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Comparative Study in the Design of a Reinforced Concrete Structure

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Abstract: Nowadays, the application of software is popular in engineering field. This raised a problem that which software should be used in order to get the best solution. The objectives of this study are to model a double storey reinforced concrete building using Esteem Integrated Total Solution and Tekla Structural Designer and to evaluate the structural design outputs in term of the loading analysis, structural analysis, reinforcement detailing and the taking off results. A double storey reinforced concrete integrated office building was modelled, analyzed and designed complying with the Eurocode (EC) and the Malaysian Standard (MS). The load combination was designed according to serviceability load limit state and ultimate limit state. Seismic load and wind load were not considered in this study to reduce the complexity in achieving the objectives. The structure was modelled, analyzed and designed in Esteem and Tekla based on specifications and assumptions in accordance with Eurocode (EC) and the Malaysian Standard (MS). The structural design outputs and taking off results were exported form Esteem and Tekla and compared. The structural design outputs for beams and pile caps differ within 5% and 10% respectively while the structural design outputs for columns differ up to 32.2%. Tekla resulted in higher beam shear force and higher pile cap axial load in overall while Esteem resulted in higher beam bending moment, higher column axial load and higher column bending moment in overall. For reinforcement, both software had provided same reinforcement for simply supported beams and slabs meanwhile Tekla had provided about 35% greater area of reinforcement for continuous beams, columns and pile caps compared to Esteem. In term of taking off results, the concrete volume required for both software were almost similar. However, Tekla has a higher the taking off results in term of reinforcement mass which is about 8000kg. In term of material costing, Tekla cost about RM27000 higher compared to Esteem. From this study, it was found that both Esteem and Tekla have their own strengths where Esteem resulted a more cost-effective taking off result while Tekla is more conservative, flexible and user-defined.

Keywords: Esteem, Tekla, Structural Design Outputs, Taking off Results

1. Introduction

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As the world continues to move towards the new era of information technology, structural analysis and design software are developed by engineers to ease the engineering practices by providing a quick and reliable solution to engineering problems[1]. Esteem Integrated Total Solution and Tekla Structural Designer are two software used to design and analyze any kind of structure. However, these two software will give different design and analytical results for the same structural configurations due to different analytical mechanism which rise a need to carry out a comparative study between these two software to know the feasibility of these two software[2].

Esteem Integrated Total Solution is one of the leading software for the structural building design. It has been chosen as the key productivity tools in many structural consulting engineering firms. Esteem includes modelling, visualization, analysis, design and detailing of the building structures.

Tekla Structural Designer is one of the most advance structural design software that enable engineers to create accurate, information-rich 3D models that includes all the structural data of the structure. Tekla is able to undertake structural analysis and design, produce professional calculations and construction drawings, or provide full detailing services.

The characteristic loads, load combinations, reinforcements, external forces and the soil bearing capacity has to be considered for the design of a structure. As the number floor keep increasing, the information that has to be included increases causing the manual calculation to be more complex[3]. Hence, the use of a software is ideal to reduce time cost and minimize the chances of the error. This paper carried out a comparative study of design results of Esteem and Tekla software by taking the structural design output and the material taking off result of a double storey building in account.

Esteem and Tekla are two of the leading ultimate encoded design software in consulting firms in Malaysia. These software aid structural engineers to design a safe and economical structure using technologies, so that they can tackle the complex and large structures to design. Hence, the efficiency of these two structural design software has to be assessed. The structural design outputs have to be compared for building safety while the material taking off results have to be compared for construction cost.The objectives of this study are as following:

- To model a double storey reinforced concrete building using Esteem Integrated Total Solution and Tekla Structural Designer.
- To evaluate the structural design outputs in term of the loading analysis, structural analysis, reinforcement detailing and the taking off results using Esteem Integrated Total Solution and Tekla Structural Designer.

In this study, a double storey reinforced concrete integrated office building was modelled, analyzed and designed by using two of the most common commercial software used in Malaysia which are Esteem Integrated Total Solution and educational version of Tekla Structural Designer. This study complied with the Eurocode (EC) published by European Committee for Standardization and the Malaysian Standard (MS) published by the Department of Standards Malaysia. The concrete grades for superstructures and foundations are C25/30 and C30/37 respectively while the steel for main reinforcement and shear reinforcement are high yield steel, S460 and mild steel, S250 respectively. The elastic modulus, E and shear modulus of steel reinforcement, G is fixed as 210000N/mm^2 and 80769N/mm^2 respectively. The load combination was designed according to serviceability load limit state and ultimate limit state. Seismic load and wind load were not considered in this study to reduce the complexity in achieving the objectives. The structural design output of the building was evaluated in term of the the loading analysis, structural analysis, reinforcement detailing and the taking off results only.

Nowadays, analysis and design software had become a necessity for engineers to equipped with. The application of these software help and ease engineers in solving a variety of problems ranging from simple loading calculation to superstructure and substructure design and analysis[1]. Recently, the application of software in civil engineering field is very common as software reduce all the extensive works such as the complex calculations, modelling, drafting and designing activities[4]. Software that was developed to ease engineers' job include drafting and design software, geotechnical and environment software, structural engineering software, construction engineering and management software, hydraulic engineering software and road design and transportation software. Software play an important role in engineering field which increased the efficiency of work as well as time and cost. It facilitates engineering work and perform the work in an accurate, time saving and cost saving way as the workload and manpower had reduced compared to the work that is done manually[4]. The application of software assist engineers by elevating the quality of design, modelling and analysis process of the engineering tasks. Software is applicable for many engineering works such as huge structure design, virtual reality, prediction of structural behavior, equations solving, resource optimization, earth-work estimation, cost estimation, project management, structural drawing and predictive model making.

The application of software makes engineering works to be more productive and quantitative. Some examples of engineering software are AutoCAD, PLAXIS, STAAD. Pro and MS Project. Structural design software increased the efficiency of engineering practices, fulfilling the required function safely, economically and aesthetically within the service lifetime of the structure. Hence, the software have to be evaluated and their respective feasibilities will be determined at the end of this study.

2. Methodology

In order to achieve the objectives, a double storey reinforced concrete integrated office building was modelled, analyzed and designed in Esteem and Tekla based specifications and assumptions in accordance with Eurocode (EC) and the Malaysian Standard (MS). The flowchart of the procedure framework is shown in Figure 1.

The design procedure used in this study conform to the Eurocode (EC) published by European Committee for Standardization and the Malaysian Standard (MS) published by the Department of Standards Malaysia. Malaysia Standards are used together with the Malaysia National Annex to Eurocode. The codes of practice and standards used are as following:

- BS EN 1990: Eurocode - Basis of structural design
- BS EN 1991: Eurocode 1 - Actions on structures
- BS EN 1992: Eurocode 2 - Design of concrete structures
- MS EN 1990: Malaysia National Annex to Eurocode - Basis of structural design
- MS EN 1991: Malaysia National Annex to Eurocode 1 - Actions on structures
- MS EN 1992: Malaysia National Annex to Eurocode 2 - Design of concrete structures

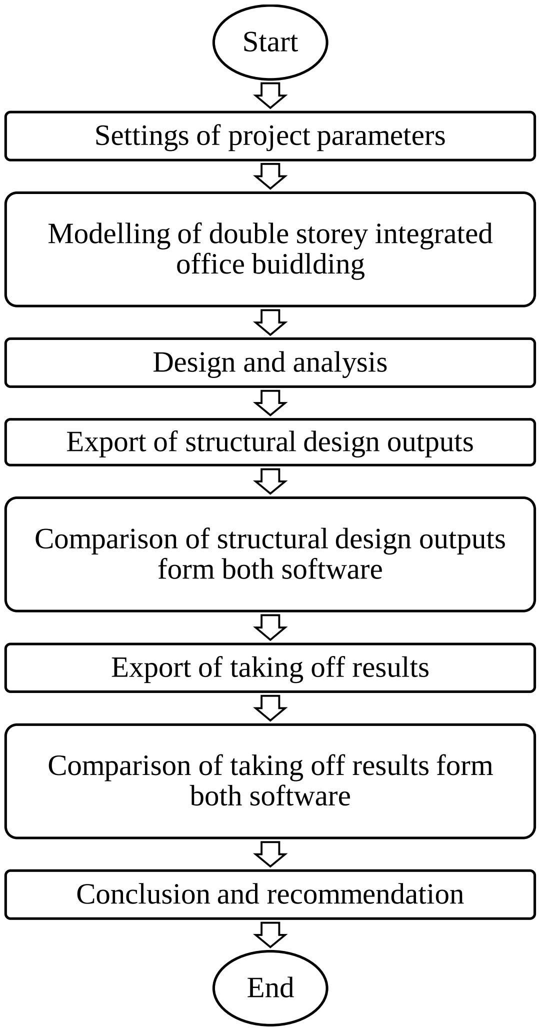

Figure 1: Flowchart of procedure framework

The materials involved in this study includes only concrete and steel reinforcement. The material properties are shown in Table 1 while the dimensions of the structural elements are shown in Table 2. In this study, all the slabs were designed as suspended slab while the roof was assumed to be flat roof.

Table 1: Material properties

Material properties	Values
Concrete grade for superstructures	C25/30
Concrete grade for foundations	C50/60
Unit weight of concrete, g_c	25kN/m^3
RC pile capacity	200kN
Steel for main reinforcement	S460
Steel for shear reinforcement	S250
Elastic modulus of steel reinforcement, E	210000N/mm^2
Poison ratio, v	0.3
Shear modulus of steel reinforcement, G	80769N/mm^2
Unit weight of steel, g_s	7850kg/m^3

Table 2: Dimensions of elements

Elements	Dimensions (mm)
Nominal cover for super-structure	30
Nominal cover for sub-structure	50
Slab thickness	150
Beam	250 x 600
Column	250 x 450
Floor height	3200
Stump	250 x 450
Stump height	1200
Brickwall thickness	115
RC pile	150 x 150

The building areas were categorized based on Table NA2 in Malaysia National Annex to Eurocode 1 and the imposed load values were based on the recommended values in Table NA3 in Malaysia National Annex to Eurocode 1 according to their respective categories. The roof structure was categorized based on Table 6.9 in Eurocode 1 as Category H where the roofs is not accessible except for normal maintenance and repair. The recommended value for imposed load on roof referred to Table NA7 in Malaysia National Annex to Eurocode 1. Wind load and seismic load was not considered in order to reduce the complexity of this study.

The structure was designed according to serviceability limit state and ultimate limit state. The load combinations were shown in *Eq.* 1, *Eq.* 2 and *Eq.* 3 while the load envelope includes all the load combinations.

$$Service\ load = 1.0G_k + 1.0Q_k\ Eq. 1$$

$$Maximum\ ultimate\ load = 1.35G_k + 1.5Q_k\ Eq. 2$$

$$Minimum\ ultimate\ load = 1.35G_k\ Eq. 3$$

In both software, the building was modelled according to the specifications and assumptions made. The structural outputs and material taking off results were exported from both Esteem and Tekla to be compared. The results were compared based on *Eq.*4 where positive percentages show that Esteem result is greater while negative percentages show that Tekla result is greater.

$$Difference(\%) = \frac{Esteem - Tekla}{(Esteem + Tekla)/2} \times 100\ Eq. 4$$

3. Results and Discussion

The structural design outputs and the taking off results from Esteem and Tekla were compared and discussed. For taking off results, the volume of concrete and mass of reinforcement used for the building structures will be compared and discussed.

3.1 Structural design outputs

For structural design outputs, two simply supported beams, two continuous beams, two interior columns, two exterior columns, three slabs and four pile caps were compared and discussed in term of loading analysis, structural analysis, reinforcement detailing. The results were tabulated.

Table 3: Difference in structural design output for beams

Element	Output	Esteem	Tekla	Difference (%)
Simply supported beam 1	Maximum shear force, V (kN)	68.56	73.2	-6.5
	Bending moment, M (kNm)	76.22	74.4	2.4
	Midspan reinforcement (mm^2)	628	628	0
Simply supported beam 2	Maximum shear force, V (kN)	41.57	36.6	12.0
	Bending moment, M (kNm)	14.89	11.7	21.4
	Midspan reinforcement (mm^2)	452	452	0
Continuous beam 1	Maximum shear force, V (kN)	60.39	64.4	-6.4
	Maximum bending moment, M (kNm)	52.21	46.1	11.7
	Reinforcement at max. moment (mm^2)	628	804	-24.6
Continuous beam 2	Maximum shear force, V (kN)	58.94	63.8	-7.9
	Maximum bending moment, M (kNm)	64.25	78.3	-19.7
	Reinforcement at max. moment (mm^2)	628	1030	-48.5

From Table 3, it shows that Tekla has an average shear force of 2.2% higher in overall while Esteem has an average bending moment of 4.0% higher in overall for both simply supported and continuous beams. For simply supported beams, both Esteem and Tekla had provided same area of reinforcement, while Tekla had provided an average area of reinforcement of 36.6% higher for continuous beams.

Table 4: Difference in structural design output for columns

Element	Output	Esteem	Tekla	Difference (%)
Interior column 1	Axial load, P (kN)	874.90	793.8	9.3
	Maximum moment, M (kNm)	34.14	24.8	27.4
	Reinforcement (mm^2)	1206	2945	-83.8
Interior column 2	Axial load, P (kN)	527.56	512.8	2.8
	Maximum moment, M (kNm)	4.73	2.8	40.8
	Reinforcement (mm^2)	1206	679	43.7
Exterior column 1	Axial load, P (kN)	273.04	176.1	35.5
	Maximum moment, M (kNm)	7.60	2.3	69.7
	Reinforcement (mm^2)	1206	1885	-43.9
Exterior column 2	Axial load, P (kN)	540.13	504.1	6.7
	Maximum moment, M (kNm)	14.03	15.1	-7.3
	Reinforcement (mm^2)	1206	1885	-43.9

For columns, Table 4 shows that Esteem has higher average axial load and bending moment of 13.6% and 32.2% higher respectively compared to Tekla. However, Tekla provided a greater average area of reinforcement of 32.0%.

Table 5: Difference in structural outputs for slabs

Element	Reinforcement layer	Direction	Reinforcement provided		
			Esteem	Tekla	Difference (%)
Corner slab	Top	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0
	Bottom	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0
Edge slab	Top	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0
	Bottom	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0
Centre slab	Top	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0
	Bottom	Parallel	T10-250	T10-250	0
		Perpendicular	T10-250	T10-250	0

For slabs, Table 5 shows that both software had provided same reinforcement arrangements. The bar diameter and bar spacing were exactly same for both software.

Table 6: Difference in structural design output for pile caps

Element	Output	Esteem	Tekla	Difference (%)
Interior pile cap 1	Axial load, P (kN)	705.0	799.2	-12.5
	Reinforcement (mm^2)	1885	2796	-38.9
Interior pile cap 2	Axial load, P (kN)	405.6	512.8	-23.3
	Reinforcement (mm^2)	1571	1571	0
Exterior pile cap 1	Axial load, P (kN)	223.1	176.1	21.1
	Reinforcement (mm^2)	1257	2356	-60.83
Exterior pile cap 2	Axial load, P (kN)	436.0	507.7	-15.2
	Reinforcement (mm^2)	1571	2749	-54.5

For pile caps, Table 6 shows that Tekla has higher axial load value and greater area of reinforcement in overall with average difference of 7.5% and 38.6%.

The software output difference in shear force for beams had a maximum of 12% while the software output difference in bending moment for beams had a maximum of 21.4%. For columns, the difference in axial load and bending moment exceeds 50%. For pile caps, the difference in pile caps is about 20%. In term of reinforcement, Tekla had provided greater reinforcement area for mostly all elements. Hence, it was concluded that the design approach for both software differs. Esteem possess a more cost-effective design while Tekla possess a more conservative design.

3.2 Taking off results

The taking off results for the building structural elements were exported from Esteem and Tekla and tabulated. The results were extracted from the Quantity Take Off Report from Esteem and Material Listing Report from Tekla. Table 7 and Table 8 shows the volume of concrete used based on the concrete grade, mass of reinforcement used based on reinforcement type, its unit prices and its costs.

Table 7: Taking off results from Esteem

Element	Amount	Unit price (RM/unit)	Material cost (RM)
C25/30 concrete	393.2 m^3	208	81784.98
C30/37 concrete	13.5 m^3	218	2936.90
High yield steel, S460	27120.1 kg	3	81360.30
Mild steel, S250	5453.6 kg	3	16360.80
Total	-	-	182442.97

Table 8: Taking off results from Tekla

Element	Amount	Unit price (RM/unit)	Material cost (RM)
C25/30 concrete	403.8m^3	208	83990.40
C30/37 concrete	12.6m^3	218	2746.80
High yield steel, S460	36316.56 kg	3	108949.68
Mild steel, S250	4638.77 kg	3	13916.31
Total	-	-	209603.19

Table 7 and Table 8 showed that the taking off results are almost similar in term of concrete volume. However, the taking off results in term of reinforcement mass has a significant difference of about 8000kg where Tekla required higher amount of high yield steel while Esteem required higher amount of mild steel. The material unit prices were referred to Quantity Surveyor Online where the concrete was assumed to be normal mix. From Table 7 and Table 8, it shows that Tekla has an about RM27000 higher total material cost compared to Esteem. This might be due to the different calculation approach of the two software. Hence, this study shows that Esteem is a more cost-effective software. The costing difference will cost a huge amount of money if it is a huge construction project.

4. Conclusion

From the structural design outputs and the taking off results from Esteem and Tekla, there were some differences for the results from both Esteem and Tekla. The structural design outputs for beams and pile caps differ within 5% and 10% respectively while the structural design outputs for columns differ up to 32.2%. Tekla resulted in higher beam shear force and higher pile cap axial load in overall while Esteem resulted in higher beam bending moment, higher column axial load and higher column bending moment in overall. For reinforcement, both software had provided same reinforcement for simply supported beams and slabs meanwhile Tekla had provided about 35% greater area of reinforcement for continuous beams, columns and pile caps compared to Esteem.

In term of taking off results, the concrete volume required for both software were almost similar. However, Tekla has a higher the taking off results in term of reinforcement mass which is about 8000kg. In term of material costing, Tekla cost about RM27000 higher compared to Esteem.

In Tekla, the properties of every element such as reinforcements can be changed singly during modelling process but the element properties can only be change as a whole in Esteem. Moreover, elements can be grouped at which the grouped elements' properties can be change together at once instead of selecting them one by one. Furthermore, failed element can be modified in Interactive Design option where the element properties that caused failure can be replaced. Lastly, the failed element in Tekla can be easily recognized as they were highlighted in red color instead of listed in a table in Esteem.

Conclusively, both Esteem and Tekla have their own strengths. In this study, Esteem resulted a more cost-effective taking off result while Tekla is more conservative, flexible and user-defined. Hence, users can select their choice of software based on their preferences concluded in this study for a better analysis and design experience. From this study, it was found that both Esteem and Tekla have their own strengths. Further studies were recommended to be carry out using three software so that there will be a decisive choice that which software should be selected for the specific purpose.

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