DEVELOPMENT OF SPREADSHEET DESIGN TOOL FOR STEEL BEAM-COLUMN AS PER INTERNATIONAL STANDARDS

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CERTIFICATE

This is to certify that project entitled "Development of Spreadsheet Design Tool for Steel Beam-column as per International Standards" submitted by Sourav Kumar Pattnaik in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my personal supervision and guidance. To the best of my knowledge the matter embodied in this project review report has not been submitted in any college/institute for awarding degree or diploma.

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Abstract

The design methodology in light of Limit State Method includes various mathematical statements and parameters, which makes the outline handle a perplexing and monotonous undertaking. Additionally outline being an experimentation procedure is extremely repetitive and time-consuming in nature. Henceforth utilization of spreadsheets can decrease the time and exertion of a planner/build extensively. On account of the minimization and adaptability, spreadsheets have turned into one of the best decisions for a designer, notwithstanding the accessibility of number of standard configuration programming packages.

Despite the fact that advancement of spreadsheets are exceptionally basic now-a-days, very few of them incorporates an itemized configuration method for different universal codes. So the primary point of this undertaking is to set up a Microsoft Excel Spreadsheet which will involve an itemized configuration of Steel beam-columns for two distinctive steel codes. The two steel codes being the Indian Steel Code (IS 800-2007), and the American Steel Code (AISC 360-2010).

The result of this venture will be an outline apparatus, which can be advantageously utilized by a specialist to check the outline status of a segment area and to strike a harmony between safety and economy through an optimum use of material and time as well.

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CHAPTER-1
Introduction

1.1 INTRODUCTION

Steel because of its different preferences has been credited as a basic configuration material. High quality/weight proportion makes steel an exceptionally appealing basic material for elevated structures, long-span bridges, structures situated on delicate ground, and structures situated in high seismic zones where strengths following up on the structure because of a tremor are as a rule corresponding to the weight of the structure. Legitimately outlined steel structures can have high ductility, which is an imperative trademark for opposing stun stacking, for example, impacts or earthquake.

Structural steel sections are usually used for construction of buildings, buildings, and transmission line towers (TLT), industrial sheds and structures etc. They also find in manufacturing of automotive vehicles, ships etc. Steel exhibits desirable physical properties that make it one of the most versatile structural materials in use. Its great strength, uniformity, light weight, ease of use, and many other desirable properties makes it the material of choice for numerous structures such as steel bridges, high rise buildings, towers, and other structure.

Elasticity: steel follows hooks law very accurately.

Ductility: A very desirable of property of steel, in which steel can withstand extensive deformation without failure under high tensile stresses, i:e., it gives warning before failure takes place.

Toughness: Steel has both strength and ductility.

Additions to existing structures: Example: new bays or even entire new wings can be added to existing frame buildings, and steel bridges may easily be widened.

1.2 STEEL BEAM-COLUMN

. Beam-columns are aptly named as sometimes they can behave essentially like restrained beams, forming plastic hinges, and under other conditions fail by buckling in a similar way to axially loaded columns or by torsional buckling similar to unrestrained beams.

Most columns are subjected to bending in addition to the axial load; considerable care should be taken in a practical situation to load a column under axial load only. When significant bending is present in addition to an axial load in a member, the member is termed as beam-column.

Beam-columns in steel structures are often subjected to biaxial bending moments, acting in two principal planes, due to the space action of the framing system. The column cross section is usually oriented in such a way to resist significant bending about the major axis of the member. When I-shaped cross sections are used for the columns, the minor axis bending may also become significant, since the minor axis bending resistance of I-section is small compared to the major axis bending resistance.

Thus, in general, beam-columns are subjected to axial forces and bending moment. The moments may be at the ends, as in rigid framed buildings, or developed at an interior point from the bracket, local beam, cable attachments. As the bending moment on a beam-column approaches zero, the member tends to become a centrally loaded column and as the axial forces on a beam-column approaches zero, the member behaves as a beam. All the parameters that affect the behavior of a beam or a column such as, length of the member, geometry, material properties, support conditions, magnitude and distribution of transverse loads and moments; will also affect the behavior, strength, and design of beam-columns

1.3 GENERAL BEHAVIOUR OF STEEL BEAM-COLUMN

Beam-columns are aptly named, as sometimes they can behave essentially like restrained beams, forming plastic hinges, and under other conditions fail by buckling in a similar way to axially loaded columns or by lateral torsional buckling similar to restrained beams. The bending moments on a beam-column may be due to any of the following effects.

(a) Eccentricity of axial force

(b) Building frame action

(c) Portal frame action

(d) Load from brackets

(e) Transverse loads

(f) Fixed base condition

Deformation and failure of a beam-column section depends on both bending moment (M) and axial force (P) resulting corresponding deflection (δ) and end point rotation (Ø). Based on this the behavior of the beam-column may be classified into the following five cases.

1. A short beam-column subjected to axial load and uniaxial bending about either axis or biaxial bending. Failure occurs when the plastic capacity of the section is reached, with the limitations set in the second case.

2. A slender beam-column subjected to axial load and uniaxial bending about the major axis z-z. If the beam-column is supported laterally against buckling about the minor axis y-y out of the plane bending, the beam-column fails by buckling about z-z axis. It represents as interaction between column buckling and simple uniaxial bending. If the beam-column is not very slender a plastic hinge forms at the end point of maximum moment.

3. When slender beam-column is subjected to axial load and uniaxial bending about the minor axis y-y it fails by buckling about the y-y axis. It also represents an interaction between common buckling and uniaxial bending.

4. A slender beam-column section subjected to axial load and bending about the major axis z-z, and not restrained out of the plane of bending, then it fails due to a combination of column buckling about y-y axis and lateral torsional buckling.

5. A slender section subjected to axial load and biaxial bending and not having any lateral support, the ultimate behavior of the section is complicated by the effect of plastification, moment magnification and lateral torsional buckling.

1.4 MOTIVATION OF THE PRESENT STUDY

Steel design codes are consistently developing through the years to meet the needed execution of the structural components. The most recent version of Indian Code of practice for general steel development, IS 800-2007 is in light of the Limit State System. The design method has experienced a radical change in examination to the prior design code IS 800-1984, which was in view of the Elastic Method of design. The same strives for the American Code of Specification for Structural Steel Structures and the British Standards also. The most recent form of the previous is AISC 360-2010 and that of the last being BS 5950-2000. The design in light of Limit State Method includes various complex comparisons and parameters. Henceforth flipping the pages of the design manual to turn upward a design quality parameter or a segment size for a given burden is time intensive as well as bulky for the designer in which case a spread sheet design tool for safety check and design considerations prove helpful for rapid analysis of different sections of the structure.

1.5 OBJECTIVE OF PRESENT STUDY

In present era many analysis softwares such as STAAD, SAP etc. are available for calculation of bending moment, shear force, sway, deflection and animation regarding effect of combined forces on the desired structure. But the spread sheet on the design of steel beam-columns that inculcates all the design steps and formulae in which we can enter different parameters required for design of a particular section of a whole structure.

The major advantage of the spreadsheet is that it allows the designer to analyze different sections of a structure separately and also finds whether it is safe or not. It is a useful handy tool to examine a particular section without analyzing the whole structure, which may be hectic and time consuming in other softwares. This venture is an endeavor to set up a Microsoft Excel Spreadsheet for the design of steel columns for Indian and American Steel codes which can be utilized to check the design status of a desired section and to strike the balance between a safe section and an economic section along with precision and flexibility.

1.6 SCOPE OF THE WORK

The extent of present work is limited to the design procedure incorporation in Microsoft Excel sheet alongside with major co-ordination with Macros and Visual-Basic Editor for storage and implementation for various section parameters in the design procedure to calculate different design output values which are required to be analysed for the safety check of beam-column. Microsoft Excel sheet is extensively used for calculation of different numerical functions and repetitive use of output values for safety check.

1.7 ORGANISATION OF THE THESIS

Following this introductory chapter, the organisation of further Chapters is completed as explained below

1. A review of literature is conducted on general behavior and failure criteria of steel beam-column under axial load flexure, design of beam-column section in accordance with Indian Standard code and American Standard code using Limit State Design Method (LSM) and Load and Resistance Factor Design method (LRFD) respectively and finally the previous ventures for development of Design Sheets are the contents of Chapter-2.
2. Using features of MS Excel sheet the different modules of design spreadsheet are developed and design methodology is implemented to Design Sheet. Trial beam-column sections for both the codes using two different design methods are designed and safety check is conducted in Chapter-3.
3. The conclusion drawn form results of Chapter-3 is disussed in Chapter-4 along with the discussion of future aspect of the study.

C H A P T E R - 2

Review of Literature

2.1 INTRODUCTION

As the present study deals with development of spreadsheet for design and safety check of steel beam-columns, a detailed analysis is discussed and the literature review has been conducted on various design procedures for steel according to different International codes of practices, modes of failure at different end conditions and modes of application of load. Most importantly the literature review also comprises prior attempts and development of design charts and spreadsheet applications fir design of steel sections.

2.2 STEEL BEAM-COLUMN

The design strength of steel beam-columns at different end conditions was considered and the failure envelope was analysed by Dowling P.J, Knowles, P.R. and Owens. In frame structures of steel columns behave like beam-columns due to the axial force acting on it due to the applied load as well as it experiences bending moment due to sway in the structure based on which the members can be classified into two categories, namely braced and unbraced. The resistance to lateral load at floor level by the barcing in case of barced frames as shown in Fig. 2.1.

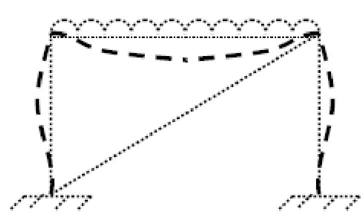


Fig 2.1 Braced Frame Structure

In case of unbraced frames the resistance to lateral loads is obtained from the members of the frames with moment resisting connections between them in case of unbraced frames as shown in Fig. 2.2.

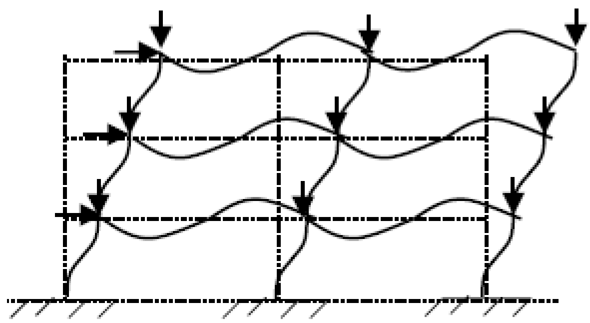


Fig. 2.2 Unbraced frame structure

Thus the relative translation in between the ends of a column in a braced frame is prevented, whereas in unbraced frames the columns are free to sway causing relative translation between their ends.

2.2.1 BEHAVIOUR AND TYPES OF FAILURE

The response of a typical beam-column for lateral deflection() and end-joint rotation (Ø) under both bending moment(M) and axial load (P) was analysed and plotted by N. Subramanian in his book Design of Steel Structures. The features that dominate the behavior of steel beam-column depends upon the strength attained form the curve shown in Fig. 2.3 in next page.

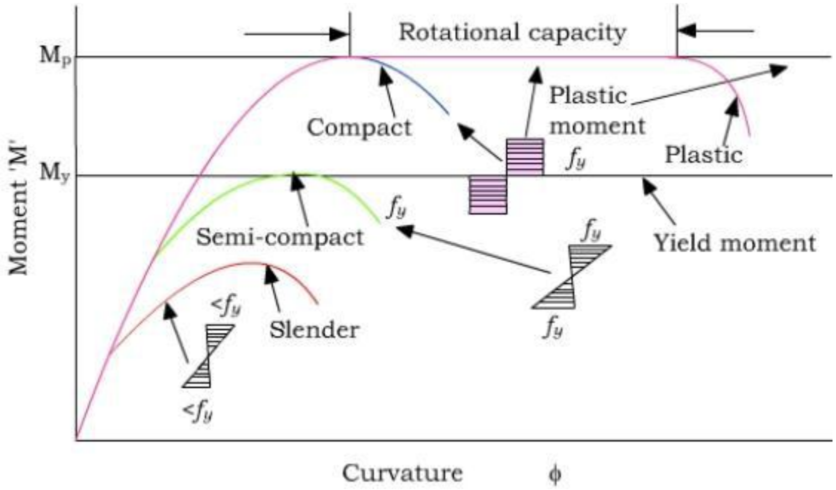


Fig. 2.3 Behaviour of different beam-column cross-sections

From the curve it can be concluded that the behavior of steel beam-column becomes non-linear almost from the start due to the P-(δ) effect which is even more substantial in increase of applied end moments. For compact section yielding may occur at the most severely stressed fibers due to combined effect of primary moment(M) and secondary(P-δ) moment. As curvature increases, subsequently secondary (P-δ) moment increases as a result of which a larger portion of moment capacity across the cross-section of beam-column is acquired by secondary moment. Plasticity gets extent into the section with increasing moment due to which local hinge is developed and the hinge will further spread a short distance down the section which results in moderate downward slope on M-Ø curve and finally the moment carrying capacity gets exceeded due to formation of plastic hinge.

When the beam-column section is slender the cross-section is weak in torsion lateral-torsional buckling may occur in elastic range or in elastic range which depends on slenderness of the section. When slenderness ratio of the member is low or when the member is bent about the minor principal axis, lateral torsional buckling does not occur. When a member has axis symmetry i.e. moment of inertia is equal along both major and minor axes lateral-torsional buckling does not occur. Local buckling of component elements is another form of failure that may occur in section with high width to thickness ratio.

An analysis on failure envelope of steel beam-column sections by Owen stress distribution over the cross-section of a beam-column under combined compression and bending moment at failure is shown in Fig 2.4.

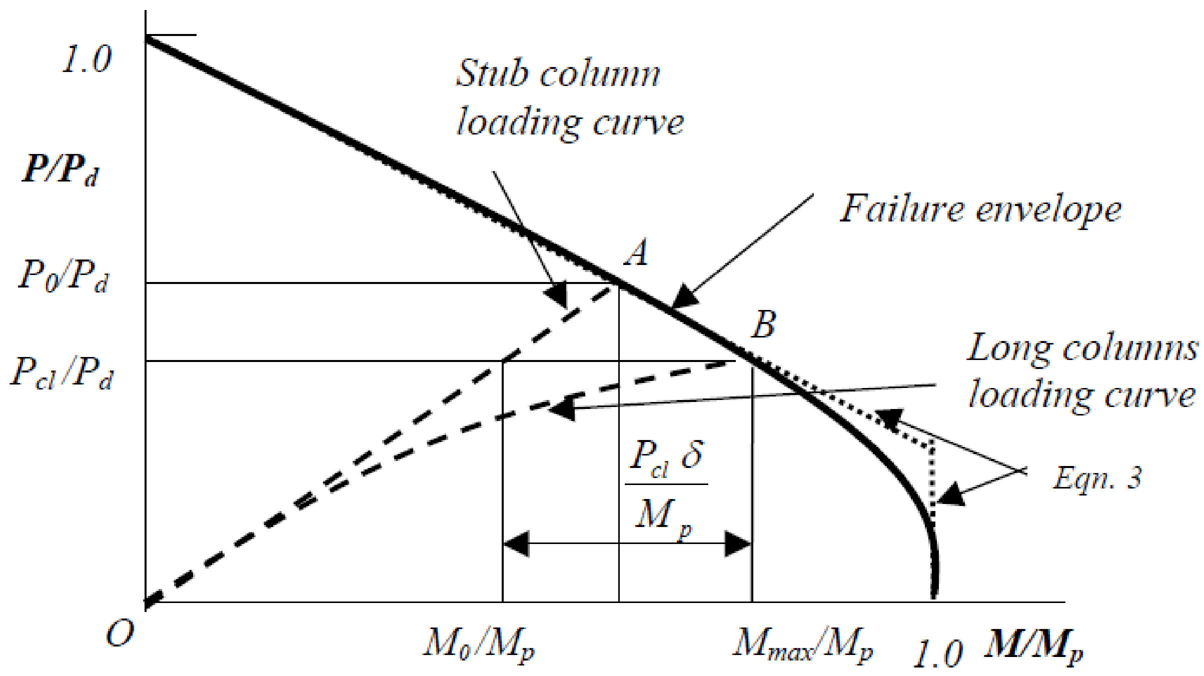


Fig. 4 Beam-column failure envelope

Considering an end beam-column made of I section and subjected to axial compression (P) and bending moment (M) corresponding failure envelope of the beam-column section is shown in Fig. 4. At smaller values of axial compression, only a small area of the cross section nearby the neutral axis is essential to balance the external compression (P). As the plastic moment capacity (M_p) of the cross section is poorly contributed by the area nearby the neutral axis, the decrease in moment capacity (M) is small when the axial compression is small. It is evident from the failure envelope that for negligible axial compression ($P / P_d < 0.15$) the decrease in the moment capacity is negligible ($M/M_p \approx 1.0$).

2.3 DESIGN CODE

International codes of practices aids as reference records for construction, maintenance, serviceability, safety check by using optimum material and maximum safety. Different countries have improvised their own standard codes of practices based on various design methods and design criteria. This section of study focuses on the reference taken in form of design methods, required safety checks, numerical relations between different parameters, design tables for the design of steel beam-column section. Two major International codes i.e. Indian Standard Code of practice for general construction of steel IS 800:2007 and American Standard Code of practice AISC 360-2010 are referred which are based on Limit State Method (LSM) and Load and Resistance Factor Design (LRFD) respectively.

2.3.1 INDIAN STANDARD CODE (IS 800: 2007)

IS 800 is the Indian Standard code of practice for general construction in steel. The earlier revision of this standard was done in year 1984 and the latest revision of 2007 was released on 22 February 2008. The earlier version of the code used Allowable Stress Design method for design of various structural elements of steel structures. As with the development of Limit State Method, which was technologically advanced and provided more economical way for construction, it was found to be essential to modify the design procedure to LSM while preserving Allowable Stress Design as a substitute method for design and the IS Code was amended in 2007.

2.3.1.1 DESIGN PROCEDURE:

The design based on LSM for beam-column design in accordance with IS 800: 2007 the following safety checks are required to be performed.

1. Local Capacity Check:

$$[(M_y/ M_{ndy})^{\alpha_1}] + [(M_y/ M_{ndz})^{\alpha_2}] <= 1.0 \qquad (2.1)$$

2. Overall Buckling Check:

$(P/P_{dy}) + K_y[(C_{my}*M_y)/M_{dz}] + K_{LT}(M_z/M_{dz}) <= 1.0$ (2.2)

$(P/P_{dz}) + 0.6K_y[(C_{my}*M_y)/M_{dz}] + K_z[(C_{mz}* M_z)/M_{dz}] <= 1.0$ (2.3)

The design procedure for design of beam-column according to IS 800:2007 as follows.

2.3.1.1.1 DESIGN COMPRESSIVE STRENGTH (Clause 7.1.2)

The design compressive strength (P_d) of a member is given by;

$P < P_d$ (2.4)

Where $P_d = A_c * f_{cd}$ (2.5)

A_c= Effective cross-sectional area

F_{cd}= Design compressive stress obtained

The design compressive stress (f_{cd}) of axially loaded compression member can be calculated using the following equation.

$f_{cd} = (f_y/\gamma_{m0}) /(\phi+(\phi^2-\lambda^2)^{0.5})$ (2.6)

Where

$\Phi = 0.5*[1+\alpha (\lambda-0.2)+ \lambda^2]$ (2.7)

Λ = Non dimensional slenderness ratio= $(f_y/f_{cc})^{0.5}= [f_y(KL/r)^2/\pi^2E]^{0.5}$ (2.8)

f_{cc}= Euler buckling stress= $(\pi^2E)/(KL/r)^2$ (2.9)

Where

KL/r = Effective slenderness ratio i.e. ratio of effective length, KL to appropriate radius of gyration, r

α = Imperfection factor as per Table 7 in IS 800:2007

Table 7 Imperfection Factor, α

(*Clauses* 7.1.1 *and* 7.1.2.1)

Buckling Class	a	b	c	d
α	0.21	0.34	0.49	0.76

Table 2.1 in Reference of IS 800:2007 Clause 7.1.1 and 7.1.2

χ = Stress reduction factor for different buckling class = $1/[\phi+(\phi^2-\lambda^2)^{0.5}]$ (2.10)

γ_{m0} = Partial safety factor for material strength

2.3.1.1.2 DESIGN STRENGTH IN BENDING (FLEXURE) (Clause 8.2)

The factored design moment, M at any section, in a beam due to external actions, shall satisfy the following relation.

$M <= M_d$ (2.11)

Where,

M_d = Design bending strength of the section calculated.

LATERALLY SUPPORTED BEAM

The design bending strength of laterally supported beam can calculated by the following relation.

$M_d = (\beta_b * Z_p * f_y)/ \gamma_{m0}$ (2.12)

To avoid irreversible deformation under serviceability loads, M_d shall be less than $1.2* Z_p*f_y/ \gamma_{m0}$ in case of simply supported and $1.5* Z_p*f_y/ \gamma_{m0}$ in cantilever beams.

Where,

β_b = 1.0 for plastic and compact sections

$\beta_b = Z_e/Z_p$ for semi compact sections

Z_e, Z_p = Plastic and elastic section moduli for the section respectively

f_y = Yield stress of the material and γ_{m0} = Partial safety factor

LATERALLY UNSUPPORTED BEAM

The design bending strength of laterally unsupported beam can calculated by the following relation.

$M_d = (\beta_b * Z_p * f_{bd})$ (2.13)

Where,

β_b = 1.0 for plastic and compact sections

$\beta_b = Z_e/Z_p$ for semi compact sections

Z_e, Z_p = Elastic section modulus and plastic section modulus with respect to extreme compression fibre

f_{bd} = Design bending compressive stress obtained

Again design bending compressive stress can be computed by the following relation

$f_{bd} = (\chi_{LT} * f_y) / \gamma_{m0}$ (2.14)

Where χ_{LT} = Bending stress reduction factor to account for lateral torsional buckling

χ_{LT} can be calculated from the following relation.

$\chi_{LT} = 1/[\phi_{LT} + (\phi_{LT}^2 - \lambda_{LT}^2)^{0.5}] <= 1.0$ (2.15)

$\phi_{LT} = 0.5[1 + \alpha_{LT}(\lambda_{LT} - 0.2) + \lambda_{LT}^2]$ (2.16)

Where,

α_{LT} = Imperfection parameter and is given as α_{LT} = 0.21 for rolled section

and 0.49 for welded section

The non-dimensional slenderness ratio, λ_{LT} is given by the relation as follows.

$\lambda_{LT} = [(\beta_b*Z_p*f_y)/M_{cr}]^{0.5} <= [1.2*(Z_e f_y)/M_{cr}]^{0.5} = [f_y/f_{cr,b}]^{0.5}$ (2.17)

Where

M_{cr} = Elastic critical moment calculated in accordance with Clause 8.2.2.1

$f_{cr,b}$ = Extreme fiber bending compressive stress corresponding to elastic lateral buckling moment in accordance with Clause 8.2.2.1 and Table-14 in Is 800:2007

2.3.1.1.3 DESIGN UNDER COMBINED AXIAL FORCE AND BENDING MOMENT (Clause 9.3)

Under combined axial force and bending moment, section strength as governed by material failure and member strength as governed by buckling failure shall be checked in accordance with Clause 9.3.1 and 9.3.2 respectively.

SECTION STRENGTH (Clause 9.3.1)

For plastic and compact sections:

In the design of members subjected to combined axial force and bending moment the following relation should be satisfied.

$[(M_y/ M_{ndy})^\wedge\alpha_1] +[(M_y/ M_{ndz})^\wedge\alpha_2] <= 1.0$ (2.18)

For standard I or H sections

For $n <= 0.2$ $M_{ndy} = M_{dy}$

For $n > 0.2$ $M_{ndy} = 1.56M_{dy}(1-n)*(n+0.6)$ (2.19)

$M_{ndz} = 1.11 M_{dz} (1-n)$ (2.20)

Where,

M_y , M_z = Factored applied moments about the minor and major axis of the cross-section, respectively

M_{ndy} , M_{ndz} = Design reduced flexural strength under combined axial force and the respective uniaxial moment acting alone

N = Factored applied axial force (tensin T or compression P)

N_d = Design strength in tension, T_d as obtained from 6 or in compression due to yielding given by

$N_d = (A_g*f_y)/\gamma_{m0}$ (2.21)

M_{dy} , M_{dz} = Design strength under corresponding moment acting alone

A_g = Gross area of cross-section

α_1 , α_2 = constants as given in Table-17

Table 17 Constants α_1 and α_2

(*Clause* 9.3.1.1)

Sl No. (1)	Section (2)	α_1 (3)	α_2 (4)
i)	I and channel	$5n \geq 1$	2
ii)	Circular tubes	2	2
iii)	Rectangular tubes	$1.66/(1-1.13n^2) \leq 6$	$1.66/(1-1.13n^2) \leq 6$
iv)	Solid rectangles	$1.73+1.8n^3$	$1.73+1.8\,n^3$

NOTE — $n = N/N_d$.

Table 2.2 in Reference of IS 800:2007 Clause 9.3.1.1

γ_{m0} = Partial factor of safety in yielding

OVERALL MEMBER STRENGTH (Clause 9.3.2)

Members subjected to combined axial force and bending moment shall be checked for overall buckling failure as given in this section.

The overall member strength of members subjected to combined bending and axial compression is determined in accordance with Clause 9.3.2.2.

BENDING AND AXIAL COMPRESSION (Clause 9.3.2.2)

Members subjected to combined axial compression and biaxial bending shall satisfy the following interaction relationships:

$(P/P_{dy}) + K_y[(C_{my}*M_y)/M_{dz}] + K_{LT}(M_z/M_{dz}) <= 1.0$ (2.22)

$(P/P_{dz}) + 0.6K_y[(C_{my}*M_y)/M_{dz}] + K_z[(C_{mz}* M_z)/M_{dz}] <= 1.0$ (2.23)

Where,

C_{my} , C_{mz} = Equivalent uniform moment factor as per Table-18 in IS 800:2007

P = Applied axial compression under factored load

M_y , M_z = Maximum factored applied bending moments about Y nad Z axis of the member respectively

P_{dy} , P_{dz} = Design strength under axial compression as governed by buckling about minor (y) and major (z) axis respectively

M_{dy} , M_{dz} = Design bending strength about minor (y) and major (z) axis respectively corresponding laterally unsupported length of cross-section

$K_y = 1 + (\lambda_y – 0.2)n_y <= 1 + 0.8n_y$ (2.24)

$K_z = 1 + (\lambda_z – 0.2)n_z <= 1 + 0.8n_z$ (2.25)

$K_{LT} = 1- [(0.1\lambda_{LT} * ny)]/(C_{mLT} – 0.25) >= 1- (0.1n_y)/(C_{mLT} – 0.25)$ (2.26)

Where,

n_y , n_z = Ratio of actual applied axial force to the design axial strength for buckling about y and z axis respectively

C_{mLT} = Equivalent uniform moment factor for lateral torsional buckling corresponding to the actual moment gradient between lateral supports against torsional deformation in the critical region under consideration.

2.3.2 AMERICAN STANDARD CODE (AISC 360-2010)

The American Standard Code (AISC 360-2010) i.e. specifications for structural steel buildings is grounded upon effective usage in prior conditions, developments in the state of knowledge, and changes in design practice. The 2010 American Institute of Steel Construction’s Specification for Structural Steel Buildings provides an incorporated treatment of Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD).

2.3.2.1 DESIGN PROCEDURE

American Standard Code (AISC 360:2010) commends two sets of section cataloguing systems. Sections are classified into two types, as slender element and non-slender element sections for study of compression. The width(w)-to-thickness(t) ratio of the compression elements should not exceed λr for a non-slender element section from Table B 4.1a. If the width(w)-to-thickness(t) ratio of any compression element surpasses λr, that section is a slender element section. For bending, sections are categorized into three types, as non-compact, compact and slender-element sections. For a compact section the flanges of the section should be continuously connected to web or webs and the width(w)-to-thickness(t) ratios of the compression elements of the section should not exceed the limiting width(w)-to-thickness(t) ratios, λp, from Table B4.1b. When the width(w)-to-thickness(t) ratios of any elements exceeds λp, but should not exceed λr from Table B4.1b, then it is a non-compact section. When the width(w)-to-thickness(t) ratio of any compression element surpasses λr, then it is a slender-element section.

The American Standard code specifications for structural steel buildings i.e. AISC 360-2010 provides the subsequent linear interaction methods for beam-columns being loaded in biaxial mode. It services only a distinct equation for the assessment of all the potential modes of failure i.e. respective member in-plane, cross-section of the member and lateral torsional strength. The two conditions required for the safety check of beam-column section in accordance with AISC 360-2010 are as follows.

Condition-1:

When $P_r/P_c >= 0.2$ then $(P_r/P_c) + (8/9)[(M_{rx}/M_{cx}) + (M_{ry}/M_{cy})] <= 1.0$ (2.27)

Condition-2:

When $P_r/P_c < 0.2$ then $(P_r/2P_c) + [(M_{rx}/M_{cx}) + (M_{ry}/M_{cy})] <= 1.0$ (2.28)

2.3.2.1.1 DESIGN OF MEMBERS FOR COMPRESSION

The design compressive strength, ϕ_c , and the allowable compressive strength, P_n /Ω_c, are determined as follows. The nominal compressive strength, P_n, shall be the lowest value obtained based on the applicable limit states of flexural buckling, torsional buckling, and flexural torsional buckling.

$\phi_c = 0.90$ (LRFD) $\Omega_c = 1.67$ (ASD) (2.29)

FLEXURAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

The nominal compressive strength, P_n, shall be by the limit state of flexural buckling.

$P_n = F_{cr} * A_g$ (2.30)

The critical stress, f_{cr}, can be determined as follows:

(a) When $(KL/r) <= 4.71(E/F_y)$ (or $F_y/F_e <= 2.25$) then $F_{cr} = [0.658^{(Fy/Fe)}] * F_y$ (2.31)

(b) When $(KL/r) > 4.71(E/F_y)$ (or $F_y/F_e > 2.25$) then $F_{cr} = 0.877F_e$ (2.32)

Where,

F_e = Elastic buckling stress determined by the following relation

$F_e = (\pi^2 E)/(KL/r)^2$ (2.33)

FLEXURAL BUCKLING OF MEMBERS WITH SLENDER ELEMENTS

This section is applicable to slender-element compression members for elements in uniform compression.

The nominal compressive strength, Pn, is found out based on a net correction factor, Q.

The nominal compressive strength, P_n, should be the minimum value based on the applicable limit sates of flexure buckling, torsional buckling and flexure-torsional buckling. Nominal compressive strength, P_n, can determined by the following relation.

$P_n = F_{cr} * A_g$ (2.34)

The critical stress, F_{cr}, can be determined as follows:

(a) When $(KL/r) <= 4.71(E/QF_y)$ (or $QF_y/F_e <= 2.25$) then $F_{cr} = Q[0.658^{(Fy/Fe)}] * F_y$ (2.35)

(b) When $(KL/r) > 4.71(E/QF_y)$ (or $QF_y/F_e > 2.25$) then $F_{cr} = 0.877F_e$ (2.36)

Where,

F_e = Elastic buckling stress

Q = Net reduction factor accounting for all slender compression elements;

= 1.0 for members without slender elements, for elements in uniform compression

= Q_s*Q_a for members with slender element section, for elements in uniform compression

2.3.2.1.2 DESIGN OF MEMBERS FOR FLEXURE

This applies to doubly symmetric I-shaped members and channels bent about their major axis, having compact webs and compact flanges as defined in Section B4.1 for flexure.

YIELDING

$M_n = M_p = F_y * Z\alpha$ (2.37)

Where,

F_y = Specified minimum yield stress of the type of steel used

$Z\alpha$ = Plastic section modulus of the section about x-axis in mm^3

2.3.2.1.3 DESIGN FOR COMBINED AXIAL FORCE AND BENDING

(a) When $P_r/P_c >= 0.2$ then $(P_r/P_c) + (8/9)[(M_{rx}/M_{cx}) + (M_{ry}/M_{cy})] <= 1.0$ (2.38)

(b) When $P_r/P_c < 0.2$ then $(P_r/2P_c) + [(M_{rx}/M_{cx}) + (M_{ry}/M_{cy})] <= 1.0$ (2.39)

Where,

P_r = Required axial strength using LRFD or ASD load combinations, kips (N)

P_c = Available axial strength, kips (N)

M_r = Required flexural strength using LRFD or ASD load combinations, kips-in (N-mm)

M_c = Available flexural strength, kips-in (N-mm)

x = Subscript symbol related to weak axis bending

y = Subscript symbol related to strong axis bending

For design according to Section B3.3 (LRFD):

P_r = Required axial strength using LRFD load combinations, kips (N)

$P_c = \phi_c * P_n$ = Design axial strength determined in accordance with Chapter E, kips (N)

M_r = Required flexural strength using LRFD load combinations, kips-in (N-mm)

$M_c = \phi_b * M_n$ = Design flexural strength determined in accordance with Chapter F, kips-in (N-mm)

ϕ_c = Resistance factor for compression = 0.90

ϕ_b = Resistance factor for bending = 0.90

Table B4.1a for width-to-thickness ratios of compression elements of members subjected to axial compression and Table B4.1b for width-to-thickness ratios of compression elements of members subjected to flexure are given in the next page.

TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements
Members Subject to Axial Compression

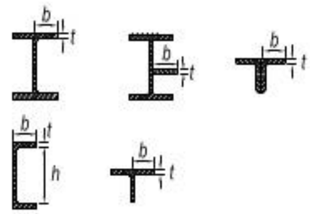
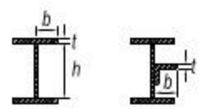
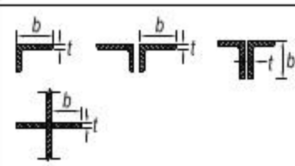
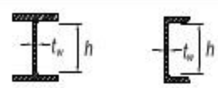
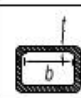
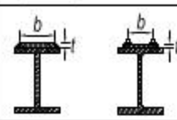
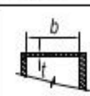
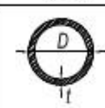
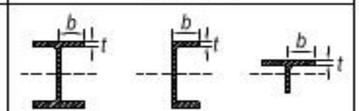
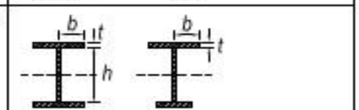
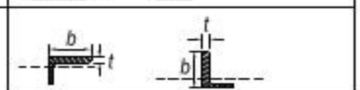
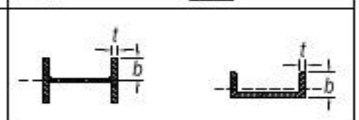
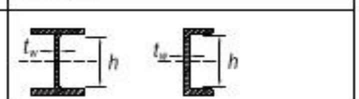
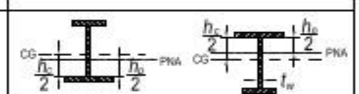
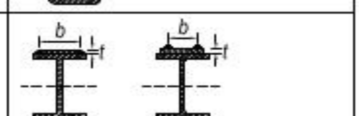
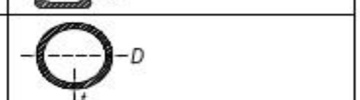
	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_cE}{F_y}}$ [a]	
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	
	4	Stems of tees	d/t	$0.75\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	5	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	
	6	Walls of rectangular HSS and boxes of uniform thickness	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$	

Table 2.3 in Reference of AISC 360-2010 Table no. B4.1a

TABLE B4.1b
Width-to-Thickness Ratios: Compression Elements Members Subject to Flexure

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio: λ_p (compact/noncompact)	Limiting Width-to-Thickness Ratio: λ_r (noncompact/slender)	Examples
Unstiffened Elements	10	Flanges of rolled I-shaped sections, channels, and tees	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	11	Flanges of doubly and singly symmetric I-shaped built-up sections	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$0.95\sqrt{\frac{k_c E}{F_L}}$ [a] [b]	
	12	Legs of single angles	b/t	$0.54\sqrt{\frac{E}{F_y}}$	$0.91\sqrt{\frac{E}{F_y}}$	
	13	Flanges of all I-shaped sections and channels in flexure about the weak axis	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	14	Stems of tees	d/t	$0.84\sqrt{\frac{E}{F_y}}$	$1.03\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	15	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$3.76\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	
	16	Webs of singly-symmetric I-shaped sections	h_c/t_w	$\frac{\frac{h_c}{h_p}\sqrt{\frac{E}{F_y}}}{\left(0.54\frac{M_p}{M_y}-0.09\right)^2} \le \lambda_r$ [c]	$5.70\sqrt{\frac{E}{F_y}}$	
	17	Flanges of rectangular HSS and boxes of uniform thickness	b/t	$1.12\sqrt{\frac{E}{F_y}}$	$1.40\sqrt{\frac{E}{F_y}}$	
	18	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.12\sqrt{\frac{E}{F_y}}$	$1.40\sqrt{\frac{E}{F_y}}$	
	19	Webs of rectangular HSS and boxes	h/t	$2.42\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	
	20	Round HSS	D/t	$0.07\frac{E}{F_y}$	$0.31\frac{E}{F_y}$	

[a] $k_c = 4/\sqrt{h/t_w}$ but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.
[b] $F_L = 0.7F_y$ for major axis bending of compact and noncompact web built-up I-shaped members with $S_{xt}/S_{xc} \ge 0.7$;
$F_L = F_y S_{xt}/S_{xc} \ge 0.5F_y$ for major-axis bending of compact and noncompact web built-up I-shaped members with $S_{xt}/S_{xc} < 0.7$.
[c] M_y is the moment at yielding of the extreme fiber. M_p = plastic bending moment, kip-in. (N-mm)
E = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)
F_y = specified minimum yield stress, ksi (MPa)

Table 2.4 in Reference with AISC 360-2010 Table no. B4.1b

2.4 IMPLEMENTATION OF DESIGN PROCEDURE INTO SPREADSHEET

A study on electronically enhanced traditional structural steel beam design using design charts by Souhail Elhouar, P.E., M.ASCE1 depicts the usefulness of spreadsheet application by using the traditional design charts and tables being incorporated into MS Excel application which produces design charts for unbraced steel beam structures. It also shows the incorporation of Microsoft Visual basic and Macro during the spreadsheet design in MS Excel sheet. Earlier attempts by Kim and Perry 1998 were made for spreadaheet solution for the design of heat treatment of steel and design of built-up wide flange steel sections. For the present study of the development of spreadsheet for design of steel beam-column sections storage steel codes for both Indian standards and American standards, Implementations of required functions, numerical functions, interaction ratios into MS Excel sheet and the input of section data into the numerical relations are reduired.

The features of MS Excel application provides the ability to calculate mathematical functions, having input parameters, for different input values and produce output values in a recursive way. This enables to provide results for comparison with interaction ratios for the safety check of beam-column under the required load and bending moment. Another brilliant feature of MS Excel application is Macro which facilitates dynamic or run time networking of data from one cell to another cell. Steel section property gets stored in an assigned macro in organized way which can be retrieved by dynamic linking on selection of desire code. Macros function in VB Editor (Visual Basic) module by which various user-defined functions can be created and linked with section property of respective column or row of datasheet. All the features of MS Excel application enables to develop a design sheet for a safety check of beam-column under applied load and bending moment and also enables to design for the appropriate section with a balance between safety and economy.

2.5 SUMMARY

The review of the present study specifies thorough analysis of behaviour of steel beam-columns under different conditions and different types of loadings, failure criteria as design of beam-columns is dominantly governed by above mentioned factors. The design procedure for steel beam-column sections in accordance two major International codes, Indian Standard (Code IS 800:2007) and American Standard Code (AISC 360-2010) is discussed. All these design procedure and design criteria are put into in a MS Excel sheet for the safety check of steel beam-column section under applied load and flexure which helps in design of steel section in an efficient way with much more flexibility providing adequate user-friendly platform.

C H A P T E R – 3

Development of Spreadsheet design tool for steel beam-column

3.1 GENERAL

This chapter is grounded on the development of a spreadsheet design tool for the design of steel beam-column section in accordance with major International codes of practices, IS 800:2007 and AISC 360-2010. Different failure criteria along with general behaviour of steel beam-column and the design procedures agreeing with Indian Standard Code and American Standard code based on Limit State Method Design (LSM) and Load and Resistance Factor Design (LRFD) respectively. The spreadsheet design is basically based on the various characteristics of MS Excel along with development in Macro and Visual Basic Editor environment. This section concentrates on input method of different design parameters, storage of section properties according to respective steel codes, dynamic linking of properties to the design sheet and finally the comparison and decision making statements of the result with standardized Interaction equations for safety check of beam-column section. The spreadsheet includes all the numerical functions and mathematical relations and expressions for different design methodologies, such as, design for compressive strength, design for flexure and design under combined axial force and bending moment. Fragmentation approach of entire spreadsheet into small segments that provides user-friendly and flexible conditions for design procedure.

3.2 OULINE OF DESIGN STEPS

The list of operations required to be performed for the design procedure of steel beam-column to complete along with safety check are discussed below.

1. A first-order elastic analysis is required for determining the factored loads and bending moments that acts on the desired steel beam-column section.

2. Initially a trial section is taken into consideration and respective section properties are implemented.

3. Classification of the section is required, such as, compact, semi-compact or plastic and accordingly the design procedure will proceed.

4. Determination of the bending strength of the cross-section of beam-colmun section about major axis and minor axis of the member.

5. (a) Determination of shear resistance across the cross-section of the beam-column section.
   (b) Check for shear buckling for taking into consideration, whether shear buckling happens or not.

6. When the section is plastic calculation of the reduced plasti flexural strength is required

.

7. Check for interaction equation for cross-section resistance for biaxial bending.

8. Calculation is required to be carried out for design-compressive strength (P_{dz}) and (P_{dy}) owing to axial force.

9. Calculation is required to be carried out of design-bending strength directed by lateral-torsional buckling.

10. Calculation of moment amplification factors is also required.

11. A Check with the interaction equation for buckling resistance whether it is fulfilled or not.

3.3 INCORPORATION OF DESIGN PROCEDURE INTO MS-EXCEL SHEET

Basically the entire spreadsheet performs primarily three basic operations, as input of section parameter, storage of section property for selection purpose and processing of numerical equations and criteria producing the result. Hence the spreadsheet comprises of three principal modules as follows:

1. Main Sheet
2. Section data Sheet
3. Design Sheet

Main sheet is the preliminary component that provides the designer to select of desired codes of practices according to which design will continue and also to select the desired section, from the steel table available. Section data sheet is a recorded Macro which contains different section properties in steel tables in an organized row-column manner from which data can be retrieved later. Design sheet contains all the numerical equations and boundary conditions are incorporated for which input comes from the Section data Sheet. The dynamic linking of data and propagation of design procedure is driven by Visual Basic Editor. The detailed discussion of the design procedure is given below.

3.3.1 DESIGN WITH MAIN SHEET

During the development of Main Sheet a DEVELOPER environment is created in MS Excel. Then two option buttons for the selection of desired International code are created in form control menu for Indian code, American code respectively (column wise). Three drop down combo boxes are created adjacent to the respective codes. When the user selects the type of code by clicking the option button it links to the corresponding combo box which contains the link of a saved macro that contains the types of steel sections allows the user to select the type. The Main Sheet data selection procedure is shown in the figure in next page.

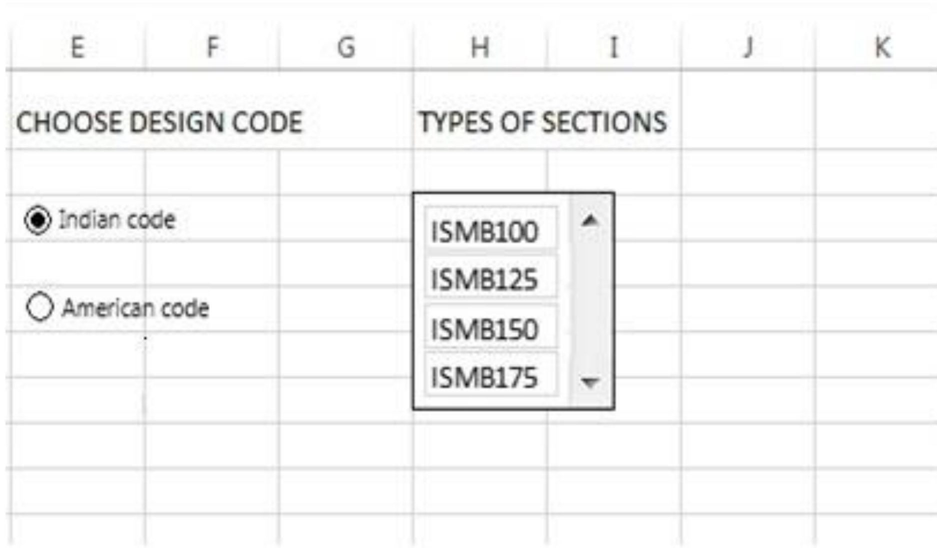


Fig. 3.1 Snapshot of Main Sheet during design for Indian Code

3.3.2 DESIGN WITH SECTION DATA SHEET

Section data Sheet in another major component in spreadsheet design which contains the detailed account of various section properties of different steel sections in row-column approach in an organized manner. A macro is created in ‘DEVELOPER’ environment which saves the section properties in column wise and sections in row wise pattern that can be retrieved by the selection of corresponding section in Main Sheet. Both Indian hot rolled sections and American hot rolled sections are saved in the Section data Sheet. Indian hot rolled section in Section data Sheet is shown below. The section properties available are mass per meter, depth of section, sectional area, thickness of web and flange, width of flange, moment of inertia, radius of gyration, section modulus, and plastic modulus.

Indian Rolled Steel Sections													
Designations	mass per meter	Depth of section	Sectional Area	Thickness		Width of flange	Moment of inertia		Radius of Gyration		Section Modulus	Plastic Modulus	Radius at Root
				Web	Flange		Axis x-x	Axis y-y	Axis x-x	Axis y-y	Axis x-x	Axis y-y	Axis x-x
		h	A	tw	tf	b	Ixx	Iyy	rxx	ryy	Z_{ez}	Z_{pz}	r
	kg/m	mm	cm2	mm	mm	mm	cm^4	cm^4	mm	mm	cm^3	cm^3	mm
ISWB 450	79.4	450	1011.5	9.2	15.4	200	35057.6	1706.7	186.17	41.08	1558.10	1760.59	14.0
ISWB 500	95.2	500	1212.2	9.9	14.7	250	52290.9	2987.8	207.69	49.65	2091.60	2351.35	15.0
ISWB 550	122.5	550	1433.0	10.5	17.6	250	74906.1	3740.6	228.63	51.09	2723.90	3066.29	16.0
ISWB 600 1	133.7	600	170.38	11.2	21.3	250	106199	4702.5	249.70	52.50	3540.00	3986.66	17.0
ISWB 600 2	145.1	600	184.86	11.8	23.6	250	115627	5298.3	250.10	53.50	3854.20	4341.63	18.0
ISHB 150 1	27.1	150	34.48	5.4	9.0	150	1455.6	431.7	65.00	35.40	194.10	215.64	8.0
ISHB 150 2	30.6	150	38.98	8.4	9.0	150	1540	460.3	62.90	34.40	205.30	232.52	8.0
ISHB 150 3	34.6	150	44.08	11.8	9.0	150	1635.6	494.9	60.90	33.50	218.10	251.64	8.0
ISHB 200 1	37.3	200	47.54	6.1	9.0	200	3608.4	967.1	87.10	45.10	360.80	397.23	9.0
ISHB 200 2	40	200	50.94	7.8	9.0	200	3721.8	994.6	85.50	44.20	372.20	414.23	9.0
ISHB 225 1	43.1	225	54.94	6.5	9.1	225	5279.5	1353.8	98.00	49.60	469.30	515.82	10.0
ISHB 225 2	46.8	225	59.66	8.6	9.1	225	5478.8	1396.6	95.80	48.40	487.00	542.22	10.0
ISHB 250 1	51	250	64.96	6.9	9.7	250	7736.5	1961.3	109.10	54.90	618.90	678.73	10.0
ISHB 250 2	54.7	250	69.71	8.8	9.7	250	7983.9	2011.7	107.00	53.70	638.70	708.43	10.0
ISHB 300 1	58.8	300	74.85	7.6	10.6	250	12545.2	2193.6	129.50	54.10	836.30	921.68	11.0
ISHB 300 2	63	300	80.25	9.4	10.6	250	12950.2	2246.7	127.00	52.90	863.30	962.18	11.0
ISHB 350 1	67.4	350	85.91	8.3	11.6	250	19159.7	2451.4	149.30	53.40	1094.80	1213.53	12.0
ISHB 350 2	72.4	350	92.21	10.1	11.6	250	19802.8	2510.5	146.50	52.20	1131.60	1268.69	12.0
ISHB 400 1	77.4	400	98.66	9.1	12.7	250	28083.5	2728.3	168.70	52.60	1404.20	1556.33	14.0
ISHB 400 2	82.2	400	104.66	10.6	12.7	250	28823.5	2783	166.10	51.60	1444.20	1626.36	14.0
ISHB 450 1	87.2	450	111.14	9.8	13.7	250	3920.8	2985.2	187.80	51.80	1742.70	1955.03	15.0
ISHB 450 2	92.5	450	117.89	11.3	13.7	250	40349.9	3045	185.00	50.80	1793.30	2030.95	15.0

Fig. 3.2 Indian rolled steel section data table in Section data Sheet

3.3.3 DESIGN SHEET

This Design Sheet advances the design procedure by dynamic linking with the Main Sheet along with the Section data Sheet that contains all the section properties and collecting the required information from both the sheets and performs generally the following operations:

• Enters the Span/length of the beam-column section, factored axial load as well as bending moments.

.• Delivers an option for the selection of essential end restraint condition.

• Calculation of design strength in both axial load and bending moment in separate as well as combined for the specified beam-column using the pre-defined formulae and relations.

• Assessment of the strength with applied load and moments.

• Lastly determination of interaction ratios and check for safety of steel beam-column section by comparing the interaction ratios.

3.3.4 CUSTOM OF MACROS FOR DYNAMIC LINKING

Macros is one of the excellent features that Microsoft Excel contains. It is an in-built module in Visual Basic Editor. Macros enable dynamic/run time connecting of data between different cells. On selection of desired code, the action invokes an allotted macro that generates an active drop-down list of various steel sections corresponding to the selected code. Macro code is used for incorporation of section properties according to the two different codes and completes the design requirements of Main Sheet and Design Sheet.

The Macro code used for the incorporation of the types of section against the Indian Standard Code which provides the "drop down list" i.e. the code for the link of macro named "Indian Macro", which contains the data for types of section according to Indian Standards, in the Main Sheet is given below.

```
Sub Indian()
'
' Indian Macro
'

'
    Sheets("Main Sheet").Select
    Range("I5").Select
    With Selection.Validation
        .Delete
        .Add Type:=xlValidateList, AlertStyle:=xlValidAlertStop, Operator:= _
        xlBetween, Formula1:="=IC!$B$6:$B$97"
        .IgnoreBlank = True
        .InCellDropdown = True
        .InputTitle = ""
        .ErrorTitle = ""
        .InputMessage = ""
        .ErrorMessage = ""
        .ShowInput = True
        .ShowError = True
    End With
End Sub
```

Fig.3.3 Indian Macro code containing section properties for Indian rolled steel sections

3.3.5 USE OF VISUAL BASIC EDITOR

Visual Basic Editor (Vb Editor) enables the designer to generate user-defined functions. These user-defined functions are generated in order to link various section properties, which are available in Section data Sheet, with the Design Sheet. In the Section data Sheet each and every section is checked by the created user-defined functions in Vb Editor window, against the section selected by the designer and finally assigning the corresponding section parameters or properties in the Design Sheet. The following figure shows the use of Visual Basic code to generate the required user-defined functions for data entry into the Design Sheet.

```
Function Zxvalue(Zx As String)
Select Case Zx
Case "W44X335"
 Zxvalue = Range("AC!K6").Value
Case "W44X290"
 Zxvalue = Range("AC!K7").Value
Case "W44X262"
 Zxvalue = Range("AC!K8").Value
Case "W44X230"
 Zxvalue = Range("AC!K9").Value
Case "W40X593"
 Zxvalue = Range("AC!K10").Value
Case "W40X503"
 Zxvalue = Range("AC!K11").Value
Case "W40X431"
 Zxvalue = Range("AC!K12").Value
Case "W40X397"
 Zxvalue = Range("AC!K13").Value
```

Fig.3.4 Visual Basic code for required user-defined functions

3.4 DESIGN OF BEAM-COLUMN AS PER IS 800:2007

The design requirements for a trial section is considered for the implementation of design spreadsheet in beam-column section designing. The design necessities for the steel beam-column trial section is as follows.

A column subjected to an axial load of 400 kN and bending moment in Z-direction is of magnitude 50 kNm, tested for section strength as well as overall buckling capacity with design procedure according to IS 800:2007 in the design Excel sheet.

- Beam-column span : 4.0 m.

- End condition : Both ends are fixed
- Condition for lateral support : “Laterally Unsupported”
- Selected beam-column section : ISHB 250
- Subjected axial compressive load : 400kN
- Applied bending moment M_z = 50 kNm

All the required section parameters are provided to the Design Sheet as shown in the following figure.

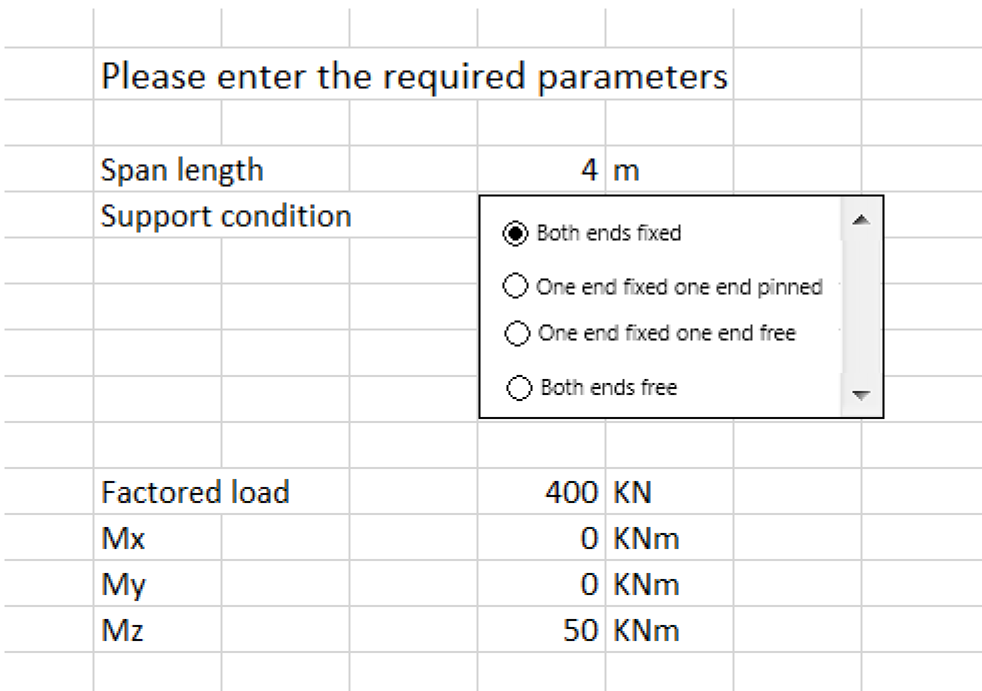


Fig. 3.5 Snapshot of Main Sheet during Indian Design

The selected section properties are provided to the design sheet by the section properties saved in ‘Indian Macro’ through the user-defined functions in Vb Editor.

Entry of section properties for the selected ISHB 250 section into Design Sheet is shown in the figure in next page.

Section properties					
Designation	ISHB 250		Ix	7736.5	cm^4
Mass/mtr.	51	kg/m	Iy	1961.3	cm^4
Depth of section	250	mm	rx	109.1	mm
Width of section	250	mm	ry	54.9	mm
Thickness of web	6.9	mm	Zez	618.9	cm^3
Thickness of flange	9.7	mm	Zpz	678.73	cm^3
Area of section	64.96	cm^2	Radius of root	10	mm

Fig. 3.6 Snapshot of Section Properties

3.4.1 CALCULATION OF COMPRESSIVE STRENGTH

The following figures shows the calculation of compressive strength for the steel beam-column section in Design Sheet.

Design compressive strength of the member,Pd				
Section Classification			h/b	
web	plastic		1	
flnage	semi-compact			
overall	semi-compact			
Buckling Class		Imperfection factor		
Major axis	a	0.34		
Minor axis	b	0.49		
Effective slenderness ratio				
Major axis	29.33	Effective cross-section area		
Minor axis	58.29		64.96	

	Non dimensional effective slenderness ratio, λ	ϕ	Design compressive strength, Pd(KN)	Design compressive stress, fcd(N/mm^2)
Major axis	0.33009	0.57659	1125.544	173.266
Minor axis	0.65597	0.82658	887.872	136.679

Fig. 3.7 Snapshot for Design Compressive Strength Calculation

Design compressive strength as well as Design compressive stress are calculated by Design Sheet.

3.4.2 DESIGN FOR FLEXURE

Design bending strength of the member is calculated in the section shown below.

Design Bending strength of th member, Md

Choose lateral support condition

- ○ Laterally supported
- ◉ Laterally unsupported

Stress corresponding to elastic lateral buckling		Non dimensional slenderness ratio
Weaker axis	495.896	0.71006

Design bending moment, Md (KNm)	94.857
Design bending stress (N/mm^2)	153.266
ϕLT	0.80565

Fig. 3.8 Snapshot for Design for Flexure

3.4.3 DESIGN CHECK FOR COMBINED AXIAL LOAD AND FLEXURE

In this section of design sheet the interaction ratios for the section are calculated and the values of interaction ratios are compared with unity. If the value of interaction ratio exceeds unity the selected steel beam-column section fails under applied load and flexure and "FAIL" will be shown under 'Section Design Status' which indicates the failure of design and the designer has to choose another section and repeat the design procedure again from start. If the interaction value is less than unity then "PASS" will be shown under 'Section Design Status' which indicates the successful completion of design procedure under the given circumstances. The figures below show the section design status for different interaction ratios.

Design check under combined axial force and bending moment										
α1	α2		(My/Mndy)^α1+(Mz/Mndz)^α2					Section strength status		
1.6933	2			0.26729					PASS	

Check for section strength as governed by Material failure is shown in the following figure.

Check for section strength as governed by Matreila failure						
Ky	Kz	KLT	Mdy	Mdz	n	
1.1826	1.0253	0.9256	105.61	83.229	0.3722	

Fig. 3.9 Snapshot of Design Check under Material Failure

Check for the member strength as governed by Buckling failure is shown in the following figures.

Uniform moment factor, Cmy	0
Uniform moment factor, Cmz	0.84
Uniform moment factor for LTB, CmLT	0.84

Check for section strength as governed by Buckling failure		
$(P/P_{dy}) + K_y[(C_{my}*M_y)/M_{dz}] + K_{LT}(M_z/M_{dz})$	Overall buckling status	
0.7322		PASS
$(P/P_{dz}) + 0.6K_y[(C_{my}*M_y)/M_{dz}] + K_z[(C_{mz}*M_z)/M_{dz}]$	Overall buckling status	
0.7831		PASS

Fig. 3.10 Snapshot of Design Check under Buckling Failure

3.4.5 RESULT

Initially during the design of steel beam-column section with the Design Sheet developed the trial section ISHB 250 was subjected under axial load 400 kN and bending moment along Z-axis 50 kNm having span length 4.0 m, laterally unsupported and with both ends fixed and design was carried out in accordance with IS 800:2007 and the following results are obtained.

- The Design Compressive Strength of the member found out be 1125.544 kN and 887.872 kN about the major axis and the minor axis respectively. Both the Design Strength values about major and minor axis of the member are greater than the applied load of 400 kN which indicates the section is safe under applied load.

- The Design Bending Moment for the member was found out to be 94.857 kNm and the Design Bending Stress was found out to be 153.266 N/mm^2. The Design Bending Moment of the section is more than the applied moment of 50 kNm along Z-axis which shows that the section is safe under applied moment.
- For design check under combined axial force and bending moment all the interactions ratios for section strength governed by Material failure as well as Overall Buckling failure

have values less than unity which shows that the trial section chosen is safe under applied load and bending moment and hence the design is successful.

3.5 DESIGN OF BEAM-COLUMN AS PER AISC 360-2010

In a similar way another trial section is selected from American rolled steel sections along with the Grade of steel used, subjected to a beam-column section subjected axial load of P_u = 300 kilo pounds(kips), bending moment about X-axis M_{ux} = 200 kilo pounds-feet(kip-ft) and bending moment about Y-axis M_{uy} = 70 kilo pounds-feet (kip-ft) is verified for safety check using design procedure in accordance with AISC 360-2010 having the following section parameters.

- Unbraced beam-column span : 15.0 m.
- End condition : Both ends are pinned
- Condition for lateral support : "Laterally Unsupported"
- Selected Grade of steel : A529 Grade 50
- Selected beam-column section : A529 W14X99
- Subjected axial compressive load : 300 kips
- Applied bending moment M_{ux} = 200 kip-ft

  M_{uy} = 70 kip-ft

All the required section parameters are provided to the Design Sheet as shown in the figure in next page.

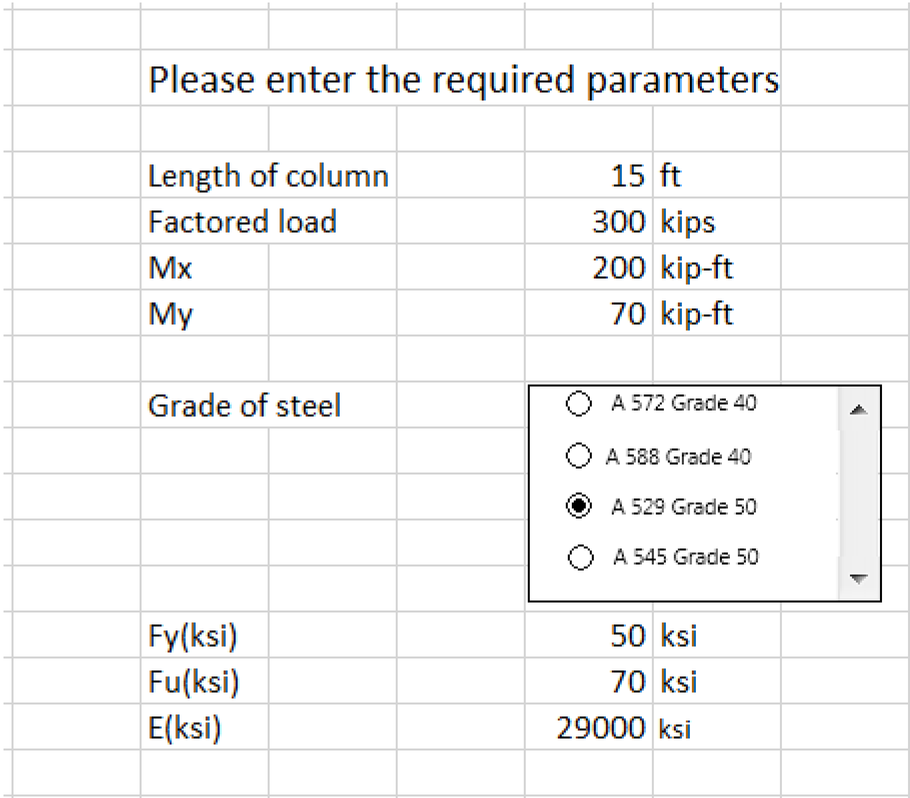


Fig. 3.11 Snapshot of Main Sheet for American Design

The required section is selected for the design of steel beam-column is selected from the macro saved in the name "American Macro" where all the section properties for American rolled steel sections are stored. The figure showing American Macro is in the next page.

American Rolled Steel Sections

Designations	mass per length W (lb/ft)	Sectional Area A (in.^{2})	Depth of section d (in.)	Width of flange b_f (in.)	Thickness Web t_w (in.)	Thickness Flange t_f (in.)	Ratio $b_f/2t_f$ (-)	Moment of inertia Axis x-x I_x (in.^{4})	Plastic Section Modulus Axis x-x Z_x (in.^{3})	Elastic Section Modulus Axis x-x S_x (in.^{3})	Radius of Gyration Axis x-x r_x (in.)	Moment of inertia Axis y-y I_y (in.^{4})	Plastic Section Modulus Axis y-y Z_y (in.^{3})	Elastic Section Modulus Axis y-y S_y (in.^{3})	Radius of Gyration Axis y-y r_y (in.)	Torsional Constant J (in.^{4})	Warping Constant C_w (in.^{6})	Effective Radius of Gyration r_{ts} (in.)	Distance b/w flange centroids h_o (in.)	Ratio h/t_w (-)
W44X335	335	98.5	44.0	15.9	1.03	1.77	4.49	31100	1620	1410	17.8	1200	236	150	3.49	74.7	535000	4.24	42.2	38.0
W44X290	290	85.4	43.6	15.8	0.865	1.58	5.00	27000	1410	1240	17.8	1040	205	132	3.49	50.9	461000	4.20	42.0	45.0
W44X262	262	77.2	43.3	15.8	0.785	1.42	5.56	24100	1270	1110	17.7	923	182	117	3.47	37.3	405000	4.17	41.9	49.6
W44X230	230	67.8	42.9	15.8	0.710	1.22	6.48	20800	1100	971	17.5	796	157	101	3.43	24.9	346000	4.13	41.7	54.8
W40X593	593	174	43.0	16.7	1.79	3.23	2.59	50400	2760	2340	17.0	2520	481	302	3.80	445	997000	4.63	39.8	19.1
W40X503	503	148	42.1	16.4	1.54	2.76	2.97	41600	2320	1980	16.8	2040	394	249	3.72	277	789000	4.50	39.3	22.3
W40X431	431	127	41.3	16.2	1.34	2.36	3.43	34800	1960	1690	16.6	1690	328	208	3.65	177	638000	4.41	38.9	25.5
W40X397	397	117	41.0	16.1	1.22	2.20	3.66	32000	1800	1560	16.6	1540	300	191	3.64	142	579000	4.38	38.8	28.0
W40X372	372	110	40.6	16.1	1.16	2.05	3.93	29600	1680	1460	16.5	1420	277	177	3.60	116	528000	4.33	38.6	29.5
W40X362	362	106	40.6	16.0	1.12	2.01	3.98	28900	1640	1420	16.5	1380	270	173	3.60	109	513000	4.33	38.6	30.5
W40X324	324	95.3	40.2	15.9	1.00	1.81	4.39	25600	1460	1280	16.4	1220	239	153	3.58	79.4	448000	4.27	38.4	34.2
W40X297	297	87.3	39.8	15.8	0.930	1.65	4.79	23200	1330	1170	16.3	1090	215	138	3.54	61.2	399000	4.22	38.2	36.8
W40X277	277	81.5	39.7	15.8	0.830	1.58	5.00	21900	1250	1100	16.4	1040	204	132	3.58	51.5	379000	4.25	38.1	41.2
W40X249	249	73.5	39.4	15.8	0.750	1.42	5.56	19600	1120	993	16.3	926	182	118	3.55	38.1	334000	4.21	38.0	45.6
W40X215	215	63.5	39.0	15.8	0.650	1.22	6.48	16700	964	859	16.2	803	156	101	3.54	24.8	284000	4.19	37.8	52.6
W40X199	199	58.8	38.7	15.8	0.650	1.07	7.38	14900	869	770	16.0	695	137	88.2	3.45	18.3	246000	4.12	37.6	52.6
W40X392	392	116	41.6	12.4	1.42	2.52	2.46	29900	1710	1440	16.1	803	212	130	2.64	172	306000	3.30	39.1	24.1

Fig. 3.12 American Rolled Steel Section Data Table in Section data Sheet

Required section properties are entered in the design sheet on choosing the appropriate section from American rolled steel section table as shown below.

Section Properties

Designation	W14X99				
Mass per weight W	99	lb/ft	Ix	1110	in^4
Depth of section h	14.2	in	Iy	402	in^4
Width of section bf	14.6	in	rx	6.17	in
Thickness fo web tw	0.485	in	ry	3.71	in
Thickness fo flange tf	0.78	in	Zx	173	in^3
Area of section A	29.1	in^2	Zy	83.6	in^3
Torsional constant J	5.37	in^4	Sx	157	in^3
Wraping constant Cw	18000	in^6	Sy	55.2	in^3
bf/2tf	9.359		Rts	4.14	in
h/tw	23.5		h0	13.4	in

Fig. 3.13 Snapshot for section Properties

3.5.1 USE OF MACRO AND VB EDITOR FOR DYNAMIC LINKING OF DATA

When American Standards for beam-column design is selected by the designer, a macro named "American Macro" come into operation. A set of American wide flange W sections in the drop-down box will be exhibited and selection of any section gets a link to the section properties kept in American macro to the Design Sheet. The macro code required for the above mentioned dynamic linking is shown in the figure given below.

```
(General)                                        american

Sub american()
'
' american Macro
'
    Sheets("Main Sheet").Select
    Range("I5").Select
    With Selection.Validation
        .Delete
        .Add Type:=xlValidateList, AlertStyle:=xlValidAlertStop, Operator:= _
        xlBetween, Formula1:="=AS!$B$6:$B$278"
        .IgnoreBlank = True
        .InCellDropdown = True
        .InputTitle = ""
        .ErrorTitle = ""
        .InputMessage = ""
        .ErrorMessage = ""
        .ShowInput = True
        .ShowError = True
    End With
    Sheets("Main Sheet").Select
    Range("I5").Select
```

Fig. 3.14 American Macro for storage of American rolled steel section properties

The section properties for the desired section is chosen through the selection of particular row and column of Macro sheet and entered in respective section of Design Sheet i.e. in corresponding row and column of Design Sheet against the required function and all the functions are controlled and linked by VB Editor window. The Visual Basic code for linking of saved American Macro information i.e. the section properties of selected section for design is shown in next page.

```
(General)                                   American_design

Sub American_design()
'
' American_design Macro
'

'
     Sheets("Design AC").Select
    Range("C5").Select
End Sub
```

Fig. 3.15 VB Editor code for user-defined functions in American Macro

3.5.2 DESIGN COMPRESSIVE STRENGTH

The design compression strength for the selected section under applied axial load is determined as shown in the following figures.

Pc = φcPn = Design axial strength determined		
Design axial strength for non-slender section		
Section classification		
Web	Non-slender	
Flange	Non-slender	
Overall	Non-slender	

	KL/r	Fe, Elastic buckling stress(ksi)	Fcr, Critical stress(ksi)	Pn = Fcr. Ag (kips)
In X-direction	23.658	354.63	45.634	1047.341
In Y-direction	40.225	121.67	39.783	973.221
			Pc = φcPn = Design axial strength determined	845.737

Fig. 3.16 Snapshot for Design Axial Strength Determination

Hence the Design Axial Strength for the required section is determined by the Design Sheet.

3.5.3 DESIGN FLEXURAL STRENGTH

The design flexural strength of the member is determined by the Design Sheet as shown in the figure below.

Design flexural strength, φbMn			
Section classification			
Web	Compact		
Flange	Non-compact		
Overall	Non-compact		
	KL/r	Nominal flexural strength, Mn=Mp=Fy.Z	
In X-direction	23.658	540.624	kip-ft
In Y-direction	40.225	288.249	kip-ft

Fig. 3.17 Snapshot for Design Flexural Strength Calculation

3.5.4 DESIGN CHECK UNDER COMBINED AXIAL FORCE AND FLEXURE

As described in the design procedure according to Indian Standard code in a similar way the interaction ratio for the section is calculated using LRFD method and the value of interaction ratio is compared with unity. If the value of interaction ratio exceeds unity the selected steel beam-column section fails under applied load and flexure and “FAIL” will be shown under ‘Section Design Status’ which indicates the failure of design and the designer has to choose another section and repeat the design procedure again from start. If the interaction value is less than unity then “PASS” will be shown under ‘Section Design Status’ which indicates the successful completion of design. The following figure shows the comparison of interaction ratio with unity and section design status check.

Design check for combined axial force and flexure					
Pr/Pc	0.372				
For Pr/Pc >= 0.2			For Pr/Pc < 0.2		
(Pr/Pc)+(8/9)((Mrx/Mcx)+(Mry/Mcy))			(Pr/2Pc)+(8/9)((Mrx/Mcx)+(Mry/Mcy		
Mrx	200		Mrx	0	
Mry	70		Mry	0	
Mcx	540.624		Mcx	0	
Mcy	288.25		Mcy	0	
Interaction ratio	0.82416		Interaction ratio	0	
Section design status		PASS	Section design status		NULL

Fig. 3.18 Snapshot of Design Check for Combined Axial Force and Flexure

3.5.5 RESULT

The design for the selected trial section W14X99 having unbraced span length=15.0 ft, both ends pinned, laterally unsupported condition, subjected under axial compressive load of 300 kips and Bending moment M_{ux} = 200 ksi and M_{uy} = 70 ksi along with safety check is done by the Design Sheet and the following results are obtained.

- For design under compression the overall section classification found out to be Non-slender and for design under flexure it was found out to be Non-compact.
- The KL/r ratio for X-axis found out to be 23.658 and for Y-axis 40.225.
- Design axial strength of the beam-column section was 845.737 kips.
- In harmony with the yielding, Nominal flexural strength found out to be 540.624 kip-ft and 288.249 keep-ft along X-axis and Y-axis respectively. Both the values are greater than the applied bending moment about axes which indicates the section is safe under flexure.

- P_r/P_c = 0.372 which greater than 0.2 and the interaction ratio found out to be 0.82416 which is less than unity. This indicates the trial beam-column section is safe under applied axial load and bending moment according to LRFD theory.

3.6 DISCUSSION

Implementation of design procedure into MS Excel sheet provided information about the design of steel beam-column section in accordance with the design procedure of IS800:2007 and AISC 360-2010. A trial section according to Indian Standards was taken into consideration subjected with axial load and compression and the design procedure was completed by the Design Sheet and results show for safe design of the beam-column section using Limit State Design Method (LSM) and also for the successful design check of another section according to American Standards using Load and Resistance Factor (LRFD) method.

C H A P T E R - 4

Conclusion

4.1 CONCLUSION

The project eyes on the development of a spreadsheet design application for successful and flexible design of steel beam-column sections in accordance with two major International codes of practices and the development of such an application is successfully completed with effectively designing two different beam-column sections along with safety check under applied load conditions. The spreadsheet applications support the effective designing of beam-column sections maintaining proper balance with economy and safety. As consumption of time in design procedures is a hectic job for a designer such spreadsheet design tools serve greatly with well-furnished and accurate results in limited time which is its greatest advantage and the application of technology in conventional design procedure is getting more and more popular among designers. Around the globe various attempts for its further development is in progress providing the use of Design Spreadsheet applications a bright future perspectives.

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