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COMPARATIVE LINEAR AND NON-LINEAR ANALYSIS OF MULTI-STOREY BUILDING USING BIM

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Abstract : An elastic analysis indicates elastic capacity and first yielding of structures but during severe seismic event building oscillate back and forth and deform in in-elastic zone, so in such case there required evaluation that consider the redistribution of the forces during in-elastic stage of structure. Performance based seismic engineering is a latest generalized design philosophy to earthquake resistance which estimate performance of any structure by application of rigorous nonlinear static technique. Nonlinear static analysis broadly known as pushover analysis is simplified and most preferred method to evaluate performance of structure. As name implies, it’s a process in which the lateral loading along any lateral direction of the structure is applied in incremental fashion in accordance with prescribed loading pattern i.e., " Applying horizontal loads at control node to push the structure & plotting total base shear & lateral displacement at each increment, until structure reaches predefined limit state or unstable condition". This paper aims to evaluate the parametric seismic analysis of multi-storey building by comparing linear static and nonlinear static pushover analysis results using Building Information Modelling (BIM) application. BIM is the complex process of developing single virtual model representative of the building by collecting data from different sources to centralize all the information which is then used in visualizing, rendering, managing, estimating, coordinating various building components of different disciplines in a virtual environment. BIM used in present work to explicate its application particularly in the structural projects.

***IndexTerms* - Performance Based Seismic Engineering, Pushover Analysis, Static Analysis, Building Information Modelling, Virtual model, CSiXRevit, Autodesk Revit, Clash Detection, Material Takeoff.**

I. INTRODUCTION

Earthquake is one of the unpredictable, devastating, dangerous and destructive natural disaster. So seismic evaluation is the only way to substantiate the buildings to resist ruinous earthquake loads. Understanding seismic behaviour of building through easy, handy and most used analysis technique that can simulate all actions possible in buildings during earthquakes is nonlinear equivalent static (pushover) analysis. As the name indicates this procedure is basically a static analysis, records quasi-static lateral inelastic response of structures to determine interrelations between the lateral force and displacement or the pushover curve for a structure. For a quick performance appraisal of buildings under a predictable seismic event pushover analysis can be dependable method.

The concept of performance based seismic engineering (PBSE) have brought pushover analysis to the limelight. PBSE is a latest generalized design philosophy to earthquake resistance which estimate performance of any structure. PBSE made up of two namely Performance Based Seismic Design and Performance Based Seismic Evaluation. These terms interchangeably use in discussion of earthquake resistant design. PBSE is the predictive method permits the design of building to meet certain pre-decided performance objectives.

Pushover analysis is a convenient method to determine the global displacement, lateral strength, ductility capacity and weak components of a building. In structural engineering, latest advancements in computing tools software applications to perform nonlinear analysis made it more exciting and special as it considers nonlinearity of structural member. In pushover analysis formation of plastic hinge in structure or structural member (of computer model) directly show their overall performance at local and global level.

Building Information Modelling (BIM) is a set of interconnected holistic process and technologies empower us to create parametric model in virtual environment to manage building related data in digital format during the building's life-cycle. BIM offers vast opportunities to architects, engineers, stakeholders to explore and discuss various alternatives in Architectural or structural (or any other) design of structure in early stage before actual construction. BIM also generate schedule of various building elements for cost estimating of project.

Main aim of BIM is to create and manage all the information generated throughout the development of the project in one model called as centralized parametric 3D model. This model encompasses all the information of the building and its components such as beams, pipes, HVAC and electrical systems hence work in collaboration can be attained without splitting up the tasks. Fig. 1 shows Versatility of BIM.

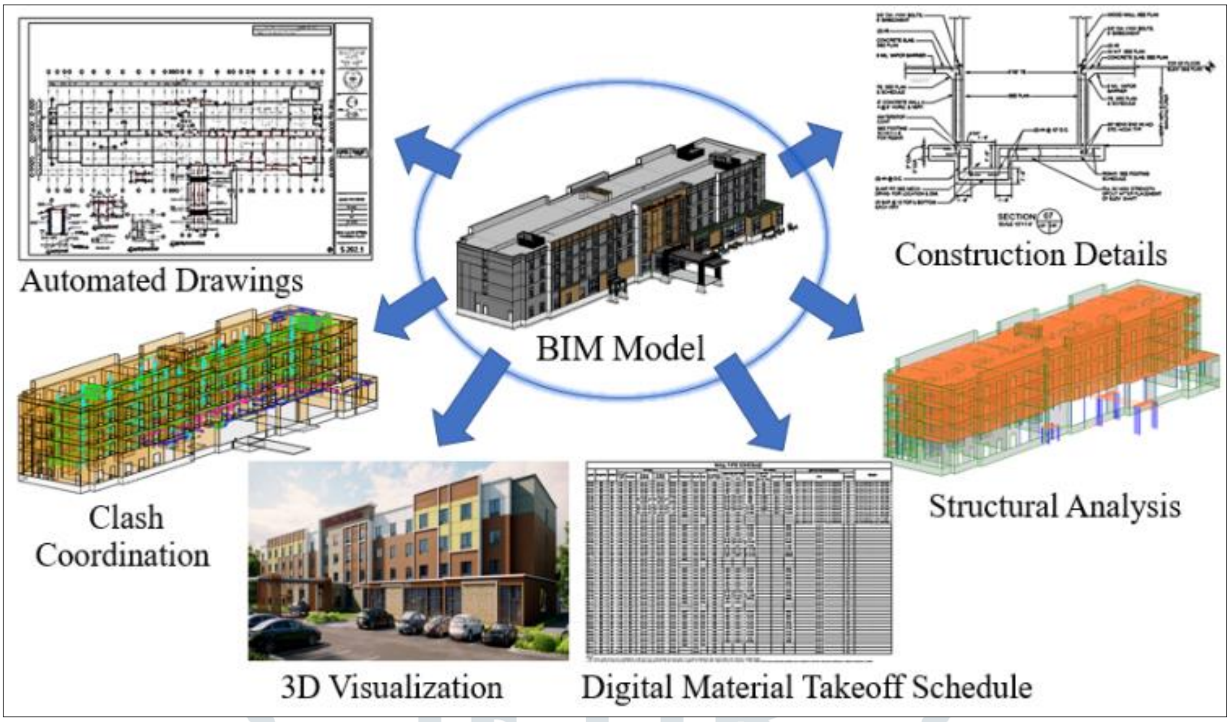

Fig.1 Versatility of BIM

BIM technology has been implemented in all domains of the Construction industry around the world but application of BIM particularly in structural engineering is quite low. the clear message is that BIM-related issues like challenges of BIM implementation on projects have overshadowed the potential of BIM for structural engineering [48]. The present study aims to evaluate the process of generation of structural BIM model after seismic analysis of building structure in ETABS and to identify potentiality, limitations of BIM based tools.

II. Literature review

Fawad Ahmed Najam (2018) reviewed modifications and improvements in nonlinear static analysis procedures (NSPs). It was found that accuracy of nonlinear response history analysis (NLRHA) procedure is more than NSPs. Although NSPs provide valuble insights of nonlinear behaviour and response of structure.

MAP Handana, R Karolina, Steven (2018) performed pushover analysis using ATC-40 capacity spectrum method on existing building structure of Indonesia for its seismic evaluation. The performance level of structure at target displacement found to be Immediate Occupancy (IO) therefore the building is safe.

Rutvik Sheth, Jayesh Prajapati et al (2018) performed Displacement-based adaptive pushover analysis (DAP) on multistorey (6,9,12,15) RC moment resisting frame to evaluate the performance, results were compared with Static Pushover analysis. It was found that results of DAP are more reliable and accurate than static pushover analysis when compared with IDA.

Dilip J. Chaudhari, Gopal O. Dhoot (2016) performed pushover analysis on a four-storey RC building to achieve LS performance level. The analysis of building shown that the performance level is between IO and LS range. Performance based seismic design in contrast to force-based design approach is more reliable method due to transparency in achieving specific performance objectives.

Haider Ali Abass, Husain Khalaf Jarallah (2021) compared ATC-40, FEMA-356 and FEMA-440 by performing pushover analysis on hospital building, Iraq. The results of the displacement coefficient method (DCM) of FEMA-440 are more accurate than capacity spectrum method (CSM) method of ATC-40. Secondly results of the CSM method by FEMA440 are conservative and by ATC40 are underestimated.

Markandeya Raju Ponnada, Poornima Reddi (2020) evaluated the seismic performance of horizontally asymmetric buildings located in New Delhi (Zone 4), manual analysis results were compared with STAAD Pro. One regular building and four irregular buildings (5, 10, 15 storey) were considered. Asymmetric geometry building showed that values of Axial force in columns and Bending moment in beams are lesser with respect to the regular geometry building. Also, base shear increases with building height.

Jeng-Hsiang Lin (2017) considered earthquake probability for performance assessment of reinforced concrete and masonry buildings. The observations from analysis demonstrated that reinforced, un-reinforced masonry building are at high seismic risk as compare to reinforced concrete buildings.

A. V. Bergami, A. Forte et al (2018) focused on proposing a procedure called Incremental Modal Pushover Analysis (IMPA) over the nonlinear Incremental Dynamic Analysis (IDA) as alternative and new technique prepared was use for analysis of concrete framed building. Results of multimodal capacity curve obtained with IMPA were closer to the IDA curve. Estimate of base shear using the IMPA was more correct than standard pushover technique when compared to IDA.

S. Swathi, Katta Venkataramana (2018) analysed a 7-storey building using Capacity Spectrum Method (CSM) of pushover analysis. Performance point lies within Operational performance objective therefore the building is completely safe.

Tatjana Vilutiene, Diana Kalibatiene et al (2019) carried out bibliometric analysis of the literature focused on BIM applications for structural engineering. Analysis result proved that BIM is applied in all fields except structural engineering. Hence this is unexplored and unassessed area.

Vittoria Ciotta, Domenico Asprone et al (2021) identified current gaps in knowledge, developments and improvements of BIM in structural engineering. With application of BIM in structural engineering help to mitigate shortcomings information management that were present in typical cultural background of structural engineers.

Alcínia Zita Sampaio, Augusto M. Gomes et al (2021) assessed the interoperability between ArchiCAD, Revit and ETABS. It was found that there is easy initial modelling but ability to transfer calculation information between them should be improved concerning structural engineering.

Bedilu Habte, Eyosias Guyo (2021) examined how the structural design activities can be collaborated with architects and other engineers of building services through use of BIM. Benefits and limitations of using BIM in a structural design project were discussed. The structural model can be created far more quickly from the architectural model. Structural elements in Revit-BIM software cannot store complete structural analysis and design data.

Chuchu Xu, Xiancun Hu et al (2018) studied the practical application BIM in developing sustainable design and construction. From survey of professionals it concluded that inadequate knowledge and clients unawareness are two major hindrance in BIM.

Naveed Anwar, Fawad Ahmed Najam (2019) presented a brief review of recent technologies specially in field of civil engineering. Advancements in computation systems in engineering resulting in quick and accurate construction of structures.

III. PERFORMANCE BASED SEISMIC ENGINEERING

The concept of performance based seismic engineering (PBSE) has become a popular in recent years specially in the field of seismic engineering. Structural engineers are also eager in concept due to its potential benefits in structural evaluation, design and better interpretation regarding behaviour of structure during strong ground motions. The aim of PBSE is to design new buildings or seismically rehabilitate existing buildings to achieve predecided set of performance objectives. It is a modern design method for structural systems in which more emphasis provided to achieve the desired and predictable structural performance. Performance based engineering concept can be applied to any type of loads such as wind, snow, earthquake but it is typically suitable and targeted for earthquake loads.

PBSE is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved [18]. Fig. 2 displays the flow chart of PBSE procedure.

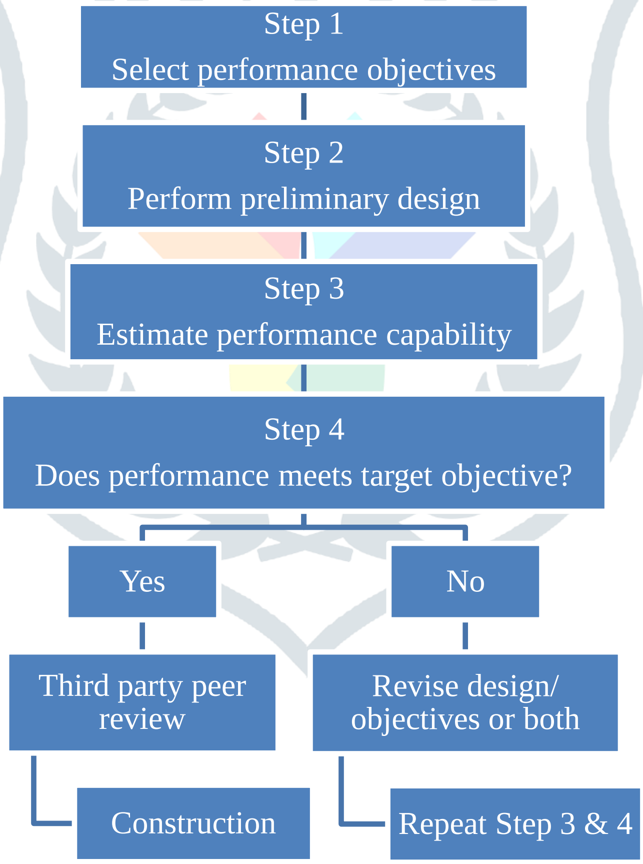

Fig.2 PBSE flow chart

In PBSE, performance objectives are related to a seismic hazard level and the expected performance level of the structure. As per FEMA 445 Performance Levels are classified as operational (O), immediate occupancy (IO), life safety (LS), collapse prevention (CP) depending upon loss in terms of property and operational capability: -

1. Operational (O)- There is negligible structural & non-structural damage in the structure but structure is intact.
2. Immediate occupancy (IO)- There is negligible structural damage & minor non-structural damage in the structure. Building is safe to occupy but utilities may not function.
3. Life safety (LS)- There is significant amount of structural damage, Building is not safe for re-occupancy until repaired.
4. Collapse prevention (CP)- There is extensive structural & non-structural damage, Repair may not be practical.

Performance levels are expressed in terms of post elastic displacements and drifts. Damage state of a structure can be related to these performance levels. Expected performance level must be decided in between owner and structural engineer depending upon budget, importance of structure and seismic hazard at the site of construction.

PBSE use nonlinear static pushover analysis technique to analyse and assess the performance of the structure under lateral loads. Pushover analysis is called as first-generation method of PBSE. For a rapid performance assessment of buildings, pushover analysis technique is always a desirable option for structural engineers. In pushover analysis, static loads are applied in an incremental pattern till the ultimate state or total collapse of the structure is achieved. It is called nonlinear as post elastic performance of various elements of structure are evaluated.

The main advantage of the nonlinear static analysis over linear static analysis is that it predicts the inelastic forces, displacements, deformations etc. by taking into account the nonlinear behaviour of the structure during a seismic event.

IV. METHODOLOGY

Initially, a building model of G+10 storey consists of 6 bays of 4 m each in X-direction and 4 bays of 5 m each in Y-direction is selected. It is modeled in Extended Three-Dimensional Analysis of Building System (ETABS) 18.0.2 software. Loads are applied to structure as per Indian standard code. First linear static analysis is executed under seismic loadings. In second stage nonlinear static pushover analysis is carried out to get the pushover curve of the structure in lateral direction X and Y. Results of static and pushover analysis is compared on the basis of roof displacement and base shear. In third stage, result of analysis are exported to Autodesk Revit software using CSiXRevit plugin for implementation of BIM technology.

Table 1, 2 and 3 are showing description of building, seismic properties and loading properties respectively. Fig. 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- Special Moment Resisting Frame
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 as per IS1893:2016 (Part I)

S.no.	**Parameters**	**Details/value**
1	Seismic Zone	III
2	Seismic Intensity, Z	0.16
3	Importance Factor, I	1.2
4	Response Reduction Factor, R	5
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

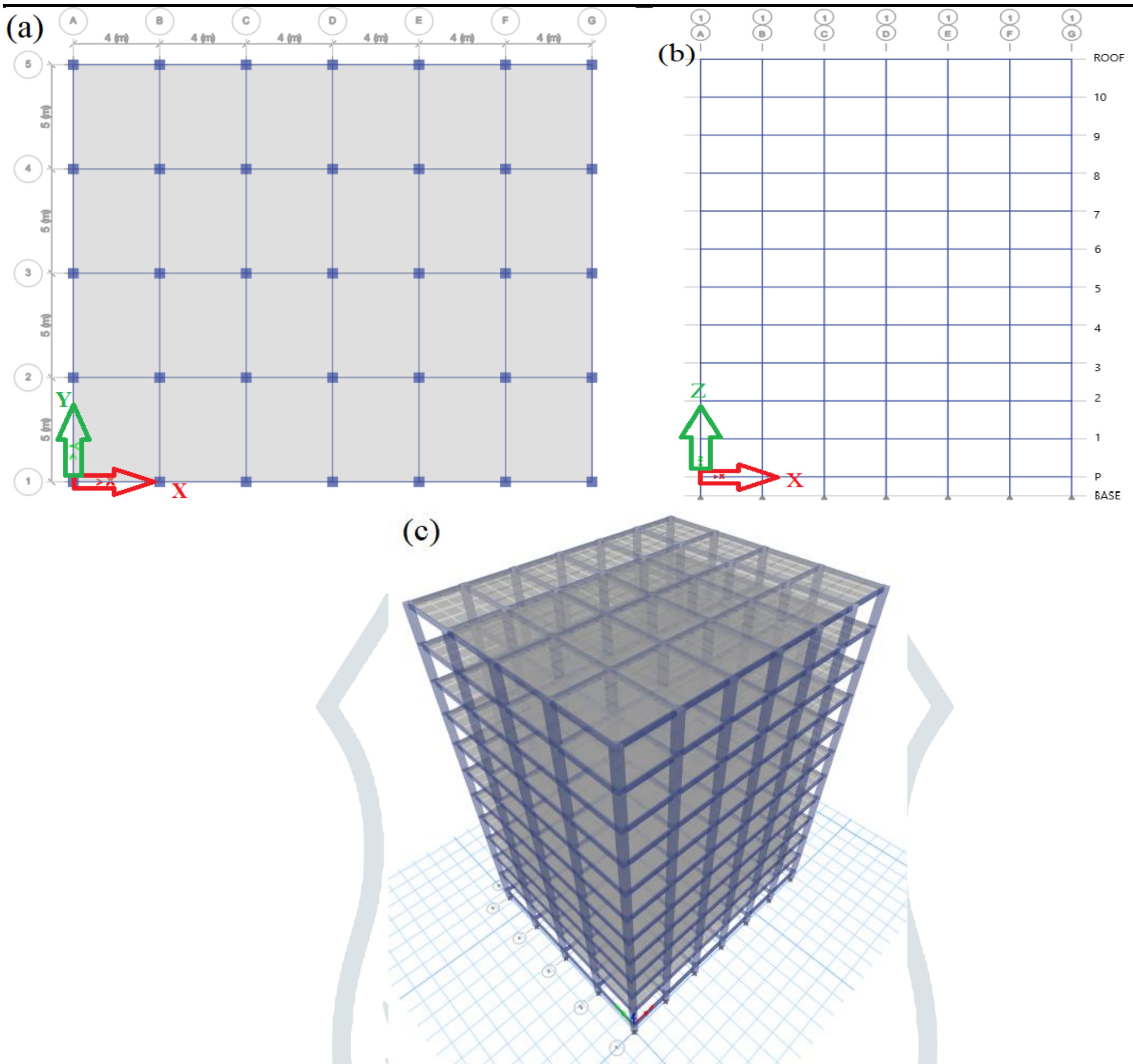

Fig.3 (a) Plan view (b) Elevation (c) 3D view of G+10 storey building

V. LINEAR STATIC ANALYSIS OF BUILDING STRUCTURE

Linear static analysis method is also called as Equivalent static force procedure (ESF) or Equivalent lateral force procedure (ELF) or Seismic coefficient method. Linear analysis meant it uses linear elastic, material or geometric properties of elements to determine structural dynamic properties and their responses. Linear static analysis is the simplest & most basic analysis procedure which assumes structural behaviour is linear & seismic loading is static. The basic notion in ELF procedure is to convert the seismic excitation to an equivalent static force which is then applied at the base of the building called as the base shear. This base shear is assigned to the various storey of building. Load on storey get increases as its corresponding height with respect to base increases. Likewise topmost storey develops maximum load. The approximate time period of the building decides amount of base shear that is considered for its design.

Linear static analysis is performed on the building structure and results are shown as follows: -

5.1 Base shear

Approximate maximal lateral force that will generate under seismic action at base of structure along any principal direction is called as base shear. Table 4 shows base shear distributed among different stories and the total base shear developed in X and Y direction. Fig.4 represents the same, The Base shear of building structure is greater in X-direction than in Y-direction.

5.2 Storey displacement

Displacement of storeys increases with height and it is maximum at topmost storey in both X and Y direction. Table 4, Fig. 5 represents the storey displacements.

5.3 Storey drift

Table 4 shows the result of storey drift in X and Y direction. Fig. 6 represents the same, the storey drift in both directions is maximum at storey 3 and then starts decreasing with height.

5.4 Storey stiffness

Table 4 shows the result of storey stiffness in X-direction & Y-direction. Fig. 7 represents the same, the storey stiffness in both directions is maximum at storey P and then starts decreasing with height.

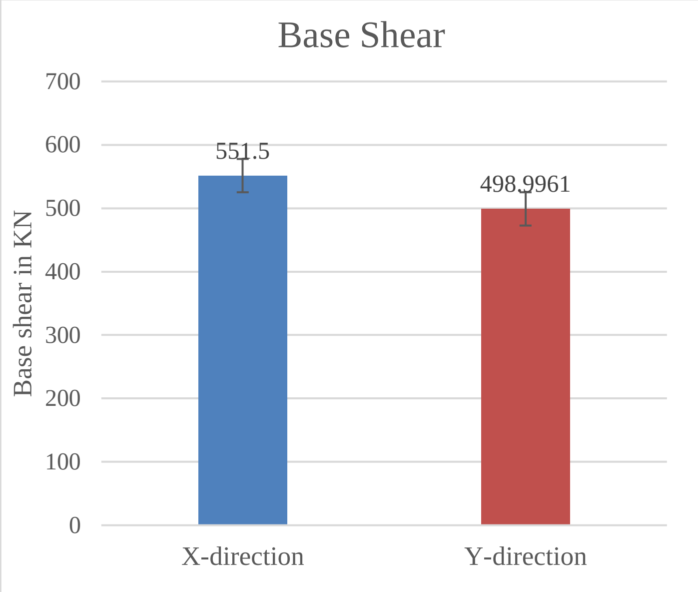

Fig.4 Variations in base shear under seismic force

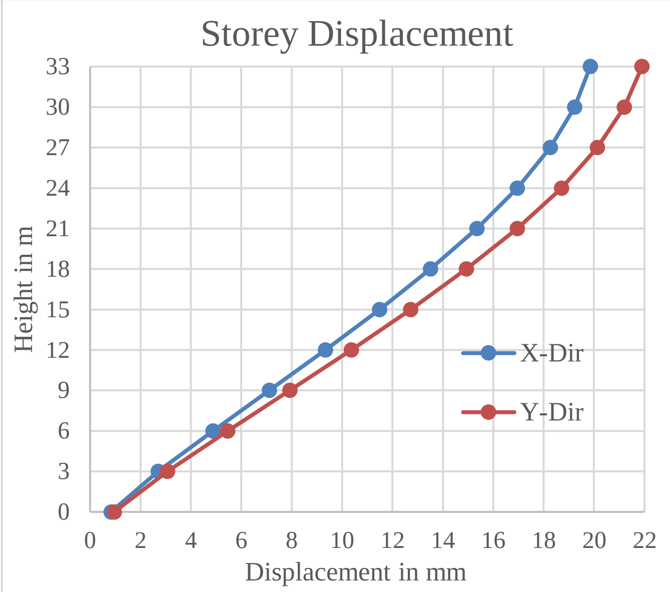

Fig.5 Storey displacement in X and Y direction

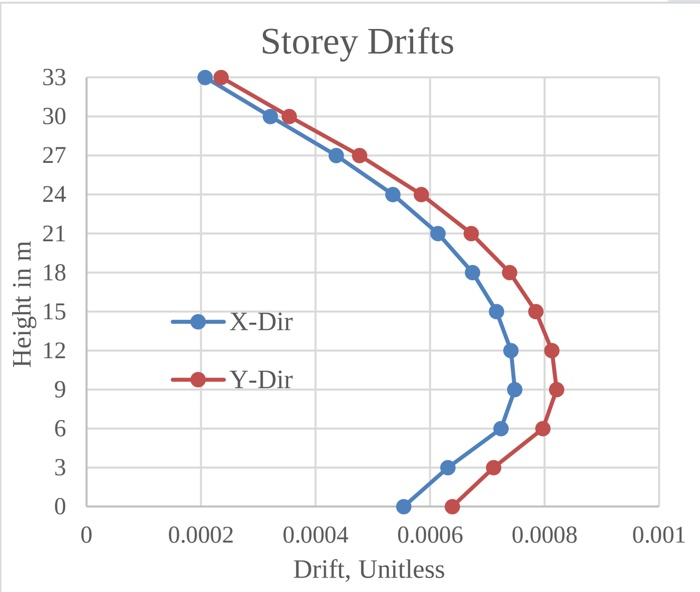

Fig.6 Storey drift in X and Y direction

Fig.7 Storey stiffness in X and Y direction

Table 4 Static analysis of building

Storey	Elevation (m)	Storey displacement (mm)		Storey Drift		Storey Stiffness (kN/m)		Storey lateral loads (kN)	
		X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
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. NON-LINEAR STATIC PUSHOVER ANALYSIS OF BUILDING STRUCTURE

In pushover analysis, seismic forces which are approximated as horizontal forces of some predetermined pattern are applied in increments to a computer model of a structure until the structure reaches its ultimate state or collapse condition, as result of analysis stepwise applied shear force is plotted with lateral displacement of structure which in turns provide global pushover curve.

Analysis engine start with very low value of lateral loads, in first few increments building behaves elastically but when elements start yielding, cracking the overall behaviour of building goes into nonlinear range.

Pushover curve is kind of X-ray of structure as this curve itself provide lot of important information about structural behaviour such as ultimate base shear of structure, yield point of structure, yield roof displacement, ductility capacity, sequence of yielding, inherent weakness in structure, possible mode of failure etc. Any kind major disease will be visible in this curve. Pushover curve represent complete life cycle of structure.

The key idea of this analysis method is it uses nonlinear computer model which is sophisticated enough to capture important aspects of material non-linearity, geometric non-linearity & seismic loading is idealized as static. In present work Lumped Plasticity Model is considered for nonlinear static pushover analysis. Plastic hinges are allocated to all the members ends. These hinges provide nonlinear force deformation relationships for the structural members, i.e., initial stiffness, yield point, post yielding stiffness, ultimate resistance, behaviour beyond the ultimate resistance. Fig. 8 represents an Idealized Force-Displacement Curve for nonlinear behaviour of components of a structure captured by plastic hinges.

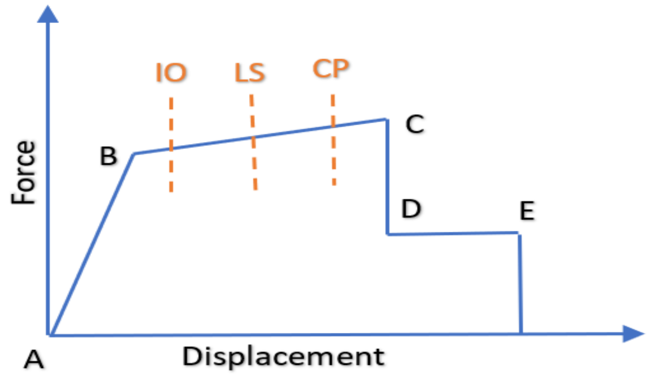

Fig.8 Idealized Force-Displacement Curve

Where, 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
The salient points in the Idealized Force-Displacement curve can be defined as follows:
point A shows to unloaded state
point B shows yield strength and yield rotation
point C shows ultimate strength and ultimate rotation
point D shows the residual strength
point E defines the maximum deformation capacity, Gravity loads are no more sustained.
Plastic hinges will activate after yield point-B, as hinges are capturing in-elastic (nonlinear) behaviour in structural element.

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 ETABS by using data in Table 5. Table 6 and 7 represents tabular results of pushover analysis in X and Y directions respectively. Graphical representation of pushover curves is provided in Fig. 9 and 10.

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	697.5943	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	3372.525	3718	746	0	0	0	4464	0	0	0	4464
4	129.638	3549.455	3678	786	0	0	0	4464	0	0	0	4464
5	129.96	3551.817	3674	790	0	0	0	4464	0	0	0	4464
6	223.215	3819.179	3620	838	6	0	0	4274	120	70	0	4464
7	223.568	3818.446	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	1140.3656	4436	28	0	0	0	4464	0	0	0	4464
2	128.227	3182.1828	3882	582	0	0	0	4464	0	0	0	4464
3	153.174	3525.1888	3800	664	0	0	0	4464	0	0	0	4464
4	153.465	3527.1759	3796	668	0	0	0	4464	0	0	0	4464
5	250.067	3796.3056	3748	706	10	0	0	4282	112	70	0	4464
6	250.431	3791.1119	3748	696	20	0	0	4282	112	60	10	4464

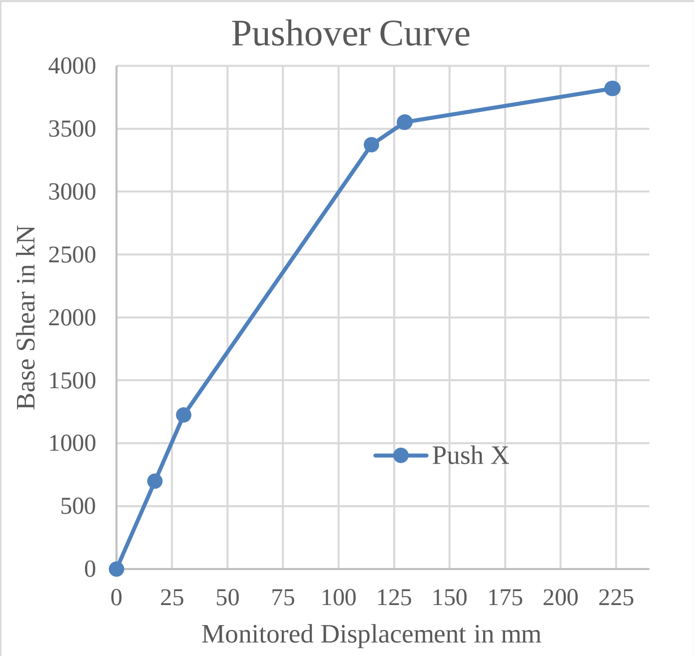

Fig.9 Pushover curve in X–direction

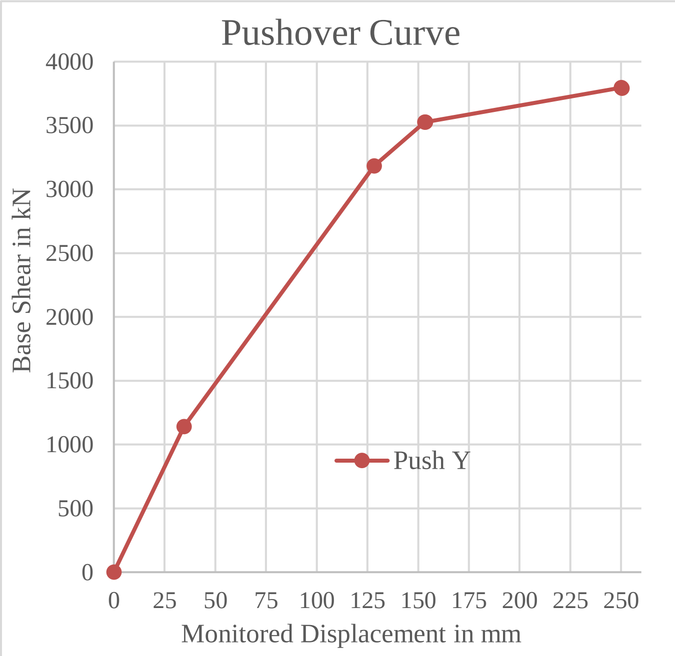

Fig.10 Pushover curve in Y–direction

VII. Results and Discussion

There are total 4464 hinges formed in the structure. In X-direction, no any hinge crossed the immediate occupancy level till step 5. Up to this stage structure lies in operational level. 790 hinges in B-C indicate nominal yielding in elements. As the lateral load further increases in step 6, 70 number of hinges cross the life safety performance level. At this point structure becomes unstable and reach the point of verge of collapse. Similarly, in Y-direction structure developed maximum base shear of 3796.30 kN at inelastic displacement of 250.067 mm. 10 hinges cross collapse prevention level at step 6 leads to 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. Pushover analysis gave base shear and displacements more than linear static analysis method due to the presence of plastic hinge and the progressive nonlinear analysis. The frame reacts linearly elastic up to a base shear value of around 1224.11 kN in X-dir. and 1140.3656 in Y-dir.

Table 8 Base shear in kN

Analysis type	Static analysis	Pushover analysis	
		At yield point B	At ultimate point C
X-Direction	551.5	1224.11	3819.1794
Y-Direction	498.9961	1140.3656	3796.3056

Table 9 Displacement in mm

Analysis type	Static analysis	Pushover analysis	
		At yield point B	At ultimate point C
X-Direction	19.849	30.276	223.215
Y-Direction	21.905	34.5	250.067

Ductility capacity of structure specifies that it can undergo inelastic displacement of (223.215-30.276) 192.93 mm and (250.067-34.5) 215.567 mm in X and Y directions respectively without collapse. Performance level and ductility of the structure can be improved by re-designing components whose hinges early cross the collapse prevention level. Calculated ductility of the structure is found approximately $\mu = 7$ as shown in Table 10.

Table 10 Ductility Capacity

Analysis type	Displacement in mm		Ductility
	Pushover analysis		$\mu_s = \Delta max / \Delta y$
	At yield point B	At ultimate point C	
X-Direction	30.276	223.215	7.37
Y-Direction	34.5	250.067	7.24

Where, Δmax - Maximum deformation, Δy - Yield deformation, μ_s - Global displacement ductility

VIII. Application of analysis results into Building Information Modelling

Structural engineers intelligently use structural elements and materials to create economical, safe and durable structural design. Structural design needs to be blended with output results of other experts such as architects, various engineers (mechanical, plumbing, electrical, fire protection) of building services. The convenient solution that furnish all these features is Building Information Modelling (BIM).

BIM is the process of developing single virtual model representative of the building by collecting data from different sources to centralize all the information which is then used in visualizing, rendering, managing, estimating, coordinating various building components of different disciplines in a virtual environment. BIM has changed a working culture between architects and engineers of different building services, offers great opportunities to improve performance. By the application of BIM, structural designers can avoid expensive clashes by inspecting structural beams, pipes, ducts, electrical systems in early stage of project and explore available design alternatives in advance. Therefore, BIM fascinated the architecture, engineering construction (AEC) industry to a great extent.

The core value of BIM is the information attached to the model. building information modelling (BIM) can be performed using any software such as Autodesk Revit, Graphisoft Archicad, Bentley Systems Microstation, ACCA Software Edificious etc. but most versatile and trending among all these is Autodesk Revit, in which it analyse the data rich parametric 3D model. Parametric 3D model meant creation of model from a set of rules i.e. parameter of element (height, width, or thickness) in the structure can be changed.

Autodesk Revit has great interoperability capacity, It comes with different plug-in that provide two-way data exchange platform between some of the most common worldwide accepted structural design software like ETABS, SAP, SAFE.
In present work, ETABS model generated in analysis is exported to the Revit. Then potentialities and limitations of BIM based tools in development of structural project are evaluated.

8.1 CSI ETABS model exported to Autodesk Revit

ETABS model can be exported to Revit using two techniques: -

8.1.1 IFC stand for industry foundation class. Using IFC file, Revit model can be generated directly but they can only be used as reference models and cannot be modified. This is the major limitation with this file format.

8.1.2 Using exr file, it is viable to generate the Revit model by CSiXRevit plug-in. The benefit of this tool is that Revit model generated in this process provide full access to make any changes in it. In present work this technique is adopted. Fig. 11 to 14 shows the process of generation of BIM Revit model from ETABS.

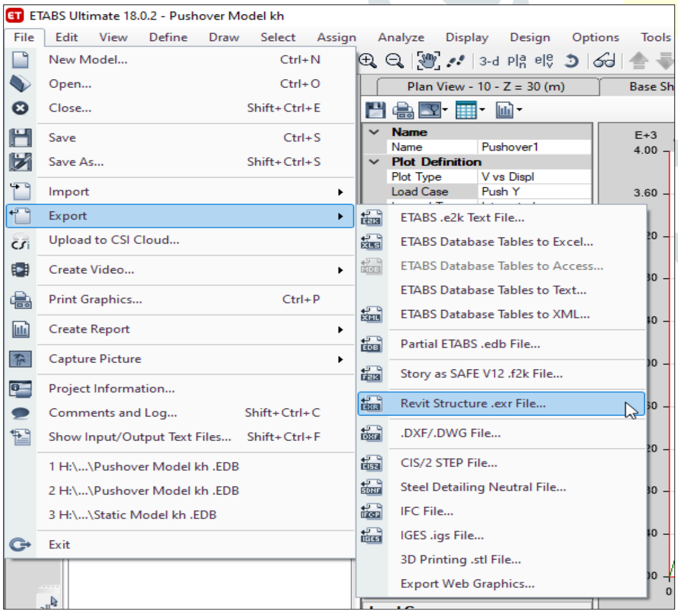

Fig.11 Export ETABS Model/file as .exr file

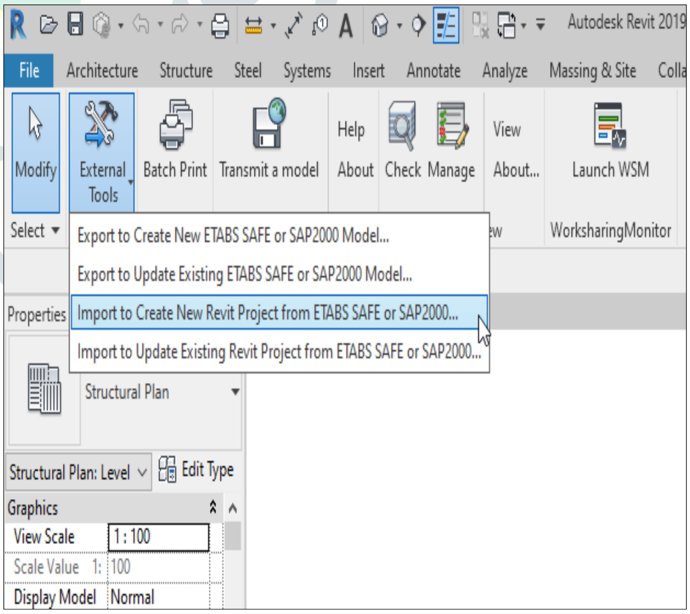

Fig.12 Import .exr file in Autodesk Revit 2019 using CSiXRevit

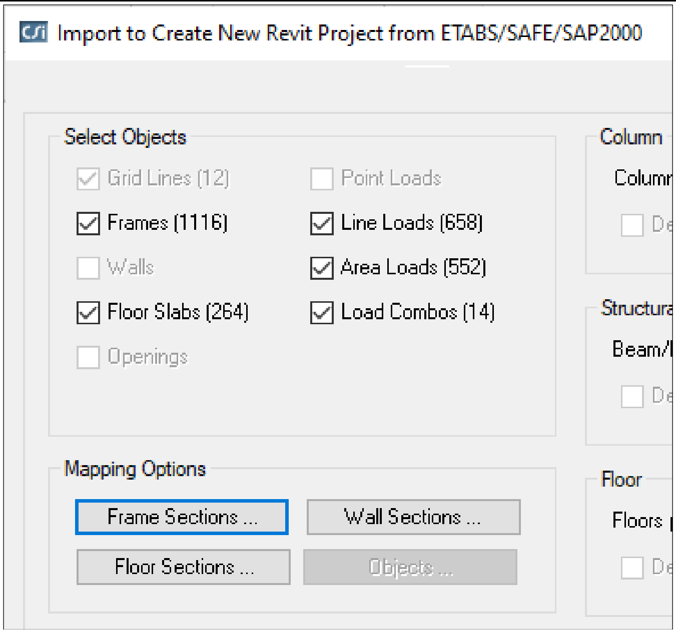

Fig.13 Select type of data to be imported into Revit 2019

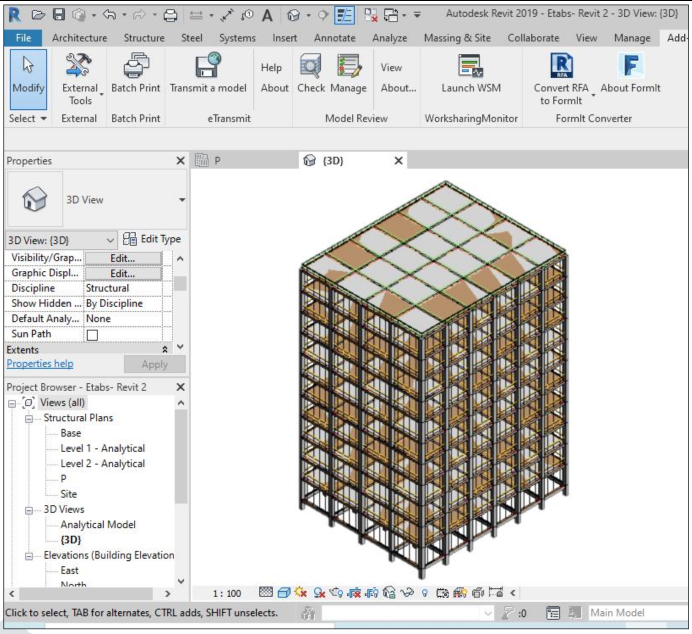

Fig.14 3D Revit model of structure

According to the Fig. 13, structural columns, beams, floors, grid lines, line load, area load and load combos were transferred from ETABS to Revit. Some of the material properties are also transferred see Fig. 15. It is noted that results of static analysis, pushover analysis and area of design reinforcement were not transferred into Revit.

Structural Material									
Class	Structural Material	Concrete compression	Density	Poisson ratio	Shear modulus	Thermal expansion coefficient	Unit weight	Young modulus	Behavior
Concrete	M30	30.0 MPa	2548.53 kg/m³	0.15	11907.0 MPa	0.00001 1/°C	25.0 kN/m³	27386.0 MPa	Isotropic

Fig.15 Material Properties

8.2 Clash detection analysis

To understand the process of clash detection one Mechanical Revit model is created. Mechanical model generally consist of MAU unit (Makeup Air Unit) which circulates and supply fresh air and remove stale air from rooms by using ducts. These ducts run under ceilings of room so sometimes they may get clash with beams depending upon their size.

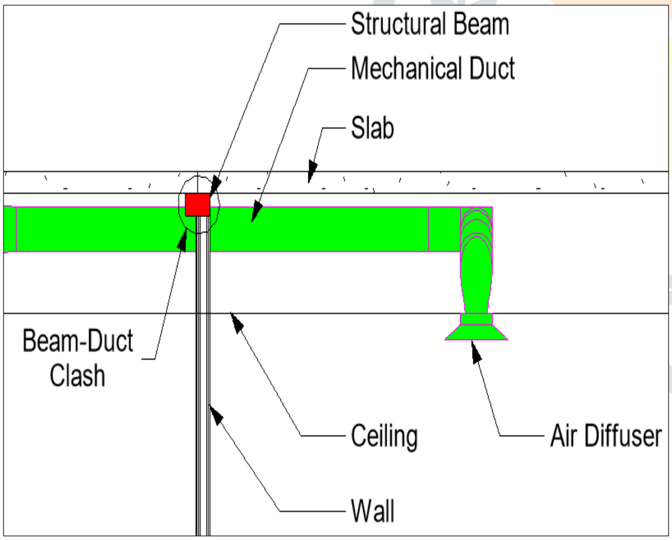

Fig.16 Clash Detection - Sectional View

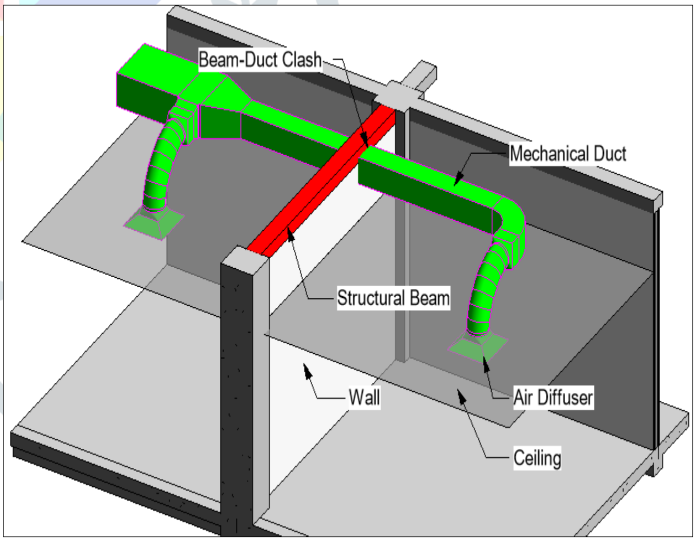

Fig.17 Clash Detection - 3D View

Interference check in Revit helps to prevent and solve clashes in early stage before they emerge on construction sites. ‘clash’ meant ‘collision’ or ‘conflict’ between elements of building Fig. 16,17 shows clash detection of structural beam with HVAC duct. In this situation, decision can take to either drop the level of duct or re-route the duct or reduce the depth of beam. Reducing level of duct also depend upon available space under the ceiling to accommodate duct in that portion, must be coordinated with architect.

8.3 Material take-offs

Manual material take-offs is complex mathematical exercise in which the estimator take computer-aided design (CAD) plans, calculate quantity of pipe, steel, lumber or any other material that is necessary to complete a structure. This is a manual process so it may lead to human error and inaccuracy.

Computerized building models integrated with digital material take-offs directly take data from data rich 3D model. Important thing is architect or any engineer should proficient with the BIM software to generate it properly. The Revit separately calculates volume of concrete in cubic meter that will be require to complete construction of beams, columns and floors in the project. From the complete volume calculation, it is also possible to calculate volume of single element with use of suitable formula in Revit. For example, volume of one column can be calculated as Width (b) X Depth (h) X Height (Length) as shown in Fig.18.

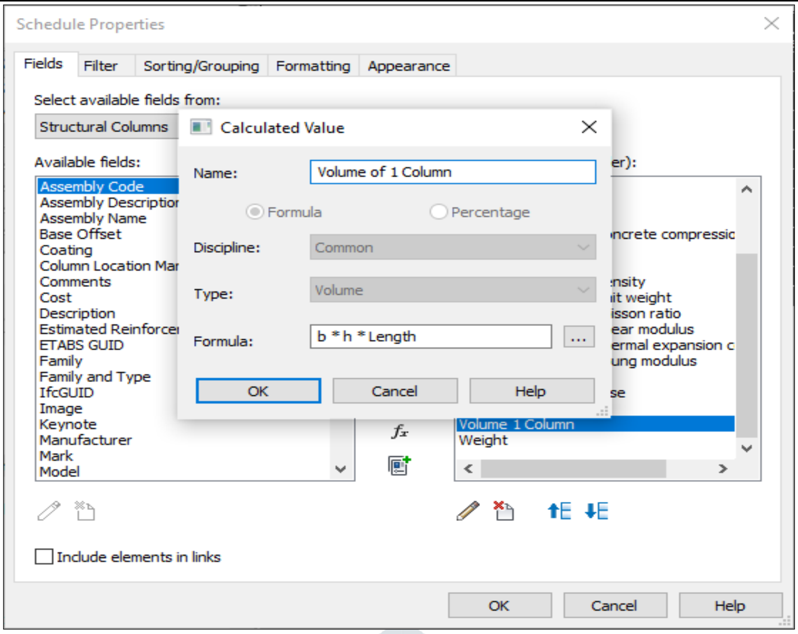

Fig.18

Revit has a feature that whenever two elements overlap with each other it considers the volume of overlap part only in one element so this avoids the double counting in volume. So, the accuracy remains maintained when relying on the Revit for quantity estimation in project.

Based on the result of pushover analysis Material take-offs schedules of column, beam and floor are prepared in Revit and tabulated as shown in Table 11,12 and 13.

Table 11 Structural Column Schedule

Base Level	Top Level	Height (mm)	Count	Structural Material	Grade	Width (mm)	Depth (mm)	Size	Total Volume (m^3)	Area (m^2)	Volume (m^3)
										1 Column	
Base	P	1500	35	Concrete	M30	500	500	500x500	13.13	0.25	0.375
P	1	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
1	2	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
2	3	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
3	4	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
4	5	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
5	6	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
6	7	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
7	8	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
8	9	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
9	10	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
10	Roof	3000	35	Concrete	M30	500	500	500x500	25.35	0.25	0.750
Grand total: 420									291.98		

Table 12 Structural Beam Schedule

Level	Top Elevation (mm)	Length (mm)	Cut Length (mm)	Count	Material	Grade	Width (mm)	Depth (mm)	Size	Total Volume (m^3)	Area (m^2)	Volume (m^3)
											1 Beam	
P	0	4000	3500	30	Concrete	M30	230	450	230x450	10.868	0.104	0.414
P	0	5000	4500	28	Concrete	M30	230	450	230x450	13.041	0.104	0.518
1	3000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
1	3000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
2	6000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
2	6000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
3	9000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276

3	9000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
4	12000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
4	12000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
5	15000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
5	15000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
6	18000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
6	18000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
7	21000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
7	21000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
8	24000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
8	24000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
9	27000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
9	27000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
10	30000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
10	30000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
Roof	33000	4000	3500	30	Concrete	M30	230	300	230x300	4.347	0.069	0.276
Roof	33000	5000	4500	28	Concrete	M30	230	300	230x300	4.968	0.069	0.345
Grand total: 696										126.37		

Table 13 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

IX. Concluding remarks

The research in this paper presents the seismic analysis of multistorey building and then implementation of analysis results into BIM to evaluate its benefit in field of structural engineering. Following are concluding remarks of present work: -

1. Linear static analysis together with nonlinear static pushover analysis can provide complete elasto-plastic behaviour of the structure. To obtain quick overall performance of structure both analysis technique can be adopted.
2. Pushover analysis help to visualize the complex nonlinear phenomenon of buildings by identifying concentrated concrete hinge degradation.
3. In performance based seismic engineering, Pushover analysis is efficient tool to expose different structural performance levels of structure at various inelastic displacements.
4. The capacity curve formed under the pushover analysis shows fundamental mode response of structures, provide good estimates of global as well as local inelastic deformation.
5. Prediction of yield point and ultimate limit in pushover curve can provide insights of ductility capacity of the structure.
6. In linear static analysis, it is assumed that stiffness (K) is always constant no matter how much lateral load is coming on the structure this statement holds good till structure is elastic but as structure crosses yield point under higher loads it behaves inelastic so this is limitation of this analysis method. It does not take inelastic effect into account.
7. Application of BIM in structural engineering provides improved productivity, coordination and visualization in analysis and design. Complex situations can be easily visualized and teams can coordinate more adequately.
8. 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.
9. The clash detection, Material takeoff all aided by Revit in collaborative engineering environment.

10. Clash detection tool in Revit can identify conflicts of structural, architectural and MEP teams in early stage hence it reduces the risk of cost overruns and request for information (RFI) from contractors in the construction phase.
11. Material takeoff from parametric Revit model bring accuracy in work, avoid mistakes and turn hours of tedious work into work of few minutes.
12. Autodesk Revit is versatile despite the fact it has certain limitations. In structural engineering point of view, current version of Revit/ETABS not able to transfer complete analysis results. Idea of BIM in centralizing all the structural information throughout life of building not satisfied in this case.
13. Revit cannot store rebar information-rebar percentage, longitudinal reinforcing, shear reinforcing etc. which is important material in overall cost estimation of RC (Reinforced Concrete) project.

X. FUTURE SCOPE OF WORK

1. The nonlinear analysis of structure can be performed using 'PERFORM 3D'.
2. Material takeoff schedule can be prepared by modelling rebars in Revit, from the results of designed sections in ETABS.
3. Rehabilitation/retrofit of important historic structures and existing structures by using SCAN to BIM prior to structural analysis.
4. Adoption of Visual programming script and Dynamo for BIM Automation in structural analysis and design of new building.

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