Analytical Estimation of Welding Time BHEL (Tiruchi)'s Experience

By R. VENKATESAN*

1.0 INTRODUCTION

1.1 Welding is the single major manufacturing operation at the High Pressure Boiler Plant Unit of Bharat Heavy Electricals Limited (Tiruchy Unit). Presently, 1,00,000 tonnes of components per year-(pressure parts and non-pressure parts for boilers and boiler house auxiliaries)—are being fabricated both at BHEL Works and sub-contractors' works. BHEL alone employs about 750 welders of whom nearly 200 are high pressure welders.

1.2 Planning and co-ordinating these welders' activities and associated welding equipment is a vital function and depends on the time estimation for carrying out various welding operations.

2.0 NEED FOR TIME STANDARDS

2.1 Standard times are one of industry's most important measurements and are commonly used for the following purposes :

(i) To plan, schedule and control the operations

(ii) To determine standard costs

(iii) To determine operative effectiveness

(iv) To set labour norms and provide the basis for setting-up incentive wages

(v) To balance the work of crews and to co-ordinate among different workers and machines

(vi) To form the basis for forecasting equipment and labour requirements

(vii) As the basis for comparison of different methods

2.2 It is thus clear that Work Measurement provides the basic information necessary for all activities of organising and controlling the work of an enterprise in which the time element plays a vital part.

3.0 STANDARD TIME

3.1 Definition

Standard Time for a welding operation is the amount of time that the qualified, properly trained and experienced welder should take to perform a specific welding operation under certain standard conditions when working at a normal pace.

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3.2 EXPLANATION

The welding operation to be studied is divided into small elements, each of which is timed with a stop watch. A selected or representative time value is found for each of these elements. The speed exhibited by the welder during the Time Study is rated or evaluated by the Time Study observer, and the selected time is adjusted by this rating factor so that a qualified welder, working at a normal pace can easily do the work in the specified time. This adjusted time is called the Normal Time. To this Normal Time are added allowances for personal time, fatigue, and delay, the result being the Standard Time for the task.

4.0 THE TECHNIQUES OF WORK MEASUREMENT

4.1 The following are the principal techniques by which Work Measurement is carried out :

(i) Time Study

(ii) Activity Sampling and its extension, rated Activity Sampling

(iii) Synthesis from Standard Data

(iv) Predetermined Motion Time Standards

(v) Estimating

(vi) Analytical Estimating

4.2 The choice of method to arrive at times for welding will be governed largely by the use to which those times will be put, and the means available to obtain them. This comes down to the accuracy required and the cost of obtaining this accuracy. It is neither economical nor sensible to have a Time Study section costing a few lakhs of rupees per annum to run, producing times for welding to the nearest hundredth of a minute, when all that is needed is a rough estimate for the organisation. Of the above techniques, we shall concern ourselves with the "Analytical Estimation" used for calculating standard time for welding operation.

4.3 In the early years of BHEL, extensive time studies were conducted which formed the basis for developing synthetic time Stds. Subsequently, based on the experience and confidence gained over years, we switched on to "Analytical Estimation" and as on date, almost all the time estimates are worked out using this technique.

5.0 ANALYTICAL CALCULATION :

5.1 In this method, arcing time, welding time, requirement of welding consumables etc. are computed based on the data from,

(i) Direct Time Studies and

(ii) Welding information like arc time, rate of deposition, current etc. normally available in electrode manufacturer's literatures and catalogues.

5.2 Analytically calculated times do not completely replace direct time studies. However, they have a number of advantages like,

(i) They reduce the number of studies that must be made,

(ii) They can be used for predicting (a) Costs, (b) Schedules and delivery periods while estimating, and (c) Quoting the Firm's offer,

(iii) Analytical calculations are economical to apply for obtaining time standards for a wider coverage of operation in the plant,

(iv) Whenever new sizes or new edge preparation etc. are being introduced, estimates could be made with accuracy and consistency without waiting for the job to be taken-up for production.

5.3 Analytical calculation of welding data, essentially involves first finding out general expression for the weight of weld metal deposited for a given edge preparation, configuration and other welding data, using previous time study results and secondly substituting the numerical values (size of the joint etc.) in the expression to get the required data. Expression for some of the standard edge preparations are given in Annexure—I.

5.4 Weight of Weld Metal Deposited :
The area of cross-section of the edge preparation when multiplied by the length would give the

volume for which the weld metal has to be deposited. To facilitate the calculation, the area of cross-section is divided into sections like rectangle, triangle or any other geometrical shape.

In case of pipe butt joints, circumferential length is the circumference passing through the centre of gravity of the section.

This volume when multiplied by the specific gravity of steel would give the weight of weld metal to be deposited to complete the joint.

From the weld metal weight, other welding details like arcing time, welding time, consumables required can be arrived at using the data obtained from time studies and welding data hand book.

Step by step calculation involved to find out the weight of weld metal to be deposited for a butt joint in pipe by manual arc welding is given below as an example (Refer Figure—1).

(i) The area of cross-section of the edge preparation is divided into layers depending on the size of electrode used.

(ii) Each layer is further divided into rectangles and/or triangles.

(iii) The volume for which weld metal is to be deposited in each section (rectangle or triangle) is found as

$$\text{Volume of the Section} = \left\{ \begin{array}{l} \text{area of the section X circumference passing through the} \\ \text{centre of gravity of that section.} \end{array} \right.$$

(iv) The volumes of all such sections in a layer are added to give the volume of metal to be deposited in that layer.

(v) The volume of weld metal to be deposited in a layer when multiplied by the specific gravity (7.85 gms/cc.) would give the weight of weld metal to be deposited in that layer.

(vi) The weight of weld metal to be deposited per joint is got by cumulating the weight for all the layers.

5.5 **Arcing Time** :

The Arcing Time per joint is the duration of time for which the arc is struck and sustained during the welding of the joint.

$$\text{Arcing time} = \frac{\text{Weight of weld metal deposited using a particular size of electrode}}{\text{Deposition rate of electrode}}$$

The Deposition Rate is the weight of weld metal deposited per unit time (i.e. gms/min.). It depends on the type of electrode, metal recovery percentage, size of electrode and the current used. It can be got from time study results or it is supplied by the electrode manufacturers themselves. Since the size of electrode used changes for each layer, the arcing time has to be found for each layer, and added to get the total arcing time per joint.

5.6 **Welding Time** :

The Welding Time can be found by multiplying the arcing time by a factor. This factor will depend on the type of joint and nature of work and can be obtained from the previous time studies on similar work. Also some welding data hand books provide this information.

5.7 **Consumables required**

$$\text{Number of Electrodes} = \frac{\text{Weight of weld metal deposited using a particular size of electrode}}{\text{Weight of metal yield per electrode}}$$

The weight of metal deposited by burning an electrode is not equal to the weight of core material of the electrode. The weight of metal deposited per electrode (i.e.) Metal Yield. depends on the metal recovery for the electrode and the length of the stub thrown away after welding.

6.0 APPLICATION

6.1 At BHEL, Tiruchy, we have compiled welding time standards using the above explained method in an ICL 1901A computer. Time standards were generated containing information like,

(i) Layerwise number of electrodes required

(ii) Layerwise weight of weld metal to be deposited

(iii) Layerwise arcing time and

(iv) Total welding time required for

(a) Tubes and pipes butt joints

(b) Set-on stubs and nipples

(c) Stub with backing ring

(d) full throat nozzles etc. having different sizes and styles of edge preparation.

6.2 Thus for a wide range of products with many variables, time standards were built in a more economical way in a very short time.

7.0 VALIDATION :

A number of shop studies were conducted to ascertain the validity of these standards at the shop floor. A few sample study results comparing the Analytical Estimated Value with actual values are given in Annexure—II.

8.0 CONCLUSION :

8.1 Among various work measurement techniques available "Analytical Estimating" is more economical with reasonable accuracy for computing welding time standards.

8.2 This analytical calculation at the best, can only supplement but, at any rate, cannot substitute time studies. The accuracy of the results obtained by this method largely depends on the norms got from time study.

9.0 ACKNOWLEDGEMENT :

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Reference :

(1) BHEL Time Standards for Manual Arc Welding.

(2) Reports of the Welding Studies conducted at the High Pressure Boiler Plant Unit of Bharat Heavy Electricals Ltd., Tiruchy.

(3) Welding Productivity and Economy by R. Venkatesan-Indian Welding Journal Vol.9 No.3 July 1977.

(4) Welding Hand Book—Published by Advani Oerlikon Limited.

(5) Welding Hand Book—Published by The American Welding Society.

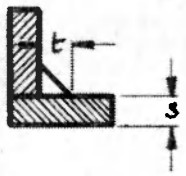
ANNEXURE—II

Comparison of Analytical Estimation with Actual Study Results

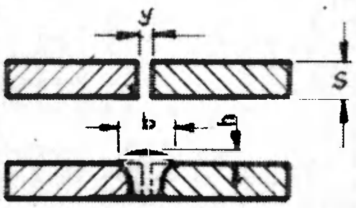
Joint details Sizes in mm.	Weight of weld Metal deposited —gm		Arcing time —minutes		Welding time—minutes (Exclusive of allowances)	
	Study	Standard	Study	Standard	Study	Standard
BUTT JOINTS—TUBES & PIPES :						
(A) Full Manual Arc Welding :						
(1) ϕ 44.5×4	43.2	44.1	5.2	5.1	11.9	11.8
(2) ϕ 88.9×6	119.2	130.0	10.8	11.8	22.5	26.0
(3) ϕ 133.0×11	441.5	408.7	28.2	30.0	61.0	63.0
(4) ϕ 219.0×24	1767.0	1686.0	67.9	64.8	159.0	149.0
(5) ϕ 323.9×35	3989.0	4042.0	192.2	194.1	406.4	376.8
(B) Root run by Manual Arc Welding and Balance Layers by Sub-merged Arc (Auto Welding) :						
(1) ϕ 273.0×36	2475.0	2366.0	19.3	17.0	34.0	40.0
(2) ϕ 323.9×32	2258.0	2373.0	29.6	32.0	54.9	57.0
(3) ϕ 323.9×45	4359.0	4200.0	32.8	31.0	70.3	68.0
SETON STUBS/NIPPLES :						
Header — Stub						
ϕ 219 — 31.8×5	57.0	53.2	3.2	2.8	7.0	6.5
ϕ 219 — 127.0×12.5	584.0	528.0	21.3	24.6	60.8	56.6

ANNEXURE I
SHEET 1 OF 4

Fillet Weld

Type of weld	Equation
	$F = \frac{t^2}{2}$ + reinforcement Reinforcement in flat position - - - 10% Reinforcement in horizontal position - - 15%

Square Butt weld without backing run

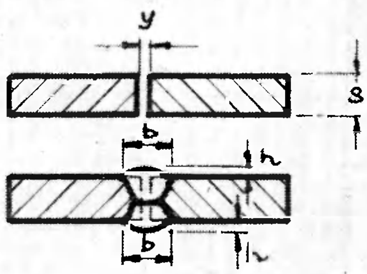


$F = (s \cdot y + \frac{2}{3} b \cdot h) \cdot k$

$k = 0,8$ (contraction - 20%)

s	y	b	h
1,5	0,75	7	1
2,0	1,0	8	1
3,0	1,5	9	1,5

Square Butt weld with backing run

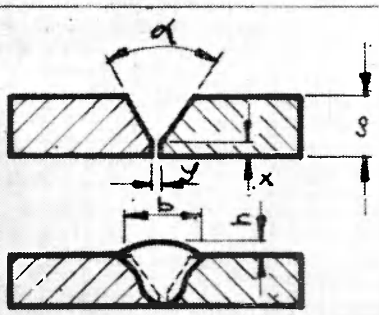


$F = (s \cdot y + \frac{4}{3} b \cdot h) \cdot k$

$k = 0,8$ (contraction - 20%)

s	y	b	h
2	1,0	8	1,0
3	1,5	9	1,5
4	2,0	10	1,5
5	2,5	10	1,5

60° - V - groove weld



$F = [s \cdot y + (s - x)^2 \cdot tg \frac{\alpha}{2} + \frac{2}{3} b \cdot h] \cdot k$

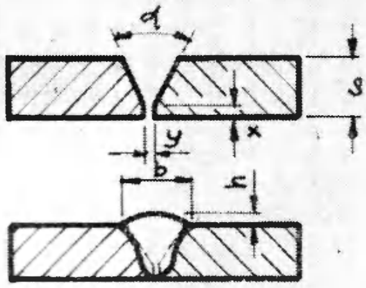
$b = y + 2 \cdot (s - x) \cdot tg \frac{\alpha}{2} + 4$

$k = 0,8$ (contraction - 20%)

s	y	x	h	α
4	2	1	1	60°
upto 10	2	1	1,5	60°
upto 20	2	1	2	60°

50° - V-groove weld

ANNEXURE I
SHEET 2 OF 4



$$F = \left[s \cdot y + (s - x)^2 \cdot tg\frac{\alpha}{2} + \frac{2}{3} b \cdot h \right] \cdot k$$

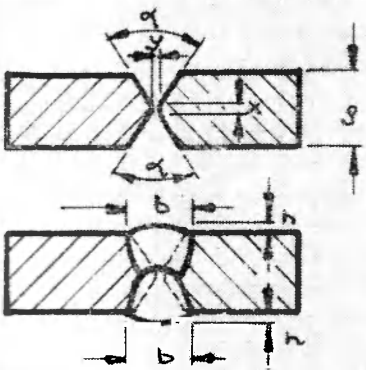
$$b = y + 2(s - x) \cdot tg\frac{\alpha}{2} + 4$$

$$tg\frac{\alpha}{2} = 0{,}46631$$

$k = 0{,}85$ (contraction - 15%)

s	y	x	h	α
4	1	1	1	50°
upto 10	1	1	1,5	50°
Upto 20	1	1	2	50°

Double V-groove weld



$$F = \left[s \cdot y + \frac{(s - x)^2 \cdot tg\frac{\alpha}{2}}{2} + \frac{4}{3} b \cdot h \right] \cdot k$$

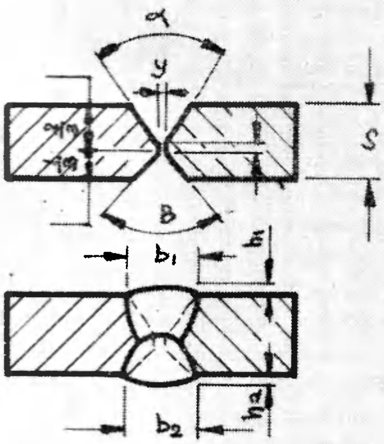
$$b = y + (s - x)\, tg\frac{\alpha}{2} + 4$$

$$tg\frac{\alpha}{2} = 0{,}57735$$

$k = 0{,}80$ (contraction - 20%)

s	y	x	h	α
8 - 30	2,5	1	1	60°
32 - 40	2,5	1	1,5	60°

Unequal Double V-groove weld



$$F = \frac{2}{3} s \cdot y + \left(\frac{2}{3} s - \frac{x}{2}\right)^2 \cdot tg\frac{\alpha}{2} + \frac{2}{3} h_1 \cdot h_1 + \frac{1}{3} s \cdot y + \left(\frac{1}{3} s - \frac{x}{2}\right)^2 \cdot tg\frac{\beta}{2} + \frac{2}{3} h_2 \cdot h_2 \cdot k$$

$$b_1 = y + 2\left(\frac{2}{3} s - \frac{x}{2}\right) \cdot tg\frac{\alpha}{2} + 4$$

$$b_2 = y + 2\left(\frac{1}{3} s - \frac{x}{2}\right) \cdot tg\frac{\beta}{2} + 4$$

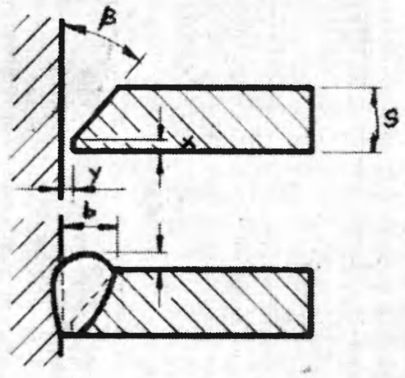
$$tg\frac{\alpha}{2} = 0{,}46631 \qquad tg\frac{\beta}{2} = 1$$

$k = 0{,}80$ (contraction - 20%)

s	y	x	h_1	h_2	α	β
8 - 20	2,5	1	1	1	50°	90°
22 - 40	2,5	1	1,5	1	50°	90°

½ V - groove weld

ANNEXURE I
SHEET 3 OF 4



$$V = \left[s \cdot y + \frac{(s - x)^2 \cdot tg\beta}{2} + b \cdot h \right] \cdot k$$

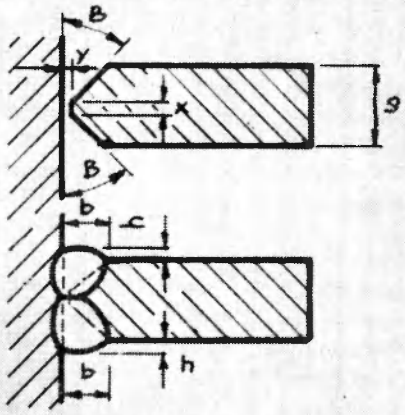
$$b = y + (s - x) \cdot tg\beta + 2$$

$$tg\beta = 1{,}192$$

$k = 0{,}80$ (contraction - 20%)

s	y	x	h	β
4	2,5	1	1	50°
10 - 15	2,5	1	1,5	50°

K - groove weld (Half double V- groove)



$$V = \left[s \cdot y + \frac{(s - x)^2 \cdot tg\beta}{4} + \frac{4}{3} b \cdot h \right] \cdot k$$

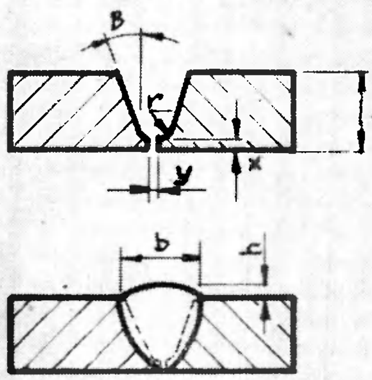
$$b = y + \frac{s - x}{2} \cdot tg\beta + 2$$

$$tg\beta = 1{,}192$$

$k = 0{,}80$ (contraction - 20%)

s	y	x	h	β
8	2,5	1	1	50°
20	2,5	1	1,5	50°
50	2,5	1	2	50°

V - groove weld



$$V = \left[s \cdot y + (s - x - r)^2 \cdot tg\beta + \frac{r^2}{2} + 2 \cdot r\,(s - x - r)) + \frac{2}{3} b \cdot h \right] \cdot k$$

$$b = y + 2 \cdot r + 2\,(s - x - r) \cdot tg\beta + 4$$

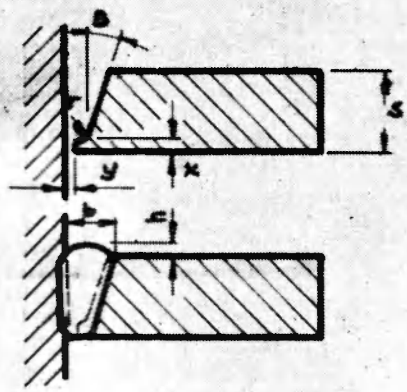
$$tg\beta = 0{,}19438$$

$k = 0{,}80$ (contraction - 20%)

s	y	x	r	h	β
20 - 40	2,75	2,5	5	2	11°

ANNEXURE I
SHEET 4 OF 4

½ V - groove weld



$$F = \left[s \cdot y + \frac{r^2}{4} + r\,(s - x - r) + \frac{(s - x - r)^2 \cdot tgB}{2} + \frac{2}{3}\, b \cdot h \right] k$$

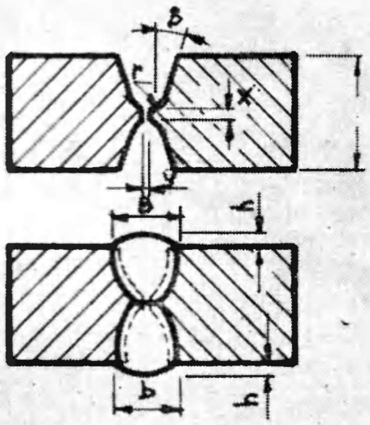
$$b = y + r + (s - r - x)\, tgB + 2$$

$$tgB = 0{,}32492$$

$$k = 0{,}80 \text{ (contraction - 20 \%)}$$

s	y	x	r	h	B
15 - 40	1,5	1,5	10	2	18°

Double V - groove weld



$$F = \left[s \cdot y + 2 \cdot r\,(s - 2 \cdot r - x) + \pi r^2 + (s - 2 \cdot r - x) \cdot tgB + \frac{2}{3}\, b \cdot h \right] k$$

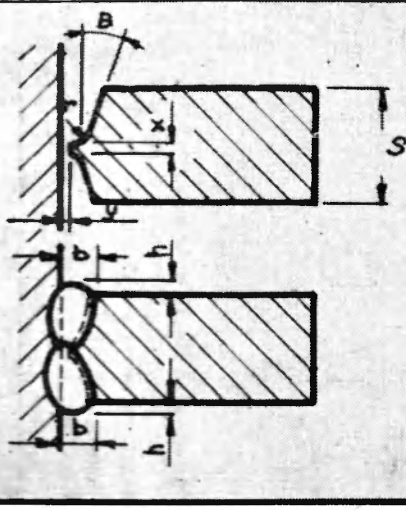
$$b = y + 2 \cdot r + (s - 2 \cdot r - x) \cdot tgB + 4$$

$$tgB = 0{,}19438$$

$$k = 0{,}80 \text{ (contraction - 20\%)}$$

s	y	x	r	h	B
30 - 200	1,5	2,5	5	2	11°

Half Double V - groove weld



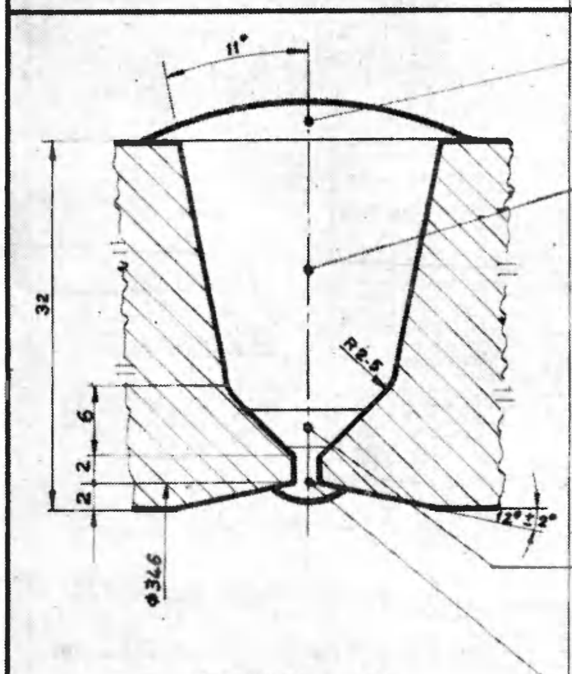
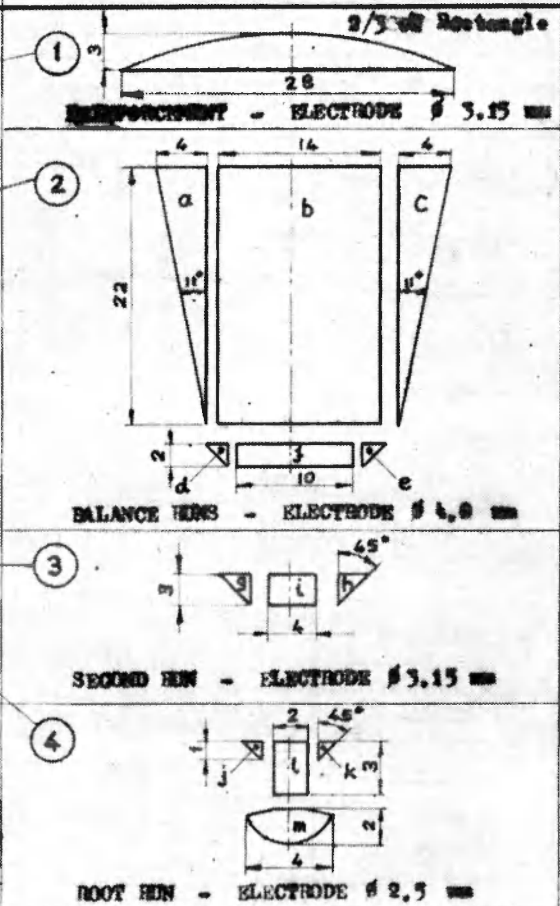
$$F = \left[s \cdot y + \frac{r^2}{2} + r \cdot (s - x - 2 \cdot r) + \frac{(s - 2 \cdot r - x)^2\, tgB}{4} + \frac{2}{3}\, b \cdot h \right] k$$

$$b = y + r + \frac{(s - 2 \cdot r - x)\, tgB}{2} + 2$$

$$tgB = 0{,}32492$$

$$k = 0{,}80 \text{ (contraction - 20\%)}$$

s	y	x	r	h	B
30 - 100	1,5	1,5	10	2	18°

BUTT JOINT φ406×32	SPLIT UP AREAS	Area Ref	Area mm²	Mean Dia. mm	Weight of weld metal gm	No. of Electrodes reqd.	Arc Time mins
	 2/3 of Rectangle — REINFORCEMENT - ELECTRODE φ 3.15 mm	-	56.0	409.0	564	86	58.3
		a	44.0	391.0	424		
		b	308.0	384.0	2915		
		c	44.0	391.0	424		
		d	2.0	361.2	18		
		e	2.0	361.2	18		
		f	20.0	360.0	177		
	BALANCE RUNS - ELECTRODE φ 4.0 mm				3976	119	202.3
		g	4.5	356.0	40		
		h	4.5	356.0	40		
		i	12.0	355.0	105		
POSITION - 5G	SECOND RUN - ELECTRODE φ 3.15 mm				185	9	12.6
		j	0.5	351.3	5		
		k	0.5	351.3	5		
		l	6.0	349.0	52		
		m	5.3	344.0	45		
	ROOT RUN - ELECTRODE φ 2.5 mm				107	11	10.7
	TOTAL		507.3		4832		263.9

Wt. of Weld Metal = Area x Mean Dia. x π x Density of Steel (1 cm³ = 7.85 gm)
Metal recovery of Electrode = 85 %
Throwaway Stub Length .. = 50 mm

Electrode Size mm	Deposition Rate gm./min.	Metal Weld per Electrode - gm
2.5 x 350	10.0	9.9
3.15 x 450	14.7	22.2
4.0 x 450	19.59	33.5