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Effect of Column Dimensions on the Punching Shear of Flat Slab

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ABSTRACT

The "flat slab" is a reinforced concrete slab bolstered by a number of columns. Punching shear is a category for collapse for reinforced concrete slabs exposed to great confined forces. In "flat slab" constructions the shear failure happens at column bolster joints. To avoid this collapse two methods are used, first method is increasing the column dimensions and the other is to use drop panel if the first method leads to uneconomical design. Two examples are used to find the effect of column dimensions increase on the punching shear failure of "flat slab". The first example is a "flat slab" of span (5 by 5) m and the other is of span (6 by 6) m. The column which examined is the interior, edge and corner columns, and the interior column is the most dangerous case. It is concluded that, the increase of column dimensions are lead to avoid of punching shear failure in "flat slab" and the drop panel is enlarge the area of the critical shear perimeter and this avoiding punching shear failure.
Keywords : Flat Slap, Punching Shear, Column Dimensions, Drop Panel

I. INTRODUCTION

The reinforced concrete "flat slab" is the term of slabs braced via one or several columns as clarified in "Fig. 1 and 2". This kind of structures can be achieved in quite a number ways turn a profit from the scanty supplication of space the columns specially steel structures involve. "flat slab"s are not providing with any mediating beams or girders; the loads are straight moved to the bolstering columns subsequent in short construction elevations. Also, the lack of beams and girders and mainly walls of load_bearing permits for more self-determination in development. [1]

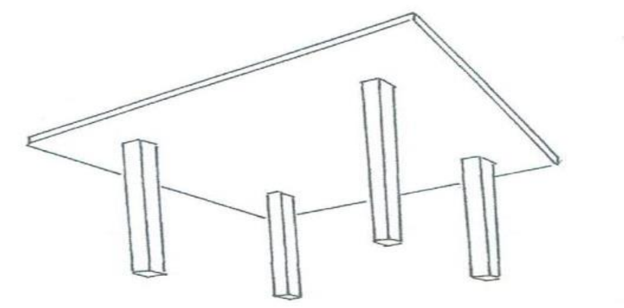

Figure 1. "flat slab"

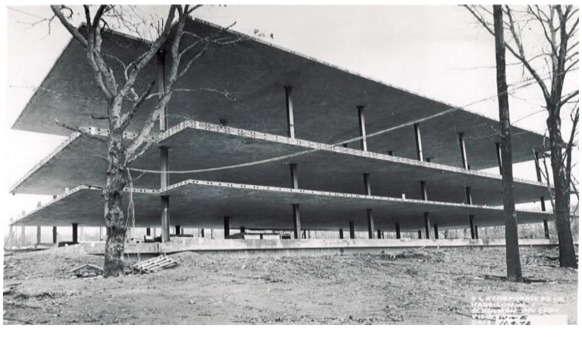

Figure 2. System using "flat slab" structures "Baumann Research and Development Corporation, 2004" [2]

It is no clear who constructed the first "flat slab". Sozen and Siess [3] prerogative that the first American authentic "flat slab" existed constructed by "C.A.P. Turner in 1906 in Minneapolis". At the similar time Millart constructed "flat slab" in Switzerland. Turner's slab were identified as mushroom slabs cause the columns widening out to make a joint of the slab, which had sated jogging in groups in four instructions (i.e the two orthogonal directions and the diagonals). These bands wrapped downcast from the top of the slab above the columns to the lowermost of the slab at mid span. Some of the slab bars were bent down into columns. Where the other bars were focused into a circle and positioned round the columns as shown in figure 3.

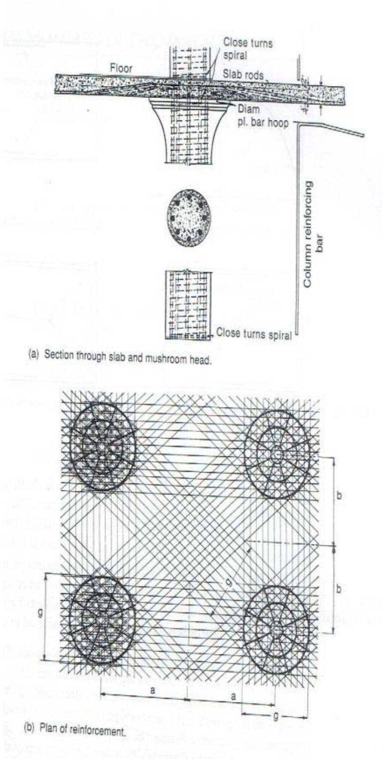

Figure 3. C.A.P. Turner mushroom slab [3]

II. METHODS AND MATERIAL

2.1 COLUMN-SLAB CONNECTION

Once the structure's external involves of non load_bearing partitions or is a glass frontage, columns may be used for the perpendicular load transmission at the structure's ends. Irrespective of the kind of column which is selected, assumed it has satisfactory capability to resist the forces that are subjected to the column's cross_section is resolute with appreciate to the probability of connection to different construction associates.

Columns of concrete were firm segments of concrete providing with both longitudinal and transverse reinforcement. Though concrete has an excessive strength of compression, the reinforcement wants to stay providing to recompense for the breakability of concrete and to assurance accurate operational beneath flexible achievement. The longitudinal bars are located in corners and when desired round the edges, at the same time as the transverse strengthening is unfold out completed the length to save the longitudinal reinforcement in location and to avoid clipping.

The variations of the connection concerning slab and column are several and the options are rather restricted to the acceptances concerning manufacture on site. Therefore when planning slabs with reverence to punching shear confrontation it is essential to consider the restrictions of applied performance. The connection is necessary to allow load transmission from the slab to the column and in some cases the joint is adequately stiff to permit transfer of moment. In case of a concrete column, the connection may be measured by way of firm in the meantime a part of the flexural reinforcement usually remains downcast the column from the slab (bent_down bars). Though the slab and the column were not cast composed the two portions establish a continuous construction. [4]

2.2 PUNCHING SHEAR

As flexural capability design of a "flat slab", the shear capacity above the columns requisite is wanted to be determined. The connection concerning the Column and the slab is precarious as the concerted forces may convince a cone molded rip over the slab depth. The damage was shaped by way of the cracks on the top surface affected by keeping moments spread down to the border of the column. Whereas a flexible failure of flexure is measured by a virtually fixed load-carrying capacity with growing movements, the quick resistance loss in failure of punching directs a stiff failure and is consequently far more risky. The punching occurrence existed below analysis chiefly throughout the 1960's and 1970's when lab experiments and general researches remained directed. Those tests preserved slabs braced on concrete columns. As progressively discerning creation techniques have been preferred, concrete columns have in some range been different by steel columns. [5].

"Punching, shear" is a category, of collapse of reinforced, concrete, slabs, exposed to great confined forces. In "flat slab" constructions this happens at column, support joints.

Collapse owes by shear. This category, of failure is cataclysmic since no observable marks are shown earlier to failure. Punching shear failure disasters have happened numerous times in this past period as shown in Figure 4.

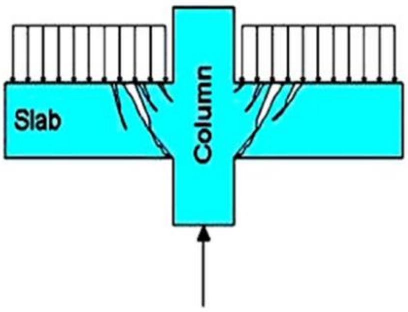

Figure 4. Punching shear failure

Punching , shear also known as two-way action shear is one of the main difficulties in such slabs at the joining between the slab and the column such type of failure is generally unexpected and leads to advanced collapse of "flat slab" structures. So, attention is needed in the design of such slabs and consideration should be given to avoid the unexpected collapse condition.

Punching shear collapse of reinforced concrete slabs happens when focused loads are started causing a high value of shear. Firstly, stress combination presentation leads to radiated cracks starting at the edge of the load application zone. Cumulative the load causes, tangential cracks nearby the load application zone. The failure, stage is reached when the inclined cracks form around the column with a usual cylindrical punching collapse cone as shown in **Figure 5**, the column splits from the slab. Without shear reinforcement , the punching, shear collapse achieves in a brittle mode within the gap region of the highly stressed slab at the column. [6]

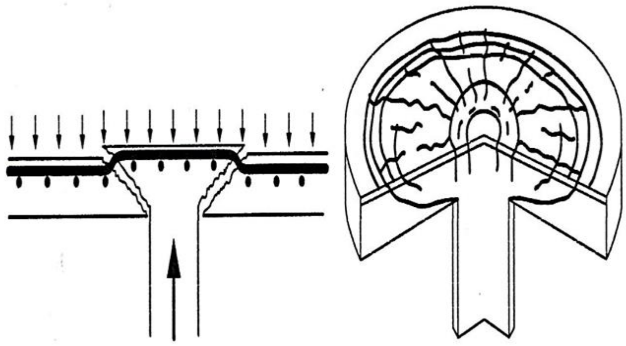

Figure **5** Cracking pattern and cylindrical cone of the punching shear failure

2.2.1 Observations on "punching shear"

Many academics have directed lab experiments to study the structural behavior of reinforced concrete slabs braced on columns. Some of the achieved tests and their results are obtainable in this section. In the obtainable literature two main sets of tests can be illustrious. The first set contracts with punching failure as the shear stress in the district of the column is expected to be constant, which is the case for most interior columns. The other set deals with non-symmetric shear stresses round the column due to unbalanced moments over the column. Unbalanced moments are affected by span incoherence across the slab's edge and crosswise loads from wind occasion. For edge and corner columns, unstable moments are continuously present due to span discontinuity. The accessible experiments can be divided into yet another two groups; those with and those without shear reinforcement. In the present study shear reinforced "flat slab"s have not been treated.

Meaningfully, no laboratory tests on slabs supported on edge columns of steel must be accomplished. The importance of distinguishing between columns of steel and concrete depends on the variance in stiffness; where generally steel columns have a very reduced stiffness than reinforced concrete columns. It must then be reserved in mind that the explanations obtainable in this unit put on to the case where transfer of moments may be predictable in the connection. Also, furthermost experimentations have been focused on isolated slab_column examples, that may not permanently agree to the reaction of the similar section in a whole construction. [7]

Effect of columns position on punching shear

Irrespective of the location of the column the failure appears to be affected by the crack of shear from the top surface getting the compacted area and affecting the volume providing by the compression region to the end. In all experimentations the mode of failure has been associated to strains measurements. Though, equating the described strains from the various trials is multifaceted and record not dependable due to the strains dependence on crack proliferation other actions of together areas and the imprecision of the checking apparatus.

In the item of corner braced slabs the failure surface was diagonal across the corner somewhat having a plane form with a radius round the support. Beside the punching cone edges was more vertical through the thickness of the slab and more inclined inside the Center. The strain formation in the slab nearby the corner columns varied from what had before been detected for interior columns. Now it appeared as if the two edges of simply supported allowed the slab to increase in the indirect path.

For the internal areas (direction vertical to the simply supported edge), the tests on edge reinforced "flat slab" presented similarity to the punching failure practical for interior columns. "The punching cone prompts of that of the corner column more perpendicular through the depth at the slab's edges and more inclined at the inner face of the column". "As the strip vertical to the edge is approximately simply supported it experiences compression in the lowest areas due to inclined compressive struts carrying the shear forces". "It seems as if the cracks on the two conflicting sides of the column extent the compressed zone which drops its capacity, the interior face of the column the probability to broadcast and cause rupture".

"Comparisons between the interior face of edge reinforced slabs and interiorly reinforced slabs have been detected. Due to the existence of controlling moment along the edges, these comparisons would be predictable for the two faces vertical to the edge comparatively than for the interior face. This could possibly be clarified by the free effort that is allowed for the concrete lengthways the simply supported edge, as observed to be the case for corner reinforced slabs" [7].

2.2.2 Shear in two way slab

In a uniformly loaded "flat slab" (flat plate), the maximum moments happens about the columns and lead to an incessant The maximum moments flexural The maximum moments crack round every column. After extra loading, the crack lead to make a fan_shaped yield_line mechanism. At the similar time, shear cracks form a reduced pyramid-shaped surface as shown in figure 6 below.

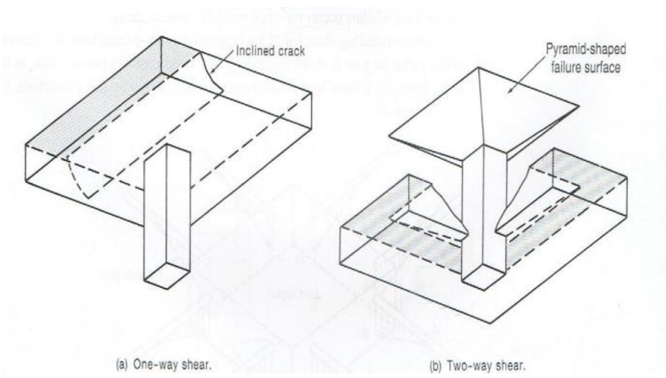

Figure 6. shear failure in slab

These cracks can be seen in figure 7. "This displays a slab that has been swan over a long two sides of the column after the slab had failed in two way shear" [7]

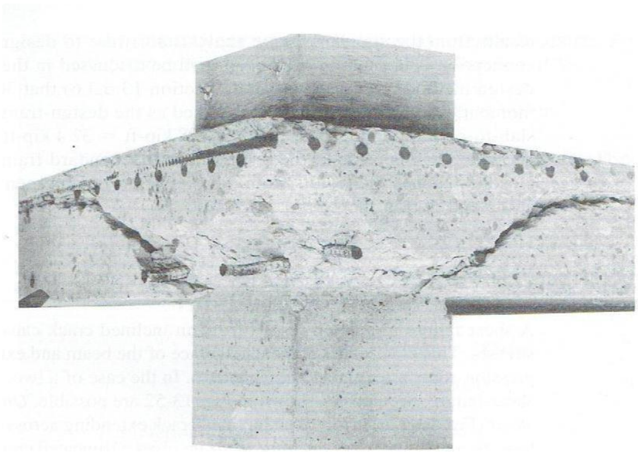

Figure 7. Shear failure with inclined cracks (photo courtesy of J.G. Mac Gregor)

Truss model were used to clarify the behavior of shear failure in beams, Alexander and Simmonds [8] have studied punching shear failures using a truss model similar to that in figure 8 below.

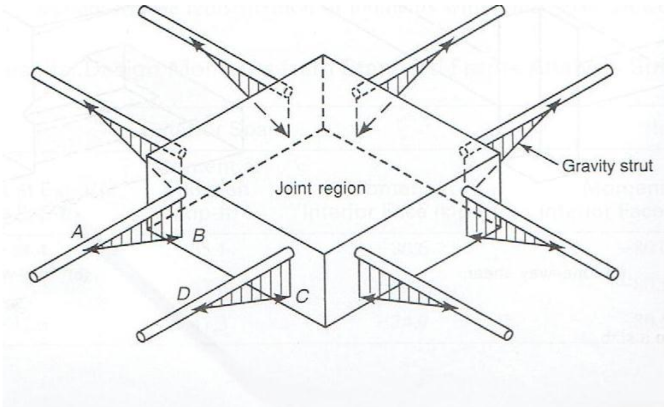

Figure 8. truss model for shear transfer at an interior column [8]

Earlier to the establishment of the inclined cracks shown in figure 7 above. The shear is transformed by shear stresses in the concrete. On one occasion the cracks have shaped only moderately small shear stresses may be transformed through them. The common of the vertical shear is transformed by inclined "struts A-B and C-D covering from the compression zone at the bottom of the slab to the reinforcement of the slab similar struts occur round the outside of the column". The horizontal constituent of the force in the struts causes a variation in the force of the reinforcement at A and D and the vertical component pushes upon the bar is resisted by tensile stresses in the concrete between the bars.

Ultimately, this concrete crack in the plane of the bars and a punching failure grades such a failure occur suddenly with little or no warning [8].

When a failure of punching shear has happened at a slab-column joint, the shear ability of that specific joint is virtually totally lost. In the case of a two way slab, as the slab slides down, the column load is transferred to the adjacent column-slab connection, there by possibly over loading them and affecting them for failure. So, while a two way slab possesses a great ductility if it fails in flexure, it "has very little ductility" if it is failing in shear [8].

2.3 Combined shear, and moment, transfer in two, way, slabs

When crosswise loads or loads of unbalanced gravity cause a transmission of moment between the slab and column, the behavior is complex- involving flexure, shear and torsion in the portion for the slab devoted to the column as shown in figure 9 and 10 below. Depending on the relative strength in these three modes, failures can take various forms [9].

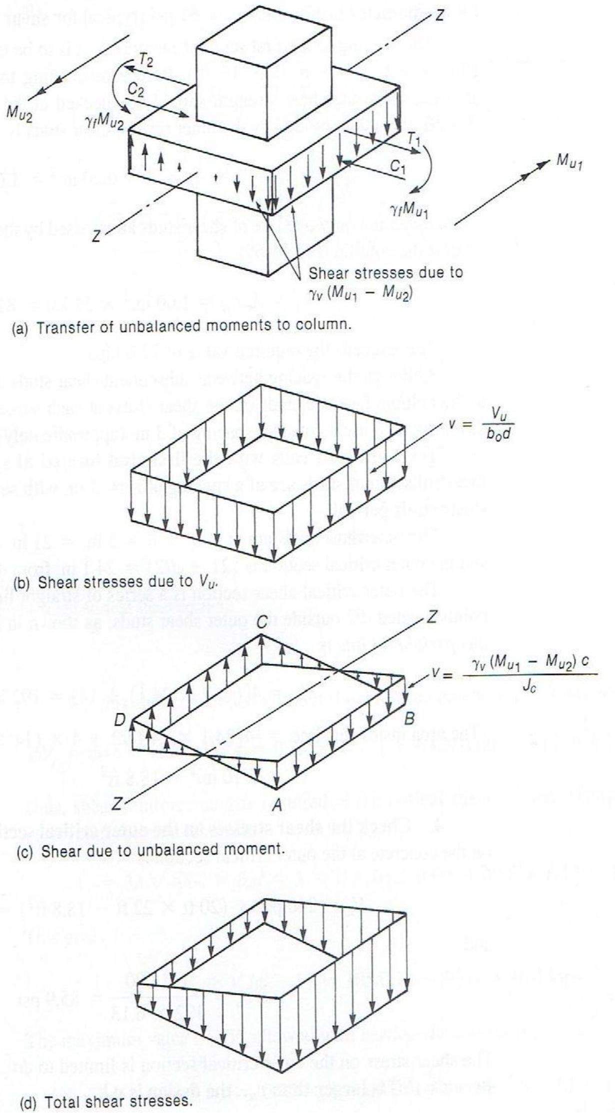

Figure 9. Shear stresses due to shear and momentum transmission

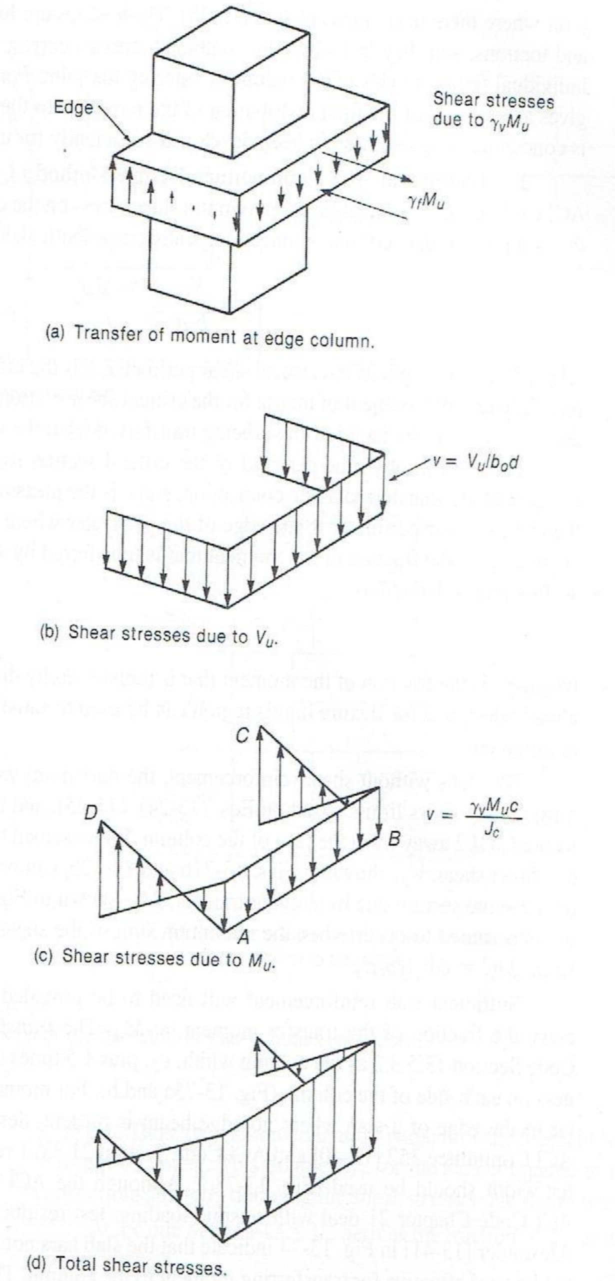

Figure 10. Shear stresses because of shear and moment transmission at the edge column

2.4 load factor

Structural failure usually occurs under combination of numerous loads. In latest years the combinations have existed in what is denoted as the confidant achievement design, this is a try to representative the predictable load combinations. The ACI code customs the subscript u to label the necessary strength, which is a load influence calculated from combinations of factored loads.

The combination of factored loads summation is U as for example:

U = 1.2 D + 1.6 L……………………………………….1

Where:

U: is referred to the factored loads summation in term of loads or in term of the effect of the factored loads Mu, Vu and Pu.

D: dead loads

L: live loads

Drop panel are the thicker part of the slab together to the columns as shown in figure 11.

2.4 Drop panel

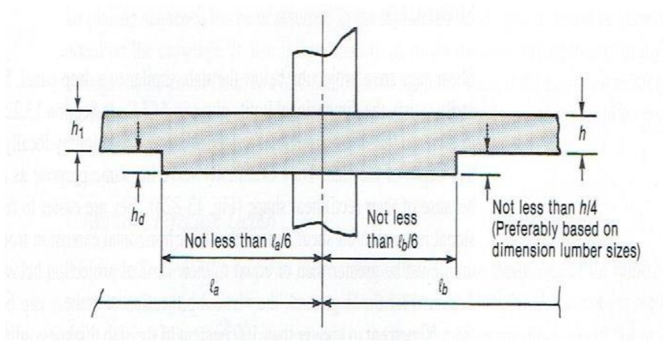

Figure 11. Drop panel

The smallest size of a drop panel from ACI code section 13.2.5 is demonstrated in figure 11 above. ACI code 13.3.7 explained that in computing the negative moment flexural reinforcement, the thickness of drop panel below the slab shall not be taken larger than one fourth of the space from the drop panel edge to the face of the column or column capital. If the drop panel are deeper than this, it is expected that the maximum stresses of compression will not move down to the bottom of the drop panel. Therefore, the full depth would not be effective.

OBJECTIVE OF THE RESEARCH

The shear ability may be enlarged as the subsequent four approaches:

1- Stiffen the slab above the whole panel (note: this can be counter-productive cause the mass of slab can be enlarge Vu considerably.
2- Thicken the slab using a drop panel adjacent to the column.
3- Add shear reinforcement.
4- Accumulative the column size or adding fillet or shear capital round the column.

So, the objective of this research is to investigate how the punching shear in "flat slab"s is affected by column dimensions and additional of drop panel, by comparing the actual shear stress with the allowable shear stress and illustrate if the "flat slab" needs drop panel or not depending on stresses values.

III. EXPERIMENTAL PROGRAM

The most important check in flat slab is the check for punching shear stress because if the load of "flat slab" is increased, the slab will be failed by punching stress not by bending stress. Firstly, the crack occurs around the columns and then failure due to punching occurs.

Therefore, the most important thing in "flat slab" design is the check of punching to avoid punching. The actual stress must be calculated, (the stress due to weight of the slab). This stress is the (Weight / Area). The area is area surrounding the columns. And the actual stress:

qpu = Qpu / Ap…………………………..2

where:

qpu: is the actual stress

Qpu: is the load of the slab

Ap: is the area surrounding the column

The actual stress must be compared with the allowable stresses.

There are four equations of the allowable stress as below:

1- $qpcu = 0.8\ (\alpha d/b_o + 0.2)\ \sqrt{Fcu}/\gamma c$ 3

Where:

qpcu: is the allowable stress

α: is factor related to the position of column as below:

α = 4 for interior column

α = 3 for edge column

α = 2 for corner column

d: is the effective thickness (thickness of slab – cover)

b_o: is the length of the line surrounding the column where crack occur

Fcu: is the ultimate concrete stress which is effective in punching failure

γc: is the unit weight of concrete

2- $qpcu = [0.316\ (0.5 + c_2/c_1)]\ \sqrt{Fcu}/\gamma c$ 4

where:

c_2: is the width of column section

c_1: is the length of column section

3- $qpcu = 0.316\ \sqrt{Fcu}/\gamma c$ 5

4- $qpcu = 1.6$ 6

The allowable stress is the lowest value of the above equations

Now, the actual stress equation becomes:

$qpu = Qpu / Ap * \beta$............................7

The actual stress multiplied by factor β which is related to stress due to bending of columns which increases the probability of punching failure depending on column position as below:

β =1.15 for interior column

β =1.3 for edge column

β =1.5 for corner column

To calculate Qpu, the following equation is used:

$Qpu = [(L1*L_2) - ((c_1+d) + (c_2+d))]* ws$.........8

Where:

L_1 and L_2: are the span width and length respectively

ws: is the weight of slab

The area Ap is calculated from :

$Ap = b_o * d$ 9

b_o = the circumferences of critical section where the punching occur depending on the position of column figures (12 and 13)

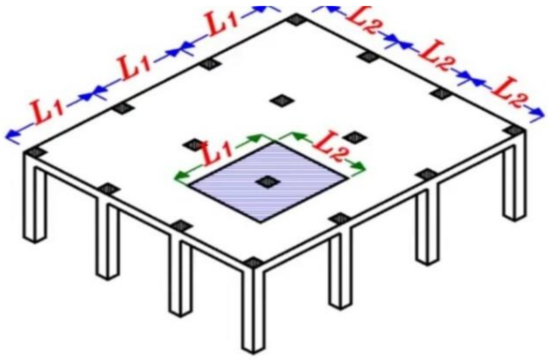

Figure 12 : span length and width

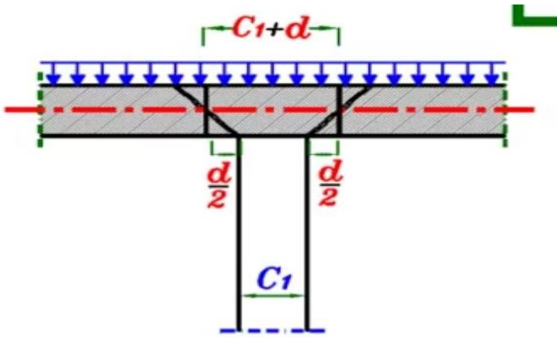

Figure 13 : Critical section of column

IV. RESULTS AND DISCUSSION

As mentioned, in paragraph above, this paper study the effect, of column position if it is interior, edge and corner columns. At all columns positions, the paper, deals with different column dimensions and compute the actual stress with, comparing its values, with the allowable stress from the equation (3 to 6). Then, draw the histogram, of all the values required.

The values differ from satisfy the requirements (i.e the actual stress qpu is less than the allowable stress qpcu) or not (vice versa).

Also this paper study and indicate if the slab need to addition drop panel or not as it is shown in the figures below.

Panel 5 by 5

The values that satisfy the requirements (qpu<qpcu) for interior column without addition drop panel more than one half about (62%) as shown in figure 14 because this column supports high values of load from four panels related to this column. And when add the drop panel for the columns that not satisfy the requirements (qpu>qpcu) the percentage exceeds to (93%), see figure 15.

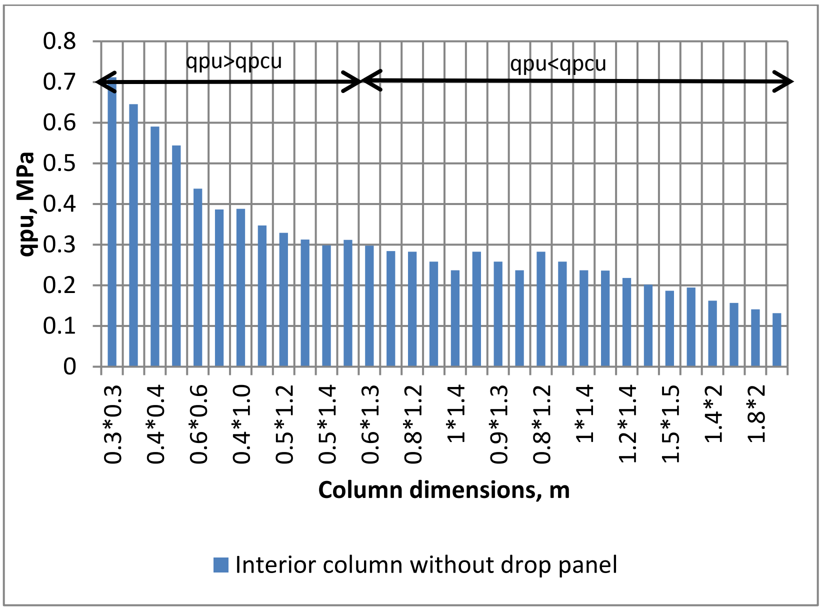

Figure 14: Interior column without drop panel of span 5*5

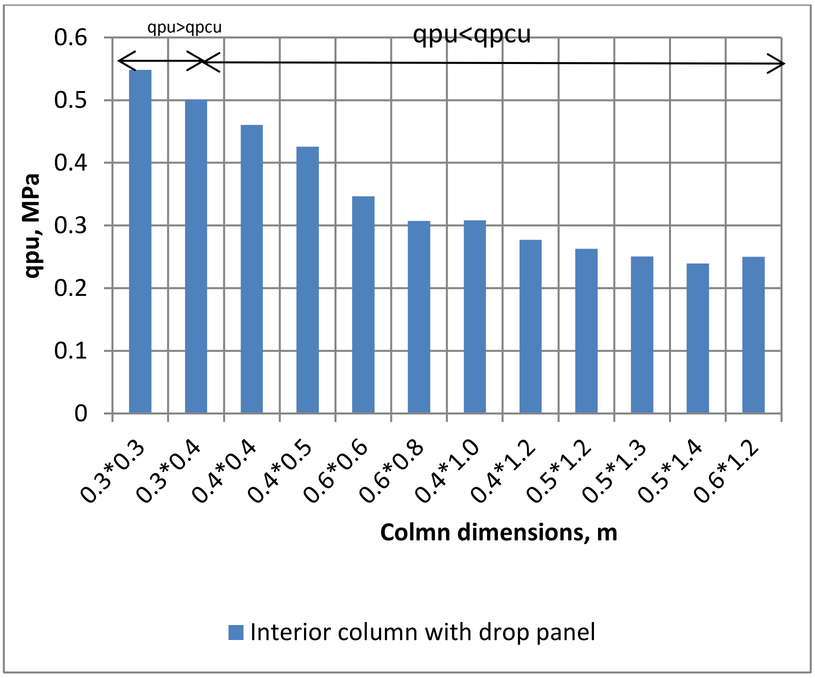

Figure 15: Interior column with drop panel of span 5*5

The figure 16 below show that the edge column without drop panel has a percentage of satisfaction the requirements of 78.5% and when add the drop panel this percentage is increased to 97% as shown in figure 17.

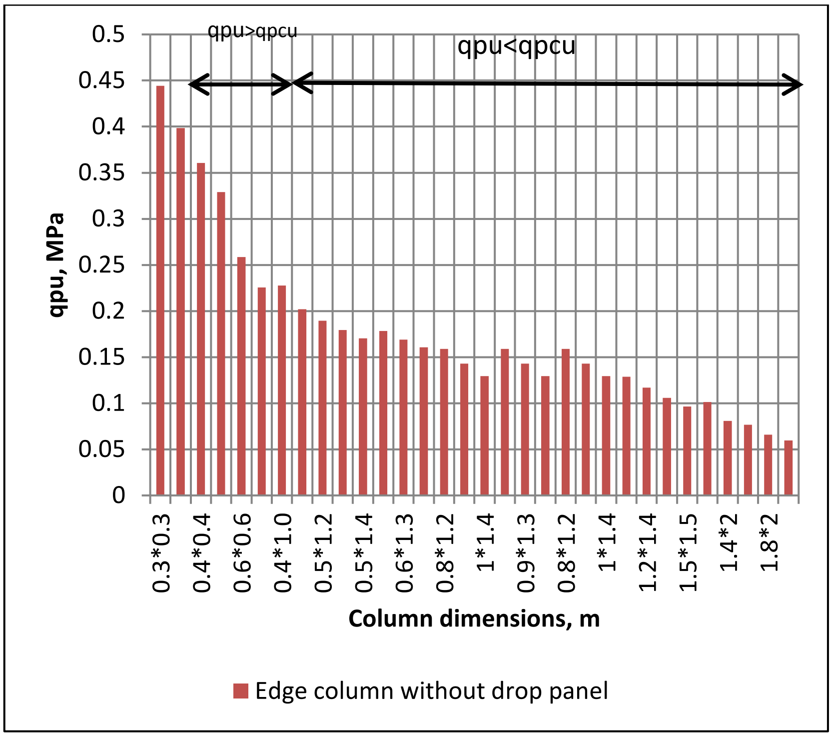

Figure 16: Edge column without drop panel of span 5*5

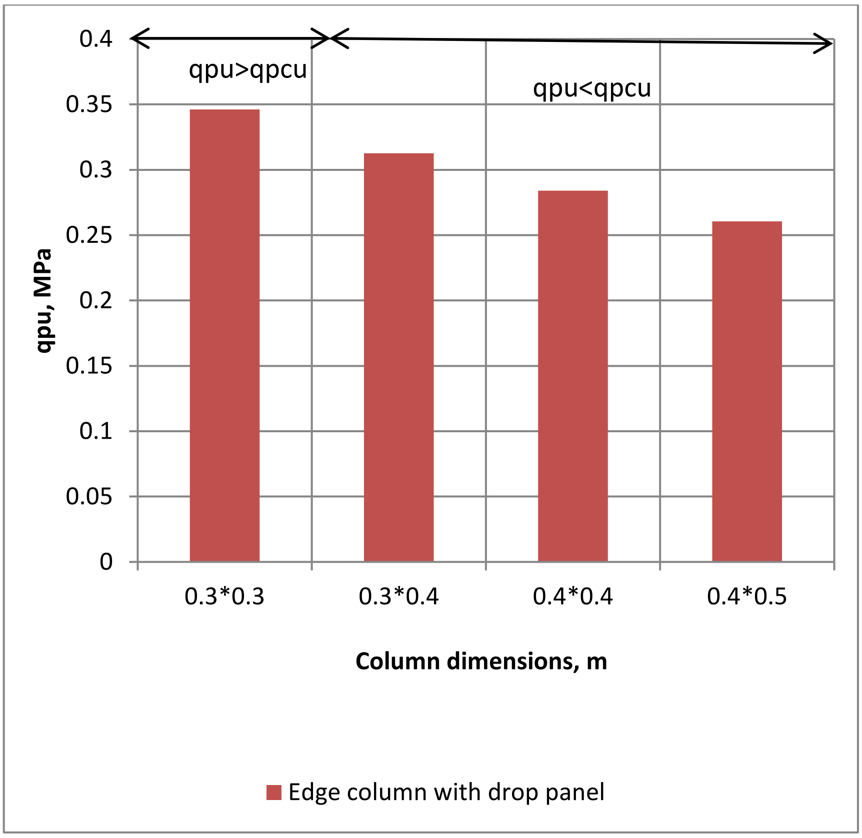

Figure 17: Edge column with drop panel of span 5*5

All the values of actual stress smaller than the allowable stress at the corner column and no need for drop panel in this case for all column dimensions as shown in figure 18.

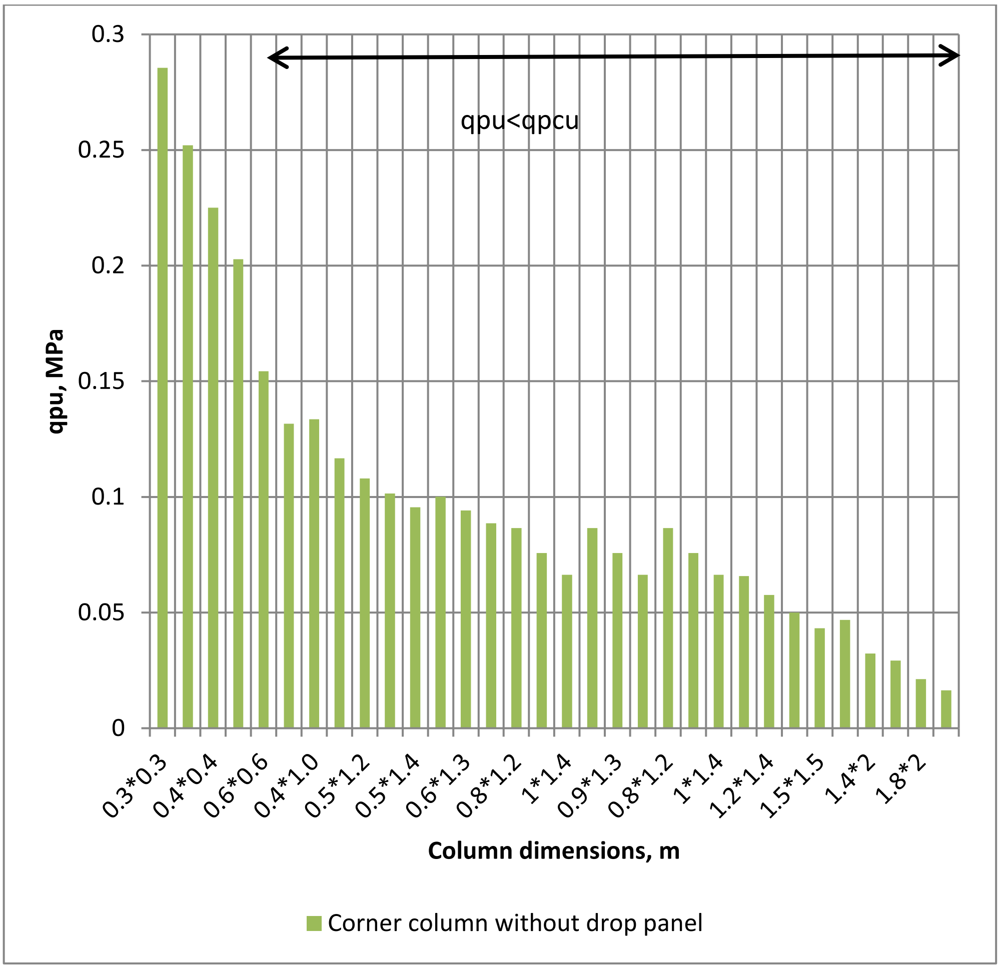

Figure 18: Corner column without drop panel of span 5*5

Panel 6 by 6

The figure 19 below shows that the interior column without addition drop panel the column dimensions have a values of actual stress greater than the allowable stress except when a column has a length of 2 m and the percentage of qpu< qpcu is about 12.5% only so, there was a need to add a drop panel to the slab in the case of large panel to distribute the loads on a large area to decrease the resulted actual stress.

When add the drop panel the percentage exceeds to 53% and it is a good range to satisfy the requirements, see figure 20.

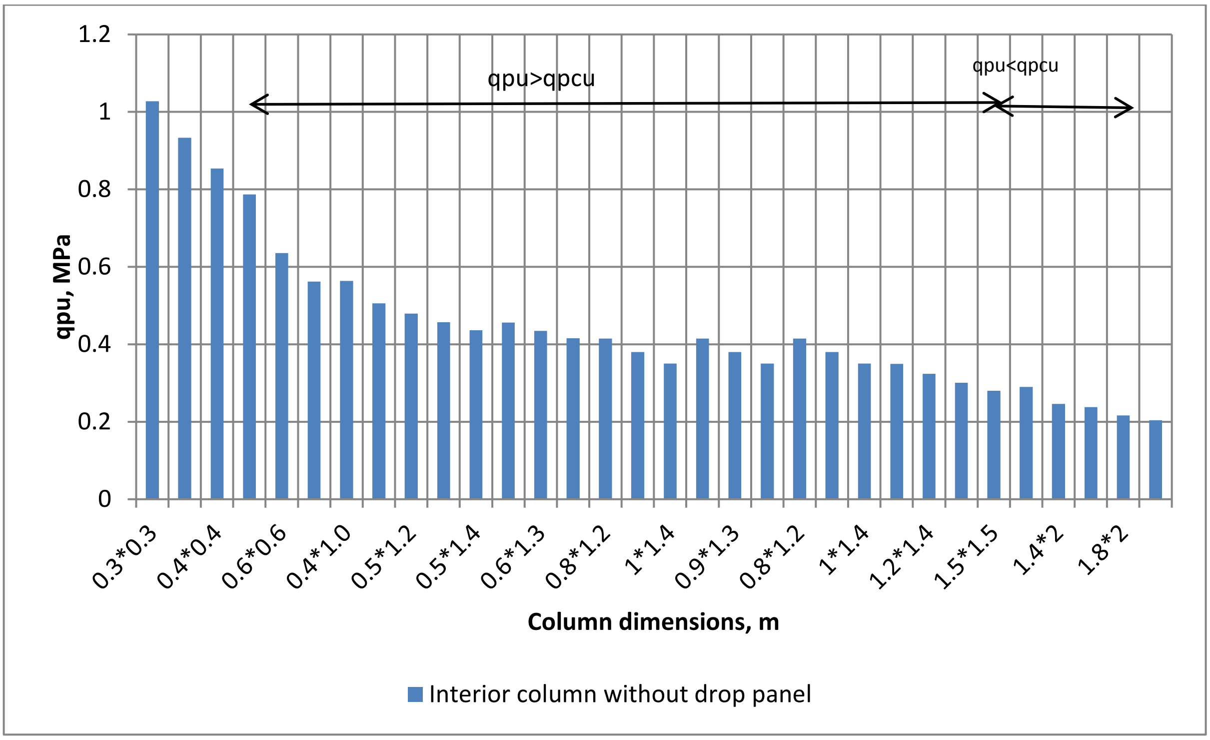

Figure 19: Interior column without drop panel of span 6*6

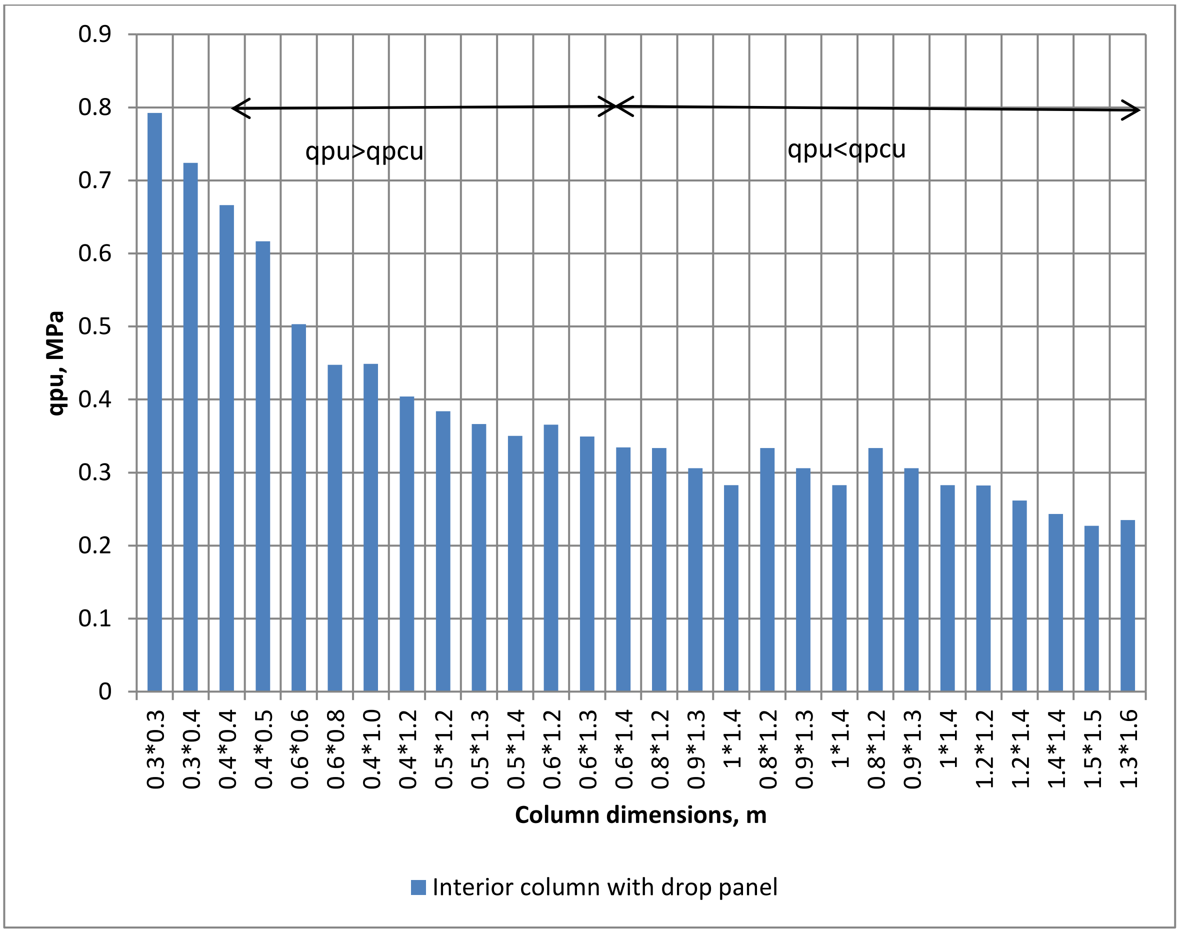

Figure 20: Interior column with drop panel of span 6*6

The edge column of the same span without drop panel the percentage of qpu<qpcu was 75% and increased to 78.5% when added the drop panel to the slab as shown in figures 21 and 22.

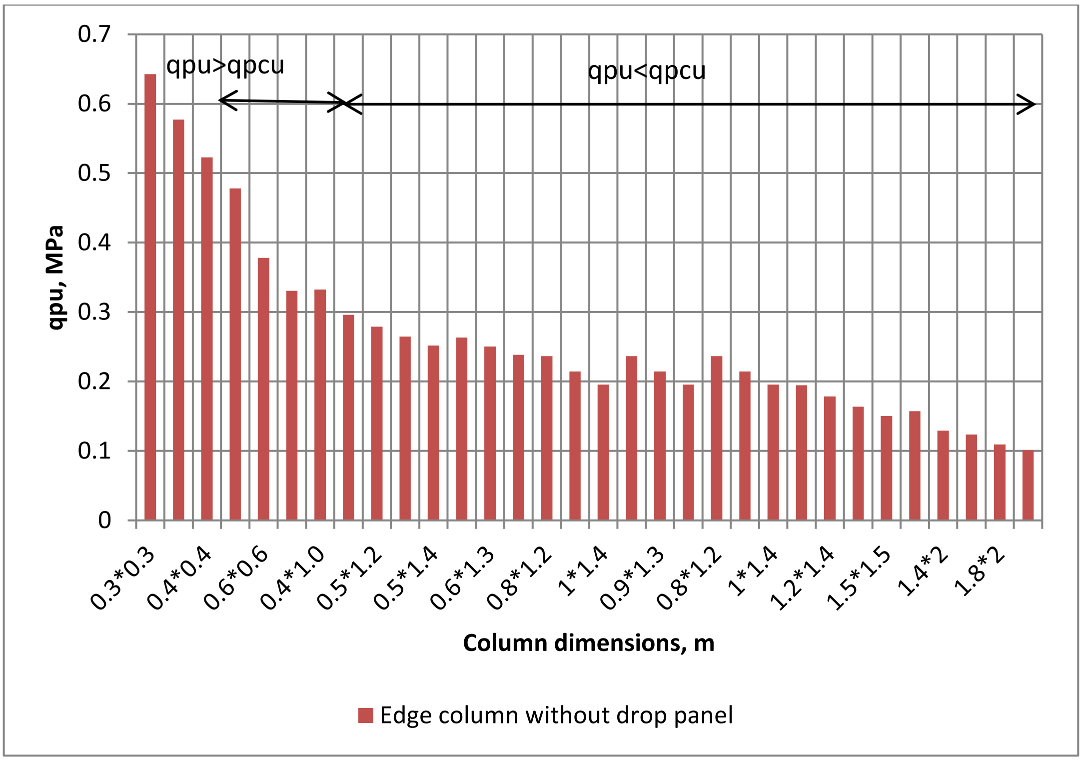

Figure 21: Edge column without drop panel of span 6*6

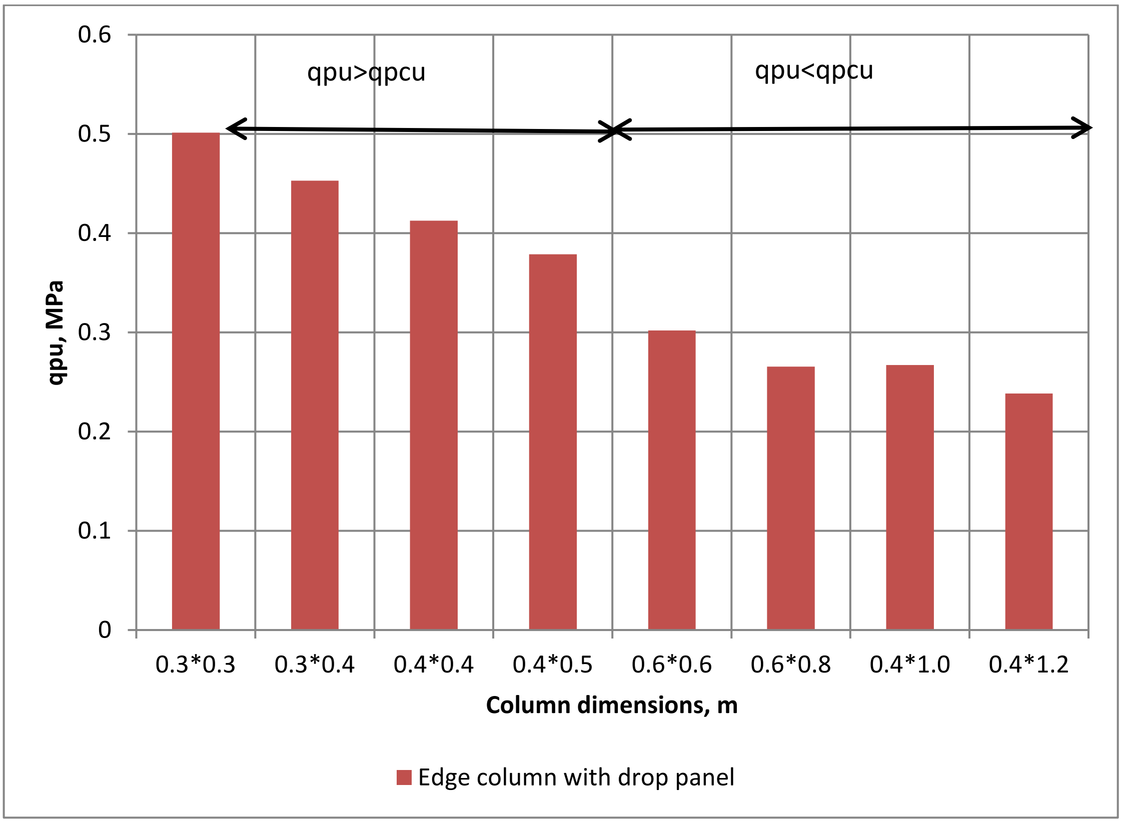

Figure 22: Edge column with drop panel of span 6*6

The corner column without drop panel has a percentage of satisfaction (qpu<qpcu) of 90% and exceeds to 97% when added the drop panel, see figures 23 and 24.

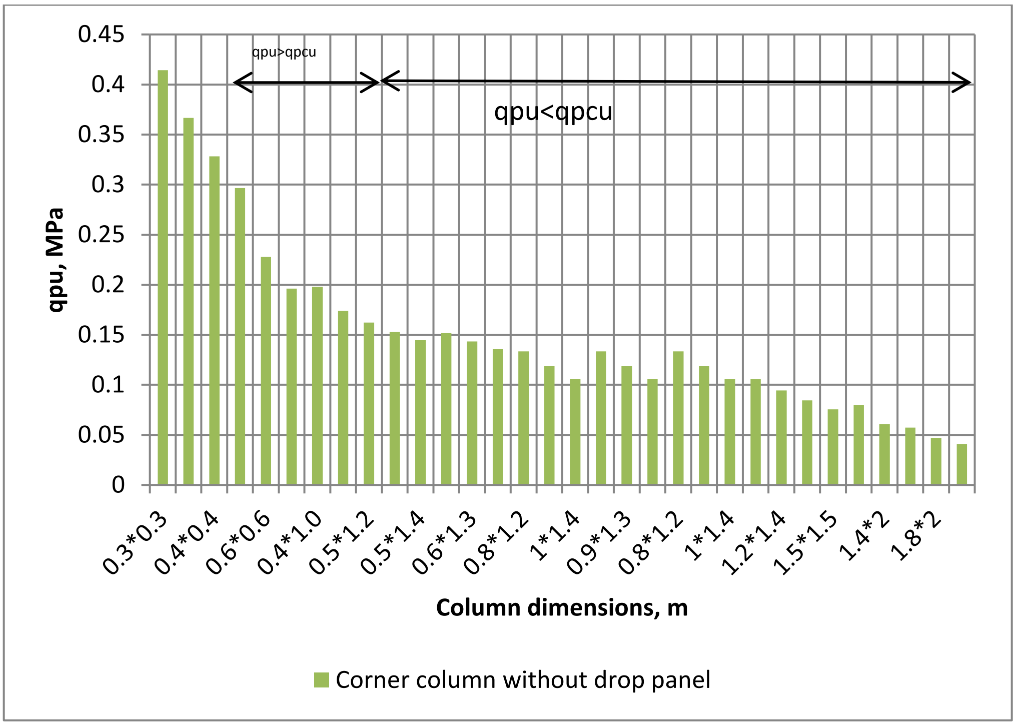

Figure 23: Corner column without drop panel of span 6*6

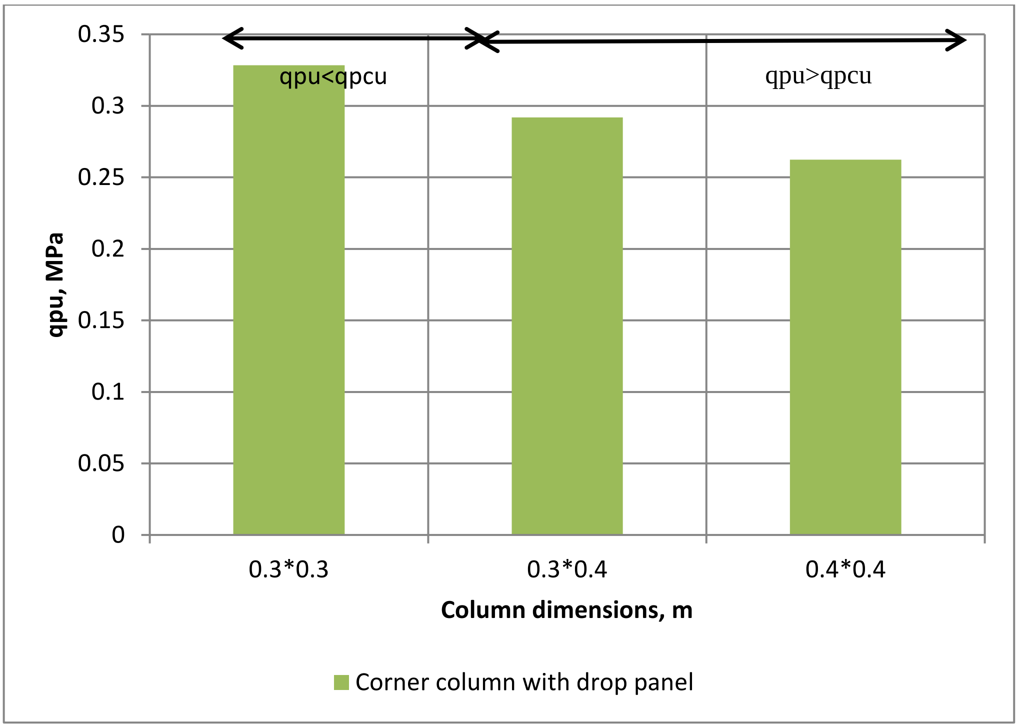

Figure 24: Corner column with drop panel of span 6*6

V. CONCLUSION

1) From this research, many things can be concluded:
2) The increase of the column dimensions is clearly affected the punching shear in "flat slab"s.
3) In "flat slab" span (5 by 5) m the punching shear is changed from 0.312 MPa to 0.29 MPa when dimensions increased from (0.6*1.2) m to (0.6* 1.3) m for interior column. Also, from 0.329 MPa to 0.258 MPa when dimensions increased from (0.4*0.5) m to (0.6* 0.6) m. while the corner column the punching shear is changed from 0.285 MPa to o.252 MPa when dimensions

increased from (0.3*0.3) m to (0.3* 0.4) m and the punching shear not occur in this column.

4) In span (6 by 6) m the punching shear is changed from 0.29 MPa to 0.25 MPa when dimensions increased from (1.3*1.6) m to (1.4* 2) m for interior column. Also, from 0.296 MPa to 0.278 MPa when dimensions increased from (0.4*1.2) m to (0.5* 1.2) m. while the corner column the punching shear is changed from 0.328 MPa to o.296 MPa when dimensions increased from (0.4*0.4) m to (0.4* 0.5) m.
5) To avoid the punching shear, the column dimensions can be increased but if the increase causes uneconomical design or the design is not comfort to the architectural design, drop panel can be used to a void punching. Where the actual shear stress in span (5 by5) m is decreased from 0.386 MPa to 0.310 MPa for the same column dimension (0.6* 0.8) m. While the effect of adding drop panel on the edge column the actual shear stress is decreased from 0.398 MPa to 0.312MPa for the same column dimension (0.3* 0.4) m. The corner column not need for adding drop panel.
6) The addition of drop panel on interior column the shear stress is decreased from 0.380 MPa to 0.306 MPa for column dimensions (0.9* 1.3) m, while the edge column for span (6*6) m the actual shear stress is decreased from 0.377 MPa to 0.302 MPa for the same column dimension (0.6* 0.6) m. The corner column the actual shear stress is decreased from 0.367 MPa to 0.292 MPa for the same column dimension (0.3* 0.4) m.
7) The minimum thickness of the slab required to limit deflection can be decreased by 10 percent if the slab have drop panel compliant to ACI code 13.2.5, "the drop, panel hardens, the slab in district of maximum moments and later decreases the deflection".
8) A drop, panel provides, extra slab, thickness, at the column, thus accumulative, the region of the critical, shear, boundary.

VI. FUTURE WORK

Future work is "the increase of column dimensions by using column capital" can be studied.

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