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Comparative Study of Ground Plus One-Story RCC Building with Etabs and Tekla Structure Designer (BIM)

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ABSTRACT

Building Information Modeling (BIM) has dramatically transformed the structural engineering landscape but analytical validation is still a key requirement. This research compares the Ground plus One-Story (G+1) reinforced concrete (RCC) building between ETABS and Tekla Structural Designer (TSD). A "triple-check" validation protocol, using manual load calculations by the Tributary Area Method as a baseline benchmark, was used to ensure the reliability of the computational outputs. Under the same loads and material properties, the structural response was investigated for identical models, including bending moments, shear, and vertical deflections. The results show a high level of analytical convergence between both platforms in the case of low-rise structures, with values for internal forces being almost equal. There was a large disparity, however, in efficiency of workflow; ETABS is very good at detailed finite element analysis but offers no integrated features for detailing and estimating. Unlike that, Tekla Structural Designer offers a better BIM integrated environment which allows for automated reinforcement detailing and full material quantity take-offs in one single application. Based on these results, this study ends up concluding that the use of BIM-based tools such as TSD could be able to streamline considerably the process of structural design to documentation, because it minimizes human error in the project and facilitates the coordination of the project.

1. Introduction

Today the construction industry in Pakistan is at a technological turning point, generating a contribution of just about 2.5% to the national GDP, and using the traditional 2D CAD process, which is still labour intensive [1]. The demand for resilient multi-story reinforced concrete (RCC) structures has risen with increasing urban density, changing the traditional method of manual analysis to integrated Building Information Modeling (BIM) platform [2]. Manual calculations using the Tributary Area Method are the seemingly "gold standard" or traditional method by which structural validation is performed, but are often not adequate for the complex and iterative design process of contemporary engineering projects [3].

In the modern structural engineering market, the most important computer programs for computations are ETABS and Tekla Structural Designer (TSD). ETABS is well known worldwide for its comprehensive finite element analysis (FEA) features, especially seismic and lateral load distribution [4]. In contrast, Tekla Structural Designer is a paradigm shift towards BIM, a physical modeling environment that synchronizes the structural analysis with automated detailing and material quantification. Although BIM has been recognized to offer various benefits such as reduction in rework, better clash detection, yet the use of BIM in Pakistan is minimal, according to recent surveys only 11% is implemented throughout the country as there are no institutional mandates and technical training [5].

To fill this gap, the present research discussed in this paper will be a comparative study of a one-story RCC building with a ground story RCC building. This study will compare manual calculations with those of ETABS and Tekla Structural Designer to validate the analytical consistency and material efficiency of each platform and to achieve a "triple-check" validation. The results give important insights for structural

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engineers to make decisions in the Sindh region as to whether BIM based workflows give a tangible benefit over traditional methods of analysis for small scale residential construction.

2. Literature Review

This shift away from traditional 2D CAD based workflows to integrated Building Information Modelling (BIM) platforms has been a hot topic in today's structural engineering research. The demand for this change is due to the necessity of better coordination, and minimization of human error and error in material estimation in increasingly complex reinforced concrete (RCC) structures.

2.1 Comparative Software Analysis and Structural Behavior

Many studies have been conducted on the analytical convergence of different structural software. For the thermal response of concrete slabs, [6] compared the results of the ACI codes with the results of ETABS and demonstrated the software's reliability in analyzing regular environmental loads. Likewise, in [7] RCC and post tensioned flat slabs were compared in ETABS, which is an efficient software to model complex floor system.

There have been additional comparative research done to investigate the differences among various platforms. The results of [8] on the evaluation of high-rise buildings with ETABS and RSA software showed that the results are generally similar, however the distribution of forces in certain areas can be different as a result of different software algorithms. This is confirmed by [9], who stressed that the choice of structural software is essential for optimal design of reinforced concrete structures. Further, [10] explored the seismic and wind load aspects of 20-storey mixed use buildings, affirming the need for the use of advanced FEA tools to conduct lateral load distribution on multi-storey frames.

2.2 BIM Integration and Material Optimization

The major benefit of contemporary BIM platforms over conventional analytical techniques is that the material quantity calculation and project coordination are performed. A comparative study between manual and BIM procedures for material quantity calculation of high rise buildings has been conducted by [11] and found that there is a great reduction of discrepancies in quantity take-off using BIM. This theme of optimization is also developed by [12] who used BIM to optimize quantities for cost effectiveness in the design of integrated technology laboratory buildings.

In addition to quantity surveying, BIM allows the smooth integration of architectural and structural processes. Regarding the architectural formation of growable light steel structure system, [13] introduced the 3D visualization and BIM integration in construction, and explained how it can enhance the accuracy of the construction process. [14] recently pointed out that BIM technology is emphasizing structural safety; its design approach of integrated modeling for prefabricated steel frame structure helps to bridge the gap between design and physical assembly.

2.3 Structural Systems and Design Processes

For irregular or complex geometries, the design process needs to be optimized, and a robust framework is needed to accomplish this. [15] Understanding of the optimal design process for complex shaped skyscrapers was achieved, with the focus on the need for integrated workflows to ensure structural integrity in non-standard systems. Moreover, [16] investigated the factors affecting the elastic stiffness factor for dual system RCCs, giving technical insights into the stiffness formulations used in modern analytical software, such as ETABS.

3. Methodology

The research takes the three-stage comparative approach to validate the digital structural outputs with the basic manual calculation. This systematic approach allows the performance of a Ground plus One-Story (G+1) RCC structure to be assessed in a very reliable analytical manner, which is the transition between the traditional engineering process and the modern Building Information Modeling (BIM) process.

3.1 Case Study and Material Specifications

The study utilizes a G+1 residential structure located in Nawabshah City, Sindh, Pakistan, as a primary case study. The structure is designed around a structural grid of 23 reinforced concrete columns, with four of these being heavy-load 15" ×15" columns and nineteen being standard 18" ×9" columns. The building is designed around a structural grid of 23 reinforced concrete columns, with four of the columns being heavy-load 15"×15" columns and nineteen

being standard 18”×9” columns. The horizontal structure is a 5” (125 mm) thick two-way slab structure. Materials properties were carefully specified to match the local construction codes, with M25 grade concrete and Fe500 grade reinforcement steel used. For self-weight calculations, the concrete density was assumed as 150 PCF.

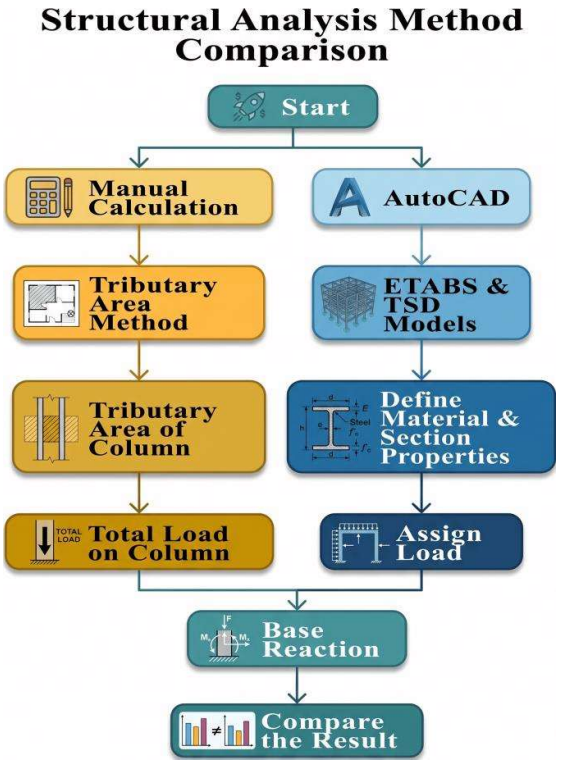

Fig.1 Methodological framework for comparative study, illustrating the parallel workflow between manual validation, ETABS finite element analysis, and Tekla BIM modeling.

Table 1: Design and Material Parameters

Parameter	Specification
Structure Type	Ground Plus One-Story (G+1) RCC
Concrete Grade	M25 (f'c approx 3,625 psi)
Reinforcement Steel	Grade Fe500
Concrete Density	150 lb/ft³ (PCF)
Slab Thickness	5 inches (125 mm)
Beam Section	6" x 18" (Standard)
Column Sections	15" x 15" and 18" x 9"
Design Codes	ACI 318-19 / ASCE 7-10

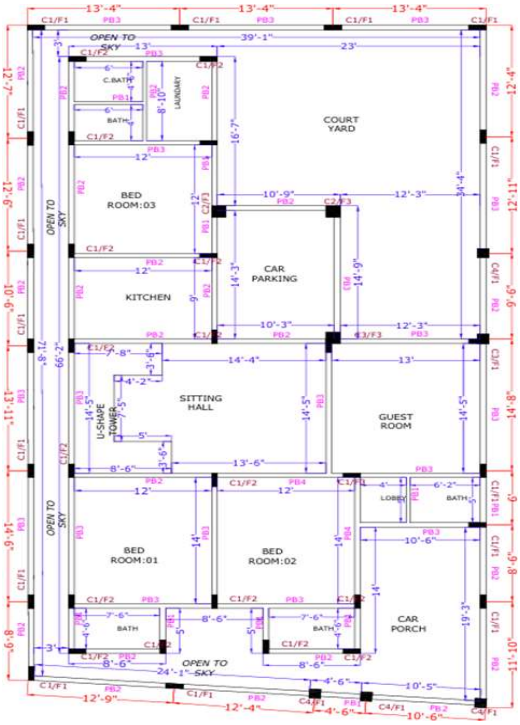

Fig. 2 Architectural floor plan illustrating the residential spatial requirements and column placements.

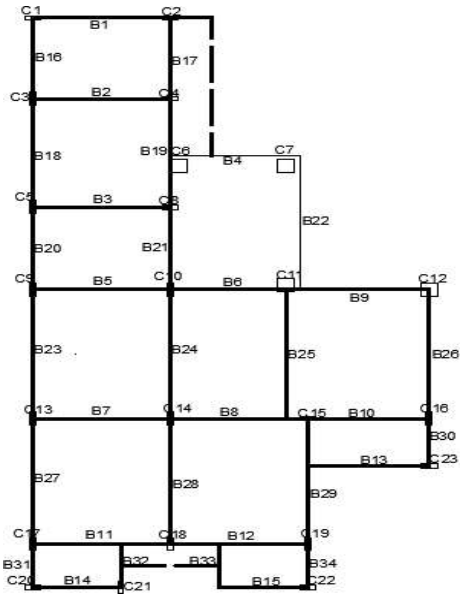

Fig.3 Structural framing plan detailing the beam-column grid (C1-C23) and primary load-bearing members.

3.2 Manual Analytical Validation (Tributary Area Method)

A thorough manual analysis was carried out to provide a baseline for structural behavior. This method, known as the Tributary Area Method, was used to calculate the exact load supported by each column of the grid to determine his or her tributary area. The load path was clearly established: floor loads are carried to the slab, the slab carries loads as Uniformly Distributed Loads (UDL) to the beams, the beams carry loads as point loads to the columns and the total loads carried by the columns are applied to isolated footings. The loads due to total gravity were computed with the ACI factored combination 1.2(DL) + 1.6(LL). The dead load (DL) components consisted of the self-weight of members, a 3" floor finishing load (36.25 PSF), 6" partition walls (0.87 kips/ft), and 6" parapet walls (0.21 kips/ft). A standard live load (LL) was used according to ACI standards; this load was 100 PSF.

3.3 Computational Analysis and BIM Modeling Workflow

Two different computational environments have been used to model the building and evaluated for consistency in analysis and for BIM efficiency.

3.3.1. ETABS Analytical Framework:

The structure was set up as an analytical wireframe to concentrate on Finite Element Analysis (FEA) in the ETABS environment. A shell element model of slabs was used to ensure accurate distribution of the internal forces throughout the frame, such as Shear Forces and Bending Moments. The main task of the ETABS phase was to extract the Joint Reactions as well as unique joint labels (such as Joint 2, Joint 3, Joint 5, Joint 11, Joint 13) to be able to make a direct numerical comparison with the manual results.

3.3.2. Tekla Structural Designer (BIM) Integration:

On the other hand, Tekla Structural Designer (TSD) was used to benefit from its high-fidelity Physical Modeling and BIM functionality. TSD can enable physical members to be directly loaded with architectural loads unlike the traditional analytical software, thereby easing the flow of work. In particular, the TSD phase was used to create detailed Estimate Reports which yielded accurate details of concrete volume (ft3) and reinforcement mass (Tons) for beams, columns and slabs. It enabled the study of the performance of BIM-integrated design in terms of material quantification and construction plan efficiency.

3.4 Evaluation and Comparative Criteria

The last step of the methodology is the multi-metric comparison of the three approaches. The main assessment criteria are:

1. **Reaction Accuracy:** Convergence between Manual Base Reactions and Software-generated Joint Reactions (kips).
2. **Material Optimization:** A comparison of the total volume of concrete and the weight of reinforcement from TSD BIM Reports to the manual method.
3. **Workflow Efficiency:** A qualitative study of the time and complexity needed to produce detailing ready output in a BIM environment vs standalone analytical platform.

4. Results and Discussion

The convergence of the analytical results with computational results obtained from ETABS and Tekla Structural Designer (TSD) of the Ground plus One-Story (G+1) RCC building was analyzed and the material efficiency was evaluated.

4.1 Comparative Analysis of Base Reactions

A comparative analysis of the base reactions is presented. The basic verification of the structural models was accomplished by comparing the factored base reactions at 23 distinct joint locations. This “Triple-Check” protocol is a guideline to help verify interpretation of the gravity load path created in the manual methodology by both ETABS and TSD.

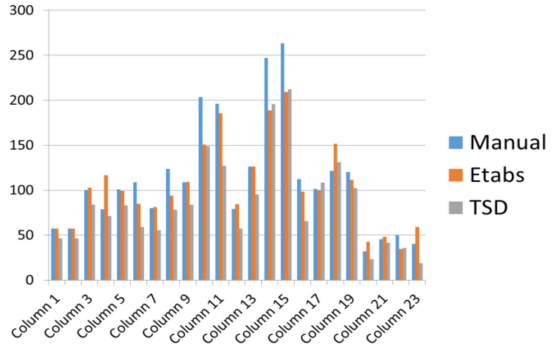

Fig.4 Comparative bar chart of factored base reactions at critical joint locations, validating ETABS and Tekla outputs against manual benchmarks.

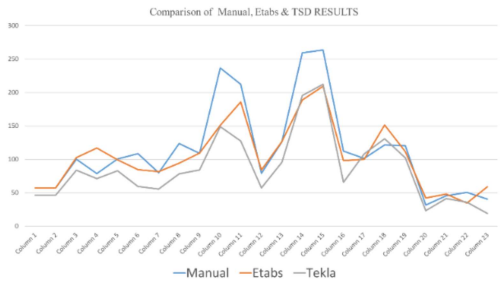

Fig. 5 Comparative line graph of factored base reactions at critical joint locations, validating ETABS and Tekla outputs against manual benchmarks.

The graphical representation

Fig.4 and **Fig. 5** shows an overall trend for most joints for all three methods. The Analytical Convergence of the Software Models is shown visually by the proximity of the bars at Joint 1 and Joint 3. The differences in the larger bars are evident, and the graph is a good indication of the conservative nature of manual calculations compared to the sophisticated load distribution algorithm used in ETABS.

4.2 Structural Behavior and Force Distribution

Structural response of RCC frame has also been analyzed by extracting Bending Moment Diagrams (BMD) and Shear Force Diagrams (SFD) for factored load combination: 1.2(DL) + 1.6(LL).

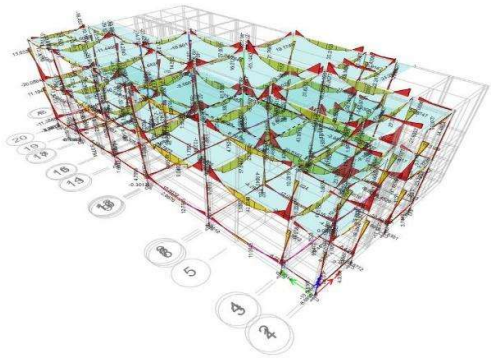

Fig.6 Shear Force & Bending on Etabs

Error! Reference source not found. and **Fig.7** are visual verification of the internal force distribution. The ETABS model includes integrated shear and bending outputs, which also exhibit smooth transitions at the continuous beam-column joints. Likewise, the Tekla Structural Designer (TSD) outputs of "Moment Major" and "Shear Major" show consistent patterns of forces with the maximum moments correctly generated at the mid-spans and supports. This similarity in the force diagrams for both software packages extend the validity of the results generated by the BIM-integrated workflow in Tekla and shows that the analytical outputs are very comparable to those available from a dedicated finite element platform such as ETABS.

Table 2: Comparison of Factored Base Reactions

Sr.no	*Manual*	*Etabs*	*Tekla*
1	*57.12*	*57.42*	*46.5*
2	*57.12*	*57.42*	*46.5*
3	*99.98*	*102.69*	*83.9*
4	*78.54*	*116.82*	*71.2*
5	*100.70*	*99.304*	*82.9*
6	*108.66*	*84.72*	*59.2*
7	*79.82*	*81.47*	*55.6*
8	*123.74*	*94.07*	*78.4*
9	*108.86*	*109.21*	*84*
10	*236.384*	*150.76*	*148.9*
11	*212.384*	*185.76*	*127.2*
12	*79.14*	*84.32*	*57.2*
13	*126.008*	*126.39*	*95.4*
14	*259.216*	*188.69*	*195.6*
15	*263.32*	*209.09*	*212.03*
16	*112.43*	*98.12*	*65.6*
17	*101.49*	*100.09*	*108.12*
18	*121.46*	*151.35*	*130.9*
19	*120.13*	*111.261*	*102.1*
20	*31.78*	*42.38*	*23.2*
21	*45.60*	*48.09*	*41.5*
22	*50.40*	*34.56*	*36*
23	*40.35*	*59.09*	*18.9*

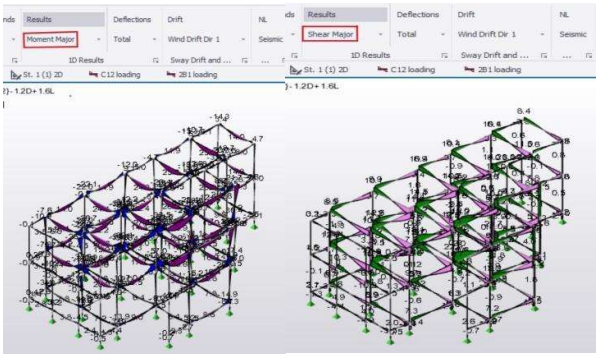

Fig.7 Shear Force & Bending on TSD

4.3 BIM-Based Material Quantification and Efficiency

One of the significant goals of this research was to evaluate the effectiveness of the BIM technology in terms of material estimating, over traditional manual quantity surveying. The physical model was used to automatically produce high fidelity Estimate Reports with Tekla Structural Designer.

The main benefit of TSD workflow in a BIM environment is highlighted in the formulation of **Table 3** and **Table 4**. The research was able to document a total volume of concrete of 2,978.9 ft3 and a total mass of reinforcement of 10.297 Tons (including a 10% detailing allowance). These quantities can be brought directly from the synchronized 3D model which reduces the possibility of human error commonly associated with the manual extraction. This is a useful feature that enables engineering practices in the Sindh region to have a better estimation of the construction cost and plan the work more accurately.

Table 3: Total Concrete Volume

Total Concrete Volume				
Material	**Weight**	**Gross Surface Area**	**Net Surface Area**	**Volume**
	[ton]	**[ft^2]**	**[ft^2]**	**[ft^3]**
Concrete	223.420	9727.3	9727.3	2978.9
Total	**223.420**	**9727.3**	**9727.3**	**2978.9**

Table 4: Total Reinforcement

Total Reinforcement	
Type	**Total Mass**
	[ton]
Beams	2.527
Columns	3.498
Slabs/Mats	3.884
Total + 10.00 % detailing allowance	**10.297**

5. Conclusion

A comparative study of a Ground plus One-Story (G+1) RCC building with manual calculation, ETABS and Tekla Structural Designer (TSD) shows that both the computational platforms are highly reliable in designing low rise structures. The research has successfully tested the accuracy of these digital tools by achieving high analytical consistency with results obtained from the manual tributary area benchmarks for bending moment, shear force and deflection. The software packages yielded very similar answers for basic structural operations, but it is a different paradigm that is illustrated in practical use. While ETABS is still a great option for detailed pure structural analysis, Tekla Structural Designer is an efficient and versatile option for real-world engineering, bringing 3D modeling, analysis, automated detailing and quantity take-off reports together in a single Building Information Modeling (BIM) ecosystem.

In addition, this research highlights the need to choose the structural software according to the project requirements and not solely based on its analytical features. ETABS is adequate for academic studies and/or purely analytical purposes where the objective is only to determine the forces and deflection values. In professional practice, where coordination with architects and contractors is crucial, however, the integrated BIM features of Tekla Structural Designer give an advantage that can be measured. The automatic Generation of quantity take-off and reinforcement detailing by TSD reduces the amount of human effort and errors needed in project documentation and cost estimation.

Future Studies

With the findings of this study, it is recommended that future structural design project be assigned to software according to its desired level of practical output: Firstly, ETABS is recommended to be used for high-precision analytical works, namely in professional works that require detailed BIM coordination in the project, Tekla Structural Designer is suggested to be used. The students and early career engineers are also encouraged to work on both platforms so that they are able to differentiate between an analysis based and BIM based methodology, making them more technically versatile to meet the current market demand for engineering.

The comparative framework is proposed to be used in future academic studies with high-rise and irregular structural configurations to analyze the seismic and torsional performance of the software with complex load scenarios. Furthermore, future research could explore the use of advanced materials and time-dependent thermal effects, including those that are

modelled for hot climates, to improve the overall model of structural behavior in different environmental conditions.

Acknowledgment

Not available

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