Effective Length Concepts for Flexural Member Design

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Abstract:- Effective Length parameters (Lz, Lx, and Ly) are crucial for the design of compression members in industrial steel structural designs utilizing STAAD software (columns). How, in contrast, are the characteristics of effective length related to flexural members?

A brief description of the relationship between flexural members and effective length parameters is given in this work, along with the effects of leaving these characteristics out of the design of flexural members.

In order to fully comprehend the subject, we will also go over some related fundamental ideas like "Lateral Torsional Buckling" and "Slenderness Ratio" from scratch.

NOTE: This document discusses industrial steel structures and uses STAAD software to analyze the results.

I. THE PROBLEM

Effective Length parameters (Lz, Lx, Ly) are crucial for compression members (columns). However, how are effective length parameters related to flexural members? Let's look at the situation below.

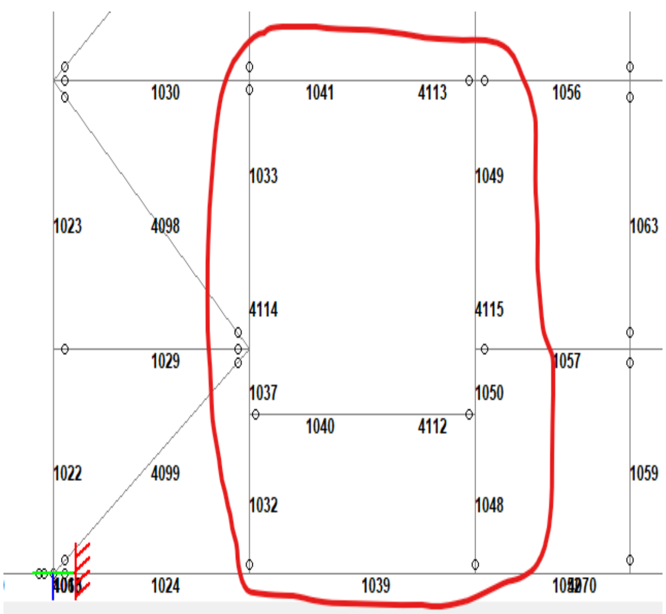

Fig 1: The Problem

As shown in the Figure 1, the members 1033, 4114, 1037, and 1032 form a beam with ISMB 100 (say B1), and the members 1049, 4115, 1050, 1048, and other connecting members furthermore form a beam with ISMB 300 (say B2). Note that there is some continuation of beam B2 to a certain extent.

Primary beams B1 and B2 are laterally supported by secondary beams about the minor axis (Y-Y axis).
STAAD has three parameters regarding this:
Lx/UNL: Effective length in lateral torsional buckling.
Ly: Effective length in the local Y-Y axis (Minor Axis) of the member.
Lz: Effective length in the local Z-Z axis (Major Axis) of the member.

II. TRIALS

The same model has been used in two trials whose only difference is the effective length parameters of beams B1 and B2.

Trial 1: The parameters defined in this trial are as under
Ly: This value takes into account the actual lengths of the individual members 1033, 4114, 1037, and 1032 for B1 and 1049, 4115, 1050, 1048, and other connecting members for B2. The effective length of beams B1 and B2 is reduced to their initial length as separate members as a result of the lateral support offered by the secondary members. As a result, the minor axis length of beams B1 and B2 corresponds to their actual member lengths.
Note: Whenever there is no value provided, the default settings in STAAD use the actual length of the individual members.
Lx/UNL: Same as Ly.
Lz: Same as Ly.
Thus, in Trial 1 no effective length parameters are provided. (STAAD considers the actual length of the members when no value is provided)

Trial 2: The parameters defined in this trial are as under
Ly: Same as Ly provided in Trial 1.
Lx/UNL: Same as Lx/UNL provided in Trial 1 (Lx/UNL=Ly).

Lz: The lengths provided for B1 and B2 in this parameter are their unsupported lengths about the Major axis (Z-Z) direction. The actual lengths of beams B1 and B2 are given because their major axes are not supported (The sum of lengths of the individual members 1033, 4114, 1037, and 1032 for B1 and 1049, 4115, 1050,1048 and other connecting members for B2).

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Thus, Lx and Ly are not specified in Trial 2, whereas Lz is the unsupported length of B1 and B2's major axis for B1 and B2.

III. OBSERVATIONS

In light of the above two trials, after analyzing it is time to compare the results of the model. We will examine the results of member 1033 for beam B1 and member 1049 for beam B2.

Trial 1 results are as under:

1. For Beam No. 1033

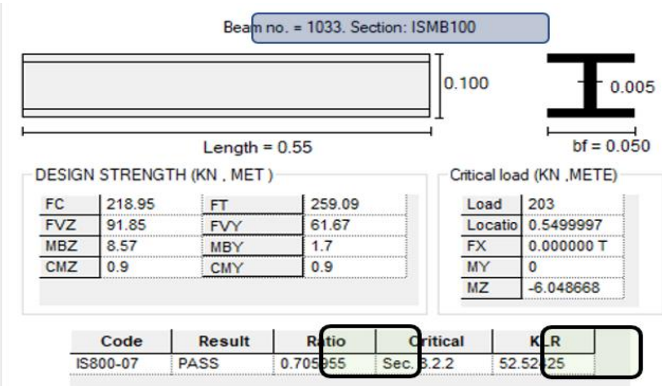

Fig 2: Result for Trial 1, Beam No. 1033 (a)

Checks	Ratio	Load Case No.	Location from Start(METE)
Tension	0.000	0	0.000E+00
Compression	0.000	0	0.000E+00
Shear Major	0.000	0	0.000E+00
Shear Minor	0.192	103	0.000E+00
Bend Major	0.706	103	550.000E-03
Bend Minor	0.000	0	0.000E+00
Sec. 9.3.1.1	0.498	103	550.000E-03

Fig 3: Result for Trial 1, Beam No. 1033 (b)

2. For Beam No. 1049

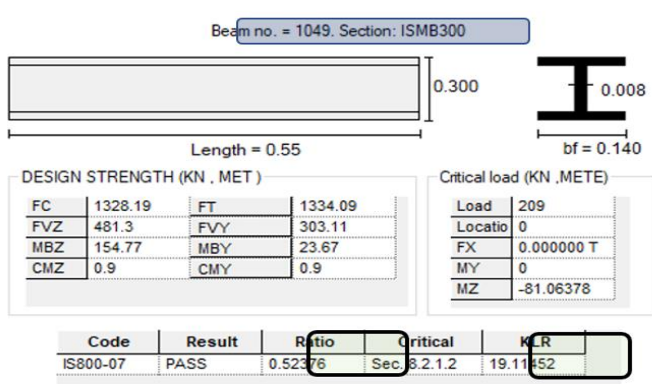

Fig 4: Result for Trial 1, Beam No. 1049 (a)

Checks	Ratio	Load Case No.	Location from Start(METE)
Tension	0.000	0	0.000E+00
Compression	0.000	0	0.000E+00
Shear Major	0.000	0	0.000E+00
Shear Minor	0.123	103	550.000E-03
Bend Major	0.524	103	0.000E+00
Bend Minor	0.000	0	0.000E+00
Sec. 9.3.1.1	0.274	103	0.000E+00

Fig 5: Result for Trial 1, Beam No. 1049 (b)

***Keep an eye on the interaction ratios/utilization ratios for major axis bending and slenderness ratios (KLR).

Trial 2 results are as under:

1. For Beam No. 1033

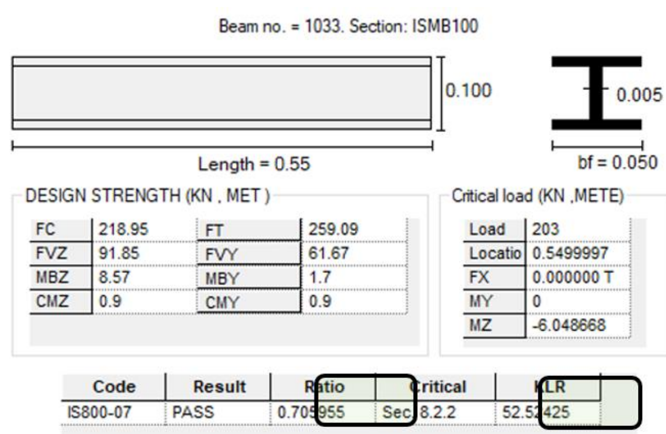

Fig 6: Result for Trial 2, Beam No. 1033 (a)

Checks	Ratio	Load Case No.	Location from Start(METE)
Tension	0.000	0	0.000E+00
Compression	0.000	0	0.000E+00
Shear Major	0.000	0	0.000E+00
Shear Minor	0.192	103	0.000E+00
Bend Major	0.706	103	550.000E-03
Bend Minor	0.000	0	0.000E+00
Sec. 9.3.1.1	0.498	103	550.000E-03

Fig 7: Result for Trial 2, Beam No. 1033 (b)

2. For Beam No. 1049

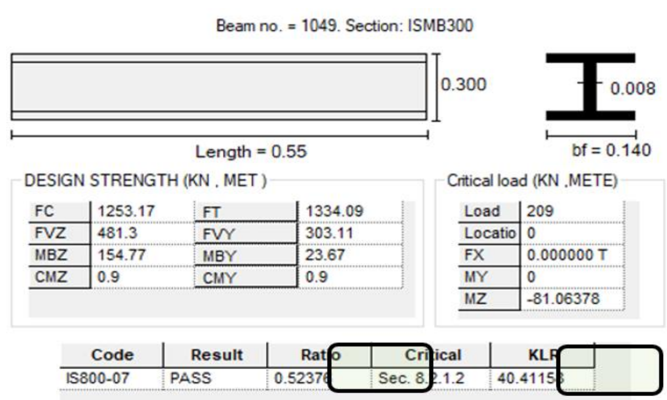

Fig 8: Result for Trial 2, Beam No. 1049 (a)

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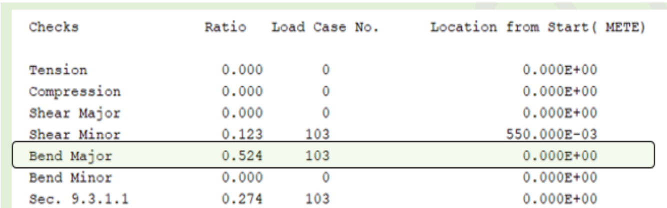

Checks	Ratio	Load Case No.	Location from Start(METE)
Tension	0.000	0	0.000E+00
Compression	0.000	0	0.000E+00
Shear Major	0.000	0	0.000E+00
Shear Minor	0.123	103	550.000E-03
Bend Major	0.524	103	0.000E+00
Bend Minor	0.000	0	0.000E+00
Sec. 9.3.1.1	0.274	103	0.000E+00

Fig 9: Result for Trial 2, Beam No. 1049 (b)

An overview of the results is provided below:

Table 1: Results Summary

Members	Trial 1		Trial 2	
	Bend Major	**KLR**	**Bend Major**	**KLR**
1033	0.706	52.524	0.706	52.524
1049	0.524	19.114	0.524	40.412

IV. FINDINGS

Both trials yield the same design results for the Major axis bending (0.706 and 0.524). In contrast, member 1049 has a different slenderness ratio (KLR).

- *Concepts:*

As a first step, let's take a deep dive into the fundamentals and design process of IS 800:2007, as well as the concept of the slenderness ratio.

Considering the general "I" section as the pure flexural member for the rest of the discussion, two types of stresses will form when the member is subjected to bending in its local major axis (Z-Z). One is compressive and the other is tensile in nature (Depending on the applied direction of the bending moment). Steel is prone to buckling when subjected to compressive stresses.

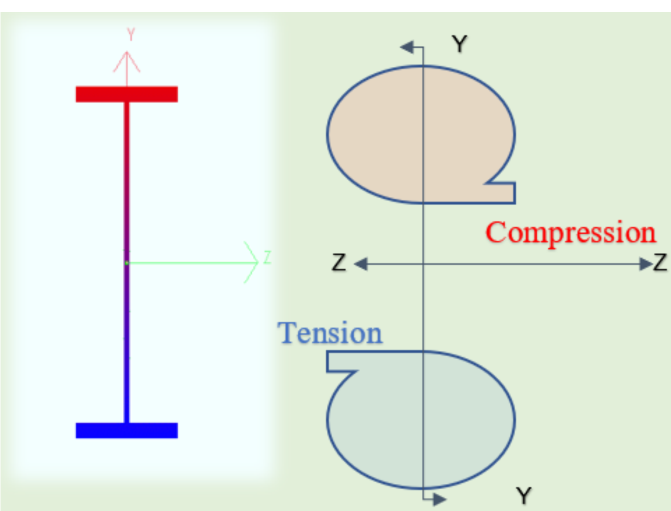

Fig 10: Concept

Consider a span "L" with a laterally unsupported member that is bending across its local major axis (Z-Z), and that has torsion restraints at both ends of the beam, thus Lz=Ly. As a result of the applied bending, the member is stressed, compressive stresses are generated as depicted in Figure 10, and the member will attempt to buckle. Considering the cross-section of the member, this buckling can happen in two directions one is about a minor axis and the other is about a major axis of the member. The slenderness ratio will now come into play and determine the direction of buckling. We all know that a member will buckle towards its higher slenderness ratio, which in this case is the minor (Y-Y) axis. Consequently, the member will tend to buckle around its minor axis.

In other words, when a flexural member bends around its major axis (Z-Z), buckling occurs due to compressive stresses generated in the member and tends to buckle around its minor (Y-Y) axis. The buckling of the member causes a twisting effect in the beam since compressive stresses may occur above or below the Neutral axis of the member (Depending on the direction of the bending moment). The entire phenomenon is known as "Lateral Torsional Buckling".

To prevent buckling, the member should have sufficient strength around its minor axis. Limiting slenderness ratio about its minor axis to some extent can ensure strength around the minor axis.

The same concept applies when bending is in the member's local minor axis (Y-Y). But, in this condition, the lateral torsional buckling of the section is not a concern due to its greater strength in the lateral direction (Z-Z). As a result, it can be considered a laterally supported member where stress should not exceed its acceptable limits.

In conclusion, we can say that "the flexural strength of a member is influenced by its minor axis strength when bent about its major axis" and "Slender members should not be employed in the construction of pure flexural members". That's fascinating, isn't it?

- *Application of the concepts:*

Now it's time to apply the concepts in our actual structure to achieve a greater economy. Earlier in our discussion, we learned that a member's flexural strength depends on the strength of its Minor axis. Further, a Minor axis' strength depends on its slenderness ratio, which is its effective length divided by its radius of gyration. We can control the strength around the minor axis of the member by either increasing the Radius of Gyration or decreasing the Effective Length (Ly). Let's explain the Radius of Gyration in simple terms rather than discussing its bookish definition. The term indicates the cross-sectional strength of a member based on the material distribution around the axis, while at the same time effective length is the length that is involved in the bending of the member.

Reducing the effective length of the member has proven to be more economical than increasing the radius of the gyration.

As we now understand, limiting the effective length of a member in its minor axis increases the strength of a pure flexural member when it is bent about its major axis. Thus, the secondary members should be located along the minor axis of the beam so that the effective length can be broken and the full strength of the member can be utilized.

- *Discussion based on IS 800:2007*

A laterally unsupported beam's design bending strength is controlled by lateral torsional buckling. Section 8.2.2 (Page No. 54) of IS 800:2007 describes the complete design technique for the bending strength of laterally unsupported beams; however, only the effective length for lateral torsional buckling is taken into account, not the effective lengths of the major and minor axes. Lx/UNL is crucial in STAAD for figuring out how strong the beam is. The effective length of a beam around the minor axis and the effective length of a beam subject to lateral torsional buckling are frequently equivalent (Lx/UNL = Ly).

- *Analysis of the Results of Trial 1 and Trial 2:*

Returning to the point of discussion, we observed that for both trials, the design results for the major axis bending (0.706 and 0.524) were the same. But the slenderness ratio for member 1049 differs.

The explanation of the fundamentals and theories of pure flexural members makes it evident that lateral torsional buckling controls the bending strength of laterally unsupported beams. Lateral torsional buckling can be modified by varying the effective length of the beam.

The results of the interaction ratios/utilization ratios for major axis bending did not vary since the effective length in lateral torsional buckling was the same in both trials.

However, for member 1049 in trial 1 and trial 2, the slenderness ratio differs, while for member 1033 it remains the same.

In trial 1, Ly is equal to the actual length of members 1033, 4114, 1037, 1032 for B1, and 1049, 4115, 1050, 1048 and other connecting members for B2, with Lx and Lz having the same value as Ly (as discussed above). A slenderness check is performed for beams B1 and B2 along both axes by STAAD. The critical slenderness ratio between them is shown as the final result. Further analysis of the trial 1 result reveals that the critical slenderness ratio for both members lies along the minor axis (because of Ly=Lx=Lz).

Trial 2 uses Ly as in trial 1, Lx is equal to Ly, and Lz is equal to the unsupported lengths of B1 and B2 about the Major axis (Z-Z) direction (as discussed earlier). For member 1033 of beam B1, Lz (Effective length about major axis direction) changes did not result in any difference in the critical slenderness ratio, indicating that the slenderness ratio about the minor axis remains critical. While changing Lz, the slenderness ratio for member 1049 of beam B2 becomes critical in terms of its major axis. This results in a different value in the final result.

V. CONCLUSION

We can summarize the discussion as follows:

1. The effective length parameters (Lz, Ly, Lx/UNL) are crucial for beams as well.
2. When a flexural member (laterally unsupported) bends around its major axis (Z-Z), buckling occurs due to compressive stresses generated in the member and tends to buckle around its minor (Y-Y) axis.
3. The effective length in lateral torsional buckling defines the strength of the laterally unsupported beam.
4. The secondary members should be located along the minor axis of the laterally unsupported beam so that the effective length can be broken and the full strength of the member can be utilized.
5. Laterally supported beams utilize the full strength of the member because the lateral torsional buckling of the section is not a concern due to its greater strength in the lateral direction.
6. In most cases, a beam's effective length about the minor axis and its effective length in lateral torsional buckling are equal (Lx/UNL = Ly).
7. A slenderness check is performed for beams B1 and B2 along both axes by STAAD. The critical slenderness ratio between them is shown as the final result.
8. Slender members should not be employed in the construction of pure flexural members.

REFERENCES

[1]. BUREAU OF INDIAN STANDARDS-MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG NEW DELHI 110002 – “INDIAN STANDARD GENERAL CONSTRUCTION IN STEEL - CODE OF PRACTICE (Third Revision)” – “IS 800: 2007”

[2]. Oxford University Press – “Steel Structures Design and Practice” by N. SUBRAMANIAN

[3]. I.K. International Publishing House Pvt. Ltd. New Delhi – “Design of Steel Structures by Limit State Method as per IS 800: 2007” by S.S. Bhavikatti

[4]. Butterworth-Heinemann “Structural Design of Steelwork to EN 1993 and EN 1994” – by Lawrence Martin and John Purkiss