Simplified Method to Optimum Design of Built-Up Steel Beam Section

طريقة مبسطة للتصميم الأمثل للكمرات المعدنية المركبة

FIKRY A. SALEM
Department of Structural engineering, faculty of Engineering
Mansoura University, Mansoura, Egypt
E-mail: drfikry_salem@yahoo.com

ملخص

المنشآت المعدنية هي واحدة من أكثر المنشآت المستخدمة حديثا. ومع زيادة تكلفة المنشآت المعدنية زادت أهمية التصميم الأمثل لعناصر هذه المنشآت. على سبيل المثال يوجد عوامل كثيرة تؤثر فى تصميم الكمرات المعدنية مثل (الطول الغير ممسوك **Unsupported Length** - الإجهاد المسموح به للانبعاج الإلتوائى العرضى **Allowable Stress in Lateral Torsional Buckling** - الأحمال **Loads** - نوع الركائز **Support Condition** - رتبة الصلب **Steel Grade** - نوع القطاع **Section class (compact, non-compact, slender)**.

فى التصميم المبدئى يتم أهمال هذه العوامل حيث يتم الحصول على عزم القصور الذاتى **The Required Inertia** ومن ثم الحصول على القطاع من الجداول وفى هذه الحالة ممكن أن يكون القطاع له عزم قصور ذاتى كبير وفى نفس الوقت يكون قطاع نحيف **slender** وبالتالى يتم تقليل تحمله طبقا للكود المصرى أو يكون القطاع له عزم قصور ذاتى قليل ولكنه **compact Section** لذا من الصعوبة معرفة أى من هذه العوامل له تأثير كبير على إختيار القطاع أو أخذ كل هذه العوامل فى خطوة واحدة.

لهذه الأسباب تم عمل برنامج كمبيوتر لإختيار القطاع المناسب عن طريق عدة محاولات للحصول على قطاع الأمثل يحقق كل متطلبات الكود المصرى.

Abstract

With the increase of steel cost the importance of optimum design increases. Many factors affect the design of beam sections such as (unsupported length – allowable stress in lateral torsional buckling- load and support condition–steel grade – section class (compact, non-compact, slender)). Choosing a section empirically or by experience and neglecting the previous factors is not correct. To design a beam section allowable stress may be assumed, the required inertia is too calculated, from sections tables a suitable section is to be chosen. At this step, the effect of unsupported length on the section properties has been neglected. The section may have large inertia but is still slender according to code limits and its properties will be reduced again, on other hand the section may have small inertia but still has considerable allowable stress as compact section. Which section is the best? , which factor has a big effect? And how to satisfy all these factors in one-step.

As explained before it is difficult to choose the most economic section. A computer program has been made to select the best section by making many trails to choose the best section satisfying all conditions of the Egyptian code of practice for steel construction for the design of beam sections. After that the results were grouped to know the way to obtain the optimum section with respect to flange width, flange thickness, ratio of flange with to thickness, web height, web thickness and lateral unsupported length.

Keywords

Optimum Design, Unsupported length, Allowable Stress, Lateral Torsional Buckling, Support Condition, Steel Grade, Section Class (Compact, Non-compact, Slender).

1- Introduction

All international steel codes of practice [1-6] attempt to improve the analysis and design of steel structural systems. In the analysis of a structural element, many factors control the design of sections and these require more accurate and more work in design. In the design of I beam (built up section). There are many factors controlling the design of section. Such that, section class (compact – non compact – slender), distance between lateral unsupported points, C_b

Received: 26 January, 2015 –Revised: 30 March, 2015 - Accepted: 4 May, 2015

(Coefficient depending on the type of load and support condition) and steel grade.

The design of I beam sections according to the applied bending moment, the section modulus is assumed as (Z_x req ≈ M_x / F_{bx}). The designer assumes F_{bx}, then find the required inertia and the suitable section can be obtained. This design does not give the optimum section (economic section). The section may have small thickness and large inertia but the section is slender and then its properties will be reduced. For some values of unsupported length, this section may be optimum while for other values this section may be a very bad choice. The best flange width to thickness ratio change with lateral unsupported length. If flange-width ratio (b_f/t_f) has a small value the section is non-compact yet the torsional buckling strength may control the design.

So, a computer program was made to find the best economic section realizes the required conditions. A program was designed to select the best section from a number of available sections about 6,000,000 section are included in the program [7].

2- Nomenclature

A= Cross-sectional area of a member (cm^2).
b_f = Flange width (cm).
C_b= Coefficient depending on the type of load and support condition.
F_b= Allowable stress in bending (t/cm^2).
F_y= Yield stress of steel (t/cm^2).
F_{ltb}=Allowable lateral torsional buckling stress (t/cm^2).
H_w= Web depth (cm).
L_u= Effective lateral unsupported length of compression flange (cm)
L_{uo} = Optimum unsupported length
M_x = Bending moment about major axis (m.t).
t_f = Flange thickness (cm).
t_w = Web thickness (cm).
Z_x= Section modulus (cm^3).
L_{um}= Maximum Lu for economic design.

3-The Best Suitable Distance between Unsupported Points

The effect of unsupported length on the designed steel section will be studied using a computer program. Under constant (C_b – F_y – M_x). The relation between (L_u) and area of the optimum section chosen by the program is shown in Fig. (1). The area of the choosen section is constant until a certain value of L_u, after which it starts to increase. This value of L_u is the optimum lateral unsupported length which gives the maximum distance between points of lateral support without any increase in section area.

For M_x=20 m.t, C_b=1, F_y=2.4, the optimum value L_u =440 cm.

When the lateral unsupported length is small, then F_b is constant (F_b=.64f_y for compact sections and F_b=.58f_y for non-compact sections). With the increase of the lateral unsupported length, the section is controlled by lateral torsional buckling in which case F_b=F_{ltb}

$$F_{ltb} = \sqrt{F_{ltb1}^{\ 2} + F_{ltb2}^{\ 2}} \leq 0.58Fy \quad (1)$$

The section may be controlled by eq. (1) but there is no reduction in allowable bending stress. The allowable bending stress begins to decrease beyond the point of L_{uo} (optimum unsupported length).

Using computer program to study affect of lateral unsupported length on area of choosing sections under several values of bending moments. It found the relation between area and L_u for several values of bending moment as shown in Fig. (2). With increasing moment the value L_{uo} increase.

And by collecting and plotting values of optimum L_{uo} in one curve the relation between L_{uo} and M_x can be estimate as Fig. (3). From Fig. (3). With value of moment can find optimum distance between lateral unsupported points.

4- Optimum Flange Width – Thickness Ratio

Studying the relation between L_u and b_f/t_f Fig. (4), b_f/t_f optimum = 28 and this value increases with the increase of L_u. At this value, the flange is noncompact (not slender) and there is no reduction in section properties. If b_f/t_f >28 the flange is slender. b_f/t_f has very small effect on Z_x. Also found that F_{ltb} increase with increase b_f/t_f . If b_f/t_f <28 F_{ltb} may be smaller where $F_{ltb1}=20b_f/\sqrt{f_y}$ decrease with decrease b_f .The second stage in curve when F_{ltb} <.58F_y to increase F_{ltb} the best solution to increase b_f/t_f ratio. The section will be slender but F_{ltb} will be increase.

4.1-Effect of CB on B_f/T_f Ratio.

As shown in Fig. (5) increasing the value of C_b increase capacity of section.

5- Optimum Web Debt-Thickness Ratio

The relation between L_u and h_w/t_w is shown in Fig. (6). $h_w/t_w \approx 122.5$

Form code condition

$$\frac{hw}{tw} \leq \sqrt{fbc}\,/145 \cong 122.5 \quad (2)$$

Minimum web thickness, maximum web depth is required for maximum Z_x.

For I-sections increasing web thickness isn't useful except for shear resistance.

6- Effect of Lateral Unsupported Length on Web Dimensions

Fig. (7) explains the change of web dimensions with the increaseof value of Lu. At first increase of value of L_u (h_w & t_w) are constant as shown in fig. (7) where F_b is constant. When F_b begins to decrease the area of the total section increases while the area of web decreases. The area is concentrated in the flanges. (t_w) decrease 1 mm to realize ($h_w/t_w \approx 122.5$) h_w decrease by 12.5 mm.

With the increase of L_u the allowable stress F_b decreases and that increase ratio of h_w/t_w eq. (2), while t_w is constant h_w increase to realized eq(2) as shown in Fig. (7).

7- Effect of Lateral Unsupported Length on Web Depth

In Fig. (7) it can be see that h_w=73 mm when M_x=25 m.t.

If moment change h_w will change as shown in Fig. (8). This curve gives an idea about the required h_w for optimum section. In the first part of the curve the moment is small which required small (h_w & t_w) but t_w is limited by 5 mm. Thus that a linear change in h_w occurs with the increase in moment until Mx reaches to 10 m.t while t_w is constant because h_w/t_w didn't arrive to optimum ratio 122.5.

Further the increase of bending moment while (h_w and t_w) being constant, no change in web dimension and the increase is in the flange only. To increase web dimensions must increase thickness to conform with h_w/t_w ratio and that causes large increases in sectional area. So that h_w is constant until big increase in the value of moment at this step web thickness increase 1 mm and h_w increasing 12.5mm.

8- Result

By using some curves for different values of lateral unsupported length and C_b can obtain the best built up I beam section realize all code condition. And with the value of moment can expected the best distance between lateral supported point.

Fig. (9), Fig. (10), Fig. (11), Fig. (12), shown four curves for different values of unsupported length with different value of C_b, and moment change from (5 m.t to 60 m.t), L_u = (200,400,600 800 cm), C_b =(1, 2).

According to value of lateral unsupported length L_u by using Fig. (9), Fig. (10), Fig. (11), Fig. (12). and with value of C_b can detedrmine the required curve. With moment can find

1. The section area Area= given (cm^2)
2. web depth h_w=given (cm)
3. $t_w \approx h_w/122.5$ then find t_w (cm)
4. Af =(Area- hw.tw)/2 (cm^2)
5. $t_f = \sqrt{(A_f /28)}$ (cm)
6. $b_f = 28\ t_f$ (cm)

9- Conclusions

1. The optimum distance between laterally supported point can be determined with the knowldge of 2 variables (M_x & C_b) only
2. We can choose the optimum section from charts without calculation.

10- References

[1.] Egyptian code of practice for steel construction and bridges (allowable stress design) Code No. (205).

[2.] American Institutes of Steel Construction. (1993). "Load and Resistance Factor Design Specification for Structural Steel Buildings," Chicago, Illinois, USA.

[3.] Buhle, H. (1954). "Complete Determination of the State of residual stress in solid and Hollow Metal cylinders, Residual stresses,"Residual Stress in Metals and Metal Construction, Edited by W.R. Osgood, Reinhold Publishing Corporation, New York, N. Y., PP .305-329.

[4.] The Behavior and design of structural steel to BS5950, by N.S. TRAHAIR the University of Sydney, M.A. BRADFORD The university of New South Wales and D.A. NETHERCOT. (2001).

[5.] Structural Steel Designer's Handbook. By Roger L. Brokenbrough Pittsburgh, Pennsylvania. And Frederick S. Merritt West PALM beach, Florida.

[6.] Eurocode 3,"Design of Steel Structures", ENV 1993 PART 1.1, General Rules for Buildings. European Committee For Standardization, Brussels.

[7.] National Instruments Carporation "Labview Software User Manual ",Jan.,1998.

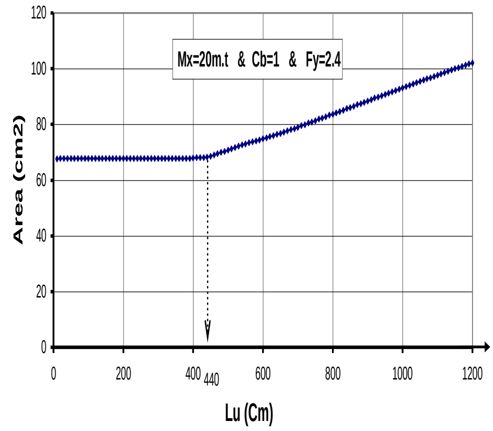

Fig.(1) Relation between Lu and Area of I section according to E.C.P .2004.

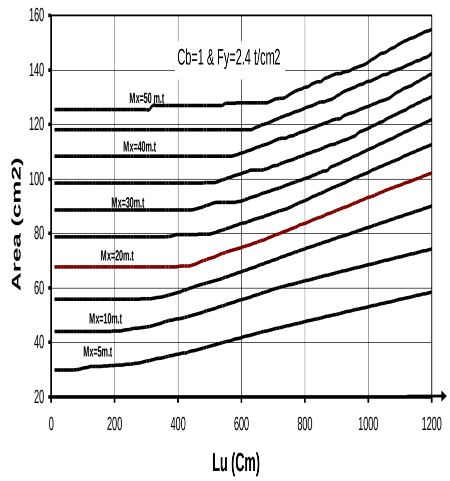

Fig.(2) Relation between Lu and Area for several bending moment values

L_{uo} (cm)

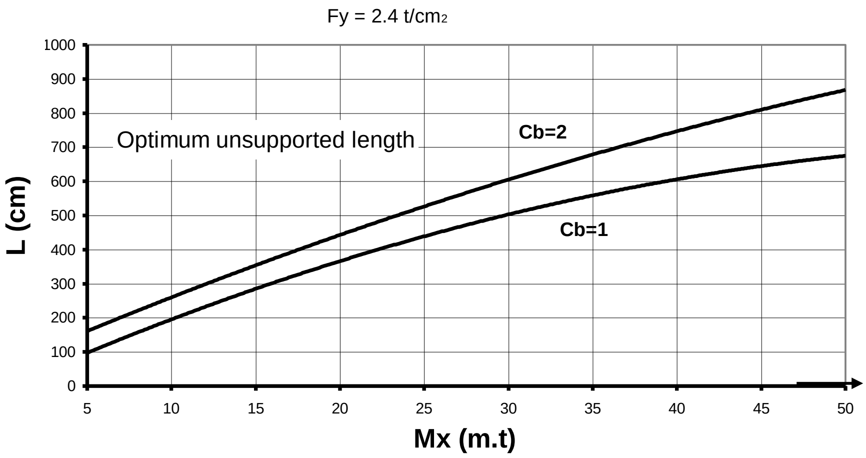

Fig.(3) Optimum distance between unsupported points

bf/tf

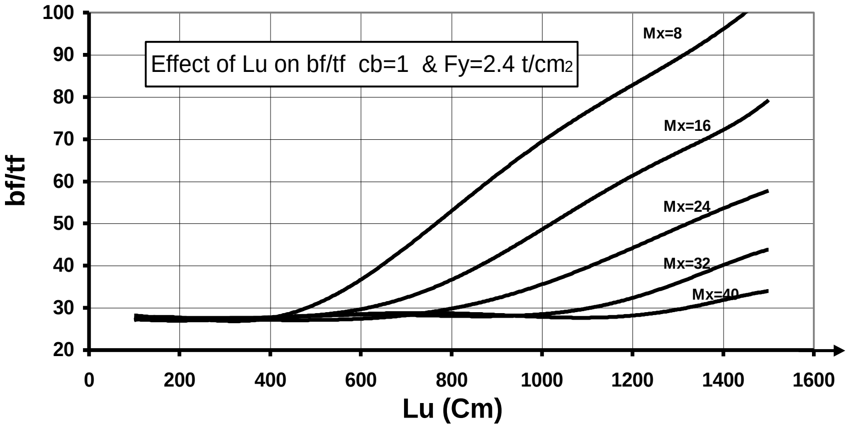

Fig.(4) Relation between Lu and ratio of bf/tf

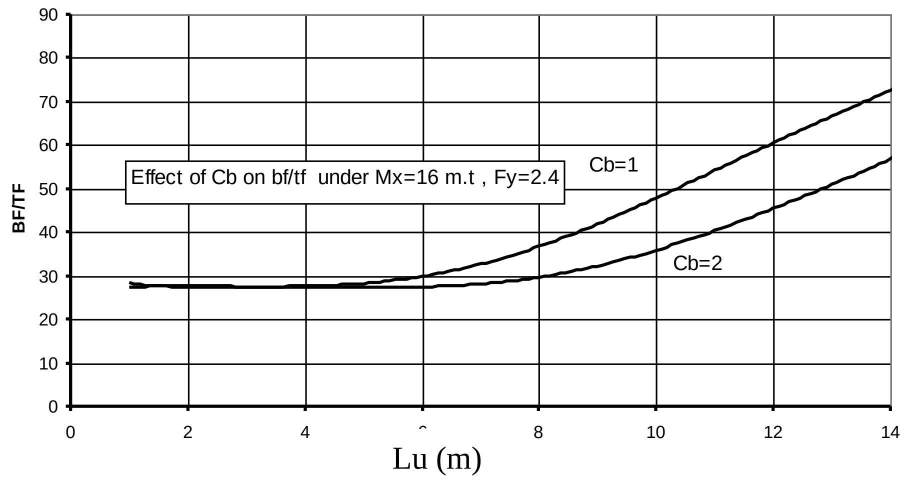

Fig.(5) Effect of Cb on ratio of bf/tf

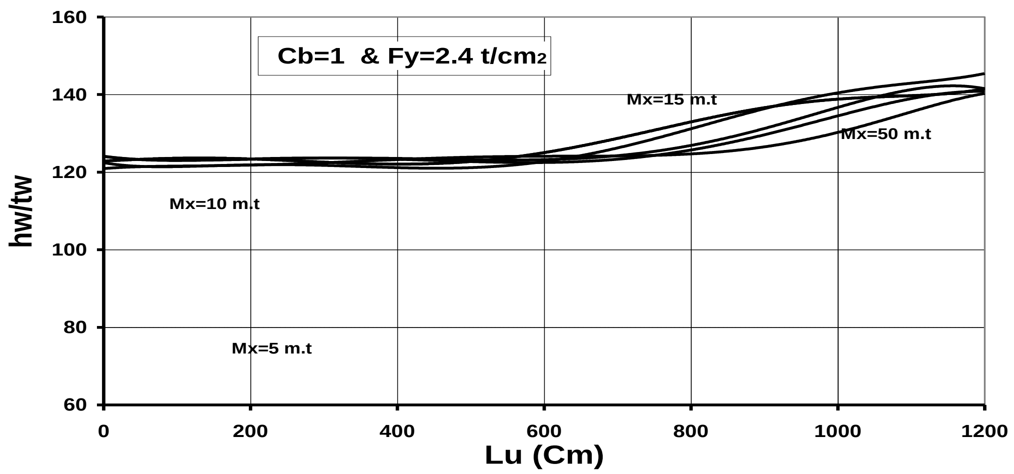

Fig.(6) Effect of Cb on ratio of hw/tw

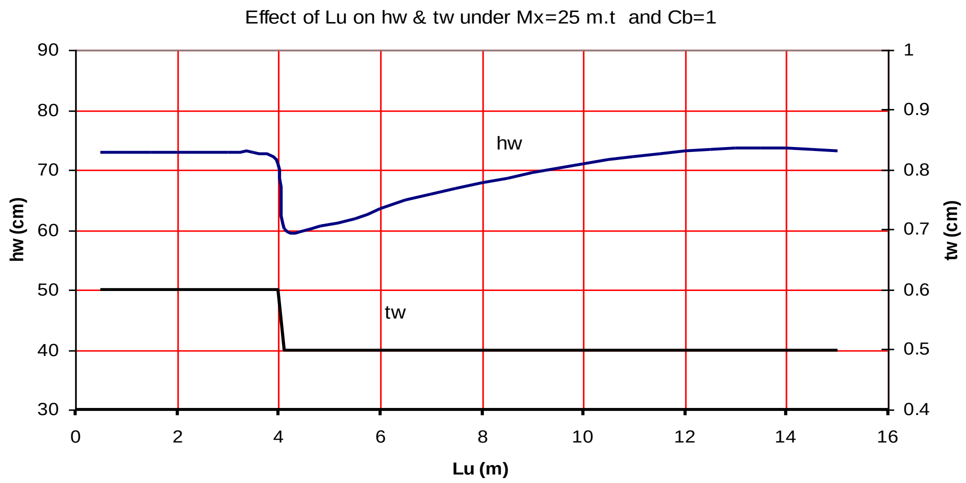

Fig.(7) Effect of Lu on hw & tw

Lu=200 cm & Cb=1

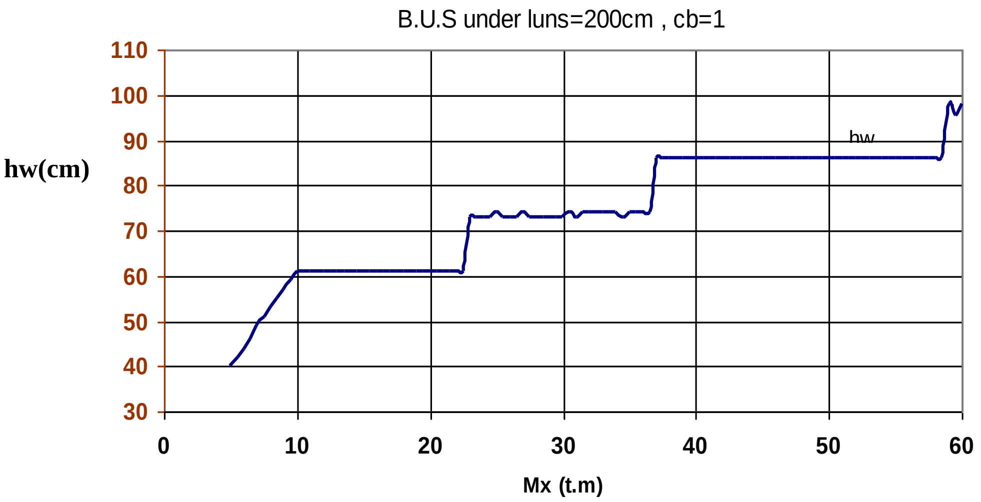

Fig.(8) Effect of Mx on hw

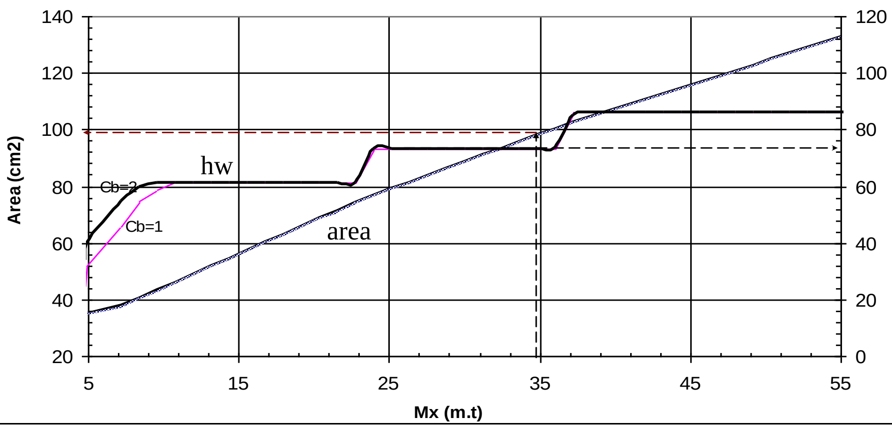

Fig.(9) Lu=200 cm

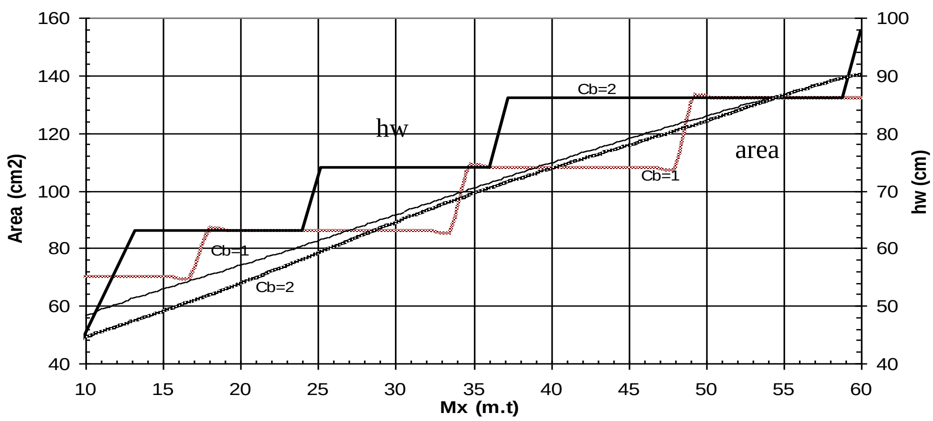

Fig.(10) Lu=400 cm

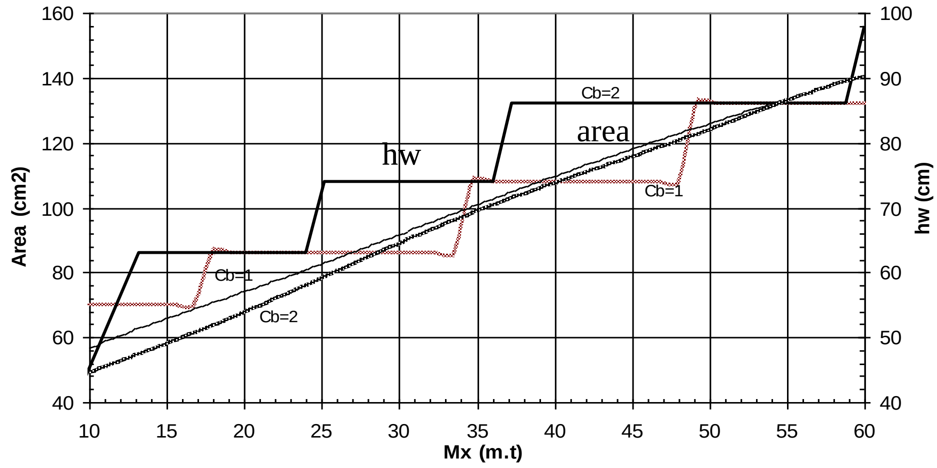

Fig.(11) Lu=600 cm

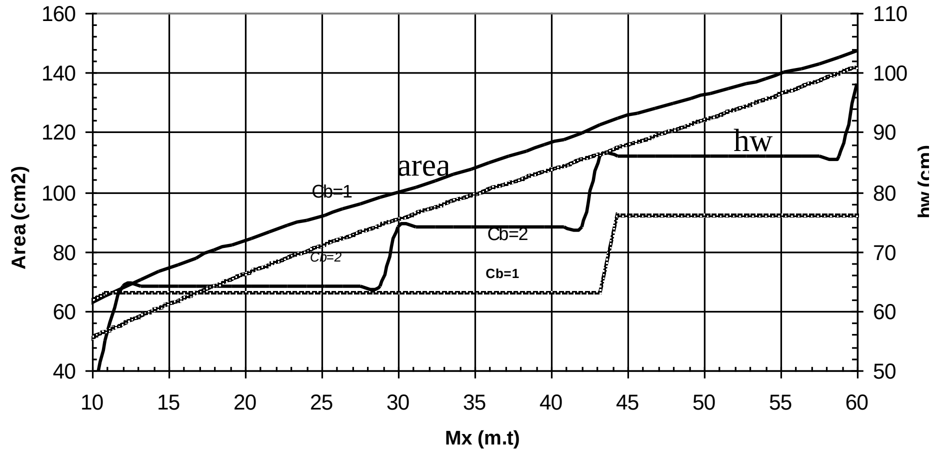

Fig.(12) Lu=800 cm