Cost Comparison between Frames with Solid Slab and Ribbed Slab using HCB under Seismic Loading

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Abstract: *The aim of this study focus on problems associated with careful evaluation, Comparison of Overall Behavior (Shear, Bending, Storey Deflections) and comparison of Frame with Solid Slab and Ribbed Slab considering seismic weight. The study was done in Ethiopia for the Frames with Solid Slab and Ribbed slab in the same seismic zone (Zone-4) and on the same Soil class or type (soil type A). Because of this the size of Column, Footing and other load bearing elements are reduced, and this enabled to select the most economical structure having good bending, Shear and Storey deflection resistance capacity. Excel Design Template carries the design of Frame with solid slabs. The methodology employed in this study consists of two parts; the first part is the analysis of structure for the data taken from standard code by using STAAD Pro 8.1 software. The second part is the design of structure which is carried out by manual calculation and Excel Design Template. The result obtained from the study shows that the Frame with Solid Slab has right Bending, Shear and Storey deflection resistance capacity making it more preferable choice for shopping /commercial (superstructure) building. Considering from the economical point of view it is less expensive than that of the Frame with ribbed slab using hollow concrete block; hence the total quantity of Steel and HCB used is less. To conclude, Frame with Solid Slab is the best alternative method in building due to its capability to reduce the cost and have a good overall Behavior.*

Key Words: **Building structure; HCB; hollow concrete block; Two-way Solid slab; Two-way ribbed slab; Excel Design Template; STAAD Pro 8.1 software.**

1. INTRODUCTION

Structure refers to a system formed by the interconnection of structural members built to support or transfer forces and to safely withstand the loads applied to it or prevents buildings from being collapsed. A structure supports the building by using a framed arrangement known as structural members [1]. There are two necessary steps for the construction of a building:

(a) Structural Analysis
(b) Structural Design

Structural analysis is the prediction of the performance of a given structure under prescribed loads and other external effects, such as support movements and temperature changes. [3]Movements and shear forces are considered as the most common effects and calculated from complicated formula and chart will be used in this calculation works, and this requires the use of computer software as well as trained and experienced engineers. The structure is analyzed to ensure that it has its required strength and rigidity. [1]

In Structural Design, we select or create suitable structural members to the given impact load obtained from the analysis of the structure. The reinforcement steel and member sizes especially (in the case RC structures) are proposed and selected. In which a particular code of practice is considered as a fundamental for the design work. In this case, the compliance with the local requirement and the design will be standardized. The Ethiopian Building Code Standards is widely used in Ethiopia for design while some other designers use other code from India and British. [1]

When designing a structure to serve a particular function for public use, the engineer must account for its safety, aesthetics, and serviceability, while taking into consideration economic and environmental constraints. This design process is both creative and technical and requires a fundamental knowledge of material proportions and the laws of mechanics which govern material response. [2]

There are three essential types of slabs; solid slab, Flat slab and Ribbed or Composite Slab but the loads and span will determine the choice of slab type largely. The solid slab has two categories, one-way slab, and two-way slab. The one-way slab is one of the simplest forms of a solid slab. It is considered economical for small span only (up to 4.6m) due to its low efficiency and weight. [4]

On the other hand, the two-way Slabs is usually used for heavy loading and large spans. The reinforcement in two-way Slab is designed to enable the Slab to act in both directions. The ratio of long to the short side of the floor panel would determine the load proportion taken by each set of reinforcement. [5]However, there are two types of the Two-way slab:

(i) Two-way slab with Edge support (Edge supports may be bearing walls or monolithic beams)
(ii) Two-way slab with a free end or without beams.

A Ribbed Slab gives considerable extra strength in one direction while a waffle slab gives added strength in both directions. And this is possible only in monolithically cast concrete which is the two-way grid of beams. In comparison to the solid slab, the span limits of ribbed slabs are considerably longer. So, longer span and light to moderate live loads (generally less than 3 kN/m²) are used for this type of slab [5].

Many software like STAAD.Pro, SAP 2014, ETABS NL V9.6 and Excel design Template was used for doing the analysis and design of the structure.STAAD .Pro V8i software selected because of its efficiency in producing accurate values and easy to use.

Moreover, there are many versions of STAAD.Pro software but the one used is STAAD. Pro, with version 8i, integrated total solution structures used for analyzing the structure. Statement of Problem is that the increment of total cost in Frame with solid and Frame with Ribbed slab due to the quantity of concrete, steel, and HCB used is the most critical problems in the present research. Reducing of total cost on Frame with solid slab concrete structure is less, in addition to that Frame with Solid Slab have right Bending, Shear and Storey deflection resistance capacity and also more efficient.

2. THE OBJECTIVE OF THIS STUDY

To compare solid slab and ribbed slab based on the quantity of concrete and steel to be consumed during construction.

To take the comparison between the solid slab and ribbed slab based on cost or economic evaluation.

To compare solid and ribbed slab based on bending and shear behavior under external loading (seismic load) and self-weight of the building.

To undertake a comparison between solid and ribbed slab based on their story deflection under external loading (seismic load).

The significance of the research is associated with how to select a preferable type Frame with slab (solid or ribbed) in Ethiopia based on Cost/economic evaluation by Considering different factors.

3. MATERIALS USED

Building Function - Shopping / Commercial [Super-Structure]

No. of Story - G+6

Regularity Criteria - Symmetry in Plan & Elevation

Floor plan - Typical all floors

Type of slab - Solid slab Vs. Rib slab

Type of cement - PPC

Structural System - Moment Resisting Frame

Structural Analysis - STAAD Pro. Software

Structural Design - Manuel Calculation and Excel Design Template

Load combinations - Dead, Live & Seismic[7]

Assumed Floor Finish Load- 1.5 kN/m2[7]

Typical Floor Height - 3.5 m

Assumed depth of foundation - 1.5 m

Grade of Concrete - C25 (Mix Proportion of 1:2:3 batching in volume)

Grade of Steel - S400

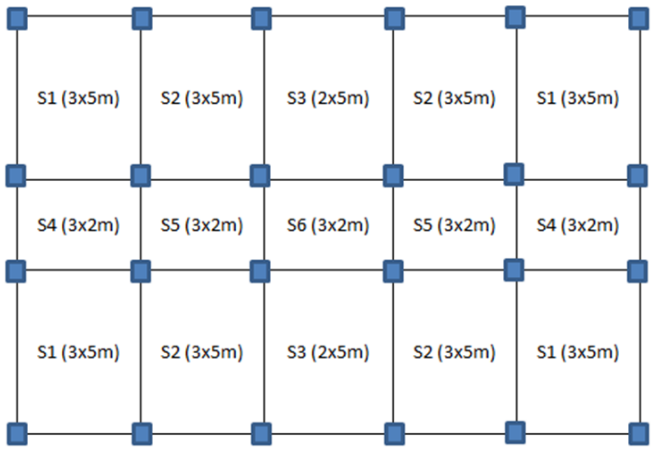

Fig-1 Typical Floor and roof slab layout

4. RESEARCH APPROACH AND METHODOLOGY

To carry out these research, different methods was used for both analysis and design part of the solid slab and ribbed slab.

1 - For general analysis, Structural Analysis and Design program (STAAD .Pro) software was used which is un-adapted or not well known in Ethiopia.

The live loads and effective depth of each slab were taken from standard code [EBCS 1-1995, Table 2.10] and [EBCS-2-1995, C: 5.2.3] respectively. Finally, the overall depth is multiplied by an area of slab and unit weight of concrete for self-weight of the slab. [7, 8]

After the loads had been obtained from above procedures, dead load, live load and design spectrum Coefficient for seismic load were assigned.

2 - For the design, the S.F.D and B.M.D were obtained from the output of STAAD. Pro .V8i. Software. Manual calculation and Excel Design Template were used to determine cross-sections of frames (beam and column) and slab thickness to determine self- weight (DL) of the building in both types of the slab. [9]

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5. EXPERIMENTAL PROGRAM

- **Specimen:** Specimen Refers to samples or models taken to carry out our research in both Solid and Ribbed slab.
- **Model for slab-** G+6 building for both solid slab and ribbed slab
- **Seismic zone (4) and soil type (A) -** For both solid slab and ribbed Slab

Seismic coefficient - For both solid and ribbed slab [10]

Seismic Zone = 4, Subsoil Class = A

Bed Rock Acceleration ratio –α= 0.1. [EBCS 8-1995, Table1.1]

Site Coefficient-S= 1……………. [EBCS 8-1995, Table 1.2]

Importance Category= 1 and

Importance Factor-I=1.

Structural Type= Frame type……….. [EBCS 8-1995, Table 3.2]

Behavior Factor-γ= 0.2

Fundamental period of building-T= CH^3……[EBCS 8-1995, Cl: 2.3.3.2.2]

For RC frame-C = 0.075

Total height of building-H = 24.5m

T=0.83sec<2sec-method of analysis is static analysis.

Design response factor-β= $1.2S/T^{2/3}$………………[EBCS 8-1995,Cl:2.1.4.2.2]

β= 1.36 <2.5

Seismic design coefficients–S_d= Iα βγ………[EBCS 8-1995, Cl: 2.5.3.2]

= 0.038

- **Material property**

The following material property is used:-

- For concrete- C25 (Mix Proportion of 1:2:3 batching in volume)
- Type of cement - PPC
- For steel - S-400
- E_{steel}= 21×0^5…….from EBCS 2
- $E_{concrete}$= 0.0035…..from EBCS2

Design constant calculation according to EBCS 2:

F_{ck}= 20 Mpa

F_{ctd}= $0.21f_{ck}^{2/3}$= 1.5473 Mpa

F_{ctd}= f_{ctk}/γ_c= 1.03153 Mpa

F_{cd}= $0.85\times f_{ck}$= 11.33 Mpa

F_{yd}= f_{yk}/γ_s= 347.83 Mpa

- **Sectional property: -**Indicates Design sections for the beam, column, and slab.

I. **Solid slab**

Beam-upper design section=200×450mm

- ✓ Lower design section= 200×250mm
- ✓ Upper bar diameter = Φ14mm
- ✓ Lower bar diameter = Φ8mm
- ✓ Upper poundage= 170.96Kg/m^3
- ✓ Lower poundage = 103.6Kg/m^3

Column-upper design section = 325×325mm

- ✓ Lower design section= 300×300mm
- ✓ Upper bar diameter= Φ20mm
- ✓ Lower bar diameter= Φ12mm
- ✓ Upper poundage of = 179.29 Kg/m^3
- ✓ Lower poundage = 67.27 Kg/m^3

II. Ribbed slab

Beam-upper design section= 200×450mm

- ✓ Lower design section= 200×250mm
- ✓ Upper bar diameter= Φ14mm
- ✓ Lower bar diameter= Φ8mm
- ✓ Upper poundage= 170.96 Kg/m^3
- ✓ Lower poundage = 103.6 Kg/m^3

Column-upper design section = 330×330mm

- ✓ Lower design section= 300×300mm
- ✓ Upper bar diameter= Φ20mm
- ✓ Lower bar diameter= Φ12mm
- ✓ Upper poundage= 181.18Kg/m^3
- ✓ Lower poundage = 67.27 Kg/m^3

- **Support condition**= Fixed Support
- **Load and Load Distribution**

Solid Slab

Slab Thickness-Upper Value= 120mm

Lower Value = 90mm

Self-Weight-Upper Value = 3kN/m^2

Lower Value= 2.25kN/m^2

Load Distribution

Number of two Way Panels= 13

Number of One Way Panels= 2

Total number of panels= 15

Ribbed Slab

- Slab Thickness including HCB= 290mm
- Self-Weight = 4.37kN/m²
- Load Distribution= Whole Panels are One Way

Load Combinations

Load combinations based on strength limit state and Serviceability of EBCS for both Solid and Ribbed Slab was used [12, 13]

Therefore, the overall Load combinations are listed as shown below:

Table -1: Load Combination

Strength Limit State	Serviceability Limit State
1.3DL+1.6LL	DL+LL
1.3DL+1.6SLX+	DL+SLX+
1.3DL+1.6SLX-	DL+SLX-
1.3DL+1.6SLY+	DL+SLY+
1.3DL+1.6SLY-	DL+SLY-
1.3DL+1.35LL+1.35SLX+	DL+0.9LL+0.9SLX+
1.3DL+1.35LL+1.35SLX-	DL+0.9LL+0.9SLX-
1.3DL+1.35LL+1.35SLY+	DL+0.9LL+0.9SLY+
1.3DL+1.35LL+1.35SLY-	DL+0.9LL+0.9SLY-
0.975DL+1.2LL+SLX+	
0.975DL+1.2LL+SLX-	
0.975DL+1.2LL+SLY+	
0.975DL+1.2LL+SLY-	

6. RESULTS AND DISCUSSIONS

6.1. Quantity and Cost Comparison

The differences in construction methods between different forms of frame construction tend to cause variation in the cost of any building project. Among different construction methods of frames, this study aims at assessing the change in construction cost between frames with solid slab and frames with ribbed slab by considering concrete quantity, steel quantity and Hollow Concrete Blocks quantity used in construction. [11]

A. Comparison of concrete quantity

To determine the amount of concrete to be consumed during construction the summation of Concrete volume for Beam, Column and Slab was taken. The unit price of concrete 3100 Ethiopian Birr/m³ for C25 Concrete grade was obtained from the municipality.

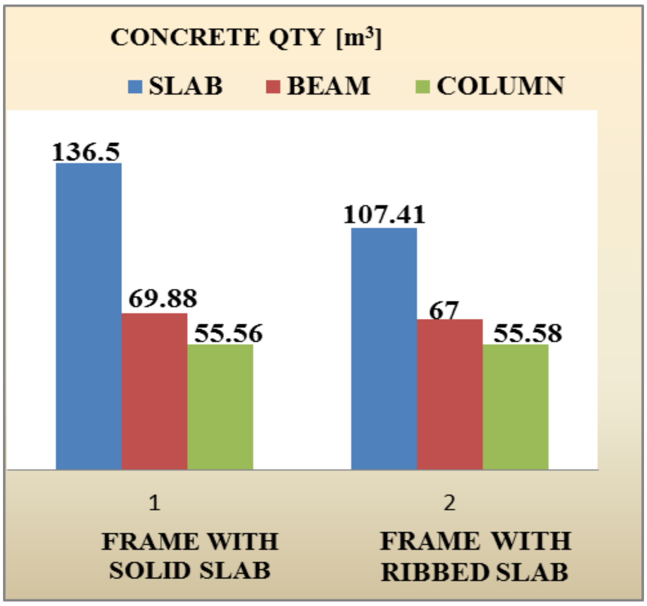

Fig- 2 Result of Comparison of Volume of concrete between Slabs,Beams,and Columns

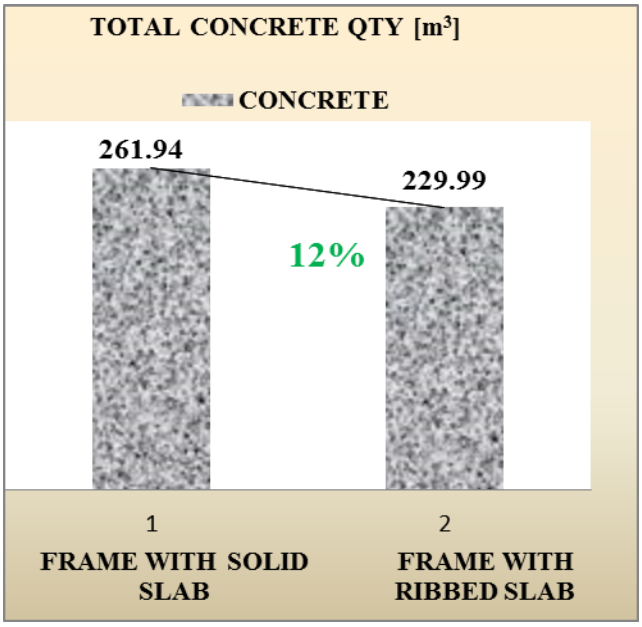

Fig-3 Result of Comparison of Total Volume of concrete between Frame with Solid and Ribbed Slab

A significant variation in Concrete Quantity between Frames with ribbed slab and Frames With solid slab is due to a large number of HCB provided in the ribbed slab.

B. Comparison of Steel quantity

To determine amount of Steel to be consumed during construction the amount of Steel used for the beam, column, and slab was added. The unit price of Steel, 30000 Ethiopian Birr/MT for deformed steel S-400 was obtained from the municipality.

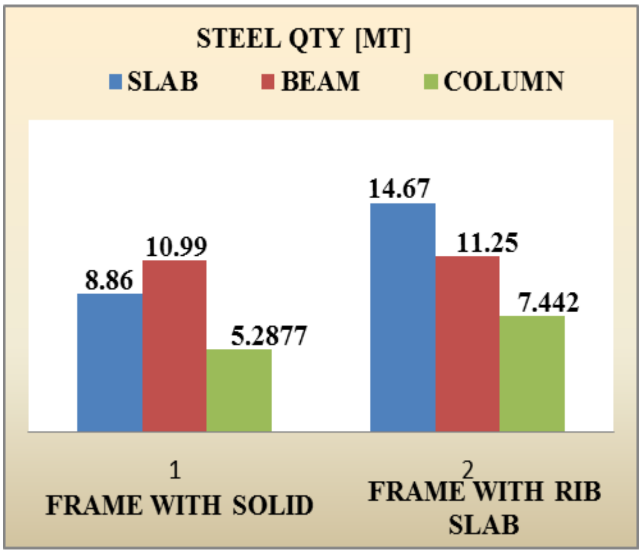

Fig-4 Result of Comparison of Volume of concrete between Slabs, Beams and Columns

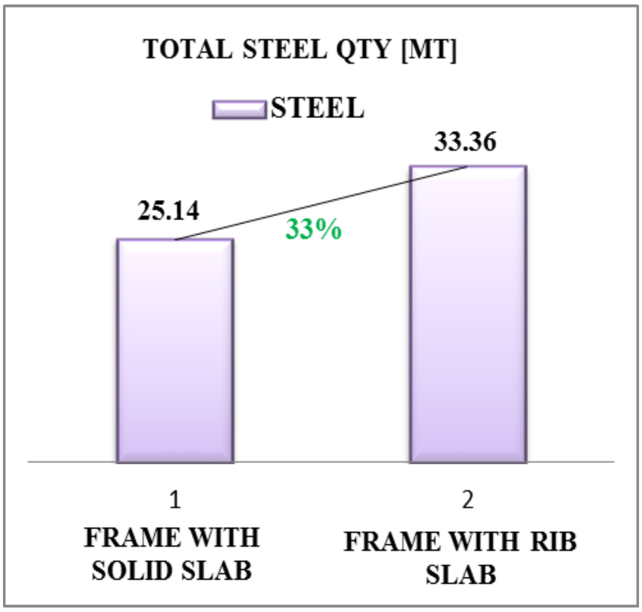

Fig-5 Result of Comparison of Total quantity of Steel between Frame with Solid and Ribbed Slab

Because of greater Seismic and Design Loads acting on the Building, the beam and column dimension of the Frame with Ribbed Slab will be higher than the beam and column size of the frames with solid slab thereby increasing the reinforcement quantity.

C. Comparison of Hollow Concrete Blocks quantity

To determine quantity of Hollow Concrete Blocks to be consumed during construction the amount of Hollow Concrete Blocks used for slab was added. The unit price of Hollow Concrete Blocks, 12 Ethiopian Birr/Nos. Was obtained from the municipality.

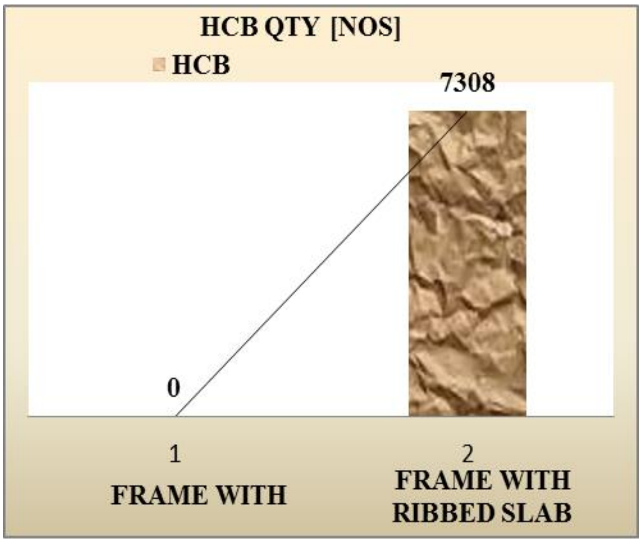

Fig-6 Result of Comparison of Quantity of HCB between Frame with Solid and Ribbed Slab

Total cost for both Frames with Solid and ribbed slab was obtained by summing up the cost of Concrete, Cost of Steel and Cost of HCB

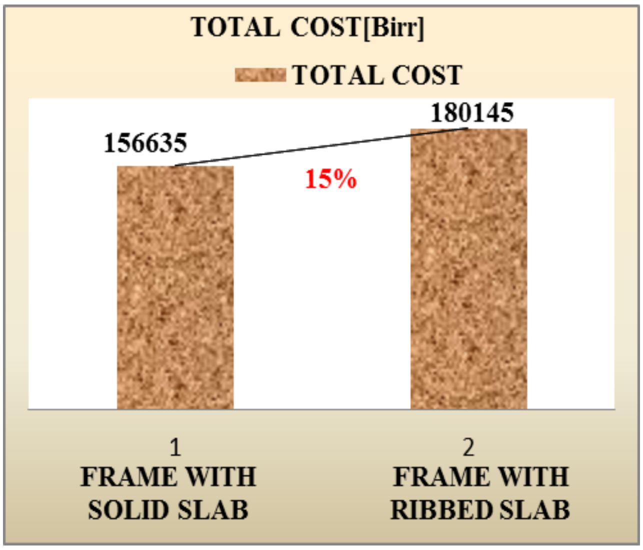

Fig-7 Result of Comparison of Total Cost between Frame with Solid and Ribbed Slab

Total Cost of Frame with Ribbed Slab is greater than that of Frame with Solid Slab because of a greater quantity of Steel and Higher amount of HCB.

6.2. STOREY SHEAR

Story shear or story collapse was created due to lateral load from a dynamic or seismic load of the building. In this study, to compare both frames with solid slab and ribbed slab, the lateral load or shear force for each story for both frame system is taken from STAAD.Pro and compared for storey shear resistance capacity. [13]

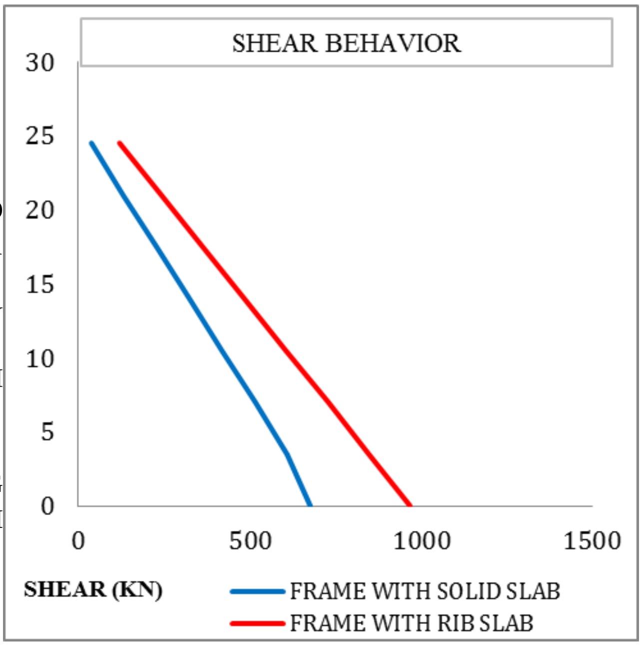

Chart-1: Result of Comparison of Shear Behavior between Frame with Solid Slab and Ribbed Slab

Shear Behavior is increasing from Top to Bottom, but Shear Behavior in Ribbed is greater Due to higher self-weight.

6.3. BENDING BEHAVIOR

Bending behavior of building was created due to the vertical and joint condition of story building. In this study, to compare both frames with solid slab and ribbed slab, the maximum bending for each story for both frame system is taken from STAAD. Pro and compared for bending resistance capacity.

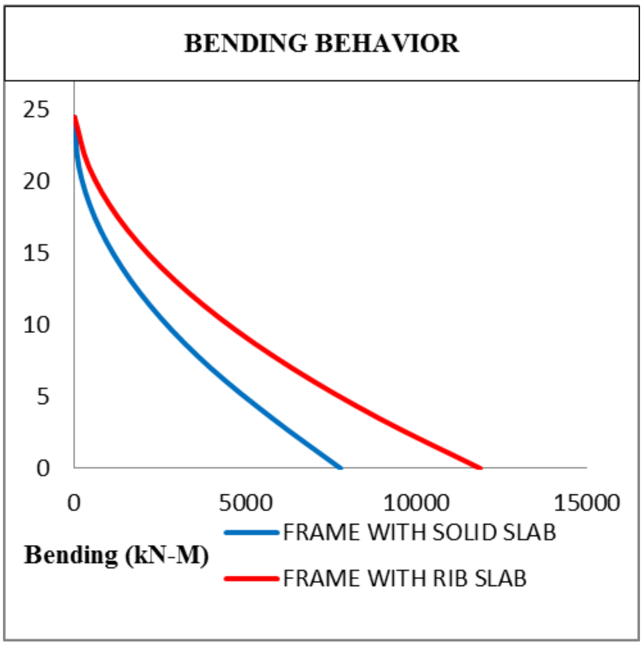

Chart-2: Comparison of Bending Behavior between Frame with Solid Slab and Ribbed Slab

Bending Behavior is increasing from top to bottom in both slab system, but Bending Behavior in the Ribbed slab is greater due to Higher Seismic Load.

6.4. STOREY DISPLACEMENT

Storey Displacement is the displacement of a building at floor level by some distance in either of the direction (x or z).

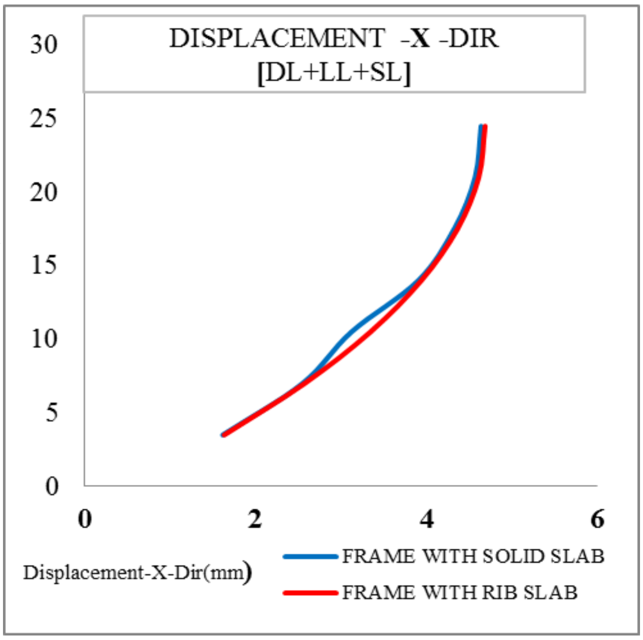

Chart-3: Result of Comparison of displacement -z -dir between Frame with Solid and Ribbed Slab

6.5. STOREY DISPLACEMENT [Z DIRECTION]

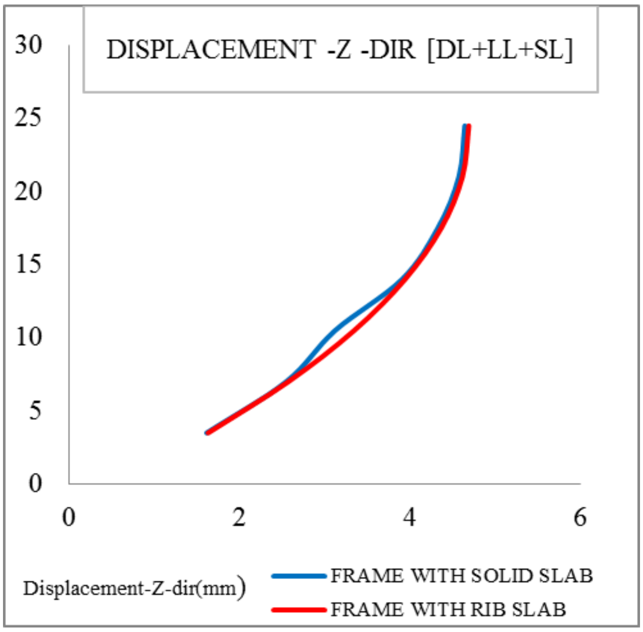

Chart-4: Result of Comparison of displacement -z -dir. between Frame with solid and Ribbed Slab

From Diagram Displacement is increasing with respect to floor height in both slab system, but the displacement of Ribbed Slab is greater due to higher Seismic Weight.

7. SEISMIC WEIGHT

Seismic Weight is the weight of a building due to the seismic effect on the structure is calculated from the STAAD output.

Frame with Solid Slab

Total dead Load of the Building = 17825.236 KN
Horizontal Seismic Coefficient = 0.038
Seismic Weight of the Building = 677.358968 KN

Frame with Ribbed Slab

Total dead Load of the Building= 17910.956KN
Horizontal Seismic Coefficient= 0.038
Seismic Weight of the Building=680.616328KN

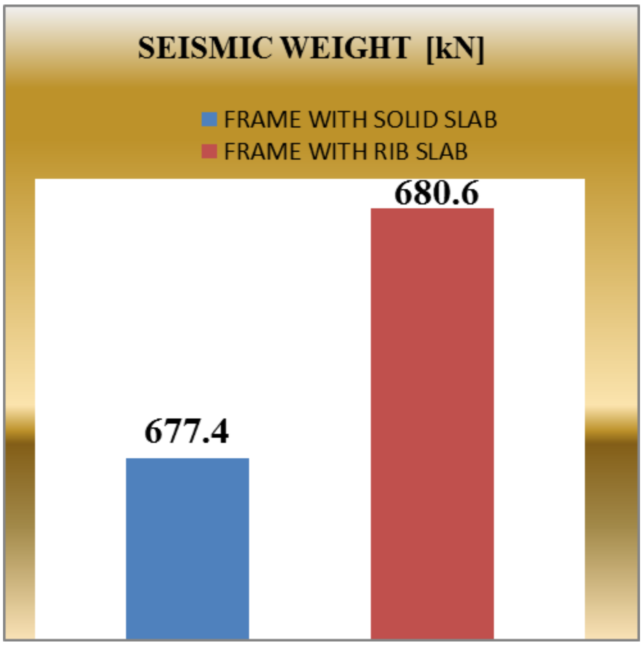

Fig-12: Result of Comparison of Seismic Weight between Frame with solid and Ribbed Slab

Seismic Weight and Self Weight of Ribbed Slab is greater due to higher Frame Cross Section and Slab thickness.

8. CONCLUSIONS

The manual calculation and Excel Design Template were used for calculation of seismic weight for frames with solid Slab and Ribbed slab. The Bending behavior, shear behavior, storey displacement along X and Z axis were studied, and economical evaluation was given due importance by examining the total quantity of concrete, steel, and HCB consumed during construction. Based on the above the following conclusions were drawn:

1. Frame with Solid Slab is more Economical than that of Frame with Ribbed Slab. Because the self-Weight of Ribbed Slab is greater than that of Solid Slab, due to this reason the Columns and Beams dimension used is also larger and require more amount of steel for reinforcement. In addition to this even if the Quantity of Concrete in Frame with Solid Slab is more, the Cost for HCB is larger in Frame with Ribbed Slab and this increase the total amount of Cost of during Construction.

2. Frame with Solid Slab has less Seismic Weight than that of Frame with Ribbed Slab this can give the Structure to have good shear Behavior, Bending Behavior and Storey Displacement resistance Capacity.

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