Proceedings of the 20th Association of Public Authority Surveyors Conference (APAS2015)
Coffs Harbour, New South Wales, Australia, 16-18 March 2015

The Position and Verticality of Structural Steel

Charlie Higgs
Handley Surveys
chiggs170961@gmail.com

ABSTRACT

The Australian Standard AS 4100 Steel Structures outlines the relevant positional and verticality accuracies for the erection of steel structures. The determination of these accuracies is a common task undertaken by SME (Structural, Mechanical & Engineering) surveyors. Available equipment, time constraints and access to structures often dictate the methodologies adopted. This paper explores various equipment and methodologies for determining verticality and position and their relative pros and cons. Examples are drawn from work on the Nammuldi Below Water Table Project undertaken in the Pilbara region of Western Australia.

KEYWORDS: *Position, verticality, AS 4100.*

1 INTRODUCTION

A common task for SME (Structural, Mechanical & Engineering) surveyors is the determination of position and verticality of steel structures. A typical structure could be the support frame for a train load out (TLO), as shown in Figure 1. This million-dollar structure and associated conveyors sits primarily on half a dozen columns, and the integration between the TLO and the rail line, the conveyor etc. hinge primarily on the position, level and verticality of the TLO.

Figure 1: Train load out structure.

The availability of equipment, site conditions and time constraints all impact on the methodologies adopted by SME surveyors. They also have available to them a number of traditional and modern methodologies, and sometimes the combination and permutations of equipment, methodologies and constraints can be daunting. This paper looks at a number of methodologies used for determining position and/or verticality and then focuses on one particularly methodology that combines all the measurements (position, verticality and level) into one method. It is by no means a definitive solution but one that works well and addresses a number of the constraints mentioned above.

2 AS 4100 STEEL STRUCTURES

The Australian Standard AS 4100 Steel Structures outlines (among other things) the relevant positional and verticality accuracies for the erection of steel structures. The main sections under consideration in this paper are 15.3.2 *Column base* and 15.3.3 *Plumbing of a compression member*, outlined as follows (Standards Australia, 1998):

15.3.2 Column base
15.3.2.1 Position in plan
The position in plan of a steel column base shall not deviate from its correct value by more than 6 mm along either of the principal setting out axes.
15.3.2.2 Level
The level of the underside of a steel base plate shall not deviate from its correct value by more than ±10 mm.

15.3.3 Plumbing of a compression member
The alignment and plumbing of a compression member shall be in accordance with both of the following requirements:
(a) The deviation of any point above the base of the compression member from its correct position shall not exceed height/500 or as follows, whichever is the lesser:
  (i) For a point up to 60 m above the base of the member … 25 mm.
  (ii) For a point more than 60 m above the base of the member … 25 mm plus 1 mm for every 3 m in excess of 60 m up to a maximum of 50 mm.

3 POSITIONING

Perhaps the least complicated task to be undertaken is the determination of position. Figure 2 shows the cross section of a column with a six-hole plate at its base. If the anchor bolts have been positioned correctly, it would be assumed that the column is in its correct location but variations in construction, welding etc. may mean the actual column may not be in the correct location.

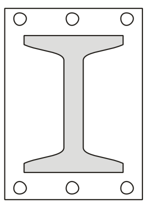


Figure 2: Cross section of a sample column and base plate.

The simplest approach is to measure the width and breadth of the column and mark, the centre points and then calculate the position of these marks relative to the design position. In the example shown in Figure 3, column A has been measured and the centre of the column found to be out of position. The column is 4 mm from the design position along the Y axis and 2 mm out of position along the X axis. The dimensions do not exceed the acceptable tolerance of ±6 mm in either of the primary axes (see section 15.3.2.1 of AS 4100), so therefore the position of the column meets AS 4100 requirements.

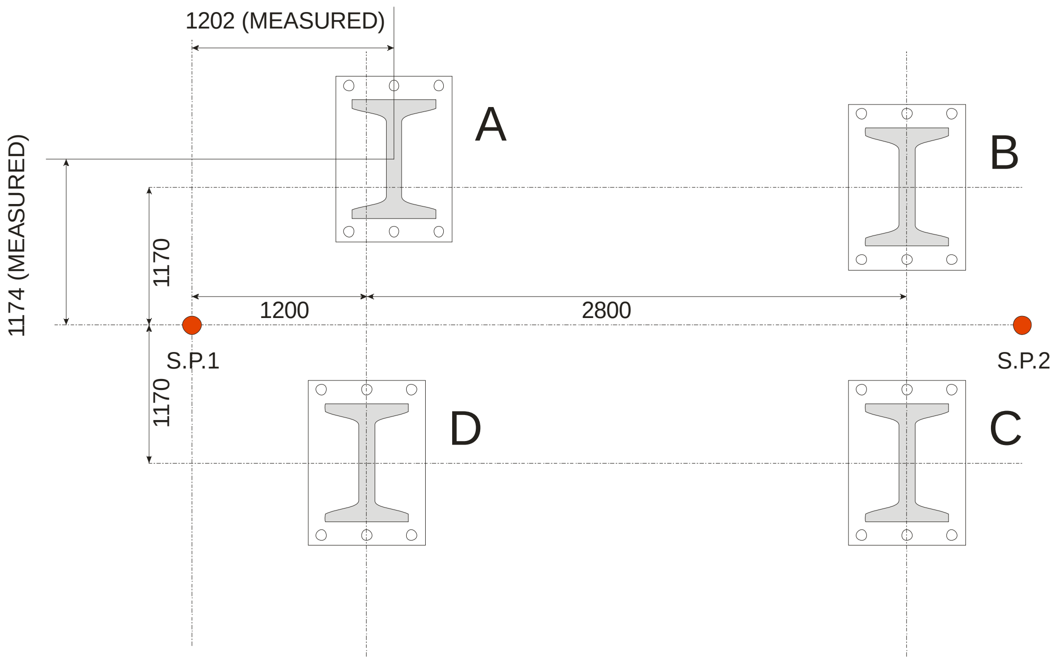


Figure 3: Column measurements.

4 PLUMBING

There are a number of approaches for measuring the verticality of a column, including direct measurement by plumb bob, optical laser plummet and total station. Occam's razor (Encyclopaedia Britannica, 2015) suggests that sometimes the simplest solution is often the best (apologies to William of Ockham c. 1287–1347/49 for the loose interpretation). The verticality of a column can be determined quite simply with a plumbob or spirit level (Figure 4).

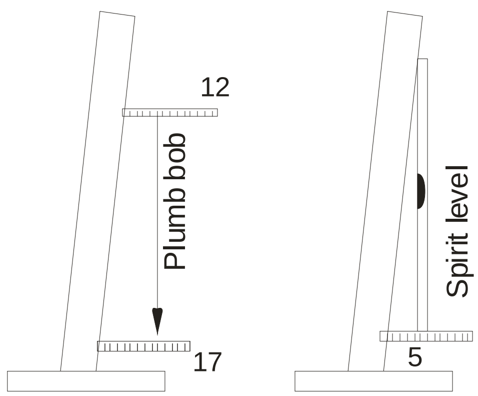


Figure 4: Determining column verticality using plumb bob and spirit level (leaning 5 mm).

An alternative method involves sighting a point near the top of the column and then observing the same point near the base and determining the difference. This requires the line of sight to approximate the axis and hence requires two setups to determine the 'lean' of the column in each axis (Figure 5).

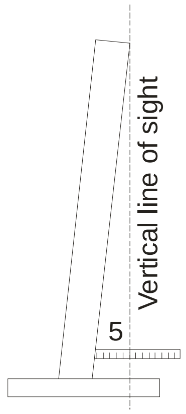


Figure 5: Determining column verticality using a total station (leaning 5 mm).

5 ACCESS AND SITE RESTRICTIONS

One of the most significant limitations to checking location or verticality is physically accessing the columns and base plates. Site safety requirements often dictate a drop or exclusion zone around working areas and this significantly restricts access to columns and base plates. Figure 6 illustrates the exclusion zone that may surround the columns and provides a photo of an exclusion zone (yellow hard barricading) due to the elevated work platform (EWP) being raised into the structure.

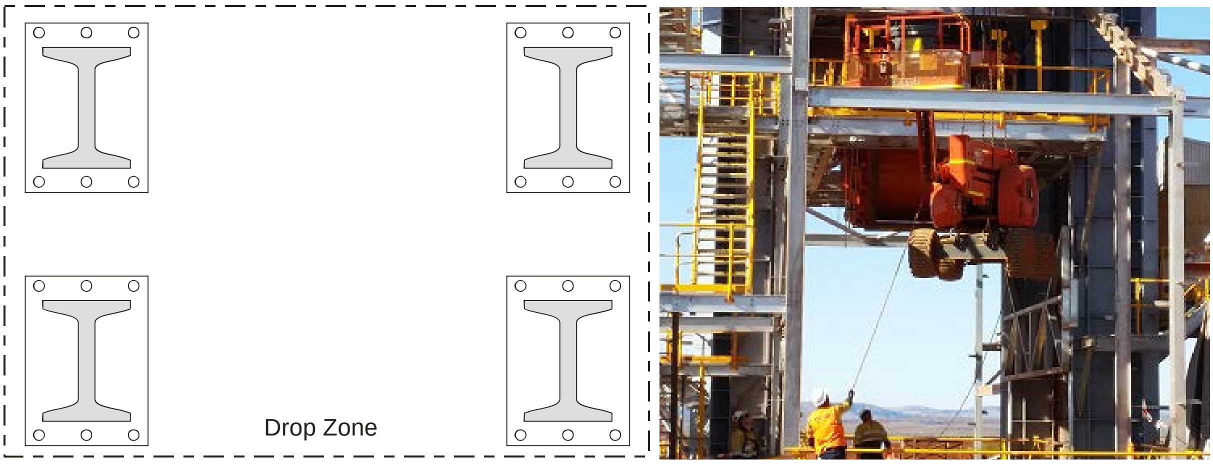


Figure 6: Drop or exclusion zone (left) and drop zone example (right).

6 REMOTE METHODOLOGY

In an ideal world, accessing the columns to measure location and verticality would be easy but in practice site access is an issue and therefore a different, remote methodology is required. It should be noted that the following methodology can be modified for sites where access is fully available or partially limited, but the basic premise is that access is not readily available.

6.1 Assumptions

For the sake of this paper three assumptions are made, based on current work practices.

6.1.1 Assumption 1: Standard Beam/Column Dimensions

The first assumption is that the dimensions for the columns are standard across the project. Although there are slight variations, this assumption has been mostly valid on site and readily been checked prior to construction. The dimensions most relevant for this paper are the distance between the flanges and the web (Figure 7).

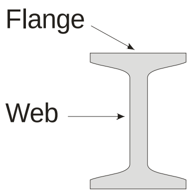
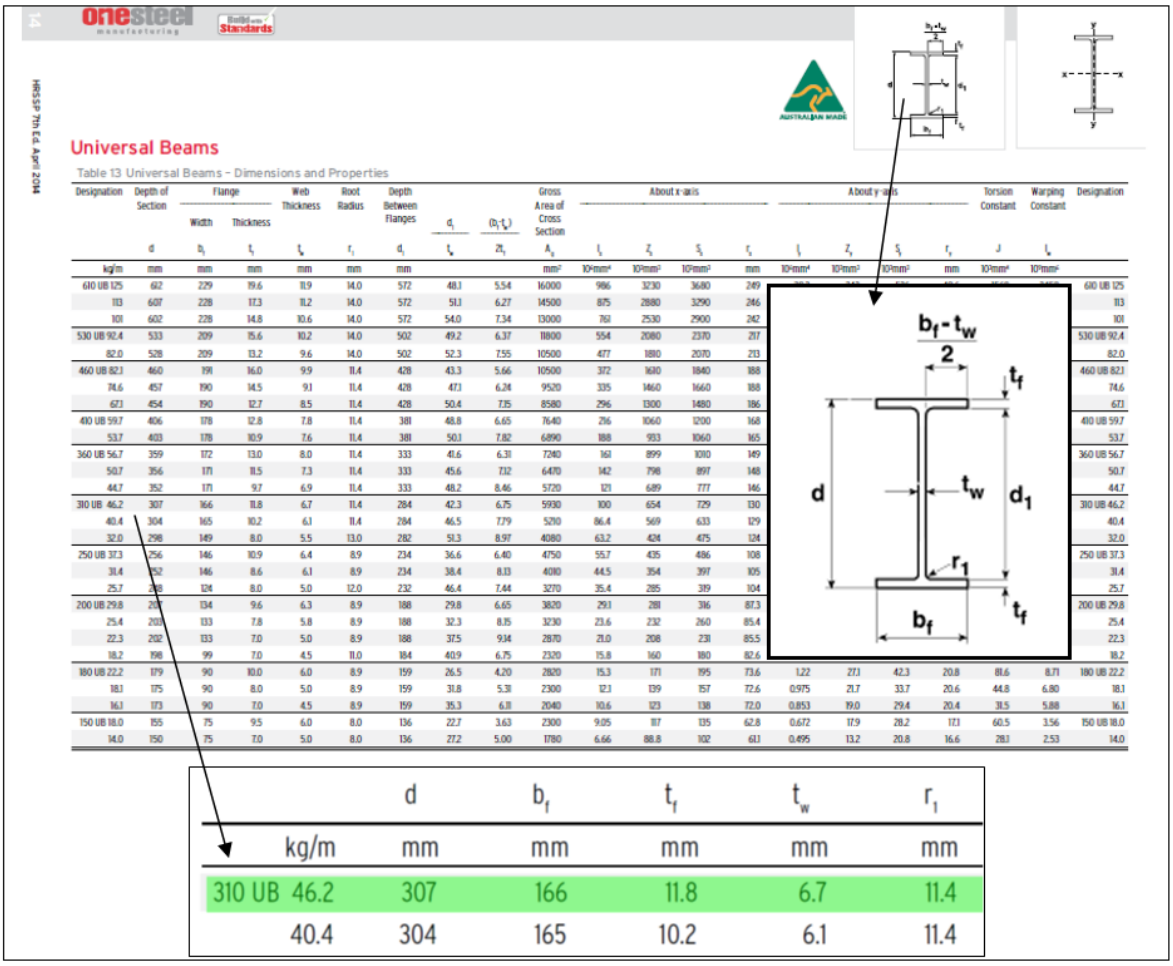


Figure7: Flange and web.

Figure 8 provides an example of a table of dimensions for standard columns as supplied by OneSteel. Let us assume we are observing columns that have the dimensions highlighted above. The flange to flange dimension (D) is 307 mm and the web thickness (t_w) is 6.7 mm.



	d	b_f	t_f	t_w	r_1
kg/m	mm	mm	mm	mm	mm
310 UB 46.2	307	166	11.8	6.7	11.4
40.4	304	165	10.2	6.1	11.4

Figure 8: OneSteel beam/column dimensions (OneSteel, 2014).

6.1.2 Assumption 2: Setup Position

For simplicity, let us assume that it is possible to set up a reflectorless total station such that the web and flange of each column is visible from a single setup position (Figures 9 & 10). It should be noted that this is not always a reality and sometimes more than one setup is required.

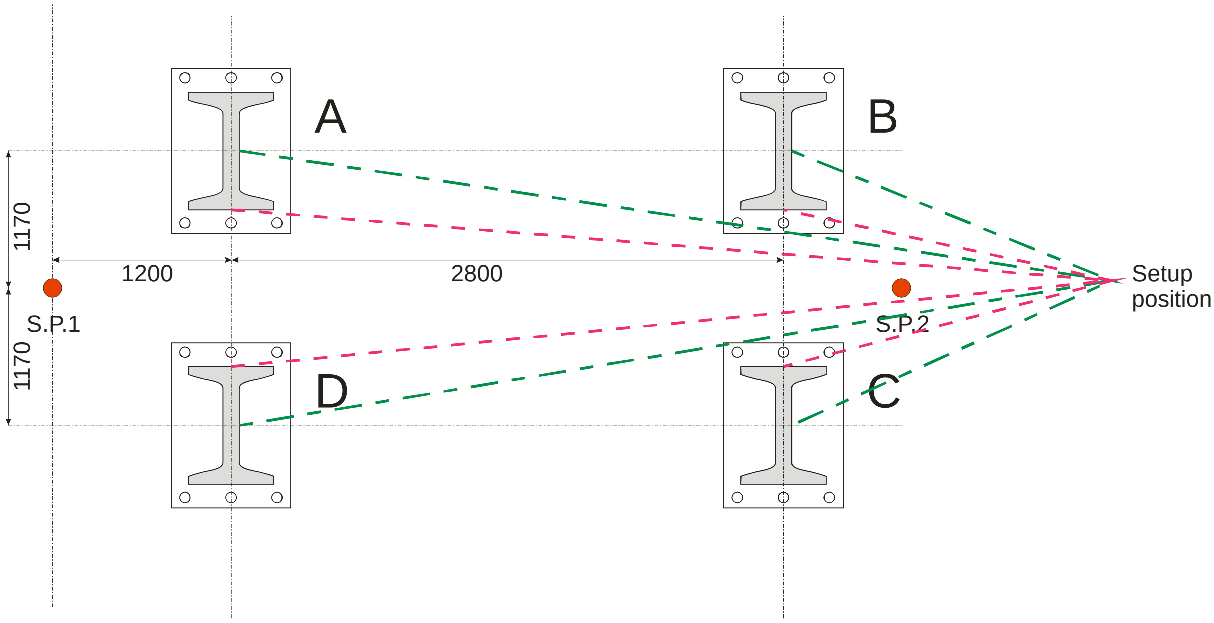


Figure 9: Total station setup.

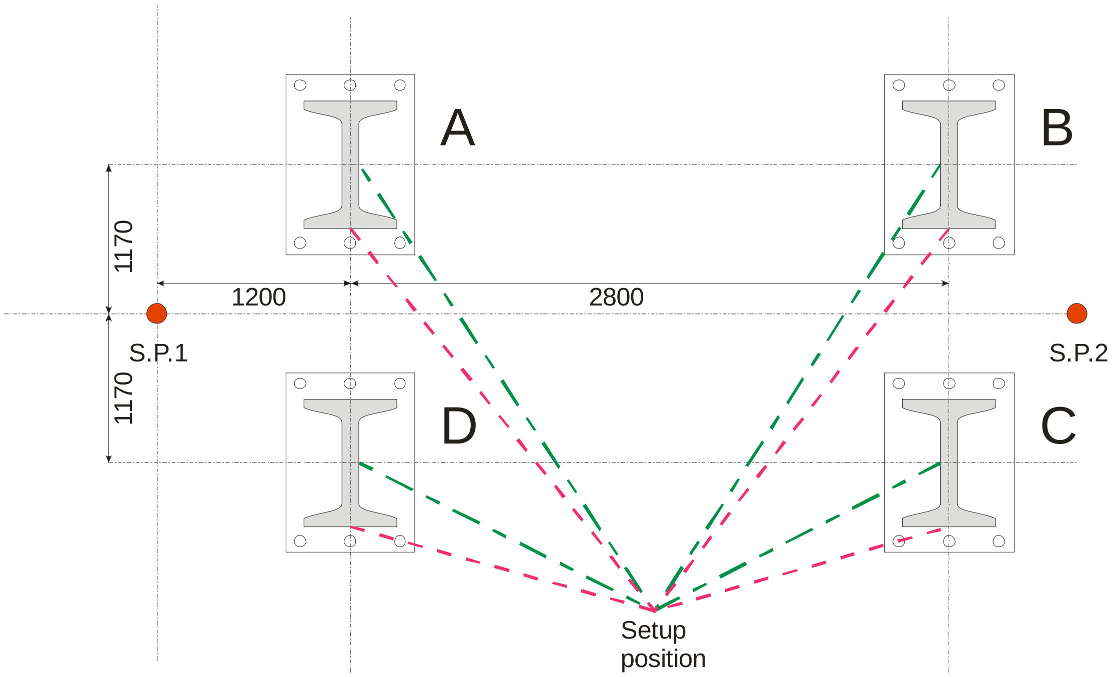


Figure 10: Alternative total station setup.

6.1.3 Assumption 3: Software

The third assumption is that there is access to software capable of calculating chainages and offsets based on a reference line between setout points (S.P.1 and S.P.2 in Figures 9 & 10). This software can be either on board the total station or part of a Computer-Aided Drafting (CAD) package used for post-processing. One example is the ‘Ref Line’ software on board Leica TS15/30 total stations.

6.2 Observation Procedures

The steps followed during observation are straight forward:
1. Set up at a point where you can see the flanges and webs of all columns (or as many as possible because multiple setups may be required).
2. Observe the top of the base plate (or bottom edge of the base plate if practical).
3. Observe the flange of each column as close as possible to the base.
4. Observe the flange of each column as close as possible to the top.
5. Observe the web of each column as close as possible to the base.
6. Observe the web of each column as close as possible to the top.

In this regard, the following should be noted:
- Observations to the web (at the base) are used to calculate the position of the column along the X axis (defined by the line from S.P.1 to S.P.2).
- A comparison of the observations to the web at the base and the web at the top are used to calculate the verticality of the column in the X axis.
- Observations to the flange (at the base) are used to calculate the position of the column along the Y axis (perpendicular to the line from S.P.1 to S.P.2).
- A comparison of the observations to the flange at the base and the flange at the top are used to calculate the verticality of the column in the Y axis.

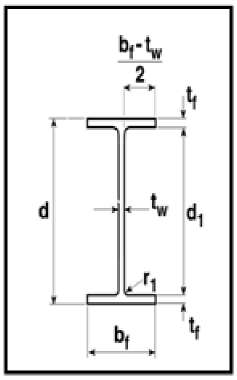
6.3 Calculations

Figure 11 presents an example of results based on a setup similar to Figure 9. Observations to the web and flange are reduced to a horizontal distance (chainage) or horizontal offset from a reference line through the setout points (S.P.1 and S.P.2), then corrected for the observational position relative to the true centre of the column, taking into account which side of the flange and web are observed, the web thickness and the flange width.

The spreadsheet highlights the observations that indicate out of tolerance issues. In this example, the positions of columns B and D exceed tolerances, the verticality of column D exceeds tolerance, and the RL (underside of base) for column C also exceeds tolerance.

Location:	TLO
Date:	12/11/2014
Surveyor:	C. Higgs
Instrument:	TS15 s/n 1234567

		mm
Bf		307
Tw		6.7
Plate		18
RL		10
Vert.	+/-	25
Posit.	+/-	6



Design

	A	B	C	D
Chainage	1200	4000	4000	1200
Offset	-1170	-1170	1170	1170
U/side base (m)	7.450	7.450	7.450	7.450

Colours
Data input
In tolerance
Out of tolerance

NOTE:

+/- Represents observed position relative to centre

t/u Represents top or underside of base plate

Web	A	+/-	B	+/-	C	+/-	D	+/-
Web base	1207	1	4013	1	4002	1	1208	1
Web top	1209	1	4011	1	4001	1	1180	1
X Position	4		10		-1		5	
X Verticality	2		-2		-1		-28	

Flange	A	+/-	B	+/-	C	+/-	D	+/-
Flange base	-1016	1	-1020	1	1011	-1	1008	-1
Flange top	-1017	1	-1018	1	1016	-1	1011	-1
Y Position	1		-4		-6		-9	
Y Verticality	-1		2		5		3	

Plate	A	t/u	B	t/u	C	t/u	D	t/u
RL (m)	7.451	t	7.444	u	7.461	u	7.453	u
RL diff. (mm)	1		-6		11		3	

Figure 11: Extract from spreadsheet calculations.

7 CONCLUDING REMARKS

The remote methodology described in this paper is simple to use and does not require direct access to columns or base plates. It is quick to perform and if onboard software is available the results can readily be determined in the field, a distinct advantage when the construction crew is waiting to grout the base plates or move on to the next phase of construction. This methodology can be easily modified to meet different layout and designs while still being true to the basic assumptions and calculations involved.

ACKNOWLEDGEMENTS

The ideas and methodologies presented in this paper are not my own. They come from shared conversations and shared experiences from a number of surveyors with whom I have worked. Special thanks to Bartek Kocon, a Polish surveyor and friend with whom I worked in Newcastle on the Kooragang Island project, and the team at the Nammuldi Below Water Project in the Pilbara who helped refine the remote methodology presented.

REFERENCES

Encyclopaedia Britannica (2015), Occam's razor, http://www.britannica.com/EBchecked/topic/424706/Occams-razor (accessed Jan 2015).

OneSteel (2014) Hot rolled and structural steel products (7th edition), http://www.onesteelmetalcentre.com/~/media/OneSteel%20Reinforcing/Technical%20Resources/Seventh%20Edition%20Hot%20Rolled%20and%20Structural%20Steel%20Products.pdf (accessed Jan 2015).

Standards Australia (1998) AS/NZS 4100 Steel Structures.