the sun. A study by *Tan and Chen(2020),*found that window shades effectively reduce energy consumption used in air conditioning. It reduces the annual air conditioning energy consumption. However, in Bhutan, since the climate is cooler, the effect of window shade is not expected to be vast.

5. Thermal And HVAC System

A report by *Zhao et al.(2015)*found that the energy efficiency of the building's thermal and HVAC systems helped achieve building energy savings. Thermal comfort will definitely help save energy by reducing electric energy usage on heaters and an efficient HVAC system will also provide better thermal comfort with efficient energy usage.

6. Solar Panels

*Hong (2020),*in an article, provides in detail, the processes involved in performing Solar Analysis. The process outlined the design methodology to make a sustainable building by running simulations for energy, heating, cooling, day lighting and solar radiation. In this study, this process is used as a basis for the design of solar panels on the roof and the estimate generation of electric energy from the Solar Panels

7. Structural Walls

Structural walls help resist seismic forces. However, it depends on the type of structural wall, their placement and the seismic force. The study conducted by *J Tarigan(2018)*found that placing structural walls at the core symmetrically provides the best performance in resisting earthquakes. This study provides an insight on the effects of the location of structural walls.

A case study, by *Mukesh(2019)*compares the structural cost of low-rise buildings having moment resisting frames and moment resisting frames with Structural wall for different seismic zones. The study found that structural walls were costly in zone III, but total structural cost of the building did not exceed 10% of the cost of structure having moment resisting frames. For zone IV, it was found to be costly up to 0.79% . And in the most seismically active zones, structural walls proved to be economical over moment resisting frames. A review done by *Resmi (2016),* on the performance of shear walls stated that it is not necessary to build the structural walls up to the whole height of the building. A mid height structural wall is sufficient.

A study performed by *Deepna (2017),* showed that the base shear reduces when the thickness of the plate is reduced. However, reducing the thickness of the structural wall will cause increase in storey drift.

Mohammad (2015), studied the effect of shear wall shapes and placements for RC asymmetric multi-storey buildings, and found that shear walls with Z-shape and T-shape cross-section, placed in the outer frames of the building, provides a reliable seismic behaviour. But the shapes may create some architectural limitations.

8. Hypothesis

Based on the literature review, architectural design of the building is done for energy efficiency. Decreasing the WWR may increase the efficiency while insulated walls and roofs will reduce energy consumption. Solar panels provide a greener and renewable source of energy for the building, insulating window glasses will provide thermal comfort, and an efficient HVAC system will help save money. Structural walls, if placed appropriately, will resist the seismic vibrations.

9. Objectives

Through this project, we intend to:

- Determine the amount of energy savings by conducting the energy analysis in Revit software.
- Conducting the Cost-Benefit analysis i.e., comparing the cost of energy-efficient construction materials in the building with the total energy savings in the building.
- Compare the earthquake-resistance of a structure equipped with structural wall and without a structural wall. Check how much load is reduced off the frames when a structural wall is installed.
- Perform a Cost-Benefit Analysis to check the value and requirement of Structural walls.

10. Methodology

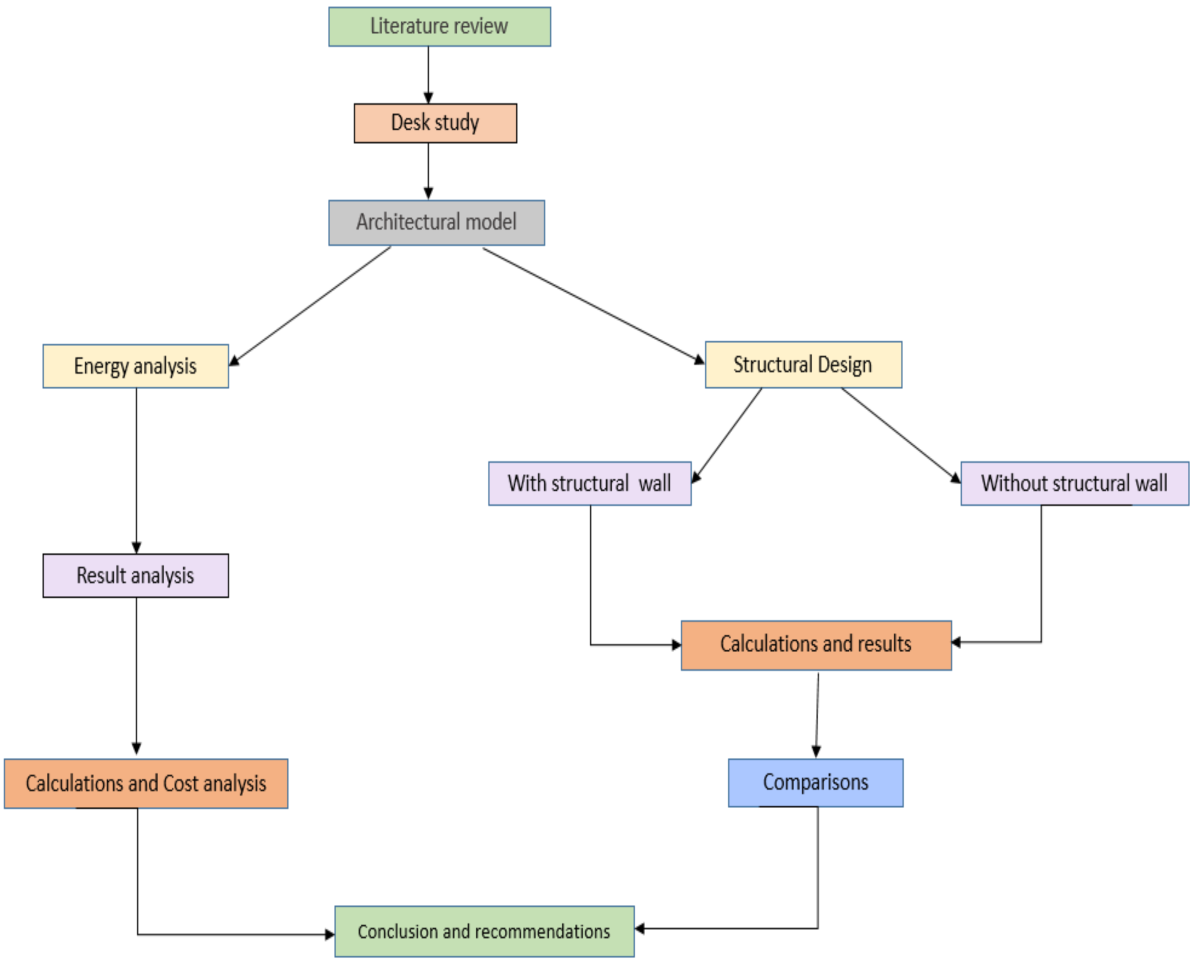

Fig.3 Methodology

In the first phase of our project, an architectural model of an under-construction structure is obtained. It is designed and modelled in Revit and an energy analysis is performed on the structure. Parameters such as window sizes, window shade sizes, materials used and building orientations are modified to obtain an energy efficient structure. Further, the solar analysis is conducted to obtain the estimates for the amount of energy generated if the roofs are fitted with solar panels. We assessed the building by modelling three types of solar panels and found the estimates for each when the roof is covered 100% and 50% . Most of these extra equipment and materials which can help insulate the building and lower energy usage add to the total cost of the building. To check the cost fluctuations, an estimate for the cost of each most efficient material is done and compared with the actual material used in the construction of the structure. Based on the energy optimization and cost benefit analysis of the construction materials, the plans of the building are finalized.

The second phase of this project will be structural design. The architectural building drawings will be structurally modelled in STAAD Pro after which the structural design of the beams and columns will be conducted. The load combinations of live load, dead load and seismic load will be applied on the structural frame as per IS 875 (live load and dead load) and IS 1893(earthquake load) for the design. After the initial design, the deflection, shear force, and bending moment will be obtained from the structural analysis. Further, the same procedure is repeated after addition of structural walls at appropriate locations with the application of same load as previous model. The changes in reinforcements, further the deflection, shear force and bending moment are obtained from the software. After the analysis of both the frames, the results will be compared to assess the effectiveness of structural walls in earthquake-resistant design. Furthermore, a cost-benefit analysis will also be performed to draw our final conclusions and provide design recommendations.

CHAPTER 3

ARCHITECTURAL AND ENERGY EFFICIENT BUILDING DESIGN

1. Site Location

Fig.4 Satellite Map of the Site

The site of our project is at a place called Namselling, which is located at about 8 kilometres from the capital city, Thimphu. It is a 300 m drive from the nearest highway diversion. It lies at an altitude of 2300 metres. The average temperature is 6.3^{0}C in winter and 20^{0}C in summer. Snowfalls are likely in winter. The annual average daily sunshine duration is 7.1 hours. These data clearly shows that it is generally cold at the location of the site.

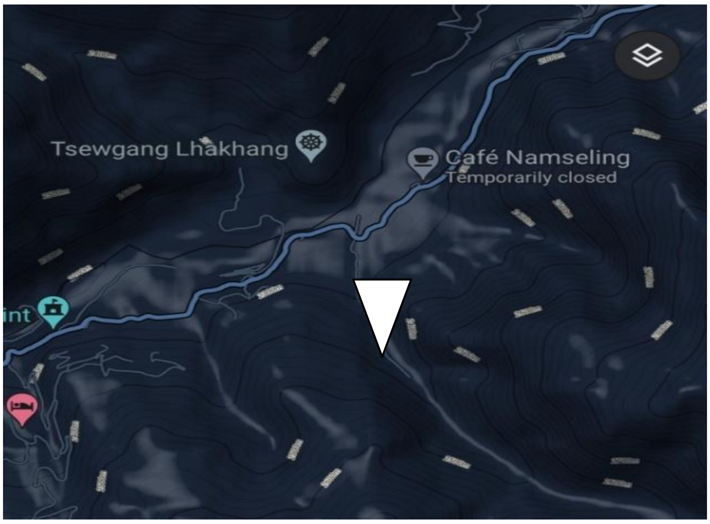

Fig.5 Topography of Project Location

The building is connected with roads which lead from the highway, right to the doorstep. All necessities can be bought from a market at the junction of the highway. There is a stream running right across the road. There is constant water supply and electric connections are also established with minimal inconveniences. The views visible for the occupants are rich paddy fields and a wide valley at the base of mighty mountains from the north and lush green cypress laden hills from the south.

2. Architectural Model

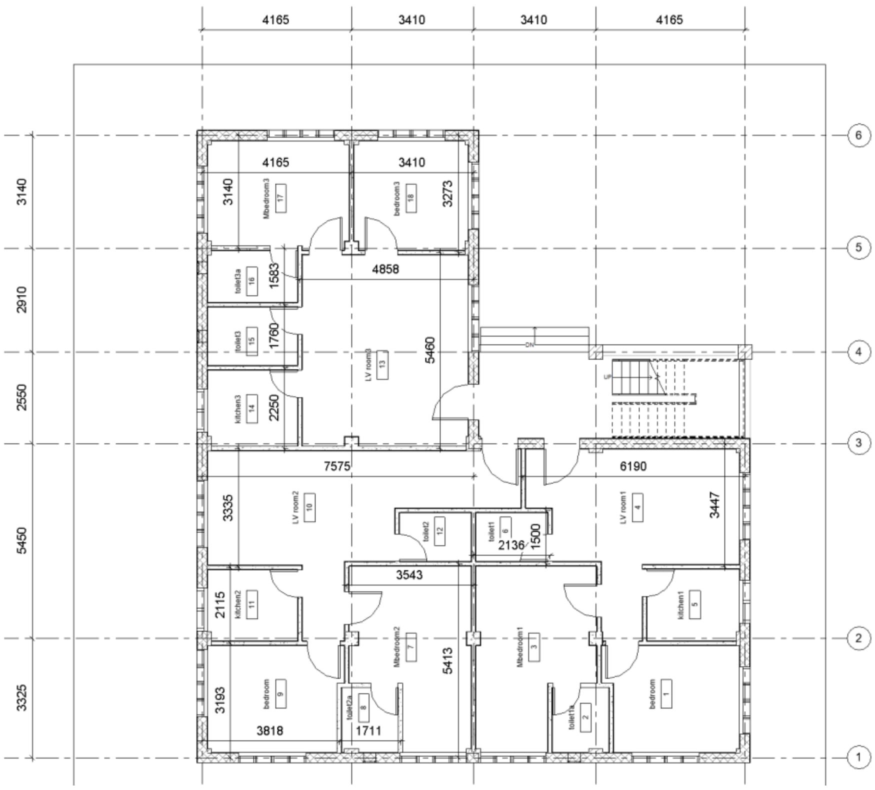

Fig.6 Floor Plan

Each floor accommodates 3 apartments. Each apartment has a living room, a kitchen, 2 washrooms, and 2 bedrooms. The floor plan in figure 6 shows the arrangement of the ground floor, first floor and the second floor. The third floor is used as as water tank storage.

Fig.7 South Elevation

Fig.8 West Elevation

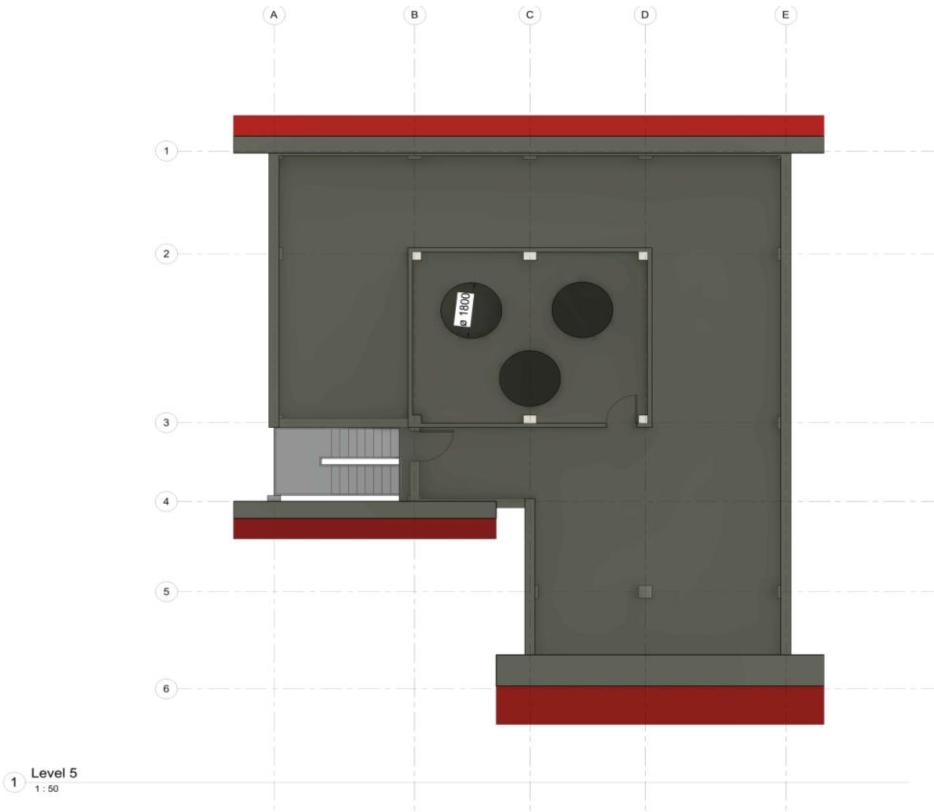

Fig.9 Roof Floor Plan

For architectural designs to be approved in Bhutan, the building must have at least one Bhutanese traditional design. This is why the windows in the model are large and shaped uniquely in accordance with the Bhutanese architectural design requirements. The building is aesthetically pleasing due to the vibrant contrast of white-washed walls and dark polished wooden frames.

Each apartment will be equipped with a fire extinguisher behind the main entrance doors for emergency purposes.

The third floor will be used to accommodate three 1000 Litre water storage tanks.

3. Energy Analysis

Using the initial plans of the building, we have conducted the energy analysis in the Revit software. To perform the energy analysis, the location of the structure is specified along with the location of the closest weather station. Furthermore, all the rooms are allocated in the architectural model. From the energy analysis, this project focuses on the parameters such as building orientation, operating schedule, window wall ratio, window glass material, roof and wall materials, HVAC systems, and solar panel installations, to optimize the energy generation and consumption of the building.

3.1 Building Orientation

From the energy analysis, the results showed that a rotation of 90^0 or 270^0 clockwise was the most efficient, with costs of -1.4 USD/m^2/year and -1.47 USD/m^2/year.
Taking this data into account, the whole model was rotated 270^0 clockwise and the energy model was updated and analyzed again.

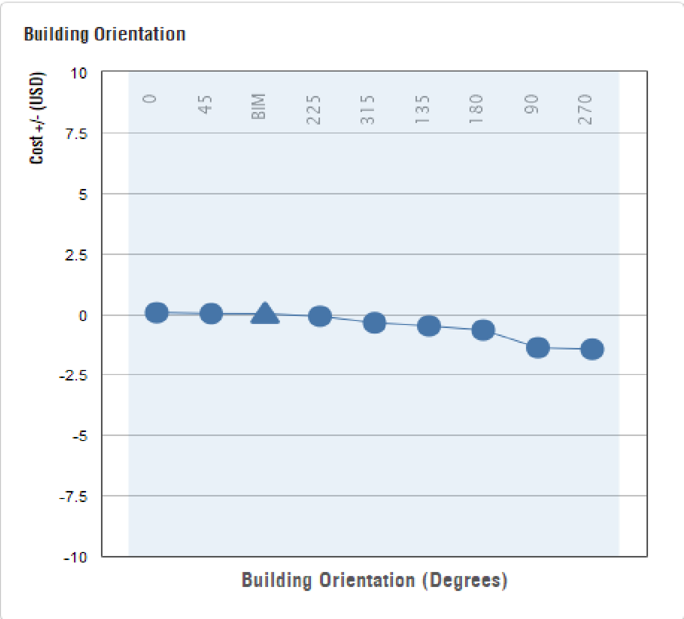

Fig.10 Building Orientation Results

3.2 Operating Schedule

The operating schedule results tell us about how much energy can be saved when the structure is not occupied and therefore, energy left unused. However, our model being a residential one, we had to consider it as occupied 24/7.

Table.1 Operating Schedule

Sl.no	Schedule	Cost(USD/m^2/year)
1	24/7	1.91
2	12/7	-4.30
3	12/6	-5.81
4	12/5	-6.83

3.3 Window Wall Ratio (WWR)

The ratio of total sizes of windows to the total size of the wall will also influence energy usage, as windows do not provide the insulation which can be provided by comparatively thick walls although they allow sunlight to pass through.

Revit provides the cost that can be saved per meter square per year according to the WWR for each faces of the wall, namely East, West, North and South.

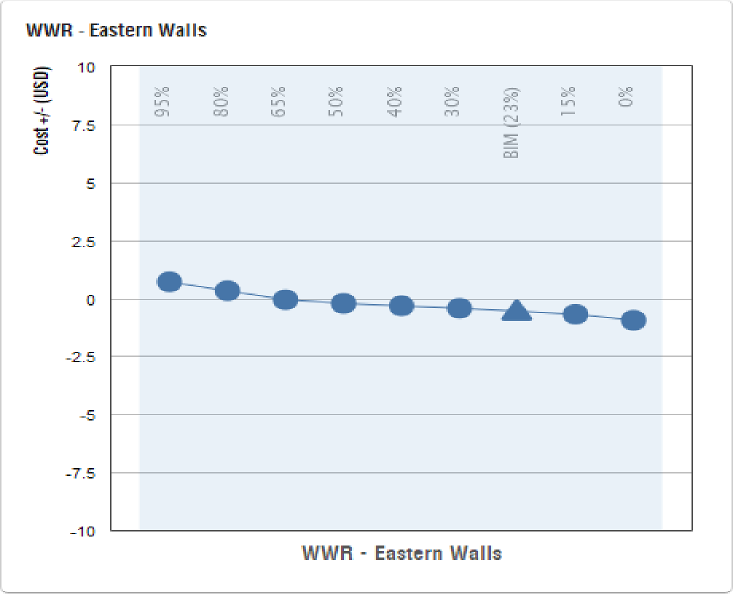

Fig .11 WWR- Eastern Walls

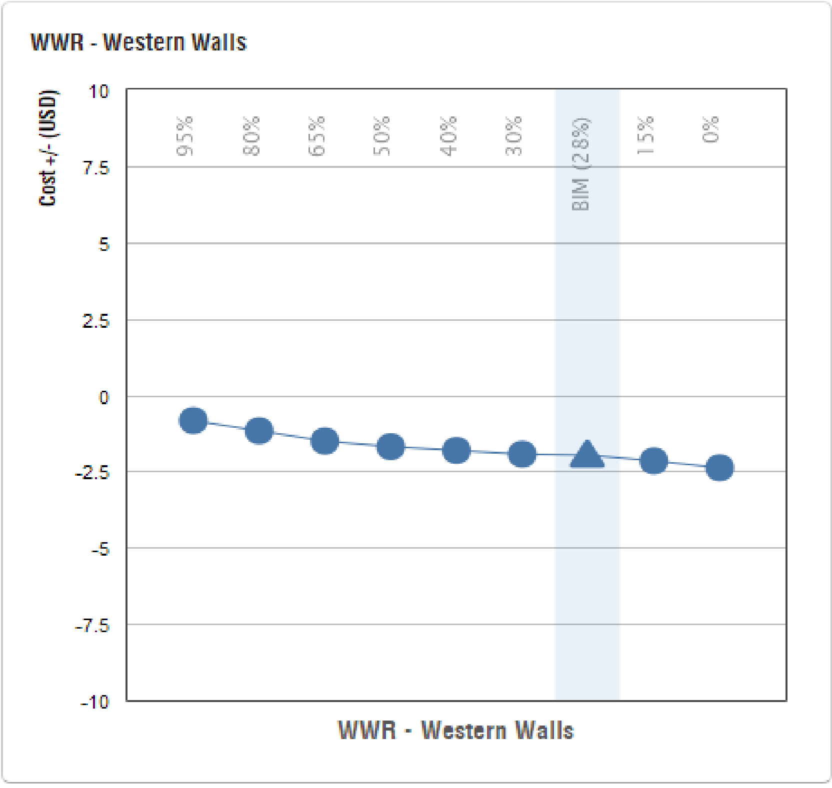

Fig.12 WWR-Western Walls

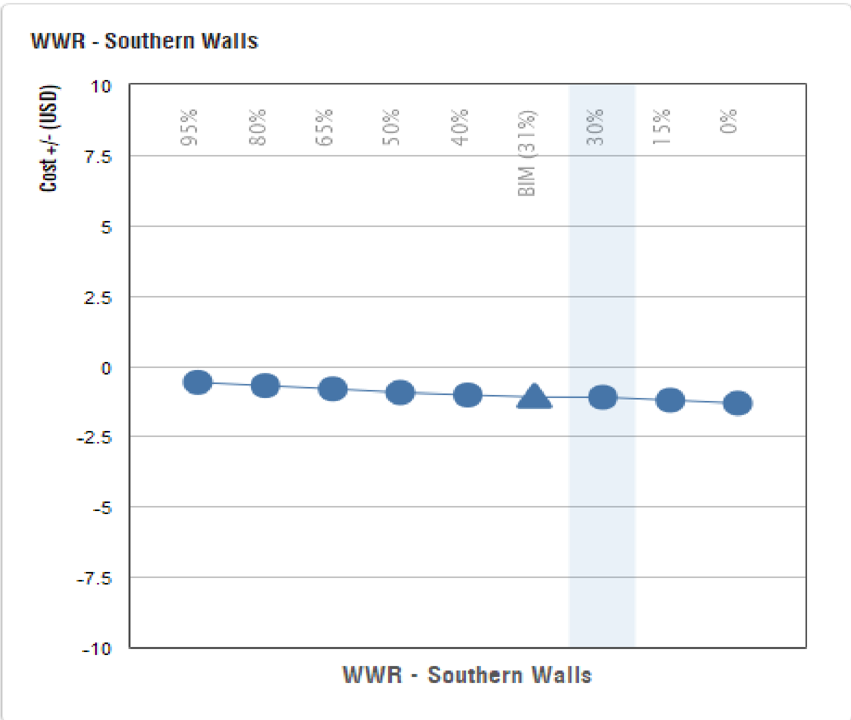

Fig.13 WWR-Southern Walls

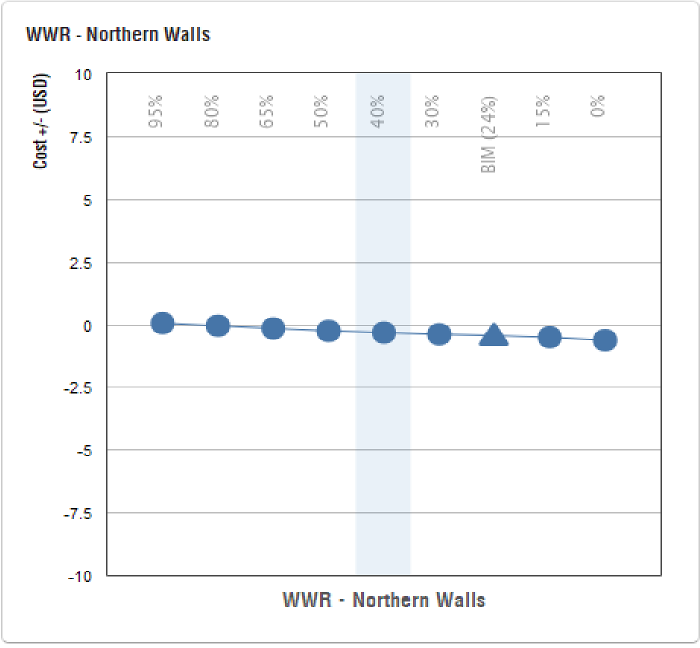

Fig.14 WWR- Northern Walls

Table.2 WWR results

Sl. No	Face	WWR	Cost (USD/m^2/year)
1	East	23	-0.56
		15	-0.69
2	West	28	-1.97
		15	-2.17
3	North	24	-0.45
		15	-0.52
4	South	31	-1.11
		15	-1.12

It is clearly visible from the data provided that the size of windows is inversely proportional to efficiency. The data from the weather station suggested that the location of project is in a cold place, so the energy analysis results suggest minimizing the window sizes, to reduce heat loss through the glasses of the windows.

3.4 Window Shades

Window shades are elements which project out of the wall just above the door and windows to prevent the entry of rain and also the direct glare of the sun when looking out. The energy analysis also provides us the cost reduction in the presence of different lengths of window shades.

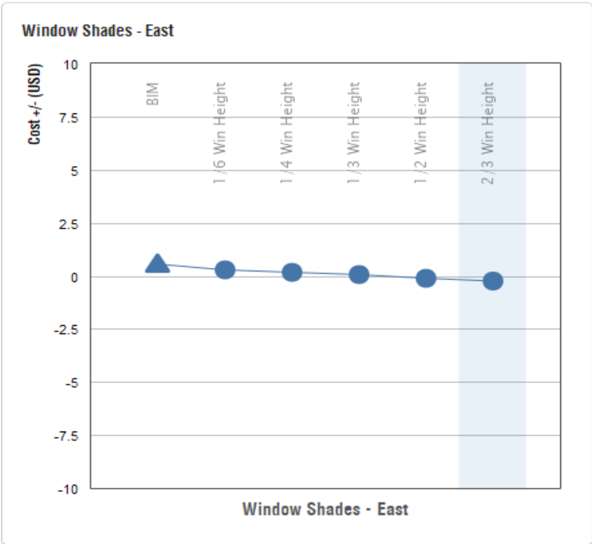

Fig.15 Window shades- East

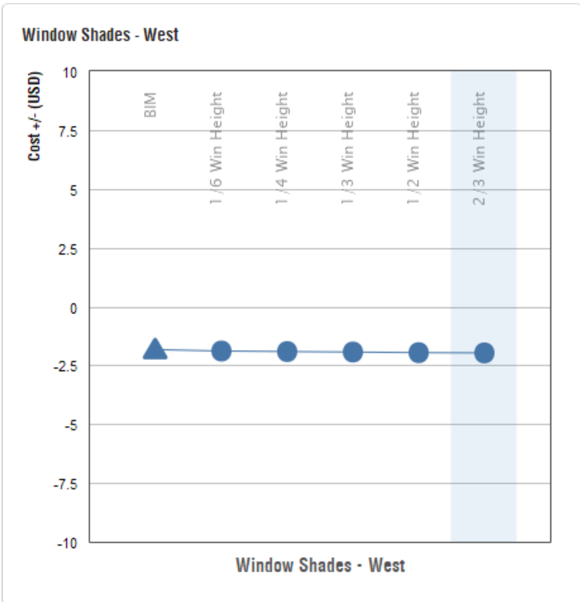

Fig.16 Window Shades- West

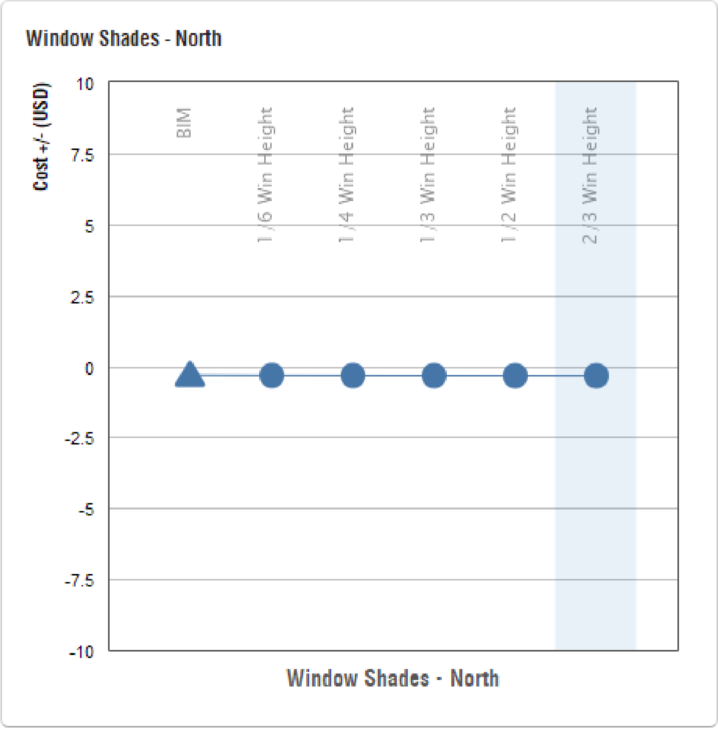

Fig.17 Window Shades- North

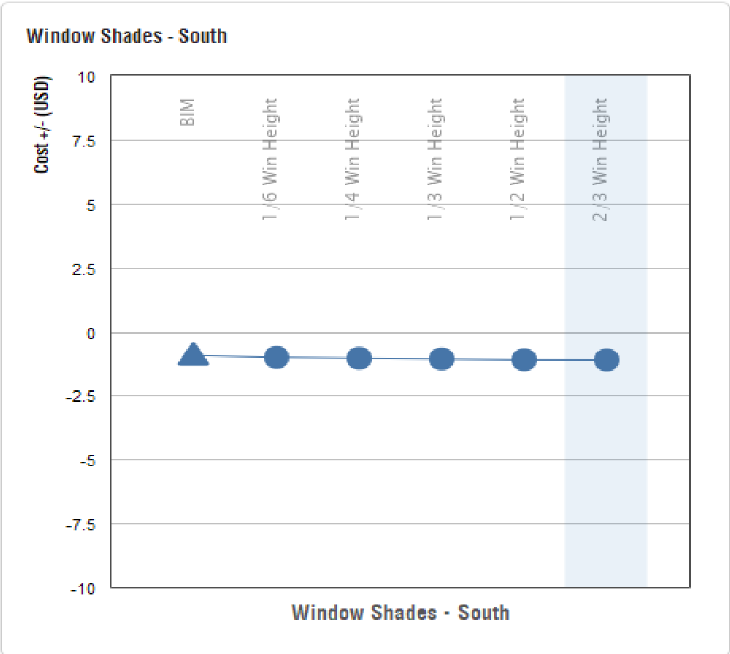

Fig.18 Window Shades- South

Table.3 Window shade results

Sl. No	Face	Shade Length/Window Height	Cost (USD/m^2/year)
1	East	0	0.55
		2/3	-0.25
2	West	0	-1.83
		2/3	-1.97
3	North	0	-0.32
		2/3	-0.34
4	South	0	-0.93
		2/3	-1.11

It is evident with these graphs that window shades help save very little amount. This is again because of the climate of the place, being very cold, sunlight is an indispensable asset. And window shades will not only block the glare of the sun, but also its heat with it.

3.5 Window Glass

The glasses that are fitted into the windows are available in many types. Some can contain the heat in a room and some are very bad heat insulator. This is based on their U-Value. U-Value is the Insulating performance of a glass. Lower the U value, higher the insulating property. Therefore, in a cold climate, glasses with lower U-Values are preferred. Single pane clear glass has a U-Value of about 1, which is high compared to the other types like Double Clear (0.48), Double LoE(Low Emissivity) (0.36) and Triple LoE (0.18). *Modernize (2021).*
LoE are Low emissivity glasses which does a better job at keeping the rooms warmer at night than single and double pane windows. The results obtained are as follows;

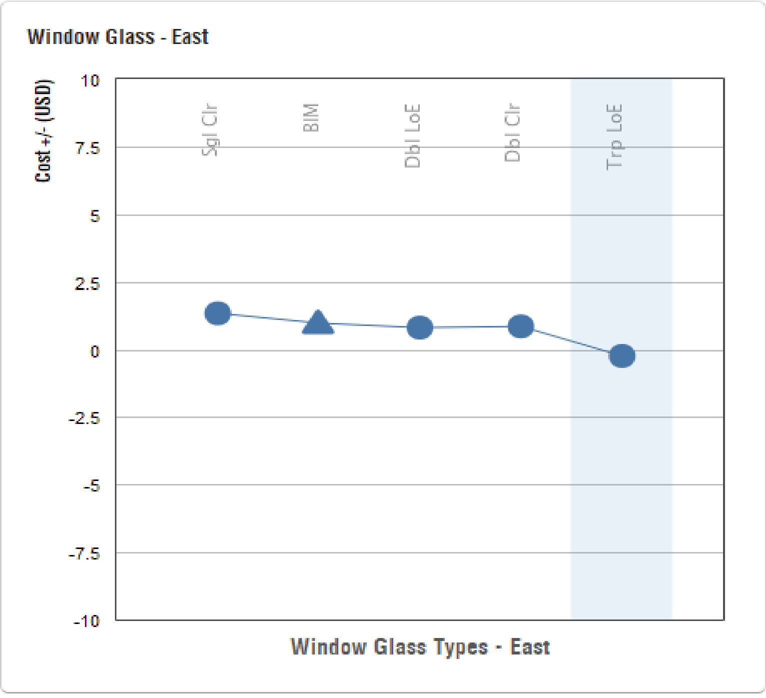

Fig.19 Window Glass Types- East

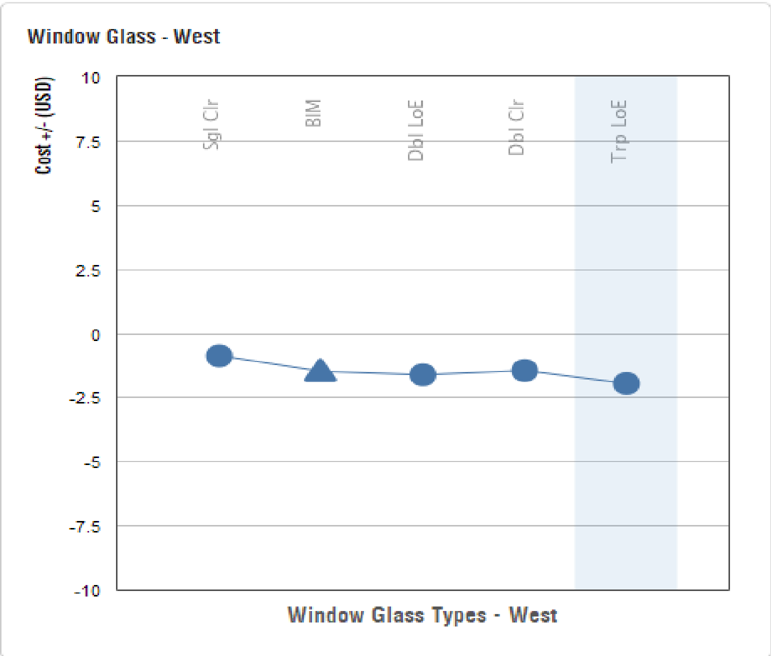

Fig.20 Window Glass Types- West

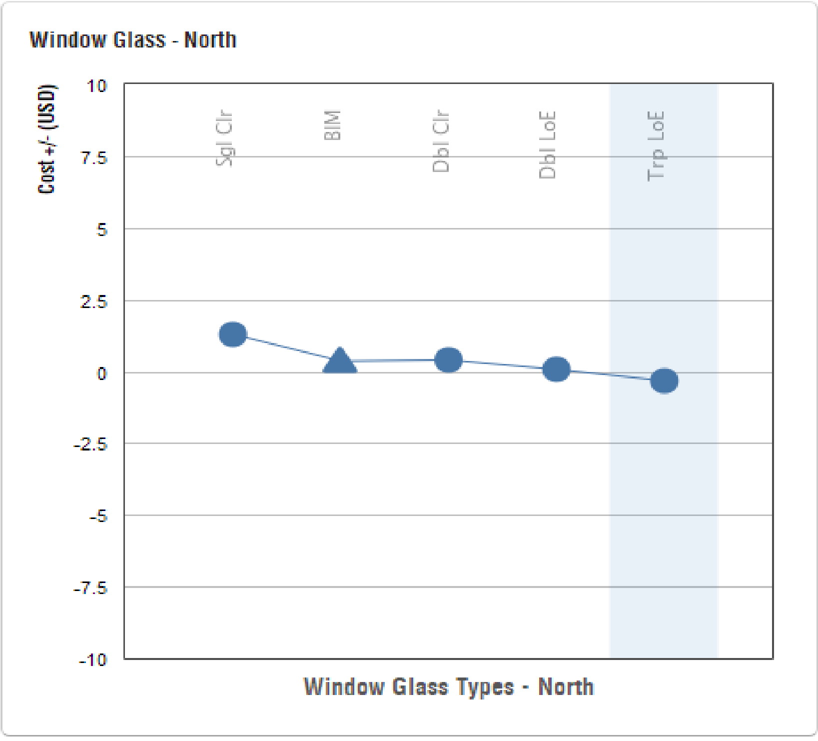

Fig.21 Window Glass Type- North

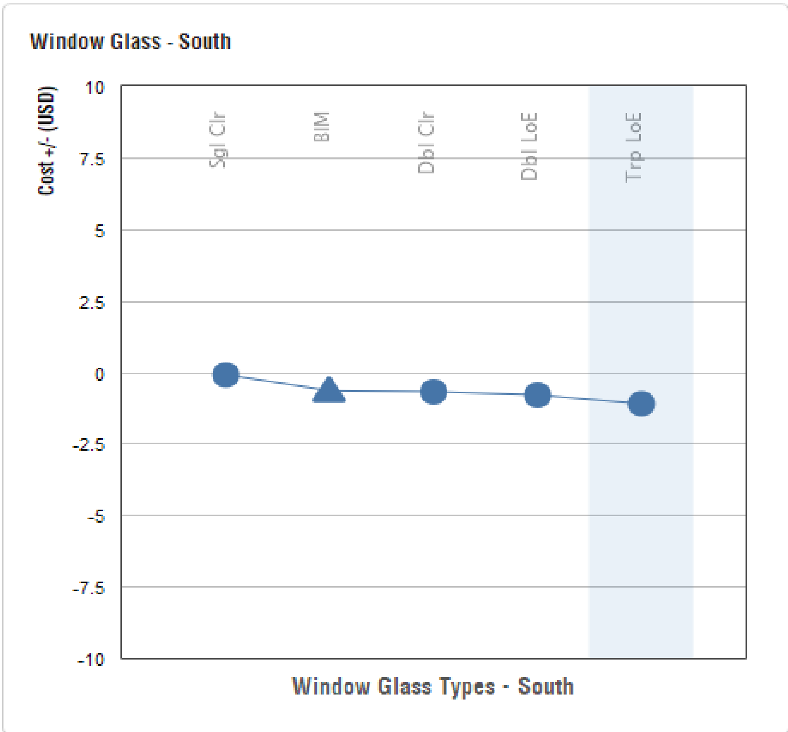

Fig.22 Window Glass Types- South.

Table.4 Glass Type results

Sl. No	Face	Glass Type	Cost (USD/m^2/year)
1	East	Single Clear	1.33
		Triple LoE	-0.25
2	West	Single Clear	-0.90
		Triple LoE	-1.97
3	North	Single Clear	1.28
		Triple LoE	-0.34
4	South	Single Clear	-0.11
		Triple LoE	-1.11

These results confirm that the type of glasses used for windows will help us save some amount by reducing electric heater usage times. Although they help in insulation, they cost more than the regular single pane glasses. This cost analysis will be done in the later part of this project.

3.6 Roof and Wall Construction

Insulation can also be done for the roofs and the walls. Instead of regular metal sheet roofs, and concrete walls we can provide different materials having different thermal resistivity (R-Value). Higher the R-Value, better the material insulates. We can also use Structural insulated panels (SIP), which a roof is made of two boards, with rigid insulating foam in between them, or Insulating Concrete Foam (ICF).

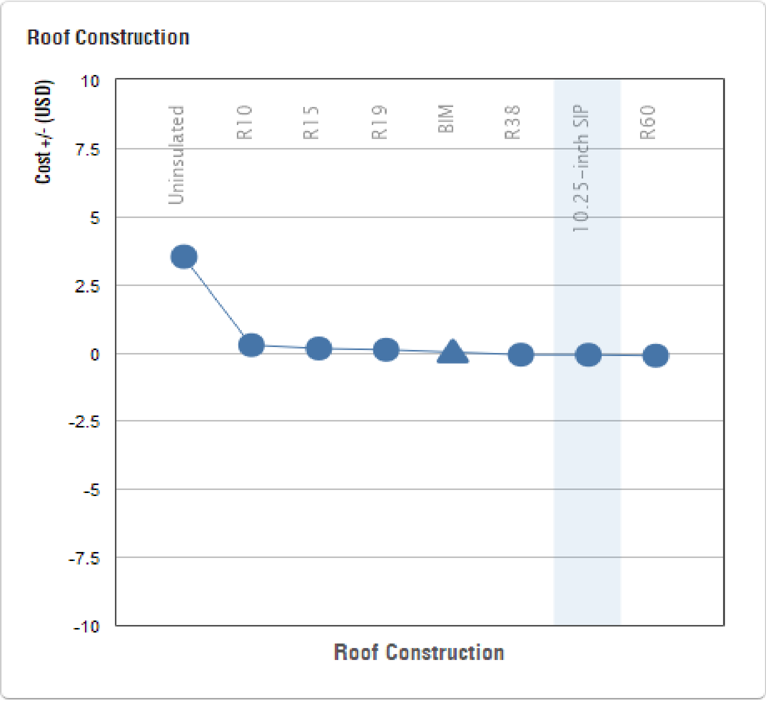

Fig.23 Roof Construction

Table.5 Energy saving/Consumption based on Resistivity of Roof Materials

Sl. No	Roof Material	Cost (USD/m^2/year)
1	Uninsulated	3.5
2	R 10	0.37
3	R 15	0.14
4	R 19	0.09
5	R 38	-0.09
6	(R 35) 10.25-inch SIP	-0.10
7	R 60	-0.13

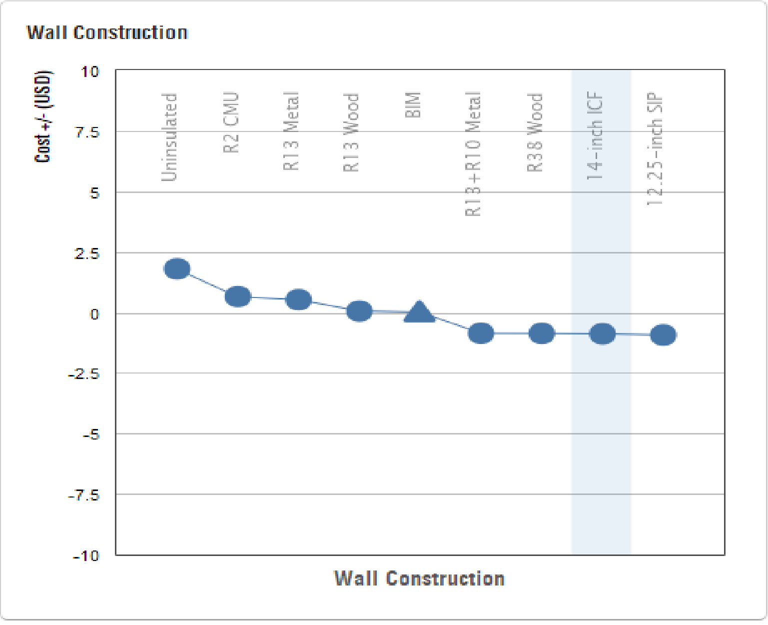

Fig.24 Wall Construction

Table.6 Wall Materials

Sl. No	Wall Material	Cost (USD/m^2/year)
1	Uninsulated	1.79
2	R2 CMU	0.65
3	R13 Metal	0.52
4	R 13 Wood	0.05
5	R 13+ R 10 Metal	-0.87
6	R 38 Wood	-0.87
7	14-inch ICF	-0.89
8	12.25-inch SIP	-0.94

3.7 HVAC (Heating, Ventilation, and Air Conditioning)

Heating, Ventilation, and Air Conditioning (HVAC) is an essential aspect of energy model because of the role it plays for heating when it is cold and cooling when it is hot. Energy Analysis is mainly based on thermal comfort, trying to maximize the utilization of natural heat sources and minimizing energy usage. However, HVAC systems also need energy to serve its purpose of transferring warmer outdoor air into the living spaces in winter and reverse in summer. And different types of HVAC systems require different amounts of energy to function. Based on this, the cost is as follows;

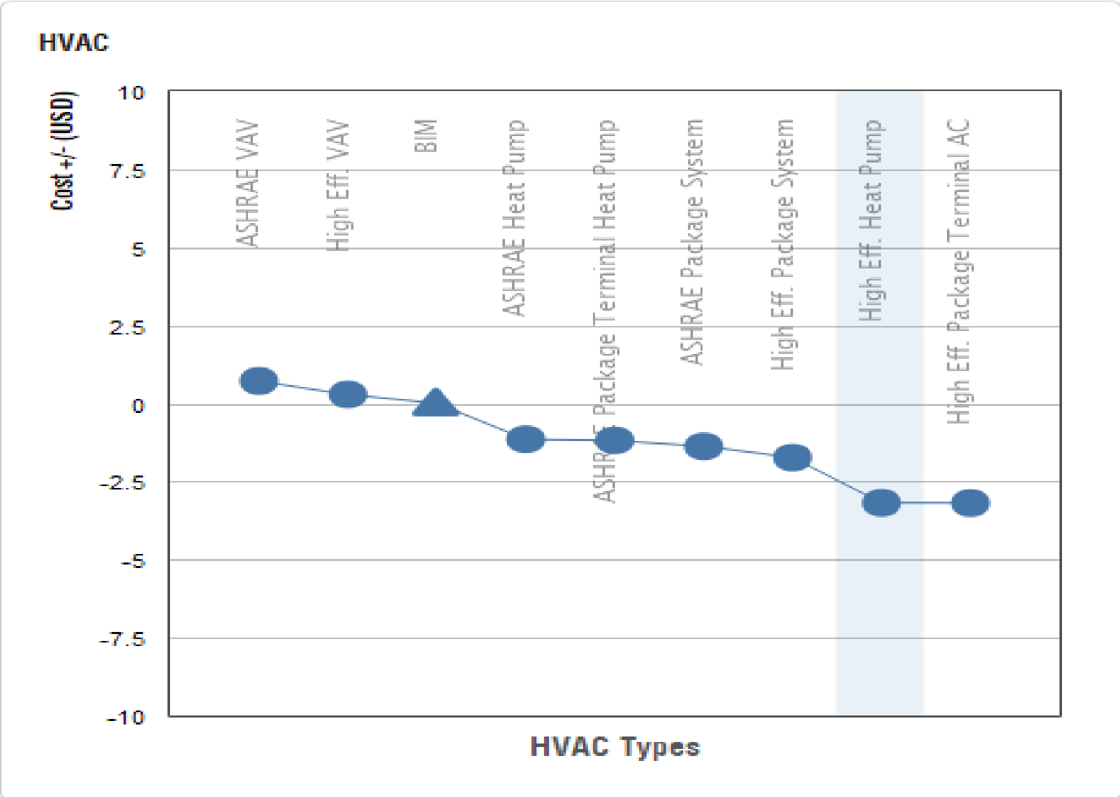

Fig.25 HVAC Types

Table.7 HVAC Types

Sl. No	HVAC types	Cost (USD/m^2/year)
1	ASHRAE VAV	0.72
2	High Efficiency VAV	0.28
3	ASHRAE Heat Pump	-1.15
4	ASHRAE Package Terminal Heat Pump	-1.18
5	ASHRAE Package System	-1.38
6	High Efficiency Package System	-1.74
7	High Efficiency Heat Pump	-3.19
8	High Efficiency Package Terminal AC	-3.19

3.8 Solar Analysis

From the energy analysis, the electricity generation from Photovoltaic (PV) Solar Panels placed on the roof of the building is also calculated. Three different panels are assessed, namely:

- A polycrystalline solar panel with an efficiency of 16% and costs $2.86 per installed watt.
- A polycrystalline solar panel with an efficiency of 18.6% and costs $3.06 per installed watt.
- A monocrystalline solar panel that has an efficiency of 20.4% that costs $3.47 per installed watt.

Monocrystalline solar panels are more efficient because it is made of single pure silicon crystal. However, they cost more because of the wastage in their production, caused by cutting these crystals into several sheets to make one cell.

Polycrystalline solar panels, on the other hand, cost less but they are not as efficient as the monocrystalline types.

Furthermore, the coverage area of roof for each type of solar panel is also changed between 50% and 100% to assess the overall saving in the cost of electricity for the building. The cost per kWh in Bhutan is $0.05.(*Electricity Tariff 2020*) The average household electricity consumption in Thimphu is about 4,500 kWh per year. (*Luv and Boonrod 2018*) The building in interest accommodates 9 households, 3 on each floor. The total energy consumption of a year is estimated to be around 40,500 kWh per year. This costs the residents a total of about Rs.150,000 per year and about Rs.17,000 per household per year.

Table.8 Solar Analysis Results

Sl. No	Panel Type	Coverage	Electricity Generation(kWh/year)
1	16% $2.86/installed watt	50%	42604
		100%	72780
2	18.6% $3.06/installed watt	50%	49527
		100%	84173
3	20.4% $3.47/installed watt	50%	54320
		100%	91258

3.9 Cost Estimations

Table.9 Cost-Benefit analysis for energy efficiency of the building

Sl. No	Parameter change	Increase in Construction Cost(Rs)	Savings (Rs/year)	Maintenance cost (Rs/year)
1	Window wall ratio lowered to 15%	-	18,600/-	-
2	Window shade of 2/3 window height	-	51,684/-	-
3	Triple pane LoE window glasses	3,681,000/-	230,000/-	-
4	10.25-inch SIP roof installed	-75,000/-	164,576/-	-
5	12.25-inch SIP wall	-15,790/-	123,769/-	-
6	High Efficiency Heat Pump installed	150,000/-	141,630/-	15,000/-
7	18kW monocrystalline solar panels (50%)	4,684,500/-	203,700/-	-

In the next 5 years of the completion of this project, the total cost that can be saved, is around Rs. 4,760,585 and the total extra cost incurred is around Rs. 8,515,500.

In the first 10 years in the lifespan of this building, it will have saved Rs. 9,339,590.

The extra expenditure spent on the building will be covered within the first 10 years and assuming the lifespan of the structure to be 65 years, there is still 55 years worth of saving to be done (about Rs. 1,000,000 annually).

CHAPTER 4

EARTHQUAKE RESISTANT DESIGN

1. Introduction

Earthquake is the sudden shaking of the earth's surface, resulting from a sudden release of energy due to the fracture at a fault plane. The seismic waves travel from the source to the ground through earth's crust to dissipate the released energy. An earthquake is caused by a sudden slip on a fault plane as the strain, in the rock near the fault, accumulated over a long period exceeds the strength of the rock.

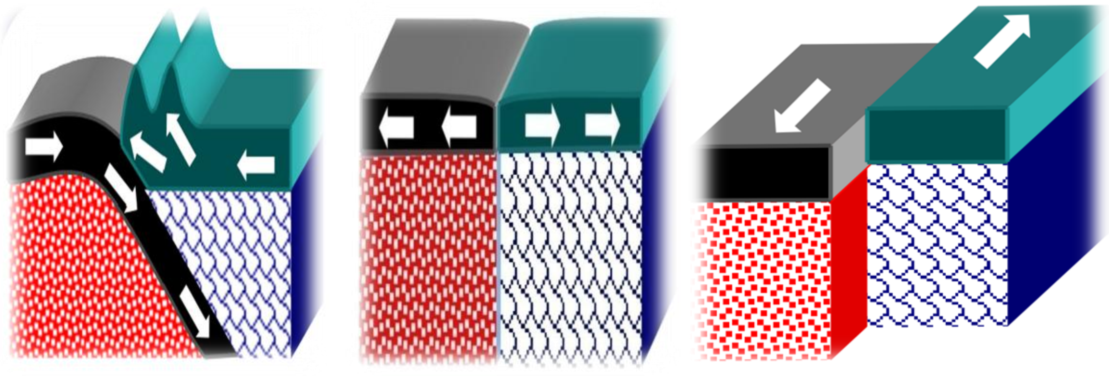

Fig.26 Types of Plate Interactions

The damage dealt by earthquakes is not only by the shaking of the ground, but sometimes by rupture of the ground as well, where the earthquakes cause the surface of the earth to break. Seismic forces may also cause liquefaction of the soil, which causes heavy damages to structures on the surface due to overturning, differential settlements, etc. Landslides, fires and tsunamis are also sometimes initiated by earthquakes and these effects are known to bring much destruction to infrastructures. Earthquakes have destroyed countless structures and taken countless lives with them.

During an earthquake, the ground oscillates at frequencies ranging from 0.1 to 30 Hz. Since the foundation of a building is rooted in the ground, the superstructure oscillates with the ground. If the structure does not have a regular configuration, a strong foundation and strong columns, the chances of collapse are high. This study assesses the earthquake resistant design strategies to maintain the structural integrity of a building during a seismic hazard.

a) Rupture of Earth's Surface

b) Liquefaction

c) Differential Settlement

d) Damage by Tsunami

Fig.27 Damage Done by Earthquake

2. Basics of Structural Dynamics

Newton's first law states that a body in motion will stay in motion and a body at rest will stay at rest unless acted on by an outside force and this is called an inertia.

When it comes to buildings in an earthquake, the law of inertia is crucial. A building can be viewed as a massive mass that, according to the law of inertia, prefers to remain at rest and remain motionless unless pushed upon by an external force. Because of inertia, the bottom elements of the building move while the higher parts of the building remain stationary during an earthquake. This is referred to as inertial force. This puts a lot of stress on the parts that make up the building.

The Newton's LawsofMotionarecrucial in evaluating the behavior of a structure subjected to a ground motion. A building can be viewed as a massive mass that, according to the law of inertia, prefers to remain at rest and remain motionless unless pushed upon by an external force. Due to the ground motion caused by an earthquake, the base of building moves with the ground while the superstructure, due to inertia, opposes the movement leading to deflection of columns. The structure opposes the movement by Inertial Force and tries to return to the original position.

The motion of the structure is opposed by the following forces:

- Inertial Force (caused by the mass of the structure)
- Damping Force (due to internal resistance of the building material)
- Static Force (due to the stiffness of the lateral force resisting elements such as columns, structural walls, etc.)

3. Response and Design Spectrum

When an earthquake originates from a fault, the seismic waves propagate from the fault to the site of interest. When these seismic waves reach the earth's surface, they cause ground motions. The motion of the ground is represented in terms of its displacement, velocity or acceleration.

To understand the effect of ground motions on a structure, ground motion response spectrum (GMRS) is calculated. GMRS is a relationship between the natural period of vibration of a single degree of freedom (SDOF) system and the maximum absolute acceleration that the SDOF experiences due to the ground motion. GMRS is different for different ground motions.

As the earthquakes and hence, the ground motions are random, a structure cannot be designed based on GMRS obtained from one ground motion. At a site, a suite of GMRS are generated from different recorded motions to generate a Design Spectrum. Hence, a Design Spectrum is defined as the envelope of multiple GMRS. The value at each natural period/frequency is evaluated by calculation mean plus one standard deviation of values at same period from all GMRS.

Since calculating design spectrum at every site is not possible due to unavailability of data, design spectrum in this project is calculated from Indian Code, IS 1893:2016(Criteria for Earthquake Resistant Design of Structures)

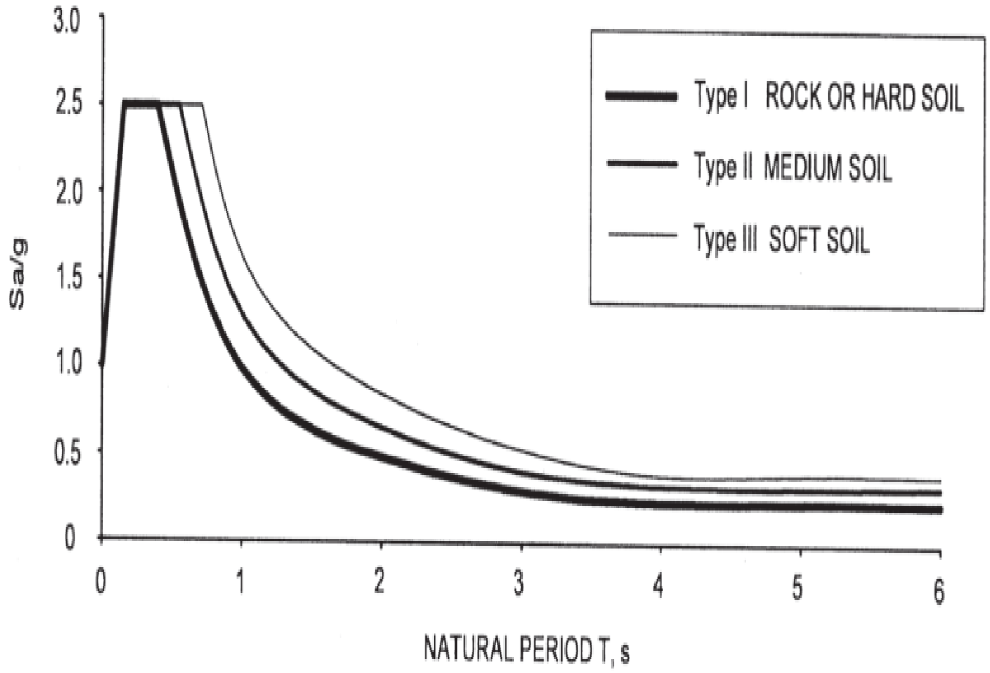

Fig.28 Design Spectrum for different types of soil(IS 1893 clause 6.4.3)

4. Loading

4.1. Calculation of Design Spectrum and Lateral Load from IS 1893

According to IS 1893, clause 7.2.1, the design lateral force is calculated as,

$$v_B = A_h \times W \quad \textbf{(i)}$$

Where;

A_h is the design horizontal acceleration coefficient.

W is the seismic weight of the structure

The design horizontal acceleration coefficient can be calculated as per IS 1893, clause 6.4.2;

$$\mathbf{A_h} = \frac{\left(\frac{\mathbf{Z}}{\mathbf{2}}\right)\left(\frac{\mathbf{S_a}}{\mathbf{g}}\right)}{\left(\frac{\mathbf{R}}{\mathbf{I}}\right)} \qquad \text{(ii)}$$

For our building, we selected the zone factor, ***Z*** as0.36 because the zone of interest falls in seismic zone ***V***.The building type is a reinforced concrete (RC) Special Moment Resisting Frame, hence, the reduction factor, ***R*** is '5'. Finally, the structure is a residential building, thus the importance factor, ***I***is taken as 1.2. The last factor, $\frac{S_a}{g}$, depends on the soil type at the site.

The soil at the site is medium stiff, so according to IS 1893,clause 6.4.2;

$S_a/g=$ 1+15T T<0.1s

$S_a/g=$ 2.5 0.1<T<0.55s

$S_a/g=$ 1.36/T 0.55<T<4s

$S_a/g=$ 0.34 T>4s

Time Period (T) for RC infill structures according to clause 7.6.2 is

$$T = \frac{0.09h}{\sqrt{d}} \qquad \textbf{(iii)}$$

Where ***h*** is 11.45m, the height of the building. And ***d*** is the length of the building and is split into d_x and d_z, the length of building in x and z directions respectively. The building is 15.15m in x direction and 17.375m in z direction.

We get T= 0.25s

Therefore, S_a/g= 2.5

The final value of A_h= 0.108

W is the seismic weight of the building. The seismic weight includes all the live loads and appropriate percentages of live loads.

4.1.1 Dead Loads

Dead load is self-weight of beams, columns, slabs and the weight of walls.

Table.10 Self-Weight of Beams, Columns and Slabs

Weights	Thickness(m)	Width (m)	Length (m)	Volume (m^3)	Unit weight (kN/m^3)	Total weight (kN)
Self-weight of beams (4 floors)	0.4	0.3	141.85	17.002	25	1702.2
Self-weight of columns (22 columns)	0.3	0.3	11.45	1.0305	25	592.54
Self-weight of slabs (4 floors)	0.15	-	-	29.7	25	2970

Table.11 Weight of Walls

Walls	Thickness (m)	Height (m)	Length (m)	Number of floors	Unit weight (kN/m^3)	Total weight (kN)
External walls	0.3	3	65	3	6	1053
Partitions walls	0.135	3	80	3	6	582
Roof partition walls	0.135	3	24.5	1	6	59.5
Roof exterior wall	0.3	1.5	64.87	1	6	116.77

4.1.2 Live Load.

According to IS 1893, clause 7.3.2, for the seismic weight of the building, 25% of the imposed load is taken for Live loads up to 3kN/m^2 and 50% is taken for imposed loads above 3kN/m^2. Therefore, the imposed load on the structure is as given below;

Table.12 Live Loads For Seismic Weight Of The Building

Description	Load (kN/m^2)	Percentage imposed	Floor area (m^2)	Number of floors	Total load (kN)
Floor load	2	25%	173.5	3	206.25
Stairs and corridors	3	50%	19.32	3	28.98
Water tank load	20	50%	37.17	1	371.7

The seismic weight of the building is obtained by adding all the above values (dead loads and live loads), which gives;

W = 7794.83 kN.

And V_B= A_h x W

So, V_B= 0.108 x 7794.83

V_B= 841.84 kN

To find the lateral forces on each floor, the following table is made;

Table.13 Lateral Forces on Each Floor

Storey	W_i (kN)	h_i (m)	$W_i h_i^2$	k_i	$Q_i = k_i \times V_B$	
					X	Z
Roof	1879	11.45	246341.6	0.55	463.01	463.01
Second	1991.8	8.3	137215.1	0.308	259.3	259.3
First	1991.8	5.15	52827.5	0.12	101.02	101.02
Ground	1991.8	2	7967.2	0.018	15.15	15.15
		$\sum W_i h_i^2$	444351.4			

Where W_i is the seismic weight of each floor and h_i is the height of each floor from the foundation.

$$K_i = \frac{w_i \times h_i^2}{\sum w_i \times h_i^2} \tag{iv}$$

The results generated by STAAD.Pro are as follows;

W= 7560.33

A_h= 0.108

V_B= 0.108 x 7560.33 **= 816.52**

Table 14 Lateral Forces Generated by STAAD.

Storey	h_i (m)	$Q_i = k_i \times V_B$	
		X	Z
Roof	11.45	429.294	429.294
Second	8.3	268.334	268.334
First	5.15	103.308	103.308
Ground	2	15.58	15.58

The calculated and computer-generated results match closely.

When shear walls are constructed, the design base shear and lateral forces on each floor are as follows;

S_a/g = 0.108

W= 10644.63

V_B= 0.108 x 10644.63 = 1149.62 kN

Table 15 Lateral Forces For Structure With Structural Wall

Storey	h_i (m)	$Q_i = k_i \times V_B$	
		X	Z
Roof	11.45	588.015	588.015
Second	8.3	352.595	352.595
First	5.15	136.659	136.659
Ground	2	20.433	20.433

4.1.3 Dead Loads

Floor loads= weight of floor + weight of partition walls

= ((thickness x unit weight) + 2kN/m^2 floor finish) + (((thickness x height x unit weight)x length)/ Area)

= ((0.15m x 25kN/m^3)+ 2kN/m^2) + (((0.135m x 3m x 6kN/m^3) x 80m)/ 173.5m^2)

=6.85kN/m^2 up to 2nd floor. (Includes internal partition wall load)

External wall load= (thickness x height x unit weight)

= 0.3m x 3m x 6kN/m^3

=5.4kN/m up to 2nd floor

Roof floor load= (thickness x unit weight) + 2kN/m^2 Floor finish

= (0.3m x 25kN/m^3) + 2kN/m^2

= 5.75kN/m^2

Roof exterior wall load of 1.8kN/m

Roof partition load= (thickness x height x unit weight)

=(0.135m x 3m x 6kN/m^3)

= 2.43kN/m

4.1.3 Live Loads

As per IS 1893, clause 7.3.1;

For Live loads up to 3kN/m^2, 25% is taken. And for live loads greater than 3kN/m^2, 50% is taken.

25% of 2kN/m^2 floor load up to 2nd floor= 0.5kN/m^2

25% of 3kN/m^2 floor load for staircase and corridor= 0.75kN/m^2

50% of 20kN/m^2 roof water tank load = 10kN/m^2

5 Strategies for Earthquake Resistant Design

5.1 Ductility

Concrete material has high compressive strength but it is brittle and cannot withstand much tensile force. The beams and columns gain their ductility from the reinforcement provided. A structure can be made earthquake resistant by designing the beams and columns for more ductility. The ductility is achieved by detailing the reinforcements for beams and columns. This makes the frame of beams and columns less brittle, and therefore, can withstand much more lateral load. A ductile structure, when subjected to seismic forces, can release the energy by undergoing large deformations, without collapsing.

5.2 Base Isolation

When the superstructure is separated from the substructure, it greatly reduces the transfer of ground motion from the foundation to the superstructure. It makes the whole structure more resistant to earthquake. Some widely used base isolation mechanisms are;

I. Roller and Ball Bearing- the substructure and superstructure are separated using cylindrical rollers and balls.
II. Sliding Bearing- a sliding mechanism is used where the friction is predefined. This mechanism helps reduce the transfer of energy from the base to the superstructure.

III. Springs- springs are not commonly used since they allow the movement in both horizontal and vertical plane.

IV. Elastomeric Rubber Bearings- it is the most widely used base isolation mechanism. Horizontal layers of rubber between steel plates resist vertical deformation but allow movement in the horizontal direction.

Base isolation provides resistance to seismic ground motions, but unlike structural walls, they do not add to the weight of the structure, and therefore, do not increase the base shear.

5.3 Structural Walls

Structural walls are reinforced walls that help the building resist lateral loads(wind and earthquake) along the plane of the structural wall. When a building is equipped with structural walls, at appropriate positions, (symmetrically at the core or periphery) its ability to resist lateral loads is enhanced by increasing the stiffness of the structure. A structure with high stiffness will experience reduced displacement and storey drift, which means that the damage caused by earthquakes can also be reduced.

A structural wall built till half the height of the building will be equally efficient compared to a structural wall built up to the full height of the building. However, these are only necessary for buildings in earthquake prone zones (Zone IV and V) and important buildings. Constructing these walls are costly, so they are not constructed for low risk areas (zones III and II).

6. Methodology

The initial step in the structural analysis is to create the geometry. The frame of beams and columns of the structure is made. Then the dimensions for beams and columns are assigned as required. Fixed supports are added at the base of each column to simulate foundation. Then the concrete material is assigned for the whole structure.

The process of loading for Seismic design starts with defining the seismic load. This is done automatically by the software, as per IS 1893. All the dead loads and live loads are calculated and assigned to the respective beams. The self weight of the structure includes the weight of beams, columns, slabs, and walls in the building. The live loads are assigned as per IS 875.

The loading process is followed by analysis. An analysis is run and errors are rectified if any. The results of the analysis provides us with the lateral forces on each floor, displacements and storey drift values, which helps in comparison when the model with structural wall is analyzed.

To obtain the volume of concrete and weight of steel reinforcements required, the model is designed by giving inputs of M25 concrete and Fe415 steel. Then after adding commands of take off, design beams and columns, and design slabs (for model with structural wall), we analyze the model again, to obtain the values of volume of concrete and weight of steel required for the structure.

Another replica model is created, and structural walls placed as parametric models. The beam and column size, along with the thickness of structural walls are assigned. Analysis is performed to obtain the values of lateral forces on each floor, displacement and storey drift. And the structure is designed similarly to get the estimates for volume of concrete and weight of steel reinforcements required.

The final results are compared to visualize the effect of structural wall during seismic activities. The volume of concrete and weight of steel reinforcements is used to estimate the additional cost incurred for the construction of structural walls, and perform a cost-benefit analysis.

7. Structural Specification of the Building

7.1 Geometry

The frame of beams and columns in the structure is constructed in the software.

Then, beam and column sizes are assigned as follows;

Beams = 300mm x 400m

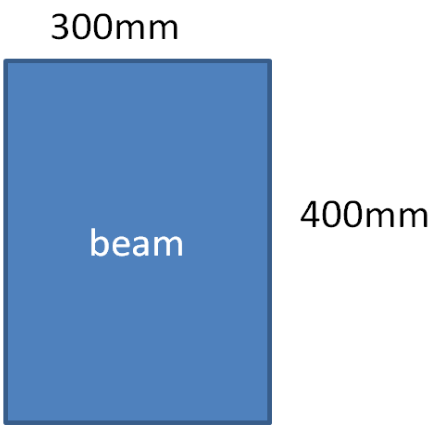

Fig.29 Beam Cross-Section

Columns= 300mm x 300mm

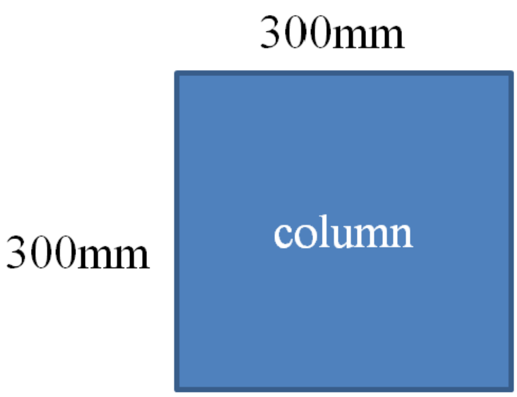

Fig.30 Column Cross-Section

Concrete material is given and fixed supports are provided as foundation.

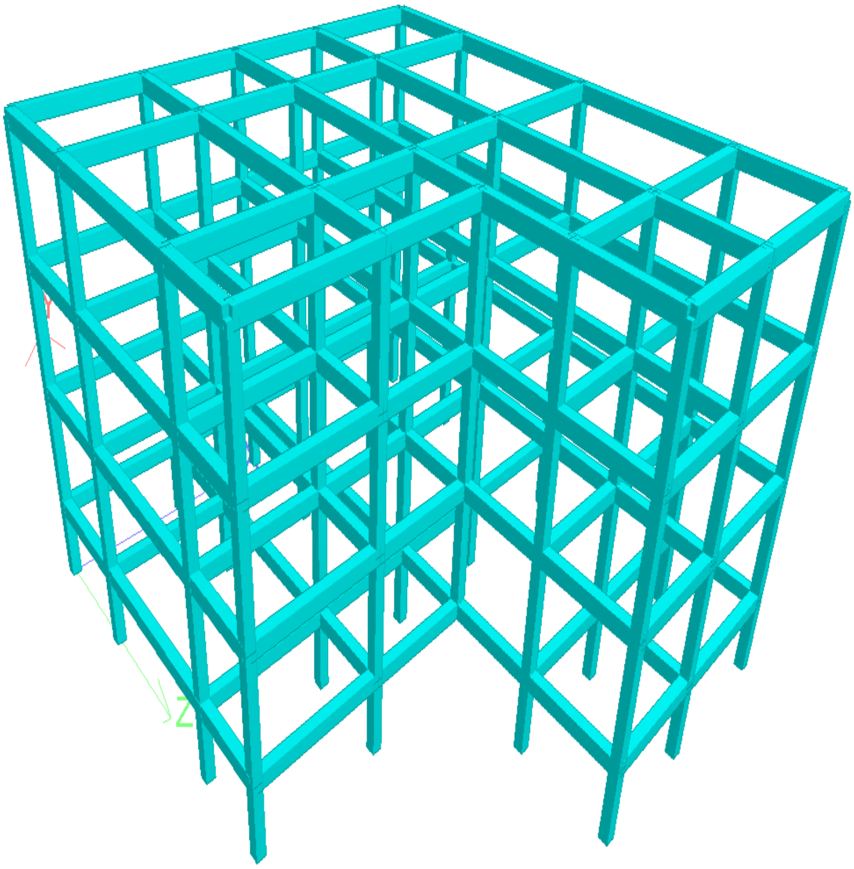

Fig. 31 Frame of beams and columns

7.2 Placement of Structural Wall

L-shaped Structural walls are placed at three corners of the building. These are modeled as parametric models in STAAD.Pro. They go up to the second floor and the openings for windows are given.

The placement of structural walls is decided according to previous researches done about structural walls, where it was found that placing the structural walls symmetrically at the core or periphery, increases the efficiency of the structural walls. Furthermore, the structural walls were not brought up to the full height of the building because it was found in previous studies that structural walls provided till half the height of building will be strong enough.

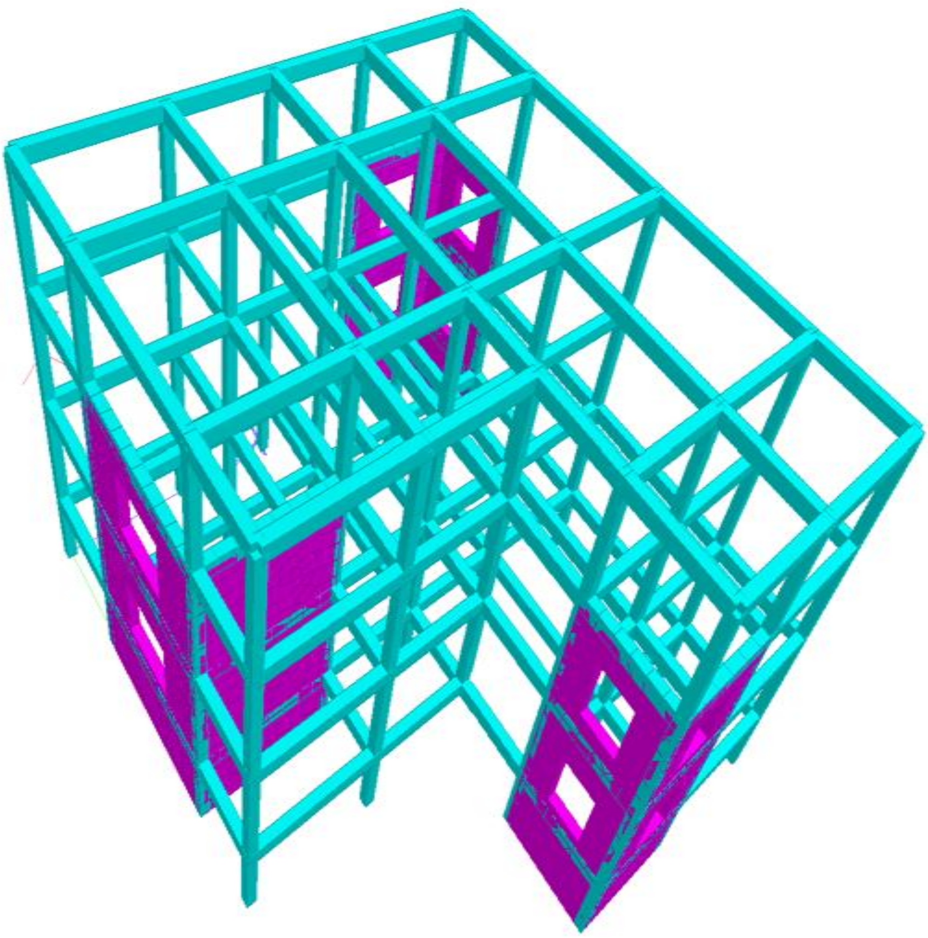

Fig.32 Frames with structural wall

8. Hypothesis.

The results of this project will help us visualize the strengthening effect of structural wall in the terms of lateral load, displacement and storey drift. It will help us better understand the effect of absence and presence of structural wall.

The extra weight of the structural wall will increase the seismic weight. Therefore, it is hypothesized that the structural wall will increase the base shear, which will lead to an increase in the lateral loads in all the floors.

Structural walls reduce storey drift by resisting seismic vibrations in the plane of the wall. And structural walls are designed upto the 2^{nd} floor, leaving one floor without the structural wall vulnerable to the increased lateral loads. Moreover, the lateral load increases with height, so the 3^{rd} floor has to withstand high magnitudes of lateral forces. Therefore, the displacement and storey drift of the 3^{rd} floor is expected to increase.

9. Results

After analysis of both the structures, we get the results of lateral forces on each floor, displacement and storey drift. The results are used to compare and draw conclusions.

Displacement and Storey drift values are also generated by the software;

Table.16 Displacement And Storey Drift In X And Z Direction For Structure Without Structural Wall.

Storey height (m)	Displacement (mm)		Storey drift (mm)	
	X	Z	X	Z
2	2.861	2.781	2.861	2.781
5.15	12.889	12.457	10.028	9.676
8.3	22.032	21.312	9.143	8.885
11.45	27.751	26.936	5.720	5.624

The displacement and storey drift when the structure is equipped with structural walls are;

Table.17 lateral forces in x and z direction for structure with structural wall.

Storey height (m)	Displacement (mm)		Storey drift (mm)	
	X	Z	X	Z
2	0.311	0.346	0.142	0.085
5.15	1.322	1.528	0.103	1.158
8.3	2.806	3.172	1.179	2.481
11.45	9.543	9.911	6.738	6.739

The maximum allowable drift is 0.004 times the storey height,

0.004 x 3.15m = 0.0126m

=12.6mm

The storey drifts are within the limits.

The final results reveal that building a structural wall will increase the seismic weight of the structure, which increases the base shear and therefore, the lateral forces acting on each floor also increases by an average of 33.35%, as hypothesized. And the construction of the structural wall added about Rs.5,00,000/- to the total cost of construction for the G+2 residential building.

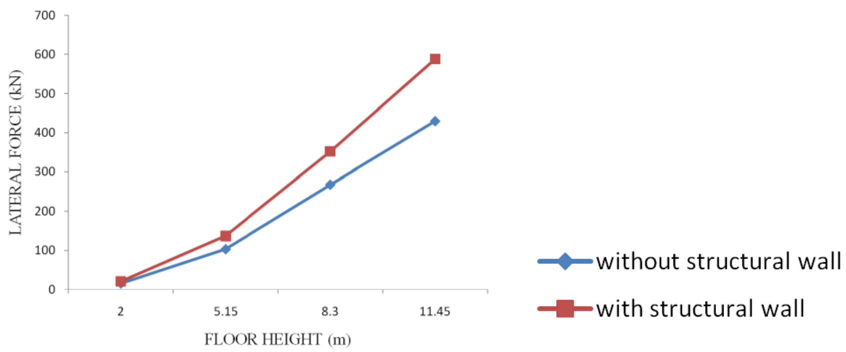

Fig.33 Lateral force comparison.

Nevertheless, the displacement and storey drift is greatly reduced. The structural wall reduced the storey displacements by an average of 79.76% and the storey drift was also reduced by an average of 51.28%. However, the storey drift of the 3rd floor increases by an average of 19.2% when structural walls are present. Hence, the hypothesis is verified; that the storey drift increases for the floors without structural wall, since structural walls cause increase in base shear. But, since the storey drift values does not exceed the allowable limit, it can be neglected.

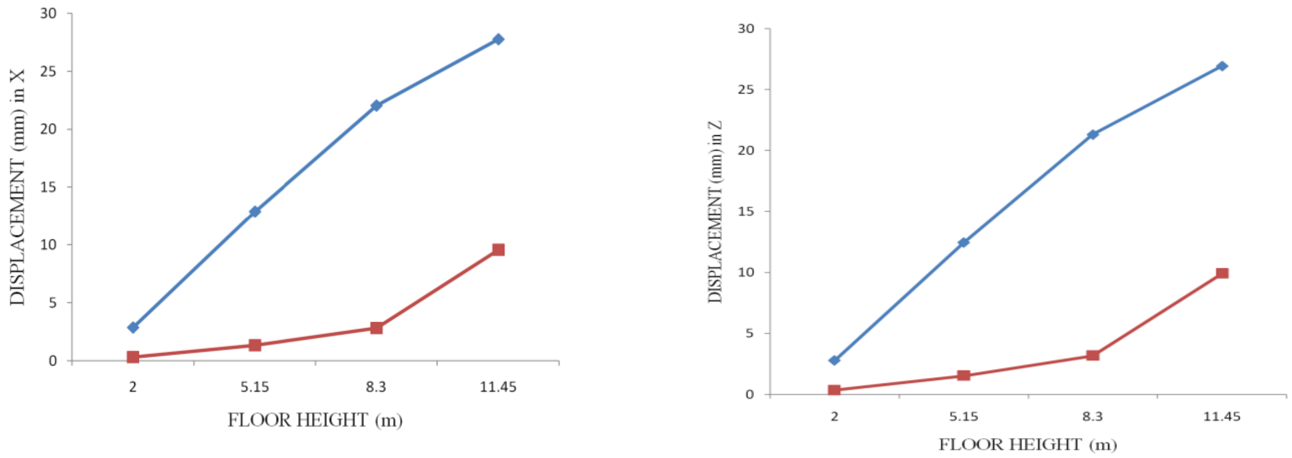

Fig.34 Displacement comparisons

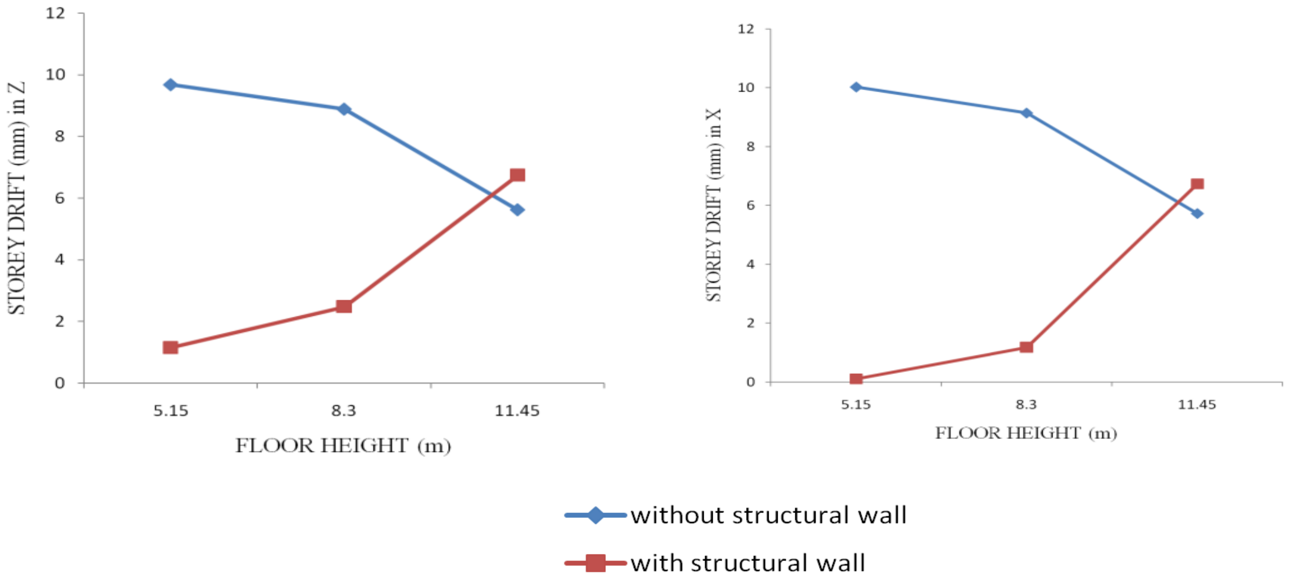

Fig.35 Storey drift comparisons

The results generated by the software shows that the amount of concrete and steel required for the structure are as follows;

- Structure without shear wall;
  Volume of Concrete- 93.2 m^3
  Reinforcement bar Weight - 78437 kg.
- Structure with shear wall;
  Volume of concrete = volume of concrete in beams and columns + volume of concrete in structural wall

  = 93.2 m^3+ 55.68 m^3

  = 148.88 m^3

  Reinforcement bar weight= reinforcement for beams and columns + reinforcement for structural wall.

  = 78437 kg + 11693.5 kg

  = 90130.5 kg.

Taking the cost of construction of 1 m^3 of concretes Rs.2500 and Fe 415 reinforcing steel bars priced 42 per Kg, we get the costs as;

Cost without structural wall = cost of concrete + cost of steel bars

= 2,33,000 + 3,294,354

= Rs. 3,527,354/-

Cost with structural wall = cost of concrete + cost of steel bars- cost of bricks reduced

= 3,72,200 + 3,785,481- 1,36,150

= Rs. 4,021,531/-

10. Cost Benefit Analysis

The volume of concrete and steel required for both the structures are compared to understand the cost benefit of the structural element.

The construction of structural wall increased the cost of construction by 14.2% .The 14.2% increase in cost reduced the displacement by 79.76% and storey drift by 51.28%. The cost-benefit analysis suggest that constructing the structural wall is very beneficial, given that the building is located in the zone of highest seismic activity.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

1. Conclusion

Energy efficiency can be achieved by decreasing the window wall ratio, providing window shades, installing better insulating glasses in windows, using SIP for roofs and walls and changing the orientation of the building in the design stages. Although HVAC systems and Solar Panel installations are very expensive, they help save lots of energy in the long run. Moreover, Structurally Insulated Panels are cheaper to install and also provide better insulation compared to traditional masonry brick walls.

To optimize the building for energy efficiency, the window wall ratio is reduced to 15%. This came into effect because the climate of the location specified was cold and therefore required minimum size of windows to minimize heat loss from the glasses of the windows. A window shade of 2/3 length is provided, but it did not contribute much in saving energy. The type of glass used for windows was one of the most controlling factor for optimization. A well insulating triple pane LoE glass enables a huge amount of savings per year. A High Efficiency Heat Pump will add up to the total cost of construction, but it will be worth every penny. The extra cost added will be recovered in a year. Solar panels are very costly to purchase and install. However, if the initial cost is covered somehow, it proves to be the most energy saving element of the building.

If the owner can cover all the costs of these elements during the construction, the extra cost incurred can be recovered in a period of 10 years and then there will be about a million rupees saved every year for as long as the building stands.

The results of the structural analysis showed that the structure experiences about 33.35% increase in lateral force. This is due to the weight of the structural wall increasing the seismic weight of the structure. A heavier structure will experience more base shear. This results in higher lateral forces on each floor. As a result, the floor without structural wall experiences an increase in storey drift.

Nevertheless, the total storey drift is reduced by 51.28% and displacement is reduced by 79.76%, suggesting that structural wall is an excellent earthquake resistant strategy.

2. Recommendations

It is recommended, from the results of this work that decreasing the window sizes, providing window shades and using Structurally Insulated Panels is the cheapest way to save energy. These changes cost very less and furthermore SIPs even reduce the total cost of construction.

Using Triple Pane LoE for Window glasses can save lots of energy but it is very expensive and it takes about 16 years of its savings to pay back its initial investment costs. Therefore, triple pane LoE glasses are recommended to be used for small residential homes.

If the budget for the construction is plenty, Solar Panels and High Efficiency Heat Pumps are recommended due to its efficiency in the long run although the price is high.

Lastly, every building should be designed for energy efficiency whether it is a small house or a multi-storied building. Though the initial cost of construction may increase, it will definitely save lots of money in the long term.

The result of structural analysis shows that structural walls benefit greatly in reducing the displacement and storey drift of the structure. However, the storey drift is found to be reduced only for the floors up to which the structural walls are built. So, it is recommended that structural walls be built throughout the height of the building, like lift walls for important buildings like hospitals.

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