Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

First Engineering Scientific Conference
College of Engineering –University of Diyala
22-23 December 2010, pp. 268-285

DECISION MAKING TO IDENTIFY SECTION DIMENSIONS THAT PRODUCE ECONOMIC DESIGN FOR REINFORCED CONCRETE BEAMS

Khattab Saleem Abdul-Razzaq
Engineering College , Diyala University

ABSTRACT:- In our life, it is on accepted fact that one of the most important human activities is decision making. It does not matter what field of activity one belongs to. Whether it is political, military, economic, or technological, decisions have a far-reaching influence on our lives. It also could be said that decision making plays an important role in structural design too. The very purpose of which is to find the best way so that a designer or a decision maker can derive a maximum benefit from the available resources.

In the work here, the aim is to find the dimensions of a rectangular beam which may give minimum cost. That was done by variation of rectangular beam height (h) from maximum height (h_{max}) –which it is here two or three times the beam width (b) – to the minimum beam height (h_{min}) which it is here indicated from the ACI-code 318-08 deflection minimum heights requirements tables. During this variation of (h), computer program calculates beam reinforcement and cost. Finally, the reader chooses the height (h) and width (b) that give the minimum cost. This search is restricted by ACI-code 318-08 beam design requirements.

This work consists of five parts. The first part deals with the economic design of simply supported rectangular beams with different (b/h) ratios for spans ranging from 2.5m to 12.5m.

The second part deals with the economic design of both fixed ends supported rectangular beams with different (b/h) ratios. The third part deals with the economic design of fixed-pinned ends supported rectangular beams with different (b/h) ratios. The fourth part deals with the economic design of continuous rectangular beams with different (b/h) ratios.

The fifth part deals effect of changing the concrete cost Cc to reinforcement cost Cs ratio (i.e. Cs/Cc ratio) and the effect of changing the ratio (b/h) on design results.

FORMULATION OF COST MINIMIZATION PROBLEM

There are many methods to search for minimum cost deign, one of them is "Graphical Method" [3]. As a matter of fact, the complexity of using the minimization method is not a measure of solution efficiency because it depends upon the nature of the objective function which identifies the most suitable method that can be used.

OBJECTIVE FUNCTION

The objective cost function consists of the cost of concrete and cost of steel reinforcement involving labor cost.

Cost = Volume of concrete *Cc + Volume of steel *Cs* γ_s ………………(1)

Where:

Cc= Unit price of concrete, involving labor cost.

Cs=Unit price of steel, involving labor cost.

γ_s =Density of steel in Ton/m^3.

Volume of concrete = b * h * L

Volume of steel = As * L = ρ * b * d * L

Thus Eq.(1) becomes:

Cost = b * h * L *Cc + ρ * b * d * L *Cs+ A_b * num * scir*Cs ……………….…(2)

Where:

b = Width of beam section.

h = height of beam section.

L = Length of beam.

A_b = Cross area of stirrups' bars. (assumed 79 mm^2).

num=Number of stirrups.

Scir= Circumference of stirrups.

For parameters b and L still constants for three types of beams obtained by this work, steel ratio (ρ) is computed from the maximum moments in each beam caused by self weight and live load in addition to super imposed dead load. In this way the maximum moment for simply supported beam is w *L * L / 8 and the same value to fixed and pined ends, for both fixed ends it is w *L * L / 12, where w is the uniformly distributed load per unit length of beam. The parameter (num) refers to the number of stirrups segments along the entire length of the beam, (scir) refers to stirrups' circumference and this term exists as the beam dimensions governed by shear reinforcement and it equals to 2* (b + h), if that does not exist, then (num) is zero.

At last it is worth to mention that equation (2) plotted by using computer program with a loop of the rise (h) to obtain cost function vs h. Also it is worth to mention that b is obtained in terms of h (b=0.33 h and\or b=0.67 h), as recommended by[1].

GRAPHICAL METHOD

Computer program helps plotting the cost variation because of the rectangular beam height (h) variation from maximum height (h_{max}) to the minimum height (h_{min}). During this variation of (h), computer program calculates beam reinforcement and cost. Finally, the reader chooses the height (h) and width (b) that give the minimum cost. This search is restricted by ACI-code 318-08 beam design requirements.

CONSTRAINTS

The constrains involve serviceability and flexural strength requirements as below:

1-Serviceability Constraints

According to table 9.5(a) ((ACI 318M-08) chapter 9), which deals with members not supported or attached to partitions or other construction likely to be damaged by large deflections, the permissible depths for beams are, [2]:

-For Simply supported beam minimum h= L / 16.

-For fixed and pined ends beam (one end continuous) minimum h= L / 18.5.

-For both fixed ends beam (both ends continuous) minimum h= L / 21.

Where:

h = Depth of beam section.

L = Length of beam.

Most of the references such as [1,4] refer to that the most economic dimensions (d/b) falls between 1.5 to 3 or 2 to 3, in this way the starting point to begin plotting is h = 2*h_{min} and some times h=1.5*h_{min}.

2-Flexural Strength Constraints

$$\rho_t = 0.85\beta_1 \frac{fc'}{fy}\frac{0.003}{0.003+0.005} \quad \text{...............................(3)}$$

If ρ is less than ρ_{min} then we obtain $\rho = \rho_{min}$ which it is $\frac{1.4}{fy}$.

REASONABLE VALUES TO PLOT

Here we obtain a reasonable values for the plotted function, the loop begins with $h=2*h_{min}$ and (h) decreases (0.005 m) in order to search for (h) which produce minimum cost.

This work presents economic h for spans (2.5, 7.5, 12.5) meters and for (b/h) values 0.67 and 0.33. If any other b/h ratio is required the user can use linear interpolation.

INPUT DATA

The input data of the programs are:

d_b = 20 mm.

fy =400 MPa.

$f'c$= 30 MPa.

Live load =25 kN/m.

Supper imposed dead load=15 kN/m.

For all cases Cs/Cc =12.

Where the considered prices for materials are:

- 22000 ID/m^3 for Gravel.
- 20000 ID/m^3 for sand.
- 8750 ID/50kg for cement.
- 900000 ID/ton for reinforcement steel.

So, for 1:2:4 concrete mix; the price is 75580 ID/m^3. In addition to that; the considered prices for labor work are:

- 100000 ID/ton for reinforcement steel.
- 20000 ID/m^3 for concrete.

The input data for the program are f'_c, f_y, d_b, width to height ratio (b/h) and span length (L). According to the input data, program designs the required beam and calculates its cost. This step is repeated with new value of the beam height (h) according to a specific (h) loop.

Figures (2) to (21) and equations (4) to (9) are showing the economic rectangular reinforced concrete section dimensions and costs. It is also clear that the height value (h) is checked with ACI-Code serviceability and shear requirements.

PROGRAM FLOW CHART

Program flow chart is given by Fig (1). This program was written in QBasic programming language.

ECONOMIC BEAM DESIGN

1. Simply Supported Beam Case

1.A. Considering b=0.33 h, see figures 2, 3 and 4.

1.B. Considering b=0.67 h, see figures 5, 6 and 7.

2. Both ends are Fixed Beam Case

2.A. Considering b=0.33 h, see figures 8, 9 and 10.

2.B. Considering b=0.67 h, see figures 11, 12 and 13.

3. Fixed end - Pinned end Beam Case

3.A. Considering b=0.33 h, see figures 14, 15 and 16.

3.B. Considering b=0.67 h, see figures 17, 18 and 19.

4. Continuous Beam involved into Six R.C. Slab Panels Example

Figure (20) shows the layout of multistory building roof. It is required to design B1 according to previous shown way by using "Method Π". Live load $=2KN/m^2$, and super imposed dead load $=3KN/m^2$.Use b/h ratio=0.33 , fy= 400 MPa, $f'c$= 30 MPa.

Solution:

Using Method II, [5]:

$$h=\frac{2(6250+5000)}{180}=125mm$$ use h=150.

Dead load =0.15*24+3=6.6 KN/m^2.

Wu=1.2DL+1.6LL=11.12 KN/m^2.

S=5.25 m.

L=6.5 m

Thus m=0.8

$$We=\frac{Ws}{3}(\frac{3-0.8^2}{2})=22.96KN/m$$ from each side.

From that:

h economic (h_{ec})= 0.5110 meter.

b economic (b_{ec})= 0.1703 meter.

THE SUMMARY OF (H_{EC})

1. Simply Supported Beams, see figure (22), also see the best fit equations for each curve

$For\ b \backslash h = 0.67 \qquad h_{ec} = \frac{L^4}{2757.4} - \frac{L^3}{87.617} + 0.120933L^2 - 0.4526L + 0.82$ ………..……..(4)

$For\ b \backslash h = 0.33 \qquad h_{ec} = \frac{L^4}{3232.76} - \frac{L^3}{97.15} + 0.118867L^2 - 0.485667L + 0.97$ ………..……..(5)

2. Both Fixed Ends Beams, see figure (23), also see the best fit equations for each curve

$For\ b \backslash h = 0.67 \qquad h_{ec} = -\frac{L^4}{15625} + \frac{L^3}{625} - 0.014L^2 + 0.086L + 0.03$ ....(6)

$For\ b \backslash h = 0.33 \qquad h_{ec} = -\frac{L^4}{3024.194} + \frac{L^3}{101.351} - 0.1019333L^2 + 0.462333L - 0.41$ ....(7)

3. Pinned-Fixed ends Beams, see figure (24), also see the best fit equations for each curve

$For\ b \backslash h = 0.67 \qquad h_{ec} = \frac{L^4}{31250} - \frac{L^3}{815.217} + 0.015L^2 - 0.026333L + 0.27$ ....(8)

$For\ b \backslash h = 0.33 \qquad h_{ec} = -\frac{L^4}{4076.1} + \frac{L^3}{136.861} - 0.0752667L^2 + 0.37033L - 0.25$ ....(9)

THE EFFECT OF CHANGING THE COST RATIO CS/CC ON DESIGN RESULTS

The ratio steel cost to concrete cost Cs/Cc was changed for a 10 meters span beam –for example– from 15 to 60 in order to determine the effect of the change of the price ratio on the decision making process for choosing the dimensions that produce minimum cost, noting that b/h=0.33 was used. It was noticed that increasing Cs/Cc ratio from 15 to 60 leads to reinforcement steel ratio increment by about 200%, see Fig (26).

CONCLUSIONS

1- The relation between the economic height (h_{ec}) of the reinforced concrete rectangular beam section and its span length is proportional.
2- It is not necessarily that the minimum beam section dimensions produce the minimum cost because of the role of reinforcement which was seen that it related to dimensions inversely.
3- It was noticed that the increment of reinforcement steel price leaded to steel ratio decrement for the beam section.

4- Using the minimum beam section height (h_{min}) based on ACI-08 (table 9.5.a) dose not give the minimum cost design especially with small span lengths. While with the larger span lengths, the (h_{min}) of ACI-08 Code (table 9.5.a) sometimes could be used as a minimum cost causative.
5- It is not a must that using doubly reinforcement gives lower cost than singly.
6- Decreasing the section width to height ratio (b/h) is favorable from economic point of view especially with high loads.
7- Decreasing the section width to height ratio (b/h) leads to costs decrement.
8- Economic design charts and equations that give best (h_{ec}) values from economic point view are presented here to save money, time and efforts for engineers.

REFERENCES

1- Nilson H., David Darwin, Charles W. Dolan, 2004, "Design of concrete structures" Thirteenth Edition. United States, McGraw Hill, pp^{82-420}
2- Building Code Requirements for Structural Concrete, (ACI 318M-08) and Commentary, 2008.
3- Brain D. Bunday, 1985, “Basic Optimization Methods”, London, School of Mathematical Science, University of Bradford, Edward Arnold Publishers Ltd.
4- Chu Kia Wang, Charles G. Salamon and Jose A. Pincheira, 2007, "Reinforced Concrete Design “, seventh edition, John Wiley & Sons, pp^{66}
5- جمال عبدالواحد فرحان الظاهر, 2005, "تصاميم المنشأت الخرسانية المسلحة" ، الطبعة الاولى ، جامعة الانبار، ص261، .

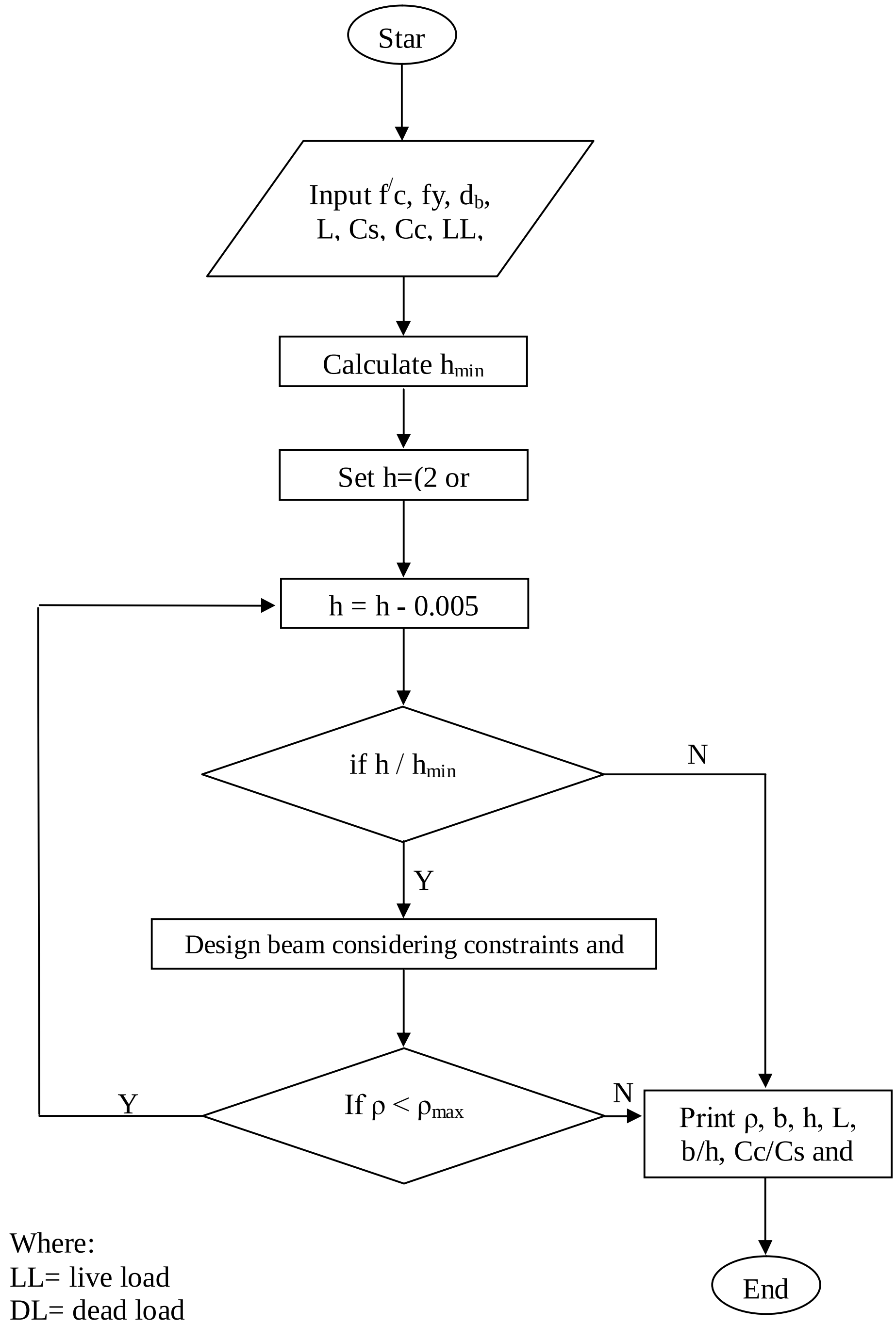


Fig (1): Flowchart of the Program**.**

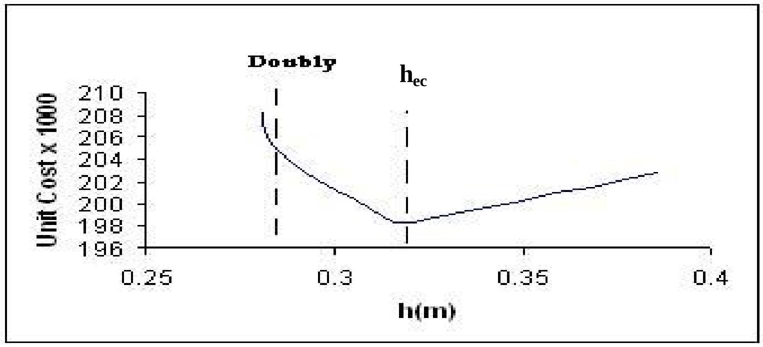


Fig (2): Cost vs h for simply supported beam b=0.33h and span 2.5 meters.

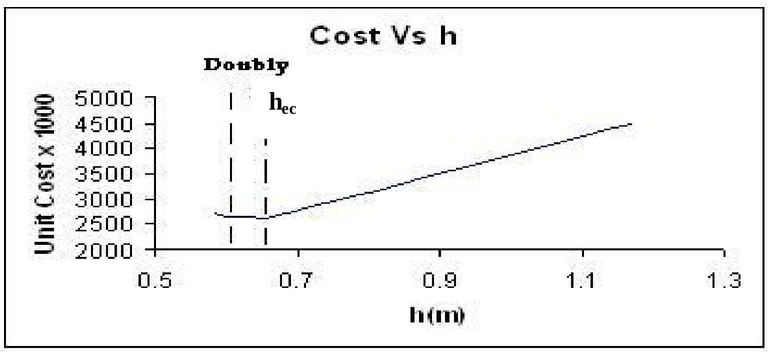


Fig (3): Cost vs h for simply supported beam b=0.33h and span 7.5 meters**.**

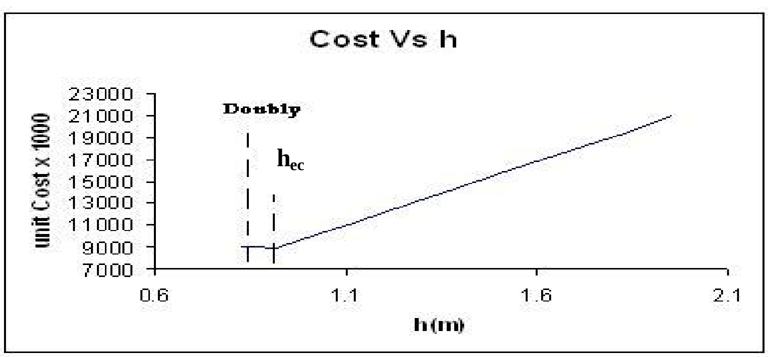
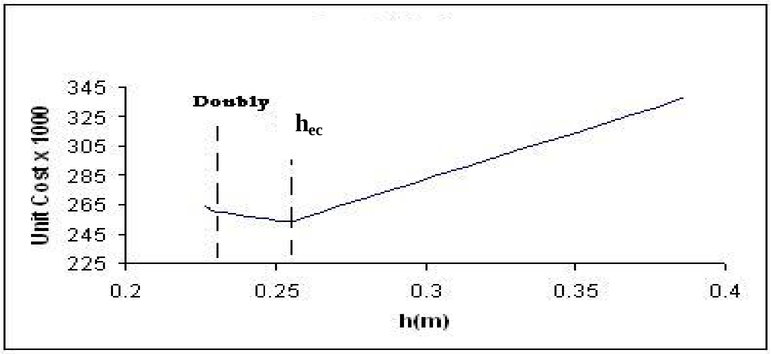
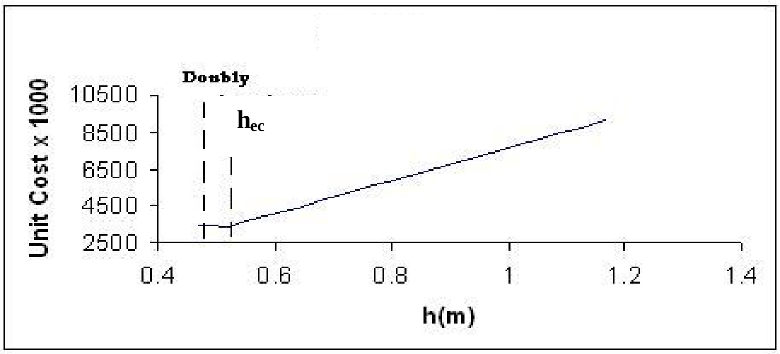


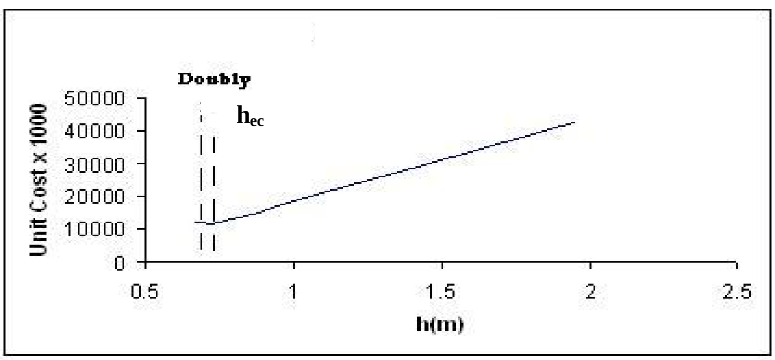
Fig (4): Cost vs h for simply supported beam b=0.33h and span 12.5 meters.



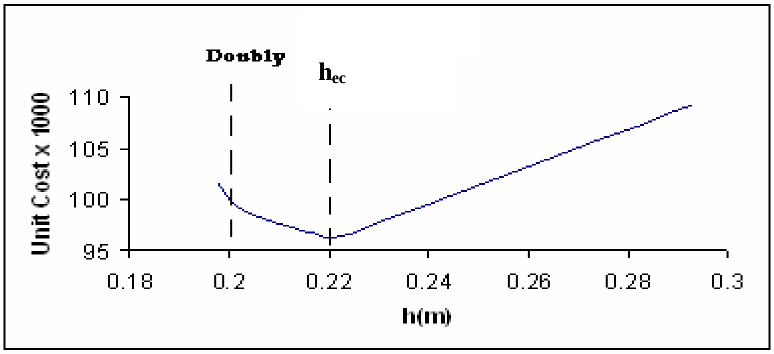
Fig(5): Cost vs h for simply supported beam b=0.67h and span 2.5 meters.



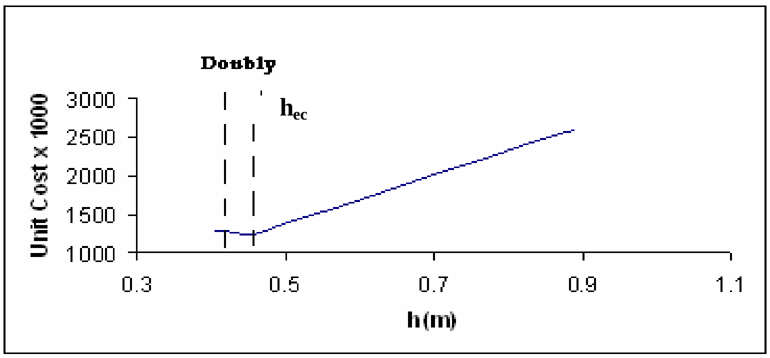
Fig(6): Cost vs h for simply supported beam b=0.67h and span 7.5 meters.



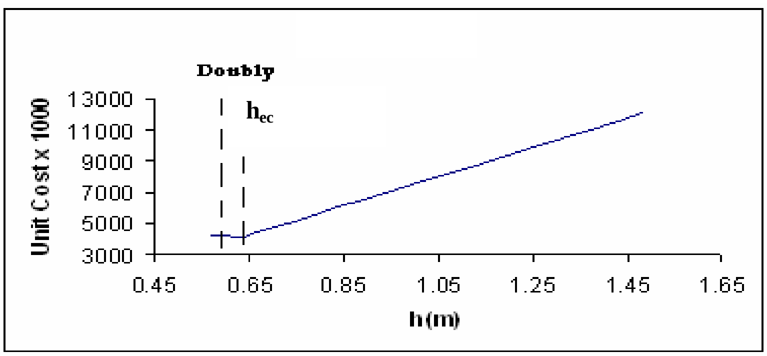
Fig(7): Cost vs h for simply supported beam b=0.67h and span 12.5 meters.



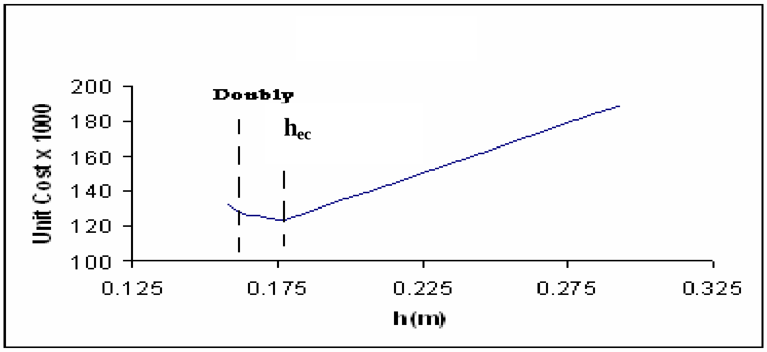
Fig(8): Cost vs h for both fixed ends beam b=0.33h and span 2.5 meters.



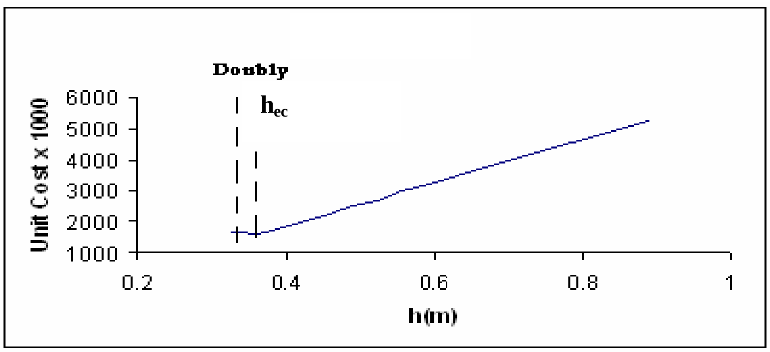
Fig(9): Cost vs h for both fixed ends beam b=0.33h and span 7.5 meters.



Fig(10): Cost vs h for both fixed ends beam b=0.33h and span 12.5 meters**.**



Fig(11): Cost vs h both fixed ends beam b=0.67h and span 2.5 meters.



Fig(12): Cost vs h both fixed ends beam b=0.67h and span 7.5 meters.

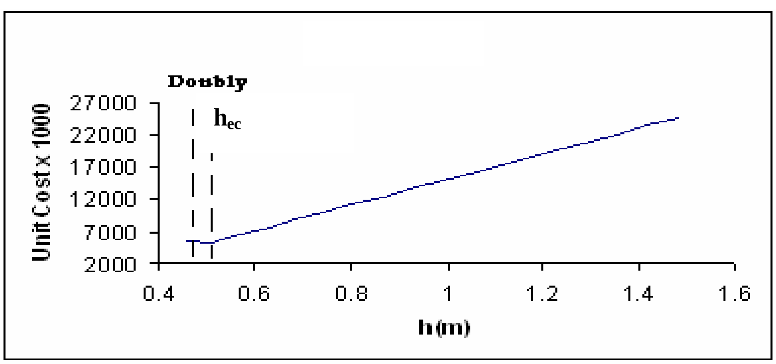
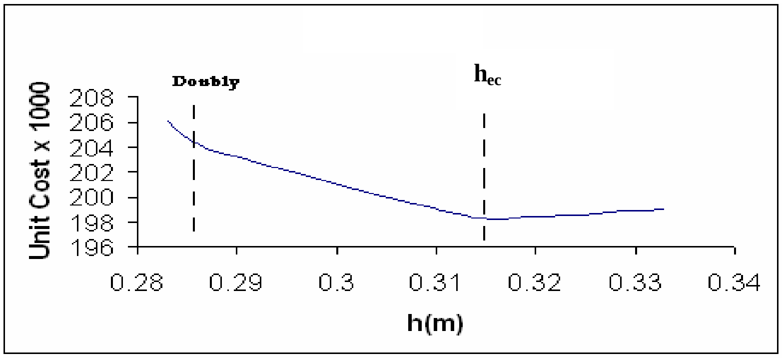
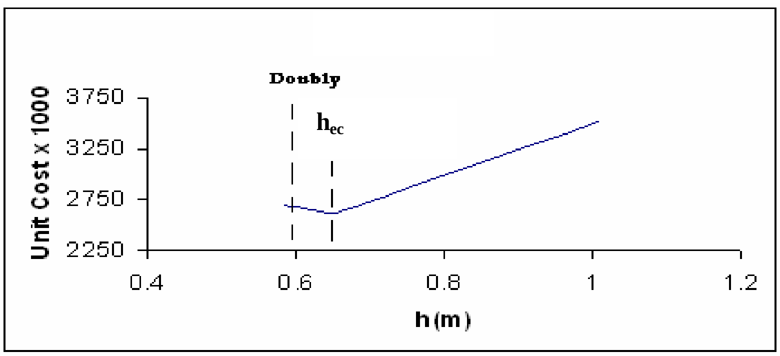


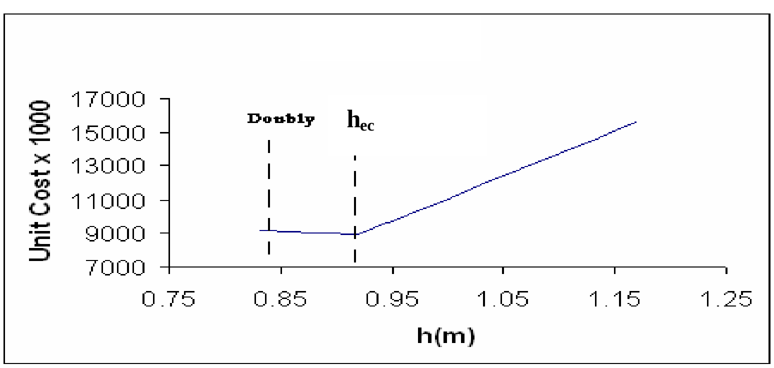
Fig (13): Cost vs h for both fixed ends beam, b=0.67h and span 12.5 meters.



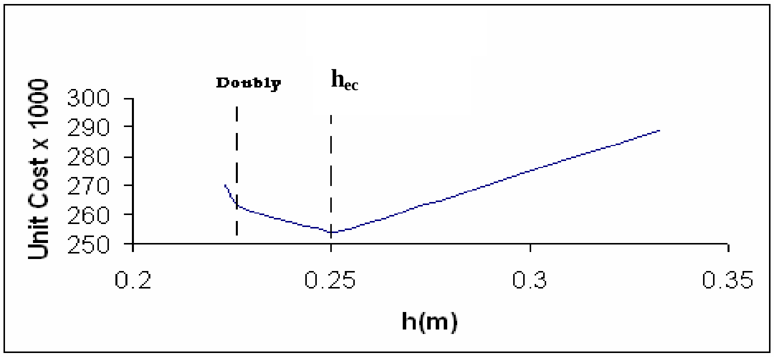
Fig(14): Cost vs h fixed-pin ends beam b=0.33h and span 2.5 meters.



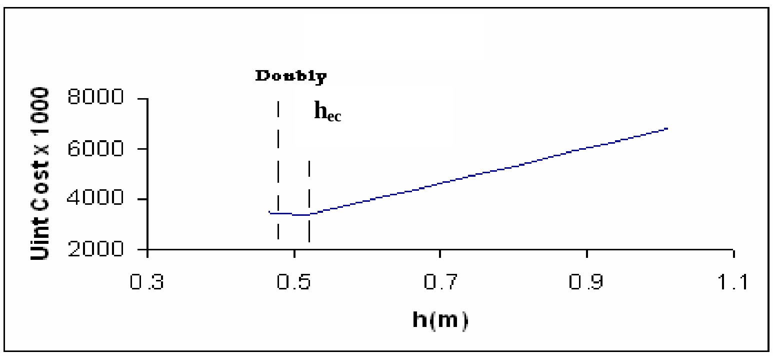
Fig(15): Cost vs h fixed-pin ends beam b=0.33h and span 7.5 meters.



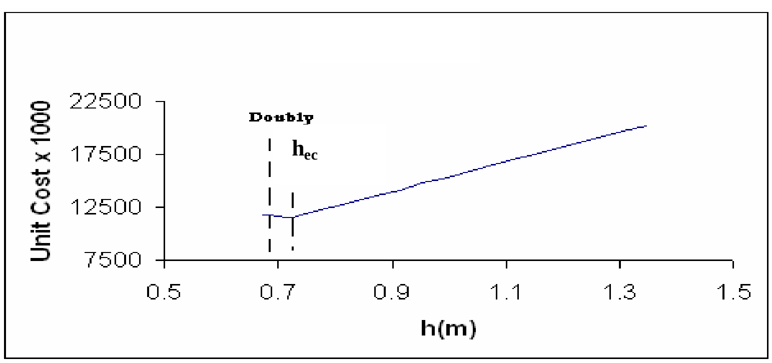
Fig(16): Cost vs h fixed-pin ends beam b=0.33h and span 12.5 meters.



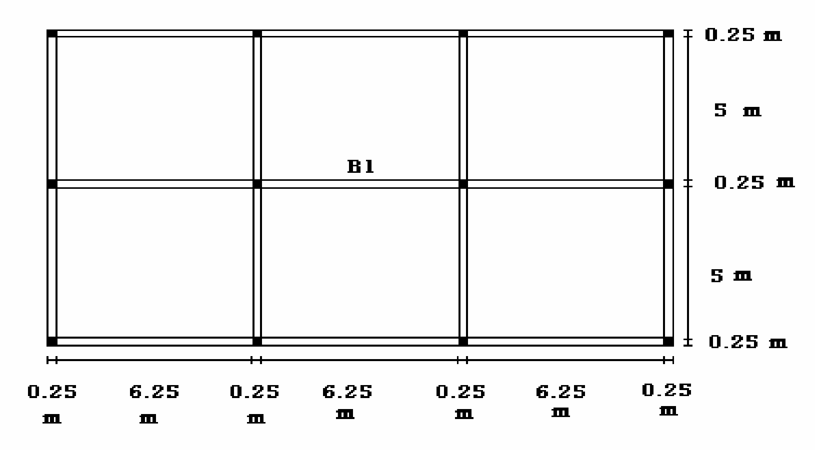
Fig(17): Cost vs h fixed-pin ends beam b=0.67h and span 2.5 meters.



Fig(18): Cost vs h fixed-pin ends beam b=0.67h and span 7.5 meters.



Fig(19): Cost vs h fixed-pin ends beam b=0.67h and span 12.5 meter.



Fig(20): Method Π example layout**.**

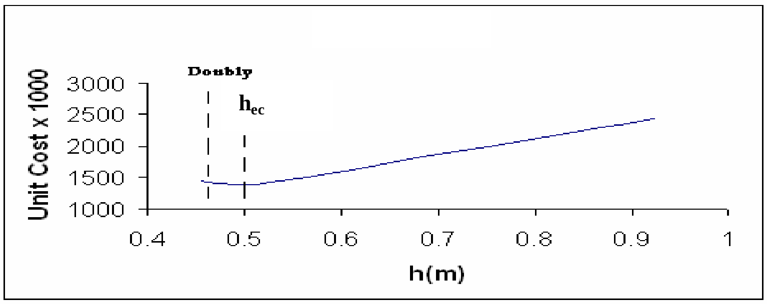


Fig.(21): Cost vs h for continuous beam (B1) .

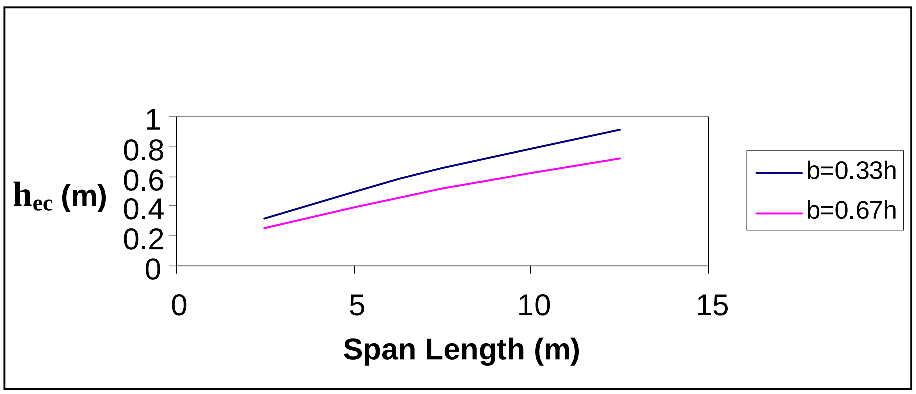


Fig (22): h_{ec} summary for simply supported beams.

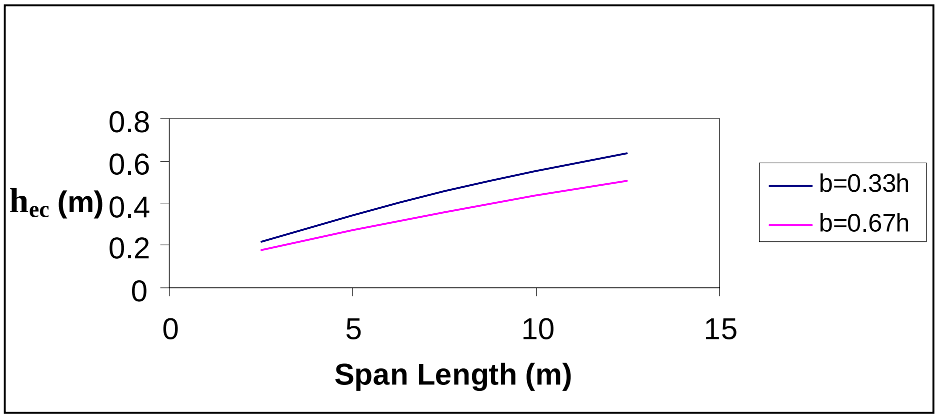


Fig (23): h_{ec} summary for both fixed ends beams.

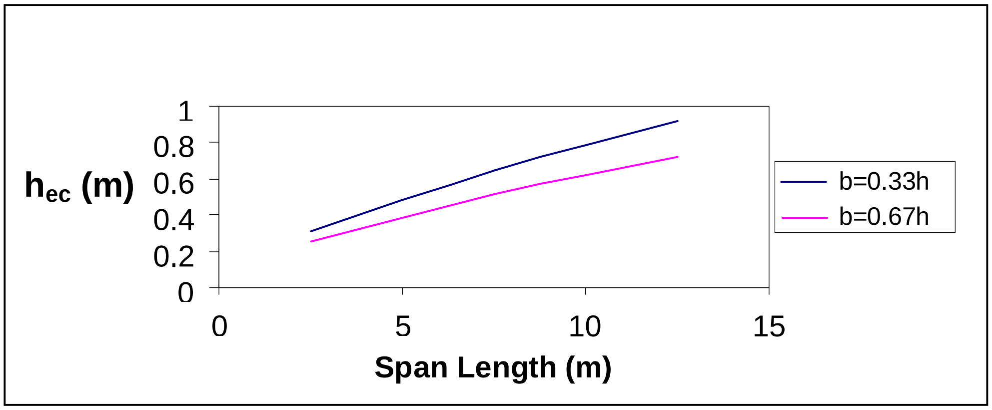


Fig (24): h_{ec} summary for fixed-pinned ends beams

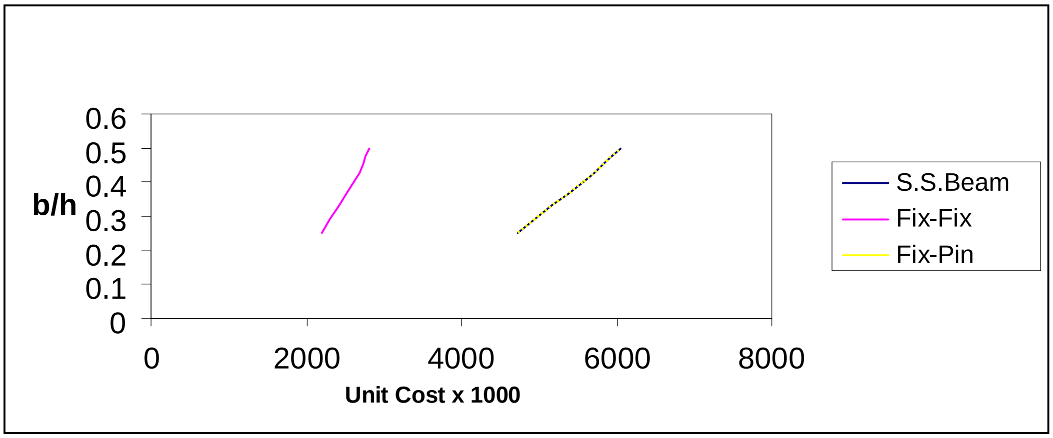


Fig (25): The effect of the ratio (b/h) on the design results.

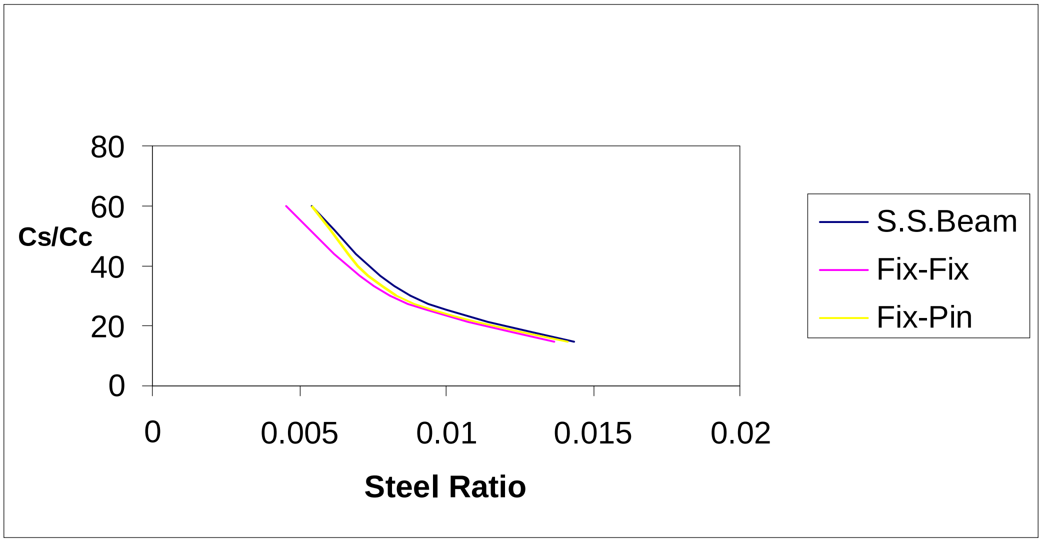


Fig.(26): The effect of (Cs/Cc) ratio on the design results.

اتخاذ القرار المناسب في اختيار أبعاد مقطع العتبة الخرسانية المسلحة التي تفضي إلى التصميم الاقتصادي

د. خطاب سليم عبد الرزاق
مدرس
كلية الهندسة . جامعة ديالى

الخلاصة

في الحياة، من المسلم به ان من اهم ما يقوم به الانسان هو اتخاذ القرار بغض النظر عن المجال الذي يقوم باتخاذ القرار فيه سواء اكان مجالا سياسيا او عسكريا او قتصاديا او تقنيا لأن للقرار تأثير كبير على حياتنا. و من المسلم به كذلك ان عملية اتخاذ القرار تؤثر بشكل كبير على التصميم الهندسي. لأن من الواجب الان ان يصب قرار المصمم في استحصال افضل النتائج من الموارد المتوفرة لديه.

لذلك يهدف هذا البحث الى مساعدة المهندسين على اختيار ابعاد العتبة الخرسانية المسلحة التي تعطي اقل التكاليف بشكل مباشر و سريع. و قد تم عمل ذلك عن طريق تغيير قيمة ارتفاع العتبة من قيمتها القصوى الى قيمتها الدنيا (و بالاستناد الى المواصفات الانشائية التي يقرها الكود الامريكي لسنة 2008) و تصميمها عدة مرات بواسطة برنامج حاسوب تمت كتابته لهذا الغرض حيث يقوم البرنامج بحساب الكلفة الكلية للعتبة في كل مرة يتغير بها الارتفاع ليتسنى بعدها اختيار الابعاد التي تقودنا الى الكلفة الاقل.

ينقسم هذا العمل الى خمسة اقسام، القسم الاول يتناول التصميم الاقتصادي لعتبات بسيطة الاسناد بفضاءات تتراوح من (2.5م) الى (12.5م) و بأستخدام نسب متتغيرة لارتفاع مقطع العتبة الى عرضه (b/h). كما ان القسم الثاني و الثالث و الرابع يتناولون نفس الموضوع لكن بأشكال اسناد مختلفة لنهايات العتبة. اما القسم الخامس فأنه يحوي على دراسة مدى تأثير نسبة ارتفاع مقطع العتبة الى عرضه (b/h) و كذلك دراسة مدى تأثير نسبة سعر الخرسانة الى سعر التسليح (Cc/Cs) على نتائج التصميم.

و في النهاية يتوصل العمل الى بعض الاستنتاجات و الرسومات و المعادلات التصميمية والتي تساعد المهندسين على الوصول الى التصميم الاقل كلفة بسلاسة و يسر.