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An Evaluation Study of Structural Analysis and Design Software

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Abstract: Analysis and design structure without computer use is unimaginable and unavoidable in this era compared to the previous generation, especially when it comes to complex structures involving complex geometry. Because of the rapid technology has involved, several software has been developed throughout the year, which has its unique feature on each software. However, the comparative study between different structure design software in Malaysia was not well established. Therefore, this study aims to investigate the differential between analysis and design software commercially available in the Malaysian market. A four-story reinforced concrete building was chosen as a case study throughout this project using three different Softwares, namely as ESTEEM, Tekla, and Robot Structure Analysis. Based on the comparative study conducted, the results indicated that each software's structural analysis and design output were identically similar. However, there are marginal differences between the analysis and design result via manual calculation. The time-consuming design and analysis are tedious, making software necessary to be used. Due to the area of reinforcement required and provided in detailing produced by the computer software is similar, it is shown that the software used is capable of analysis and design structure

Keywords: Software, Analysis & Design

1. Introduction

Structural engineers have been using various operating systems to analyze and design structures. Dated back to the 19th to 20th century, the time taken to analyze and design the structure is longer and the possibility for such human error in complex structures can be expected. The software has made it easier for structural engineers to analyze and design structures in a shorter period. Many software focusing on structural analysis and design have been developed and available to serve structural engineers' requirements in today's technology. Each operating system available in the market has its advantage, quickly analyzing and designing complex structures.

In this study, three available structural analysis and design software were considered, namely as Tekla Structural Designer by Trimble's, Esteem 10 by Esteem Innovation, and Robot Structural

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Analysis. by AutoDesk's. A four-story reinforced concrete building was used as a case study where a model of architecture plan was utilized to replicate the analysis and design structure situation. The building estimation, structural analysis and design process were conducted in according to the code of practice, MS EN 1991-1-1:2010 (National Annex) and MS EN 1992-1.1:2010 This study compare against the output of loading distribution, structural analysis and design structure with each operating system. A selected element of the structure was picked. A manual calculation was compared with an operating system to find the more economical design and accurate analysis. It will be considered an operating system suitable for structural engineers

1.1 Structural Engineering And Design

Structural design is a stage that involves conceptual design, preliminary design, and detailed design. Conceptual design is the first stage in design and analysis, which requires various considerations such as calculation, safety, the client's requirement, and the design brief. Apart from that, stability and service are something that must be considered. This stage also involved professionals such as architects, geotechnical engineers, services engineers, and quantity surveyors [1] .

For Preliminary design, things that need to be considered, such as the calculation stage, which includes both hand calculation and computer, involved simple analysis for a manual calculation. In contrast, the computer is related to calculating the structure as a whole. However, computers play a large part in analysing and designing structures. Therefore, engineers should understand in-depth in analysing the structure to detect if the software produces the wrong result.

1.2 Tekla Structural Designer By Trimble

Tekla is a combination of analysis and design that performs flawlessly and delivers safe, effective, and indirectly quicker regardless of structural material [2].

It is fully automated while containing various unique features for concrete and steel design. It also improves engineering in dealing with businesses that maximize profits and handle more work. Cost-effective and seamless BIM collaboration is also a key feature that Tekla offers.

It can cover design through detailing and includes gravity and lateral systems with one single model. Tekla Structural Designer also needs no additional modules to be purchased, whereas there is no need to switch between various operating systems to get your ultimate design solution.

Tekla offers a complete analysis result which we can analyze and study while also evaluating the calculation. It can analyze multi-material buildings in steel and reinforced concrete in a short amount of time. Early cost estimation can also be provided because Tekla can generate the whole building automatically when it comes to material quantities [3].

1.3 Esteem 10 By Esteem Innovation

Esteem product has been in the market since 1994 in leading building intelligence modeling software. This operating system provides intuitive input with fully integrated project management. It also contains comprehensive output regarding detailing slab, Beam, column, wall, and footing. Esteem is widely used in the consulting engineer offices and the developers. Based on a comparison between the three operating systems used, Esteem is the easiest to handle due to the parameters already provided according to the code of practice preferred in this country [4].

Esteem is one of the highest operating systems widely used among Malaysia's consultant company because it is easy in analysis and design structure. It provides various codes of practice, including the Malaysia Annex. Based on the study that has been made, Esteem operating system produce designed that meet the criteria for multi-story building in suggested that Esteem to be an efficient and accurate instrument that is reliable to be used in making the analysis and calculations [5].

1.4 Robot Structural Analysis Professional By Autodesk

Robot Structural Analysis it is considered an affordable operating system. It has various key features, such as being compatible with BIM and effectively and accurately doing a wind load simulation [8].

The Robot is straightforward to learn quickly and provides enough information for the structural engineer to see the available data and make modifications according to the wishes of the structural engineer.

Robot is compatible with Revit; it automatically makes this operating system smoothly and transparently using BIM Robot operating system provides steel and reinforced concrete without purchasing other accessories compared to other operating systems which only provide a certain feature. That needs to be purchased separately [6].

Every software is different from one another, and even the purpose is the same. For Robot Structural analysis, instruction is necessary for new users to use the software appropriately; one study was conducted. They made an instruction media for using the robot structural analysis and compared to a student using them without instruction. The result shows a massive gap between the two data showing that students who are provided instruction are more understanding than those without instruction [6].

One study made to analyse a structural building using Robot Structural analysis with manual calculation aims to discover any difference between manual and software calculation. This study concludes that "traditional manual calculations are almost impossible to execute due to many possible combinations that lead to difficulties finding out the critical load, which leads to an overestimation of critical load by introducing a high value for safety factors manual calculation takes a tremendous amount of time than using the software [7].

1.5 Black Box And White Box Testing

Black-box testing is a study conducted on software or mechanical tools where the user's internal knowledge of the software or mechanical tools is unknown. where the white box is something testing or study done on software or mechanical tools where internal knowledge and also outside knowledge can be accessed by the user [10]. To do a white box test, we must know the foundation knowledge to enable us to estimate the result. several methods have also been produced [11]

2. Methodology

2.1 Building Selection

Figure 1 shows a model of architecture plan contain four level.

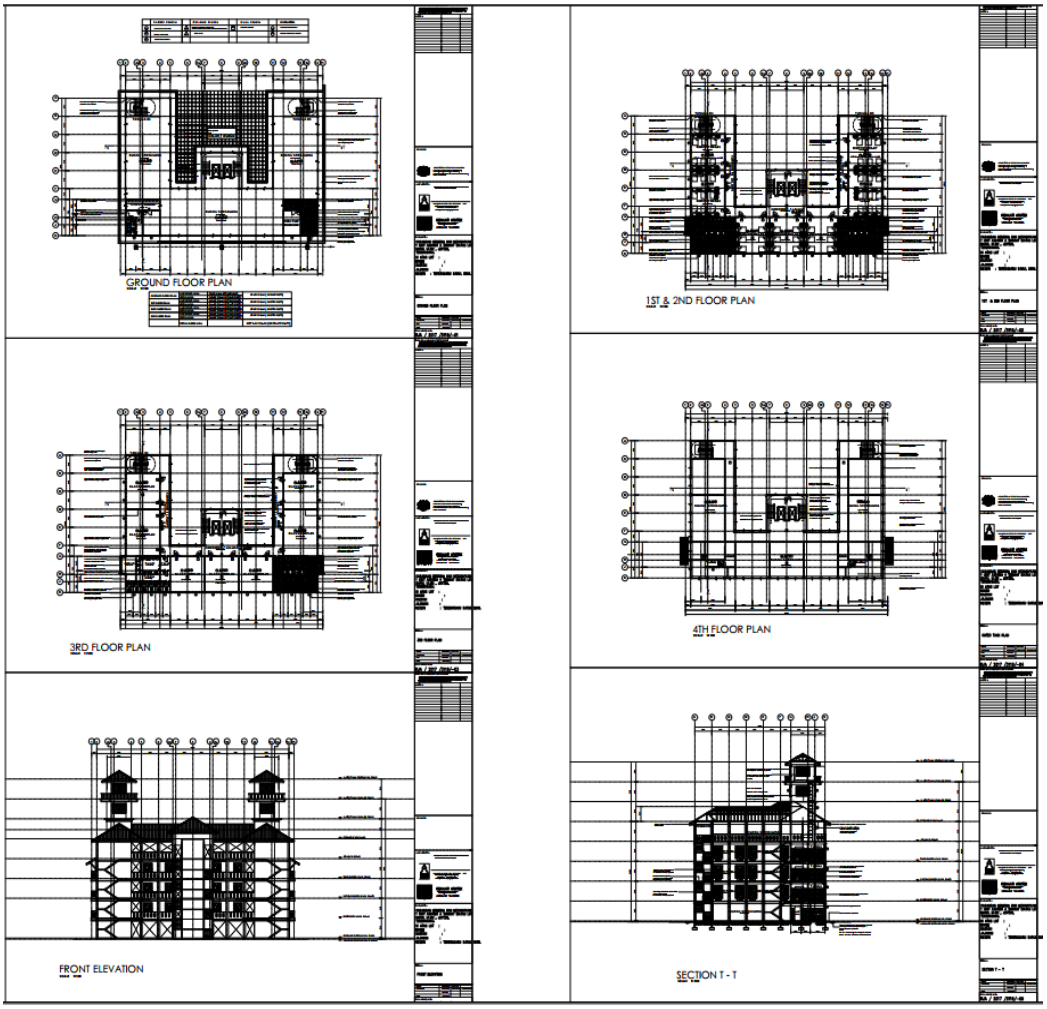

Figure 1: Architecture plan

2.2 Design Specification and Assumptions

This study assumes that wind load will not affect the structure. Moreover, the structural form is considered a brace column. And for the values given to dead load and imposed load depend on the situation of the plan architect.

2.3 Design Parameter

Table 1 shows that a Structure reinforcement uses the parameter shown below to analyze and design structure.

Table 1: Parameter of Structure

Design parameter		
MATERIAL PROPERTIES		
$fck(characteristics\ of\ compressive\ strength)$	=	30 N/mm^2
fyk(characteristic yield strength)	=	460 Mpa
MAIN REINFORCEMENT		
Minimum Main Bar Diameter	=	12 mm
Maximum Main Bar Diameter	=	25 mm
SHEAR REINFORCEMENT		
Minimum Link Diameter	=	6 mm
Maximum Link Diameter	=	12 mm
Minimum Link Spacing	=	100 mm
Maximum Link Spacing	=	275 mm
DESIGN		
Cover	=	30 mm

2.4 Structural Element Size

Table 2 shows the structure size element that is used for software and manual calculation.

Table 2: Element of Structure Size

NO	Element of structure	Size (mm)
1	Column	450x250
2	Main Beam	230x550
4	column	325x325x200
3	Slab	125

Based on Table 3, the size chosen ensures that the information can be compared and evaluated between each software. The size element of structures such as column, slab, and Beam will be in the same size as shown in Table 3.

2.5 Software Design

Figure 2 shows the workflow implemented when analyzing and designing the structure.

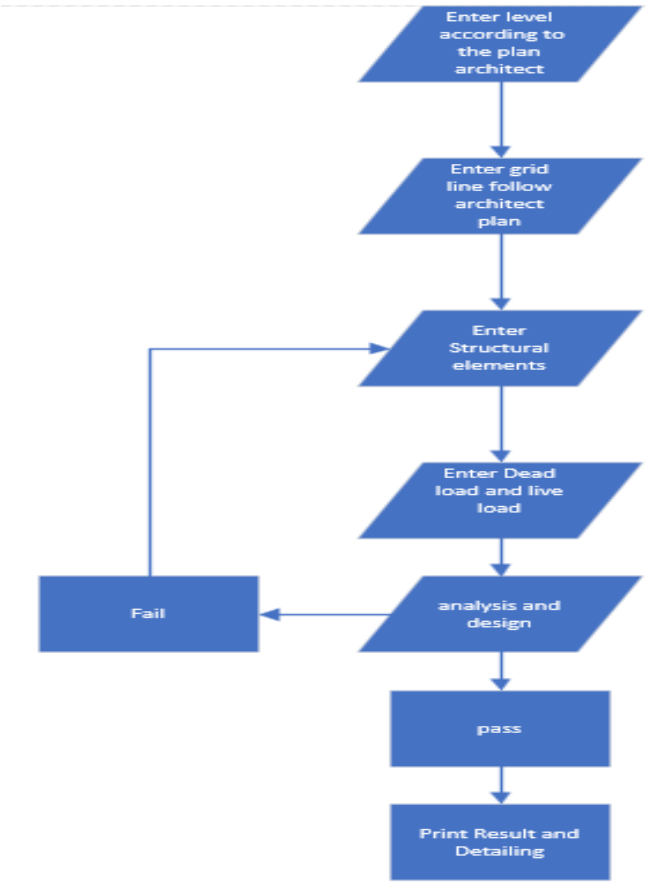

Figure 2: Workflow of operating Software

As shown in Figure 2, the steps need to be taken to generate the result accordingly.the steps shown below are the basic steps to obtain a result.

3. Results and Discussion

3.1 Column analysis

Table 3 shows an axial load column recorded and located at A-2 from ground floor until roof top.

Table 3: Axial load column A-2

NO	RSA axial load	%	Tekla axial load	%	Esteem axial load	%	Manual axial load
Roof Top	27.1	85.5	33.33	95.1	38.71	81.9	31.69
Level 4	68.27	92.8	67.8	93.4	79.33	79.8	63.34
Level 3	108.14	87.9	101.12	94.0	114.89	82.7	95.01
Level 2	146.71	86.3	133.5	94.9	148.34	85.4	126.68
Level 1	193.86	81.7	165	96.0	181.16	87.4	158.35
Level GB	260.93	89.2	241.8	96.3	249.83	93.2	232.84

The table above shows an axial load (A-2) from the ground floor to the rooftop. At the top floor, the column at the rooftop contains a load of 27.1 kN for RSA with 85.5% compared to manual, 33.33kN for Tekla with 95.1% compared to manual, 38.71 kN for Esteem with 81.9% compared to manual, and 31.69 kN for manual. Compared to the ground floor level, the result obtained is lesser because the column holds no load other than the load at the column's level. While if viewed from the lowest floor gets 260.93 kN for RSA, 241.8 kN for Tekla, 249.83 kN for Esteem, and 232.84 for a manual. Table 3 shows a beam reinforcement area located at A(2-5) designed by RSA, Tekla, Esteem, and manual calculation.

Columns designed at each level cause each column at each level to have a different reinforcement. This can indirectly save the rate of reinforcement usage in the column. The location that is being discussed is located on the ground floor (A-2).

Table 4 show column axial load and area reinforcement located at (A-2).

Table 4: column axial load and area reinforcement located at (A-2)

	RSA			Tekla			Esteem			manual		
	axial load (kN)	longitudinal reinforcement Area	Longitudinal bars	axial load	longitudinal reinforcement Area	Longitudinal bars	axial load	longitudinal reinforcement Area	Longitudinal bars	axial load	longitudinal reinforcement Area	Longitudinal bars
Roof Top	27.1	628.3	8t10	33.33	628.3	8t10	38.71	628.3	8t10	31.69	628.3	8t10
Level 4	68.27	628.3	8t10	67.8	628.3	8t10	79.33	628.3	8t10	63.34	628.3	8t10
Level 3	108.14	628.3	8t10	101.12	628.3	8t10	114.89	628.3	8t10	95.01	628.3	8t10
Level 2	146.71	628.3	8t10	133.5	628.3	8t10	148.34	628.3	8t10	126.68	628.3	8t10
Level 1	193.86	628.3	8t10	165	628.3	8t10	181.16	628.3	8t10	158.35	628.3	8t10
Level GB	260.93	628.3	8t10	241.8	628.3	8t10	249.83	1609	8t10	232.84	1609	8t10

In this design for manual calculation, only the column stump is designed because it contains the higher axial load. The software design column level by level, which means every level imposed to different axial load and different levels may contain different reinforcement.

As shown in Table 4, only Esteem provides 16 diameter reinforcement at column stump while others provide 10 diameters at every level. The figure below shows the detailing drawing that is being produced by the software.

As shown in Table 4, all software and manual calculation provide 10 diameter reinforcement at every level. The figure below shows the detailing drawing produced by the software.

3.2 Beam Design and analysis

Table 5 shows a beam reinforcement area located at C(2-5) ground floor.

Table 5: Beam Reinforcement Area located at A(2-5)

	beam	length mm	bottom reinforcement at mid-span	top reinforcement at support	bottom reinforcement at (Max)		top reinforcement (Max)	
					$A_{s,req}$	$A_{s,prov}$	$A_{s,req}$	$A_{s,prov}$
RSA	230x550	7800	2H20	2H18	625.44	628	483.2	534.34
Tekla	230x550	7800	2H20	2H20	590	628	481	628
Esteem	230x550	7800	2H20	2H20	577	628	492	628
Manual	230x550	7800	2H12	2H25	324.12	402	647.77	982

The table above shows the area of reinforcement required by the selected Beam and the area of reinforcement provided by the software and manual calculation. The length of the chosen Beam is 7800 mm, and the dimension of the Beam is 230 mm x 550 mm. The bottom reinforcement for each software is 2H20 which is the same, but if looking at the top reinforcement, only RSA provides 2H18; the other software does not contain a diameter of 18.

Table 5 shows the area requirements for each software. The higher value is RSA following Tekla. Esteem only requires 577-millimeter square. Figure 4.2, max moment for RSA is 124.57 kNm followed by esteem 117.91 kNm, which is why AsReq is higher than the other. Table 4.3 also shows that all the software is the same, 628-milliliter square.

Top reinforcement required for all the same software is the same only minor difference, but for provided reinforcement, RSA provides 534.34-millimeter square; as mentioned early, this is because RSA can provide that size while the other cannot.

The manual calculation is different from the other software because when it comes to analysis, the result is different from other at support and mid-span; for software, the maximum moment happens at the mid-span, while manual calculation happens at support.

Table 6 shows the maximum moment and shear force for all software and manual calculation.

Table 6: Result obtained from Beam located at C (2-5)

	support left				**support right**				**mid-span**			
	RSA	**Esteem**	**Tekla**	**Manual**	**RSA**	**Esteem**	**Tekla**	**Manual**	**RSA**	**Esteem**	**Tekla**	**Manual**
Shear (kN)	111.33	103.68	107.4	107.62	111.24	101.34	108.4	107.62	0	0	0	0
moment(kNm)	76.04	75.15	63.8	139.9	76.04	74.6	67.8	139.9	141.14	144.33	140.5	69.99
% compare to manual Shear (kN)	96.67	96.34	99.80	-	96.75	94.16	99.28	-	-	-	-	-
% compare to manual moment (kNm)	54.35	53.72	45.60	-	54.35	53.32	48.46	-	49.59	48.49	49.81	-

For shear force at left support, RSA got the higher result. Compared to the manual calculation, the most accurate result is Tekla, which is 99.8%, and the lowers Esteem, which is 96.34%. For right

support, the highers is also RSA, which is 111.24 kN, and the most accurate compared to the manual is also Tekla which accuracy 99.28%.

Shear force at support left and right for manual calculation is the same. This is because the load is symmetrical, but what happens for all software is different because the left and right support are not the same.

3.3 Continuous Beam Design

Table 7 shows the reinforcement required and provided by the three software and manual calculation.

Table 7: Beam Reinforcement Area located at 2 (A-k)

	beam	**bottom reinforcement**	**reinforcement (Max)**	
			AsReq	**AsProv**
RSA	230x550	2H12	69	226
Tekla	230x550	2H12	59	226
Esteem	230x550	2H12	74	226
manual	230x550	2H12	38.94	226

The table above shows the reinforcement required and provided by the three software. In general, all got the same reinforcement area. The figure below shows the detailing image provided by the software. It can be seen that the arrangement of reinforcement is the same for all three software.

$A_{s,req}$ by manual calculation is the lowers while the highest is Esteem. But because $A_{s,req}$ for all software and manual calculation is below Area reinforcement minimum, a minimum Area reinforcement is being used as a beach mark.

4. Conclusion

Based on analysis and design performed on selected elements of the structure. It was found that the result in every software, including manual calculation is not the same, although similar. The ability to detect the dissimilarity is impossible because the test conducted is a black box test. The area of reinforcement required by all the software providers is similar. The area reinforcement provided in detailing is also the same, which means that all software can analyze and design structure. For detailing drawing provided by RSA is less function than other software such as it cannot produce combined Beam into AutoCAD.

RSA, compare to other software, also needs a higher-end computer to run smoothly; otherwise, it won't run properly. Esteem and Tekla provide a calculation for the user to review and inspect. In contrast, RSA only provides data property without providing calculation manually; this makes it hard for an engineer to detect and study the information given by the software.

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