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Enhancing Structural Design Efficiency Through Building Information Modelling (BIM) Based Analysis and optimization Using ETABS

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Abstract - With today's rapid evolution, the construction industry is seeing better times with advanced tools and methodologies focused on improving efficiencies and accuracy in design and analysis. Building Information Modeling (BIM) is one advanced technology, offering a much better platform for integrating various aspects of building design. The project, called "Enhancing Structural Design efficiency by BIM-Based Analysis and Optimization Using ETABS" has exploited the synergy of BIM and ETABS toward an even more efficient workflow for structural engineering. This paper is also concentrating on the design and analysis of mid-rise reinforced concrete structures starting with detailed modelling of structural components including beams, columns, slabs, and foundations in Revit.

A comparative study is carried out to establish the efficiency and effectiveness of the BIM-integrated workflow as compared to the traditional ETABS-only approach. This comparison considers the basic parameters, such as time consumption, frequency of error, material optimization, and ease of accommodating changes in design. The results indicate that BIM-integrated workflows result in faster completion time, greater accuracy, and better material usage. Beyond this, the project details optimization techniques within ETABS which help minimize the amount of material used on a project without compromising structural performance

Keywords –Concrete, Basalt Fiber Reinforced Polymer, Ground Granulated blast Furnance Slag

I. INTRODUCTION

The building industry is due for growth since technologies and strategies in constructing have been developed that are economical, accurate and environmentally friendly. In this context, it seems that Among the quickly developing building technologies which enhance possibilities for the construction and full management of the project ETABS and Building Information Modeling are as one of them cause the preparation of a fully digital representation of the building information model during the course of the project. In the same vein, the joint use of ETAPS and BIM provides virtually continuous flow from design to engineering work enabling one to perform the design work without interruption.

This is A Guide on How to Make ETABS and BIM Work Together to Optimize the Design Process of a Mid Rise Building and it describes the structural design of a middle rise building in ETABS and demonstrates how the design can easily be modified during the building process using BIM. This is complemented by the presentation of and interpretation of three-dimensional models using ETABS and demonstrates the potential use of these technologies in today's world of construction

1.2 OBJECTIVES OF THE STUDY

- The primary goals of the project are

- BIM modelling of reinforced concrete structural elements using Revit and setting up analysis with ETABS.
- BIM modeling of reinforced concrete structural elements using Revit and setting up analysis with ETABS.
- Structural analysis for material input in construction to achieve the sustainability of building practice.

1.3 SCOPE OF THE STUDY

The scope of the project is

A mid-rise reinforced concrete building was prepared using the Revit BIM software followed by taking the model for structural analysis and design optimization process with ETABS. This has been done in a manner by comparing the degree of efficiency and effectiveness of BIM Integrated workflows over ETABS only designs.

These also would consider efficiency with time, availability of resources, and flexibility of amendment.

II. LITERATURE SURVEY

The objective of this literature review is to showcase the performance a Structure Information Modeling (BIM) is the electronic representation of physical and functional characteristics of a structure that has revolutionarily changed the field of armature, engineering, and construction. BIM allows stakeholders involved in a design to express opinions, coordinate, and come together in much better ways across a design's lifecycle as articulated by Eastman et al. (2011). Implicit of using combination confines — from 3D modeling to through-time(4D), to cost(5D)-operation-affords BIM a more holistic design perpetration approach. BIM has been widely surveyed in structural engineering. According to Azhar (2011), mastermind can imagine and analyze elaborated structural systems much more through BIM. By adding structurally detailed models in the project, masterminds will pretend and prognosticate those gestes of the structure under colored cargo conditions. Also, the integration of BIM with structural analysis tools similar to ETABS improves the intricacy of the analysis and design workflows which lowers crimes and rework. Studies by Kaner et al. (2008) establish how BIM supports the earlier identification of conflicts in designs which perfects design issues [1]. ETABS for Structural Analysis and Design ETABS is considered to be very effective in modeling and assaying high-rise structures and complex structures. It has been developed by Computers and Structures, Inc. (CSI), where the advanced features of the program are proved, including dynamic analysis, response diapason analysis, and time-history analysis. When integrated into BIM platforms, ETABS enables transfers without redundancy during the modeling. According to Basha and Baskar, (2019), the combination supports iterative design, which allows masterminds to have improved versions of their models for their maximum efficiency [2]. Effective structural design operates on a base of optimization. Deb and Agrawal (2002) talk about how inheritable algorithms and parametric modeling can be helpful in the structural design process for BIM workflows [3].

III. PROPOSED METHODOLOGY

The methodology shows the step-by-step procedure and their detailed explanation about this project works on improving the efficiency in structural design by integrating Building Information Modeling (BIM) with ETABS. The methodology is to create an elaborated 3D BIM model and then perform structural analysis and optimization using ETABS. Such an integrated approach will reduce errors and make the

process more streamlined and deliver better performance overall.

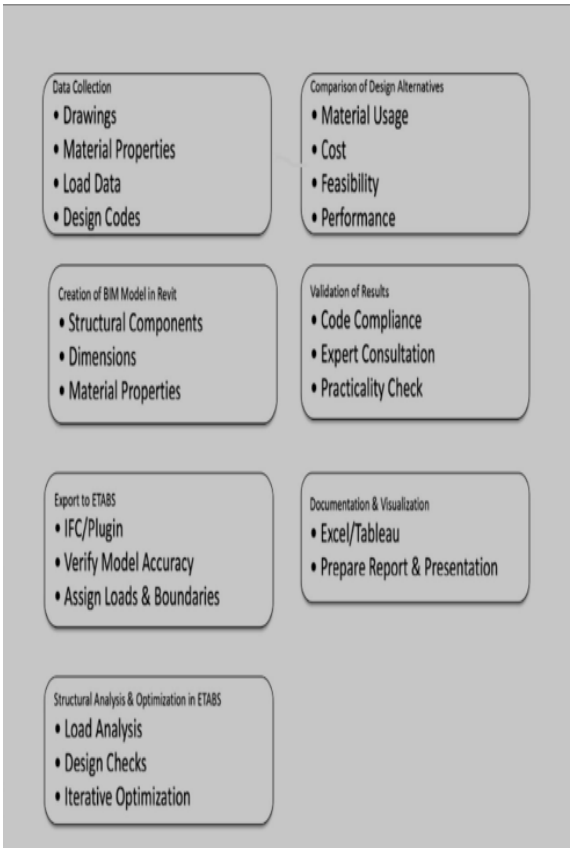


Figure 3.1: Flow chart of Methodology

3.1.1 Data Collection

Collect all the information related to an accurate analysis including architectural and structural drawings of a building, properties of materials such as strength, density, elasticity, design parameters based on building codes and standards that may be IS 456, ACI 318, Eurocode, dead loads, live loads, wind loads, and seismic loads.

This information will ensure that the analysis is comprehensive and derived from reliable inputs.

3.1.2 Creation of BIM Model:

A 3D model of the building is created using BIM software, such as Revit. The process involves the following steps:

- Define the building layout and dimensions.
- Add details for structural components such as beams, columns, slabs, and foundations.
- Assign material properties to each structural element.

3.1.3 Importing to ETABS:

The BIM model is imported into ETABS for the structural analysis. This includes the following:

- The model can be exported in a format suitable for use in ETABS using IFC tools or direct plugins.
- Assigning load cases and boundary conditions in ETABS.
- This ensures that the transition from design to analysis is smooth.

3.1.4 Structural Analysis and Design Optimization:

The structural analysis and optimization process in ETABS involve the following:

- **Load Analysis**: The calculation of forces, moments, and stresses for various load conditions.
- **Design Checks**: It checks if the design meets strength, stability, and serviceability criteria.
- **Optimization**: This process includes the iterative modification of the design parameters to reach an optimal balance between material usage, cost, and performance.

This stage guarantees that the design is efficient and economical.

3.1.5 Comparison of Design Alternatives:

The design alternatives evolved in the optimization process are compared on the following aspects:

- Material consumption.
- Structural performance indicators, such as stress distribution and deflection.

- Cost efficiency.
- Construction feasibility.
- By doing this, the best design that is most practicable and efficient is identified.

3.1.6 Validation of Results:

In the final stages, the solutions are validated through:

- Meeting building codes and standards Practicality of real-world construction conditions.
- Consulting with experts or peers for additional feedback.

3.2. Tools and Software:

Revit: For developing the BIM model.

ETABS: For structural analysis and optimization.

Visualization Tools: Tools like Excel or Tableau to present data trends and outcomes.

3.3 Expected Outcomes:

The methodology is designed to achieve the following:

- Save time in the structural design process.
- Improve accuracy through an integrated workflow.
- Reduce costs by optimizing material usage and labor.

IV. EXPERIMENTAL INVESTIGATION:

4.1 The Materials Used for Construction is Reinforced concrete with

1. M-25 Grade of Concrete
2. M-30 Grade of Concrete
3. Fe-500 Grade of Steel

The Type of the project working on is for the Structural Analysis design of an Apartment Building.

Type of the Building = Apartment Building.

Location of the Building: Hyderabad, Uppal, Near Rajiv Gandhi International Cricket Stadium.

Type of columns Used:

- Rectangular Concrete Shape
  1. 9” x 18”
  2. 9” x 24”
  3. 9” x 12”
  4. 12” x 12”
  5. 12” x 18”
  6. 12” x 24”

Type of Slabs Used:

- Thickness of the slab: 4.5” THK
  1. One- way Slab
  2. Two-way Slab

Total Built-Up Area: 2250 SFT

Types of the Beams Used:

- Rectangular Concrete Shape
  1. 9” x 22.5”
  2. 9” x 13.5”
  3. 9” x 10.5”
  4. 6” x 10.5”

The Material Properties of The Structure.

- The Grade of Concrete and Steel used
  1. M-25 and M-30
  2. Fe-415 and Fe500.

As per Methodology the collection of the information of the structure of the building like,

1. The Architectural plan by the Architecture who will be usually using an AutoCAD Software for making of architecture plan.
2. After collection of the Architecture plans assigning of the columns will be done analysing the architecture plan.
3. So, the need of the information is as follows:

The Final Architecture plans.

The Center Line layout after analyzing the Architecture plan.

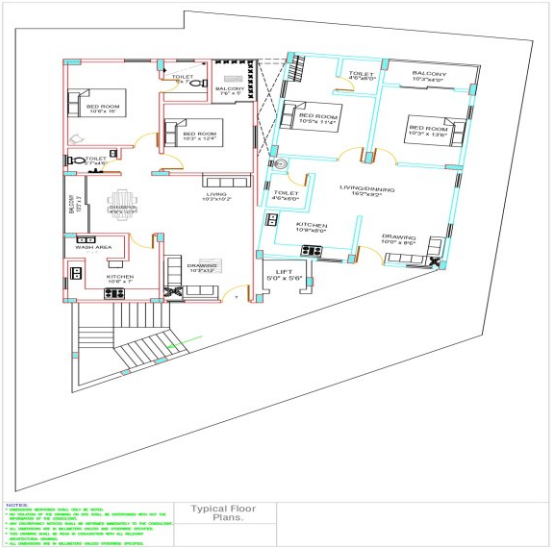


Fig. 4.1 Architectural plan of the Apartment Building of Typical Floors with Conceptual Columns.

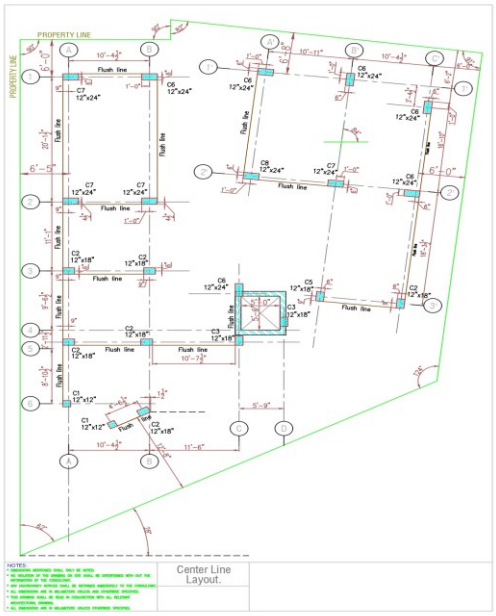


Fig. 4.2 The Center-Line Layout plan of the Conceptual Columns.

V. STRUCTURAL 3D MODELING USING REVIT STRUCTURE

5.1 Procedure for Modelling:

The first procedure involves obtaining all essential information.

I obtained and organized all essential information before beginning the modeling work. Like Collection of Architecture plans of typical floors and Parking floor and as well a center line layout plan of the conceptual columns given by the architectural designers.

5.2 So now Revit Application is required me to Construct The structural Model.

The structural modeling process will start when I open Autodesk Revit as shown in the fig 1 fig 2 as the interface of Revit 2021, while having access to all necessary data from the Architectural department.

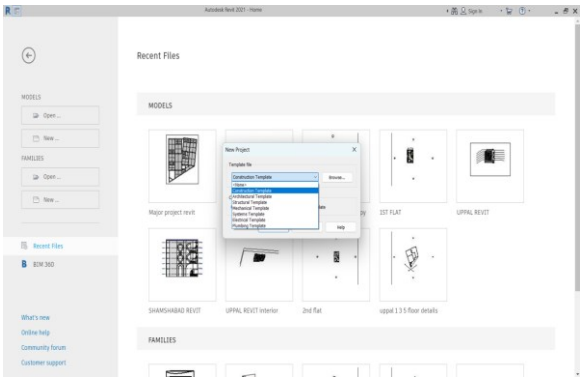


Fig. 1 Interface of the Revit 2021.

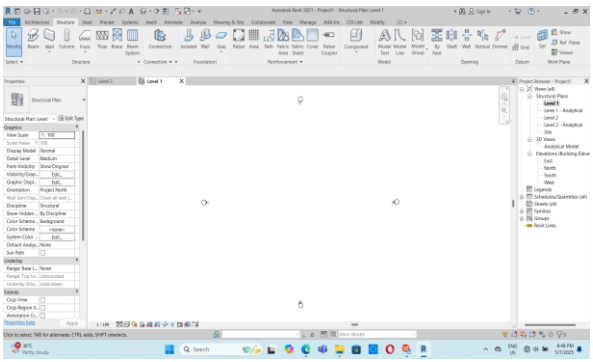
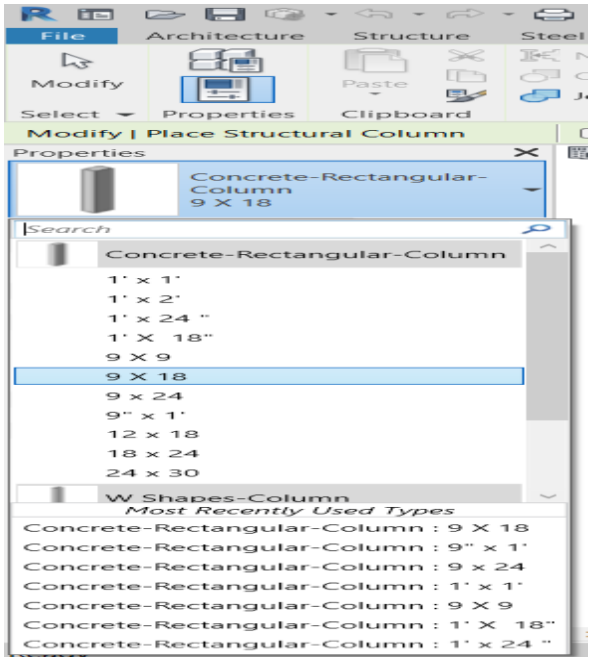


Fig. 2 Interface of Structural Template for 3d Modelling in Revit 2021.

Importing CAD drawing into the Revit:

Importing cad drawing into the Revit will help placing of the structural columns at the exact place and helps for further no clashes.

5.3 Making of required sizes of Columns, Beams and slabs.



Required Sizes are

- **i.** 9” x 12”
- **ii.** 9” x 18”
- **iii.** 9” x 24"
- **iv.** 1’ x 1’
- **v.** 1’ x 24”
- **vi.** 1’ x 18”

5.4 Placement of columns and beams at Base and Parking Level:

After importing of the AutoCAD drawing Place, the column from the Structure tab and click the column and then select the sizes and what material properties you will be using can be edited in the edit option over the left side present in the properties title bar.

After selection of the size and material property of the column place it accordingly taking the reference of the centerline layout plan imported in the Revit.

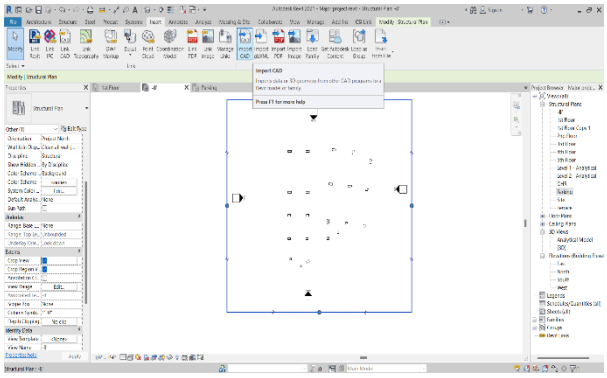


Fig. 1 Importing of CAD DWG and placement of columns as shown.

1. As Shown in the Fig 1 After importing the cad Dwg drawing in the Revit I have placed the columns as per the sizes required at the level -8 feet.
2. As per the instruction and after studying the client requirements and going as per the government rules, and as per the architecture drawing the columns placed at the Base level are gone up to the parking level.
3. At these two levels the sizes of the columns are taken stronger like,
   - i. 1’ x 12”
   - ii. 1 ‘x 18”
   - iii. 1’ x 24”
   - iv. 9” x 12”
   - v. 9” x 18”
   - vi. 9” x 24”

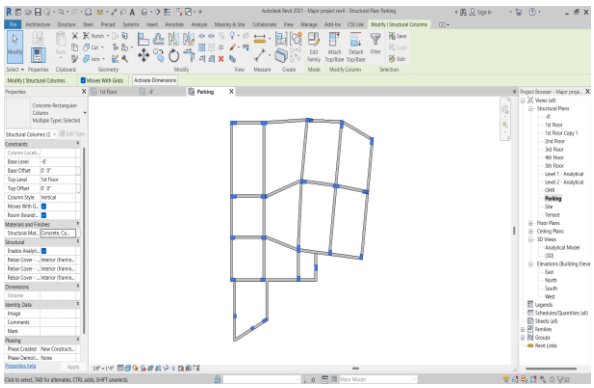


Fig. 2 Placement of columns and Beams at Parking Level.

At the Parking level the columns are brought from the base level according to the base level.

The Beams are then arranged accordingly from column to column.

Here at the parking level the beams sizes are used as per the sites and load conditions conceptually.

At these Parking level the sizes of the beams are taken as follows:

9” x 12” PB1

9” x 18” PB2

For better Understanding of the Parking Framing plan we can export it to the AutoCAD for the details,

5.5 Placement of columns and beams at Typical floor Levels:

1. Moving towards the 1st Floor to Terrace The columns and beams are placed according to the conceptual.
2. The orientation of some columns is changed according to the architectural planning given, so that with the change of column orientation there’s no disturbance to the architecture planning.
3. Here the breadth of the columns is reduced compared to the sizes at the base and parking level.

The various sizes of the columns used at the typical floor level are as follows:

9” x 12”

9” x 18”

9” x 24”

1’ x 1’

Coming towards the beams, the beam sizes are increased, so there will be no failure while transferring of loads to the columns.

The Various sizes of the beams used at the typical floor level are as follows:

9” x 22.5”

9” x 13.5”

9” x 10.5”

6” x 10.5”

1. The beams are connected accordingly towards observing the distances from column to column.
2. The beam size of 6” x 10.5” is placed at around the toilets where sunken slabs also will be placed.
3. Checking around the architecture plan and confirming the Positions of the washrooms.
4. From the fig 3 and 4 we can see the framing plan of the typical floors.

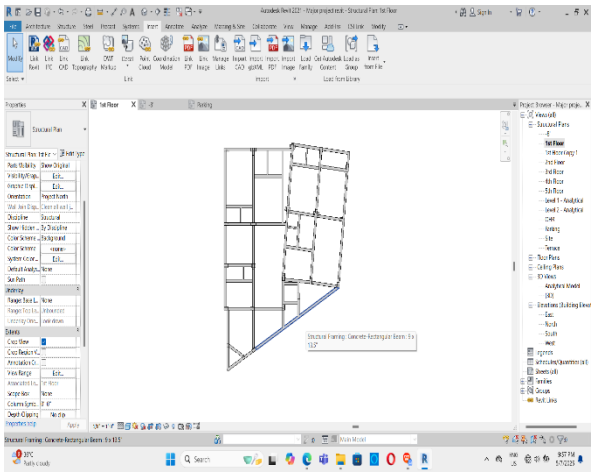


Fig. 3 Typical Floor Framing plan with Beams and columns.

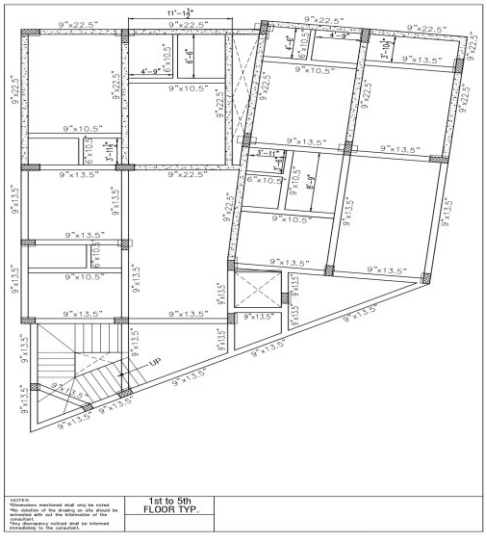


Fig. 4 Typical Floor Framing plan with Beams and Columns Details.

5.6 Placement of Slab at Typical floor Levels:

1. For Placement of Slabs the Slab Thickness the we will be taking is

   4.5" THK.

2. So, by calculating the

   i. Ly/Lx>2

   ii. Ly/Lx<2

   iii. Ly/Lx=2
3. We will be asking it as a One-way slab or Two-way slab.
4. We will also place the suken slab at the washroom areas, where the slab will be 6" sunken compared to the other slabs.
5. As seen in the fig 5 the arrow on 4 sides showcases the two-way slabs.

And the arrow that showcases on just two sides are the one-way slabs.

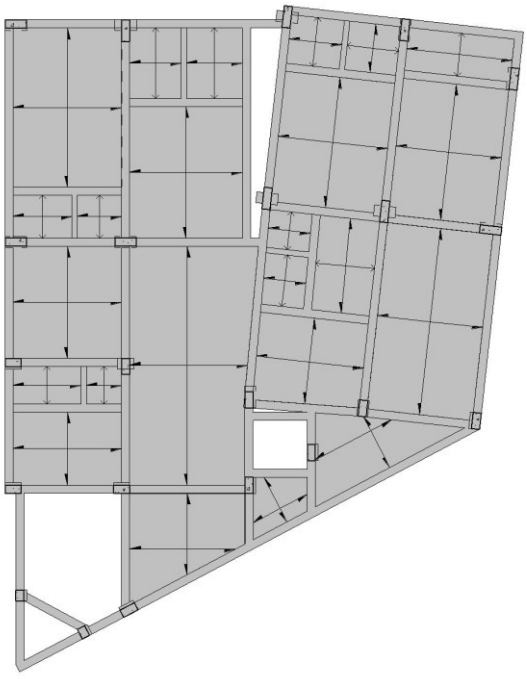


Fig. 5 One way and two-way slab placement.

5.7 Procedure After the placement of Structural Element:

5.7.1 3d model of the structure:

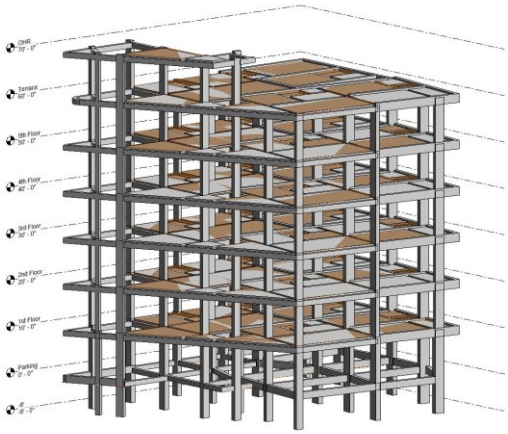


Fig. 5.7.1 3D model of the structure.

1. According to the Fig 5.7.1 the 3D model of the Structure is ready without any clashes seen between the beam's columns and slabs.
2. The 3D model is ready with the proper material properties so that after exporting it to the etabs will be having to do the analysis.

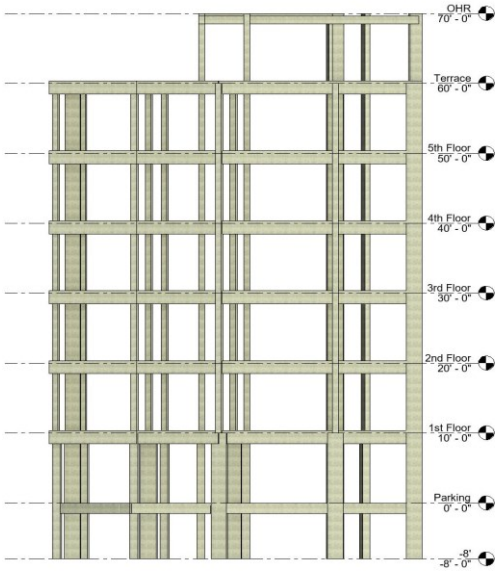


Fig. 5.7.2 North Side Elevation View in Revit.

VI. STRUCTURAL ANALYSIS AND OPTIMIZATION IN ETABS

There is several computer software for building structure analysis and design of which ETABS is one of the most popular. It is produced by Computers and Structures, Inc. (CSI) and it is popular among engineers, thanks to its effectiveness and easy use in every stage of construction of structures that feature reinforced concrete and steel reinforcing bars.

I calculated in ETABS version 21 which also seems to have an added advantage in terms of its efficiency compared to the previous version. This type of system can accommodate high level of analysis while it is easy to use when it comes to modeling, loading or any other design aspects. ETABS allows its user to perform simple and complex load doing namely – gravity loads, wind loads and seismic loads all within the set industry standards.

Since my building model was created in Revit and I needed to transfer it to ETABS, I used CSI Revit-ETABS Link plugin to export structure to ETABS.

ETABS also contains the provisions of Indian Standards in the following:

IS 456:2000 for RCC design

IS 875 – Dead and Live Loads

IS 1893:2016 for earthquake load calculation

6.1 Material Properties and Design Standards

The Material Properties was checked and confirmed or Reassigned as per the structural project design.

Concrete Grade used M-25 M-30

Steel Grade used Fe-415 Fe-500

The analysis and design were done following Indian Standard (IS) codes:

IS 456:2000

IS 875 (Part 1 & 2) – Dead and live loads.

IS 1893 (Part 1) – Seismic design for buildings.

6.2 Load Cases and Load Combinations

- Dead Load (DL)
- Live Load (LL)
- Seismic Load
- Wind Loads

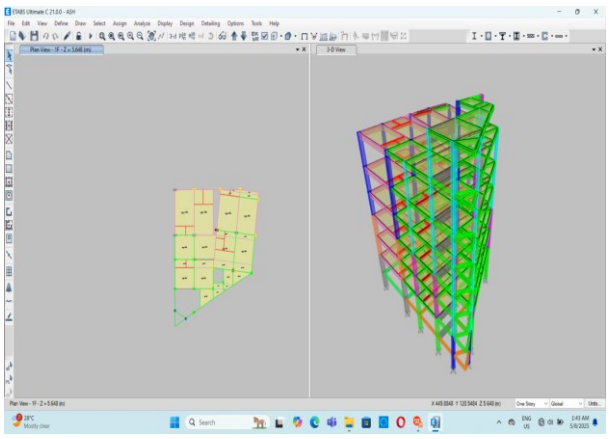


Fig 6.2.1 Plan and 3d Model in Etabs.

After Importing the Revit Structure Model in etabs with the desired Material properties of

the structural elements, we can observe the plan view and the 3d view in the Etabs software on which we can do analysis and optimization if any.

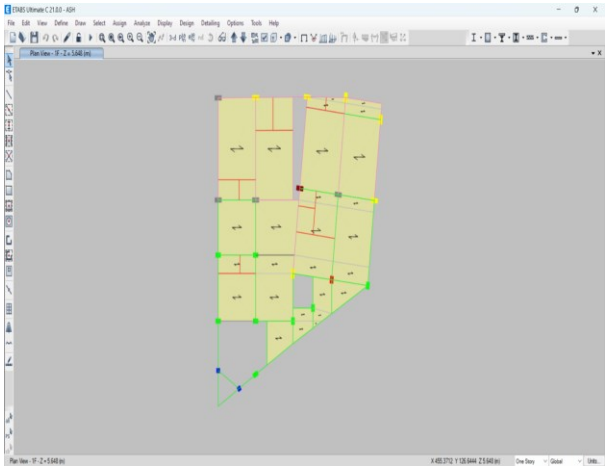


Fig 6.2.2 Plan view In Etabs.

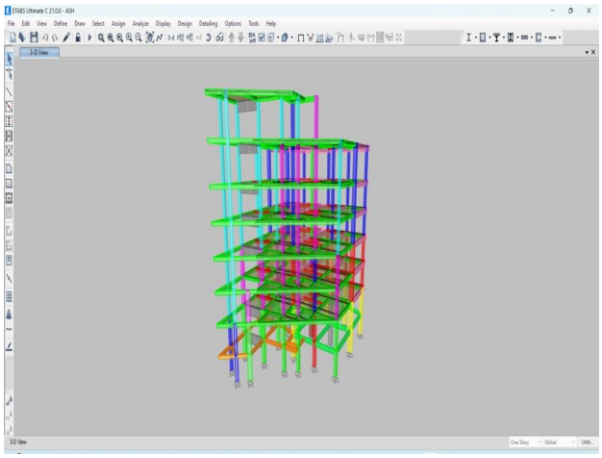


Fig 6.2.3 3D view In Etabs.

VII. RESULTS AND DISCUSSIONS.

After running Analysis, we got in this respect, the results of the critical analysis from ETABS after importing the structural model are presented in this chapter. It implies therefore, that the purpose is to examine the behaviour of the building subject to different loads; that is, dead loads, live loads and the seismic forces. Among the examined diagrams, bending moments, shear forces axial forces and lateral displacements are computed. These results help validate the assumptions in the design and performance of the structure in respect to safety and serviceability (is codes). The graphics outputs generated from ETABS aid in understanding how the forces are distributed and how the building reacts to the forces.

Below the image is an animation representing an important structural performance aspect with a brief interpretation.

VIII. CONCLUSION

The concept of this project was to research and work on BIM based Mid Rise RCC Building workflow in structural modeling and analysis with the help of Autodesk Revit and ETABS v 21. All stages of the modeling were carried out in Revit to find the precise location for the pivotal structural elements of the barrel, column, beam, and slab in the first place. After the completed BIM model was exported to ETABS the special structural analysis was carried out.

ETABS implementation allowed both dead load, live load and seismic forces applied in the X and Y directions to be examined. Results showed the bending moment diagrams, shear force diagrams, axial force distribution, story displacement and drift graph. Outputs of such combinations in analysis of the structure's response was researched.

The merging of Revit & ETABS to some extent propelled the suppression of the errors of manual modeling and offered a possibility to simplify the solution optimization process. In all the results proved positive; the result of which is that the building was structurally sound and sound serviceable and this against IS codes. The project explains that a combination of BIM tools with analysis abilities could positively influence a better structured and more efficient, coordinated design process with less cycles of changes of drawings.

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