DESIGN CRITERIA FOR MINIMUM WEIGHT OF SIMPLY SUPPORTED PLATE GIRDERS IN FLEXURE

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ABSTRACT
This studies concerned with the optimum weight design of steel plate girders which have been used in long spans and heavy loads constructions. AISC-1989 Specification was used for design calculations. A computer program was prepared to achieve the optimum design. Flexure and deflection were considered. The correlation between the clear depth (h) and the weight per unit length of the girder were established for different loads, spans, steel grades, minimum theoretical web thickness, and minimum practical web thickness. It was found that the optimum weight is obtained when the flange width is nearly equal to the clear distance (h) between the flanges. Also it was found that small difference in optimum weight is obtained when using the minimum theoretical web thickness and the minimum practical web thickness. It is also found that the steel grade variation results in minor effects on the optimum weight.

الخلاصة

تتضمن الدراسة التصميم الأمثل لأقل وزن للروافد اللوحية الفولاذية المستعملة في المنشأت بفضاءات كبيرة واحمال عالية، اعتمدت المواصفات AISC-1989 في حسابات التصميم الأمثل لأقل وزن. وقد أخذ بالاعتبار كل من الانحناء والهطول، وقد تم رسم العلاقات بين العمق الصافي(h) و وزن الرافده لوحدة الطول ولعـدة أحمال وفضاءات وأنواع فولاذ وأصغر سمك نظري للوترة (web) وأصغر سمك عملي للوترة. لقد وجد بأن الوزن الأمثل قد تحقق عندما كان عرض الشفة (flange) تقريباً مساوياً للعمق الصافي (h). وأيضاً وجد بأن الفرق في الوزن الأمثل طفيف عند المقارنة بين استخدام القيمة النظرية والقيمة العملية لسمك الوترة .كـذلك وجد بأن الفرق في الوزن الأمثل طفيف عند أستخدام فولاذ باجهاد خضوع مختلف.

KEY WORDS
Steel plate girder, Flexural design, Optimum.

INTRODUCTION

The steel plate girder **Figs. (1) and (2)** is used in long spans and heavy load construction, because it is considered as the most economical type of construction. The steel plate girder is usually composed of three plates connected together by welds or by fasteners. But now, the most practical method of construction of plate girders is by using welds as shown in **Fig. (2).**

The design of component dimensions of plate girders depends on many factors; such as the bending moment, the shear force at critical sections, the width / thickness ratio of compression flange and web, grade of steel and the lateral support spacing on the compression flange.
In this study, a computer program was prepared to achieve the optimum design calculations by using "the method of Hooke and Jeeves"(Bunday B.D., 1984) as an optimization technique. The design of the plate girder has been performed according to AISC-Specifications 1989.

DESIGNING METHOD OF CALCULATIONS

In plate girders for flexure according to AISC-Specifications 1998, the allowable compressive flexural stress is determined from the following equations :-

When $\frac{\ell_b}{r_T} \leq \sqrt{\frac{102000 \quad Cb}{F_y}}$

$F_b = 0.6\ F_y$

When $\sqrt{\frac{102000 \quad Cb}{F_y}} < \frac{\ell_b}{r_T} \leq \sqrt{\frac{510000 \quad Cb}{F_y}}$

$$F_b = F_y\left[\frac{2}{3} - \frac{(\ell_b / r_T)^2 F_y}{1530 \times 10^3 Cb}\right] \leq 0.6\ F_y \qquad (1)$$

When $\frac{\ell_b}{r_T} \geq \sqrt{\frac{510000 Cb}{F_y}}$

$$F_b = \frac{170000\ Cb}{(\ell_b / r_T)^2} \leq 0.6\ F_y \qquad (2)$$

where

- A_f Area of compression flange.
- C_b Bending coefficient dependent upon moment gradient (=1).
- d Depth of the plate girder.
- F_b Allowable bending stress.
- F_y Specified minimum yield stress of steel .
- ℓ_b Actual unbraced length in plane of bending.
- r_T Radius of gyration of a section comprising the compression flange plus 1/3 of the compression web area, taken about an axis in the plane of the web.

Since the compression flange is solid, rectangular within area not less than the area of the tension flange, the following equation should also be used in addition to eqs. (1) or (2) as applicable :-

$$F_b = \frac{12000 Cb}{\ell_b d / A_f} \leq 0.6\ F_y \qquad (3)$$

The allowable bending stress in compression is the larger value calculated from eqs.(1) and (3), or from eqs.(2) and (3) as applicable.

WIDTH/ THICKNESS RATIO (B/T RATIO)

In using eqs.(1),(2) and (3), b/t ratio of the compression flange and the web should be limited as follows:

$$\frac{b_f}{2t_f} \leq \frac{95}{\sqrt{F_y / k_c}}$$

where $k_c = 1$ when $\frac{h}{t_w} \leq 70$

$$k_c = \frac{4.05}{(\frac{h}{t_w})^{0.46}} \quad \text{when } \frac{h}{t_w} > 70$$

$$\frac{d}{t_w} \leq \frac{14000}{\sqrt{F_y(16.5 + F_y)}}$$

when $F_y = 36$ ksi, $\frac{d}{tw} \leq 322$

when F_y=50 ksi, $\frac{d}{tw} \leq 242.8$

The value of C_b is taken 1.0, since the girders studied, are simply supported and braced laterally at the ends only.

The minimum thickness of the web is taken as:

$t_w = \frac{d}{322}$ when F_y= 36 ksi , and

$t_w = \frac{d}{242.8}$ when F_y= 50 ksi.

Since values of (t_w) determined from the above criteria are too small for practical purposes, the value of (t_w) is also taken $\frac{1}{8}$ in .(3.2mm) and the results are compared with that when (t_w) is minimum.

DISCUSSION OF RESULTS

Several numerical case studies have been considered, these case studies include different span lengths of the girder and different uniform loads applied to the girders. For a specific span length loaded by a specific uniform load, the optimum clear distance between flanges is obtained based on several trail solutions and using the procedure discussed above. Accordingly, the optimum weight is obtained using a persumed minimum thickness or a calculated one. Results of these numerical examples are assembled, plotted and shown in **Figs. (3) & (4)** for the cases of assumed minimum practical web thickness (Fy =36 ksi & 50 ksi respectively) and in **Figs (5) & (6)** for the cases of calculated minimum web thicknesses.

Examining these plots, one can notice that the minimum flange thickness is always obtained on the bases of the limitation given by:

$$\frac{b_f}{2t_f} = \frac{95}{\sqrt{F_y / k_c}}$$

It is also seen that for an optimum design, the flange width (b_f) nearly equals to the clear depth between the flanges (h).

CONCLUSIONS

The major conclusions obtained from the study can be summerized as follows:

1- An increase in the clear depth between the flanges results in a minor increase of the minimum weight of the plate girder.

2- The minimum weight of a plate girder is found to be function of the bending moment and the span length of the girder.

3- Steel grade has minor effect on the optimum weight of a plate girder.

4- It is preferable to use minimum web thickness of 1/8" rather than calculated minimum values, such a choice results in little increase of the optimum girder weight.
5- At an optimum weight of a girder, the flange width (b_f) is nearly equal to the clear depth between the flanges (h).

RECOMMENDATIONS

For optimum design of the plate girders, the following notes are recommended :

1- The clear depth between the flanges (h) is nearly equal to the flanges width (b_f).
2- The web thickness (t_w) at least $\frac{1}{8}$ in. (3.2 mm).
3- The flange thickness (t_f) is the minimum value as limited by b/t ratio.

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NOMENCLATURE

A_f Area of compression flange.
B_f Flange width of the plate girder.
C_b Bending coefficient dependent upon moment gradient (=1).
d Depth of the plate girder.
F_b Allowable bending stress.
F_y Specified minimum yield stress of steel .
h Clear distance between the upper and the lower flanges.
L Span length .
ℓ_b Actual unbraced length in plane of bending.
r_T Radius of gyration of a section comprising the compression flange plus 1/3 of the compression web area, taken about an axis in the plane of the web.
t_f Flange thickness.
t_w Web thickness.
WT Weight of the plate girder per unit length (kg/m) .

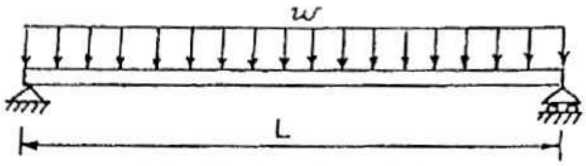

Fig. (1) The plate girder

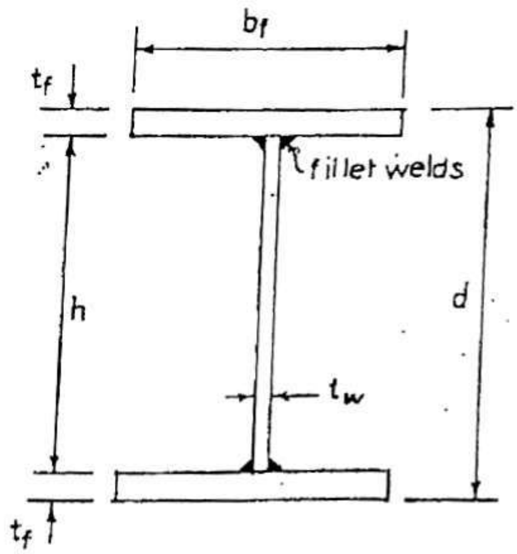

Fig. (2) The cross section of the girder

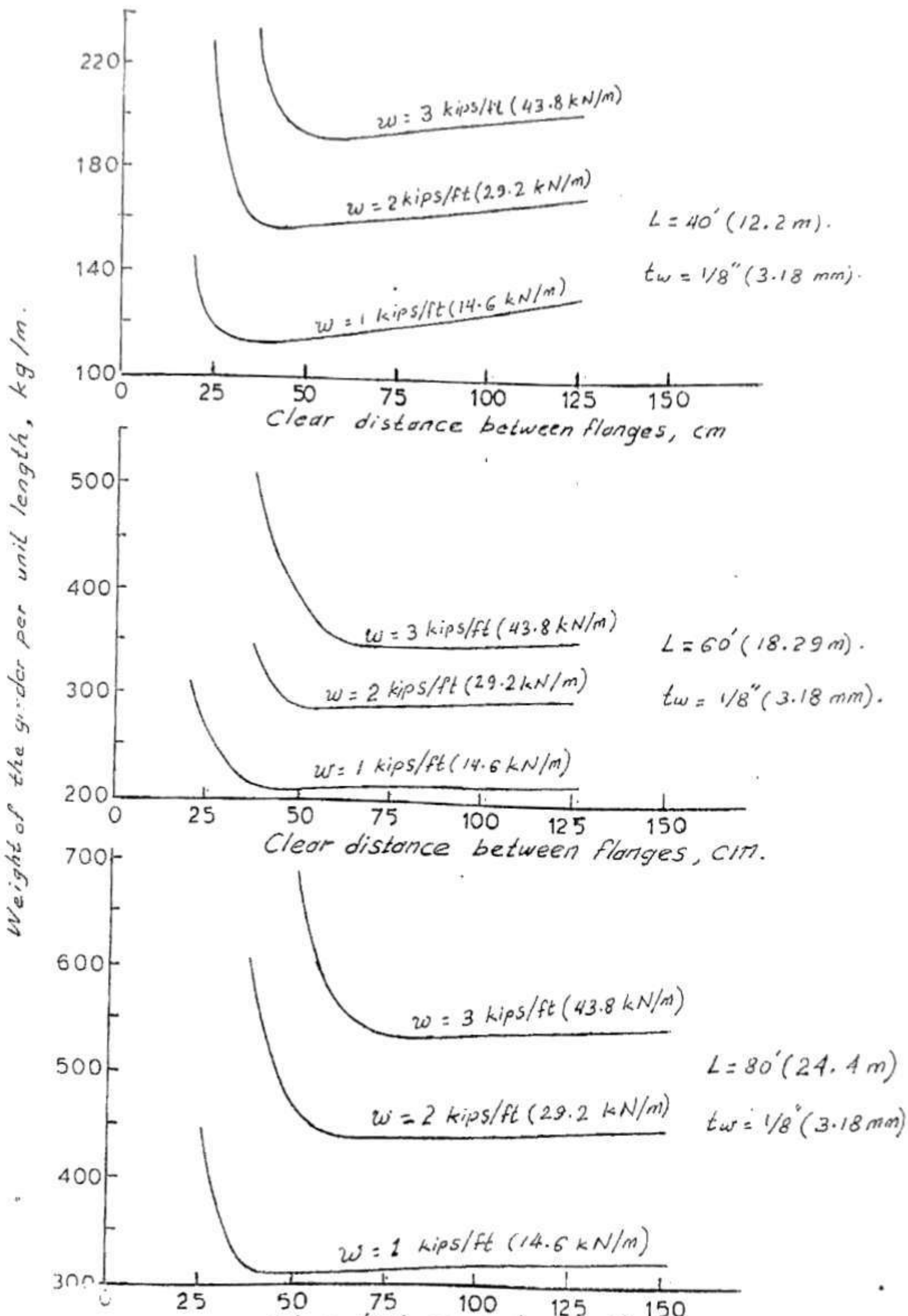

Fig. (3) The relation between clear distance between the flanges and the weight of the girder per unit length for fy= 36 ksi (248 MPa)

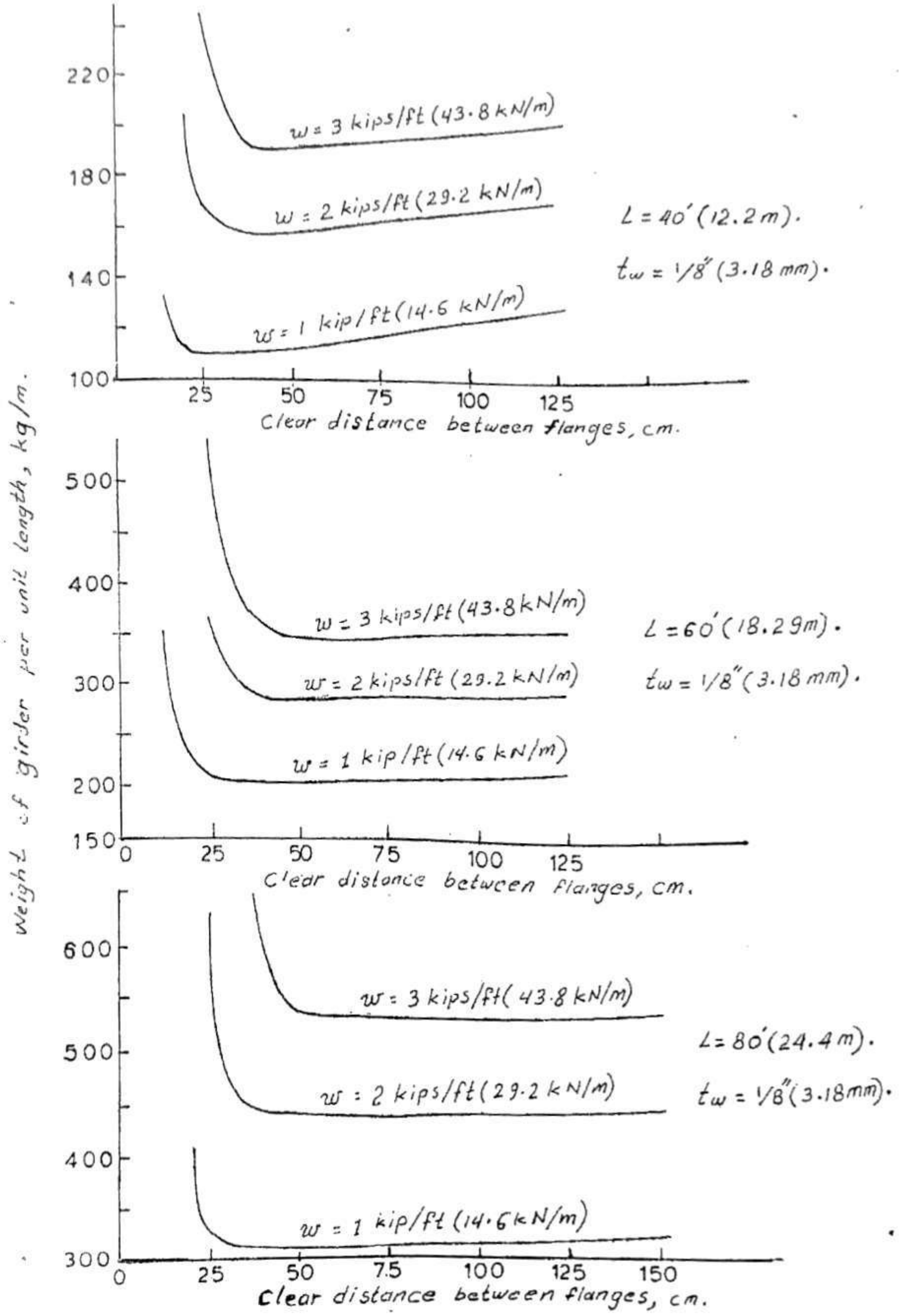

Fig. (4) The reiation between clear distance between the flanges and the weight of the girder per unit length for Fy = 50 ksi(345 MPa).

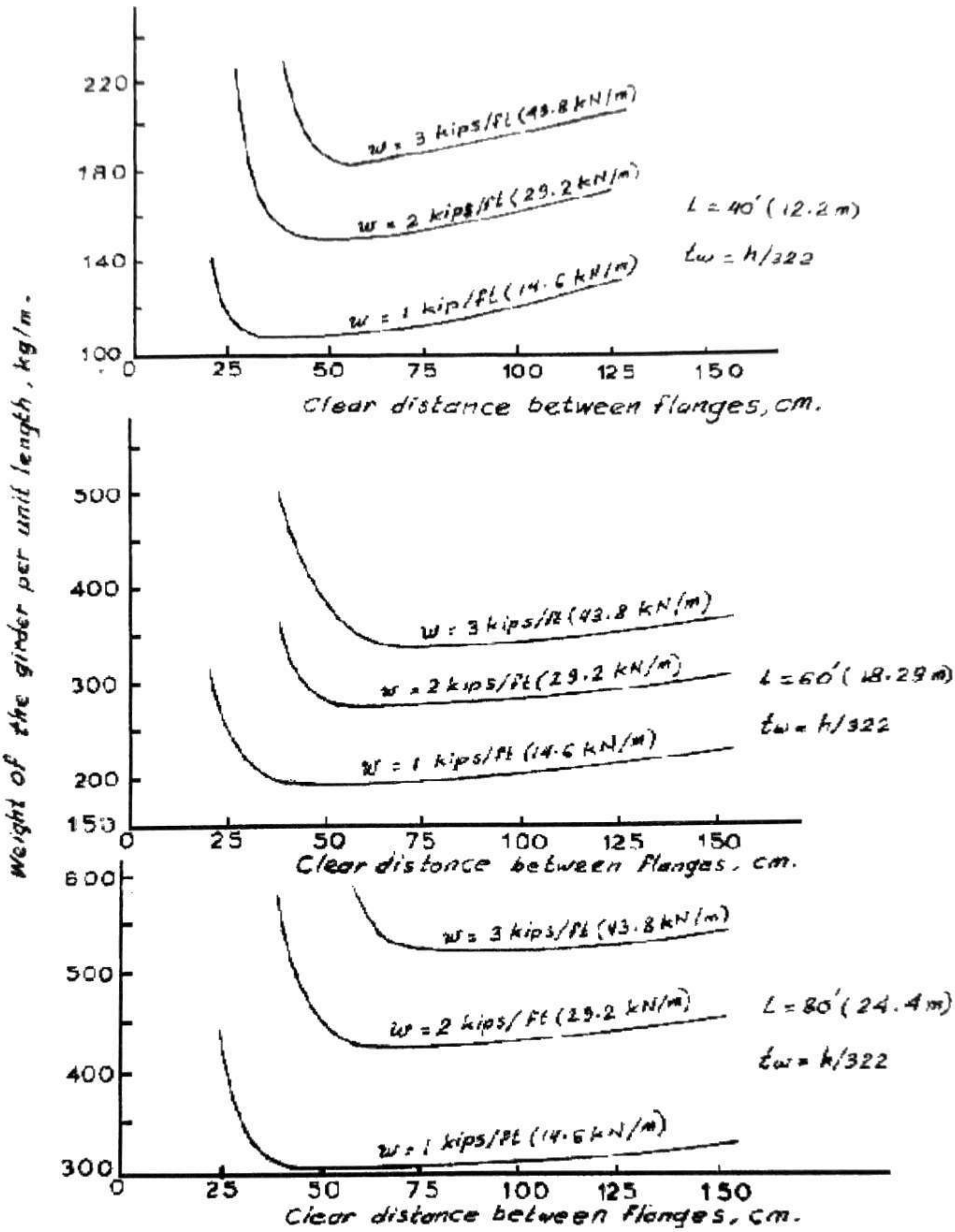

Fig. (5) The reiation between clear distance between the flanges and the weight of the girder per unit length for Fy = 36ksi(248 MPa).

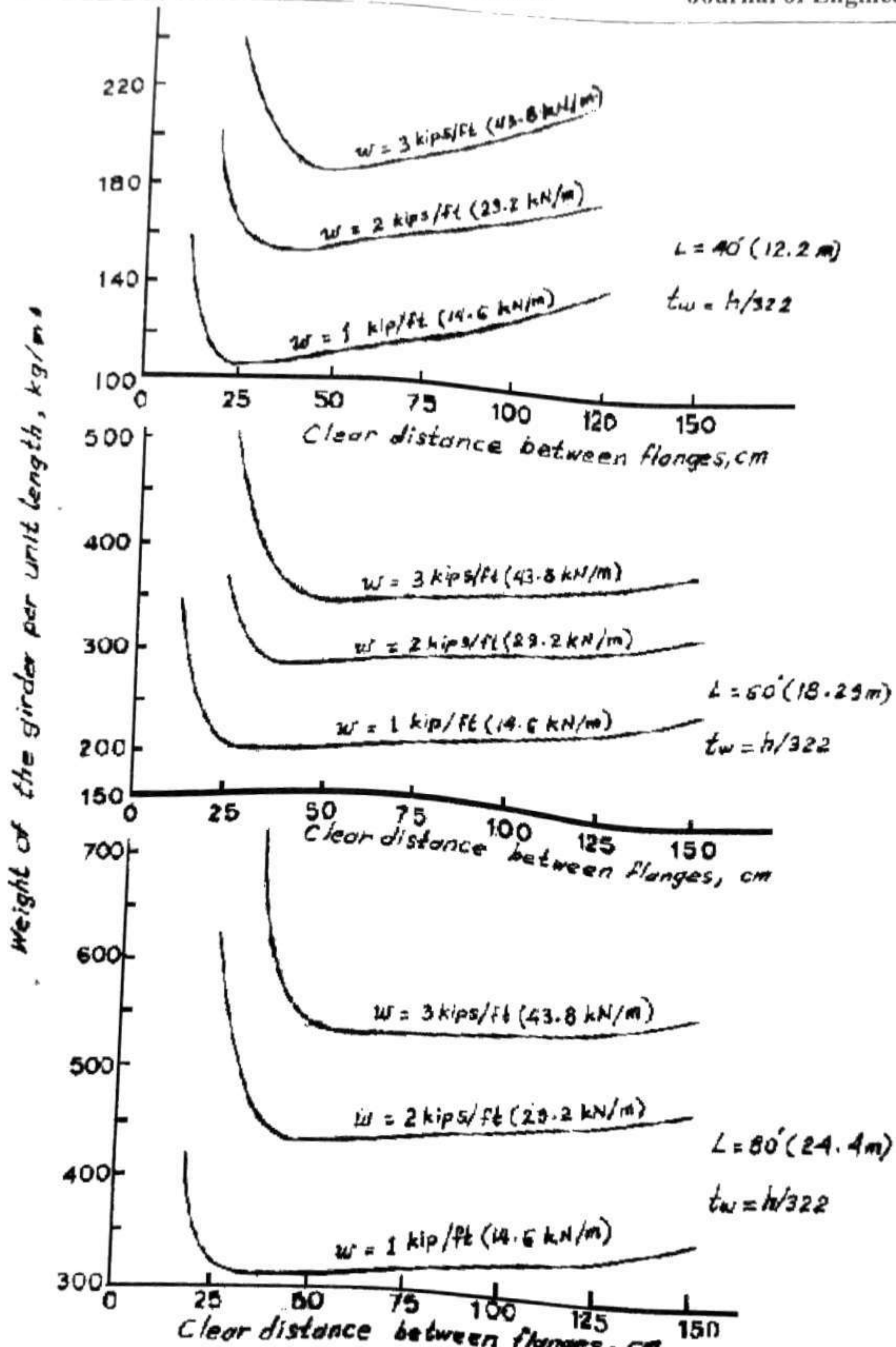

Fig. (6) The reiation between clear distance between the flanges and the weight of the girder per unit length for Fy = 50ksi(345 MPa).