THE DESIGN OF STEEL SECTIONS FOR COMBINED AXIAL LOAD AND BENDING

Angus Low
Director
Ove Arup & Partners Ltd
13 Fitzroy Street
London W1T 4BQ
Angus.Low@arup.com

Angus Low, born 1947, graduated from Cambridge University and joined Arup in London in 1968 where he has since spent most of his career designing bridges. He is interested in understanding design at a fundamental level, which helps him to find simpler solutions.

Summary

The concept of Magnel Space is introduced, and it is used to find the locus of yield forces on a steel section consisting of two flanges and a web. It is shown how the locus can be fitted to a plotted array of moment and force loadcases and the size and position of the flanges and the web can be derived.

1. Introduction

The word "design" usually describes any process by which the defining parameters of some artefact are selected. It is used here, in the title, in a more specific sense to indicate a deterministic process for selecting parameters of both position and size directly from functional requirements.

Papers which cover the theory of design in this sense are rare. The author refers to this lack as the Empty Quarter. Papers in structural engineering can be split either between theory and practice or between behaviour and design. This results in the four quarters indicated below.

	Theory	Practice
Structural behaviour	*many*	*many*
Structural design	*few*	*many*

More specifically it is methods which fix position that are rare. They are usually graphical methods. An example is the method proposed by Gustave Magnel [1] to determine the optimum level of a cable in a prestressed concrete section. His construction known as the Magnel Diagram is the basis of the method proposed here.

The method was discovered while the author was designing tied steel arch bridges for a road in China. The arches rose above the roadway. The arch members were slender so all the major moments in the structure, caused by patch live loading, were carried by the tie beams. These beams carried their maximum axial load under full length loading with only small moments. Large moments, both hogging and sagging, were carried with a lesser axial loads. The beams were designed as fabricated plate girders with two flanges and a web. How was the material to be shared between these elements to meet the requirements efficiently?

2. Magnel Space

The Magnel Diagram is drawn in what can be called Magnel Space which is a space in which two dimensions define position within the section being considered and the third dimension is the inverse of force components acting on or within the section. Magnel's method covers uniaxial

https://doi.org/10.2749/222137908796292344

bending for which a two dimensional Magnel Space is sufficient and the same limitation is imposed here.

Two dimensional Magnel Space is depicted in this paper with a vertical section axis which fixes the level or position of a force within a section. The horizontal axis gives the inverse of the magnitude of the force. The horizontal axis is usually, but not necessarily, drawn at the level of the section centroid.

Magnel Space is well suited to graphical methods for two reasons:
- For many actions the locus of forces of equal effect is a straight line.
- There exists a simple construction for adding the effects of two forces in Magnel Space.

The construction for addition is shown in Fig. 1. W and B are two forces. Their combined effect in magnitude and position is given by point X which is the intersection of and B_SW and BW_S, B_S and W_S being the respective positions of B and W on the section axis. The truth of this proposition can be checked by taking moments on the section at any level and by applying the rules of similar triangles. The procedure for subtraction is implicit, noting that W = X - B.

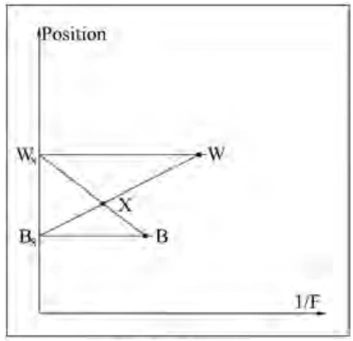

Fig.1. Addition

3. A Plate Girder in Magnel Space

A typical plate girder is shown in Magnel Space in Fig.2. Points T, W and B represent the top flange, web and bottom flange respectively. They are shown as fully yielded in tension. For simplicity it is assumed that the yield forces in tension and compression are equal but if required the method could be reworked for the unequal case to model sections with slender plates which are only partially effective in compression. In general the force in an element can be anywhere between yield in tension and yield in compression so the top flange could be represented by a horizontal line from T running to infinity to the right, reappearing at the left and ending at T', the negative of T. The single point T is shown because it contains sufficient information on its own.

By adding points B and W point X is found which is the force resultant due to the bottom flange and web at yield. Adding T to X gives point A which represents the whole section at yield. Subtracting T from X gives C. It can be seen that AC is the locus of force resultants in the section as it evolves through its first stage from the case of total tension yield at A through to fully plastic combined tension and bending towards full plastic flexure. This is referred to as the plastic locus. As the neutral axis progresses through the top flange point X is reached first when the tension and compression forces in the flanges are equal. C marks the completion of the journey of the neutral axis through the top flange and the start of its journey through the web. Beyond C the plastic locus curves away from the straight line.

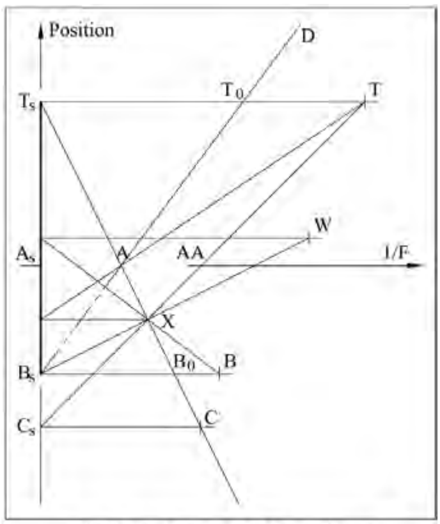

Fig.2. Steel Section in Magnel Space

The method is developed to show how the yield locus DAC can be fitted to multiple loadcases plotted in Magnel Space. Hence, for a given steel area A, positions of T, B and W can be found.