Elasto-Plastic Analysis of Multi-Storey Building using BIM

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Abstract **The construction industry is moving towards digitalization, with greater amount of information being stored digitally. This development is being addressed by Building Information Modelling (BIM) technology. BIM is process of creating virtual building model which is parametric in nature, supporting collaboration among different specialists, provides the ability to analyse the building in simulated 3-D environment. BIM is disruptive technology which enables faster, safer, less wasteful construction of structure thereby offers more cost effective, sustainable operation and maintenance. BIM has many inherent advantages but the employment of the same in structural engineering is limited. The present work is an effort to understand seismic analysis of building and concept of BIM jointly.**

This paper examines the performance evaluation of the (G+10) storey reinforced concrete (RC) frame building designed as per Indian code. Both linear elastic and nonlinear in-elastic responses of building is investigated. These structural responses are evaluated using the static analysis and the nonlinear static (pushover) procedures. Later, results of static and pushover analysis is compared with few parameters include base shear, roof displacement and ductility in the structure. Also, the role of BIM in structural engineering is assessed in order to determine its advantages. The interlinking of BIM with ETABS- structural analysis software is evaluated. Application of BIM such as visualization, clash coordination and material takeoff are also presented. The research work in this paper paves the way for future research into field of structural engineering in conjunction with BIM.

Keywords —Building Information Modelling (BIM), Clash Detection, Digitalization, Disruptive Technology, Material Takeoff, Pushover Analysis, Static Analysis, Sustainability.

I. INTRODUCTION

The term earthquake is the treacherous phenomenon turn out when blocks of the earth surface slip past each other suddenly. Earthquake forces are random in nature & unpredictable, have the potential for causing the greatest damages [1]. When it comes to construction industry this kind of incident jeopardise precious lives, properties result in economic loss. It is impossible to prevent future earthquakes, but careful design of structure can certainly help to minimize the loss.

Existing structures have shown that traditional earthquake design approach is ineffective and inadequate to meet safety
and economy. To address the traditional method of earthquake resistant design, extensive research is devoted to establish a feasible way to predict actual behaviour of structure during seismic event.

Performance Based Design (PBD) is a present-day modern design process to create earthquake resistant structure. Its goal is to figure out and anticipate the performance of structures in future earthquake. This notion permits the owners and designers to select personalized performance goals for the design of different structures [2]. According to PBD, damage is more closely related to displacement than force so displacement should be the governing element. The nonlinear Response History Analysis and Pushover Analysis both are considered as a robust approach for seismic assessment and PBD of building structures. The nonlinear Response History Analysis procedure can accurately predict the seismic demands and capacity of buildings However due to the inherent complications and uncertainties in the method, it is often limited to research and design verification of important projects [3]. Hence Pushover analysis can serve as an alternative and an attractive option for structural engineers.

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Pushover analysis is a convenient and quick method to explore the nonlinear behaviour of building. The analysis involves applying horizontal loads, in a prescribed pattern, to the structure incrementally, i.e. pushing the structure and plotting the total applied shear force and associated lateral displacement at each increment, until the structure reach collapse condition [4]. Linear analysis is far from accurate, while nonlinear analysis is more difficult but can give rational result [5]. Pushover analysis used to determine the force displacement relationship i.e. the capacity curve and observe the successive damage states of a building structure [5,6]. It also estimates the global lateral strength, global displacement and ductility of a structure under lateral forces.

The arrival of recent computing tools, software applications revolutionized the nonlinear analysis methods. Pushover analysis is carried out on the computer simulation structural analysis program. Extended Three-Dimensional Analysis of Building System (ETABS)-structural analysis software can perform nonlinear analysis of structural systems. In ETABS in-elastic deformation of members is capture by hypothetical element- plastic hinge.

The construction industry is moving towards digitalization, with greater amount of information being stored digitally. The industry also paid more attention to product appearance, performance, sustainability and other aspects. The performance mandates of a sustainable building are building integrity conditions such as Building automation/smart building systems, building structural stability, fire safety, earthquake resistance, maintainability, resource (energy, water and materials) efficiency, and building security condition. The development of Building Information Modelling (BIM) technology caters to such demands [9,10].

BIM is process of generating virtual building model which is parametric in nature, supporting collaborative design among different specialists, provides the ability to analyse the building in simulated 3-D environment. BIM gained great importance as it support digitization along with centralization of all building related information at one place.

Structural engineers in the building industry face many challenges like design change, when a design change is requested, it affect collaboration between teams. When including analysis into the BIM process, changes in the model can be quickly conveyed to other project specialists. Structural engineers gain project insight in preconstruction stage of the project and help to provide accurate information to fabricator. Figure 1 depicts various BIM applications.

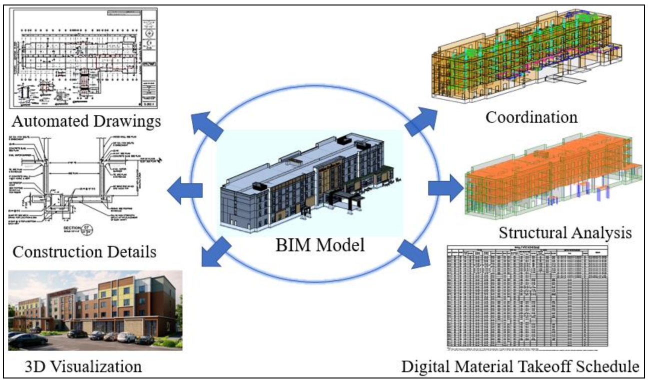

Figure 1 BIM applications

The currently available methodologies like BIM have the potential to improve the structural design process by using the advantage of automation. Despite various capabilities, using BIM in facilitating structural design has remained an unexploited area [11].

This paper is an effort to bridge the gap between structural engineering and BIM. Therefore, the paper aims to perform seismic analysis of building structure using ETABS then provide a practical automated process to generate a structural BIM model to recognize BIM benefits and hindrances in structural engineering.

II. LITERATURE REVIEW

Timothy Sullivan, Daniel Saborio-Romano et al (2018) created a simplified pushover analysis for RC frame structures to find displacement profile of RC frames from contributions of previous research work in same field.

Maysam Jalilkhania, Seyed Ghasemib et al (2020) combined multi-modal and adaptive pushover analysis and performed seismic analysis on 4,8,12 and 20 stories special moment resisting RC frames. This method provided satisfactorily estimate of interstory drift ratio and hinge plastic rotation.

Samir Al-jassim, Mohanned Husssain (2018) performed nonlinear static procedure for G+5 storey RC building, located at Basrah, Iraq by considering irregular plan and elevation. The result showed building irregularity does not affect analysis output.

Mohamad Amini, Mehdi Poursh (2018) proposed adaptive force-based multi-mode pushover (AFMP) procedure to predict the seismic response of midrise building. It was examined that AFMP procedure offers acceptable accuracy to estimate responses of midrise building.

Karanpal Singh, Arshad Hashmi et al (2021) evaluated response reduction factor value for regular frame structure by varying stories and compared calculated response reduction factor with IS 1893 values. The results proved that the values in Indian code are on the safer side and the response reduction factor value changes as the storey

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number changes.

Tofigh Hamidavi, Sepehr Abrishami (2020) conducted survey and distributed the questionnaire to professional structural engineers to ask most challenging tasks in completion of project. It was found that interoperation with other team, structural design automation are main reported challenges. Study in this paper also examined that applications of BIM in structural design is limited while BIM has great potential and capability to facilitate structural design.

F. Hewavitharana, A. Perera (2020) reviewed articles to evaluate how BIM and Enterprise Resource Planning (ERP)
integration in construction project addresses sustainability. BIM perform the complex building performance analysis, ERP does integrate and streamline the business processes, cost reduction, and quality improvements. It is identified that ERP together with BIM can be beneficial to facilitate sustainability in project.

Alcinia Sampaio, Augusto Gomes (2021) evaluated interoperability between BIM-based software with structure analysis software. BIM tools can perform design of structures with many benefits.

Bilal Manzoor, Idris Othman (2021) examined causes of accidents at construction site. Research outlined that visualization technology in BIM can identify the risks involved in construction of project in early stage and help to
enhance safety.

Darren Olsen, and J. Mark Taylor (2017) conducted surveys
and questionnaires to ask General contractor (GC) about BIM based quantity take-off (QTO) and CAD-based traditional QTO as comparison. Results of surveys and interviews suggested that BIM-based QTO is advantageous but software complexity is the main problem with it. Another problem during QTO, BIM models provided to GC are not complete in terms of data.

F. Ugliottia, A. Oselloa et al (2019) investigated BIM methodology and tools to create structural BIM model of existing pavilion school complex, Turin. Best and reliable way to convert the BIM model into a finite element model was investigated. Parametric nature of BIM model helped to make the most of the data for analysis and minimise the modelling effort in structural analysis program.

Lino Maia, Pedro Mêda et al (2015) created BIM model of laundry of a hospital using BIM tool and its advantages and
disadvantages in various operations such as preparation, revision, coordination are evaluated. It was concluded that higher RAM capacity of computer is required to work in virtual BIM environment, also high early time is consumed to fill in the data in BIM model.

D Savitri, A Pramudya et al (2020) performed structural, architectural, and MEP clash analysis on mid-rise building using BIM-based software. Clash detection and coordination between elements modified quantity and cost estimation of project.

Botagoz Akhmetzhanova, Abid Nadeem et al (2022) aimed to find current practice of clash detection analysis using BIM in the Republic of Kazakhstan. Recent three years shown that Kazakhstan's (architecture, engineering, and construction) AEC industry has started to use modern technology such as BIM. Main causes of clash collision is complexity of the modelled objects, incomplete model information, insufficient time, utilization of different file formats during the design phase.

Felipe Muñoz-La Rivera, Juan Vielma et al (2019) defined a methodology to implement and adopt BIM in the structural engineering companies (SECs) to provide well integrated and coordinated platform. BIM-focused workflow, generation of protocols, efficient assignment of roles, training strategies and other specific elements are key elements for successful BIM implementation.

Ryan Solnosky (2018) researched on traditional curriculums for structural engineering and different mechanisms to deploy BIM. BIM Implementation can transform and improve learning. The concepts of structural engineering can be easily visualized by the engineers.

III. METHODOLOGY

The methodology adopted for the present study is divided into two parts. (1) This part compares the analytical conclusions of linear static analysis with nonlinear static pushover analysis of building so as to evaluate complete elasto-plastic behaviour. The mathematical model is evaluated using a computer-based tool, ETABS 18:0:2 software. (2) This part aim to identify the potential benefits and challenges associated with using BIM in structural engineering. In this systematic Revit Model generation from ETABS using CSiXRevit tool is presented. Centralization of all the information i.e., work in collaboration, clash coordination, digital material take-off are also discussed. Figure 2 represent current methodology in graphical format.

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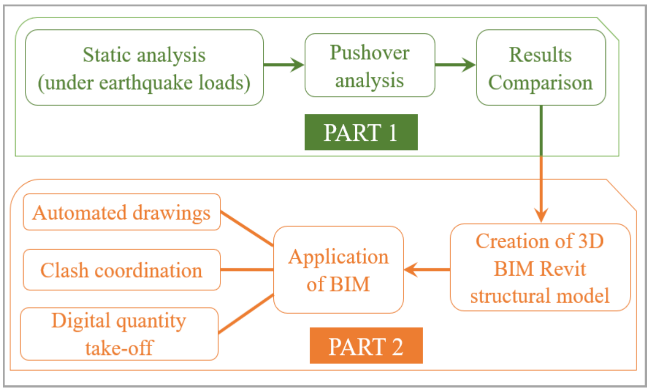

Figure 2 Methodology

IV. EXAMPLE BUILDING

A G+10 storey reinforced concrete frame building is considered. The structure is having 24 m × 20 m plan area which is same through the height is considered. Bay spacing between columns along longer side is taken as 4 m c/c with 6 number of bays while along shorter direction taken as 5 m c/c with 4 bays. Loads are applied to structure as per Indian standard code. Table 1, 2 and 3 define description of building, seismic properties and loading properties respectively. Figure 3 represent ETABS model of building.

Table 1: Description of Building

S.no.	Parameters	Details/value
1	Plan dimensions	24 m × 20 m
2	Stories	G + 10
3	Height of building	33 m
4	Storey height	3m
5	Grade of concrete	M30
6	Grade of steel	Fe 500
7	Frame type	SMRF
8	Outer wall	230 mm
9	Inner wall	115 mm
10	Parapet wall	115 mm
11	Slab thickness	150 mm
12	Exterior column	0.5 m × 0.5 m
13	Plinth beam	0.23 m × 0.45 m
14	Floor beam	0.23 m × 0.3 m

Table 2: Seismic Properties- IS1893:2016 (Part I)

Parameters	Details/value
Seismic Zone	III
Seismic Intensity, Z	0.16
Importance Factor, I	1.2
Response Reduction Factor, R	5
Soil Profile Type	Medium

Table 3: Loading Properties

Load Type	Structural Element	Value
Dead Load (DL)	Outer wall	12.42 kN/m
	Inner wall	6.21 kN/m
	Parapet wall	2.07 kN/m
	Floor finish	0.75 kN/m^2
Live Load (LL)	Typical floors	3 kN/m^2
Roof Live Load (RL)	Roof floor	1.5 kN/m^2

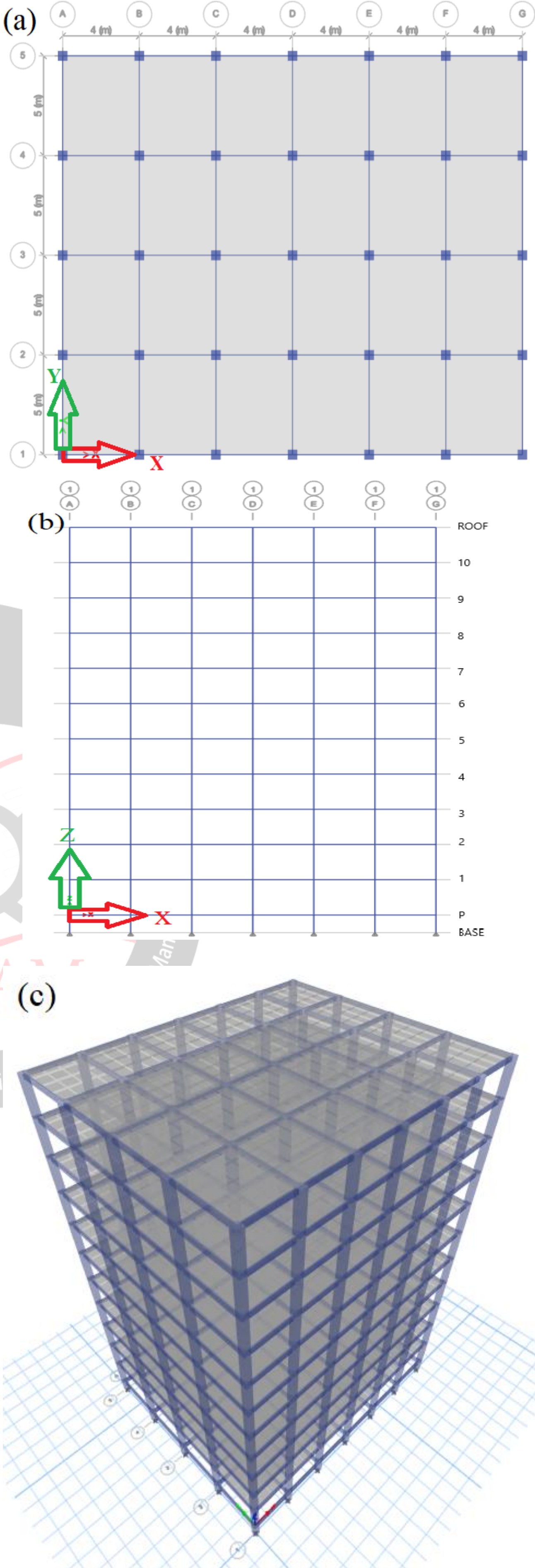

Figure 3 (a) Plan view of G+10 tall building. (b) Elevation of G+ 10 tall building. (c) 3D view of G+10 tall building.

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V. Linear Static Analysis of Building

Equivalent lateral force procedure (ELF), Equivalent static force procedure (ESF), and Seismic coefficient method are all names for the linear static analysis approach. Linear static analysis is the simplest & most basic analysis procedure which assumes structural behaviour is linear & seismic loading is static. In this analysis, the member's deformation is related to the internal forces and is recoverable again when the forces are withdrawn i.e., There is a linear relationship among the applied force and the displacement. Linear analysis refers to determining structural dynamic qualities and their responses using linear elastic, material, or geometric properties of elements. The basic idea of the ELF method is to convert the excitation of an earthquake into an equivalent static force and apply it to the base of the building. This is called the base shear. This base shear is allotted to the numerous stories of building. The storey load increases as the corresponding height to the base increases. Likewise top storey generates maximum load. The approximate duration of the building determines the amount of base shear considered in design step. Building is evaluated by linear static analysis procedure and

outcomes of elastic assessment are shown as follows: -

A. *Base shear*

Table 4 shows base shear distributed among different stories and the total base shear developed in X and Y Direction. Figure 4 represents the same. The building producing more base shear in X-direction than in Y-direction.

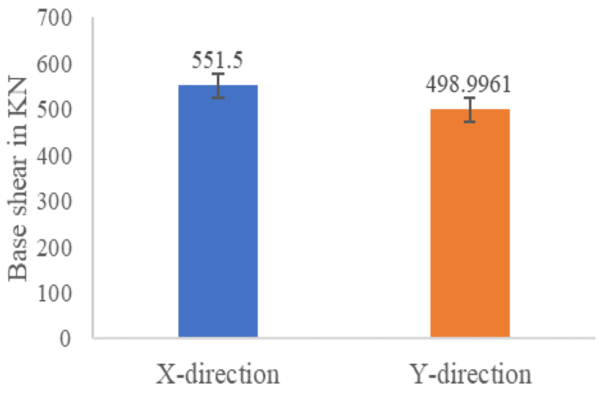

Figure 4 Base shear for seismic force in X and Y direction

B. *Storey displacement*

As stated in Table 4, lateral displacement of storeys increases with height and it's far most at top storey in each X and Y direction. The results of storey displacements is illustrated in Figure 5.

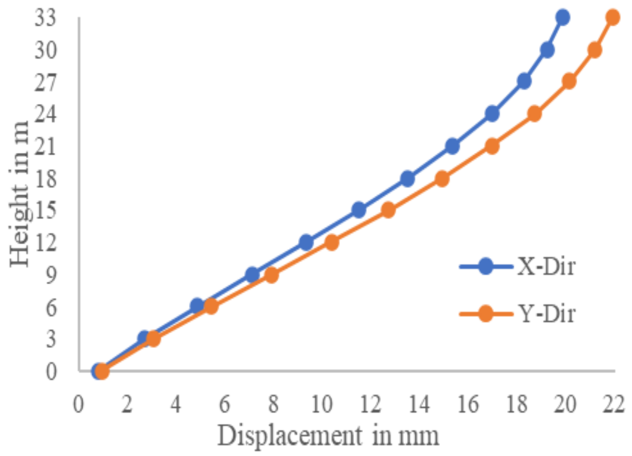

Figure 5 Storey displacement in X and Y direction

A. *Storey drift*

Table 4 defines the result of storey drift in X and Y direction. Storey drift in each directions is maximal in storey 3 and begins to decrease with height. Figure 6 illustrates the storey height versus lateral drift curve.

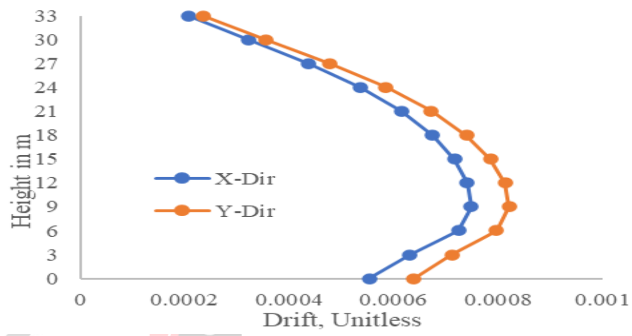

Figure 6 Storey drift in X and Y direction

B. *Storey stiffness*

The result of Storey stiffness in X & Y-direction is tabulated in Table 4. Figure 7 represents the same, it was observed that there was a sudden drop of stiffness from plinth level to first floor level. The storey stiffness in both directions is maximum at storey P, with increase in height the value of storey stiffness goes on decreasing and vice versa. Storey stiffness indicates the energy dissipation capacity of building produced to seismic vibrations.

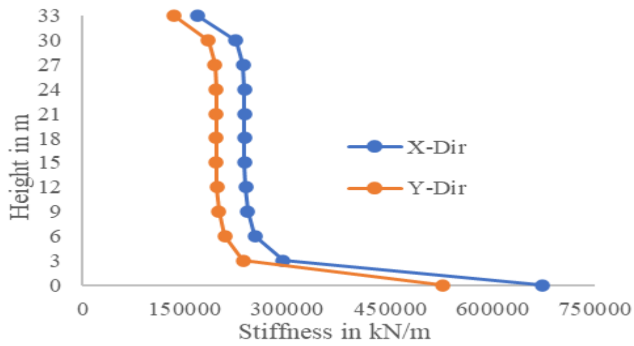

Figure 7 Storey stiffness in X and Y direction

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Table 4: Static Analysis of Building

Storey	Elevation (m)	Storey displacement		Storey Drift		Storey Stiffness		Storey lateral loads	
		X-Dir (mm)	Y-Dir (mm)	X-Dir	Y-Dir	X-Dir (kN/m)	Y-Dir (kN/m)	X-Dir (kN)	Y-Dir (kN)
ROOF	33	19.849	21.905	0.000207	0.000235	168816.5	134691.5	104.8845	94.8993
10	30	19.227	21.2	0.000321	0.000354	224738.3	184325.3	111.2541	100.6625
9	27	18.266	20.139	0.000436	0.000477	234954.2	194154.2	91.0719	82.4017
8	24	16.958	18.708	0.000535	0.000585	236861.8	195913.2	72.908	65.967
7	21	15.353	16.952	0.000614	0.000672	237135.9	195986	56.7623	51.3584
6	18	13.511	14.935	0.000674	0.000739	237190.3	195825.9	42.6348	38.5759
5	15	11.489	12.72	0.000716	0.000785	237480.3	195903.1	30.5255	27.6194
4	12	9.342	10.364	0.000741	0.000813	238546.9	196701.1	20.4344	18.489
3	9	7.118	7.924	0.000748	0.000821	241908.7	199419.9	12.3616	11.1847
2	6	4.874	5.461	0.000724	0.000797	252773.6	207768.8	6.3069	5.7065
1	3	2.701	3.07	0.000631	0.000711	293167.6	235141.5	2.2705	2.0543
P	0	0.831	0.958	0.000554	0.000639	672065.5	526441.2	0.0855	0.0774
Base Shear								551.5	498.9961

VI. PERFORMANCE BASED DESIGN & PUSHOVER ANALYSIS OF BUILDING

In Performance Based Design, it is identified that the inelastic seismic demands are related to the inelastic capacity of structure so whenever inelastic capacity increases, the period of structure elongate, damping rises and demand decreases. This process primarily requires that the expected performance objectives be clearly defined. These objectives analogous to a seismic hazard level and the anticipated performance levels of the structure. FEMA 445 guidelines prescribed following performance levels according to damage in in-elastic state of structure: -

- Operational (O)- Negligible damage in building but building is intact
- Immediate-occupancy (I.O.)- Negligible damage in building, safe to occupy but possibly utilities may not function
- Life-safety (L.S.)- Building is safe during event but possibly it undergoes significant amount of structural damage, cannot occupy until repair.
- Collapse-prevention (C.P.)- Building is on verge of collapse, repair is not practical, probable total loss of structure.

Out of above, the objective of most codes is to provide life safety performance during large and infrequent earthquakes where major focus paid to reduce the threats to life.

Figure 8 shows the typical process of PBD

PBD requires rigorous nonlinear analysis for in-elastic analysis and performance evaluation of structure. Pushover analysis is a static, nonlinear method in which monotonically increasing static (lateral) loads are applied to the structure until specified displacement is attained or a collapse mechanism has occurred. It offers an idea about maximum base shear that the structure can withstand at the time of the seismic action.

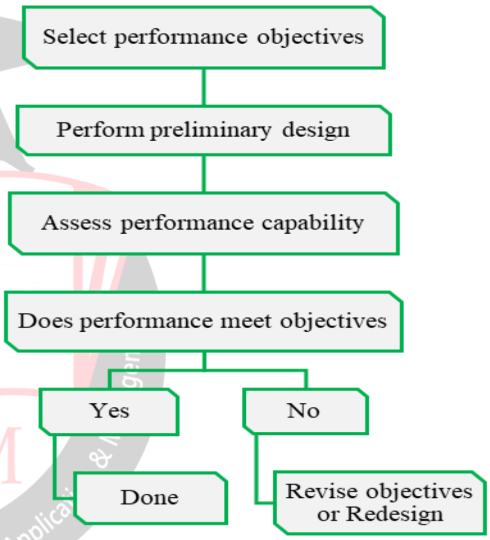

Figure 8 Performance Based Design procedure

Pushover analysis is used to arbitrate a structure's force displacement relationship, often known as the capacity curve/pushover curve. The initial stiffness, ultimate strength, yield displacement, yield strength, displacement ductility, sequence of component yielding, probable mode of failure, and last state of the structure are all represented and determined by the capacity curve. This provides a clear understanding of variations in structural response and the achievement of various limit states as the structure enters in inelastic range.

Pushover analysis can be conducted by software computing tool, where the Non-linear (mathematical) computer model of the structure is laterally pushed with step-by-step loading increments. In present work ETABS is used for pushover analysis. Using plastic hinge concept of ETABS lumped plasticity model of structure is created. The

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structure is pushed until enough hinges are created to allow for the development of a pushover curve. Table 5 define the pushover analysis criteria considered in ETABS.

Nonlinearity of components is denoted by hinges and corresponding Idealized Force-Displacement Curve is shown in Figure 9.

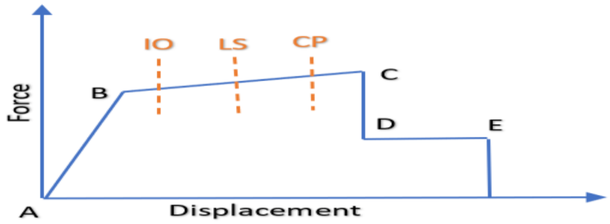

Figure 9 Idealized Force-Displacement Curve

Where,

Points A, B, C, D and E represent the force deformation behaviour of plastic hinge

point A to B represents elastic range

point B to C represents plastic range

point C to D represents strain hardening

point D to E represents only gravity loads sustain

Table 5: Pushover Analysis Assumed Criteria

S. No	Parameters	Details
1	Initial conditions	Zero initial conditions-start from unstressed state
2	Load type	Acceleration
3	Load application	Displacement control
4	Control node	Roof

Non-Linear static pushover analysis is performed on the example building. Table 6 and 7 represents results of pushover analysis in X and Y directions respectively. Figure 10 and 11 shows pushover curves base shear vs. (control node) roof displacement of building, in X and Y directions.

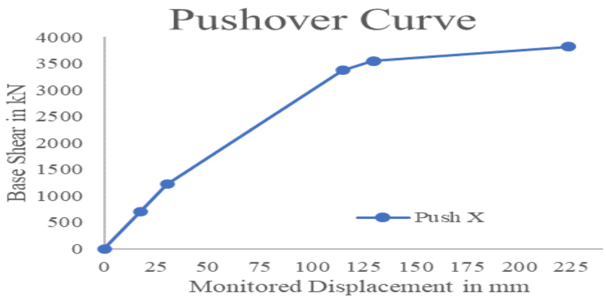

Figure 10 Pushover curve in X–direction

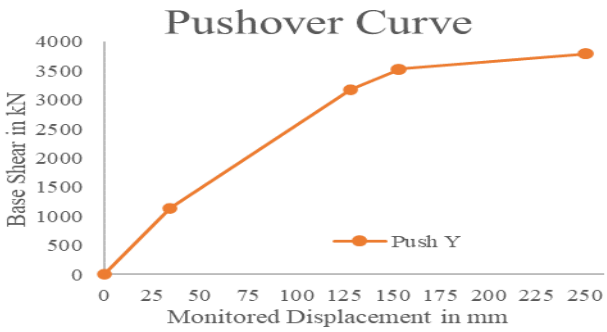

Figure 11 Pushover curve in Y–direction

Table 6: Base Shear vs Monitored Displacement-Push X

Step	Monitored Displacement (mm)	Base Force (kN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	4464	0	0	0	0	4464	0	0	0	4464
1	17.25	697.59	4464	0	0	0	0	4464	0	0	0	4464
2	30.276	1224.11	4444	20	0	0	0	4464	0	0	0	4464
3	114.824	3372.52	3718	746	0	0	0	4464	0	0	0	4464
4	129.638	3549.45	3678	786	0	0	0	4464	0	0	0	4464
5	129.96	3551.81	3674	790	0	0	0	4464	0	0	0	4464
6	223.215	3819.17	3620	838	6	0	0	4274	120	70	0	4464
7	223.568	3818.44	3620	838	6	0	0	4274	120	65	5	4464

Table 7: Base Shear vs Monitored Displacement-Push Y

Step	Monitored Displacement (mm)	Base Force (kN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	4464	0	0	0	0	4464	0	0	0	4464
1	34.5	1140.36	4436	28	0	0	0	4464	0	0	0	4464
2	128.227	3182.18	3882	582	0	0	0	4464	0	0	0	4464
3	153.174	3525.18	3800	664	0	0	0	4464	0	0	0	4464
4	153.465	3527.17	3796	668	0	0	0	4464	0	0	0	4464
5	250.067	3796.30	3748	706	10	0	0	4282	112	70	0	4464
6	250.431	3791.11	3748	696	20	0	0	4282	112	60	10	4464

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VII. Results And Discussion

Pushover analysis is conducted on building in order to determine Base shear, Roof displacement and Ductility capacity. There are overall 4464 plastic hinges formed within the structure. Performance of elements were recognized by the plastic hinge rotations. In the X direction, hinges does not cross the immediate occupancy level until step 5. Up to this level, the structure is at the operational level.790 hinges in BC range indicating nominal yield in elements. As the lateral load continues to increase in step 6, 70 hinges will exceed the life safety performance level. At this point structure becomes unstable and approaches to the point of verge of collapse. Similarly, in Y-direction structure generated a maximum base shear of 3796.30 kN with inelastic displacement of 250.06 mm. In step 6, 10 hinges cross collapse prevention level results in failure of the structure.

Base shear value obtained from static and pushover analysis is compared and shown in table 8. Similarly, comparative roof displacement values are shown in table 9. Under Pushover analysis, building produced more base shear and displacements than linear static analysis method because pushover analysis continue further analysis in in-elastic part.

Table 8: Base Shear (kN)

Analysis type	Static analysis	Pushover analysis	
		At yield point B	At ultimate point C
X-Direction	551.5	1224.11	3819.17
Y-Direction	498.99	1140.36	3796.30

Table 9: Roof Displacement (mm)

Analysis type	Static analysis	Pushover analysis	
		At yield point B	At ultimate point C
X-Direction	19.84	30.27	223.21
Y-Direction	21.90	34.5	250.06

Ductility capacity of structure indicates that it is able to undergo inelastic displacement of (223.21-30.27) 192.93 mm and (250.06-34.5) 215.56 mm in X and Y directions respectively without collapse. Performance level and ductility of the structure can be improved by re-designing components where hinges pass the collapse prevention level early. Calculated ductility of the structure is found approximately $\mu = 7$ as shown in Table 10.

Table 10. Ductility Capacity

Displacement			Ductility
Analysis type	Pushover analysis		$\mu_s = \Delta max / \Delta y$
	At yield point B	At ultimate point C	
X-Direction	30.27mm	223.21mm	7.37
Y-Direction	34.5mm	250.06mm	7.24

VIII. Building Information Modelling In Structural Engineering

The building industry's fast growth has created more sustainability challenges than ever before. Some of the main issues are; over usage of energy and resources, negative environmental impacts, excess use of money, non-adherence to standards. To mitigate these negative effects, sustainable methods should be included during the project design, construction, use, maintenance, and demolition phases. The BIM approach has shown to be an excellent tool for advancing sustainable construction. BIM is the cohesive process of developing federated virtual model for centralization of all building related design information and sharing this information between various disciplines in virtual environment.

BIM is disruptive technology transforming the way of work across the architecture, engineering, and construction (AEC) industry. BIM focuses on the creation of optimized sustainable structures. It demonstrates architects and engineers to simulate sustainability measures like the best orientation of the building for energy saving based on passive solar construction strategy, high-performance thermal insulation, sound levels, natural wind speed and direction, natural ventilation, light affection, and performance of the building envelope. All of these comparisons are quickly performed in a simulated BIM environment to determine the most appropriate and sustainable option for the building. BIM also encourages safety management-reduce casualty, illness, injuries and fatality rates by highlighting the hazards and critical locations at construction site in early stage, promotes sustainability practices.

Use of BIM in structural engineering can achieve sustainability during design and analysis as discussed below:

- Visualization and digital drawings- Visualization will provide clear idea about structure thereby provide ability to take better engineering decisions, structural engineer can explore different design options, owner also get clear picture about the structure, using digital drawings- design changes can be made without delay of time or increase of cost in early stage.
- Clash coordination- If team member of discipline (structural, architectural, mechanical, electrical, plumbing, fire protection) makes a change, all other disciplines are aware and can adjust their parts accordingly so it minimise errors and miscalculations in future (during actual construction)
- Digital material take-off- It material quantity is calculated through BIM it eliminates over ordering and reduce wastage of material.

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In present work, Pushover model in ETABS is converted to BIM model. Once the BIM model is created these above-mentioned BIM applications is further investigated.

There are many software that proffer building information modelling (BIM) based platform such as Autodesk Revit, Vico, Vector Works, Tekla Structures, Navisworks, Bentley etc. All in all, Autodesk Revit is most preferred among AEC industries. Revit includes tools that specifically designed to support BIM. Revit is committed to support interoperability with wide range applications from vendors throughout the industry by add-ins/Plug-ins that enhance ability to perform bi-directional data transfer.

A. Creating the Autodesk Revit Model

There are namely two techniques for data transfer from ETABS to Revit, see Figure 12. Both the methods are discussed below

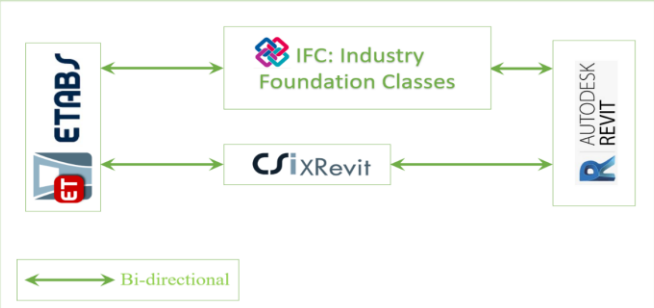

Figure 12 Methods of creating Revit model from ETABS

- Using the IFC format

IFC stand for industry foundation class. Using IFC file, Revit model is generated as illustrated in flowchart of Figure 13. As per step 1 of flowchart-Type of data exported from ETABS into Autodesk Revit 2019 is also shown in Figure 14.

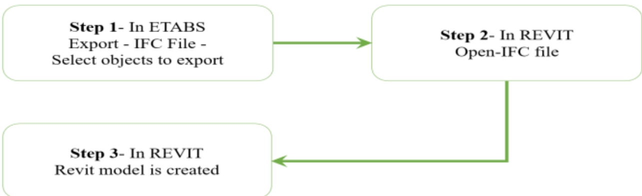

Figure 13 Flowchart of the procedure

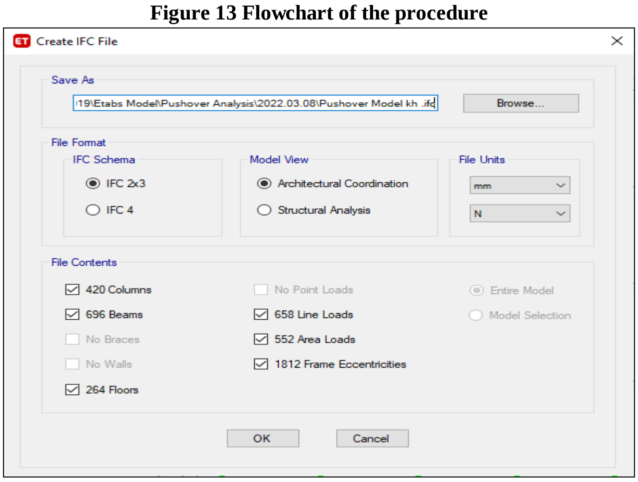

Figure 14 Step 1 of flowchart

From the Figure 14, it can be seen that grid lines which are use to identify position of columns are not transferred into Revit. Inconsistency errors in Revit model were detected after transfer. Specifically, countless neighboring components become separated, requiring a particular check and change. Also, all the components are view only type and can not be changed. So, the IFC format incorporated to generate BIM model is still very limiting as the optimal level of efficiency has not yet been reached.

- Using add-in CSiXRevit

CSiXRevit is bi-directional data transfer tool act as an interoperable bridge or platform for exchanging data between ETABS and Revit. Step-by-step Procedure of creating Revit model using this tool is illustrated in flowchart of Figure 15. Consistency of the Revit model is achieved using this add-in tool.

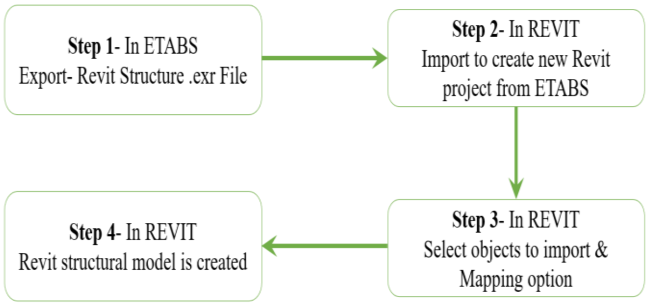

Figure 15 Flowchart of the procedure

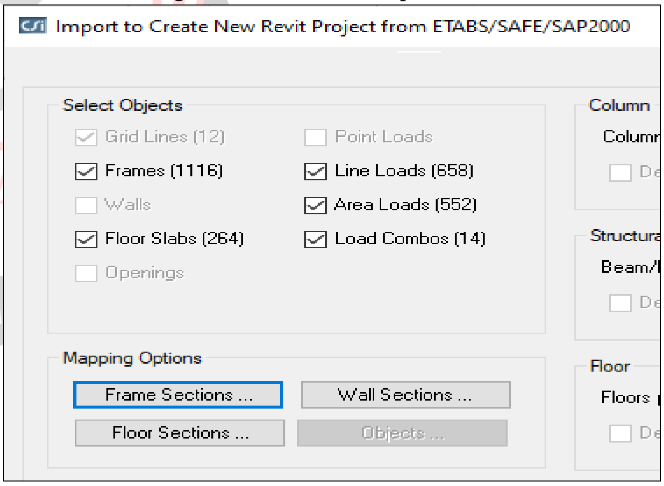

Figure 16 Step 3 of flowchart

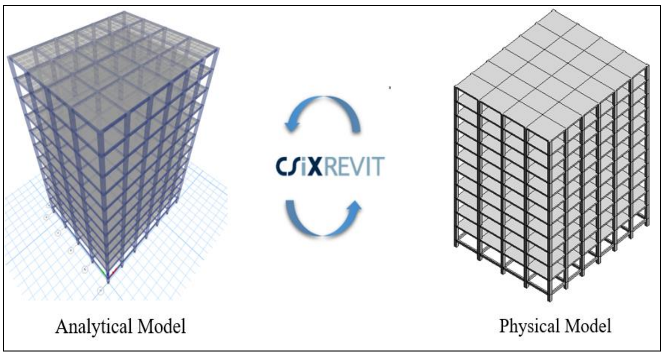

Figure 17 Transformation from ETABS to BIM

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In consonance with Figure 16, along with frames (i.e. structural columns, beams), floor slabs, grid lines, different types of load are also transmitted to Autodesk Revit. Figure 17 depict BIM model generated from ETABS model. As compare to IFC format (technique), model created by CSiXRevit tool is superior as gridlines and loads are also transferred. Based on the model generated using CSiXRevit, different application of BIM is investigated further.

B. Documentation-Digital drawing

From 3D building model in Revit, 2D drawings of floors can be recognized automatically from model. See Figure 18.

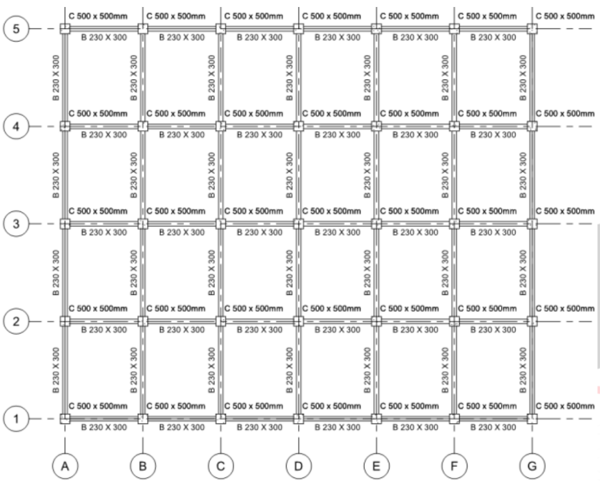

Figure 18 Digital drawing of 1st floor beam level plan

C. Clash analysis and detection

It is a 3D visualization application that can detect physical collisions between the project elements of different disciplines such as structural, mechanical, plumbing and architectural so that it can resolved in the preconstruction phase prior to construction, eliminating the risk of duplication, improving multidisciplinary collaboration and reducing errors.

In this section, clash analysis and detection is accomplished through evaluating models, specifically among structural & MEP. For this, one mechanical Revit model is created. Mechanical model basically made up of mechanical equipment, air terminals, ducts. mechanical equipment which also called as air handling unit (AHU), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system. These AHU are typically connected to a ductwork ventilation system that allows conditioned air to pass through the building and back into the AHU. Typically ducts of ventilation system run through voids between suspended ceiling and floor slab. Clash occurs when structural beam and duct go through one another or are assuming up a similar position.

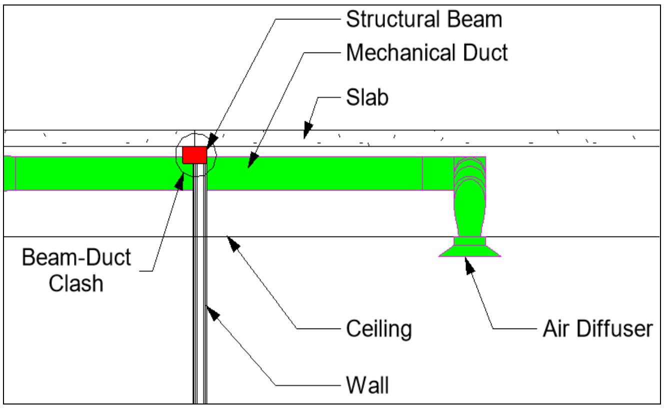

Figure 19 Beam-Duct Clash - Sectional View

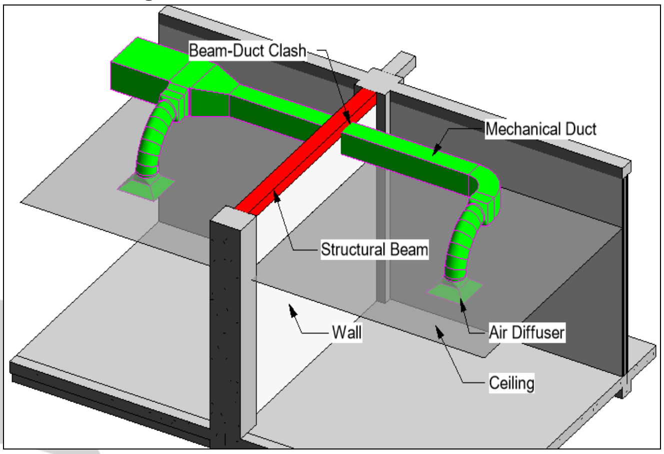

Figure 20 Beam-Duct Clash - 3D View

Interference check tool detected 24 clashes between structural beam and mechanical duct. Figure 19,20 shows one of clash detected between structural beam and mechanical duct. In this situation, clashes can be resolved either by changing the height of duct/re-route the duct or by reducing the depth of beam.

D. BIM-based quantity take-off (QTO)

Traditional QTO is a manual process that involves manually selecting the individual elements, namely (beams, columns, walls and slabs), from the floor plans, elevations and cross sections drawings. Since it is manual process based on human interpretation this approach is very error prone and required estimators to spend a substantial amount of time. If there is any error in drawing this will again lead to miscalculation, It is also very hard to find quantity at complex situations particularly-connections between various building elements (Ex. Joint connection of a beam, a column, and a slab).

Estimators and companies can use BIM to avoid all of these issues. Revit- The BIM platforms has a lot of potential. The BIM program scan 3D model into which it analyzes the drawings and generates a list of material quantity directly from it. As a result, accuracy improves and uncertainty decreases. BIM technologies include 3D object libraries with relevant data that may be incorporated

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into drawings. Modelling the building with "3D objects" (smart objects with attached descriptive data) rather than predetermined lines causes an accurate takeoff in the BIM system.

In this section, based on BIM model QTO schedule for structural column, floor and beam is prepared and shown in Table 11, 12 and 13 respectively.

Table 11: Structural Column Schedule

Base Level	Top Level	Height (mm)	Count	Structural Material	Grade	Width (mm)	Depth (mm)	Size	Total Volume (m³)
Base	P	1500	35	Concrete	M30	500	500	500x500	13.13
P	1	3000	35	Concrete	M30	500	500	500x500	25.35
1	2	3000	35	Concrete	M30	500	500	500x500	25.35
2	3	3000	35	Concrete	M30	500	500	500x500	25.35
3	4	3000	35	Concrete	M30	500	500	500x500	25.35
4	5	3000	35	Concrete	M30	500	500	500x500	25.35
5	6	3000	35	Concrete	M30	500	500	500x500	25.35
6	7	3000	35	Concrete	M30	500	500	500x500	25.35
7	8	3000	35	Concrete	M30	500	500	500x500	25.35
8	9	3000	35	Concrete	M30	500	500	500x500	25.35
9	10	3000	35	Concrete	M30	500	500	500x500	25.35
10	Roof	3000	35	Concrete	M30	500	500	500x500	25.35
Grand total: 420									291.98

Table 12: Floor Schedule

Level	Top Elevation (mm)	Count	Structural Material	Thickness (mm)	Area	Volume
1	3000	24	Concrete	150	480 m²	72.00 m³
2	6000	24	Concrete	150	480 m²	72.00 m³
3	9000	24	Concrete	150	480 m²	72.00 m³
4	12000	24	Concrete	150	480 m²	72.00 m³
5	15000	24	Concrete	150	480 m²	72.00 m³
6	18000	24	Concrete	150	480 m²	72.00 m³
7	21000	24	Concrete	150	480 m²	72.00 m³
8	24000	24	Concrete	150	480 m²	72.00 m³
9	27000	24	Concrete	150	480 m²	72.00 m³
10	30000	24	Concrete	150	480 m²	72.00 m³
ROOF	33000	24	Concrete	150	480 m²	72.00 m³
Grand total: 264					5280 m²	792.00 m³

Table 13: Structural Beam Schedule

Level	Top Elevation (mm)	Length (mm)	Cut Length (mm)	Count	Structural Material	Grade	Width (mm)	Depth (mm)	Size	Total Volume (m³)
P	0	4000	3500	30	Concrete	M30	230	450	230x450	10.868
P	0	5000	4500	28	Concrete	M30	230	450	230x450	13.041
1	3000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
1	3000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
2	6000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
2	6000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
3	9000	4000	3500	30	Concrete	M30	230	300	230x300	4.347

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3	9000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
4	12000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
4	12000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
5	15000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
5	15000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
6	18000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
6	18000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
7	21000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
7	21000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
8	24000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
8	24000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
9	27000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
9	27000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
10	30000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
10	30000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
Roof	33000	4000	3500	30	Concrete	M30	230	300	230x300	4.347
Roof	33000	5000	4500	28	Concrete	M30	230	300	230x300	4.968
Grand total: 696										126.37

IX. CONCLUDING REMARKS

The research carried out in this article involves the seismic analysis of multi-storey building and the use of the BIM methodology to showcase the potential and capability of BIM to facilitate structural design. Following are concluding remarks of present work: -

1) Linear static analysis combined with nonlinear static pushover analysis can provide complete elastic and in-elastic behaviour of the structure. Both analysis techniques must be used to obtain overall performance of the structure.

2) Pushover analysis helps to visualize the complex in elastic phenomenon of buildings by identifying degradation of concentrated concrete hinges.

3) The capacity curve formed under pushover analysis shows the fundamental mode response of structures and provides good estimates of global and local inelastic deformation.

4) The prediction of the yield limit and the ultimate limit from pushover curve can provide information on the ductility capacity of the structure.

5) Linear static analysis assumes that the stiffness (K) is always constant, regardless of the lateral load applied to the structure. This statement is true until the structure is elastic, but when the structure exceeds the elastic limit under higher loads, it behaves inelasticly, which is a limitation of this method. The inelastic effect is not taken into account.

6) The Present work has assessed the current degree of interoperability between the BIM-based system (Revit) and the structural analysis system (ETABS). Building model created in ETABS and the same model is used to create BIM model.

7) Due to support of Revit (BIM authoring tool) to plugin 'CSiXRevit', two-way data transfer is possible between ETABS and Revit, hence quick multidisciplinary collaboration is possible.

8) Construction documents/technical drawings are generated fully automatically when using a building information model, which significantly reduces the time required for detailing.

9) BIM adoption improve construction planning and allows better visualization and collaboration between team members.

10) Due to work in collaboration in BIM platform it increases cross-discipline knowledge among teams.

11) BIM is disruptive technology play important role to deliver the sustainable building.

12) The work indicates a significant area of overlap between BIM and sustainability. BIM system is more efficient when addressing to sustainability issues in construction.

13) Revit's clash detection tool can detect structural, architectural, and MEP team clashes at an early stage, alleviate the risk of cost overruns and request for information (RFI) from contractors during construction .

14) Extracting quantities of materials from parametric Revit model brings precision to work, eliminates errors, and turns hours of tedious work into minutes of work.

15) Autodesk Revit is versatile despite some limitations. From a structural point of view, the current version of Revit/ETABS is not able to transfer complete analysis results. The idea of BIM to centralize all structural information throughout the life of the building is not fulfilled in this case.

16) It appears that Revit cannot store reinforcement

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information: reinforcement percentage, longitudinal reinforcement, shear reinforcement. etc. which is important material in estimating the total cost of the Reinforced Concrete (RC) project.

17) The research in this paper would provoke broader discussions and raising awareness on the BIM technology particularly in the field of structural engineering.

X. Future Scope Of Work

1) Nonlinear structural analysis can be performed with 'PERFORM 3D'.

2) Quantity takeoff of steel can be assessed by modelling rebars in structural beams, columns and slabs in Revit.

3) This paper present one directional transfer of model (From ETABS to Revit). Bi-directional data transfer can also be performed to evaluate its advantages and limitations.

4) Use of SCAN to BIM prior to structural analysis.

5) Adoption of BIM Automation (using DYNAMO) in structural analysis.

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