

# A DYNAMIC TEACHING SYSTEM TO SUPPORT THE DESIGN OF STRUCTURAL STEEL MEMBERS

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**Abstract:** Advanced computer programs used for structural analysis and design have become widely used, however, classical and easy-to-use tools, such as design charts and tables, are still preferable by students, who need simple tools instead of sophisticated and time-consuming programs. These tools help students electronically retrieve section properties-related information and use this information in the design of structural members. It is, therefore, clear that design charts, tables, and section properties should be made electronically available to engineering students. In this study, Microsoft Visual Basic, a widely-used and easy-to-use programming language, was used to develop a system that provides students with the ability to create powerful forms that can be used for different steel sections and their properties. The system was developed to produce steel section properties provided in the AISC and CISC Manuals of Steel Construction and needed in the design charts. This paper describes how the system was developed and presents some real-world examples to illustrate its ease-of-use and powerful capabilities over current practices. Comments and recommendations pertaining to future developments in the field are then presented in the conclusions.

## 1 INTRODUCTION

The complete design of any structure, including steel structures, involves the design of the various structural members as well as the connections between the members. The integrity of the load path depends on the strength of the different members and attachments between members. The designer has a choice of several steel sections several types of connections; welded, bolted, riveted, or combination of the above. Load calculations are quite complex and lend themselves well to the use of a spreadsheet. Spreadsheets have evolved into sophisticated computation and presentation tools with a tremendous potential for use as design tools. This paper discusses the design of a steel plate girder and how spreadsheets and Basic Visual programming can facilitate the iterative design process by incorporating the steel section properties needed. The spreadsheet is designed for stand-alone use for many common situations (Adeli and Wilcoski, 1993; Wang et al., 2005; Yassin and Nethercot, 2007).

Spreadsheets have become increasingly popular and widely used among structural engineers because of the ease with which repetitive calculations can be done for a series of variables (Zaneldin and Ashur,

2008; Zaneldin and El-Ariss, 2010). When a design spreadsheet needs information for different steel sections, the most efficient way to get this information is to link the design spreadsheet to the AISC Database. Microsoft Visual Basic (Microsoft Visual Basic, 1998) offers users with the ability to create database that can be used for different steel sections and their properties. This database stores the dimensions and properties for each steel section listed in the Manual of Steel Construction. Accessing this database allows users to automatically lookup and input data that would otherwise need to be manually referenced and entered into a spreadsheet. This simple automation process will allow a job to be done faster and will lower the possibility for errors to occur, particularly for students. Only a section's designation needs to be entered into a design spreadsheet, which can be programmed to retrieve the necessary information from the database. In this paper, an overview of spreadsheets and its macros programming capabilities was first presented and a dynamic system was then developed using Visual Basic programming language. The developed system can be used to provide students with an easy access to retrieve steel section properties that can be used for

different structural steel members. The system was developed to store and modify the different steel section properties as provided in the AISC and CISC Manuals of Steel Construction and needed in the design charts. This paper describes the main components of the system and presents a real-world example to illustrate its ease-of-use and powerful capabilities over current practices. Comments and recommendations pertaining to future developments in the field are then presented in the conclusions.

## 2 SPREADSHEETS

Spreadsheets are becoming increasingly popular. Although spreadsheet programs developed by various software firms have their own special features, they are based on the same working principles and, most of them, are compatible with each other. The spreadsheets developed for the graphic-based operating systems have commonly and efficiently been used in recent years. A user can move around among cells and write information on them. The information may be numeric or alphanumeric values or formulae. Values of variables are written on the cells. The cells or the group of cells can be named if required and formulations can be expressed clearly with the help of these names. All operations concerning spreadsheets are conducted by a core program. This program scans all the filled cells in the sheet and searches for logical relations and updates the operations at once when entering new information into the cells. This feature is called automatic interaction. One of the important concepts of spreadsheets is that of range. A range covers one or more rectangular cells of a sheet. The address of a range can be defined by the addresses of both ends of its diagonal. The addresses representing the ranges can be used as parameters. Some formulations can also be written on their defined range. These types of formulations are used particularly in matrix operations.

One of the most powerful tools of spreadsheets is the use of Macros. Macros are small and powerful code programs which can be written and executed in spreadsheets. This makes it convenient for students as it provides them with the spreadsheet environment while, at the same time, provides the user with the powerful programming capabilities of visual basic. Macros are defined in special sheets called macro sheets. They use the cells of the sheets as variables. There are two kinds: command macros and function macros. Function macros assign the

values of special functions used in spreadsheets while Command macros need special commands to be executed.

## 3 THE DEVELOPED SYSTEM

When using a spreadsheet for the design of structural steel members, and the design requires information for different steel sections, the most efficient way to get this information is to link the design spreadsheet to the AISC or CISC Databases. In this research, an easy-to-use system was developed for the selection of different steel members using Visual Basic. The different steel section properties listed in the AISC and CISC manuals of steel construction were stored in a database that was developed using Microsoft Access 2007 (Microsoft Office Access, 2007). A VBA macro was developed to allow students to easily retrieve the databases by a click of a button in the spreadsheet. This will also allow for automatic lookup and input of steel section properties for use in structural design that would otherwise need to be manually referenced and entered into a steel design spreadsheet. A screen capture of the developed system main screen is shown in Figure 1.

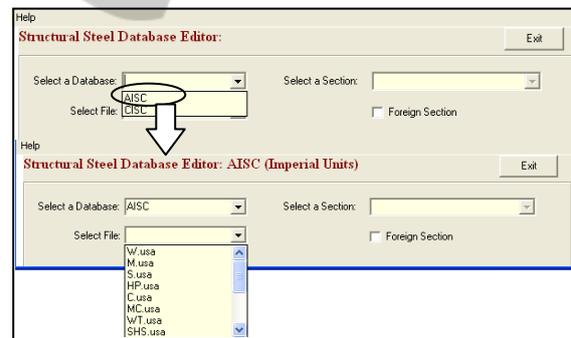


Figure 1: The developed system main screen.

As shown in Figure 1, when a database is selected, all the available shapes will appear in the bottom left part of the screen. When a shape is selected, the different sections related to this shape will be listed and the user can select a shape section. Once a shape section is selected, all its properties will appear in the bottom part of the screen as shown in Figure 2. As shown in the figure, users can modify sections, remove sections, or add new sections. Only a section designation needs to be entered into a design spreadsheet, which is programmed to retrieve the

necessary information from the database generated by the developed system.

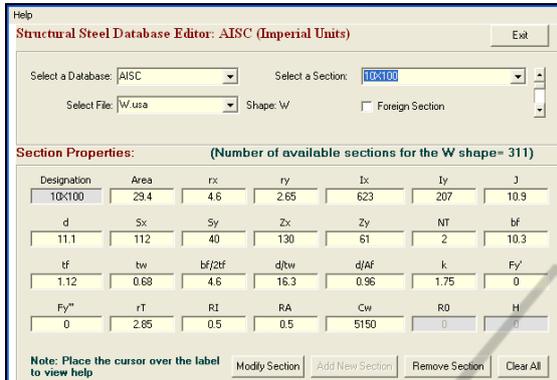


Figure 2: Properties of W10X100 AISC section.

Similarly, a user can also select a shape and section using the CISC and the corresponding section properties will appear as shown in Figure 3.

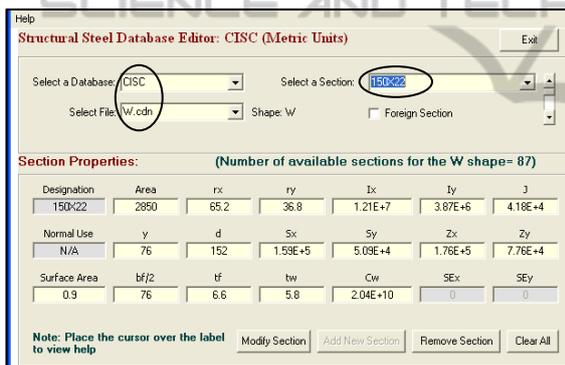


Figure 3: Properties of W150X22 CISC section.

## 4 APPLICATION EXAMPLE

In this example, the flexural yielding limit state is used to analyze structural steel plate girders. The flexural yielding limit state represents the absolute maximum nominal moment that a section can support. At this condition the section is fully yielded. The limit state for strong axis bending in I-shaped member is found in the 13<sup>th</sup> edition of the AISC specifications of Steel Construction Manual (SCM) F2.1 (AISC, 2005; ASCE, 2005) and for weak axis bending in SCM F6. Other situations are covered in other sections of SCM Chapter F and are similar to those presented here. A brief background about the limit state, lateral torsional buckling, and

cover plates was first given and a sample spreadsheet calculation using the developed system was then presented.

### 4.1 The Limit State

The basic limit state follows the standard form. The statement of the limit states and the associated reduction factor and factor of safety are given here:

<b>LRFD</b>	<b>ASD</b>
$M_u < \phi_b M_n$	$M_a < M_n / \Omega_b$
Req'd $M_n = M_u / \phi_b < M_n$	Req'd $M_n = M_u \Omega_b < M_n$
$M_u / (\phi_b M_n) < 1.00$	$M_a / (M_n / \Omega_b) < 1.00$
$\phi_b = 0.90$	$\Omega_b = 1.67$

The values of  $M_u$  and  $M_a$  are the LRFD (Load Resistance and Factor Design) and ASD (Allowable Stress Design) factored loads, respectively, applied to the flexural member. In this case  $M_n$  is the nominal flexural yielding strength of the member. For doubly symmetric compact I-shaped members and channels bent about their major axis:

$M_{nx} = M_{px} = F_y Z_x$  for strong axis bending (AISC 2005 equation F2-1)

$M_{ny} = M_{py} = \min(F_y Z_y, 1.6 F_y S_y)$  for weak axis bending (AISC 2005 equation F6-1)

Where:  $M_p$  is the plastic flexural strength of the member;  $F_y$  is the material yield stress; and  $Z$  is the plastic section modulus for the axis of bending being considered.

### 4.2 Lateral Torsional Buckling

Lateral torsional buckling (LTB) is a strong axis phenomenon. It needs not be considered for weak axis bending. The equations for each of the cases shown in SCM Table User Note F1.1 are found in Chapter F sections referenced in the table. The general form used to compute LTB effects is the same for cases F2, F3, F4, and F5. The differences are in the computation of the key quantities and the details of the equations used in various buckling ranges. Note also that web slenderness is considered in several of the LTB cases. As a result, Web Local Buckling (WLB) is integrated in the LTB equations, making WLB only a consideration for HSS and other square and rectangular tubes.

### 4.3 Cover Plates

Cover plates are plates added to the flanges of beams

to increase the flexural capacity of the beam over some portion of the beam. The use of cover plates in regions of high moment allows the use of a section of lesser weight and lesser flexural capacity to be used as the primary beam. This may result in a cost savings in some cases. This technique is useful for compact beams that are not subject to the limit state of LTB. SCM F13.3 specifies many of the parameters associated with the design of cover plates.

In the case of a compact beam not subject to LTB, the flexural limit state is stated as:

$$\text{Req'd } M_n = (M_u/\phi \text{ or } M_a\Omega) < F_y Z_{\text{total}}$$

Adding cover plates increases the Z of the section. For symmetrical cross sections with symmetrically applied plates, the design inequality becomes:  $\text{Req'd } M_n < F_y (Z_{\text{section}} + Z_{\text{plates}})$

For design purposes, this equation can be re-written as:  $Z_{\text{plates}} > (\text{Req'd } M_n/F_y) - Z_{\text{section}}$

For symmetrical plates, Z is the area of one plate times the distance between the centers of the two plates, so the strength requirement for symmetrical cover plates becomes:

$$Z_{\text{plates}} = bt(d+t) > (\text{Req'd } M_n/F_y) - Z_{\text{section}}$$

Where: d is the overall depth of the steel section to which the cover plates are being added; and t is the thickness of the cover plates.

For unsymmetrical plates (i.e. the cover plates are of different sizes or a cover plate is applied to only one flange), the Z for the whole section must be recomputed using basic concepts. This will involve finding the centroidal axis, locating the center of the areas above and below the centroidal axis, then finding Z by:

$$Z_{\text{total}} = (A_g/2) (\text{distance between the centroids of the two halves})$$

A restriction on the relative values of b and t is the requirement that the plate be compact. As the plate is generally connected to the flange with welds or bolts on both sides, the cover plated is considered a stiffened element and SCM Table B4.1 case 12 applies:  $b/t < 1.12 \sqrt{E/F_y}$

As there are two design variables, b and t, there are an infinite number of combinations of the variables that will result in a  $Z_{\text{total}}$  that matches  $Z_{\text{req'd}}$ . The best solution is generally the one that yields the smallest area. The end result of the analysis process is that the internal moment is larger than the moment predicted by normally used first order (i.e. equilibrium on the un-deflected shape) analysis. It is important that the increased moment (sometimes referred to as a "magnified" moment) be used when comparing required strength to actual strength. Failure to do so is non-conservative.

#### 4.4 Sample Spreadsheet Calculations

Because the calculations above must be performed, the analysis can be done efficiently with a spreadsheet. The spreadsheet example shown in Figures 4 and 5 show some of the analysis steps for a steel plate girder. The database generated using Visual Basic stores the dimensions and properties for each steel section listed in the Manual of Steel Construction. Accessing this database using macros executed from within spreadsheets, allows for automatic lookup and input of data that would otherwise need to be manually referenced and entered into the spreadsheet. This simple automation process will help students in easily enter corresponding section properties and allow a job to be done much faster with fewer errors.

As shown in Figures 4 and 5, the spreadsheet was used to calculate the width to thickness ratios for both the web and flange of the structural steel section. The allowable flexural strength was then calculated based on AISC 360-05 Chapter F4. For these calculations to take place several section properties need to be input to the spreadsheet. The system was used to automatically input these properties as soon as the structural steel shape and section is selected. This makes it easy for students to automatically input the section properties instead of doing this manually. Students will use the spreadsheets to perform the necessary calculations and the already-developed VBA macro shown in Figures 4 and 5 can then be used to retrieve any

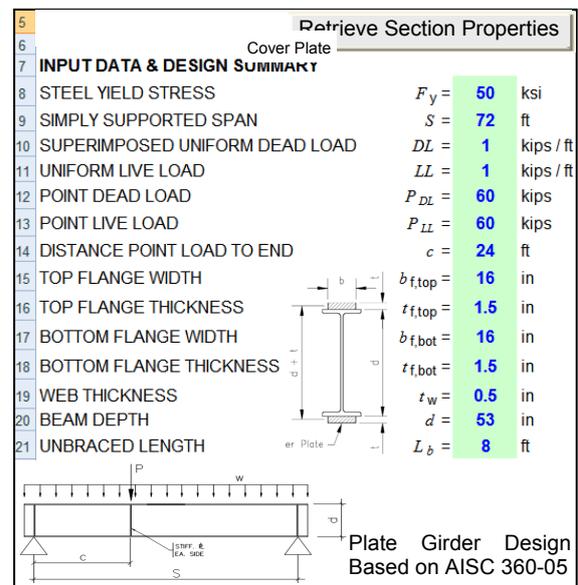


Figure 4: Plate girder input data.

**ANALYSIS** Retrieve Section Properties

CHECK LIMITING WIDTH-THICKNESS RATIOS FOR WEB (AISC 360-05 Table B4.1)

$h_c / t_w = 100.00 < \lambda_r = 137.27$   
 $> \lambda_p = 90.55$

**Noncompact Web**

where  $E = 29000$  ksi  
 $\lambda_r = 5.7 (E / F_y)^{0.5} = 137.27$   
 $\lambda_p = (h_c / h_p) (E / F_y)^{0.5} / (0.54 M_p / M_y - 0.09)^2 = 93.26$  ,for  $A_{f,top} \neq A_{f,bot}$   
 $\lambda_p = 3.76 (E / F_y)^{0.5} = 90.55$  ,for  $A_{f,top} = A_{f,bot}$   
 $h_c = 50.00$  in  $h_p = 50.00$  in  
 $M_p = 6452.1$  ft-kips  $M_y = 5824.6$  ft-kips

CHECK LIMITING WIDTH-THICKNESS RATIOS FOR FLANGES (AISC 360-05 Table B4.1)

$0.5 b_{f,top} / t_{f,top} = 5.33 < \lambda_r = 17.04$   
 $< \lambda_p = 9.15$

**Compact Flanges**

where  $\lambda_r = 0.95 (k_c E / F_L)^{0.5} = 17.04$   
 $\lambda_p = 0.38 (E / F_y)^{0.5} = 9.15$   
 $k_c = \text{Min} [0.76, \text{Max} (0.35, 4 / (h / t_w)^{0.5})] = 0.39$   
 $S_{xt} = 1398$  in<sup>3</sup>  $S_{xc} = 1398$  in<sup>3</sup>

DETERMINE ALLOWABLE FLEXURAL STRENGTH,  $M_n / \Omega_b$ , BASED ON AISC 360-05 Chapter F4

$L_p = 1.1 r_t \sqrt{\frac{E}{F_y}} = 9.59$  ft  
 $L_r = 1.95 r_t \frac{E}{F_L} \sqrt{\frac{J}{S_{xc} h_0}} \sqrt{1 + \sqrt{1 + 6.76 \left( \frac{F_L S_{xc} h_0}{E J} \right)^2}} = 38.20$  ft

where  $a_w = h_c t_w / (b_{fc} t_{fc}) = 1.04$   
 $C_w = I_y h_0^2 / 4 = 679321$ , (AISC 360-05 F2.2)  
 $J = [t_w d (t_w^2 + d^2)] / 12 = 6203.8$  in<sup>4</sup>, (not applicable if taken web only, EIT Manual page 26)  
**(Use  $J = 70.504$  in<sup>4</sup>)**  
 $r_{ts} = [(I_y C_w)^{0.5} / S_x]^{0.5} = 4.34$  in  
 $c = 1.0$   $C_b = 1.0$ , (AISC Manual 13th Table 3-1, page 3-10)

$F_{cr} = \frac{C_b \pi^2 E}{\left( \frac{L_b}{r_{ts}} \right)^2} \sqrt{1 + 0.078 \frac{Jc}{S_x h_0} \left( \frac{L_b}{r_{ts}} \right)^2} = 596.94$  ksi

$M_{n,F2} = \begin{cases} M_p, & \text{for } L_b \leq L_p \\ \text{Min} \left( C_b \left[ M_p - (M_p - 0.7 F_y S_x) \left( \frac{L_b - L_p}{L_r - L_p} \right) \right], M_p \right), & \text{for } L_p < L_b \leq L_r \\ \text{Min} (F_{cr} S_x, M_p), & \text{for } L_r \leq L_b \end{cases} = 6452.1$  ft-kips

**$M_{allowable, F2} = M_n / \Omega_b = 3863.5$  ft-kips** where  $\Omega_b = 1.67$ , (AISC 360-05 F1)

Figure 5: Plate girder analytical results.

required AISC or CISC section properties. It also avoids errors and mistakes resulting from inputting the wrong section properties.

## 5 CONCLUSIONS

In this paper, dynamic system was developed using Visual Basic programming language. The developed

system can be used to provide students with an easy access to retrieve section properties that can be used for different structural steel members. The system was developed to store and modify the different steel section properties as provided in the AISC and CISC Manuals of Steel Construction and needed in the design charts. This paper described the main components of the system and presents a real-world example to illustrate its ease-of-use and powerful capabilities over current practices. The developed dynamic system can also be used by professional engineers during the structural design of steel buildings as an automated tool to replace the manual use of steel charts and manuals. Once a design spreadsheet is programmed, a user only needs to input a section designation and the spreadsheet will determine the other desired information. This can be done quickly and accurately for a series of steel sections making spreadsheets a very powerful design tool.

Authors are currently working in automating the structural design process and linking it with required design codes, standards, charts, and manuals. The developments made in this regard will be presented in a separate paper.

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