Research Journal of Applied Sciences 2 (12): 1207-1217, 2007
ISSN: 1815-932X

Effectiveness of Base Plate Thickness Design Criteria in Steel Columns

O.S. Abejide
Department of Civil Engineering, University of Ahmadu Bello, Zaria, Nigeria

Abstract: Steel column base plates are one of the most fundamental parts of a steel structure, yet the design of base plates is commonly not given the attention that it should. This result in base plate details that are expensive, difficult to fabricate and may even contribute to the hazards of the steel erection process by not providing stability for erection load applied to the column(s). The effective area method recommended in BS5950 has been used to study the effectiveness of base plate thickness under various loading conditions with due comparison to AISC provisions. Results indicate that although it is a semi-empirical method, it is more reliable than the empirical method recommended in BS5950; also the approach offers more economy and can be used for all column sections.

Key words: Steel columns, base plate thickness, design provisions, steel structure

INTRODUCTION

Every structure must transfer vertical and lateral loads to the supports. In some cases, beams or other members may be supported directly, although the most common system is for columns to be supported by a concrete foundation. The column will be connected to a base plate, which will be attached to the concrete by some form of so-called holding down assembly.

The function of a column base plate is to distribute the column forces to the concrete foundation. In general, a plate on a slab base is used for pinned conditions when there is very little tension between the plate and the concrete. A gusseted base is used occasionally to spread very heavy loads but more generally for conditions of large moments in relation to the vertically applied loads, the principal function of the gusset being to allow the holding down bolt lever arm to be increased to give maximum efficiency while keeping the base plate thickness to an acceptable minimum. Gusseted or built-up bases give an ideal solution for compound or thin crane stanchions in industrial shed buildings (MacGinley and Ang, 1990).

Fixed bases are used primarily in low rise constructions either in portal buildings specifically designed as fixed bases or industrial sheds in which the main columns cantilever from the foundation. They are also used, though less frequently, in multi-storey rigid-frame constructions. In each of these cases, it is assumed by definition that no angular rotation takes place and although this is unlikely to be achieved. It is generally accepted that sufficient rigidity can be obtained to justify the assumption (Steel Construction Institute, 2005).

Pinned bases are those in which it is assumed that there is no restraint against angular rotation. However, this is quite difficult to achieve, but it is accepted that there is sufficient flexibility and a reduction in the anchorage system. Pinned bases are used in portal and in multi-storey connections.

It is common practice to design a building or structure beam-column with a moment resisting or fixed base. Therefore, the base plate thickness must be capable of transferring shear loads, axial loads and bending moment to the supporting foundations (Drake and Elkin, 1999). Typically these base plates are designed and/or analyzed by using service loads or by approximating the stress relationship assuming bearing location likewise comparing with the approach using factored loads directly in a method consistent with the equations of static equilibrium and the LRFD specifications. The moment-resisting base plate must have design strengths in excess of the required strengths; flexural (M_n), axial (P_n) and shear (V_n) for all combinations (Drake and Elkin, 1999).

The empirical method for determining the size of base plates in BS5950 (1990) was not suitable for use with deep Universal Beams (UB) or with bases that have very small outstand dimensions (i.e., a and b). The empirical method was replaced in BS5950 (2000) by the effective area method which offers more economy than the empirical method while still producing safe designs when compared to test results. However, the current design method needs some evaluations in order to justify its confidence in base plate designs (Fig. 1).

The effective area method for base plate designs may initially seem to be more complex than the empirical

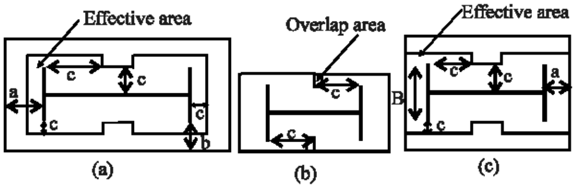

Fig. 1: Slab base design using the effective area method

method given in BS5950 (1990). However, the approach is much more reliable and may be used for all column sections.

This study uses the effective area method recommended in BS5950 (2000) for the determination of base plates effectiveness thickness. The method takes into account the area required to transmit the compressive forces under the base plate at the appropriate strength of the concrete. The stress block may be assumed to be rectangular with a maximum stress of $0.60f_{cu}$. The method also considers the value of plate thickness (t_p) for varying outstands of effective area distance, c, at different plate design strengths P_{yp} (Steel Construction Institute, 2005).

The scope of this study covers the evaluation of plate thickness to determine an effective thickness criterion, using different steel sections (e.g., I, H, CHS, RHS) at varying plate design strengths, P_{yp}. A comparison is made to designed values according to Dewolf's method recommended in the AISC (2005) using the Load Resistance Factor Design (LRFD) method.

LOADING OF COLUMN BASE PLATES

The technical literature concerned with the thickness of base plates may be treated under the following cases. The progression of beam-column loadings in order of increasing moments, is presented in four load cases (Drake and Elkin, 1999).

- Case A is a load condition in which axial compression and shear without bending moment are considered. This case results in a full length uniform pressure distribution between the base plate and the supporting concrete. It may be referred to as a no moment or uplift condition.
- Case B evolves from case A by the addition of a small bending moment. The moment changes the full length uniform pressure distribution to a partial length uniform pressure distribution, but is not large enough to cause separation between the base plate and the supporting concrete. This is practically a base plate sustaining a small moment without uplift.
- Case C evolves from Case B by the addition of a specific bending moment such that the uniform pressure distribution is the smallest moment length without separation between the base plate and the supporting concrete. This corresponds to the common elastic unit where any additional moment would initiate separation between the base plate and the supporting concrete. These are base plates sustaining maximum moment without uplift.
- Case D evolves from Case C by the addition of sufficient bending moment to require anchor rods to prevent separation between the base plate and the supporting concrete. This is a common situation for fixed base plate in structural office practice. That is, a rigid frame with a fixed base plate will usually attract enough bending moment to require anchor rods to prevent uplift of the base plate from the supporting concrete. These are base plates sustaining moment with uplift.

Determination of outstand of effective area: The effective bearing area (A_e) and bearing strength (P_{yp}) is calculated according to Eurocode 3 (1992) Annex L1 in BS5950 (2000b) and provisions of AISC (2005). The area is useful in calculation for strength. It has been suggested that the bearing stresses increases with bigger eccentricity of normal force. The formula for calculation of the effective bearing area around the column section can be based on estimation of the effective width or outstand width, c. The prediction of this width can be based on the T-stub model. The calculation secures that the yield strength of the base plate is not exceeded.

Elastic bending moment resistance, M_e, of the base plate per unit length should be taken as;

$$M_e = \frac{P_y t^2}{6} \tag{1}$$

While the bending moment per unit length on the baseplate acting as a cantilever of span, c, is as in Fig. 2 is given as:

$$M_e = \frac{f_j C^2}{2} \tag{2}$$

When these moments are equal, the bending moment of resistance is reached and the formula for evaluating can be obtained thus;

$$\frac{f_j C^2}{2} = \frac{P_y t^2}{6} \tag{3}$$

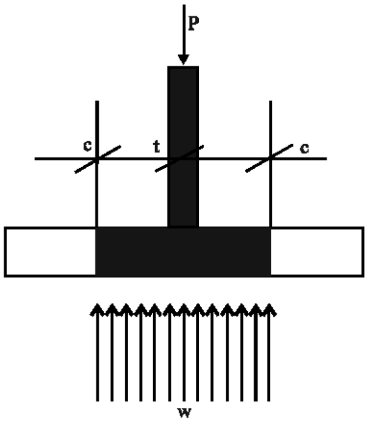

Fig. 2: T-stub in compression using the effective outstand width calculation

$$C = t.\sqrt{\frac{P_y}{3f_j \gamma M_0}} \tag{4}$$

In the course of this study, the prediction of outstand of effective area, c, tallies with that recommended in Eurocode 3 (1992) Annex L. Likewise, note was taken to ensure that the characteristic strength of the concrete satisfies recommended values in the code where the characteristic strength of the concrete foundation, that is, $f_{cu} > 0.02\ f_c$ and the thickness of the grout is not greater than 0.2 times the smaller dimension of the base plate, $t_g < 0.2$ min. But it has been stated (Sophianopoulous *et al.*, 2005) that the parameter having the most significant influence on the connection behavior are the base plate thickness, the dimension of the bolts and the quality of the concrete as found from both theoretical and experimental studies on base plates. Thus these parameters are considered herein.

Design guidelines for materials and fabrication: Engineers have numerous types of steel to choose from when designing anchor bolts and base plate assemblies. However, materials are often specified that are not readily available or are not suitable for specific applications. Base plate details are often hard to fabricate, overly complicated, call for expensive or sometimes unrealistic welds requirement. However, it is important to specify the correct grade of nuts that correspond to the specified anchor bolt material. For plates, the availability of plate material should follow guidelines. Typically, except for very large columns with very heavy base plates, such as for high rise buildings; base plates are shop welded to the columns. Unless the weld is complete penetration weld, the bottom end of the column needs to be cut square so that there will be full bearing where the column is in contact with the base plate.

When considering steel fabrications with reference to labour, a common suggestion from steel fabricators for engineers is that material is cheap relative to labour. But adequate care must be taken to ensure that specification for thicker base plates will eliminate the use of stiffeners in plates and which should consequently result in less labour for fabrication and more economic designs. It has been noted that adding stiffeners and other plates to a base plate assembly is labour intensive compared to using a thicker base plate that could eliminate the need for these additional stiffener plates. Practically, the engineer should attempt to at least match the thickness of the base plate with the column flange thickness in order to prevent warping during welding, particularly if heavy welding, such as partial or complete penetration welds is required to connect the column to the base plate.

When column shear forces are resisted by the anchor bolts, they must be checked for a combination of column shear, bending and tension. If oversize holes are used in the base plates for anchor bolts, placement tolerance welded washer plates must be added so that the base plates will not slip before engaging the anchor bolts. The washer plates are added to the top of the base plate and the additional bending in the anchor bolts must be accounted for due to the increased distance from the concrete to the washer plate.

There is a practical limit to the amount of shear the anchor bolt/concrete interface can resist before the anchor bolts become very large. When shear forces are high, other methods such as the use of shear keys, side plates and struts should be considered (Dewolf and Ricker, 1990).

MATERIALS AND METHODS

The fundamental concept behind the effective area method includes the determination of the required area which is obtained by dividing the axial load by the ultimate bearing pressure that can act under the base plate. This is given by ($0.60f_{cu}$) as recommended (Steel Construction Institute, 2005). Outstand of the effective area, c, is then obtained by equating the expression for effective area to the required area. The expression for the actual effective area for an I or H section may be approximated as in Eq. 5

$$A_e = 4c^2 + (\text{column perimeter})c + \text{column area} \tag{5}$$

In the case of a circular hollow section, the dispersal dimension, k, taken radially on either side of the tube wall gives an annular contact area between the plate and the bedding material as;

$$A_e = (2k + t)(D - t)n \tag{6}$$

A check is carried out to ensure that there is no overlap of effective area between flanges as this will occurif 2c is greater than the distance between the inner faces of the flanges. If the overlap exists, the expression for effective area would have to be modified and recalculated. It is also important to check that the effective area fits perfectly on the size of the base plate selected otherwise a larger plate is selected. The plate thickness is then obtained using the value of the outstand, c, obtained with the following expression;

$$t_p = C\left(\frac{3w}{P_{yp}}\right)^{0.5} \tag{7}$$

Where

w = 0.6 f_{cu} and P_{yp} is the plate design strength.

The procedure is similar for tubular sections (for example, SHS, RHS and CHS), however in the course of this study, trial sections were taken for UB, UC, SHS and RHS using their properties to determine the expression for the effective area; thereby leaving outstand of effective area as a variable parameter. The outstand width, c, was varied between 5 mm and the maximum value of the distance between the inner faces of the flanges that is (D -2T). Note that T is the flange thickness and D depth of column section.

The expression provides an alternative method for the determination of the effective area using the variable value of c. With the areas obtained it was checked that the effective area fits perfectly on the selected base plate. The plate thickness, t_p, was then evaluated from Eq. 7 for various values of plate design strengths, P_{yp}. Eq. 7 can also be derived from equating the moment produced by the uniform load (w) to the elastic moment capacity of the base plate (both per unit length). For example, let moment from uniform load on cantilever be equal to the elastic moment capacity of plate, then;

$$\frac{wC^2}{2} = P_y Z(\text{per unit length}) \tag{8}$$

$$\frac{wC^2}{2} = \frac{P_y t_p^2}{6} \tag{9}$$

and

$$t_p = C\left(\frac{3w}{P_y}\right)^{0.5} \tag{10}$$

In the study of effectiveness of base plate thickness, the effects of bearing plates and bolts cannot be neglected. The beam bearing plates are required to distribute the beam reaction to the masonry support at stress levels within the capacity of the masonry and to ensure that the web-crushing capacity of the beam is not exceeded. The distribution of bearing stresses under the plate is extremely complex (Dewolf and Ricker, 1990) although simplifying assumptions are usually made in appropriate cases. The bending of the plate in the direction transverse to the beam will depend on the stiffness of the flange and the fixing of the flange to the plate (Dewolf and Ricker, 1990). It is usual to assume that the position of maximum bending is outside the edge of the root of the web and that the plate carries the whole of the bending. In the longitudinal direction, the deflection and rotation of the beam due to its loading will cause a concentration of bearing at the front edge and depending upon the load from above the bearing, there could be a lifting of the back edge of the plate. It is assumed that the distribution will be either trapezoidal or triangular, but possibly the stress triangle may not reach the back of the bearing (Sophianopoulos *et al*., 2005). If it is expected that the front edge concentration will be high, the plate is set back from the front of the pier. This is to reduce the possibility of spalling of concrete at the front of the pier but also has the advantage of applying the reaction more centrally to the masonry.

A method of assessing the rotation of the bearing was proposed by Lothers (1999). Furthermore, the complex model presented by Wald is based on the analytical prediction of the elastic-plastic stress distribution under the base plate and the corresponding modeling of base plate and anchor bolts.

RESULTS AND DISCUSSION

Results were obtained using the effective area method with outstand width and plate design strength as variable parameters. These parameters were used to obtain values for plate thickness, t_p (mm), for the various

Table 1: Plate thickness for various design strengths (universal beams)

C (mm)	235	270	275	315	355	400	450
5	2.4	2.3	2.2	2.1	2	1.9	1.8
10	4.8	4.5	4.4	4.1	3.9	3.7	3.5
15	7.2	6.8	6.6	6.2	5.9	5.6	5.3
20	9.6	9	8.8	8.2	7.8	7.4	7
25	12.0	11.3	11	10.3	9.8	9.3	8.8
30	14.4	13.5	13.2	12.3	11.7	11.1	10.5
35	16.8	15.8	15.4	14.4	13.7	13	12.3
40	19.2	18	17.6	16.4	15.6	14.8	14
45	21.6	20.3	19.8	18.5	17.6	16.7	15.8
50	24.0	22.5	22	20.5	19.5	18.5	17.5
55	26.4	24.8	24.2	22.6	21.5	20.4	19.3
60	28.8	27	26.4	24.6	23.4	22.2	21
65	31.2	29.3	28.6	26.7	25.4	24.1	22.8
70	33.2	31.5	30.8	28.7	27.3	25.9	24.5
75	36.0	33.8	33	30.8	29.3	27.9	26.3
80	38.4	36	35.2	32.8	31.2	29.6	28
85	40.8	38.3	37.4	34.9	33.2	35.5	29.8
90	43.2	40.5	39.6	36.9	35.1	33.3	31.5
95	45.6	42.8	41.8	39	37.1	35.2	33.3
100	48.0	45	44	41	39	37	35
105	50.4	47.3	46.2	43.1	41	38.9	36.6
110	52.8	49.5	48.4	45.1	42.9	40.7	38.5
115	55.2	51.8	50.6	47.2	44.9	42.6	40.3
120	57.6	54	52.8	49.2	46.8	44.4	42
125	60.0	56.3	55	51.3	48.8	46.3	43.8
130	62.8	58.5	57.2	53.4	50.7	48.1	45.5
135	64.8	60.8	59.4	55.9	52.7	50	47.3
140	67.2	63	61.6	57.4	54.6	51.8	49
145	69.6	65	63.8	59.5	56.6	53.7	50.8
150	72.0	68	66.0	61.5	58.5	55.5	52.5
155	74.4	70	68.2	63.6	60.5	57.4	54.3
160	76.8	72	70.4	65.6	62.4	59.2	56
165	79.2	74	72.6	67.7	64.4	61.1	57.8
170	81.6	77	74.8	69.7	66.3	62.9	59.5
175	84.0	79	77.0	71.8	68.3	64.8	61.3
180	86.4	81	79.2	73.8	70.2	66.6	63
185	88.5	83.3	81.4	75.9	72.2	68.5	64.8
190	91.2	86	83.6	77.9	74.1	70.3	66.5
195	93.6	88	85.8	80.0	76.1	72.2	68.3
200	96.0	90	88.0	82.0	78.0	74.0	70
205	98.4	92.3	90.2	84.1	80.0	75.9	71.8
210	100.8	94.5	92.4	86.1	81.9	77.7	73.5
215	103.2	96.8	94.6	88.2	83.9	79.6	75.3
220	105.6	99	96.8	90.2	85.8	81.4	77
225	108	101.3	99.0	92.3	87.8	83.3	78.8
230	110.4	103.5	101.2	94.3	89.7	85.1	80.5
235	112.8	105.8	103.4	96.4	91.7	87.0	82.3
240	115.2	108	105.6	98.4	93.6	88.8	84
245	117.6	110.3	107.8	100.5	95.6	90.7	85.8
250	120	112.5	110.0	102.5	97.5	92.5	87.5
255	122.4	114.8	112.2	104.6	101.4	96.4	89.3
260	124.8	117	114.4	106.6	103.4	96.2	91
265	127.2	119.3	116.6	108.7	103.4	98.1	92.5
270	129.6	121.5	118.8	110.7	105.3	99.9	94.5
275	132	123.8	121	112.8	107.3	101.8	96.3
280	134.4	126	123.2	114.8	109.2	103.6	98
285	136.8	128.3	125.4	116.9	111.2	105.5	99.8
290	139.2	130.5	127.6	118.9	113.1	107.3	101.5
295	141.6	132.75	129.8	121.0	115.1	109.2	103.3
300	144	135	132	123.0	117	111	105
305	146.4	137.3	134.2	125.1	119	112.9	106.8
310	148.8	139.5	136.4	127.1	120.9	114.7	108.5
315	151.2	141.8	138.6	129.2	122.9	116.5	110.3
320	153.6	144	140.8	131.2	124.5	118.4	112
325	156	146.3	143	133.3	120.3	113.8	113.8
330	158.4	148.5	145.2	135.3	122.1	115.5	115.5
335	160.8	150.8	147.4	137.4	124	117.3	117.3
340	163.2	153	149.6	139.4	125.8	119.0	119
345	165.6	155.3	151.8	134.6	127.7	120.8	120.8
350	168	157.5	154	136.5	129.5	122.5	122.5
355	170.4	159.8	156.2	138.5	131.4	124.3	124.25

Table 2: Plate thickness for various design strengths (universal columns)

C (mm)	235 N mm^{-2}	270 N mm^{-2}	275 N mm^{-2}	315 N mm^{-2}	355 N mm^{-2}	400 N mm^{-2}	450 N mm^{-2}
5	2.2	2.1	2.0	1.9	1.8	1.7	1.6
10	4.4	4.1	40.0	3.8	3.6	3.4	3.2
15	6.6	6.2	6.0	5.7	5.4	5.1	4.8
20	8.8	8.2	8.0	7.6	7.2	6.8	6.4
25	11.0	10.3	10.0	9.5	9.0	8.5	8.0
30	13.2	12.3	12.0	11.4	10.8	10.2	9.6
35	15.2	14.4	14.0	13.3	12.6	11.9	11.2
40	17.6	16.4	16.0	15.2	14.4	13.6	12.8
45	19.8	18.5	18.0	17.1	16.2	15.3	14.4
50	22.0	21.0	20.0	19.0	18.0	17.0	16.0
55	24.0	22.6	22.0	20.9	19.8	18.7	17.6
60	26.4	24.6	24.0	22.8	21.6	20.4	19.2
65	28.6	26.7	26.0	24.7	23.9	22.1	20.8
70	30.8	28.7	28.0	26.6	25.2	23.8	22.4
75	33.0	30.8	30.0	28.5	27.0	25.5	24.0
80	35.2	32.8	32.0	30.4	28.8	27.2	25.6
85	37.4	34.9	34.0	32.3	30.6	28.9	27.2
90	39.6	36.9	36.0	34.2	32.4	30.6	28.8
95	41.8	39.0	38.0	36.1	34.2	32.3	30.4
100	44.0	41.0	40.0	38.0	36.0	34.0	32.0
105	46.2	43.1	42.0	39.9	37.8	35.7	33.6
110	48.4	45.1	44.0	41.8	39.6	37.9	35.2
115	50.6	47.2	46.0	43.7	41.4	39.1	36.8
120	52.8	49.2	48.0	45.6	43.2	40.8	38.8
125	55.0	51.3	50.0	47.5	45.0	42.5	40.0
130	57.2	53.3	52.0	49.9	46.8	44.2	41.3
135	59.4	55.4	54.0	51.3	48.6	45.9	43.2
140	61.6	57.4	56.0	53.2	50.4	47.6	44.8
145	63.8	59.5	58.0	55.1	52.2	49.3	46.4
150	66.0	61.5	60.0	57.0	54.0	51.0	48.0
155	68.2	63.6	62.0	58.9	55.8	52.7	49.6
160	70.4	65.6	64.0	60.8	57.6	54.4	51.2

Table 3: Plate thickness for various design strengths (rectangular hollow sections)

C (mm)	235 N mm^{-2}	270 N mm^{-2}	275 N mm^{-2}	315 N mm^{-2}	355 N mm^{-2}	400 N mm^{-2}	450 N mm^{-2}
5	2.2	2.1	2	1.9	1.8	1.7	1.6
10	4.4	4.1	4	3.8	3.6	3.4	3.2
15	6.6	6.2	6	5.7	5.4	5.1	4.8
20	8.8	8.2	8	7.6	7.2	6.8	6.4
25	11	10.3	10	9.5	9	8.5	8
30	13.2	12.3	12	11.4	10.8	10.2	9.6
35	15.4	14.4	14	13.3	12.6	11.9	11.2
40	17.6	16.4	16	15.2	14.4	13.6	12.8
45	19.8	18.5	18	17.1	16.2	15.3	14.4
50	22	20.5	20	19	18	17	16
55	24.2	22.6	22	20.9	19.8	18.7	17.6
60	26.4	24.6	24	22.8	21.6	20.4	19.2
65	28.6	26.7	26	24.7	23.4	22.1	20.8
70	30.8	28.7	28	26.6	25.2	23.8	22.4
75	33	30.8	30	28.5	27	25.5	24
80	35.2	32.8	32	30.4	28.8	27.2	25.6
85	37.4	34.9	34	32.3	30.6	28.9	27.2
90	39.6	36.9	36	34.2	32.4	30.6	28.8
95	41.8	39	38	36.1	34.2	32.3	30.4
100	44	41	40	38	36	34	32
105	46.2	43.1	42	39.9	37.5	35.7	33.6
110	48.4	45.1	44	41.8	39.6	37.4	35.2
115	50.6	47.2	46	43.7	41.4	39.1	36.8
120	52.8	49.2	48	45.6	43.2	40.8	38.4
125	55	51.2	50	47.5	45	42.5	40
130	57.2	53.3	52	49.4	46.8	44.4	41.6
135	59.4	55.4	54	51.3	48.6	45.9	43.2
140	61.6	57.4	56	53.2	50.4	47.6	44.8
145	63.8	59.5	58	55.1	52.2	49.3	46.4
150	66	61.5	60	57	54	51	48

Table 3: Continued

C (mm)	235 N mm^{-2}	270 N mm^{-2}	275 N mm^{-2}	315 N mm^{-2}	355 N mm^{-2}	400 N mm^{-2}	450 N mm^{-2}
155	68.2	63.6	62	58.9	55.8	52.7	49.6
160	70.4	65.6	64	60.8	57.6	54.4	51.2
165	72.6	67.7	66	62.7	59.4	56.1	52.8
170	74.8	69.7	68	64.6	61.2	57.8	54.4
175	77	71.8	70	66.5	63	59.5	56
180	79.2	73.8	72	68.4	64.8	61.2	57.6
185	81.4	75.9	74	70.3	66.6	62.9	59.2
190	83.6	77.9	76	72.2	68.4	64.6	60.8
195	85.8	80	78	74.1	70.2	66.3	62.4
200	88	82	80	76	72.2	68	64
205	90.2	84.1	82	77.9	73.8	69.7	65.6
210	92.4	86.1	84	79.8	75.6	71.4	67.2
215	94.6	88.2	86	81.7	77.4	73.1	68.8
220	96.8	90.2	88	83.6	79.2	74.8	70.4
225	99	92.3	90	85.5	81	76.5	72
230	101.2	94.3	92	87.4	82.8	78.2	73.6
235	103.4	96.4	94	89.3	84.6	79.9	75.2
240	105.6	98.4	96	91.2	86.4	81.6	76.8
245	107.8	100.5	98	93.1	88.2	83.3	78.4
250	110	102.5	100	95.1	90	85	80

Table 4: Plate thickness for various design strengths (square hollow sections)

C (mm)	235 N mm^{-2}	270 N mm^{-2}	275 N mm^{-2}	315 N mm^{-2}	355 N mm^{-2}	400 N mm^{-2}	450 N mm^{-2}
5	2.2	2.1	2	1.9	1.8	1.7	1.6
10	4.4	4.1	4	3.8	3.6	3.4	3.2
15	6.6	6.2	6	5.7	5.4	5.1	4.8
20	8.8	8.2	8	7.6	7.2	6.8	6.4
25	11	10.3	10	9.5	9	8.5	8
30	13.2	12.3	12	11.4	10.8	10.2	9.6
35	15.4	14.4	14	13.3	12.6	11.9	11.2
40	17.6	16.4	16	15.2	14.4	13.6	12.8
45	19.8	18.5	18	17.1	16.2	15.3	14.4
50	22	20.5	20	19	18	17	16
55	24.2	22.6	22	20.9	19.8	18.7	17.6
60	26.4	24.6	24	22.8	21.6	20.4	19.2
65	28.6	26.7	26	24.7	23.4	22.1	20.8
70	30.8	28.7	28	26.6	25.2	23.8	22.4
75	33	30.8	30	28.5	27	25.5	24
80	35.2	32.8	32	30.4	28.8	27.2	25.6
85	37.4	34.9	34	32.3	30.6	28.9	27.2
90	39.6	36.9	36	34.2	32.4	30.6	28.8
95	41.8	39	38	36.1	34.2	32.3	30.4
100	44	41	40	38	36	34	32
105	46.2	43.1	42	39.9	37.5	35.7	33.6
110	48.4	45.1	44	41.8	39.6	37.4	35.2
115	50.6	47.2	46	43.7	41.4	39.1	36.8
120	52.8	49.2	48	45.6	43.2	40.8	38.4
125	55	51.2	50	47.5	45	42.5	40
130	57.2	53.3	52	49.4	46.8	44.4	41.6
135	59.4	55.4	54	51.3	48.6	45.9	43.2
140	61.6	57.4	56	53.2	50.4	47.6	44.8
145	63.8	59.5	58	55.1	52.2	49.3	46.4
150	66	61.5	60	57	54	51	48
155	68.2	63.6	62	58.9	55.8	52.7	49.6
160	70.4	65.6	64	60.8	57.6	54.4	51.2
165	72.6	67.7	66	62.7	59.4	56.1	52.8
170	74.8	69.7	68	64.6	61.2	57.8	54.4
175	77	71.8	70	66.5	63	59.5	56
180	79.2	73.8	72	68.4	64.8	61.2	57.6
185	81.4	75.9	74	70.3	66.6	62.9	59.2
190	83.6	77.9	76	72.2	68.4	64.6	60.8
195	85.8	80	78	74.1	70.2	66.3	62.4
200	88	82	80	76	72.2	68	64

Table 5: Plate thickness for various design strengths (circular hollow sections)

C (mm)	235 N mm^{-2}	270 N mm^{-2}	275 N mm^{-2}	315 N mm^{-2}	355 N mm^{-2}	400 N mm^{-2}	450 N mm^{-2}
5	2.4	2.3	2.2	2.1	2	1.9	1.8
10	4.8	4.5	4.4	4.1	3.9	3.7	3.5
15	7.2	6.8	6.6	6.2	5.9	5.6	5.3
20	9.6	9	8.8	8.2	7.8	7.4	7
25	12.0	11.3	11	10.3	9.8	9.3	8.8
30	14.4	13.5	13.2	12.3	11.7	11.1	10.5
35	16.8	15.8	15.4	14.4	13.7	13	12.3
40	19.2	18	17.6	16.4	15.6	14.8	14
45	21.6	20.3	19.8	18.5	17.6	16.7	15.8
50	24.0	22.5	22	20.5	19.5	18.5	17.5
55	26.4	24.8	24.2	22.6	21.5	20.4	19.3
60	28.8	27	26.4	24.6	23.4	22.2	21
65	31.2	29.3	28.6	26.7	25.4	24.1	22.8
70	33.2	31.5	30.8	28.7	27.3	25.9	24.5
75	36.0	33.8	33	30.8	29.3	27.9	26.3
80	38.4	36	35.2	32.8	31.2	29.6	28
85	40.8	38.3	37.4	34.9	33.2	35.5	29.8
90	43.2	40.5	39.6	36.9	35.1	33.3	31.5
95	45.6	42.8	41.8	39	37.1	35.2	33.3
100	48.0	45	44	41	39	37	35
105	50.4	47.3	46.2	43.1	41	38.9	36.6
110	52.8	49.5	48.4	45.1	42.9	40.7	38.5
115	55.2	51.8	50.6	47.2	44.9	42.6	40.3
120	57.6	54	52.8	49.2	46.8	44.4	42
125	60.0	56.3	55	51.3	48.8	46.3	43.8
130	62.8	58.5	57.2	53.4	50.7	48.1	45.5
135	64.8	60.8	59.4	55.9	52.7	50	47.3
140	67.2	63	61.6	57.4	54.6	51.8	49
145	69.6	65	63.8	59.5	56.6	53.7	50.8
150	72.0	68	66.0	61.5	58.5	55.5	52.5
155	74.4	70	68.2	63.6	60.5	57.4	54.3
160	76.8	72	70.4	65.6	62.4	59.2	56
165	79.2	74	72.6	67.7	64.4	61.1	57.8
170	81.6	77	74.8	69.7	66.3	62.9	59.5
175	84.0	79	77.0	71.8	68.3	64.8	61.3
180	86.4	81	79.2	73.8	70.2	66.6	63
185	88.5	83.3	81.4	75.9	72.2	68.5	64.8
190	91.2	86	83.6	77.9	74.1	70.3	66.5
195	93.6	88	85.8	80.0	76.1	72.2	68.3
200	96.0	90	88.0	82.0	78.0	74.0	70
205	98.4	92.3	90.2	84.1	80.0	75.9	71.8
210	100.8	94.5	92.4	86.1	81.9	77.7	73.5
215	103.2	96.8	94.6	88.2	83.9	79.6	75.3
220	105.6	99	96.8	90.2	85.8	81.4	77
225	108	101.3	99.0	92.3	87.8	83.3	78.8

trial sections. The variable parameters of outstand width was taken from 5 mm at 5 mm intervals up to D-2T, which represents the distance between the inner faces of the flange, while plates design strengths, P_{yp}, were taken as per BS5950 (2000a, b) recommendations for universal beams and columns, rectangular and square hollow sections. Typical results of compact or hot-rolled steel sections in BS5950 (1990, 2000) and BS7668 (1994) provisions are given in Table 1-4 and Fig. 3-6. The results displayed in the tables show that there is a direct relationship between the outstand width and plate thickness; that is, as outstand width increases the base plate thickness also increases. However, thinner plates are obtained as the base plate strength increases. But for practical and economic purposes, the optimal values for design of base plate strengths should not be greater than 270 N mm^{-2} as can be clearly seen. Also, the tables give calculated outstands in base plates with reference to recommendations of BS5950 (1990, 2000). Generally, the code provisions are two or three times of the calculated values, which are just the structural requirement for safety. This indicates that the code provisions for base plates are not economical but only follow rule of thumb or experience criteria. This could be reviewed downwards in the light of this investigation.

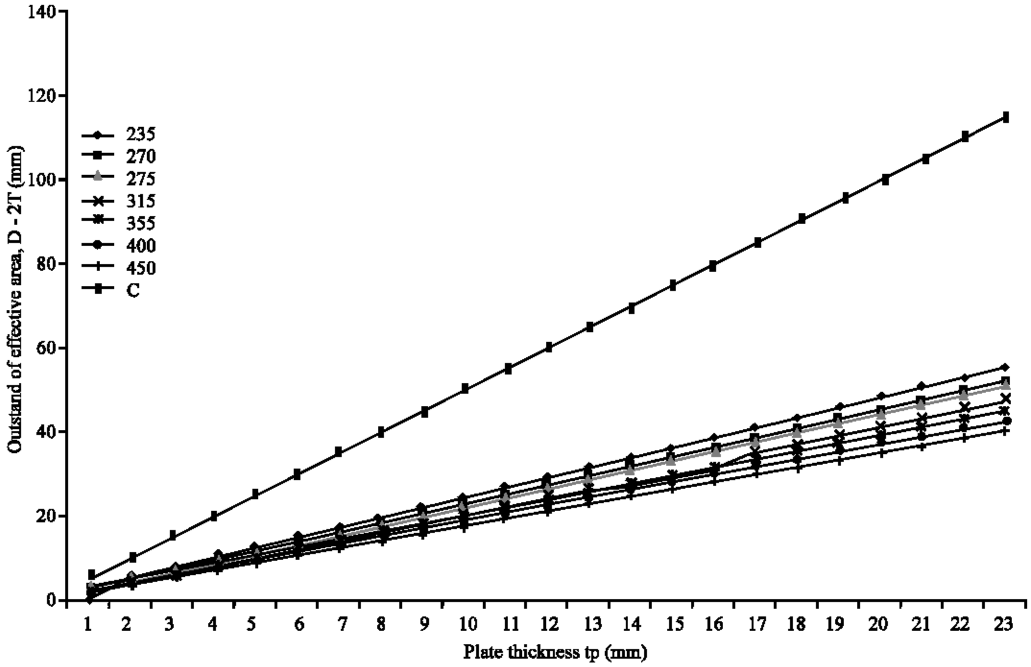

Fig. 3: Plate strength and thickness in outstand of Universal Beams (254×146×43kg m^{-1} UB)

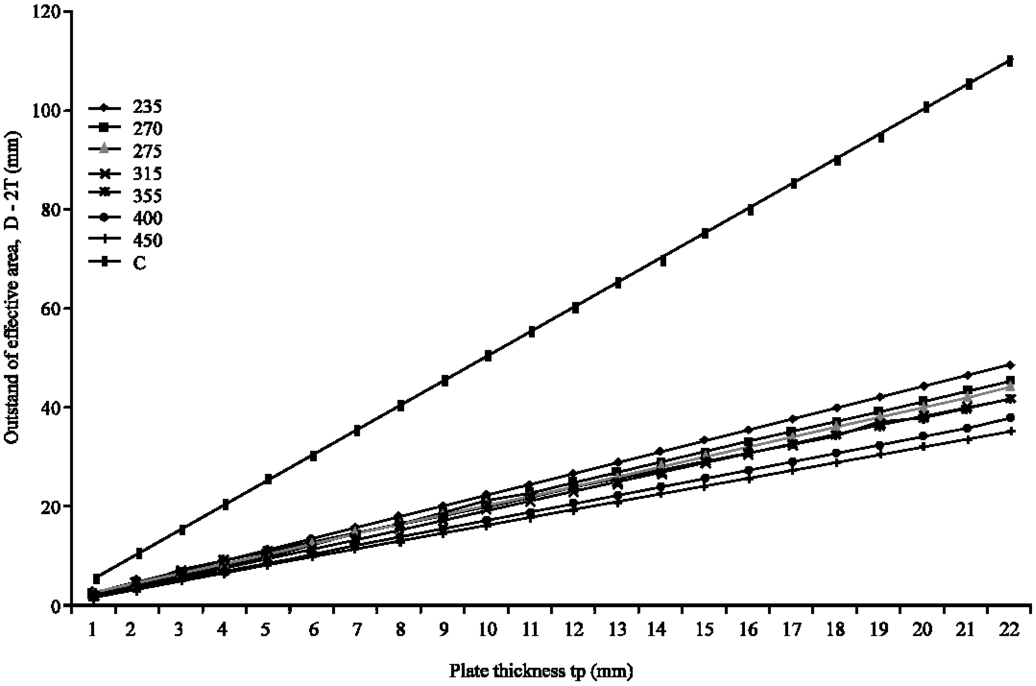

Fig. 4: Plate strength and thickness in outstand of Universal Columns (254×254×73kg m^{-1} UC)

The axial load and moments induced by it were the basic governing factors in the determination of the base plate size and with the assumption that the axial load should not exceed the bearing pressure in the concrete lest failure by crushing occurs. Hence, it is obvious that the base plate dimensions should be sufficient to accommodate the column dimensions plus provision for anchor bolt holes with sufficient column flanges and to the edge of the base plate as recommended in the codes. Finally, it is good practice and more economical to design

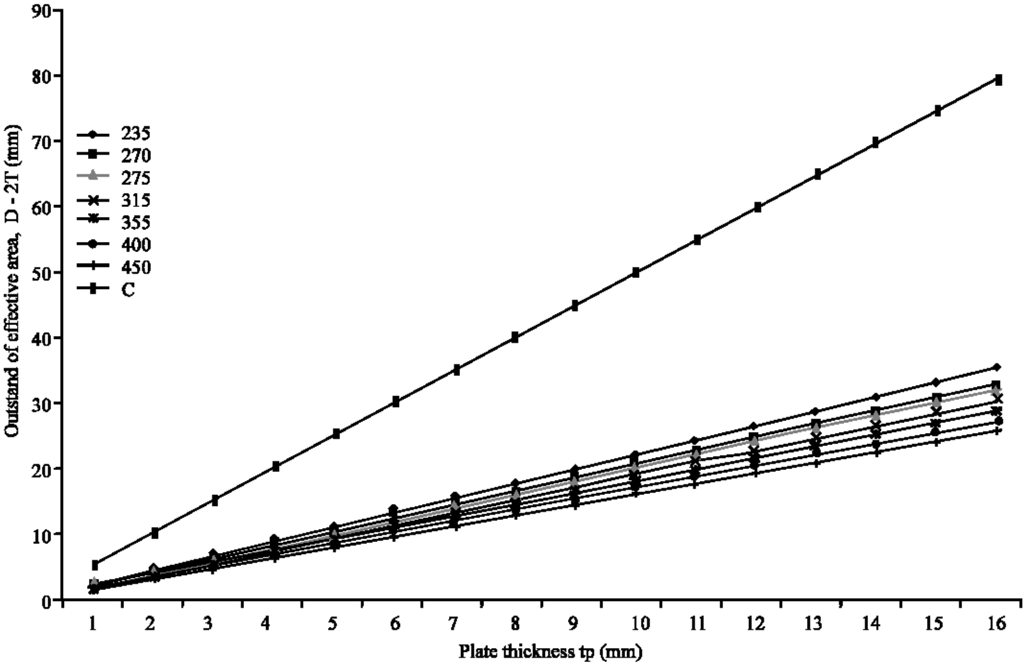

Fig. 5: Plate strength and thickness in outstand of Rectangular Hollow Sections (160×80×12.5 mm RHS)

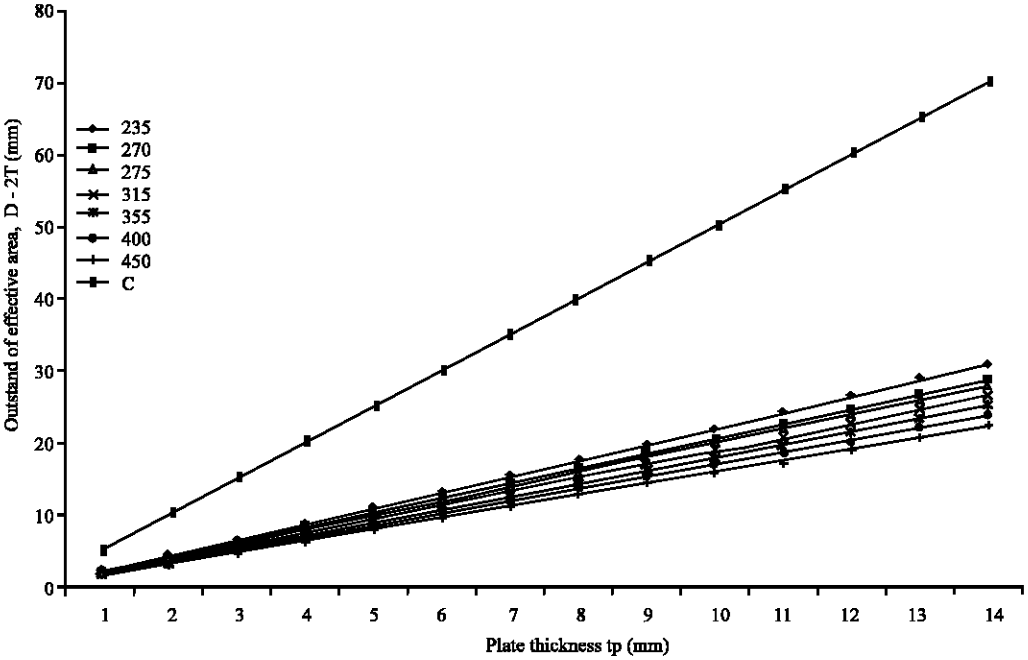

Fig. 6: Plate strength and thickness in outstand of Square Hollow Sections (140×140×12.5 mm SHS)

larger base plates to cover more than one column size in a column group than design specific base plates for each column size and such as not to exceed the concrete strength.

CONCLUSION

It is required that columns be provided with adequate steel base plates to distribute the compression forces in the compressed parts of the columns, over a bearing area such that the bearing pressure does not exceed the design strength of the plate and grout or concrete. This study has been able to verify a range of effective thicknesses for base plates on the effective area method recommended in BS5950 (2000a, b).

The methodology summarizes the provisions for beam-column base plates using variable expressions generated from the effective area method, while holding the outstand width as variable. However, it is important to remember that the method given in BS5950 (2000b) is a design model and the remainder of the plate (not only the effective area) does exist and carries load. With this in mind, the moment induced in the column flange due to unbalanced cantilevers does not need to be explicitly considered in the design of either the column or base plate.

The effective area method that has been used in the verification of the effectiveness of base plate thickness design criteria is also essentially an empirical method.

REFERENCES

AISC, 2005. Specification for General Steel Buildings, ANSI /AISC 360- 05. One East walker Drive Suite 700, Chicago Illinois USA.

BS5950, 1990. Structural Use of Steelwork in Buildings. Part 1. British Standards Institution Her Majesty's Stationery Office, London.

BS7668, 1994. Specification for Weldable Structural Steels. British Standards Institution Her Majesty's Stationery Office, London.

BS5950, 2000a. Structural Use of Steelwork in Buildings. Part 1: Code of Practice for design in simple and Continuous Construction-Hot rolled Sections. British Standards Institution Her Majesty's Stationery Office, London.

BS5950, 2000b. Eurocode 3 (ENV 1993-1-1:1992): Design of Column Bases, Edited Approved Draft. British Standards Institution Her Majesty's Stationery Office, London.

Dewolf, J.T. and D.T. Ricker, 1990. Column Base Plate, Design Guide Series No. 1. American Institute of Steel Construction, Chicago, Illinois. USA. http://www.aisc.org/epubs. Design guide 1.

Drake, R.M. and S.J. Elkin, 1999 Beam-column Base Plate Design LRFD Method. AISC Engineering Journal, First Quarter, http://www.asce.org/pubs.engineering journal/full text /1999.pdf, Vol. 36.

Lothers, J.E., 1999. Design in Structural Steel. 6th Edn. Prentice Hall Engleword Cliffs, NJ. USA.

MacGinley, T.J. and T.C. Ang, 1990. Structural Steelwork Design to Limit State Theory. Butterworth-Heinemann Publishers, pp: 243-250.

Sophianopoulous, D.S., P.G. Asteris and G.T. Michaltsos, 2005. Equilibrium-based Evaluation of Stress Distribution Under Steel Column Baseplate 1: Governing Equations. http://civag.unimelb.edu/ejse/Archives/fulltext/2005/200504.pdf.

Steel Construction Institute, 2005. Steel Designers Manual. 6th Edn. Owens, G.W. and B. Davison (Eds.). Blackwell Publishers, pp: 822-927.