International Institute of Welding — Institut International de la Soudure

HUNGARIAN DELEGATION — DÉLÉGATION HONGROISE

FABRICATION COST CALCULATIONS OF WELDED STRUCTURAL PARTS

by

József FARKAS

and

Károly JÁRMAI

University of Miskolc

Hungary

IIW-Doc.XV-823-93

46th IIW Annual Assembly

Glasgow, Scotland

1993

FABRICATION COST CALCULATIONS OF WELDED STRUCTURAL PARTS

Abstract

In order to minimize the cost of welded structures, optimization studies should be performed, which need mathematical formulation of the cost function. In the first author's previous structural optimization studies the approximate formulae of the Pahl-Beelich method have been used. In the present study these formulae are compared to numerical results of other authors and, on this basis, some corrections are proposed to obtain more suitable numerical results. The fabrication times are divided into three parts as follows: 1/ preparation, assembly and tacking, 2/ welding, 3/ electrode changing, deslagging and chipping. The cost of electrode and painting is treated separately. Some numerical examples illustrate the proposed calculation method.

1. Introduction

Calculations have shown that the fabrication costs play an important role in welded structures. For instance, in welded stiffened or cellular plates, the fabrication costs take about 60% of the total (material and fabrication) cost. To minimize the costs the optimum design methods should be used. In the optimum design procedure the cost function is minimized considering the design constraints. In this procedure a mathematical formulation is needed for the cost function and for the design constraints. The design constraints relate to the strength, stability, stiffness, vibration, damping, fabrication requirements and can be formulated on the basis of structural analysis.

The mathematical formulation of cost functions is more difficult because of the complexity of fabrication procedures and because of the lack of realistic cost data.

In the industry is common to use the cost/tonne concept (Firkins 1990), but it is not suitable for optimization. If we use a cost/tonne cost factor for fabrication cost, then the material and fabrication costs will give similar, non-conflicting functions which do not lead to an optimum. For an optimum we need conflicting functions, thus, we should use a more suitable fabrication cost calculation method based on a more detailed cost analysis.

The first author has used in some studies (Farkas 1988, 1991, 1992a-b) the cost formulae proposed by Pahl and Beelich (1982) based on industrial data. The aim of the present study is to revise these formulae and data in the light of other publications. The study of selected literature has shown that, in this context, the Aichele's book (1985) and the paper of Ott and Hubka (1985) may be considered.

2. A brief survey of selected literature

Some publications in this field have been earlier mentioned by the first author (Farkas 1992b). Relative cost factors for different welded joints have been given by Donnelly (1968). Likhtarnikov (1968) has analyzed the fabrication times and costs for various building structures. Czesany (1972) has studied and compared the costs of various welds welded by different technologies. In the Peurifoy's book (1975) cost data can be found for welded joints. Volkov (1978) has given formulae and factors for fabrication time calculations of roof trusses, columns and crane runway girders of industrial buildings. Yeo (1983) published a formula and factors for the calculation of welding costs. Winkle and Baird (1986) have investigated the fabrication cost of stiffened plates used in ship structures.

3. Calculation of fabrication costs

The total cost of a structure can be calculated as

$$K = K_m + K_f + K_{add} \tag{1}$$

where K_m is the material cost, K_f is the fabrication cost and K_{add} are additional costs of non-destructive testing, repair, painting, corrosion protection, transportation, erection,maintening, etc.

Considering only K_m and K_f, (1) can be written in the form

$$\frac{K}{k_m} = \rho V + \frac{k_f}{k_m} \sum_i T_i \tag{2}$$

where k_m and k_f are the material and fabrication cost factors, respectively, ρ is the material density, V is the volume of the structure and T_i are the times necessary for fabrication. T_i can be divided in three parts treated as follows.

3.1 Cost of preparation, assembly and tacking

For a plated structure consisting of $\varkappa$ elements the time for this part of fabrication is proportional to the perimeter, for the ith element it is

$$T_i = c_1 P_i$$

The mass of an element is proportional to the square of the perimeter

$$G_i = c_2 P_i^2$$

thus $\quad P_i = c_3 \sqrt{G_i} \quad$ and $\quad T_i = c_4 \sqrt{G_i}$

For the total structure, in average, it is $G = \varkappa G_i$ and

$$T_1 = \varkappa T_i = c_5 \varkappa \sqrt{\frac{G}{\varkappa}} = c_6 \sqrt{G \varkappa}$$

This formula has been derived in Likhtarnikov's book (1968) and applied by Pahl and Beelich (1982) in the form

$$T_1 = C_1 \delta \sqrt{G \varkappa} \quad ; \; C_1 = 1.0 \text{ min/kg}^{0.5} \tag{3}$$

δ is a difficulty factor, proposed values for it are given in Table 1.

Table 1. Proposed values for the difficulty factor δ. For skewed angle joints add 1-2 points

		V-weld 60°	Fillet weld 90°
planar structure	long welds flat position	1.0	2.0
spatial structure	short welds plates, flat steel	1.5	2.5
	U-, L-profiles tubes	2.0	3.0
	I-, T-profiles	2.5	4.0

3.2 Cost of welding

Pahl and Beelich have proposed the following calculation

$$T_2 = \sum C_{2i}\, a_{wi}^{1.5}\, L_{wi} \qquad (4)$$

with constants

$$C_2 = 0.8\text{x}10^{-3}\ \text{min}/(\text{mm}^{1.5}\text{xmm}) \qquad (4a)$$

for manual-arc welding

$$C_2 = 0.5\text{x}10^{-3}\ \text{min}/(\text{mm}^{1.5}\text{xmm}) \qquad (4b)$$

for MAG (CO_2) welding

where a_w is the weld size, L_w is the weld length. According to the data given by Aichele (1985, p.309) the exponent $a_w^{1.4}$ would be better instead of $a_w^{1.5}$, but the differencies between the calculated values of T_2 are small, so it is proposed to use $a_w^{1.5}$ in further calculations. Note that, based on Aichele's data, for T_2 times, multiplying factors of 1.5 and 1.8 can be proposed for vertical and overhead welding positions, respectively.

3.3 Changes of electrode, deslagging and chipping

According to Pahl and Beelich

$$T_3 = C_3 \sqrt{\delta}\, a_w^{1.5} L_w \; ; \quad C_3 = 1.2\text{x}10^{-3} \text{ min}/(\text{mm}^{1.5}\text{xmm}) \qquad (5)$$

Ott and Hubka (1985) proposed to use values of

$$C_3 = (0.2 - 0.4)\, C_2 \quad \text{in average} \quad C_3 = 0.3\, C_2 \qquad (6)$$

Comparing the data in Aichele's book (1985, pp.311-312) it can be taken

$$(C_2 + C_3)_{CO_2} = \frac{1}{2}(C_2 + C_3)_{\text{manual}} \qquad (7)$$

Based on (6) and (7) and eliminating $\sqrt{\delta}$ from (5), the revised formula for T_3 is

$$T_3 = \sum_i C_{3i}\, a_{wi}^{1.5} L_{wi} \qquad (8)$$

with the values

$$C_3 = 0.24\text{x}10^{-3} \text{ min}/(\text{mm}^{1.5}\text{xmm}) \qquad (8a)$$

for manual arc welding

$$C_3 = 0.12\text{x}10^{-3} \text{ min}/(\text{mm}^{1.5}\text{xmm}) \qquad (8b)$$

for CO_2 welding

and the times T_2 and T_3 can be added up as follows

$$T_2 + T_3 = \sum_i (C_{2i} + C_{3i})\, a_{wi}^{1.5} L_{wi} \qquad (9)$$

where $C_2 = 0.8\text{x}10^{-3} \text{ min}/(\text{mm}^{1.5}\text{xmm})$ for manual arc welding (9a)

$C_2 = 0.4\text{x}10^{-3} \text{ min}/(\text{mm}^{1.5}\text{xmm})$ for CO_2-welding (9b)

Thus, it can be concluded that the formulae (8) and (9) give more realistic values than (4 b) and (5).

3.4 Other cost components

The material cost of steel Fe 360 varies in a range of k_m = 0.5 - 1.2 \$/kg. The fabrication cost factor including overheads can be taken as k_f = 15 - 45 \$/manhour = 0.25 - 0.75 \$/min.

For the cost of electrode Pahl and Beelich proposed the following formula

$$K_e = k_e C_4 a_w^2 L_w \qquad (10)$$

where k_e is the electrode cost factor k_e = 10 DM/kg $\cong$ 6 \$/kg,

$$C_4 = 0.01 \times 10^{-3} \text{ kg/(mm}^2\text{xmm)} \text{ for manual arc welding} \qquad (10a)$$

$$C_4 = 0.008 \times 10^{-3} \text{ kg/(mm}^2\text{xmm)} \text{ for } CO_2\text{-welding} \qquad (10b)$$

It will be shown by numerical examples that the cost of electrode can be neglected comparing with material and fabrication costs.

The cost of surface preparation and painting, as it has been illustrated in a first author's paper (Farkas 1992b), significantly affects the optimal sizes of structures. In the mentioned study the painting cost factor k_p = 12 \$/m^2 has been considered according to literature sources (Hare 1990, Mensdorf 1991).

4. Numerical examples

The results obtained by the revised Pahl-Beelich formulae are compared to those calculated according to Aichele.

4.1 Butt-welded tube (Fig.1)

This example has been treated by Aichele (1985, p.170).
The density of steel is ρ = 7850 kg/m^3. The total mass is

$$G = \rho AL = \rho D \pi t L = 509 \text{ kg}$$

The difficulty factor is δ = 1, number of elements $\varkappa$ = 1.

$$T_1 = \sqrt{509} = 22 \text{ min.}$$

For manual arc welding

$$T_2 + T_3 = (C_2 + C_3)\, a_w^{1.5} L_w = (0.8+0.24)\times 10^{-3} \times 6^{1.5} \times 1850 = 28 \text{ min,}$$

$T_1 + T_2 + T_3$ = 50 min. According to Aichele $T_1+T_2+T_3$ = 33 min.

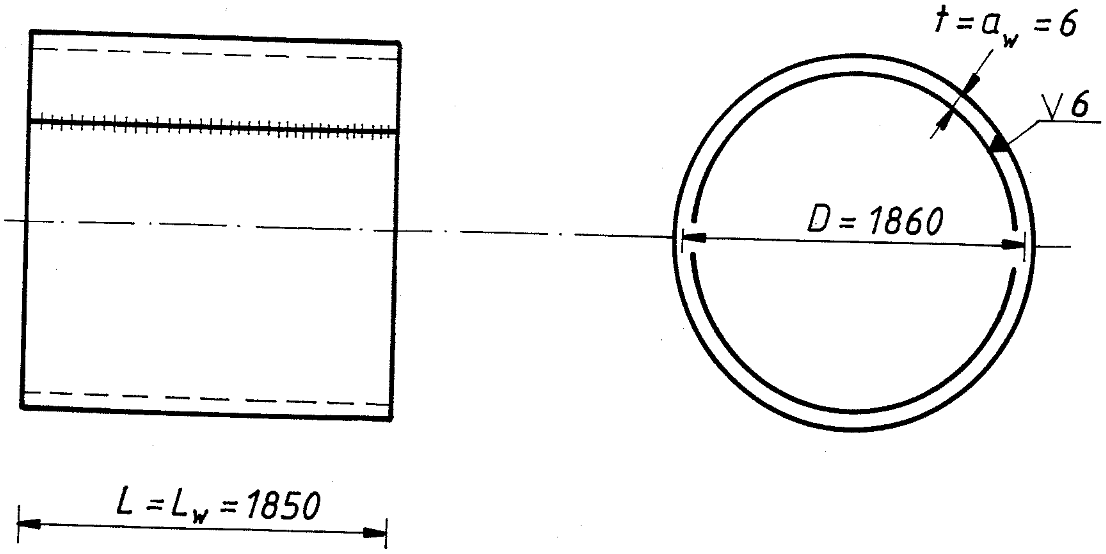

Fig. 1

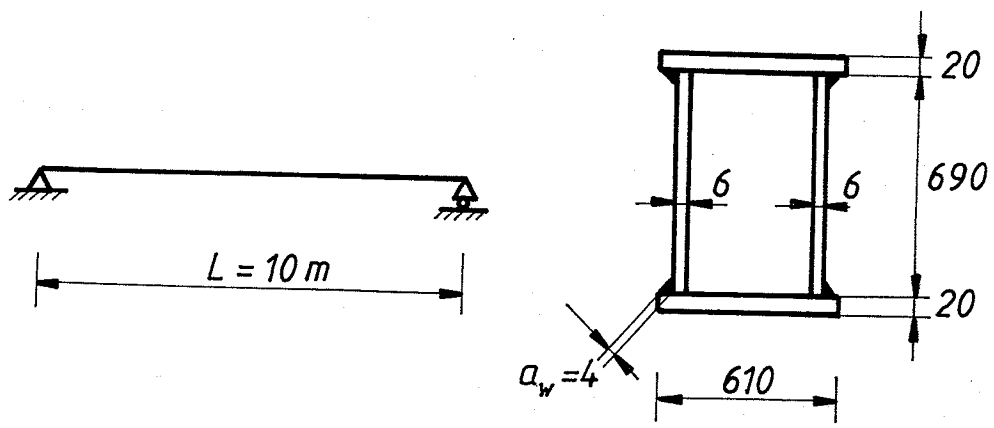

Fig. 2

The Aichele's value is smaller since it does not consider the relatively large mass.

The cost of electrode is

$$K_e = 6x0.01x10^{-3}x6^2x1850 = 4\ \$.$$

The total cost including the cost of electrode and taking $k_m = 1.0$ \$/kg and $k_f = 0.75$ \$/min is

$$K = k_m G + k_f(T_1+T_2+T_3) + K_e = 509 + 38 + 4 = 551\ \$.$$

It can be seen that K_e is small and can be neglected.

4.2 Welded box beam (Fig.2)

The cross-sectional area is $A = 32680\ mm^2$, $\rho = 7850\ kg/m^3$,

$$G = \rho AL = 2565\ kg.$$

With $\delta = 3$ and $\varkappa = 4$ $T_1 = 3\sqrt{2565}\sqrt{4} = 304$ min

For manual arc welding

$$T_2 + T_3 = (0.8 + 0.24)10^{-3}x4^{1.5}x4x10^4 = 333\ min,$$

$$T_1 + T_2 + T_3 = 634\ min.$$

According to Aichele (1985, p.309) $T_1+T_2+T_3 = 14x40 = 560$ min.

$K_e = 6x0.01x10^{-3}x4^2x4x10^4 = 38$ \$; with $k_m = 1.0$ \$/kg and $k_f = 0.75$ \$/min the total cost is

$$K = 2565 + 0.75x634 + 38 = 3079\ \$.$$

4.3 Welded cellular plate (Fig.3)

This plated structure consists of 4 cold-formed channels and 6 deck plates welded from outside to channels by fillet welds. The area of cross-section is

$$A = 2x4x1500 + 4x3x600 = 19200\ mm^2$$

$\rho = 7850\ kg/m^3$, the length of the plate is $L = 4$ m, the total mass is $G = \rho AL = 603$ kg.

$\delta = 3$, $\varkappa = 10$, $T_1 = 3\sqrt{6030} = 233$ min.

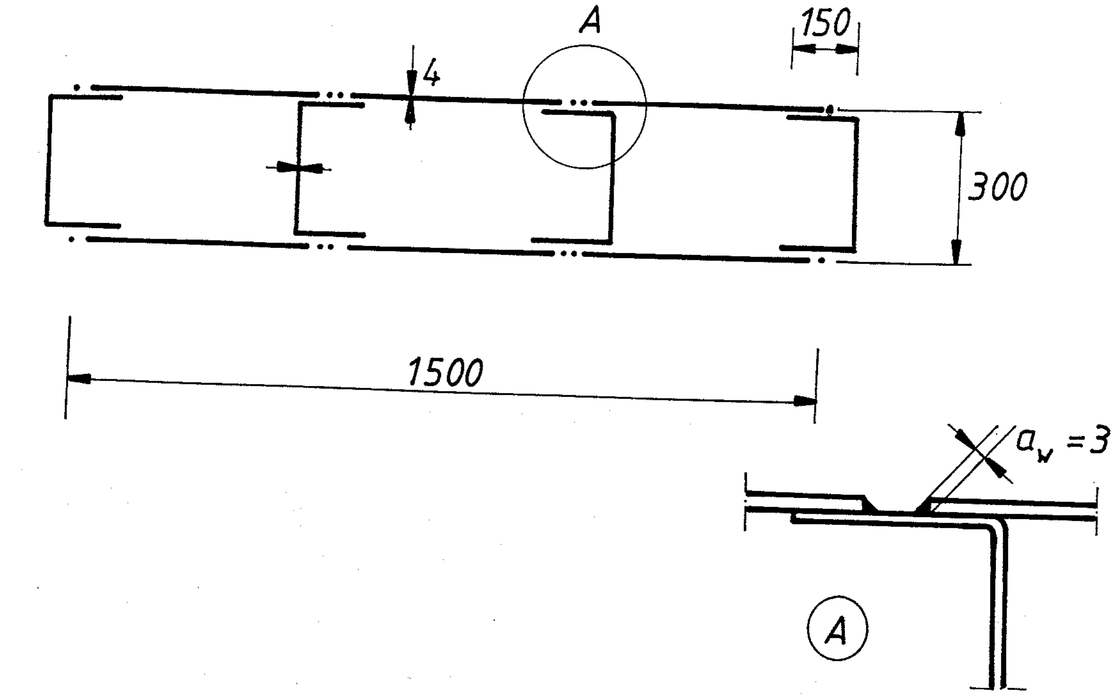

Fig. 3

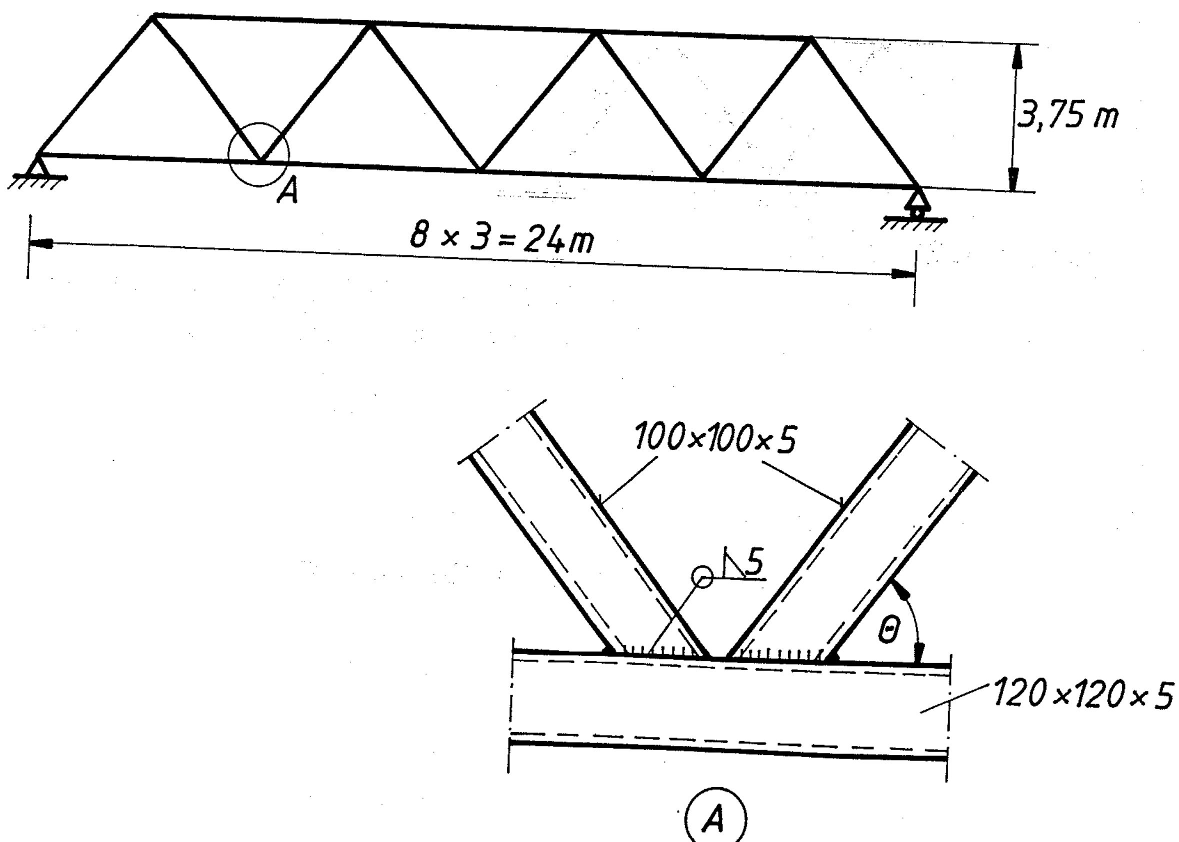

Fig. 4

For manual arc welding

$$T_2 + T_3 = (0.80 + 0.24)10^{-3}x3^{1.5}x48x10^3 = 260 \text{ min}$$

$$T_1 + T_2 + T_3 = 493 \text{ min.}$$

According to Aichele (1985, p.309) $T_1+T_2+T_3 = 11x48 = 528$ min.

$K_e = 6x0.01x10^{-3}x3^2x48x10^3 = 26$ $.

$k_m = 1.0$ $/kg, $k_f = 0.75$ $/min, K = 999 $.

4.4 Welded planar tubular truss (Fig.4)

The cross-sectional area of all chords $A_1 = 4x120x5 = 2400 \text{ mm}^2$ and that of all diagonals $A_2 = 4x100x5 = 2000 \text{ mm}^2$.

The total volume is

$$V = 42x10^3A_1 + 8x4.8x10^3A_2 = 1.776x10^8 \text{ mm}^3$$

$\rho = 7850 \text{ kg/m}^3$, $G = \rho V = 1394$ kg.

$\delta = 3$, $\varkappa = 10$; $T_1 = 3\sqrt{13940} = 354$ min.

The total weld length is $L_w = 16x2(100 + 128) = 7296$ mm.

For manual arc welding

$$T_2 + T_3 = (0.80+0.24)10^{-3}x5^{1.5}x7296 = 85 \text{ min,}$$

$$T_1 + T_2 + T_3 = 439 \text{ min.}$$

According to Aichele (1985, p.309) $T_1+T_2+T_3 = 19x7.296 = 139$ min, this does not contain the time necessary for preparation, assembly and tacking of a more complicated structure in which the mass is large comparing to the weld length.

$K_e = 6x0.01x10^{-3}x5^2x7296 = 11$ $.

With $k_m = 1.2$ $/kg and $k_f = 0.75$ $/min

$K = 1.2x1394 + 0.75x439 + 11 = 2013$ $.

5. Conclusions

The proposed cost calculation formulae are based on the Pahl-Beelich method with new coefficients corrected by comparisons with other methods. It is proposed to use formula (3) for T_1, formulae (8) and (9) for T_2 and T_3 respectively with constants C_2 and C_3 given by (8a-b) and (9a-b), resp., instead of (4b) and (5). Numerical examples verify the suitability of the proposed formulae. A greater difference is between T_1 values given by Aichele and Pahl-Beelich, because Aichele does not consider the effect of mass and number of structural elements.

A formula is given also for cost of electrode, but this cost can be in most cases neglected.

6. References

Aichele,G. (1985) Kalkulation und Wirtschaftlichkeit in der Schweisstechnik. (Costing and economy in welding.) Deutscher Verlag für Schweisstechnik, Düsseldorf.

Czesany,G. (1972) Kostenrechnung beim Schweissen. (Cost calculation for welding.) Essen, Vulkan-Verlag W.Classen.

Donnelly,J.A. (1968) Determining the cost of welded joints. AISC (American Institute of Steel Construction) Engineering Journal Vol.5. pp.146-147.

Farkas,J. (1988) Consideration of fabrication costs in the optimum design of welded tubular trusses. IIW-Doc.XV-677-88.

Farkas,J. (1991) Techno-economic considerations in the optimum design of welded structures. Welding in the World Vol.29. No.9-10.pp.295-300.

Farkas,J. (1992a) Cost comparisons of plates stiffened on one side and cellular plates. Welding in the World Vol.30. No.5-6. pp.132-137.

Farkas,J. (1992b) Minimum cost design of welded structures. In "Engineering Design in Welded Constructions. Proceedings International Conference Madrid, Spain. Pergamon Press, Oxford etc. 1992." pp.135-142.

Firkins,A., Hemphill,D. (1990) Fabrication cost of structural steelwork. Steel Construction (Australia) Vol.24.No.2. pp.2-14.

Hare,C.H. (1990) Painting of steel bridges and other structures. New York, Van Nostrand Reinhold.

Likhtarnikov,Ya.M. (1968) Metal structures (in Russian). Moskva, Stroyizdat.

Mensdorf,W. (1991) Kalkulation von Schweisskonstruktions-bauteilen. (Calculation of welded construction components.) Stahlbau Vol.60.No.9.pp.265-269.

Ott,H.H., Hubka,V. (1985) Vorausberechnung der Herstellkosten von Schweisskonstruktionen. (Fabrication cost calculation of welded structures.) Proceedings International Conference on Engineering Design ICED, Hamburg. Edition Heurista, Zürich, 1985. pp.478-487.

Pahl,G., Beelich,K.H. (1982) Kostenwachstumsgesetze nach Ähnlichkeitsbeziehungen für Schweissverbindungen. VDI-Bericht Nr.457. Düsseldorf.pp.129-141.

Peurifoy,R.L. (1975) Estimating construction costs. 3rd ed. Mc Graw Hill, New York, etc.

Volkov,V.V. (1978) Determining fabrication times for structural parts of industrial buildings (in Russian). Trudi TsNII Vol.23. Proektstalkonstruktsiya, Moskva. pp.34-45.

Winkle,I.E., Baird,D. (1986) Towards more effective structural design through synthesis and optimisation of relative fabrication costs. Transactions Royal Inst. Naval Archit. RINA No.128. pp.313-336.

Yeo,R.B.G. (1983) Cost effective steel fabrication. Part 2. Design for welding. Metal Construction Vol.15.No.3. pp.151-156, 158.