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Effect of Column Spacing on Economy of G+5 R.C Moment Resisting Frame – A Typical Computer Aided Case Study

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Abstract

The economy of a multistory building depends on the spacing of columns which in turn depends on panel size of slab. The objective of this work is to design an economical G+5 building by finding the optimum spacing of columns. This work is limited to plot area of 30 m X 30 m (with Aspect ratio of Panel varied from 1 to 4) for first case and in second case they were 30 m x 30 m, 30 m X 24 m, 30 m X 18 m and 30 m X 12 m (with Aspect ratio of sites varied from 1, 0.8, 0.6 and 0.4 respectively). In case two each plot area is again divided into panels of different aspect ratios. Here, Aspect ratio is ratio of longer dimension to shorter dimension of panel. The structure is modeled, analysed and designed as per IS : 456 – 2000 using Staad.Pro. Failed members are re-designed till all members are safe. This procedure is repeated for all cases and the quantities of steel and concrete are noted. It was observed that for 30 m x 30 m plot area for aspect ratio = 1, in Case 1-Case 41 with 25 columns and in Case 2- Case 31 with 12 columns were observed to be the most economical. In these two cases, Case-1 is more economical. In Case 1, Square module 30 m X 30 m with spacing of columns at 5 m and 25 panels in both sides was found to be cost effective. In Case-2 rectangular module 30 m X 24 m for aspect ratio 0.8 with spacing of columns 15 m X 12 m and 4 panels in both sides was found to be cost effective. For rectangular module 30 m X 18 m for aspect ratio 0.6 with spacing of columns 15 m X 6 m and 6 panels in both sides was found to be cost effective. For rectangular module 30 m X 12 m for aspect ratio 0.4 with spacing of columns 15 m X 6 m and 4 panels in both sides was found to be cost effective.

Keywords: *multistory building, Optimum column spacing, aspect ratio, plot area, panel size, Staad.Pro, re-design, concrete and steel quantity*

1. Introduction

With increased population and land requirement for residential and commercial purposes in urban areas, multistoried buildings are becoming common in construction industry. When compared to low-rise buildings, apartments and multistory buildings accommodate more people per unit of area of land and also decrease the cost per unit area of the construction. The quantity of steel and concrete requirement for footings, beams, columns and slabs contribute mostly to the overall cost of the structure. Further these quantities are variable while cost of finishing's and building services is constant for a constant built up area. Hence, in the economy point of view, it is important to reduce the quantities of both steel and concrete without compromising on quality and design requirements.

The total quantity of steel and concrete requirement depends on the spacing's of columns which is the panel size of the slab. If the spacing of columns is more, the number of columns is less and hence

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- the quantity of concrete requirement in columns will be less
- the quantity of steel requirement in columns will be more
- the quantity of concrete requirement in beams will be more
- the quantity of steel requirement in beams will be less

Hence, as spacing of columns increases, bending moments increase and ultimately design may become uneconomical.

If the spacing of columns is less, number of columns is more and hence

- the quantity of concrete requirement in columns will be more
- the quantity of steel requirement in columns will be less
- the quantity of concrete requirement in beams will be less
- the quantity of steel requirement in beams will be more

Hence, reduced spacing of columns may also lead to uneconomical design.

Therefore, if in a multistory building, column positioning is not a constraint, then it is advisable to arrive at optimum spacing of columns that results in minimum quantities of steel and concrete requirement for a given built up area and hence economical design. In some countries, concrete would be very costly while in others, steel. Perhaps the best option here would be an interactive, trial and error approach using good software, and the governing minimum quantities.

The optimal spacing of columns in a building generally depends on some of the following factors.

1) Scale of economics in project. For small projects, even if % saving is high, net saving is less.
2) Bearing capacity of soil as close proximity of columns end up in designing combined strip footings which is obviously not cost effective compared to isolated footings.
3) Column height which affects buckling and bending moments derived from the horizontal loads.
4) Material of construction. If it is steel structure the spacing is determined by steel sections like girders, channel sections or angles and impact of live load has to be considered. Structural engineer likes closer columns to give economical floor plate (with or without beams). However, foundations are not cost effective with closer columns. It is variable by SBC.
5) Required stiffness (1/150 to 1/1000...) in the earthquake resistance requirement point of view.
6) Limitations on height, size and number of floors based on local building bye laws
7) Function / usage of the building space i.e. if it is a carpark then the gap between 3 car bay spaces (3 m to 8 m) dictates the spacing of columns, if it is a concrete deck, it is different.
8) Economic span/depth ratios of the supporting beams in limiting deflections. Generally 6 m to 9 m practical span of beams and thus column spacing's are adopted.
9) Cost and user's convenience via-a-vis architect's planning. The architect would like large spans and hence will place columns more for aesthetic values rather than economics.

The economy from a builder's point of view is, more the number of car parks, more the earning compared to saving by reducing the spacing of columns. Service engineer, Likes larger open spaces and very thin floor plate to accommodate services and less floor volume for energy efficiency. Contractor wants simple structure without

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cantilevers, transfer girders. Hence, to determine the true and optimum values of column spacing is more a research problem of mathematics and not engineering alone. The objective of this work is to arrive at the optimum spacing of columns assuming that the above factors do not interfere with the spacing of columns.

2. Literature Review

Vyas and Raisinghani, 2007 [1] conducted a study on Optimum spacing of Columns based on Cost of Construction in Laboratory Buildings. Several engineering laboratory modules for technical institutions have been investigated with respect to structural cost per unit floor area. The module with a spacing of columns at 6 m (20 ft) centre distance along length was found to be cost effective for laboratory blocks up to two storey's and columns with 4.27 m centre distance along length are cost effective for laboratory blocks more than two storey's high. Detailed cost analysis of structure and material requirement revealed that the volume of M20 cement concrete for RCC structure will be 22.9 % of floor area for laboratory buildings. Vyas and Raisinghani, 2005 [2] determined the optimum spacing of columns and Material consumption in library buildings. They observed that optimum spacing between columns is 5.94 m centre to centre both ways assuming size of columns as 450 mm × 350 mm. The cost of library module does not vary much for 6.86 m spacing of column. Clark and Kingston [3] made an observation that High-rise office buildings, which are developed as a response to population growth, rapid urbanization and economic cycles, are indispensable for a metropolitan city development. The political ideology of the city plays an important role in the globalization process (Newman and Tornely [4]; Abu-Ghazalah [5]). The current trend for constructing office buildings is to build higher and higher, and developers tend to compete with one another on heights. The high technology styles have accompanied nearly all new tall buildings and became landmark of many cities internationally (McNeill and Tewdwr-Jones [6]). Nonetheless high-rise office buildings are more expensive to construct per square meter, they produce less usable space and their operation costs are more expensive than conventional office buildings. By the end of 1990s, at more than 30 stories, net to gross floor area ratios of 70-75% were common in office buildings (Davis Langdon and Everest [7]). However, Yeang [8] stated in his book "The Skyscraper: Bioclimatically Considered" that net-to-gross floor area should not be less than 75%, while 80% to 85% is considered appropriate. Watts and et al. [9] compared and revealed the similarities and differences between tallest office buildings at abroad and in Turkey in terms of space efficiency. Although there are no universal formulas for responding to the client's needs or to local influences and constraints such as climate, codes or constructional conditions related to floor slab size and shape, the fundamental design considerations are almost identical almost in office buildings (Kohn and Katz [10]; Strelitz [11]). The space efficiency of a high-rise office building can be achieved by maximizing the Gross Floor Area (GFA) and Net (usable) Floor Area (NFA) as permitted on the local site by the codes and regulations, and in order to enable the developer and owner to get maximum returns from high cost of land, the floors must have sufficient functional space (Kim and Elnimeiri [12]). According to Yeang [13], floor slab efficiency of a typical high-rise office building should generally not be less than 75%, unless the site is too small or too irregular to permit a higher level of space efficiency. Watts et al. [9] state in their recent article, floor slab efficiency is adversely affected by height of a high-rise office building, as the core and structural elements expand relatively to the overall floor slab to satisfy requirements of vertical circulation as well as lateral-load resistance. Square, circular, hexagonal, octagonal and similar plan forms are more space efficient than rectangular plans with high aspect ratios and irregular shapes. Buildings with symmetrical plan shapes are also less susceptible to wind and seismic loads (Arnold [14]; Taranath [15]; Kozak [16]). Leasing depth or lease span is distance of usable area between exterior wall and fixed interior element, such as the core or the multi-tenant corridor. In Germany maximum leasing depth is determined by building codes and cannot be more than 8.0 m, whereas in Japan it is typically 18.0 m (Kohn and Katz [10]). According to Ali and Armstrong [17] the depth of lease span must be between 10.0 and 14.0 m for office functions, except where very large single tenant groups are to be accommodated. As floors become deeper, the marketability of space decreases significantly (Crone [18]). With reference to floor-to-floor / floor-to-ceiling height, Baum [19] defines quality in office buildings and suggests that the plan layout and the ceiling height are more significant than the following three determinants of building quality: (i) Services and finishes; (ii) external appearance and (iii) durability of materials. Another research project by Ho [20] reveals that functionality of the floor slab is the most important category indicated by all the respondents of the investigation, except for users, who emphasized services as the relative importance of functionality. Commercial functions require a variety of floor-to-ceiling heights ranging between 2.7 and 3.7 m (Ali and Armstrong [17]), and the depth of the structural floor system varies depending on the floor loads, size of structural bay, and type of floor framing system. Layout of core is critical to the development efficiency and operational effectiveness of a high-rise office building, while also playing a significant role in the way the structure copes with lateral loads (Watts et al [9]). This building type is very attractive to users without cellular offices and has until recently been the standard in Japan and Korea (Kohn and Katz [10]). In United States, steel is commonly used as the structural material and lightweight fire-rated drywall is used to form the walls in order to reduce its thickness and save the foundation cost and construction time (Ho [21]). In 1969 Fazlur Khan [22] classified structural systems for high-rise buildings according to their height. Later, he upgraded these diagrams (Khan [23], [24]), and developed schemes for both steel and concrete (Ali [25]; Ali and Armstrong [17]; Schueller [26]; Iyengar [27]). As per literature review by Ali and Moon [28], structural systems for high-rise buildings are divided into two categories, interior and exterior structures. They are usually arranged as planar assemblies in two principal orthogonal directions and may be employed together as a combined system in which they interact. Another important system in this category is core-supported outrigger structure, which is very widely used for super high-rise buildings (Ali and Moon [28]). The early application of tubular concept is attributed to Fazlur Khan [22] in 1961 (Ali [25]). Widely spaced framed tube, braced tube, tube-in-tube and bundled tube are subcategories of this structural system (Taranath [15]). Other types of exterior structures include space trusses, super frames and exoskeletons (Ali and Moon [28]). These systems are effective in resisting to both lateral and gravity loads, thus enabling maximum space efficiency for office workers, as in the case of Bank of China.

3. Objective and Scope

3.1 Aim and Objective

If the problem of optimizing the spacing of columns for economical design without compromising on safety and structural stability in a multi-storey building is solved by programming, then impractical values may be obtained like “adopt 25 mm sq columns at 110 mm centre to centre. To arrive at a practically executable solution to such optimization problems, it takes a process of permutations and combinations. Main aim of this project is to design an economical G+5 multistoried building for different sizes of slabs and for different plot areas. An attempt is made to determine the optimum spacing of columns in order to keep the cost minimum. Several multistoried buildings with different spacing of columns have been designed using Staad.Pro software and their indirect effect on the cost of the building was studied. A G+5 multistoried building different panel sizes and combinations based on aspect ratios were adopted for design and

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variations on quantities of concrete and steel quantities was observed and compared. Model plans, square and rectangular in shape were developed for different aspect ratios of site area / slab panel for multistoried buildings. Detailed quantities were worked out and relationships were established for cost of cement concrete and steel for a constant floor area of multistoried buildings.

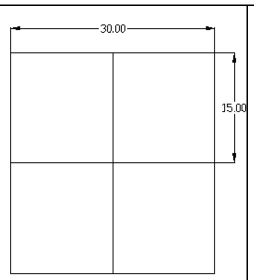
3.2 Scope

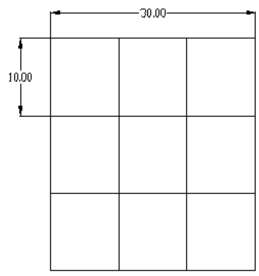
Without setting some known value, the cases to be studied would be infinite. Some assumptions are inevitable in order to obtain a practicable output. This project was limited for to plot area of 30 m X 30 m for first case and in second case they were 30 m x 30 m, 30 m X 24 m, 30 m X 18 m and 30 m X 12 m. For these plot areas based on aspect ratio, area was divided into panels. It was assumed that quantities of steel and concrete alone effect economy of a building. Cost comparison for steel and concrete quantities as per existing rates (Concrete Rs.5000/per m^3 and Steel Rs.50/per kg) for different panels for the above mentioned sizes was performed. Based on different panel sizes and plot areas, two cases are considered.

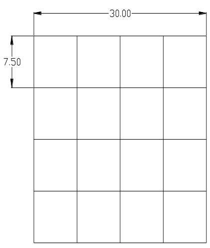
CASE 1

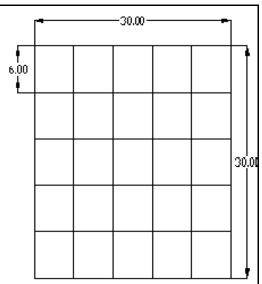
In this CASE 1, the Plot area size is constant and is equal to 30 m x 30 m and the Aspect ratio of Panel is varied from 1 to 4. Aspect ratio of panel size is defined as ratio of longer dimension of the panel to the shorter dimension of the panel.

For Panel Aspect ratio = 1





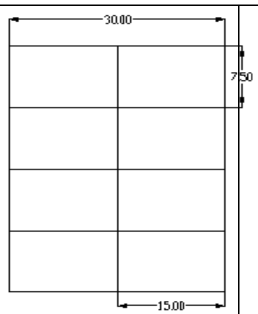


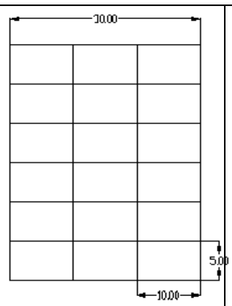


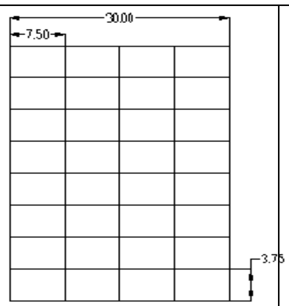
CASE 21, Number of panels 4, panel size is 15 X 15	CASE 31, Number of panels 9, panel size is 10 X 10	CASE 41, Number of panels 16, panel size is 7.5 X 7.5	CASE 51, Number of panels 25, each panel size 5 X 5

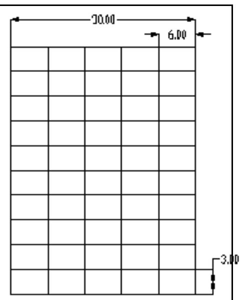
Figure 1. Plot Area of 30m X 30m with Aspect Ratio of Panel as One

For Panel Aspect ratio = 2





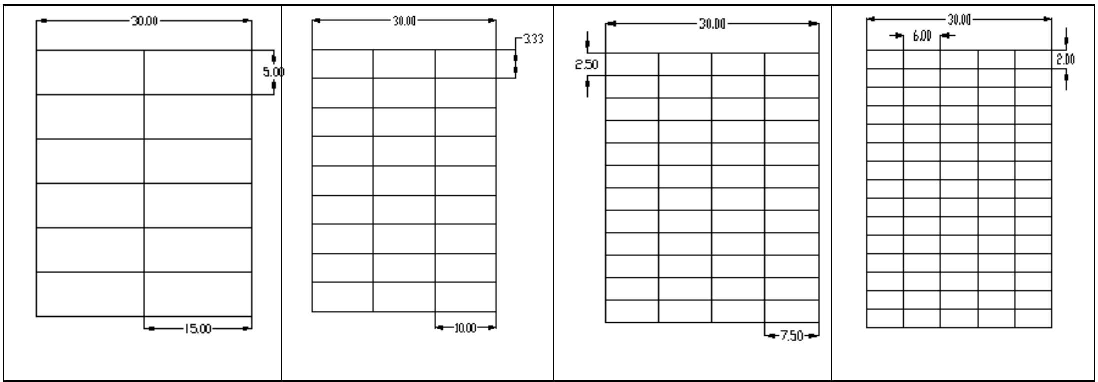




CASE 22, Number of panels 8, panel size is 15 X 7.5	CASE 32, Number of panels 18, panel size is 10 X 5	CASE 42, Number of panels 32, panel size is 7.5 X 3.75	CASE 52, Number of panels 50, panel size is 6 X 3

Figure 2. Plot Area of 30m X 30m with Aspect Ratio of Panel as Two

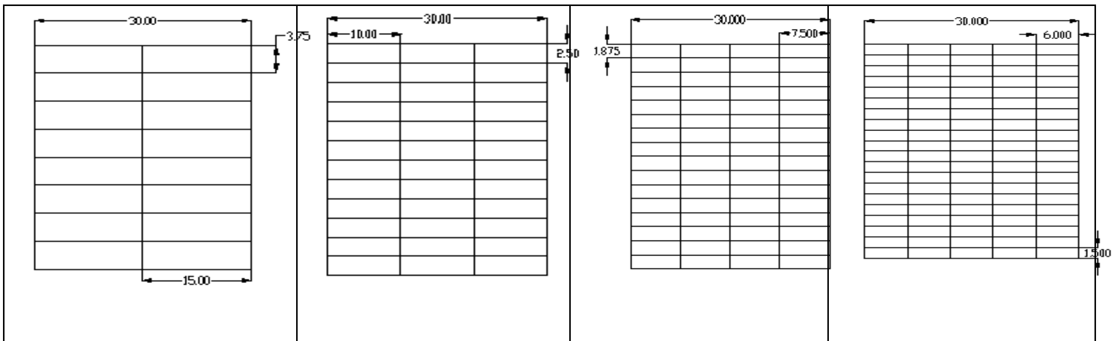
For Panel Aspect ratio = 3



CASE 23, Number of panels 12, panel size is 15 X 5	CASE 33, Number of panels 27, panel size is 10 X 3.3	CASE 43, Number of panels 48, panel size is 7.5 X 2.5	CASE 53, Number of panels 75, panel size is 6 X 2

Figure 3. Plot Area of 30m X 30m with Aspect Ratio of Panel as Three

For Panel Aspect ratio = 4



CASE 24, Number of panels 16, panel size is 15 X 3.75	CASE 34, Number of panels 36, panel size is 10 X 2.5	CASE 44, Number of panels 64, panel size is 7.5 X 1.875	CASE 54, Number of panels 100, panel size is 6 X 1.5

Figure 4. Plot Area of 30m X 30m with Aspect Ratio of Panel as Four

CASE 2

In this CASE 2, the plot area is not constant. The plot area sizes studied are 30m x 30m, 30m x 24m, 30m x 18m and 30m x 12m. The Aspect ratio's of sites considered are respectively 1, 0.8, 0.6 and 0.4. Each plot area is again divided into panels of different aspect ratios.

Aspect ratio = 1 (Plot area 30m X 30m)

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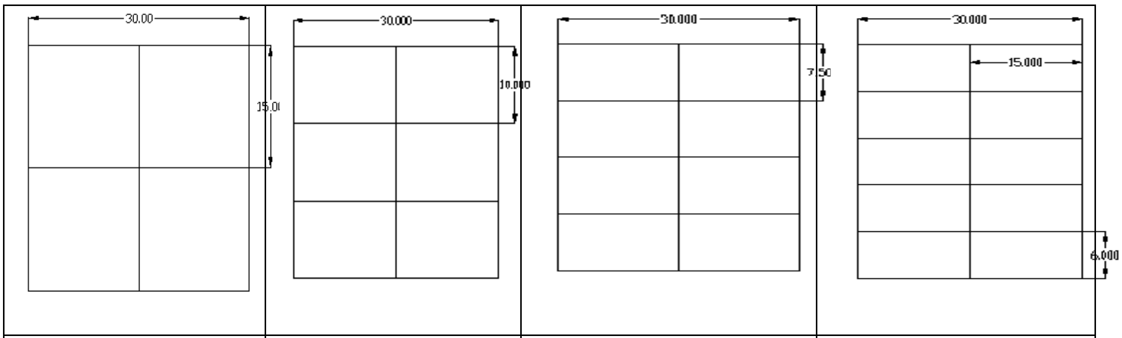
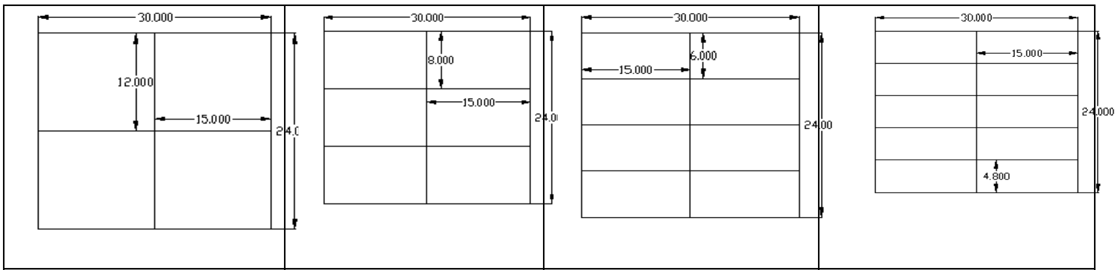


CASE 21, Number of panels 4, panel size is 15 X 15	CASE 31, Number of panels 6, panel size is 15 X 10	CASE 41, Number of panels 8, panel size is 15 X 7.5	CASE 51, Number of panels 10, panel size is 15 X 6

Figure 5. Plot Area of 30m X 30m with Aspect ratio of Panel as One

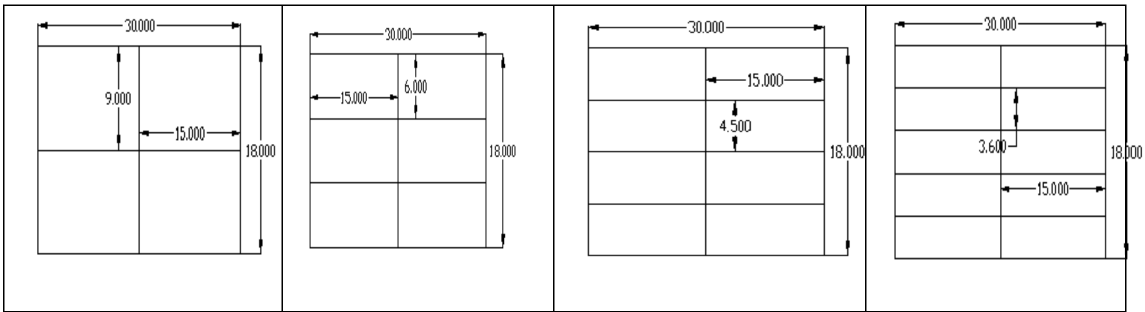
<u>Aspect ratio – 0.8</u> (Plot area 30m X 24m)



CASE 22, Number of panels 4, panel size is 15 X 12	CASE 32, Number of panels 6, panel size is 15 X 8	CASE 42, Number of panels 8, panel size is 15 X 6	CASE 52, Number of panels 10, panel size is 15 X 4.8

Figure 6. Plot Area of 30m X 24m with Aspect Ratio of Panel as 0.8

<u>Aspect ratio – 0.6</u> (Plot area 30m X 18m)



CASE 23, Number of panels 4, panel size is 15 X 9	CASE 33, Number of panels 6, panel size is 15 X 6	CASE 43, Number of panels 8, panel size is 15 X 4.5	CASE 53, Number of panels 10, panel size is 15 X 3.6m

Figure 7. Plot Area of 30m X 18m with Aspect Ratio of Panel as 0.6

<u>Aspect ratio – 0.4</u> (Plot area 30m X 12m)

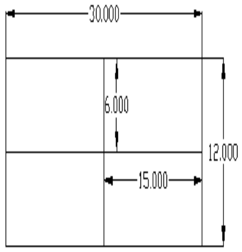
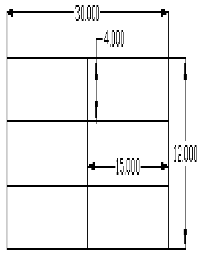
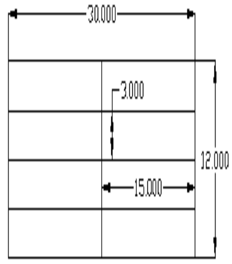
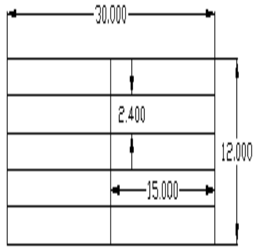
			
CASE 24, Number of panels 4, panel size is 15m X 6m	CASE 34, Number of panels 6, panel size is 15m X 4m	CASE 44, Number of panels 8, panel size is 15m X 3m	CASE 54, Number of panels 10, panel size is 15 m X 2.4 m

Figure 8. Plot Area of 30m X 12m with Aspect Ratio of Panel as 0.4

4. Methodology

4.1 Method of Analysis

The entire G+5 structure can be analyzed based on the concept of building frames which consists of multi storied and multi paneled network of beams and columns which are built monolithically and rigidly with each other at their junctions. All the members of such a frame are continuous at their ends. Besides the reduction of moments due to continuity, such structures tend to distribute the loads more uniformly and eliminate the excessive effects of localized loads. The structure can be analyzed as 3 – dimensional structure or it can be broken down into 2 – dimensional plane frames and analyzed. Staad.Pro software was used for the analysis of buildings. The methodology is described in the following flowchart. (See Figure 9)

4.2 Modeling Structural Framework

The flow chart shown in Fig. 9 describes the generalized procedure adopted for STAAD.Pro analysis.

Plan with Dimensions

The plan is generated based upon plotting of the nodes from join 1 to 216. The 3-D model of the proposed structure is shown in Figure 10.

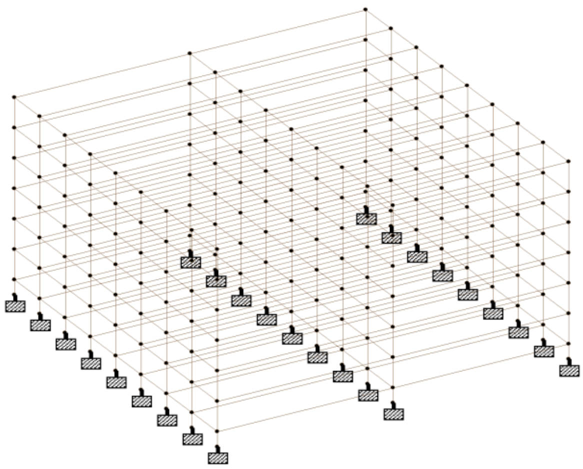


Figure 10. 3D Frame Model of a Multistoried Building

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4.3 Loads and Load Combinations Considered

This multistoried building is subjected to self-weight of the slab, beam and columns self-weight, Weights of parapet wall and outer walls in each floor and inner walls in the each floor and also live load on floor. Slab self-weight includes the floor finish. The loads and load combinations considered are as per IS: 875 – 1987 [29].

Dead load

1. Beam and column self-weight
The Multistory building is assigned self-weight of beam and column.

2. Slab self-weight
Assuming 150 mm thick slab
Total slab self weight including floor finish = 0.15 X 25 + 1 = 4.75 k N/ m^2

3. Self weight of parapet wall
Assuming Wall thickness = 230 mm, Wall height = 0.9 m and Unit weight of brick = 18.85 kN/m^3
Total load = 0.23 X 18.85 X 0.9 = 3.9 kN /m

4. Weight of outer walls in the multistoried building
Assuming Outer wall thickness = 0.23 m and Height of the wall = 3m
Total weight of outer wall = 0.23 X 18.85 X 3 = 13 kN /m

5. Weight of inner walls in the building
Assuming Inner wall thickness = 0.115 m and Height of the wall = 3m,
Total weight of inner wall = 0.115 X 3 X 18.85 = 6.50 k N /m

6. Live load
Live load was taken as 4 k N / m^2 as it is considered as an office building.

4.4 Analysis

The above loads are applied and the structure is modeled, analysed and designed as per IS : 456 – 2000 using Staad.Pro. Then the output file is checked for failed members.

4.5 Re-Designing

New properties with increased dimensions are applied to failed members to get the member safe and then the quantities of steel and concrete quantities are obtained. Re-design continues till all the members are safe and then the quantities of steel and concrete for all members are obtained.

4.6 Steel and Concrete Quantities

After running the analysis for the input file in Staad.Pro we get the output file. Output file contains the design details of the members of the building and also the quantities of steel and concrete. The steel and concrete quantities are noted and this procedure should be repeated for all cases and the obtained quantities are noted and listed in the below table for further calculations.

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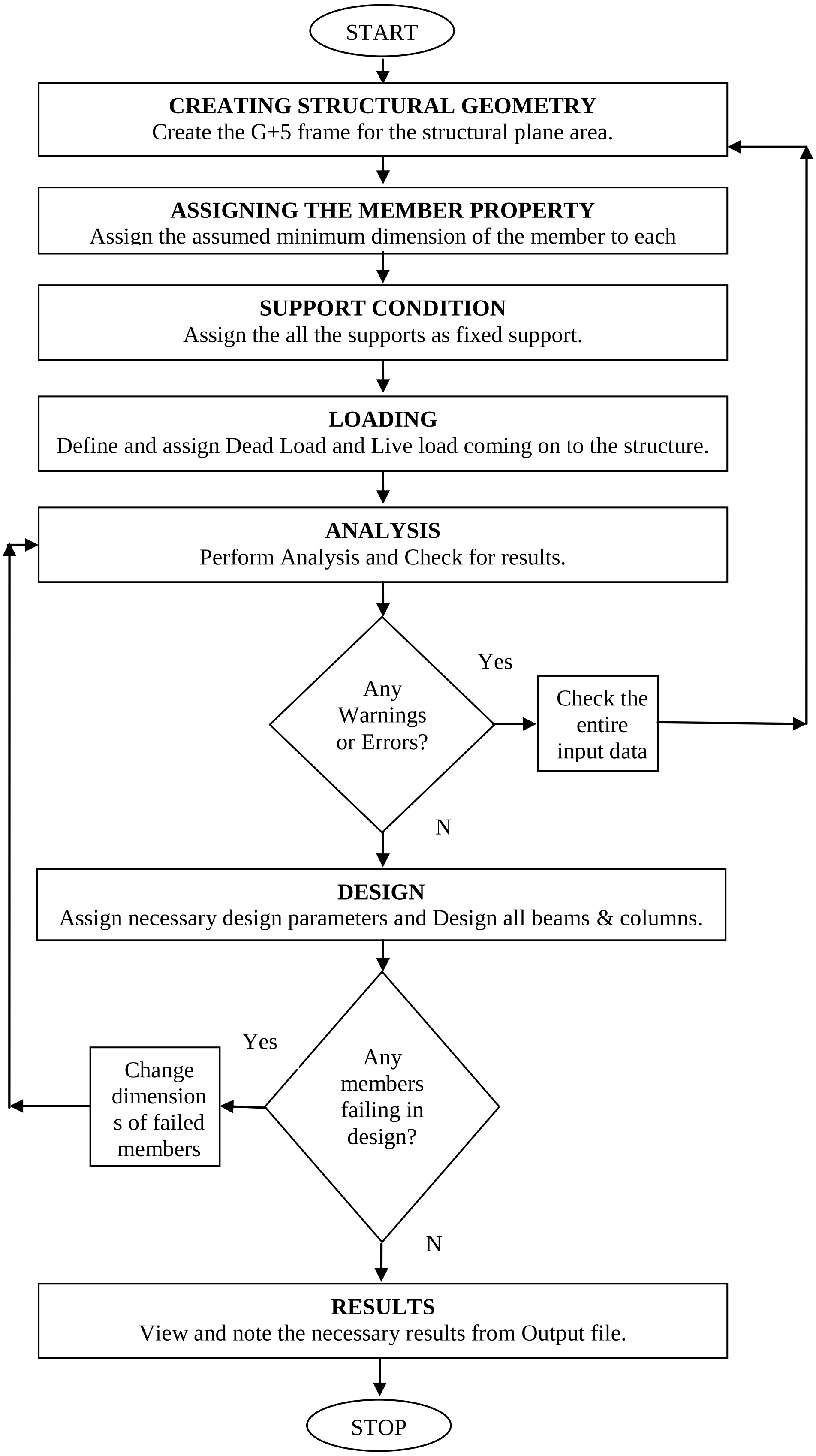

Figure 9. Analysis and Design of Multistoried Buildings Using Staad.Pro

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5. Observations and Discussions

5.1 CASE 1

For Aspect ratio = 1 and size of plot 30 m X 30 m, the concrete quantities are as follows.

Table 1. Concrete Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio One)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams+ columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
21	9	48.6	271.83	810	1130.43	5652150
31	16	86.4	202.09	810	1098.49	5492450
41	25	135	191.22	810	1136.22	5681100
51	36	194.4	180.35	810	1184.75	5923750

Steel quantities are as follows.

Table 2. Steel Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio One)

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab+ footings	Total steel Qty (kgs)	Cost of steel (50/kg)
21	9	57063.86	24423.33	81487.19	4074359.6
31	16	41911.36	17938.06	59849.42	2992471.1
41	25	42537	18205.84	60742.84	3037141.8
51	36	43163.32	18473.9	61637.22	3081861.05

For aspect ratio = 2 and size of plot 30 m X 30 m, the concrete quantities are as follows.

Table 3. Concrete Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio Two)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams + columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
22	15	81	261.1	810	1152.1	5760500
32	28	151.2	233.81	810	1195.01	5975050
42	45	243	235.16	810	1288.16	6440800
52	60	324	259.06	810	1393.06	6965300

Steel quantities are as follows.

Table 4. Steel Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio Two)

Case	No of columns	Qty of steel for beams +	Qty of steel slab+	Total steel Qty (kgs)	Cost of steel (50/kg)

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		columns	footings		
22	15	54380.79	23274.98	77655.77	3882788.41
32	28	47246.25	20221.4	67467.65	3373382.25
42	45	44185.53	18911.41	63096.94	3154846.84
52	60	45121.28	19311.91	64433.19	3221659.39

For aspect ratio = 3and size of plot 30 m X 30 m, the concrete quantities are as follows.

Table 5. Concrete Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio Three)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams+ columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
23	21	113.4	305.43	810	1228.83	6144150
33	40	216	272.2	810	1298.2	6491000
43	65	351	277.18	810	1438.18	7190900
53	96	518.4	343.43	810	1671.83	8359150

Steel quantities are as follows.

Table 6. Steel Quantity for Different Cases (Plot Size 30m x 30m, Aspect Ratio Three)

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab+ footings	Total steel Qty (kgs)	Cost of steel (50/kg)
23	21	63439.77	27152.22	90591.99	4529599.58
33	40	58406.63	24998.04	83404.67	4170233.38
43	65	54738.47	23428.07	78166.54	3908326.76
53	96	55737.44	23855.62	79593.06	3979653.22

For aspect ratio = 4 and size of plot 30 m X 30 m, the concrete quantities are as follows.

Table 7. Concrete Quantity for Different Cases (Plot Size 30m x 30m Aspect Ratio Four)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams+ columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
24	27	145.8	321.32	810	1277.12	6385600
34	52	280.8	301.4	810	1392.2	6961000
44	85	459	336.19	810	1605.19	8025950
54	126	680.4	429.92	810	1920.32	9601600

Steel quantities are as follows.

Table 8. Steel Quantity for Different Cases (Plot Size 30 m x 30 m, Aspect Ratio Four)

Case	No of columns	Qty of steel for beams +	Qty of steel slab+	Total steel Qty (kgs)	Cost of steel (50/kg)

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		columns	footings		
24	27	77887.34	33335.78	111223.1	5561156.08
34	52	71595.86	30643.03	102238.9	5111944.4
44	85	69490.98	29742.14	99233.12	4961655.97
54	126	63696.11	27261.94	90958.05	4547902.25

5.2 CASE 2

For aspect ratio = 1 and size of plot 30 m X 30 m, the Concrete quantities are as follows.

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams+ columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
21	9	48.6	288.41	810	1147.01	5735050
31	12	64.8	250.54	810	1125.34	5626700
41	15	81	274.74	810	1165.74	5828700
51	18	97.2	287.4	810	1194.6	5973000

Table 9. Concrete Quantity for Different Cases (Plot Size 30 m x 30 m, Aspect Ratio One)

Steel quantities are as follows.

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab+ footings	Total steel Qty (kgs)	Cost of steel
21	9	65739.48	28136.5	93875.98	4693798.87
31	12	57677.46	24685.95	82363.41	4118170.64
41	15	56750.26	24289.11	81039.37	4051968.56
51	18	62921.62	26930.45	89852.07	4492603.67

Table 10. Steel Quantity for Different Cases (Plot Size 30 m x 30 m, Aspect Ratio One)

For aspect ratio=0.8 and size of plot 30 m X 24 m, the concrete quantities are as follows.

Table 11. Concrete Quantity for Different Cases (Plot Size 30 m x 24 m, Aspect Ratio 0.8)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams + columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
22	9	48.6	203.5	648	900.1	4500500
32	12	64.8	225.53	648	938.33	4691650
42	15	81	234.31	648	963.31	4816550
52	18	97.2	264.58	648	1009.78	5048900

Steel quantities are as follows

Table 12. Steel Quantity for Different Cases (Plot Size 30m x 24m, Aspect Ratio of 0.8)

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab+ footings	Total steel Qty (kgs)	Cost of steel (50/kg)
22	9	52184.41	22334.93	74519.34	3725966.87
32	12	50961.67	21811.59	72773.26	3638663.24
42	15	52045.3	22275.39	74320.69	3716034.42
52	18	54065.63	23140.09	77205.72	3860285.98

For aspect ratio = 0.6 and size of plot 30 m X 18 m, the concrete quantities are as follows

Table 13. Concrete Quantity for Different Cases (Plot Size 30m x 18m, Aspect Ratio 0.6)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams + columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	cost of concrete 5000/- per cu.m
23	9	48.6	177.39	486	711.99	3559950
33	12	64.8	181.13	486	731.93	3659650
43	15	81	185.3	486	752.3	3761500
53	18	97.2	205.54	486	788.74	3943700

Steel quantities are as follows.

Table 14. Steel Quantity for Different Cases (Plot Size 30m x 18m, Aspect ratio 0.6)

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab+ footings	Total steel Qty (kgs)	Cost of steel (50/kg)
23	9	42692.42	18272.36	60964.78	3048238.79
33	12	40936.35	17520.76	58457.11	2922855.39
43	15	47094.12	20156.28	67250.4	3362520.17
53	18	49611.34	21233.65	70844.99	3542249.68

For aspect ratio = 0.4 and size of plot 30 m X 12 m, the concrete quantities are as follows.

Table 15. Concrete Quantity for Different Cases (Plot Size 30m x 12m Aspect Ratio 0.4)

Case	No of column	Footings concrete quantity in cu.m	Quantity of Beams+ columns concrete	Slab concrete quantity (cu.m)	Total concrete quantity (cu.m)	Cost of concrete 5000/- per cu.m
24	9	48.6	130.31	324	502.91	2514550
34	12	64.8	147.74	324	536.54	2682700
44	15	81	177.61	324	582.61	2913050
54	18	97.2	169.82	324	591.02	2955100

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Steel quantities are as follows.

Table 16. Steel Quantity for Different Cases (Plot Size 30m x 12m, Aspect Ratio 0.4)

Case	No of columns	Qty of steel for beams + columns	Qty of steel slab + footings	Total steel Qty (kgs)	Cost of steel (50/kg)
24	9	29671.16	12699.26	42370.42	2118520.82
34	12	34972.72	14968.32	49941.04	2497052.21
44	15	40636.39	17392.37	58028.76	2901438.25
54	18	44197.31	18916.45	63113.76	3155687.93

5.2 Cost Comparison

Based on observations from Section 5.1 and taking steel and concrete rates as per present rate, costs for two cases and for different plot areas are compared as follows.

Table 17. CASE-1 Cost per Unit Area, Plot Area is 30m X 30m (Built-up Area 4500 m^2)

Aspect ratio of panel	Case	No of columns	Cost of concrete	Cost of steel	Total cost	Cost per Unit area
1	21	9	5652150	4074359.60	9726509.60	2161.447
	31	16	5492450	2992471.10	8484921.10	1885.538
	41	25	5681100	3037141.80	8718241.80	1937.387
	51	36	5923750	3081861.05	9005611.05	2001.247
2	22	15	5760500	3882788.41	9643288.41	2142.953
	32	28	5975050	3373382.25	9348432.25	2077.429
	42	45	6440800	3154846.84	9595646.84	2132.366
	52	60	6965300	3221659.39	10186959.39	2263.769
3	23	21	6144150	4529599.58	10673749.58	2371.944
	33	40	6491000	4170233.38	10661233.38	2369.163
	43	65	7190900	3908326.76	11099226.76	2466.495
	53	96	8359150	3979653.22	12338803.22	2741.956
4	24	27	6385600	5561156.08	11946756.08	2654.835
	34	52	6961000	5111944.40	12072944.40	2682.877
	44	85	8025950	4961655.97	12987605.97	2886.135
	54	126	9601600	4547902.25	14149502.25	3144.334

For CASE-2

Plot area 30 m X 30 m with aspect ratio = 1(Built-up area is 4500)

Table 18. CASE 2 Cost per Unit Area, Plot Area 30m X 30m with Aspect Ratio of One

Case	No of columns	Cost of concrete	Cost of steel	Total Cost	Cost per unit area
9	21	5735050	4693798.87	10428848.87	2318
12	31	5626700	4118170.64	9744870.64	2166
15	41	5828700	4051968.56	9880668.56	2196
18	51	5973000	4492603.67	10465603.67	2326

Plot area 30 m X 24 m with aspect ratio = 0.8 (Built-up area is 3600)

Table 19. CASE 2 Cost per Unit Area, Plot Area 30m X 24m with Aspect Ratio of 0.8

Case	No of columns	Cost of concrete	Cost of Steel	Total cost	Cost per unit area
9	22	4500500	3725966.87	8226466.87	2285
12	32	4691650	3638663.24	8330313.24	2314
15	42	4816550	3716034.42	8532584.42	2370
18	52	5048900	3860285.98	8909185.98	2475

Plot area 30 m X 18 m with aspect ratio = 0.6 (Built-up area is 2700)

Table 20 CASE 2 cost per unit area, Plot area is 30m X 18m with aspect ratio of 0.6

No of column	Case	Cost of concrete	Cost of steel	Total cost	Cost per unit area
9	23	3559950	3048238.79	6608188.79	2447
12	33	3659650	2922855.39	6582505.39	2438
15	43	3761500	3362520.17	7124020.17	2639
18	53	3943700	3542249.68	7485949.68	2773

Plot area 30m X 12m with aspect ratio = 0.4 (Built-up area is 1800)

Table 20. Cost per Unit Area for CASE-2, (Plot Area 30m X 12m, Aspect Ratio 0.4)

Case	No of columns	Cost of concrete	Cost of steel	Total Cost	Cost per unit area
9	24	2514550	2118520.82	4633070.82	2574
12	34	2682700	2497052.21	5179752.21	2878
15	44	2913050	2901438.25	5814488.25	3230
18	54	2955100	3155687.93	6110787.93	3395

6. Conclusions

The following general and specific conclusions can be arrived based on the study conducted within the scope of this research work.

1. In Case 1 for aspect ratio = 1 and for Case 41 with 25 columns, the concrete quantity is observed to be 1136.22 cu.m and the steel quantity is observed to be 60.74 MT. This is the most economical case for 30m X 30m plot area.
2. For plot area of 30 m X 30 m in Case 2 and for aspect ratio = 1, Case 31with 12 columns was observed to be the most economical with 1125.34 cu.m of concrete and 82.36 M.T steel.
3. By comparing the above two results and costs the case-1 with aspect ratio =1 is seems to be economical.
4. In Case 1, Square module 30 m X 30 m with spacing of columns at 5 m and 25 panels in both sides was found to be cost effective.
5. In Case-2 rectangular module 30 m X 24 m for aspect ratio 0.8 with spacing of columns 15 m X 12 m and 4 panels in both sides was found to be cost effective.

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6. For rectangular module 30 m X 18 m for aspect ratio 0.6 with spacing of columns 15 m X 6 m and 6 panels in both sides was found to be cost effective.
7. For rectangular module 30 m X 12 m for aspect ratio 0.4 with spacing of columns 15 m X 6 m and 4 panels in both sides was found to be cost effective.

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