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# Effect of Columns Stiffness's and Number of Floors on the Accuracy of the Tributary Area Method

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***Abstract*****—**The using of finite element programs in analyzing and designing buildings are becoming very popular, but there are many engineers still using the tributary area method (TAM) in designing the structural members such as columns. This study is an attempt to investigate the accuracy of the TAM results with different load condition (gravity and lateral load), different floors numbers, and different columns stiffness's. To conduct this study, linear elastic analysis in ETABS program is used. The results from finite element method are compared to those obtained from TAM. According to the analysis of the data obtained, it can be seen that there is significance difference between the real load carried by columns and the load which is calculated by using the TAM. Thus, using 3-D models are the best choice to calculate the real load effected on columns and design these columns according to this load.

***Keywords*****—**Tributary area method, finite element method, ETABS, lateral load, axial loads, reinforced concrete, stiffness, multi-floor buildings.

## I. Introduction

COLUMNS are the members which carried the axial load and this load is mainly in compression [1]. These members are generally vertical [2]. The load is transmitted from slab to beam to column, and through column to soil by footing. The TAM is used in widely range in the conceptual design phase of the structures to predict the loads which are carried by members such as columns. This prediction is useful for the initial proportioning of the structural elements. Moreover, this method is used as a quick check for the validity of the results obtained by finite element programs such as SAP2000, ETABS, and SAFE, but is this method accurate enough to use or not? Thus, it is important to investigate the accuracy of this method on the resultant loads calculation.

The TAM can be considered suitable for masonry buildings because it will produce large reactions in walls and columns [3]. Kurc and Lulec [4] studied different analysis approaches to estimate the axial loads on columns and walls in high rise buildings, the final result showed that the axial loads on columns and walls might vary up to 45% and this variation will depend on the type of the analysis such as linear or non-linear analysis [5].

## II. Finite Element Models Description

ETABS version 16.2.0 [6] is used in this study. Different 3D models are simulated with different floors numbers (1, 3, 5, 7, and 10 floors). The columns are assumed to be squared in shape (C20x20 cm, C50x50 cm, and C70x70 cm). The slab is assumed to be flat plate with thickness equals to 20 cm. The distance between columns in both directions is 5 m as shown in Figs. 1 and 2. The boundary conditions for all columns are assumed to be pin supports. All structural members are made from concrete type of B300, with $f'_c$ = 24 MPa and the unit weight of reinforced concrete equals to 25 kN/m$^3$. According to ACI318M-14 the modulus of elasticity of the normal concrete is given as [7]:

$$E = 4700\sqrt{f'c} \tag{1}$$

where $f'_c$ is concrete compressive strength in MPa.

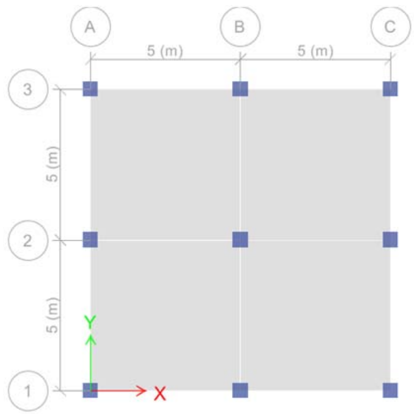


Fig. 1 Layout of the models

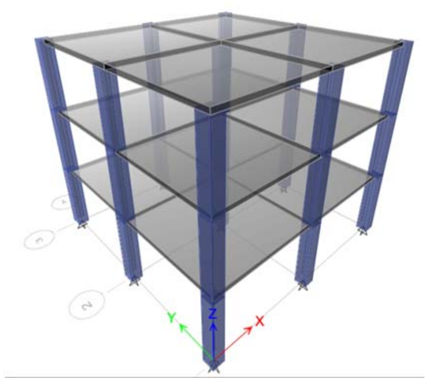

Fig. 2 General 3D model for multi-floor building

Live load of 3 kN/m$^2$ and superimposed dead load of 4 kN/m$^2$ are uniformly distributed on all slabs in the direction of gravity. Also, 1 kN/m$^2$ lateral load is uniformly distributed in

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the X direction on the slab. The reactions of the supports are calculated from the ultimate load combination 1.2D+1.6L.

## III. Calculation of Column Loads Using TAM

There are two cases of loads on columns, one from gravity loads and the other from lateral load [8].

In the first case of analysis, the multi-floor building under gravity load will be analyzed. The results of axial load on the ground columns are compared as obtained from the ETABS model to that obtained by the TAM. In this analysis, it is focused on the effect of varying floors numbers on the axial load. For the purpose of comparison the loads calculations are:

- Slab own weight = 0.20× 25= 5 kN/m$^2$
- Wu= 1.2D+1.6L=1.2(5+4)+1.6(3)=15.60 kN/m$^2$

Using T.A.M, the axial load on each column depends on its locations:

- Center column = 5× 5×15.60= 390kN
- Edge columns = 5× 2.5×15.60= 195kN
- Corner columns = 2.5× 2.5×15.60= 97.5kN

In the second case (lateral load case), the multi-floor building model under lateral load will be analyzed. The results of the carried shear force by the ground columns [9] from ETABS model will be compared against the results obtained from TAM with neglecting the slab own weight. The TAM for the lateral load calculation is conducted for each column by multiplying the ratio of the contribution in the plan area by the lateral load value [9]. Although this calculation method is not accurate, it is still commonly used [9].

- Center column shear load = 5× 5×1= 25 kN
- Edge columns shear load = 5× 2.5×1= 12.5 kN
- Corner columns shear load = 2.5× 2.5×1= 6.25 kN

## IV. Finite Element Results

After all models are simulated in ETABS with loads assignments, the analysis is conducted and the final results from the program are tabulated as shown in Tables I-VI.

TABLE I
Finite Element Axial Load in kN Results for Center Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 569 | 512.99 | 506.77 |
| 3 | 1507 | 1492.26 | 1500 |
| 5 | 2244.15 | 2410.24 | 2458.02 |
| 7 | 2835.11 | 3249.14 | 3366.77 |
| 10 | 3561.47 | 4360.52 | 4623.70 |

TABLE II
Finite Element Lateral Load in kN Results for Center Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 13.07 | 24.99 | 27.13 |
| 3 | 39.35 | 49.38 | 48.54 |
| 5 | 66.40 | 84.16 | 80.66 |
| 7 | 98.28 | 120.61 | 114.96 |
| 10 | 133.59 | 176.01 | 168.82 |

TABLE III
Finite Element Axial Load in kN Results for Edge Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 181.99 | 188.45 | 189.73 |
| 3 | 579.45 | 575.07 | 573.48 |
| 5 | 1003.20 | 973.48 | 964.36 |
| 7 | 1425.19 | 1384.82 | 1364.50 |
| 10 | 2027.18 | 2018.60 | 1981.75 |

TABLE IV
Finite Element Lateral Load in kN Results for Edge Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 11.60 | 12.46 | 12.45 |
| 3 | 34.62 | 34.84 | 34.80 |
| 5 | 57.79 | 58.28 | 58.18 |
| 7 | 80.96 | 81.84 | 81.63 |
| 10 | 115.71 | 117.24 | 117.03 |

TABLE V
Finite Element Axial Load in kN Results for Corner Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 65.76 | 73.30 | 73.85 |
| 3 | 213.85 | 221.87 | 221.53 |
| 5 | 385.76 | 373.96 | 371.14 |
| 7 | 596.03 | 532.89 | 523.81 |
| 10 | 982.50 | 791.82 | 762.33 |

TABLE VI
Finite Element Lateral Load in kN Results for Corner Column with Different Floor Numbers

| Floor number | C20x20 | C50x50 | C70x70 |
|---|---|---|---|
| 1 | 9.92 | 6.35 | 5.99 |
| 3 | 30.01 | 28.02 | 28.37 |
| 5 | 49.76 | 46.07 | 47.21 |
| 7 | 69.51 | 63.58 | 65.45 |
| 10 | 99.14 | 89.62 | 92.02 |

## V. Discussion of Axial Load Results under Gravity Loads

Figs. 3-5 show the axial load estimation in center, edge, and corner columns respectively. In these figures the load from TAM is compared to those from ETABS for different cases of columns dimensions (20x20 cm, 50x50 cm, and 70x70 cm) and for different numbers of floors (1 to 10). Overall, it can be noticed that the deviation between the results from TAM and from finite element becomes higher as the number of floors increases. This is because of the accumulation of errors in the TAM due to it is approximate nature.

In Fig. 3, the TAM will produce axial load results less than finite element in the center column and that may lead to unsafe cross sectional dimensions if the load is used only from TAM. Moreover, increasing the stiffness of the column will make the difference between TAM and finite element method rises up. Also, if the number of floors increases then the error between TAM and finite element method will increase, too.

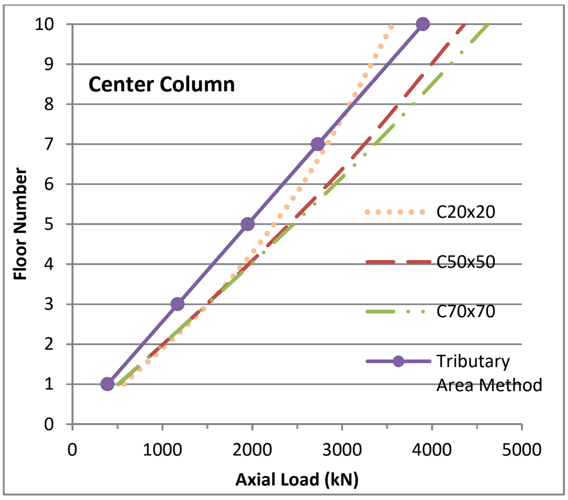


Fig. 3 Axial load for center column

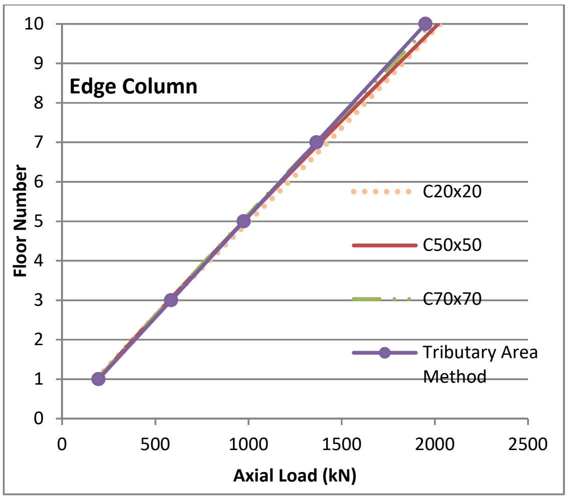


Fig. 4 Axial load for edge column

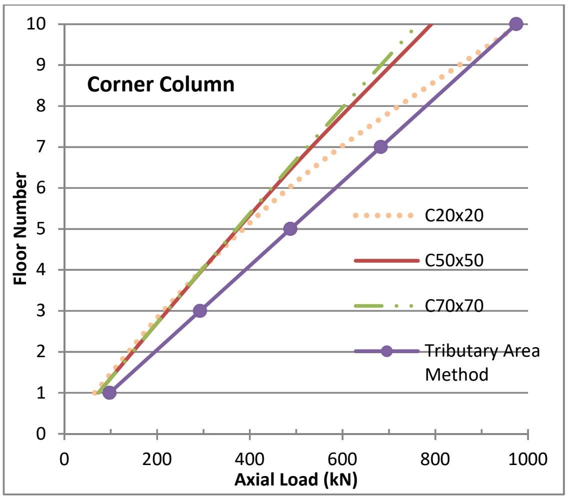


Fig. 5 Axial load for corner column

According to Fig. 4, the TAM will produce results of axial load approximately equal to the finite element results in the edge columns, and that effect of floors numbers seems to be negligible in this case.

According to Fig. 5, the TAM gives axial load results more than that from finite element method in the corner columns, and if the number of floors increases, the error between TAM and finite element method increases, too.

## VI. Discussion of Shear Load Results under Lateral Load

Figs. 6-8 show the lateral load estimation in center, edge, and corner columns respectively. In these figures, the load from TAM is compared to those from ETABS for different cases of columns dimensions (20x20 cm, 50x50 cm, and 70x70 cm) and for different numbers of floors (1 to 10). As a general trend of these figures, it can be noticed that if the stiffness of the columns increases, the results from finite element and from TAM become closer. The TAM always produces conservative results for edge and central column. However TAM seems to produce results less than that obtained by finite element method.

In Fig. 6, the TAM produces horizontal load results more than that from finite element in the center column and that may lead to unsafe cross sectional dimensions if the load is used only from TAM. Moreover, increasing the stiffness of the column will make the difference between TAM and finite element method to drop down. Also, if the number of floors increases then the error between TAM and finite element method will increase, too.

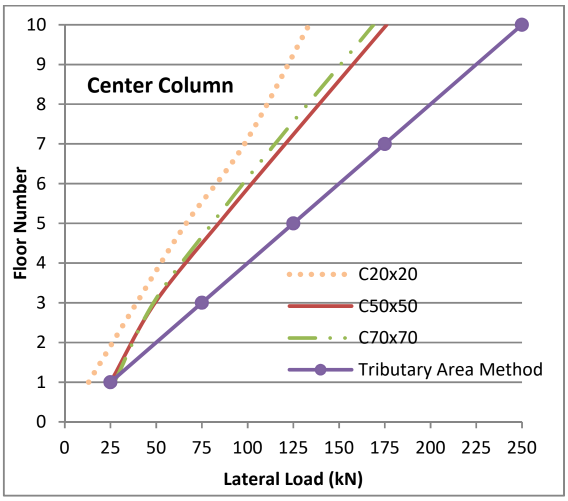


Fig. 6 lateral load results for corner column

In Fig. 7, the TAM produces horizontal load results always less than that from finite element in the corner column. Also, increasing the stiffness of the column will make the difference between TAM and finite element method to drop down. Also, if the number of floors increases then the error between TAM and finite element method will increase, too.

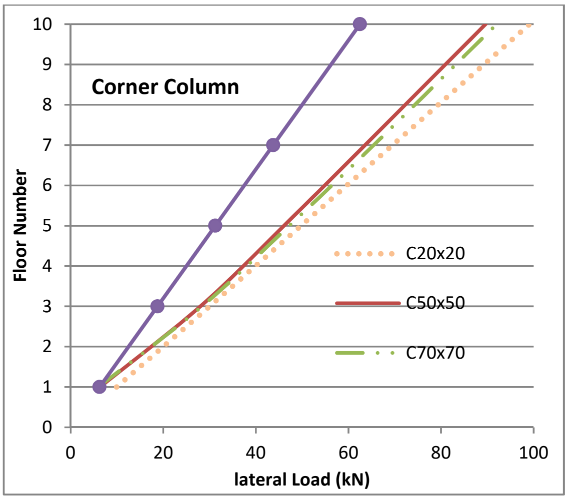


Fig. 7 Lateral load results for corner column

In Fig. 8, the TAM will produce horizontal load results always more than finite element results in the edge column, and the effect of column stiffness seems negligible. If the number of floors increases then the error between TAM and finite element method will increase.

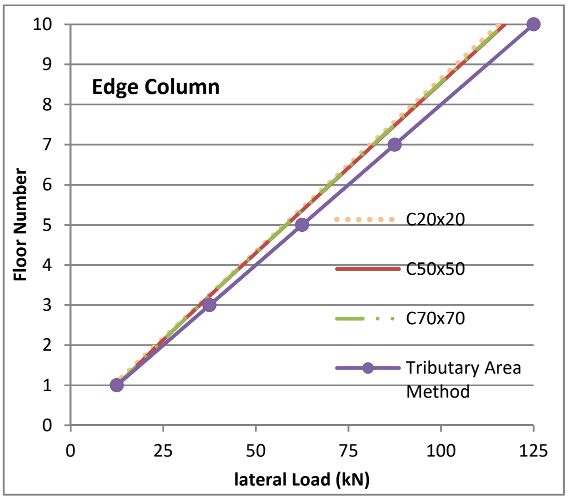


Fig. 8 Lateral load results for edge column

## VII. Conclusion

In this paper, the TAM results, which is used in the conceptual design phase, is compared to the results from finite element method to recognize the accuracy of the TAM results in the calculation of the axial load and shear load in columns with different positions.

The main conclusions from this study are as follows:

- The position and the stiffness of the column strongly affect the results of the finite element method. In contrast the TAM, only the position of the column affects the result of the loads.
- The number of floors affects the results of the loads, and increasing it will increase the difference between TAM results and finite element results.
- For edge columns, the axial load from TAM and finite element method are approximately the same.
- For central columns, the axial load from TAM is less than finite element method.
- For corner columns, the axial load from TAM is more than finite element result.
- For edge and central columns, the lateral load results from TAM are more than that from finite element method.
- For corner columns, the lateral load results from TAM are less than that from finite element method.

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