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Selection of Economical Span in RCC Building

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Abstract

In this paper an attempt was taken to determine the most economical span for a conventional RCC building. To identify that code imposed guidelines along with analysis were followed. The comparison is made in terms of the required concrete volume and reinforcement. Comparing all the facts for a given live load it is seen that shorter spans are more economical.
Key ward: *Beam, column, slab, volume, economy.*

1. Introduction

Spacing of column in a Reinforced concrete building is an important factor to determine the dimensions of columns itself, beams, slabs etc. Therefore cost of the materials is also influenced by the span length. For columns supporting heavily loaded floors minimum overall dimensions of one-fifteenth the average span of the panel is considered satisfactory. Roof columns may be somewhat lighter; one-eighteenth the average span is specified by some codes as a minimum diameter [7]. Beams sizes are usually governed by the negative moments and the shear at the supports, where the effective section is rectangular. Alternatively many designers prefer to estimate the depth of beams at about ¾ inch per foot of span, with the width equal to about one-half the depth [4]. For the reason of simplicity 1" per foot (or 1 cm per 12 cm) of span is also selected as the depth of the beam. Industrial and warehouse multistory buildings are mostly characterized by heavy floor loads, sometimes up to 1000 lb/sft (or 14.88 KN/m). For such cases flat slab with column capitals is very well suited. Also two-way solid slabs supported on beams are efficient for this type of use. Only moderate spans are economically feasible for heavy floor loading [3].

Evidently, deflections are highly sensitive to length of beam (or even slab). Also end condition as well as loading pattern contributes in deflection. In designing beams, controlling the magnitude of deflection is always a major problem. A common empirical criterion used for dead plus live load deflections is typically limited to L/240 of the span [6]. Therefore low spans contribute to less deflection leading to greater safety. Member sizes in structural design are often dictated by architectural, aesthetic and mechanical requirements. Deflection limits also play a role in determining cross-sectional dimensions. Structural efficiency and strength considerations are also the deciding factors. Once cross-sectional dimensions are determined, the structural efficiency is then considered by finding the required area of reinforcement [5]. Economy in column design favors the use of higher strength concrete on well controlled jobs. Concrete will generally be cheaper than intermediate grade steel. Steel of grades 50, 60, or 75 is cheaper than grade 40. Tied columns will generally be cheaper than spiral columns [2]. Even the economy of tube system depends on factors such as spacing and size of columns, depth of perimeter spandrels and the plan aspect ratio of the building.

Every dwelling unit in a residential building shall have at least one room which shall have not less than 9.5 m^2 of floor area with a minimum width of 2.5 m. Other habitat rooms in the dwelling unit shall have a minimum area of 5 m^2 each with a minimum width of 2 m [1]. Sometimes position of columns make the interior space of room odd looking as wall thickness is less than the column dimension. There fore column spacing differs sometimes placed at a large distance. Actually column spacing largely depends on designers' choice, customers' choice as well as purpose of the building.

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2. Methodology

To conduct this study at first simple equations were developed. Then putting different span values in those equations the most economic one was tried to identify. Focus was specially given over concrete volume. Attention over reinforcement was also given but mostly theoretical, as the calculation of reinforcement is time consuming. Both two-way beam supported slabs and flat plat were taken into account. All slabs are square in shape. Some results are also expressed in SI unit.

a) Equation for concrete volume for two-way beam supported slabs:

Let us the slab having dimensions a & b in ft.

$$\text{slab thickness} = \frac{2\times(a+b)\times 12}{180}\,\text{inch} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

For the reason simplicity the slabs are chosen such that the total structure will be square. That is, a = b

$$slab\ \ volume = \frac{2\times(a+b)\times a\times b}{180}\,cft = \frac{a^3}{45}\,cft \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

For beam volume considering 10 inch width and ‘a’ inch height for ‘a’ ft length,

$$\text{Volume of one beam} = (\frac{10\times a}{144}\times a)\ cft = \frac{5\,a^2}{72}\,cft \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Considering minimum column dimension one fifteenth of the span length ‘a’ ft and square geometrical shape and 10 ft story height:

$$\text{Volume of one column} = (\frac{a}{15}\times\frac{a}{15}\times 10)\ cft = \frac{2\,a^2}{45}\ cft \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

It is evident that the number of beam as well as column is a variable of slab number. Table 1 gives us few examples of beam and column number if slab number is changed.

Table 1: Beam and column number depending on slab number:

Slab No, s	**Beam No, b**	**Column No, c**
1	4	4
4	12	9
9	24	16
16	40	25
25	60	36
36	84	49
49	112	64
64	144	81
81	180	100
100	220	121
etc	etc	etc

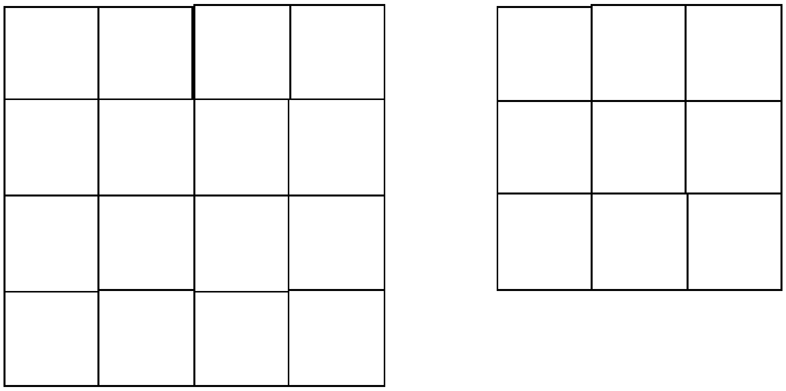


Fig 1: Example of different square plans of slab

Therefore the equation of total concrete volume becomes:

$$V = \frac{s\,a^3}{45} + \frac{5b\,a^{2}*}{72} + \frac{2c\,a^2}{45} \text{ .... (5)}$$

To find the values of s, c and b help of table 1 can be taken.

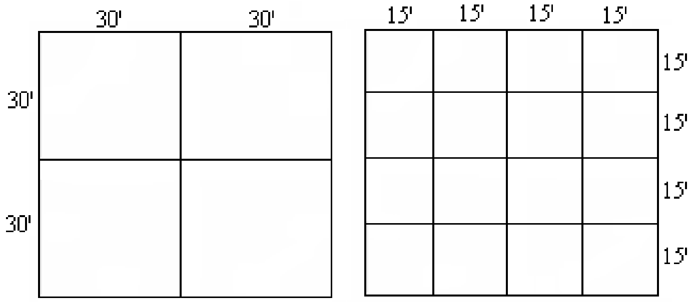
b) Equation for concrete volume for Flat plate:
For flat slabs similar approach can be taken. A flat slab without column capital, drop panel and edge beams the code imposed minimum slab thickness is $\frac{a}{30}$ where the unit is in ft, 'a' is the clear span. Therefore one slab volume $= \frac{a^3}{30}$. As only slabs and columns will exist here so the total concrete volume,

$$V = \frac{sa^3}{30} + \frac{2ca^2}{45} \text{ .... (6)}$$

To judge the reinforcement instead of development of any equation theoretical discussion with a typical example has been made.

3. Calculation

a) Comparison for Concrete volume:



s = 4, b = 12, c = 9
(a)

s = 16, b = 40, c = 25
(b)

Fig: 2: Different grid systems having the same area.

For a two way beam supported slabs let us consider an arbitrary span, L = 30 ft as shown in Fig: 2. From Table: 1 s = 4, b = 12, c = 9, with usual notations. Using equation (5) the CC volume:

$$V = \frac{4\times30^3}{45} + \frac{12\times5\times30^2 *}{72} + \frac{9\times2\times30^2}{45} = 3510\ cft\,[99.40\text{ m}^3]$$

Now for the same geometry/ plan let us consider the span, L = 15. Therefore, the number of slab, beam & columns are also increased. From Table: 1, s = 16, b = 40, c = 25. So, using equation (5) the volume:

$$V = \frac{16\times15^3}{45} + \frac{40\times5\times15^2 *}{72} + \frac{25\times2\times15^2}{45} = 2075\text{ cft }[58.76\text{ m}^3]$$

Comparing the above two numerical values safety becomes:

$$\frac{3510-2075}{3510}\times100 = 40.88\%$$

Similarly for flat slab considering an arbitrary span L = 30 ft, for which s = 4, c =9 (Fig 2) and using equation (6) the volume

$$V = \frac{4\times30^3}{30} + \frac{9\times2\times30^2}{45} = 3960\text{cft }[112.15\text{ m}^3]$$

Now for the same geometry/ plan if L = 15’ then from Table 1 s = 16, c =25 using equation (5) the volume

$$V=\frac{16\times15^3}{30}+\frac{25\times2\times15^2}{45}=2050cft\ [58.06\ \text{m}^3]$$

There fore safety becomes = $\frac{3960-2050}{3960}\times100=48.23\%$

If a 60'×60' [18m×18m] size is taken and judged with respect to different grid size then Table 2 can be formulated. This variation is also shown in Fig: 3.

Table 2: Variation in concrete volume for beam supported slab and flat plate

Grid size in ft×ft [in m×m]	No. of span	Two way beam supported slab: CC volume becomes: $V=\frac{s\,a^3}{45}+\frac{5b\,a^2*}{72}+\frac{2c\,a^2}{45}$ in^3 [m^3]	Flat plate slab CC volume becomes: $V=\frac{sa^3}{30}+\frac{2ca^2}{45}$ in^3 [m^3]
7.5×7.5 [2.30×2.30]	64	1365 [38.66]	1103 [31.24]
10×10 [3.00×3.00]	36	1602 [45.39]	1418 [40.16]
12×12 [3.66×3.66]	25	1791 [50.72]	1671 [47.32]
15×15 [4.57×4.57]	16	2075 [58.76]	2050 [58.06]
20×20 [6.00×6.00]	9	2552 [72.27]	2685 [76.04]
30×30 [9.00×9.00]	4	3510 [99.40]	3960 [112.15]

The graphical representation is shown in Fig 3

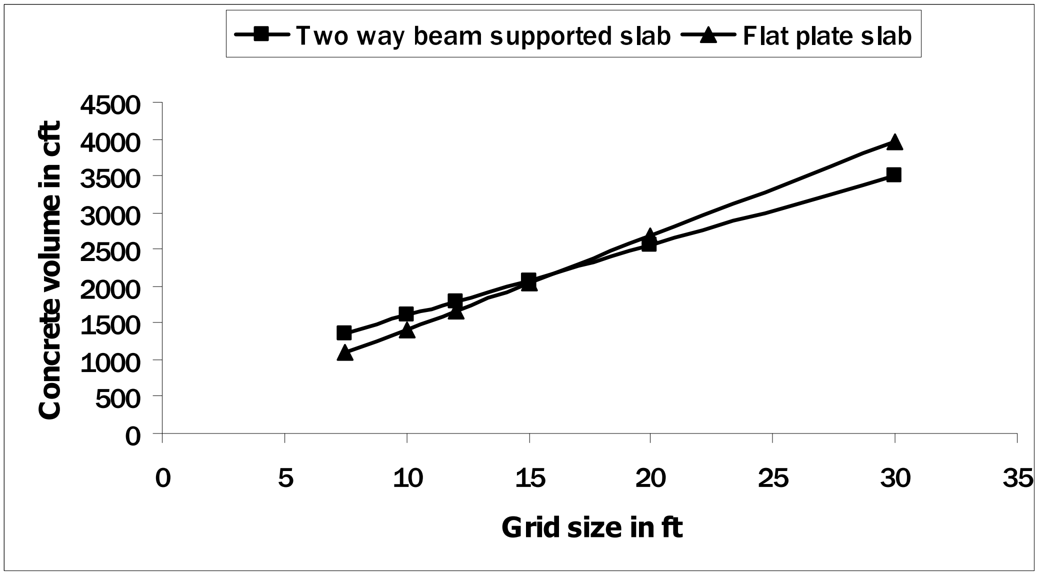


Fig 3: Variation in concrete volume for different grid size

b) Comparison for steel area:

1) Slab:

Two way slab:

It is known from the basic equation that moment:

$$M=cwl^2=\varphi A_s f_y(d-\frac{a}{2}),$$

$$\text{i.e. } l\propto\sqrt{A_s}$$

Where, c is moment coefficient, w is load, φ is safety factor, d is effective depth, a is depth of stress block, fy is ultimate steel stress. That is amount of steel used must be increased with the increase of clear span.

Moreover not only in concrete volume but also in steel, saving can be ensured. Concentration on fig: 2 for a live load of 40 psf (i.e. a typical residential building) a 15'X15' slab needs #3@8"c/c as the main steel arrangement with 2#3 bars and 1#3 bar in continuous and discontinuous ends respectively. But for the same live load a 30'X30' slab needs #3@5"c/c as the main steel arrangement with 3#3 bars and 1#3 bar in continuous and discontinuous ends respectively. Which ensures that smaller span also leads to more economic use. It has to be noted that for both cases USD is followed. If the above reinforcements are expressed in terms of weight it is seen that about 3 and 5 ton of No.3 bars are required for the construction of fig: 3(b) and fig: 2 (a) respectively. It ensures more than 66% cost saving.

2) Beam:

Now let us focus our attention over the reinforcement of beams. We can judge it taking the help of fig: 3.

$$\text{Slab thickness} = \frac{2\times(a+b)\times 12}{180} = \frac{2\times(30+30)\times 12}{180} = 8"$$

$\text{slab load} = 150\times\frac{8}{12} = 100\,\text{psf},$ Considering floor finish 25 psf the total dead load is 125 psf. It is evident that an exterior beam will carry half of the load of the interior one. Careful & systematic calculations give us the following conclusions. For all cases USD is followed.

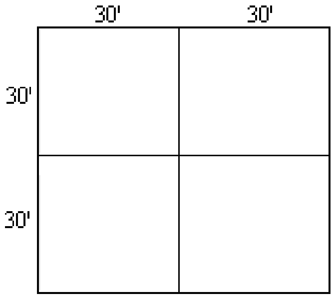
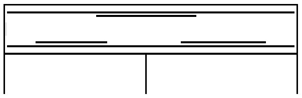


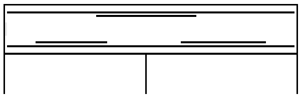
Fig: 4(a)

For exterior beams the section is



Top bars: 2#5
Bottom bars: 2#5
Extra top: 2#5
Extra bottom: 1#6

For interior beams the section is



Top corner bars: 2#8
Bottom corner bars: 2#6
Extra top: 4#8
Extra bottom: 2#9

Total flexural reinforcement needed: 3 kip
Total shear reinforcement needed: 1.6 kip

Total: 4.6 kip

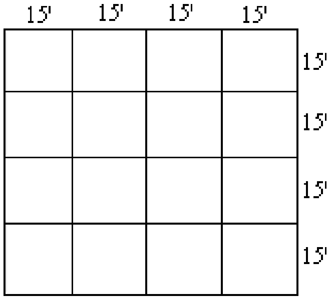
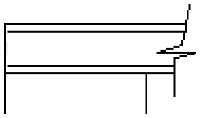


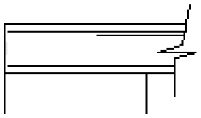
Fig: 4(b)

For exterior beams the section is



Top bars: 2#5
Bottom bars: 2#5
Extra top: None
Extra bottom: None

For interior beams the section is



Top corner bars: 2#5
Bottom corner bars: 2#5
Extra top: 1#5
Extra bottom: None

Total flexural reinforcement needed:2.7 kip
Total shear reinforcement needed: 1.5 kip

Total: 4.2 kip

3) Column:

Calculation on the reinforcement for columns of Fig: 4 (a) and Fig: 4 (a) gives minimum 4#8+4#6 bars having 24X24 in^2 column dimension and minimum 8#6 bars having 12X12 in^2 column dimension respectively. For tie bar #3@6” c/c is satisfactory. If number of columns and unit weight of each steel bars are considered then it is seen that same reinforcement is required for both spans. Ofcoures the above calculation for column is just for one story, where minimum (1%) reinforcement enough. But if the story is increased then smaller spans seem to be more economic.

4) Reinforcement of flat plate:

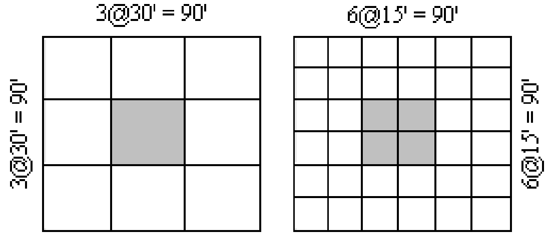


Fig: 5: Flat plates in different grids

Considering the shaded portion of the above (Fig: 5) flat slabs it can be seen that smaller span (i.e. 15') uses about 60% less reinforcement than that of larger span (30’) having the same live load (40 psf). It is evident that if the total geometry is considered then the same thing will happen.

4. Result and Discussion

Though no general formula was developed in this study yet it is evident from the above that lower spacing of column is more economical. Because it leads to less volume in slab, beam and even in column. Also a considerable reduction in steel is exhibited. If disaster situation is considered then it is evident that both concrete and steel requirement will be increased. But for the reason of simplicity such situation is not considered. If we consider 12" as the minimum column dimension then the column spacing will be 15' ($\frac{L}{15}=\frac{15\times12}{15}=12"$). Of course excess column spacing increases deflection, cracking etc. Therefore it can also be said that lower spacing leads to safety also. Depending on the number of story and amount of load size, of structural members will be increased or decreased. Considering them a common thing and focusing over spacing of column it ensures that lower column spacing is economical. Form Table 2 it is also seen that in a building system use of flat plate instead of beam supported slab becomes uneconomical for a grid size of larger than $15'\times15'$.

5. Conclusion

It has to be confessed that large spacing is an important part of aesthetics especially for large seminar rooms, car parking zones. Yet as it is found that small spacing of column are economical therefore emphasis has to be given to ensure it as much as possible by designers or architects. In the study only the superstructure is taken into account.

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