STUDY OF SHEAR LAG EFFECT IN BOX GIRDER BRIDGE

A

THESIS

Submitted in partial fulfilment of requirements for the award of the

degreeof

MASTER OF TECHNOLOGY

IN

CIVIL ENGINEERING

With specialization in

STRUCTURAL ENGINEERING

Under the supervision

of

KAUSHAL KUMAR

Assistant Professor

by

Khetup Namgial

(225024007)

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

MAY - 2024

STUDENTS' DECLARATION

I hereby declare that the work presented in the project report entitled **"Study of Shear lag effect in box Girder Bridge."** submitted in partial fulfillment of the requirements for the degree of Master of Technology in Structure Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Kaushal Kumar.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of this project report.

Signature
Name: Khetup Namgial
Roll No: 225024007
Department of Civil Engineering
Jaypee University of Information Technology, Waknaghat

CERTIFICATE

This is to certify that the work which is being presented in the thesis titled “Study of shear lag effect in Box- girder Bridge” in partial fulfilment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in “Structural Engineering” and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Wakhnaghat is an authentic record of work carried out by Khetup Namgial (225024007) during a period from Aug- 2023 to June- 2024 under the supervision of Mr. Kaushal Kumar, Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: - ………………………

Signature of Supervisor	Signature
Kaushal Kumar	Dr. Ashish Kumar
Assistant Professor	Professor and HOD
Department of Civil Engineering	of civil Engineering Department
JUIT, Waknaghat	JUIT, Waknaghat

ACKNOWLEDGEMENT

I would like to thank God Almighty, my parents, and numerous individuals who have inspired and supported me, worked tirelessly to provide details on various related topics, and ultimately made the thesis and report successful. I also thank our Department Head, Prof. (Dr.) Ashok Kumar Gupta, for his guidance, encouragement, and support. I would like to take this opportunity to thank everyone who felt that the thesis work was successful.

I am very grateful to KAUSHAL KUMAR Assistant Professor, for his unwavering commitment, direction, inspiration, and assistance during the thesis process, all of which allowed me to finish the work on schedule. In addition, I appreciate his giving me time with his extremely busy schedule. I usually find inspiration in his insightful and imaginative thoughts when working on my dissertation.

By:

Khetup Namgial

(225024007)

ABSTRACT

Box girder bridges are widely employed for their structural efficiency, spanning medium to long distances with aesthetic appeal. However, the shear lag effect, causing non-uniform axial stress distribution along the cross-sectional direction, poses challenges to the traditional assumptions of structural analysis. This study focuses on a comprehensive examination of shear lag effects in box girders, particularly in the context of bridge design. Utilizing three-dimensional finite element analysis and incorporating dead loads and pre-stressing, the research evaluates the behaviour of a steel box-girder under different loading conditions.

The study aims to deepen the understanding of shear lag effects on stress distribution, deformations, and the overall structural response. By employing advanced analytical techniques and considering real-world bridge configurations, the research contributes valuable insights to bridge engineers and designers, informing optimized design practices and ensuring the structural integrity of box girder bridges.

TABLE OF CONTENT

Analytical formulation and solution

Results And Discussion

LIST OF ABRIVATION

FEA: Finite Element Analysis

EBT: Elastic Beam Theory

Is: Moment of inertia of the stiffeners

Ip: Moment of inertia of the plate

E: Young's modulus (a measure of the stiffness of a material)

G: Shear modulus (a measure of the material's response to shear stress)

w: Width of the plate

l: Length of the plate

G/E: Modulus of Rigidity (Shear Modulus, G) to Young's Modulus (E) Ratio

G: Shear Modulus (Modulus of Rigidity)

E: Young's Modulus

l/w: Length to Width Ratio

w/l: Width to Length Ratio

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

In the field of bridge engineering, it is crucial to comprehend how structures behave under different forces to create safe and efficient bridges. An important area that engineers focus on is studying shear lag, particularly within the framework of box girder bridges.

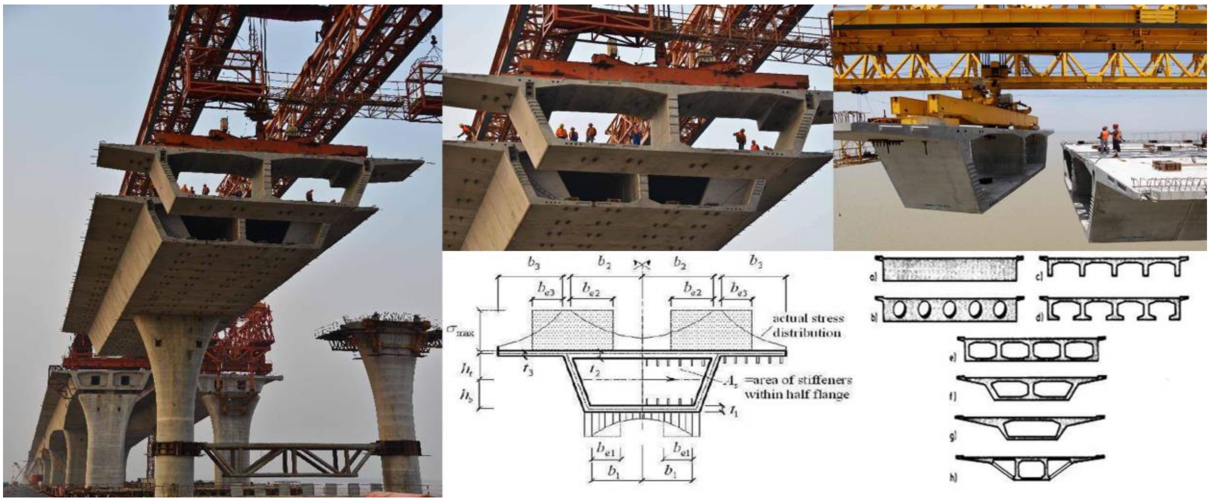
Shear lag is a phenomenon that occurs when shear forces act upon a box girder, a commonly used structural component in bridge construction. Unlike a simple beam where forces are evenly spread across the cross-section, the intricate geometry of a box girder can lead to an unequal distribution of shear stresses.

Imagine a rectangular or box-shaped beam where the corners and edges exhibit greater effectiveness in resisting shear forces when compared to the center of the structure. This leads to an uneven distribution of stress along the cross-section of the box girder.

When subjected to shear forces, the box girder undergoes deformation. Yet, the deformation is not uniform across all parts. The corners undergo more deformation than the central areas, thereby exacerbating shear lag.

The box-girder bridge

A box girder is a style of bridge girder characterized by a hollow, rectangular shape. It is composed of two flat plates (referred to as top and bottom flanges) joined together by vertical plates (known as webs) to create a box-like framework. Box girders are commonly employed in bridge construction for their structural efficiency, offering robustness and rigidity while minimizing the use of materials. The hollow structure facilitates effective weight distribution and resistance to twisting forces, rendering box girders suitable for a variety of bridge spans and layouts.



(Fig 1.2.1)

- They provide strength and stiffness while minimizing material usage.
- The hollow design allows for effective weight distribution.
- They also offer resistance to torsional forces.

1. Background

1.1 The Importance of Investigating Shear Lag in Box Girder Bridges,

Structural Integrity:

Ensuring the structural integrity of box girder bridges requires a comprehensive understanding of shear lag. Shear lag plays a critical role in the distribution of shear forces within the girder's cross-section, impacting the structure's stability overall.

Load Distribution: Shear lag analysis assists engineers in foreseeing how loads are distributed across various sections of the box girder. This knowledge is crucial for developing a bridge capable of effectively sustaining expected traffic and environmental loads.

Optimized Design: Through the examination of shear lag, engineers can refine the design of box girder bridges. They can make knowledgeable choices regarding geometry, material selection, and reinforcement strategies to mitigate shear lag effects and enhance the overall bridge performance.

Economic Efficiency: A comprehensive grasp of shear lag has the potential to lead to more cost-effective designs. By addressing shear lag with suitable design adjustments, engineers may be able to decrease the required materials or optimize the application of specific construction methods, thereby enhancing cost efficiency.

Long-Term Durability: Shear lag could influence the enduring resilience of a bridge. By considering shear lag during the design stage, engineers can improve the structure's ability to withstand cyclic loads, environmental influences, and other factors that could impact its longevity.

1.1.1 The positive shear lag effect

Uneven bending stress distribution along the flange width is caused by positive shear lag, with noticeably greater stress levels at the web-flange joint. This phenomena contradicts the accepted hypothesis of simple bending and was first studied by Reissner (1945) and Foutch and Chang (1982). The past development of PSL understanding and its effects for structural design are reviewed in this paper. A general formula for the class of box-beams with symmetry over span-wise vertical and horizontal planes crossing the neutral axis is sought after by

Reissner (1945). Although symmetrical configurations are the main focus, unsymmetrical beams can also be included in the process, but the derivations will become more challenging. The primary focus of this article is on the structural analysis of box-beams, particularly those having symmetrical properties about span-wise vertical and horizontal planes through the neutral axis. The main goal is to develop an equation that characterises how these beams behave under different loading scenarios. While the results are initially designed for symmetrical instances, the authors highlight that they can be used to unsymmetrical beams as well, albeit equivalent the results could require greater detail. The suggested method is based on the finding that the distribution of normal stress across the beam closely resembles a parabolic shape in all symmetrical examples that have been investigated so far. Inspired by this finding, the writers assume that these curves are authentic parabolas, defined simply by the values of their vertex curvature. As such, the important work is to find an equation regulating this vertex curvature's span-wise variation. The authors use the minimum energy principle, which they believe to be the most practical method, for achieving this. This study successfully obtains an equation for symmetrical box-beams and provides an approach that can be used, though more complexly, for unsymmetrical conditions. The equation controlling the span-wise variation of the vertex curvature can be formulated with a strong foundation provided by the minimal energy principle. The developed equation's practical uses in resolving shear-lag issues highlight its importance in engineering analyses. This research advances our knowledge of structural behaviour and gives engineers a useful tool for understanding the complex characteristics of box-beam designs.

1.1.2 The Negative shear lag effect.

On the other hand, compared to positive shear lag, negative shear lag presents the opposite pattern. The knowledge of NSL has been greatly advanced by Chang and Zheng (1987), Shushkewich (1991), Singh and Nagpal (1994), Singh et al. (2019), and Lee et al. (2002). In order to provide consistent stress variation in bending across the width of the flange, the exploration of NSL presents difficulties. The impact of NSL on structural integrity is examined, together with its historical background and experimental verification.

1.2 The importance of the shear lag effect in structural analysis.

The behaviour and performance of various types of structures are influenced by the shear lag effect, which is a significant factor in structural analysis. For reliable forecasts of stress distribution, deformations, and overall structural response, shear lag must be understood and taken into account.

Real Stress Distribution: The distribution of shear forces over a structural member's cross-section is influenced by shear lag. Including shear lag into the calculation of stress distribution yields a more accurate picture, enabling engineers to precisely evaluate the structural capacity and possible mechanisms of failure.

Sensible Design: Excessively optimistic estimates of a structure's capacity can result from ignoring shear lag. By reducing the possibility of underestimating the stresses and improving the structure's safety and dependability, taking shear lag into account during analysis helps to a more conservative design.

Optimised Structural Design: Engineers can create structural elements with the best possible design by knowing the impacts of shear lag. The optimisation process could entail modifying the geometry, adding stiffeners, or switching out the materials in order to improve load distribution and overall efficiency.

Effective Material Use: Shear lag analysis makes it possible to use materials more effectively. By effectively using the complete cross-section, engineers can create structural features that save material waste and contribute to designs that are more economically sound.

Accurate Predictions of Deformation: Shear lag affects the displacements and deformations that occur inside a structure. It is essential to evaluate serviceability and overall performance to make more precise predictions about the structure's response to applied loads by taking shear lag into account during the study process.

Advanced Finite Element Analysis: Taking shear lag into consideration improves the modelling accuracy while performing advanced structural analysis with finite element methods. It enables engineers to accurately represent the behaviour of intricate structures under varied loading conditions.

1.3 Uses of Box Girder

(a) Bridge construction.

Highway Bridges: Box girder bridges are frequently used in highway construction to span over roads, rivers, valleys, or other obstacles. They provide a durable and efficient solution for supporting heavy traffic loads.

(Fig.1.4.1)

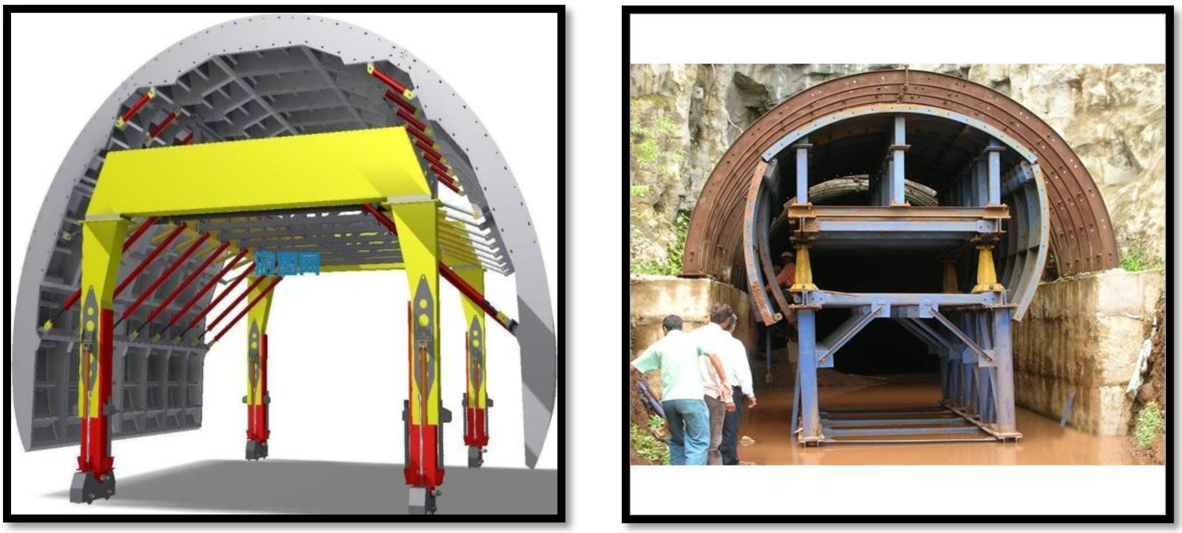
(a) **Railway Bridges:** Box girder bridges are suitable for railway applications, providing a stable and robust structure for supporting railroad tracks. They can be used for both urban and rural rail infrastructure.

(B) Infrastructure Projects:

(a) Flyovers and Overpasses: Box girders are commonly used in the construction of flyovers and overpasses, especially in urban areas where space constraints may require efficient use of available space.

(Fig 1.4.2)

(b) Tunnels: In tunnel construction, box girders can be used as support structures to reinforce tunnel openings or as part of the tunnel lining.



(Fig. 1.4.3)

(C) Aqueducts and Culverts:

(a) Water Crossings: Box girders can be utilized in the construction of aqueducts and culverts to facilitate the flow of water over roads or other obstacles.

(D) Culverts and Drainage Systems: Box beams are employed in the construction of culverts and drainage systems, where their enclosed shape facilitates efficient water flow while maintaining structural integrity.

(Fig. 1.4.4)

(E) Utility Bridges and Crossings:

Pipeline and Cable Bridges: Box girders can be used in the construction of bridges designed to carry pipelines, cables, or other utility lines.

The use of box girders offers advantages such as high strength-to-weight ratio, efficient use of materials, and the potential for accommodating services within the hollow structure. The specific application will depend on factors such as the load requirements, span length, and environmental condition

Due to their well-known structural effectiveness and adaptability, box girder bridges are a common option for modern bridge design. Their importance is rooted in multiple important elements:

Strength and Stability: Because of their closed, hollow construction, box girder bridges have amazing strength and stability. Effective load distribution and stress minimization are achieved by this design, which maintains structural integrity even over long spans.

Long Span abilities: Without the requirement for secondary supports, these bridges are ideal for covering large distances. Because of this, they are perfect for spanning large bodies of water, steep slopes, and other impediments that would be difficult for typical bridge designs.

Flexibility in Design: Box girder bridges can be made to meet a wide range of practical and visual requirements. Because they are available in a variety of sizes and shapes, engineers may match them to the unique requirements of the project and the site.

Durability and Low Maintenance: Box girder bridges' enclosed design protects them from weathering and corrosion from the elements. As a result, long-term expenses are decreased because the construction is strong and requires less maintenance.

Quick Construction: Box girder bridges can be quickly and effectively assembled thanks to prefabricated parts and modern construction methods. By doing this, the amount of disturbance to the traffic and neighbourhood during construction can be reduced.

CHAPTER-2

LITRERATURE REVIEW

2.1 Literature Summary

1 According to Shi-Jun Zhou (2004). "Shear lag effect in simply supported pre-stressed concrete box girder."

According to Shi-Jun Zhou. It describes the unequal distribution of axial stresses caused by strain or deformation along a structural member's length throughout the member's cross-section. The majority of the time, shear lag is seen in thin members like beams and girders. Shear lag analysis is a method to evaluate the stress distribution in pre-stressed concrete box girders. It considers the effects of shear and torsion deformation on the longitudinal stresses in the webs and flanges of the box section. Shear lag analysis can yield more accurate results than the conventional flexural theory, which assumes a uniform stress distribution over the section.

The following are some consequences of shear lag in structural analysis:

Uneven Stress Distribution: The axial stresses in a member's cross-section are distributed unevenly due to shear lag. This uneven distribution of stress is especially important for deep or wide structural parts.

Decreased Material Effectiveness: The material in the centre of the cross-section contributes less to the applied load than the material on the edges, which bears a larger share of the load. The strength of the material may be neglected as a result of this uneven distribution.

Influence on Deformations: The strains or deformations inside the member are impacted by shear lag. Greater stresses cause sections to deform more, which may result in buckling or localised distortions.

Possibility of Local Failure Modes: Shear lag may play a role in the formation of local failure modes in certain areas of the structural component, such as yielding or buckling, as a result of the unequal stress distribution.

Effect on Structural Stability: Shear lag, particularly in components that are a component of a broader structural system, can affect a structure's overall stability. The stability of nearby members may be impacted by localised failure or deformations in one member.

Design considerations: To guarantee that components are proportioned correctly, structural engineers must take shear lag effects into account during the design phase. Shear lag neglect might result in cautious or expensive designs.

Impact on Load Distribution: Shear lag has an impact on the distribution of applied loads over a member's various areas. To precisely forecast how the structure would react, engineers must take this into account when doing structural analysis.

A phenomenon known as shear lag affects structures, especially the members that are subjected to axial stresses or forces. It describes the unequal distribution of axial stresses caused by strain or deformation along a structural member's length throughout the member's cross-section. The majority of the time, shear lag is seen in thin members like beams and girders.

2. According to Warburton's (1965), "The Calculation of Stress Distributions in Box Girders,"

This paper offers a methodical technique to understanding the distribution of stress in box girder bridges through analysis. The main emphasis of the research is the shear lag phenomenon, which results in an uneven distribution of stress on the box girder flanges. Warburton created mathematical models to forecast the effects of shear lag on stress patterns, especially in different geometrical configurations and loading scenarios. His research gave engineers fundamental knowledge and useful formulas to incorporate the shear lag effect into the design of safer, more effective box girder bridges.

3. According to Xu, Y., & Zhang, N. (2007). Mitigation strategies for shear lag in box girder bridges.

Xu and Zhang investigate ways to lessen the negative impacts of shear lag in box girder bridges in their 2007 study, "Control Strategies for Shear Lag in Box Girder Bridges," which was published in Engineering Structures. The authors examine different design adjustments and construction methods with the goal of reducing the uneven stress distribution brought on by shear lag. They point out using cutting-edge materials like fiber-reinforced polymers (FRPs), adding transverse stiffeners, and optimising the flange width-to-depth ratio. Numerical models and experimental validations are included in the paper to show how these tactics can improve the structural performance and lifespan of box girder bridges. Their conclusions offer engineers useful suggestions for enhancing bridge design, promising improved load distribution and heightened safety.

4. According to Harik, I. E., & Sennah, K. (1996). Experimental study on shear lag in steel box girders.

The results of a series of experimental tests to examine the shear lag effect in steel box girders are given by Harik and Sennah in their 1996 publication, "Experimental Study on Shear Lag in Steel Box Girders," which was published in the Journal of Bridge Engineering. Scaled model tests were used in the study to examine the effects of various flange width-to-depth ratios on the stress distribution throughout the girders. Their experimental results verified that shear lag causes non-uniform distribution and has a major effect on the stress distributions in wide flanges. The study offered valuable empirical data that proved how crucial it is to take shear lag into account when designing and analysing steel box girders. Their results highlighted the necessity of giving careful thought to girder geometry in order to provide precise predictions of bridge performance and enhance structural integrity.

5. According to Astaneh-Asl, A., et al. (2000). Analysis and design considerations for shear lag in the San Francisco-Oakland Bay Bridge.

In the 2000 publication "Analysis and Design Considerations for Shear Lag in the San Francisco-Oakland Bay Bridge," Astaneh-Asl and associates provide a thorough examination of the shear lag phenomena in relation to the analysis and design of the San Francisco-Oakland Bay Bridge. The paper focuses on the ramifications and practical difficulties associated with shear lag in large-scale bridge developments. The authors investigate the effects of shear lag on stress distribution and structural performance using a combination of analytical techniques, numerical simulations, and empirical data. They offer detailed design suggestions, such maximising girder dimensions and adding more structural components, to reduce shear lag. The study emphasises how crucial it is to take shear lag into account while designing new structures and evaluating those that already exist in order to guarantee their lifetime,

6. According to Chang, S. T. (2004). “Shear-lag effect in simply supported pre-stressed concrete box-girder.”

The shear lag effect in simply supported pre-stressed concrete box girders is examined in Chang's 2004 work. The study demonstrates how shear lag, especially under different loads, results in an uneven stress distribution over the girder flanges. Chang shows that shear lag has a major effect on the structural performance of pre-stressed concrete box girders by combining theoretical analysis with experimental data. The study sheds light on how these effects might be lessened by making design changes, like modifying the flange width-to-depth ratio. In order to guarantee the structural integrity and best possible performance of concrete box girders during bridge building, the study emphasises how crucial it is to take shear lag into account during the design process.

7. According to Chang, S. (2004). "Shear lag effect in simply supported pre-stressed concrete box girder."

Chang investigates the shear lag effect in simply supported pre-stressed concrete box girders in further detail in this 2004 work. The study expands on earlier discoveries by offering a thorough examination of stress distribution and how it affects bridge design. Chang examines the variables affecting shear lag, such as girder geometry and load conditions, using both analytical and numerical approaches. According to the study, shear lag can drastically lower the effective flange width, which will affect the girder's ability to support loads. In order to increase the longevity and durability of pre-stressed concrete box girders in bridge engineering, Chang suggests design techniques to reduce shear lag.

8. Zhang Y.H and Li-Xia Lin. (2014). “Shear Lag Analysis of Thin-Walled Box Girders Adopting Additional Deflection as Generalized Displacement”

The 2014 work by Zhang and Lin takes a new technique by using added deflection as a generalised displacement to analyse shear lag in thin-walled box girders. The research creates an improved theoretical model to precisely forecast the deflection and distribution of stress in box girders under different loads. Through numerical simulations and actual results, the authors confirm their model and show that it is more accurate than previous methods. Their results demonstrate how shear lag significantly affects the way thin-walled box girders behave structurally and suggest useful design changes to lessen these impacts. The study makes significant contributions to the field of structural engineering, especially in terms of improving box girder bridge design.

9. According to Lee S.C, M.ASCE; Chai H.Yoo, M.ASC, and Dong Y. Yoon. (2002). “Analysis of Shear Lag Anomaly in Box Girder”

Lee, Yoo, and Yoon examine the shear lag anomaly in box girders and discuss its consequences for structural performance in their 2002 work. The study looks into the causes and effects of shear lag in box girder bridges using both analytical models and finite element analysis (FEA). The stress distribution within the girder flanges is significantly changed by shear lag, according to the authors, which may result in a decrease in the overall structural integrity and load-bearing capability. The study also looks at several design techniques, like the usage of transverse stiffeners and girder dimensions that are optimised, to reduce shear lag. Their research offers engineers vital information to improve the safety and design of box girder bridges.

10. According to Luo Q. Z., Q. S. Li, and J. Tang. (2002). Shear Lag in Box Girder Bridges.

The shear lag effect in box girder bridges is investigated in Luo, Li, and Tang's 2002 paper, which offers a thorough examination of its causes and effects. The stress distribution in box girders is investigated using a combination of theoretical models and finite element analysis (FEA). The authors identified girder shape, material qualities, and loading conditions as the main determinants of shear lag. According to their research, shear lag can have a substantial effect on box girder structural performance, especially when it comes to decreased stiffness and strength. The study makes recommendations for design changes to lessen the impacts of shear lag and enhance the general performance of box girder bridges, such as adding more stiffeners.

11. According to Luo Q.Z. and Y.M. Wu. Experimental studies on shear lag of box girders.

The experimental work by Luo and Wu focuses on data analysis and empirical observations to examine the shear lag effect in box girders. The study employs a battery of controlled laboratory experiments on box girder models to investigate the effects of shear lag on the distribution of stress and the behaviour of the structure under various loading scenarios. According to the study, shear lag significantly affects the load-carrying capacity and longevity of box girders by causing non-uniform stress distribution in the flanges. The authors offer useful suggestions for designing bridges, such as maximising girder diameters and adding stiffening elements to make up for shear lag. Their research adds important empirical data to our knowledge of shear lag in structural engineering and how to minimise it.

12. According to Dhaher, B., & A. A. Hadithy. (2021). "Analysis techniques for folded plate roofs and cellular bridges general review and comparisons".

The 2021 work by Dhaher and Hadithy offers a thorough overview of the analysis methods for cellular bridges and folded plate roofs, along with a discussion of the impacts of shear lag. The structural behaviour of these systems is studied using a variety of analytical, mathematical, and experimental techniques, which the authors compare. The review emphasises how crucial it is to take shear lag into account when designing and analysing cellular bridges since an uneven distribution of stress can have a major negative effect on their performance. The study highlights the main drawbacks and restrictions of the analysis methods used today and makes recommendations for future directions, like the creation of computer models that are more precise and effective. For engineers and academics working on the design and optimisation of folding plate and cellular structures, their review provides helpful data.

2.2 Research gap

-It has not been well studied how novel materials, like high-strength concrete or innovative composites, affect the shear lag effect. Studies could examine how these materials impact shear lag and whether they offer solutions to lessen its effects.

-Additional research is still required to examine the impact of various parameters on the shear lag effect in box girders.

2.3 Objective:

- Study of box Girder Bridge and its use.
- To estimate and evaluate the shear lag effect within box girder bridges under uniform loading conditions.
- To study comparison of shear leg by different analysis approach.

CHAPTER-3

METHODOLOGY AND INSIGHTS

3.1 Methodology

Analysing shear lag effects in a box girder using ABAQUS software involves setting up a finite element model that accounts for the geometric and loading conditions of the structure. Here's a general methodology for conducting a shear lag analysis in ABAQUS:

3.1.1 Define Geometry and Material Properties:

Create the Model Geometry: Use ABAQUS's modelling capabilities to define the geometry of the box girder, including dimensions, cross-sectional shape, and any openings or voids.

Assign Material Properties: Specify material properties such as elastic modulus, Poisson's ratio, and any other relevant properties.

If the box girder is pre-stressed, define the material properties related to pre-stressing, including the magnitude and direction of pre-stressing forces.

3.1.2 Apply Boundary Conditions:

Define Constraints: Apply appropriate boundary conditions to represent the structural constraints, such as fixed supports or rollers, based on the actual support conditions of the box girder.

3.1.3. Apply Loads:

Define Loading Conditions: Apply the desired loading conditions to represent the external loads acting on the box girder. This may include uniform loads, point loads, or any other load distribution.

If the box girder is pre-stressed, include the effects of pre-stressing forces.

3.1.4 Mesh Generation:

Create a Mesh: Generate a finite element mesh using appropriate element types and mesh sizes. Ensure that the mesh is refined enough to capture the stress variations accurately.

Consider refining the mesh near areas where stress concentrations or significant shear lag effects are expected.

3.1.5 Shear Lag Analysis:

Select a Suitable Analysis Procedure: Choose an appropriate analysis procedure within ABAQUS to perform the shear lag analysis. This may involve a static or dynamic analysis, depending on the loading conditions and the response of interest.

Consider Nonlinear Effects: If shear lag effects are significant, consider incorporating nonlinear material or geometric effects in the analysis.

Evaluate Results: Post-process the results to obtain information on stress distribution, deformations, and any other relevant outputs.

Examine the stress distribution across the cross-section to identify areas with higher or lower stresses due to shear lag.

4.1.6 Optimization and Validation:

Optimize the Model: Based on the shear lag analysis results, consider making adjustments to the model geometry, material properties, or loading conditions to optimize the design and mitigate shear lag effects.

3.1.7 Documentation and Reporting:

Document the Analysis: Create a detailed report documenting the methodology, assumptions, and results of the shear lag analysis.

Include relevant plots, stress distributions, and other key findings.

3.2. Stress distribution in a box girder bridge.

In a box girder bridge, stress distribution refers to how the forces or loads applied to the bridge are spread across its structure. Imagine the bridge as a rectangular box with a hollow interior. When the bridge supports the weight of vehicles or other loads, the stress is not uniformly distributed. Instead, it's concentrated more at the edges or sides of the box girder, and less at the centre. This uneven distribution is known as shear lag. The edges of the box experience higher stress because they bear more of the load, similar to pressing down on the edges of a box. When a box girder bridge carries a load, like the weight of vehicles or other forces, it experiences stress. This stress is not the same everywhere in the bridge.

Edges vs. Centre: Imagine the bridge is like a sandwich box. The edges or sides of the box feel more stress than the centre. It's like when you press down on the edges of a sandwich, the pressure is stronger there.

Uneven Pressure: This uneven stress distribution is because of something called "shear lag." It means that the load isn’t perfectly spread across the whole bridge; it's a bit more concentrated at the edges.

Designing for Safety: Engineers use this information to design the bridge materials and shape so that it can safely carry the loads without any part being overstressed. It's like making sure every part of the sandwich box can handle the pressure without breaking.

Balance and Stability: Engineers need to balance the distribution of stress to ensure the bridge is stable and doesn’t deform or buckle under heavy loads.

In simple terms, stress distribution in a box girder bridge is like understanding how the pressure or force from vehicles and other loads is spread across the structure. Engineers use this knowledge to design strong and safe bridges that can handle the different stresses they might face.

3.3 Boundary Conditions and assumptions;

Shear lag is a phenomenon that occurs in box girder bridges, where not all parts of the cross-section contribute equally to resisting the applied shear forces. The shear lag effect can have a significant impact on the distribution of shear stresses and deformations within the box girder. When analysing the shear lag effect, certain boundary conditions and assumptions are typically made to simplify the analysis and make it more practical. Here are some common boundary conditions and assumptions related to shear lag in box girder bridges:

Assumption of Plane Sections: Shear lag analysis often assumes that cross-sections remain plane during deformation. This simplifies the analysis and is generally reasonable for small deformations in typical bridge structures.

Longitudinal Stiffeners: The presence of longitudinal stiffeners is often assumed. These stiffeners help to distribute the shear forces more uniformly across the width of the box girder.

Elastic Material Behaviour: Linear elastic material behaviour is assumed for the analysis. This means that the material properties, such as Young's modulus, remain constant within the range of stresses encountered in the structure.

Homogeneous Material: The material of the box girder is assumed to be homogeneous, with consistent material properties throughout the cross-section.

Longitudinal Beams: The box girder is often idealized as a series of longitudinal beams connected by a thin web. This assumption helps to simplify the analysis and is suitable for many practical cases.

Transverse Shear Deformation: The analysis may neglect transverse shear deformations in the web. This assumption is often valid for slender webs with small thickness compared to the other dimensions.

Perfect Bonding between Flanges and Web: The connection between the flanges and the web is assumed to be perfect without slip. This simplifies the analysis but might not always reflect the actual behaviour in real-world conditions.

Uniform Load Distribution: Uniform load distribution is often assumed when calculating the shear lag effect. However, in reality, the distribution of live loads may vary along the length of the bridge.

Simplified Boundary Conditions: The boundary conditions at the supports are often simplified to facilitate the analysis. Common assumptions include pinned or simply supported conditions at the ends.

It's important to note that the specific assumptions and boundary conditions may vary depending on the analysis method and the design codes or guidelines used

3.4 Bending stress distribution.

When a beam is subjected to bending, different layers within the material experience varying amounts of stress. The outer layer, located farther from the neutral axis (the axis about which the beam bends), experience higher tensile or compressive stresses, while the inner layer experience lower stresses.

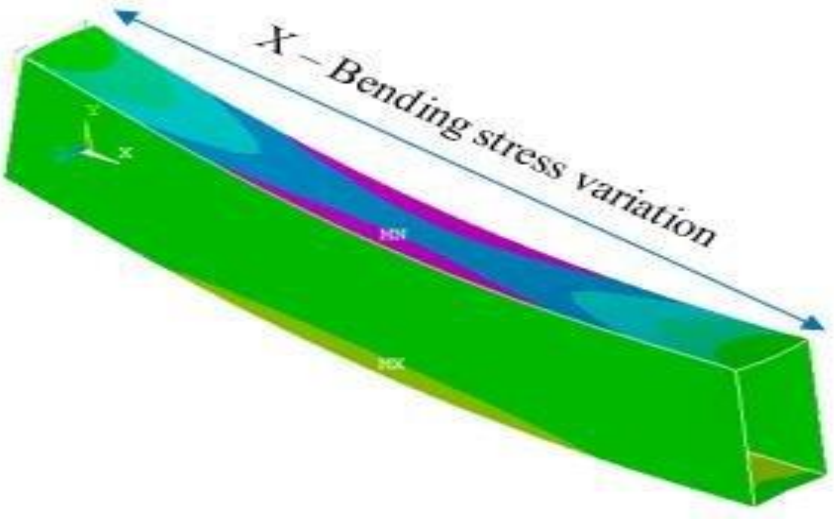


Fig 3.1(The impact of shear lag on stresses and deflections in different beam configurations are).

CHAPTER-4

ANALYTICAL FORMULATION

4.1 Analytical formulation

The present study considers a stiffened plate as a beam with length l. It has a width of w and a plate thickness of t_p. The number of stiffeners in the beam is m, and their width and depth are b and d, respectively. It is assumed that the equivalent span-wise displacement for shear deformation combined with normal stress is a polynomial function. The coordinates y and z are perpendicular to the x-direction, assuming that x is the span wise coordinate. The neutral direction of the beam's deflection is represented by the coordinate z(x).

These are the presumptions:

- The plate's components are securely attached together.
- The forces are distributed evenly along the width.
- The corresponding span-wise displacement of the plate may be expected to be as follows, assuming shear deformation along with normal stress:

$$u((x,y)) = \pm h\left(\frac{dz}{dx} + \frac{y^3}{w^3}U(x)\right) \tag{4.1}$$

The elastic potential energy of the load system Γll, the strain energy of the stiffeners Γls, and the strain energy of the plate Γlp can make up the potential energy of the beam.

For a distribution of bending moments M along a length l, the elastic potential energy of a load system is given by:

$$\Pi_l = \int M\frac{d^2z}{dx^2}dx \tag{4.2}$$

Matching the typical strain at the positions of the flange plates and stiffeners, the average normal strain in the stiffeners is

$$\varepsilon_s = \pm h_s\left(\frac{d^2z}{dx^2} + \frac{y^3}{w^3}U'\right) \tag{4.3}$$

Where, $h_s = \left(h_{pb} + \frac{d}{2}\right)$ and

h_{pb} is the distance of the bottom fiber of the plate from the neutral axis.

It is expected that stiffeners with constant size are uniformly distributed and closely spaced along the flange width. As a result, the complete stiffener that is fastened to a flange can be fashioned into a plate, or stiffener sheet.

The stiffener sheet shares the same centroid position and moment of area as stiffeners, with dimensions of 2w and ts, respectively.

The strain energy of the stiffeners (stiffener sheet) with respect to the normal strain of the flange may be written as follows, where Es is the stiffener's modulus of elasticity:

$$\Pi_s = \frac{1}{2}\iint E_s t_s \varepsilon_x^2 dxdy \tag{4.4}$$

Where, $t_s = \frac{mbd}{2w}$, and *bd* is the area of a stiffener

Putting the values of linear strain from Eq. 5.3 in Eq. 5.4, the strain energy of the stiffeners (stiffener sheet) is

$$\Pi_s = \frac{1}{2}\int E_s I_s \left\{(z'')^2 + \frac{1}{7}(U')^2 + \frac{1}{2}z''U'\right\} dx \tag{4.5}$$

(I_s = moment of area of the stiffeners)

The span-wise linear and shear strain in the plate can be calculated from Eq. 5.1 as follows:

$$\varepsilon_x = \pm h\left(z'' + \left(\frac{y^3}{w^3}\right)U'\right); \qquad \gamma = \pm\frac{3h}{w}\frac{y^2}{w^2}U \tag{4.6}$$

E_p is the modulus of elasticity of the steel plate and G is the modulus of rigidity of the steel plate. The strain energy of the plate is

$$\Pi_p = \frac{1}{2}\iiint\left\{E_p \varepsilon_x^2 + G\gamma^2\right\} dxdydh \tag{4.7}$$

By putting the values of Eq. 5.6 in Eq. 5.7.

$$\Pi_p = \frac{1}{2}\int E_p I_p \left\{(z'')^2 + \frac{1}{7}(U')^2 + \frac{1}{2}z''U' + \frac{G}{E_p}\frac{9}{5w^2}U^2\right\} dx \tag{4.8}$$

Where, (I_p= moment of area of the plate)

Combining Eq. 5.2, Eq. 5.5, and Eq. 5.8.

$$\Pi_T = \int\left\{\frac{1}{2}E_o I_o (z'')^2 + Mz''\right\} dx + \int \frac{1}{2}E_o I_o \left\{\frac{1}{7}(U')^2 + \frac{1}{2}z''U' + \frac{9}{5w^2}\Gamma U^2\right\} dx \tag{4.9}$$

Where, $E_o I_o = E_p I_p + E_s I_s$, and

$\Gamma = G I_p / E_o I_o$ is a shear flow parameter introduced by Singh (2023).

With the use of the minimal potential energy theorem, the differential equation and boundary condition for z and U may be determined., i.e., $\delta \Pi_T = 0$. Thus, with x_1 and x_2 denoting the interval of integration, and making.

$$\delta \Pi_T = \int \left\{ \left[E_o I_o z'' + M + \frac{1}{4} E_o I_o U' \right] \delta z'' + E_o I_o \left[-\frac{1}{7} U'' - \frac{1}{4} z''' + \frac{9}{5w^2} \Gamma U \right] \delta U \right\} dx + \left\{ E_o I_o \left[\frac{1}{7} U' + \frac{1}{4} z'' \right] \delta U \right\}_{x_1}^{x_2} = 0 \qquad (4.10)$$

The following relations can be established.

$$\left[z'' + \frac{1}{4} U' + \frac{M}{E_o I_o} \right] = 0 \qquad (4.11)$$

$$E_o I_o \left[\frac{1}{7} U'' - \frac{9}{5} \Gamma \frac{1}{w^2} U + \frac{1}{4} z''' \right] = 0 \qquad (4.12)$$

$$\left\{ E_o I_o \left[\frac{1}{7} U' + \frac{1}{4} z'' \right] \delta U \right\}_{x_1}^{x_2} = 0 \qquad (4.13)$$

From Eq. 4.11 and Eq. 4.12, eliminated the U’ and U” and arranging the term one can get.

$$z'' - \frac{z^{IV}}{k^2} = -\frac{M}{E_o I_o} + \frac{n}{k^2} \frac{M''}{E_o I_o} \qquad (5.14)$$

The Reisner’s parameters are.

$$n = \frac{16}{9} \qquad \text{and} \qquad k = \frac{1}{w} \sqrt{\frac{112}{5} \Gamma} \qquad (4.15)$$

4.2 Analytical Solution

The solutions are given for the cantilever stiffened plate in the following equations for uniform and point loading. The closed-form solutions of the differential equations are derived equivalently as followed by Singh et al. (2020) and Singh (2023). The boundary conditions applied to solve Eq.4.14 are as follows. At the fix end of the cantilever stiffened plate

z' = U' = 0.

The cantilever stiffened steel plate with uniform force, assuming origin at the free end, has the following bending moment equation.

$$M = -\frac{ql^2}{2} \left(\frac{x}{l} \right)^2 \qquad (4.16)$$

The equation for bending stress and the deflection profile is derived and given in the following equations.

$$\sigma_x = \pm \frac{ql^2}{2} \frac{E_p h_{pt}}{E_o I_o} \left[\left(\frac{x}{l}\right)^2 + \frac{8}{(kl)^2} \left\{ \frac{1}{4} - \frac{y^3}{w^3} \right\} \left\{ \frac{\cosh(l-x) + kl \sinh kx}{\cosh kl} - 1 \right\} \right] \tag{4.17}$$

$$z(x) = \frac{ql^4}{8E_o I_0} \left[\frac{1}{3} \left(\frac{x}{l}\right)^4 - \frac{4}{3} \left(\frac{x}{l}\right) + 1 + \frac{8\,(n-1)}{(kl)^2} \left\{ \frac{1}{2} \left(1 - \left(\frac{x}{l}\right)^2 \right) + \frac{\cosh kx - \cosh kl}{(kl)^2} - \right.\right.$$

$$\left.\left. \frac{\sinh kx - \sinh kl}{(kl)^2 \cosh kl} (\sinh kl - kl) \right\} \right] \tag{4.18}$$

CHAPTER-5

A STIFFENED FLANGE STEEL BOX-BRIDGE

When building box and plate girder bridges, intentional placement of longitudinal stiffeners is a common practice that is supported by major codes and standards like BSI (1982), CEN (2004), and AASHTO (2020). A crucial part of improving the structural integrity of box girders are longitudinal stiffeners, which offer a strong way to reinforce the structure without adding a lot of weight to it. Concurrently, as shown in Figure by Moffatt and Dowling (1975), a sequence of parallel stiffeners on the flange plate are used to prevent any tendency towards out-of-plane flexibility.

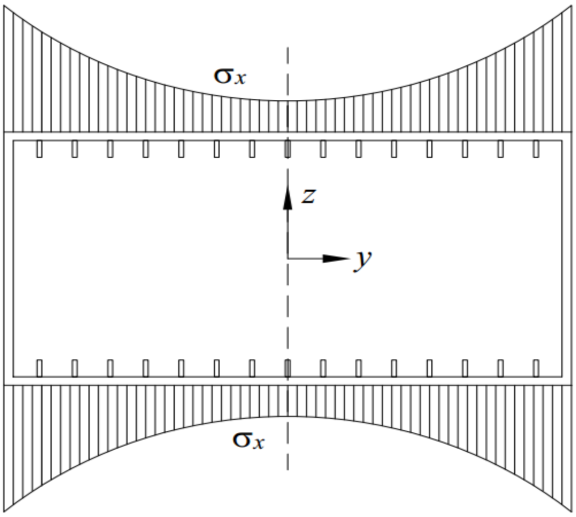


Fig. 5.1.1 (The variation of normal stresses across the width of stiffened flange box beams cross section)

Cantilever plates are often used in engineering design for loads that are unusual, concentrated, flexible, or discontinuous. Examples of cantilever plates are cantilever walls, projecting pier heads, projecting floor slabs, and gear teeth (Young and Budynas 2002). Other thin cantilever plates supported by a connected component include boxes, U, T, and I beams with thin cover plates serving as flanges. These beams are utilised in aeroplanes, flooring, tanks, tubular-tall structures, and box-girder bridges. The stress distribution in large beams is not constant across their width, much like the stresses in narrow beams that are described by elementary beam theory (EBT). These types of beams do not satisfy the fundamental premise of beam theory, which states that the normal stress in the flange does not change in direction across the width, due to the shear deformation on the flanges (Reissner 1945).

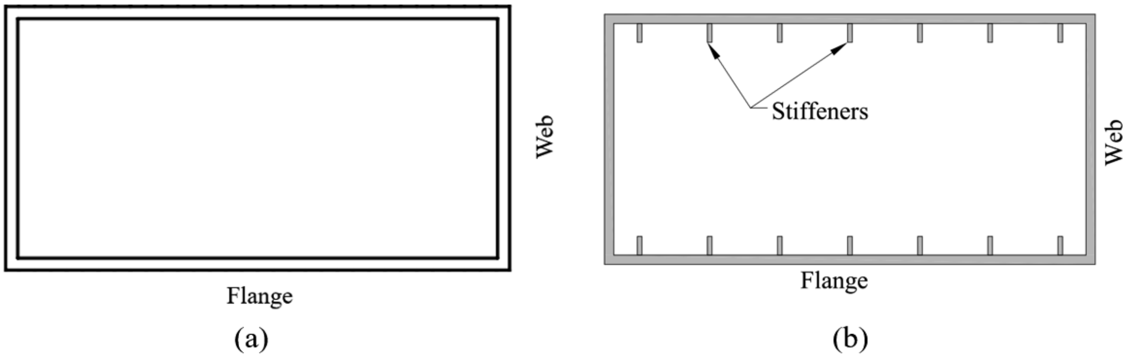


Fig 5.1.2 (a) Steel box beam without stiffeners, (b) Box beam with stiffeners at flanges

5.1 Finite element method. (FEM)

Presents a more complex and advanced method for analysing shear lag in box girders, depending on finite element approaches that frequently need the use of computer tools. Leading this group is Finite Element Analysis (FEA), a computational method that has changed structural engineering by offering an extensive understanding of the complicated behaviours displayed by sophisticated systems. Finite Element Analysis is a very powerful instrument that can yield results that are not possible using standard beam theory. It makes it possible to study structural effects like deformation and shear lag, giving rise to a more precise and in-depth picture of how a box girder reacts to outside forces. Because FEA is so good at capturing the subtleties of structural behaviour, it is especially useful when working with complex loadings and designs.

Finite Element Analysis's power does, however, come with a unique set of difficulties. Using this strategy effectively demands a high degree of skill in selecting the right element kinds and sizes within the selected computer tool. In order for the model accurately represent the physical reality of the box girder, engineers have to carefully arrange the finite components. The complex nature of the software being used as well as the fundamental structural concepts at work must be thoroughly understood for this process to be completed. Also, a crucial step in the analytical process involves understanding the FEA data. Even though FEA can produce intricate and nuanced data, it takes considerable thought to extract insights that are valuable. The output data must be carefully examined by engineers, who must take into account variables including stress distributions, deformations, and the interaction of forces within the structure. The engineer's interpretive abilities are necessary to convert the numerical results into useful design decisions, which highlights the significance of having experience with Finite Element Analysis. The use of advanced computational methods like finite element analysis (FEA) becomes essential as structures get more intricate and require an increased level of precision. The advantages of using finite element analysis (FEA) to gain intricate and subtle insights into structural behaviour much outweigh disadvantages, which makes FEA a vital technique for today's engineers. By leveraging the power of finite element methods, structural engineers can more effectively address the difficult problems raised by shear lag in box girders, leading to the development of designs that are not only accurate but also well-grounded in the fundamental principles of structural mechanics.

5.2 Analysing a steel beam model in ABAQUS (CAE)

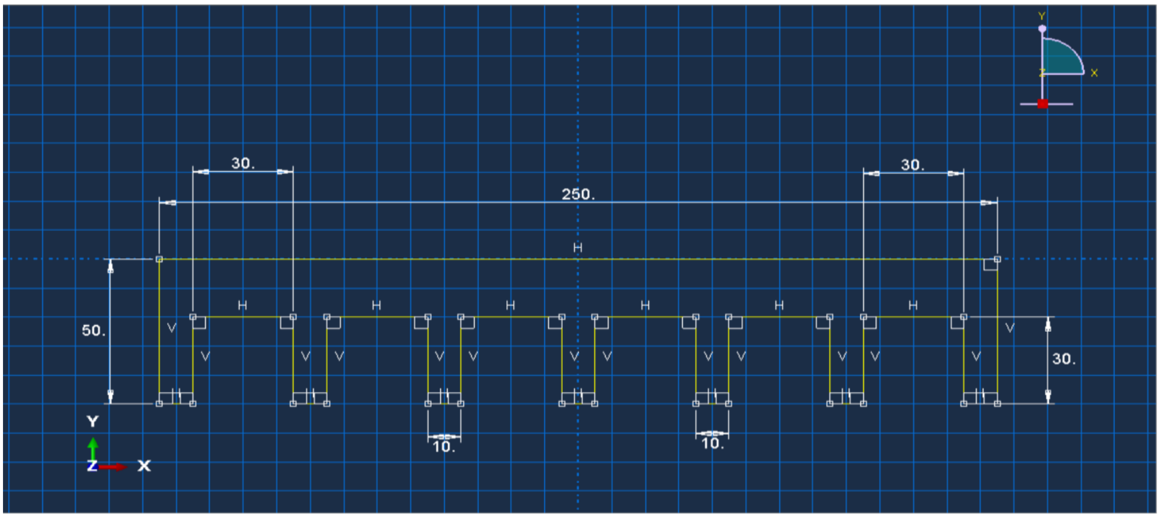
Model Geometry

Total length of beam= 1250mm, Width of flange =250mm,

Thickness of plate =20 mm,

Stiffener thickness= 10mm, depth= 30mm.

ABAQUS fig (5.a)

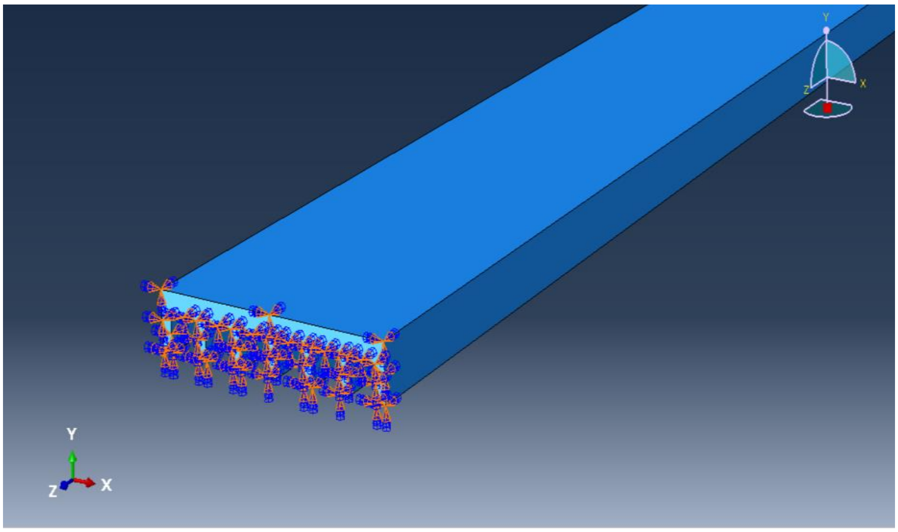


(Stiffened plate cross-section with plate and stiffener dimensions and coordinate system.)

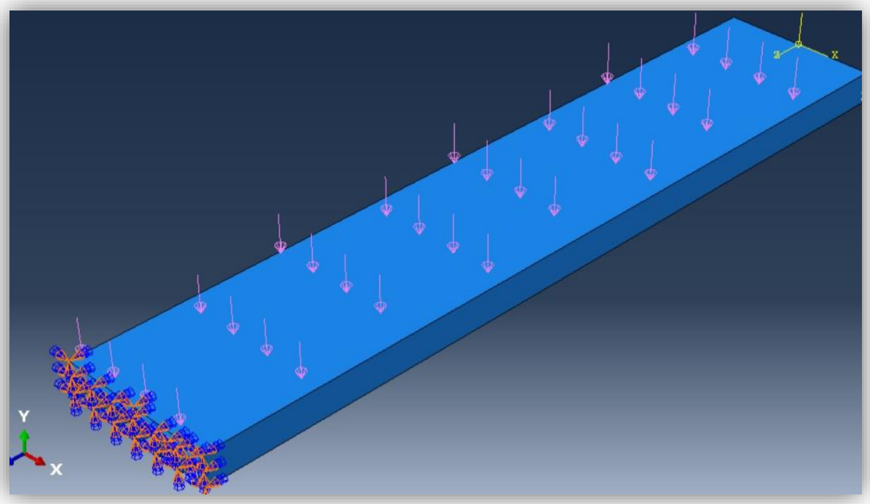
Applying boundary condition, end Load

One end of the beam is fixed, and load applied 800kN.

ABAQUS fig. - (5.b)



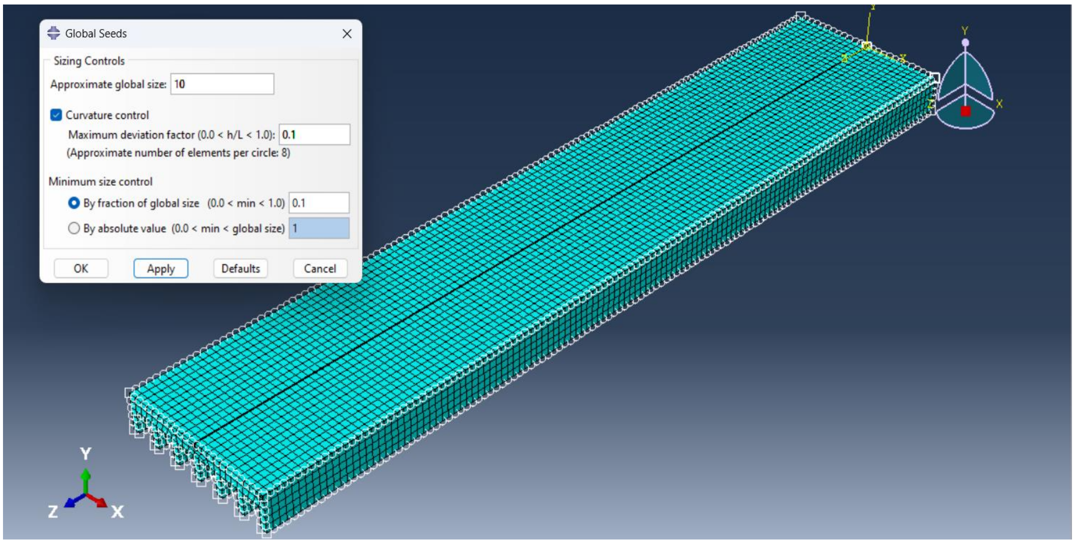
ABAQUS fig.- (5.c)



Mesh Generation and Submitting a job and visualization.

Generating the mesh size of 10mm, to achieve better results. We prepare a job for analysing the member.

ABAQUS fig. - (5.d)



Sizing Controls

Approximate global size: 10

☑ Curvature control

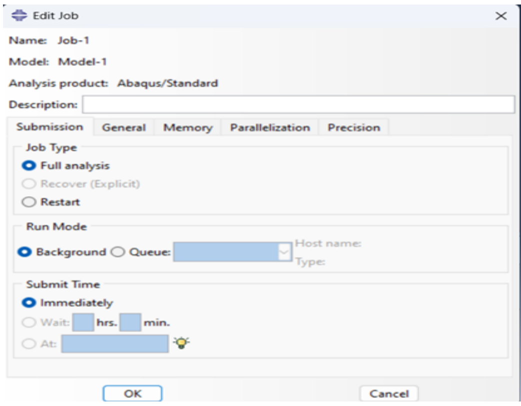
Maximum deviation factor (0.0 < h/L < 1.0): 0.1

(Approximate number of elements per circle: 8)

Minimum size control

● By fraction of global size (0.0 < min < 1.0) 0.1

○ By absolute value (0.0 < min < global size) 1



Name: Job-1

Model: Model-1

Analysis product: Abaqus/Standard

Description:

Job Type

● Full analysis

○ Recover (Explicit)

○ Restart

Run Mode

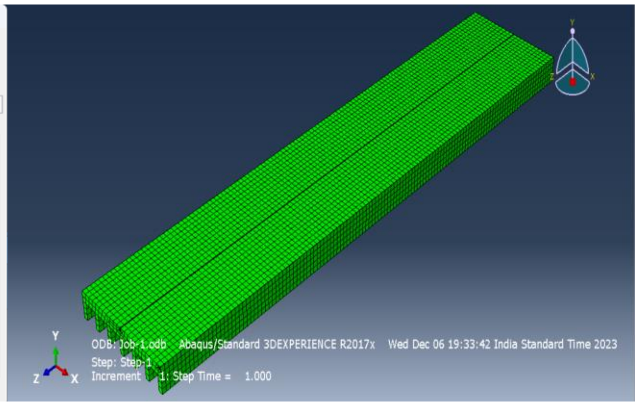
● Background ○ Queue: Host name: Type:

Submit Time

● Immediately

○ Wait: hrs. min.

○ At:



ODB: Job-1.odb Abaqus/Standard 3DEXPERIENCE R2017x Wed Dec 06 19:33:42 India Standard Time 2023

Step: Step-1

Increment 1: Step Time = 1.000

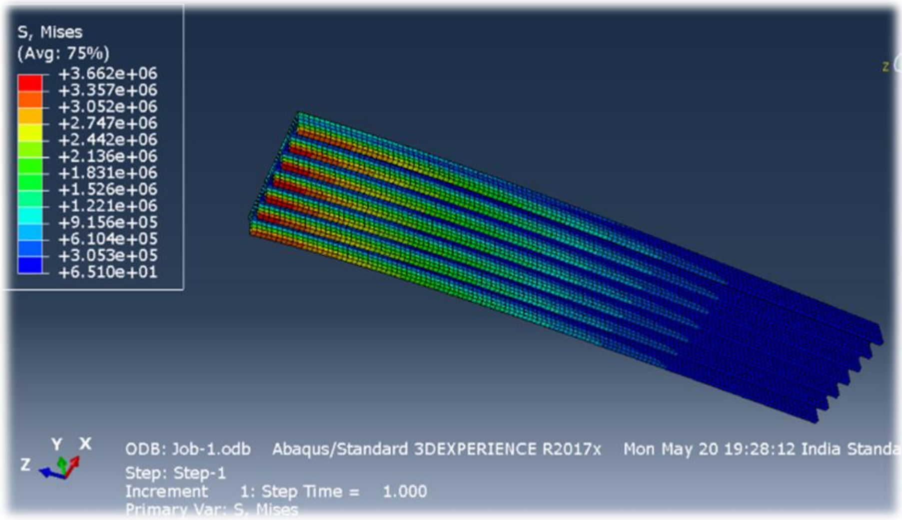
CHAPTER-6

RESULT AND DISCUSSION

6.Results

6.1 Stress distribution in beam.

ABAQUS fig (6.a)



A cantilever stiffened plate consisting of the plate and stiffeners made of steel is used. The length of the beams is l= 225 mm; $2w$ = 250 mm; thickness of plate t_p=20mm; b = 10 mm; d = 30 mm; m= 5, and $Ep = Es = 210$ GPa. In this beam, l/w =10, and G/E_p is equal to 0.385. According to the parameters n and kl are equal to 1.788, and 4.329. The parameter Γ is equal to 0.9136. Furthermore, the normal stresses are calculated using Eq.

$$\sigma_x = \pm \frac{ql^2}{2} \frac{E_p h_{pt}}{E_o I_o} \left[\left(\frac{x}{l} \right)^2 + \frac{8}{(kl)^2} \left\{ \frac{1}{4} - \frac{y^3}{w^3} \right\} \left\{ \frac{\cosh(l-x) + kl \sinh kx}{\cosh kl} - 1 \right\} \right]$$

6.2 Spatial displacement at nodes (U)

Create a path from the beam surface.

ABAQUS Fig. (6.b)

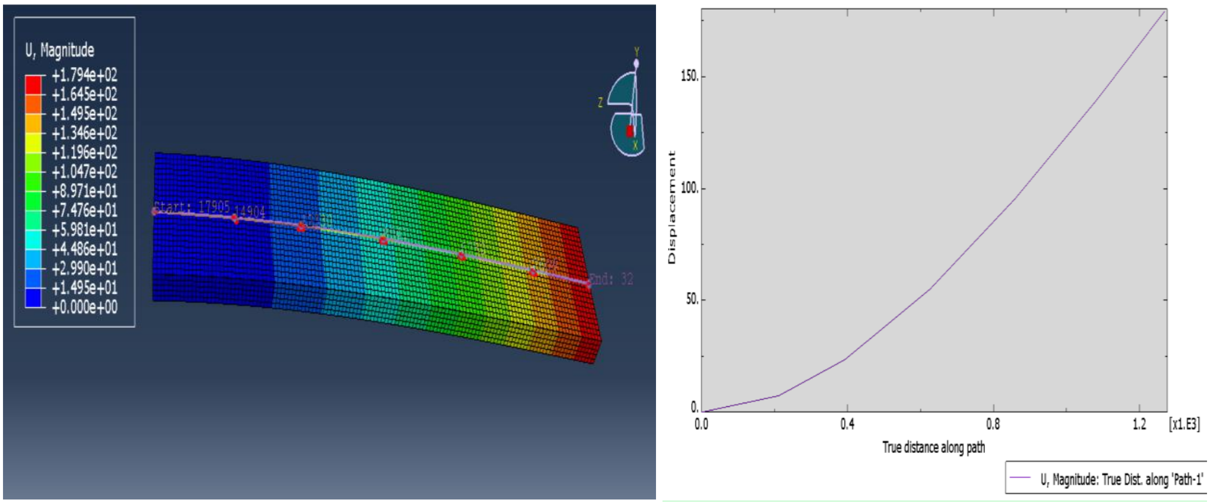
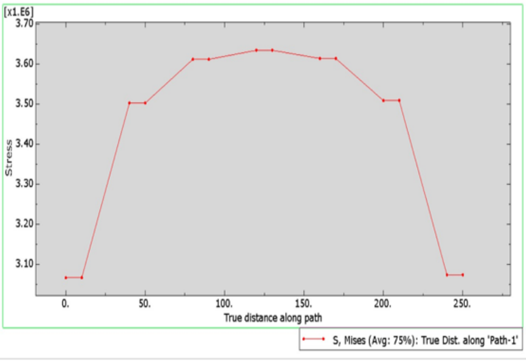
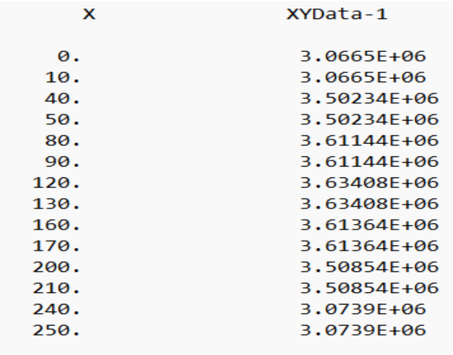
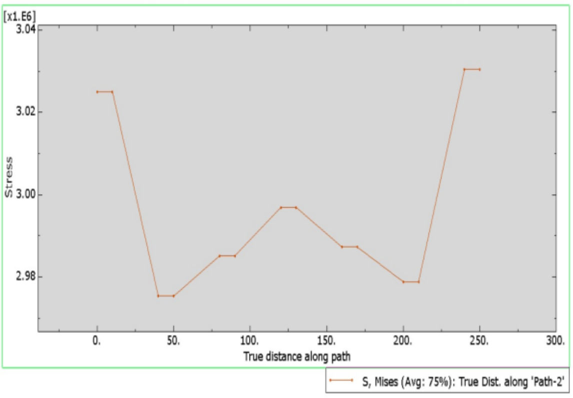


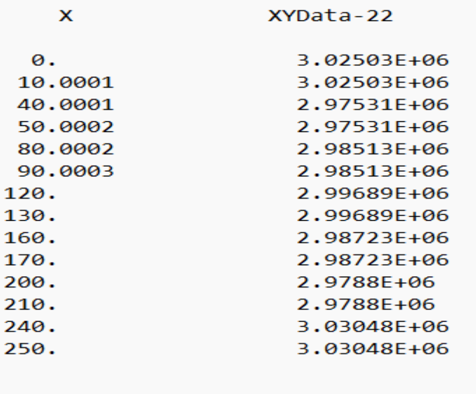
Fig. 6.1.1(Displacement at the beam along the length.)



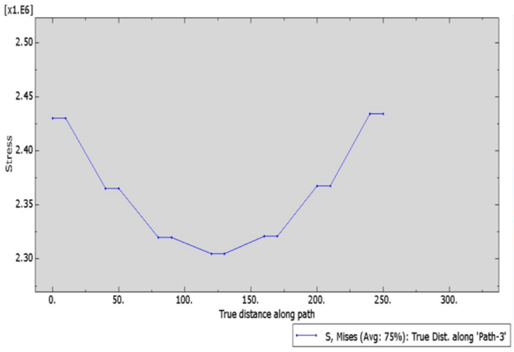


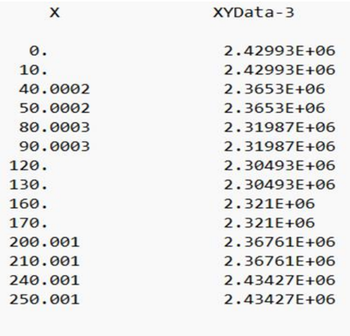
X	XYData-1
0.	3.0665E+06
10.	3.0665E+06
40.	3.50234E+06
50.	3.50234E+06
80.	3.61144E+06
90.	3.61144E+06
120.	3.63408E+06
130.	3.63408E+06
160.	3.61364E+06
170.	3.61364E+06
200.	3.50854E+06
210.	3.50854E+06
240.	3.0739E+06
250.	3.0739E+06



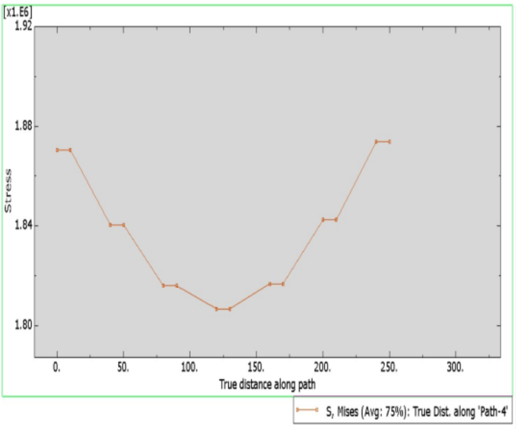


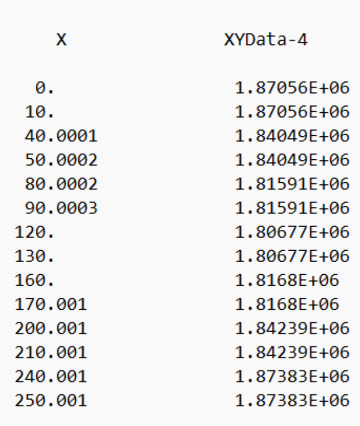
X	XYData-22
0.	3.02503E+06
10.0001	3.02503E+06
40.0001	2.97531E+06
50.0002	2.97531E+06
80.0002	2.98513E+06
90.0003	2.98513E+06
120.	2.99689E+06
130.	2.99689E+06
160.	2.98723E+06
170.	2.98723E+06
200.	2.9788E+06
210.	2.9788E+06
240.	3.03048E+06
250.	3.03048E+06



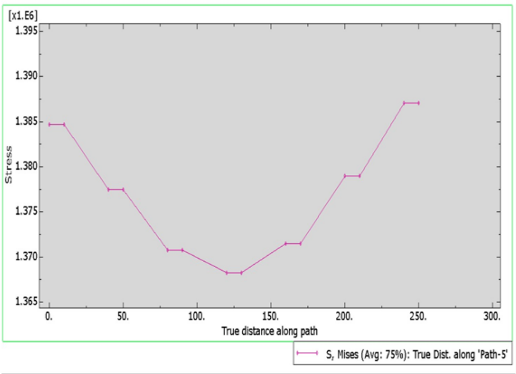


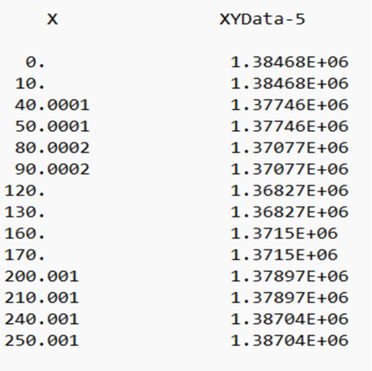
X	XYData-3
0.	2.42993E+06
10.	2.42993E+06
40.0002	2.3653E+06
50.0002	2.3653E+06
80.0003	2.31987E+06
90.0003	2.31987E+06
120.	2.30493E+06
130.	2.30493E+06
160.	2.321E+06
170.	2.321E+06
200.001	2.36761E+06
210.001	2.36761E+06
240.001	2.43427E+06
250.001	2.43427E+06



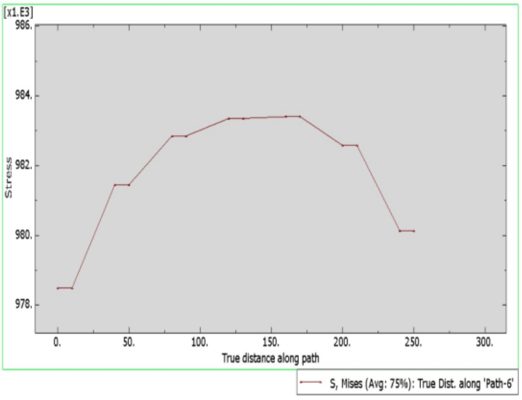


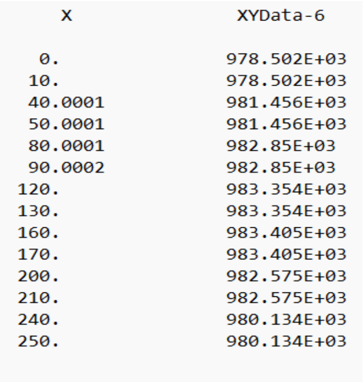
X	XYData-4
0.	1.87056E+06
10.	1.87056E+06
40.0001	1.84049E+06
50.0002	1.84049E+06
80.0002	1.81591E+06
90.0003	1.81591E+06
120.	1.80677E+06
130.	1.80677E+06
160.	1.8168E+06
170.001	1.8168E+06
200.001	1.84239E+06
210.001	1.84239E+06
240.001	1.87383E+06
250.001	1.87383E+06



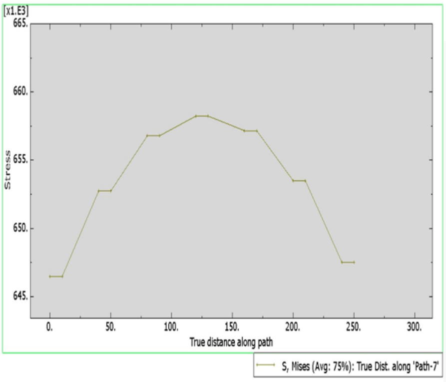


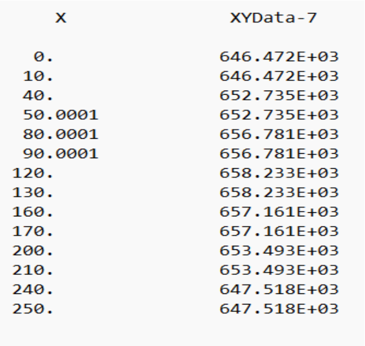
X	XYData-5
0.	1.38468E+06
10.	1.38468E+06
40.0001	1.37746E+06
50.0001	1.37746E+06
80.0002	1.37077E+06
90.0002	1.37077E+06
120.	1.36827E+06
130.	1.36827E+06
160.	1.3715E+06
170.	1.3715E+06
200.001	1.37897E+06
210.001	1.37897E+06
240.001	1.38704E+06
250.001	1.38704E+06



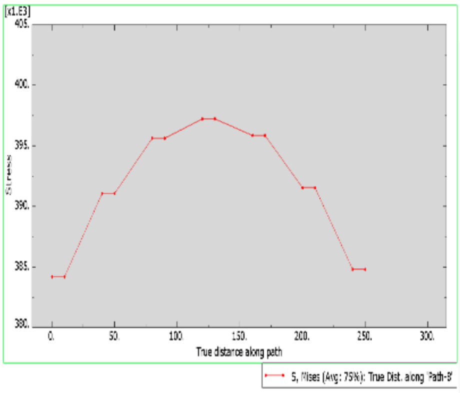


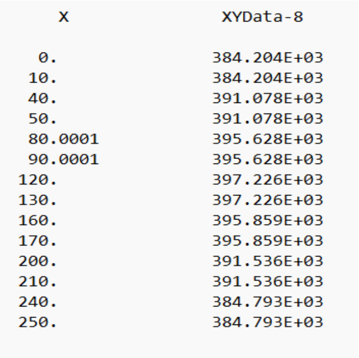
X	XYData-6
0.	978.502E+03
10.	978.502E+03
40.0001	981.456E+03
50.0001	981.456E+03
80.0001	982.85E+03
90.0002	982.85E+03
120.	983.354E+03
130.	983.354E+03
160.	983.405E+03
170.	983.405E+03
200.	982.575E+03
210.	982.575E+03
240.	980.134E+03
250.	980.134E+03



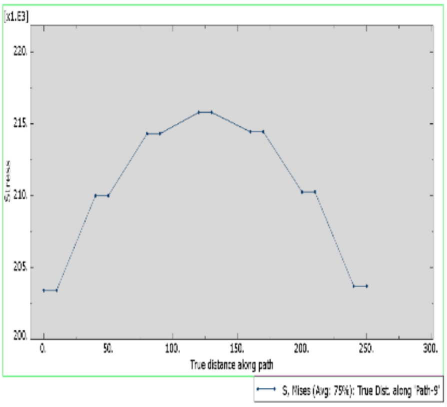


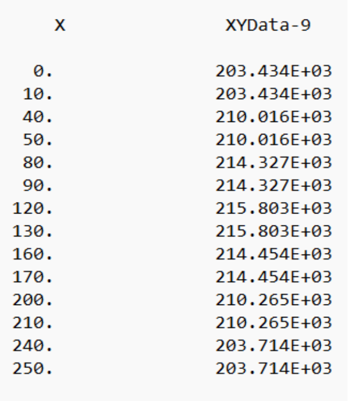
X	XYData-7
0.	646.472E+03
10.	646.472E+03
40.	652.735E+03
50.0001	652.735E+03
80.0001	656.781E+03
90.0001	656.781E+03
120.	658.233E+03
130.	658.233E+03
160.	657.161E+03
170.	657.161E+03
200.	653.493E+03
210.	653.493E+03
240.	647.518E+03
250.	647.518E+03



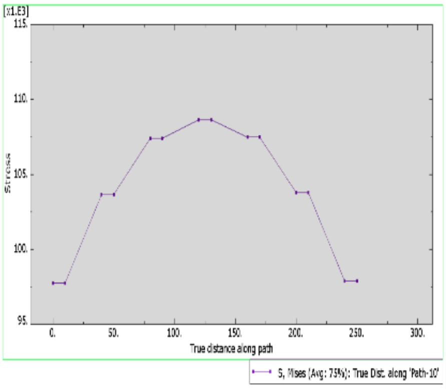


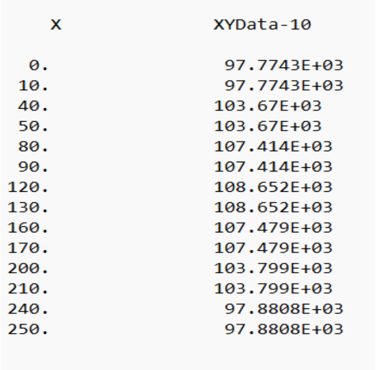
X	XYData-8
0.	384.204E+03
10.	384.204E+03
40.	391.078E+03
50.	391.078E+03
80.0001	395.628E+03
90.0001	395.628E+03
120.	397.226E+03
130.	397.226E+03
160.	395.859E+03
170.	395.859E+03
200.	391.536E+03
210.	391.536E+03
240.	384.793E+03
250.	384.793E+03

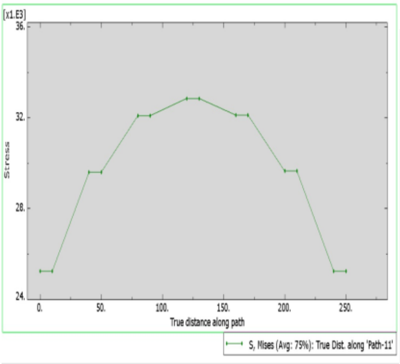


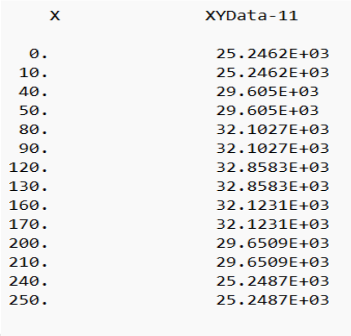


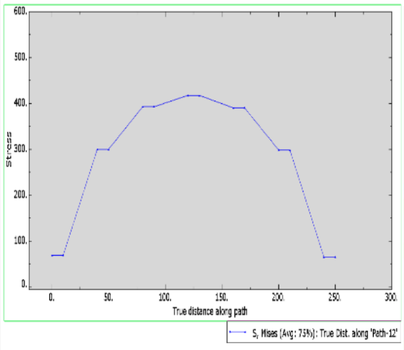
X	XYData-9
0.	203.434E+03
10.	203.434E+03
40.	210.016E+03
50.	210.016E+03
80.	214.327E+03
90.	214.327E+03
120.	215.803E+03
130.	215.803E+03
160.	214.454E+03
170.	214.454E+03
200.	210.265E+03
210.	210.265E+03
240.	203.714E+03
250.	203.714E+03

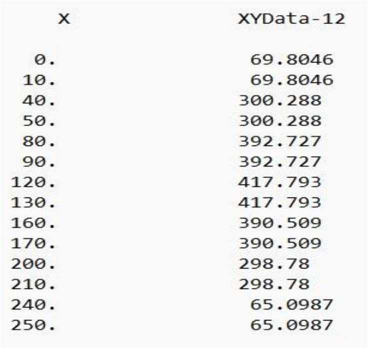



```
     X                 XYData-10

    0.                  97.7743E+03
   10.                  97.7743E+03
   40.                 103.67E+03
   50.                 103.67E+03
   80.                 107.414E+03
   90.                 107.414E+03
  120.                 108.652E+03
  130.                 108.652E+03
  160.                 107.479E+03
  170.                 107.479E+03
  200.                 103.799E+03
  210.                 103.799E+03
  240.                  97.8808E+03
  250.                  97.8808E+03
```




```
     X                 XYData-11

    0.                 25.2462E+03
   10.                 25.2462E+03
   40.                 29.605E+03
   50.                 29.605E+03
   80.                 32.1027E+03
   90.                 32.1027E+03
  120.                 32.8583E+03
  130.                 32.8583E+03
  160.                 32.1231E+03
  170.                 32.1231E+03
  200.                 29.6509E+03
  210.                 29.6509E+03
  240.                 25.2487E+03
  250.                 25.2487E+03
```

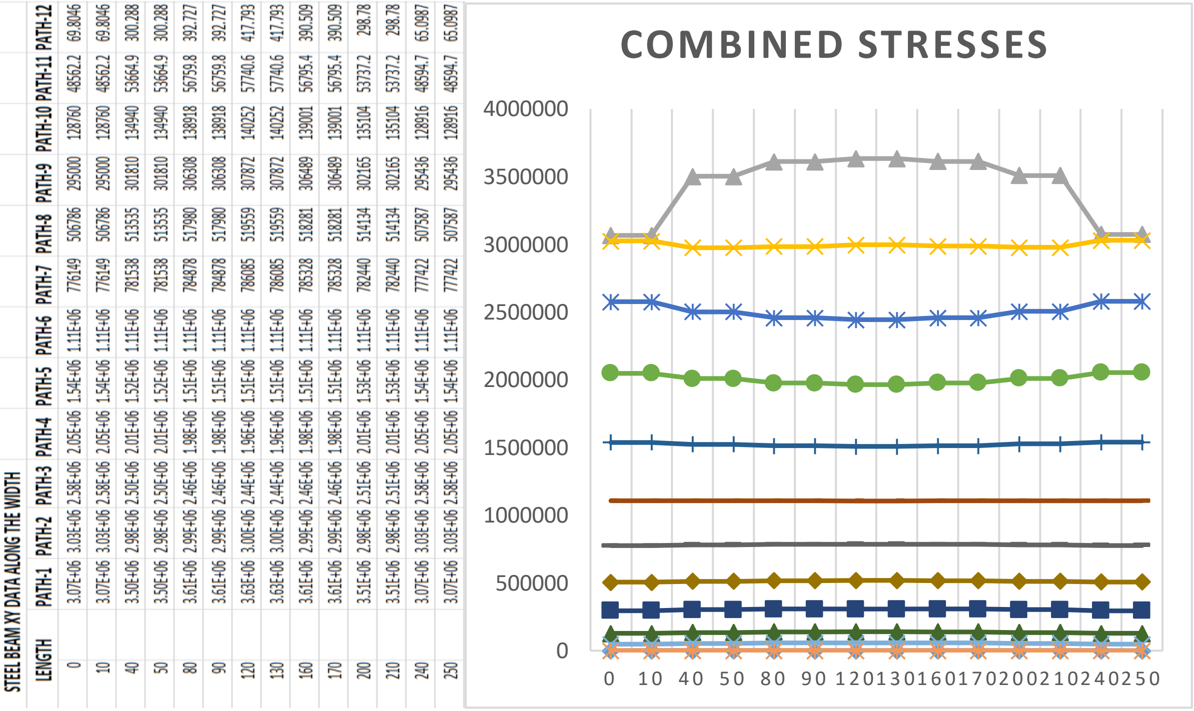



```
     X                 XYData-12

    0.                  69.8046
   10.                  69.8046
   40.                 300.288
   50.                 300.288
   80.                 392.727
   90.                 392.727
  120.                 417.793
  130.                 417.793
  160.                 390.509
  170.                 390.509
  200.                 298.78
  210.                 298.78
  240.                  65.0987
  250.                  65.0987
```

(ABAQUS stress path values. (Stress path 1-12)

The results of the stress path generated from the Abaqu(CAE), finite element analysis along the cantilever beam's length offer a thorough understanding of the stress distribution under uniform loading circumstances. Significant variations in stress along the length of the beam are shown by the analysis, and these variations are impacted by both the geometric features of the beam and the applied load. Because of the constraint constraints, stress concentrations with larger stress values are seen near the fixed end of the cantilever. The stress values steadily fall towards the beam's free end, showing the normal stress distribution that can be anticipated in cantilever beams under uniform loading. Stiffeners improve the load-carrying capacity of the beam by modifying the stress distribution further and lowering peak loads in specific areas. By more equally distributing the loads, these stiffeners help to reduce the possibility of stress concentrations that could cause failure.

EXCEL 2013 RESULT (6.C)



STEEL BEAM XY DATA ALONG THE WIDTH

LENGTH	PATH-1	PATH-2	PATH-3	PATH-4	PATH-5	PATH-6	PATH-7	PATH-8	PATH-9	PATH-10	PATH-11	PATH-12
0	3.07E+06	3.03E+06	2.58E+06	2.05E+06	1.54E+06	1.11E+06	776149	506786	295000	128760	48562.2	69.8046
10	3.07E+06	3.03E+06	2.58E+06	2.05E+06	1.54E+06	1.11E+06	776149	506786	295000	128760	48562.2	69.8046
40	3.50E+06	2.98E+06	2.50E+06	2.01E+06	1.52E+06	1.11E+06	781538	513535	301810	134940	53664.9	300.288
50	3.50E+06	2.98E+06	2.50E+06	2.01E+06	1.52E+06	1.11E+06	781538	513535	301810	134940	53664.9	300.288
80	3.61E+06	2.99E+06	2.46E+06	1.98E+06	1.51E+06	1.11E+06	784878	517980	306308	138918	56759.8	392.727
90	3.61E+06	2.99E+06	2.46E+06	1.98E+06	1.51E+06	1.11E+06	784878	517980	306308	138918	56759.8	392.727
120	3.63E+06	3.00E+06	2.44E+06	1.96E+06	1.51E+06	1.11E+06	786085	519559	307872	140252	57740.6	417.793
130	3.63E+06	3.00E+06	2.44E+06	1.96E+06	1.51E+06	1.11E+06	786085	519559	307872	140252	57740.6	417.793
160	3.61E+06	2.99E+06	2.46E+06	1.98E+06	1.51E+06	1.11E+06	785328	518281	306489	139001	56795.4	390.509
170	3.61E+06	2.99E+06	2.46E+06	1.98E+06	1.51E+06	1.11E+06	785328	518281	306489	139001	56795.4	390.509
200	3.51E+06	2.98E+06	2.51E+06	2.01E+06	1.53E+06	1.11E+06	782440	514134	302165	135104	53737.2	298.78
210	3.51E+06	2.98E+06	2.51E+06	2.01E+06	1.53E+06	1.11E+06	782440	514134	302165	135104	53737.2	298.78
240	3.07E+06	3.03E+06	2.58E+06	2.05E+06	1.54E+06	1.11E+06	777422	507587	295436	128916	48594.7	65.0987
250	3.07E+06	3.03E+06	2.58E+06	2.05E+06	1.54E+06	1.11E+06	777422	507587	295436	128916	48594.7	65.0987

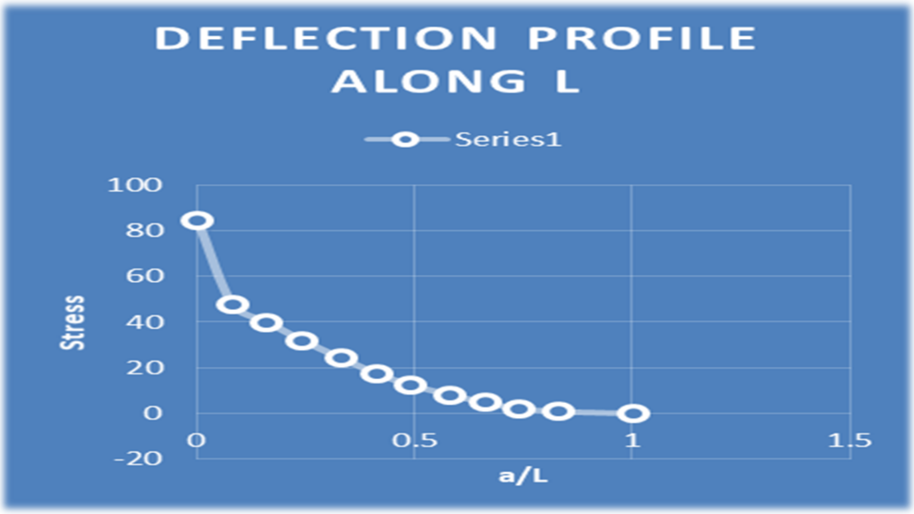
6.1.3 Effect of material properties *G/E* ratio

The *G/E* (modulus of rigidity to Young's modulus) ratio is a fundamental material property that plays a significant role in the behaviour of materials, particularly in the context of shear and torsional loading. G/E is a measure of the material properties that influence the elastic response of the beam. In analysing this ratio, researchers gain valuable insight into how material characteristics influence the effective width ratio, shedding light on the complexities involved in shear lag analysis. The mechanical response and overall performance of box beams and structural analysis are significantly influenced by the G/E ratio. Tenchev (1996) suggests that when assessing the shear lag effect in composite structures, it's preferable to use G/E ratios instead of Poisson's ratios (Song and Scordelis in 1990a, 1990b), The Poisson's ratio frequently causes mistakes when assessing the shear lag effect in flanges.

In relation to axial deformation, the *G/E* ratio serves as a direct indicator of a material's resistance to shear deformation. A material with a high G/E ratio possesses a greater shear modulus than Young’s modulus, indicating enhanced resistance to shear deformation. When analysing the behaviour of materials subjected to complex loading conditions, such as box beams, this distinction becomes particularly important. The interaction between the aspect ratio and the G/E ratio becomes particularly important in the context of the box cantilever beam. For beams to effectively resist shear lag effects, it is crucial to understand how these parameters affect the effective width ratio or shear lag factors.

When it comes to wide beams and structural analysis, the G/E ratio can have several effects: (a). The G/E ratio reflects the material's resistance to shear deformation compared to its resistance to axial deformation. Materials have a high G/E ratio have a higher shear modulus relative to Young's modulus, indicating greater resistance to shear deformation. (b).In the context of wide beams, where shear lag effects can be pronounced, materials with a high G/E ratio are advantageous. The higher shear modulus helps in distributing shear stresses more evenly across the cross-section, reducing shear lag effects. (c).In torsional applications, materials with a high G/E ratio exhibit greater torsional stiffness. This is particularly relevant in wide beams subjected to torsional loading, where materials with higher G/E ratios can resist twisting and maintain stability.

6.1.4 Deflection profile of beam along length and width of beam.



(a)

(b)

(Fig.6.1.2 The deflection profile of the cantilever steel beam for uniform loading (a),(b))

6.1.5 Peak stress factor variation with aspect ratio

Aspect ratios—which are the length to width (l/w) ratios of box beams—are crucial in determining how much shear lag occurs in these structural components. Understanding aspect ratios is essential for the effective design and analysis of stiffened box beams, as they have a significant impact on shear lag. We examine the complex dynamics of aspect ratios in this investigation, providing theoretical and empirical support for their importance. The centre of the flange and the fixed end are two crucial areas in a cantilever stiffened box beam. Where the stress variables related with peak stress are visually represented in Figure. This example emphasises how crucial aspect ratios are in controlling how these kinds of structural elements behave. When peak stresses in these beams are analysed, it can be seen that their patterns are quite similar to those of the box beam (Lin and Zhao, 2011; Singh et al., 2020; Singh, 2023).

The results show a significant relationship between aspect ratios and peak stresses, with a focus on the negative effects of smaller aspect ratios. This finding motivates more research into specific stresses linked to different aspect ratios. The peak stress factor for a square beam with an aspect ratio of 2 (l/w = 2) is 1.125 for point loading and 1.21 for uniformly distributed loading. When l/w = 1, the beam's dimensions expand even further, and the peak stress factor increases even further to 1.316 for evenly distributed loading and 1.340 for point loading. These numerical results clearly show that stress concentration increases significantly with decreasing aspect ratio. Thus, in such situations, the cantilever composite box beam with stiffeners strength is affected. On the other hand, when we investigate the effects of larger aspect ratios, we find an interesting pattern. Peak stresses within the composite box beam decrease accordingly with increasing aspect ratio. The beam aligns more closely with elementary beam theory when aspect ratios of 12 and above are used to successfully minimise stress causes, as indicated by this inverse relationship. Higher aspect ratios are thought to produce a more uniform distribution of stresses, more like the behaviour of a simple beam under loads, according to theoretical underpinnings. Aspect ratios are crucial in determining the structural performance of cantilever box beams with stiffeners, as supported by both actual data and theoretical foundations.

The analysis's conclusions add to the larger conversation on how to best design and operate these kinds of structural components in a range of engineering contexts. In order to fully understand the significance of aspect ratios, it is necessary to explore the complex nature of shear lag effects. When discussing box beams, the term "shear lag" describes the unequal distribution of loads along the beam's width. For engineers and designers, understanding shear lag is essential since it directly affects the structure's overall stability and ability to carry loads. These findings have practical effects that go beyond theoretical research and into actual engineering operations. When constructing box beams for buildings, bridges, and other structures, engineers must find a careful balance between minimising the effects of shear lag and maximising aspect ratios. The knowledge gathered from this investigation offers a useful road map for striking this balance, pointing engineers in the direction of solutions that optimise structural integrity and efficiency.

In conclusion, the dynamic interaction that greatly affects the structural behaviour of cantilever box beams with stiffeners is represented by the complex relationship between aspect ratios and shear lag. Theoretical considerations and empirical data together highlight how important aspect ratios are in determining stress distribution patterns and, consequently, the overall performance of these structural components. As we observe that our investigation is proof of the never-ending search for new information and improvement in structural and technical design.

6.1.6 The Aspect ratio (*l/w*)

The stress concentration in wide beams, or plates, is largely determined by the length to width ratio (l/w). For the sake of simplicity, many research on plate bending use infinitely wide plates. Researchers like Young and Budynas (2002) adopted this idea of limitless breadth under certain assumptions. The assumption that the theory derived for beams of infinite width applies to beams whose width does not exceed four times their span is resilient for reasonably large beams, as proved by empirical data presented by Wellauer and Seireg (1960). Shows the durability of this assumption for reasonably wide beams and validates the theory derived for beams of infinite width applied to beams whose width does not exceed four times their span. The aspect ratio is frequently reversed to w/l rather than l/w in talks centred on particularly wide beams in order to emphasise breadth over length. Figure 4.13 illustrates the stress characteristics at the fixed end of a stiffened plate on a cantilever, emphasising how crucial this aspect ratio is.

The maximum stress factor increases as the w/l ratio rises, as seen in Figure 4.13. This study's unique numerical example revealed that, in a cantilever-stiffened plate, the peak stress levels tend to stabilise at a particular position, showing a convergence of peak stress values. This convergence implies that the increase in stress concentration brought about by the beam's widening has a maximum value, after which further width increases have a decreasing impact on stress concentration.

These results highlight the importance of the aspect ratio in the structural analysis and design of wide beams, providing guidance to researchers and engineers in the estimation of stress concentrations and highlighting the necessity of taking beam dimensions into account when designing beams. By reducing stress concentrations, particularly in crucial locations like the fixed ends of cantilevers, where the stress factors are significantly influenced by the beam's proportions, this understanding aids in optimising structural integrity and durability.

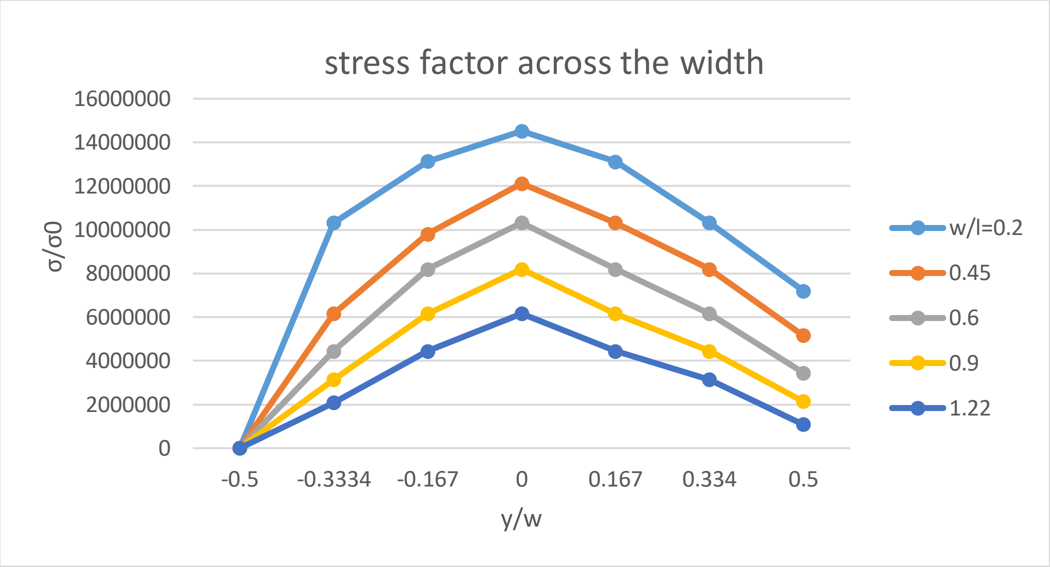


FIG. 6.1.3 (Stress factor variation throughout the breadth at the cantilever stiffen plate's fixed end with a changeable w/l ratio)

The variation of peak stress calculated at the cantilever strengthened plate's fixed end is depicted in Figures 6.3. The peak stress factor converges to 2 for w/l > 10. In this manner, the idea of the plate's unlimited width might be developed. Peak stress factor is around 1.99 for both evenly distributed loading and point loading when the w/l is 10. The peak stress factor is between 19.53% and 28.11% lower than 2 when the stiffened plate's width to length ratio is one, or when the width is twice the length. Furthermore, when the w/l is 2, the peak stress factor is between 8.75% and 10.67% lower than 2.

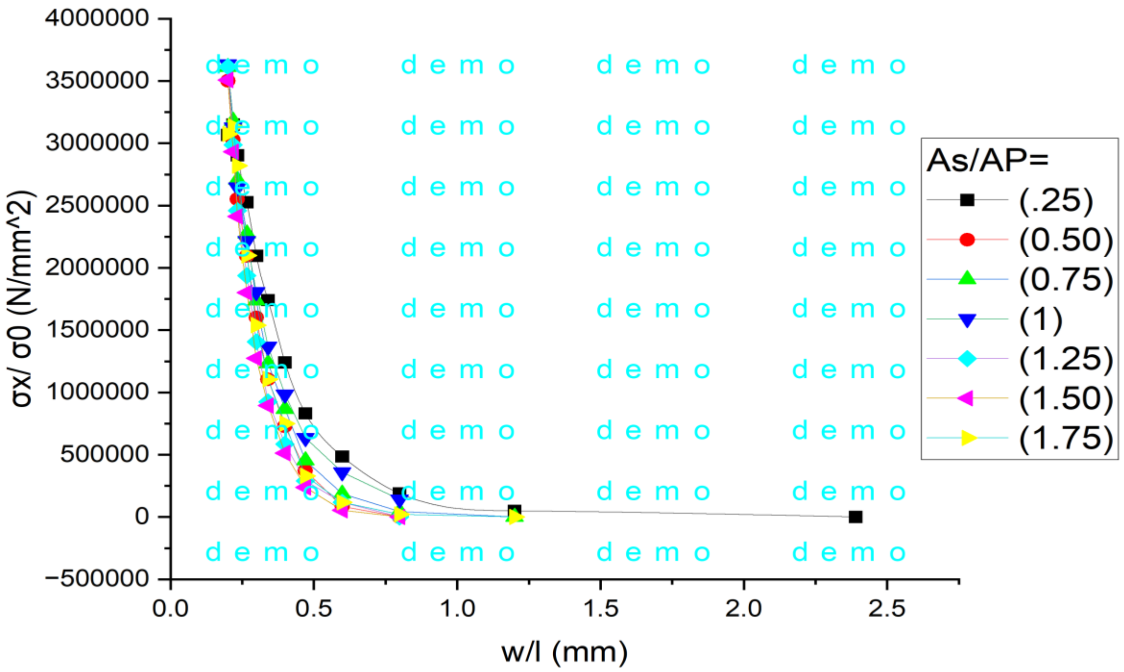


Fig.6.1.4 (Variation of peak stress factor at the fixed end of the cantilever stiffened plate with As/Ap at a constant depth of stiffeners, and varying w/l ratio.)

As a result, peak stress factors may be estimated with errors less than 7.97% and 11.20%, respectively, for evenly distributed transverse loading and concentrated loading, assuming a plate with w/l higher than 2 is thought to be infinite wide. Observe that for w/l equals 2, the beam's width is four times greater than its length. Moreover, at a beam width to length ratio of 4, meaning that the width is eight times longer than the length, the peak stress factor is only 2.67% and 3.55% lower, respectively, than at two uniformly distributed transverse loading and concentrated loading. Therefore, beams having a width-to-length ratio larger than 4 can be regarded as infinitely wide. Here, the inaccuracy is quite little. According to earlier studies, a beam is considered infinitely wide if its breadth is greater than four times its length. Concentration of stress under load was also taken into account in this study. To make the issue more broad, a uniform loading case is also taken into consideration. Ignoring stress concentration under load, the peak stress factor for point load corresponds to uniformly distributed loading for infinite-width stiffened plates.

6.1.7 Loading and Boundary condition

The capacity for shear flow of stiffened plates influenced by loading and support conditions. Eq. 5.14 may be solved with various loads and boundary conditions to find the stress factor. Table 1 displays the outcomes of various boundary conditions for uniform loading. Boundary conditions have a major impact on shear lag in T-beams and box beams (Reissner 1945; Chang and Zheng 1987; Lin and Zhao 2011; Singh et al. 2020; Singh 2022). Fixed-end beams have a larger aspect ratio (l/w), but they are more susceptible to shear lag. Compared to a cantilever beam, the inner support of a propped cantilever beam is more important. Peak stress factor rises with decreasing degree of freedom of the stiffened upper flange. Estimating the shear flow capacity of a stiffened plate is required to determine the intensity of shear lag. The current technology allows for the direct determination of a stiffened plate's stress concentration and shear flow capacity. If there are other loading scenarios not covered in this study, the stress factor in a continuous beam can be determined. The stress factor at zero bending moment cannot be calculated using the existing methods. One twentieth of the span length's distance away, it can be computed at the closest point (Chang 2004).

Table 6.1. The Peak stress factor in stiffened plate under different boundary conditions for UDL.

Sprt. Conditions	**l/w**	**Location.**	**Peak stress factor**
Simply Supported beam	5	Mid-span	1.151
Cantilever beam	10	Fixed end	1.098
Cantilever beam with props	10	Mid-span	1.654
		Fixed end	2.132
Built-in edge beam	20	Mid-span	1.322
		Fixed end	1.778

The shear lag effect's features and severity are greatly influenced by the loading-induced shear gradient. There are situations in which point loading may not produce a positive shear lag, particularly when the cantilever is far from its fixed end. This section explores the ways in which loading shear gradients affect the kind and strength of the shear lag effect on stiffened plates. This investigation looks at how different loading shear gradients affect the shear lag phenomenon. Shear flow characteristics can affect the shift in the shear lag effect in both uniform and point loading scenarios, as shown in Fig. 6.16. A significant amount of positive shear lag is seen under uniform loading at distances beyond the fixed end; Singh et al. (2020) have explained this observation in their research on composite cantilever beams. On the other hand, stiffened plates that experience a constant shear gradient due to loading show very little variation in the amount or location of positive shear lag.

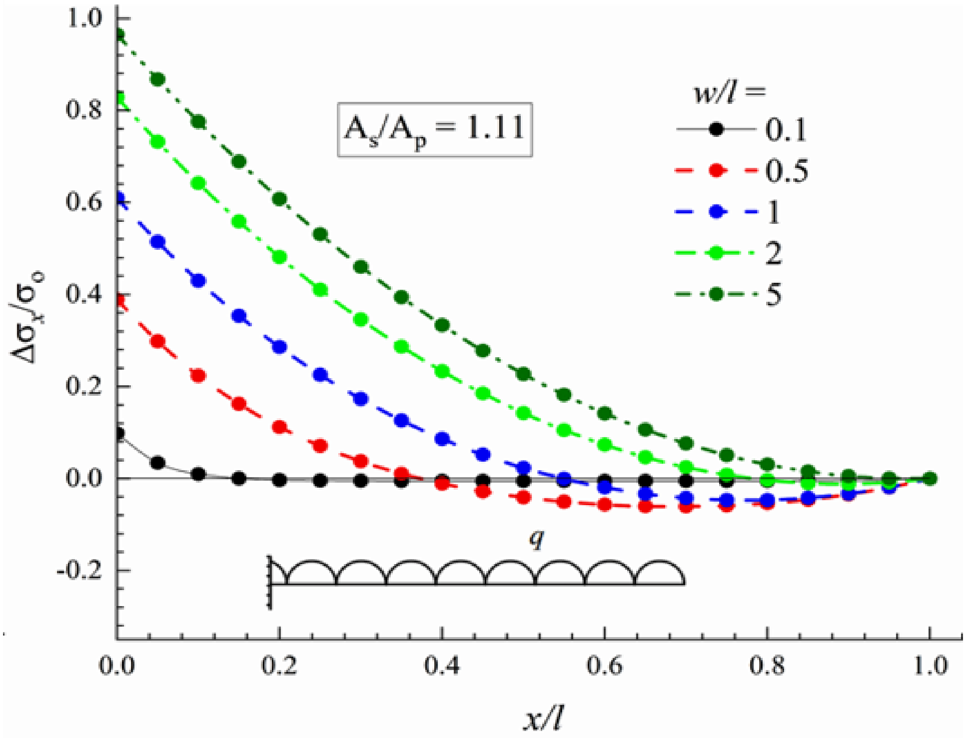


Fig.6.1.5 (Variation of additional peak stress factor along the length of the cantilever stiffened plate)

The stiffened plate's shear flow capacity can be evaluated using the present method. It may also assess the shear lag effect under different loading and support scenarios, as well as its magnitude and chances of positive shear lag.

CHAPTER-7

CONCLUSSION

By the use of fundamental stress distribution assumptions, this study provides a simplified approach to the analysis of stiffened plates under shear stresses, leading to an accurate closed-form solution. Elastic Beam Theory (EBT) and Finite Element Analysis (FEA), along with comparisons to previous research, are used to validate the method's simplicity and accuracy. While cantilever beams with uniform and point loads are the main focus, the methodology may be applied to different loading scenarios and support configurations.

This work presents a simplified method to the analysis of stiffened plates under shear pressures. A simple, closed-form solution is achieved using reduced assumptions for stress distributions. The precision and simplicity of the simplified method are demonstrated by this numerical example. Finite Element Analysis and Elementary Beam Theory are used to verify the results, which are then compared with previous research. The concept can be expanded to varied loading and support situations. A cantilever beam with uniform load is studied. Furthermore, the ensuing reductions are made:

1. At the fixed end of the cantilever solidified plate, a high concentration of stress is seen in the central line. When stiffeners are applied equally along the plate's width, shear flow changes direction. The behaviour of negative shear lag in a stiffened plate at the fixed end of the cantilever is shown by the stress concentration, An increase in stress concentration occurs at the centre of the fixed end of the cantilever solidified plate as a result of this negative shear lag.
2. The capacity of shear flow at the plate determines stress concentration. The shear flow value of a stiffened plate determines its shear flow capacity. When Is equals zero, the shear flow value, which is a function of Is/Ip, becomes constant. The plate's E/G ratio affects the concentration of stress. A high E/G ratio results in a higher concentration of stress.
3. The aspect ratio of the plate has a significant impact on stress concentration. When the plate width is infinite, the stress factors converge to 2. When subjected to uniform

loading and point loading, stiffened plates with a width four times length (w/l=2) have a stress concentration that is roughly 7.97% and 11.20% lower than infinite broad beams. The inaccuracy is insignificant when w/l = 4.

7.2 Recommendations for Further study:

To further refine and expand on this analysis, future research could focus on:

- Different Pre-stressed Profiles: Investigate how shear-lag coefficients vary with different configurations of pre-stressed tendon profiles. Analysing profiles other than broken straight lines can provide additional rules for shear lag.
- Non-Uniform Loadings: Extend the study to include cases with non-uniform loadings on the box girder. Examine how shear-lag effects change under varying load distributions.
- Practical Design Guidelines: Develop practical design guidelines for engineers considering shear lag in pre-stressed concrete box girders. Provide recommendations for optimizing pre-stress force configurations to minimize shear-lag effects.
- Include exploring the real shear lag effect in PSC box girders and utilizing advanced analysis techniques.
- Extending the analysis to consider dynamic loads and real-world scenarios.

REFRENCE

- * BY ERIC REISSNER (201) Massachusetts IChang, S. T. (2004). “Shear-lag effect in simply supported pre-stressed concrete box-girder.” J. Bridge Eng., 9(2), https://doi.org/10.1061/(ASCE)BE.1943-5592.0000179
- Chang, S. (2004). "Shear lag effect in simply supported pre-stressed concrete box girder." Journal of Bridge Engineering, vol. 9, pp. 178-184. doi:10.1155/2012/273295.
- Zhang Y.H and Li-Xia Lin., 2014 “Shear Lag Analysis of Thin-Walled Box Girders Adopting Additional Deflection as Generalized Displacement”. https://doi.org/10.1061/(ASCE)EM.1943-7889.0000705
- Lee S.C, M.ASCE ; Chai H.Yoo, M.ASC, and Dong Y. Yoon. “Analysis of Shear Lag Anomaly in Box Girder”. Journal of Structural Engineering, Vol. 128, No. 11. https://doi.org/10.1061/(ASCE)0733-9445(2002)128:11(1379)
- Luo Q. Z., Q. S. Li, and J. Tang, 2002. Shear Lag in Box Girder Bridges. https://doi.org/10.1061/(ASCE)1084-0702(2002)7:5(308)
- https://link.springer.com/article/10.1007/s40030-012-0001-i institute of Technology.
- Chang, S. T. (2004). “Shear-lag effect in simply supported pre-stressed concrete box-girder.” J. Bridge Eng., 9(2), https://doi.org/10.1061/(ASCE)BE.1943-5592.0000179

- Chang, S. (2004). "Shear lag effect in simply supported pre-stressed concrete box girder." Journal of Bridge Engineering, vol. 9, pp. 178-184. doi:10.1155/2012/273295.
- Zhang Y.H and Li-Xia Lin., 2014 “Shear Lag Analysis of Thin-Walled Box Girders Adopting Additional Deflection as Generalized Displacement”. https://doi.org/10.1061/(ASCE)EM.1943-7889.0000705
- Lee S.C, M.ASCE ; Chai H.Yoo, M.ASC, and Dong Y. Yoon. “Analysis of Shear Lag Anomaly in Box Girder”. Journal of Structural Engineering, Vol. 128, No. 11. https://doi.org/10.1061/(ASCE)0733-9445(2002)128:11(1379)
- Luo Q. Z., Q. S. Li, and J. Tang, 2002. Shear Lag in Box Girder Bridges. https://doi.org/10.1061/(ASCE)1084-0702(2002)7:5(308)

- Dhaher.B And A.A Hadithy 2021. “Analysis techniques for folded plate roofs and cellular bridges general review and comparisons”. IOP Publishing Materials Science and Engineering 518 (2019) 022060. DOI 10.1088/1757-899X/518/2/022060
- The doi:10.1090/QAM%2F17176 Investigations on shear lag in box girders Written by Q.Z. Luo and Y.M. Wu. URL: 10.1016/S0141-0296(01)00113-4

Google. Box Beams - Jackel Enterprises, Inc. Wood that is meant to be seen

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT

PLAGIARISM VERIFICATION REPORT

Date: ....

Type of Document (Tick): PhD Thesis [✓ M.Tech/M.Sc. Dissertation] B.Tech./B.Sc./BBA/Other

Name: Khelup Namgial Department: Civil Enrolment No 225024007

Contact No. 8091817886 E-mail. 225024007@juitsolan.in

Name of the Supervisor: Kaushal Kumar

Title of the Thesis/Dissertation/Project Report/Paper (In Capital letters): Study of shear lag effect in box-girder bridge.

UNDERTAKING

I undertake that I am aware of the plagiarism related norms/ regulations, if I found guilty of any plagiarism and copyright violations in the above thesis/report even after award of degree, the University reserves the rights to withdraw/revoke my degree/report. Kindly allow me to avail Plagiarism verification report for the document mentioned above.

- Total No. of Pages = 48
- Total No. of Preliminary pages = 9
- Total No. of pages accommodate bibliography/references = 2

(Signature of Student)

FOR DEPARTMENT USE

We have checked the thesis/report as per norms and found **Similarity Index** at ....5........(%). Therefore, we are forwarding the complete thesis/report for final plagiarism check. The plagiarism verification report may be handed over to the candidate.

Kaushal Kr. 10/6/24
(Signature of Guide/Supervisor)

Signature of HOD

FOR LRC USE

The above document was scanned for plagiarism check. The outcome of the same is reported below:

Copy Received on	Excluded	Similarity Index (%)	Abstract & Chapters Details	
11th/06/2024	• All Preliminary Pages • Bibliography/Images/Quotes • 14 Words String	08%	Word Counts	9545
			Character Counts	53,644
Report Generated on		Submission ID	Page counts	49
11th/06/2024		2400308127	File Size	5.18 M

Checked by
Name & Signature

11/06/2024

LIBRARIAN
LEARNING RESOURCE CENTRE
Jaypee University of Information Technology
Waknaghat, Distt. Solan (Himachal Pradesh)
Pin Code - 173234

Please send your complete Thesis/Report in (PDF) & DOC (Word File) through your Supervisor/Guide at plagcheck.juit@gmail.com