ANALYSIS & DESIGN OF DEEP REINFORCED CONCRETE BEAMS USING STRUT-TIE METHOD

Thesis Submitted in Partial Fulfillment of Requirements for the Degree of M.Sc in Structural Engineering

By

EMAD IBRAHIM AHMED MOHAMED KHAIR

Supervisor:

DR. MAHGOUB OSMAN MAHGOUB

Dec 2005
DEDICATIONS

To

My Father

My Mother

My Brother

My Sister

My Friend

And

All People in My Life
ACKNOWLEDGMENT

I WANT TO EXPRESS MY APPRECIATION AND GRATITUDE WITH RECOGNITION TO SUPERVISOR:

Dr. MAHGOUB  OSMAN MAHGOUB

For his help and guidance doing this thesis by his invaluable advices with ultimate patience throughout thesis period.
The Strut-and-Tie Method (STM) is an emerging and rational design procedure that has the potential to revolutionize the way that engineers design.

D- (Discontinuity) Regions in structural concrete. D-Regions are those portions of a structure in which there is a complex variation in strain, such as in joints, corbels, and deep beams, as well as in regions near a concentrated force and openings or another discontinuity.

This thesis describes a program, according to strut-and-tie model, for the shear failure of simply supported reinforced concrete deep beams under two-point or a single-point loading, with a shear span to span ratio (a/le) between 0.25 and 0.5 and span to effective depth ratio (le/d) between 3 and 5.

The results obtained using this program on deep beams considering the variation of applied loads, strain and stress in struts and ties of deep reinforced concrete beams models. The program also gave the magnitude of horizontal and vertical reinforcement required in the design of reinforced concrete deep beam.
البحث:

تسعى لتحديد كيف يمكن استخدام تقنية STM (STM) لتحديد تأثير الحركة في 


dيتطلب استخدام تقنية STM لتحديد تأثير الحركة في

(0.5-0.25)

(5-3)
# TABLE OF CONTENTS

Acknowledgment  
Abstract  
Arabic Abstract

## Chapter-1, Introduction

1.1 Deep and Ordinary Beams  
1.2 Applications of Deep Beams in Buildings  
1.3 Factors Affecting Behavior of Deep Beams  
1.4 Need to Study the Behaviour of Reinforced Concrete Deep Beams  
1.5 Objectives of this Research

## Chapter-2, Literature Review

2.1 Review of Previous Experimental Investigations  
2.2 Design Recommendations of Reinforced Concrete Deep Flexural Members  
2.3 Conclusions of Literature Review

## Chapter-3, Strut-Tie Model Method

3.1 Introduction  
3.2 Strut -Tie Models  
3.3 The Strut and Tie Model Method Design  
3.4 Design Procedures of the Strut-and-Tie Model  
3.5 Dimensioning the Struts, Ties and Nodes  
3.6 Code Provisions STM

## Chapter-4, Plastic Truss Model of Deep Beams

4.1 Plastic Truss Model of Deep Beams  
4.2 Truss Modeling of Simple Span Deep Beams  
4.3 Truss Modeling of Continuous Deep Beams  
4.4 Validity of the Plastic Truss Theory  
4.5 Major Factors Affecting the Concrete Strength  
4.6 Conclusions of Plastic Truss Model of Deep Beam

## Chapter-5, Program Model Applications, Results and Discussion

5.1 Introduction
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2</td>
<td>Problems in Sruts and Ties Applications</td>
<td>68</td>
</tr>
<tr>
<td>5.3</td>
<td>S.T.M Model Design Concept</td>
<td>68</td>
</tr>
<tr>
<td>5.4</td>
<td>Model of the Program Used</td>
<td>69</td>
</tr>
<tr>
<td>5.5</td>
<td>Program Assumptions</td>
<td>69</td>
</tr>
<tr>
<td>5.6</td>
<td>Code of Program</td>
<td>70</td>
</tr>
<tr>
<td>5.7</td>
<td>Flow Chart of Program</td>
<td>70</td>
</tr>
<tr>
<td>5.8</td>
<td>Determination of the Required Truss Forces</td>
<td>71</td>
</tr>
<tr>
<td>5.9</td>
<td>Steel Reinforcement for the Ties</td>
<td>71</td>
</tr>
<tr>
<td>5.10</td>
<td>Check the Struts</td>
<td>72</td>
</tr>
<tr>
<td>5.11</td>
<td>Design the Node Zones and Check of the Anchorages</td>
<td>72</td>
</tr>
<tr>
<td>5.12</td>
<td>Applications of Program</td>
<td>74</td>
</tr>
<tr>
<td>5.13</td>
<td>Results of Program</td>
<td>75</td>
</tr>
<tr>
<td>5.14</td>
<td>Discussion of the Results</td>
<td>76</td>
</tr>
</tbody>
</table>

**Chapter-6, Conclusions and Recommendations for Future Study**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Conclusions</td>
<td>109</td>
</tr>
<tr>
<td>6.2</td>
<td>Recommendations</td>
<td>110</td>
</tr>
</tbody>
</table>

**References**

- Appendix-A (Manual application)
- Appendix-B (List of program used)
CHAPTER [1]

INTRODUCTION
CHAPTER (1)

INTRODUCTION

A reinforced concrete deep beam may be defined as one whose depth is comparable to its span and the main factor affecting the definition of reinforced concrete deep beam is span-depth ratio \((L_n/d)\) or \((L/H)\) which should not be greater than 5.0.

Fig (1.1) Reinforced concrete deep beam

where:

- \(L\) and \(L_n\) are span and clear span of reinforced concrete deep beam &
- \(H\) and \(d\) are overall depth and effective depth of a deep beam respectively.

The \(ACI\) code \(^{[3]}\), defines a deep beam as a structural member whose span-depth ratio \((L/H)\) is 5 or less.

But the Euro- International Concrete Committee\(^{[2]}\), decided that a beam could be considered deep if \(L/H < 2\) or 2.5 for simply supported and continuous beams respectively.
Some investigators have decided that the shear - depth ratio $a/d$ is more meaningful to define deep beam, and that a beam could be considered deep if $a/d < 0.5$

The behavior of deep beams is governed by shear. Since large portion of compressive forces are directly transferred to supports by arch action, their shear strength is much greater than that predicted by usual equations.

Comparison between deep beams and ordinary beams is shown on Table (1.1).

**Table (1.1) Comparison between deep and ordinary beams**

<table>
<thead>
<tr>
<th>No</th>
<th>Deep beams</th>
<th>Ordinary beams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>● Plane section before bending does not remain plane after bending.</td>
<td>● Plane section before bending remains plane after bending.</td>
</tr>
<tr>
<td>2</td>
<td>● The resulting strain is non linear.</td>
<td>● The strain is linear.</td>
</tr>
<tr>
<td>3</td>
<td>● Shear deformations become significant compared to pure flexure.</td>
<td>● Shear deformation is neglected.</td>
</tr>
<tr>
<td>4</td>
<td>● The stress block is non linear even at the elastic stage.</td>
<td>● The stress block is considered linear at the elastic stage.</td>
</tr>
<tr>
<td>5</td>
<td>● It is subjected to two-dimensional state of stress.</td>
<td>It is subjected to one-dimensional state of stress.</td>
</tr>
</tbody>
</table>
1.2 Applications of Deep Beams in Buildings:

Reinforced concrete deep beams have many useful applications in building structures such as transfer girder, wall footings, foundation pile caps, floor diaphragms, and shear wall. Particularly the use of a deep beam at the lower level in tall buildings for both residential and commercial purpose has increased rapidly.

Fig (1.2) Deep beams location and uses.

1.3 Factors Affecting Behavior of Deep Beams
1.3.1 Method of load application:

Loads may be applied to beams on the extreme compression or tension fibers. The main effect of applying loads on the compression face to a deep beam without web reinforcement is to increase the ultimate shear capacity above the shear causing inclined cracking.

1.3.2 Types of shear reinforcement:

As the $a/d$ ratio of deep beam decreases from about 2.5 to 0.5 shear reinforcement perpendicular to the longitudinal axis becomes less effective than that in ordinary beam. At the same time, distributed reinforcement parallel to the longitudinal axis will increase the shear capacity. As the $a/d$ ratio approaches zero, this reinforcement may resist shear by the concept of shear-friction. Diagonal reinforcement is also effective in resisting shear.

1.3.3 Reinforcement details:

The development of inclined cracking tends to cause an increase in the stress in flexural tension reinforcement at the base of the crack. In deep beams, inclined cracking may extend the full length of the shear span. If the shear reinforcement is not fully effective, high tensile stresses will develop in the longitudinal reinforcement at sections where the resultant moment is zero. Sufficient anchorage length of main reinforcement must be provided to resist this tension.

1.4 Need to Study the Behavior of Reinforced Concrete Deep Beams

It is known\(^{[24]}\) that the main parameters affecting the load bearing capacity of deep beams with or without web openings are shear span to depth ratio, configuration of web reinforcements, material properties, and
geometry of openings. Despite the rigorous studies of deep beams, there have been only empirical and semi-empirical formulas for predicting their ultimate load bearing capacities due to the complexities of the structural nonlinearity and material heterogeneity. And there have been also no pertinent theory and rational design code for predicting ultimate shear strength of reinforced concrete deep beams with web openings. Hence, it is very important and necessary that study of deep beams should be carried out experimentally and analytically to verify the shear of reinforced concrete deep beams which have various loading and geometric conditions.

1.5 Objectives of this Research:

The general objective of the present research is to investigate the behavior of reinforced concrete deep beams and to study the methods of analysis and design.

This objective has been achieved through development of a computer program for the analysis and design of simply supported reinforced concrete deep beams using strut-tie models within AASHSTO LRFD 1999\[29]\, taking into consideration:

1. Method of application of load.
2. Effect of the variation of span depth ratio.
3. Effect of the variation of shear span clear span ratio.
4. Types of shear reinforcement and concrete strength.
CHAPTER [(2]

LITERATURE REVIEW
2.1 Review of Previous Experimental Investigations:

*De Pavia and Siess, (1965)* [7], described an experimental investigation on the shear strength and behavior of some moderately reinforced concrete deep beams. Main factors considered in experimental investigation were:

- Amount of tension reinforcement.
- Concrete strength.
- Amount of web reinforcement.
- *Span-depth* ratio.

They concluded that reinforced concrete deep beams without web reinforcement that were found to have high capacity of cracking beyond the diagonal cracking and that the addition of vertical stirrups and inclined bars had little effect on the ultimate strength.

*Leonhardt and Walther (1966)* [10] have also reported test on deep beams with top and bottom loading. The simply supported specimens had a *height/span* ratio of 1.5. They decided that the best means of providing main reinforcement was by means of well-anchored bars from support and the horizontal hooks are suitable for anchorage. They also recommended that main reinforcement should be distributed over the lower 20% of height of beam. It was suggested that stirrups should be extended at height equal to span. Closely spaced (<400 mm), stirrups were recommended to reduce crack widths, with vertical stirrups extending the full height of the beam.
Gergely, 1969 [11] performed an experimental model to study the contribution of aggregate interlock and dowel action to post cracking shear capacity of reinforced beam with no web reinforcement. Gergely estimated contribution of aggregate interlock to be (40-60) % of the total shear and that of dowel action was estimated to be (20-25) % of total shear. It was also concluded that the dowel action is a main factor causing splitting along main reinforcement.

Taylor, 1970 [12] conducted several experiments to investigate the effect of aggregate interlock and dowel action by studying the factors affecting the two mechanisms:

To simulate the aggregate interlock Taylor used two types of specimens:

- Block tests.
- Beam tests.

The main factors included in these tests to study their influences in aggregate interlock mechanism were:

- The displacement ratio \( \frac{\Delta N}{\Delta s} \), where:
  \( \Delta N \): is the displacement normal to crack (crack width).
  \( \Delta s \): is the horizontal displacement (shear displacement).

- Concrete strength.
- Aggregate size.
- Aggregate type.

The block test has the advantage that it requires less sophisticated set-up and measuring devices, and is also more economical and consumes less time than
the beam test. But the beam test is useful in obtaining more data about aggregate interlock mechanism.

For dowel action mechanism Taylor considered the following factors:

- Concrete strength.
- Shear span.
- Crack width.
- Concrete cover.

The main purpose of his work was to establish complete dowel load-displacement curves, and to estimate the contribution of shear resisting mechanism in reinforced concrete beam without web reinforcement. The results were as follows:

- Compression zone ……… (20-40) %
- Aggregate interlock ….. (33-50) %
- Dowel action ………….. (15-25)%

Kong and Robins (1971) [13] made tests on simply supported lightweight concrete deep beams, and developed equations that calculate ultimate load for normal weight concrete, which was found not to be suitable for lightweight concrete.

Kong and Robins (1972) [14] have also reported on lightweight concrete deep beams, they revised their previous formula in two factors: The le/d ratio; explicitly allowed for and used concrete cylinder splitting tensile strength; as has been thought that the concrete contribution to the ultimate shear strength is more directly related to tensile strength than cylinder compressive strength.

The Ln/H; had a greater effect on cracking and ultimate loads than L/H.
Prakash 1974\textsuperscript{[15]} suggested a method for determining the shear strength for span/effective depth ratio less than 1.0. The proposed formula took into account the splitting strength of concrete and influence of any steel crossing the failure crack. It was stated that failure of deep beams with small value of a/d ratio is analogous to the splitting of cylinder along its length. The ultimate shear strength calculated by the proposed formula was found to be comparable with test results.

Besser and Cusens (1984)\textsuperscript{[16]} had tested seven simply supported models of reinforced concrete wall panels with depth/span ratio in range of one to four. A beam panel with depth/span equal to 1.0 failed in shear with diagonal fracture line joining the load and support points. When the depth-span ratio is larger than 1.0, it failed by crushing of the bearing zones.

This was most common mode of failure among these members and was exhibited by panels with depth/span ratio between 1.5 to 3.5; the largest specimen tested, having a height/thickness ratio of 40, failed by buckling.

Smith and Vantsiotis (1982)\textsuperscript{[17]}, carried out test on fifty-two simply support reinforced concrete deep beams under symmetrical point load. Considerable increase in load carrying capacity was observed with increasing concrete strength and decreasing shear span to effective depth ratio. The increasing in ultimate shear strength and diagonal cracking load was attributed to arch action for specimens with shear span/depth ratio less than 2.5. It was also found that vertical stirrups became more effective with greater shear $\frac{span}{depth}$ ratio.

Horizontal web reinforcement was more efficient in beams with shear span/depth ratio less than 1.0, and the effect of concrete strength was greater on beams for controlling diagonal cracking load.
Subedi, N. K (1986)\[18\]; carried out tests on 13 simply supported reinforced concrete deep beams with different span/depth ratios. The modes of failure of deep beams have been demonstrated that failures were:

- Diagonal splitting.
- Local crushing.

Kang, et al, (1995) \[19\], also carried out and reported experimental tests on twenty-two reinforced deep beams with cylinder compressive strength exceeding 55 MPa. Main steel ratio, $\rho$, varied for different groups as shown below

<table>
<thead>
<tr>
<th>Groups</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ (%)</td>
<td>2.00</td>
<td>2.58</td>
<td>4.08</td>
<td>5.8</td>
</tr>
</tbody>
</table>

The beams were tested for different $a/d$, ranging from (0.28 to 3.14). The comparisons among the series were to highlight influence of $\rho$, and $a/d$ ratio, on the shear behavior of high strength deep and shallow beams. It was shown that transition point between High Strength Concrete (HSC) deep beams and High Strength Concrete Shallow beams in load-carrying capacity, is around $a/d$ of 1.5 for medium and low strength concrete beams, it was reported to occur between (2.0 and 2.5). The Main steel ratio, $\rho$, was not significant for the $a/d$ exceeding 1.5. The modes of failure observed were summarized in Table (2.2) as function of $a/d$.

**Table (2.2). The modes of failure**

<table>
<thead>
<tr>
<th>$a/d$</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.28</td>
<td>The beams fail in bearing shear-compression mode</td>
</tr>
<tr>
<td>0.28 – 1.12</td>
<td>The beams fail in diagonal tension mode</td>
</tr>
<tr>
<td>&lt; 1.50</td>
<td>Increasing main tension steel ratio and thus increasing the load-carrying capacity of HSC deep beams</td>
</tr>
<tr>
<td>2.50</td>
<td>The beams fail in shear-tension mode</td>
</tr>
</tbody>
</table>
The additions of \( \rho \), beyond 2.5 percent were observed not to increase the ultimate shear strength of HSC deep beams, (apart from the particularly high value of 5.80 percent). Thus, \( \rho \) of 2.00 percent represents a practical upper limit in maximizing the main steel to augment the shear strength.

Lee, J.S et al, (1994) [20], investigated experimentally the shear behavior of simply supported reinforced concrete deep beams with or without openings subject to concentrated loads. A total of 84 specimens has been cured and tested in the laboratory. The openings, compressive strength of concrete, shear span to depth ratio and web reinforcements were taken as the structural parameters for the tests. The effects of these structural parameters on the shear strength and crack initiation and propagation have been carefully checked and analyzed.

From the tests, it has been observed that the failures of all specimens were due to shear mechanism which is mostly governed by inclined cracks formed between the load application points and supports in shear span. In case of specimens without openings, their load bearing capacities have been significantly changed depending on the shear span to depth ratio. It was revealed that the ultimate strength of specimens with web openings varies according to the location of opening, which deter the formation of compression struts between the loading points and supports. Lee studied all of the test results using truss model and nonlinear behavior. The results showed that the values of the shear strengths obtained from the tests were about 1.4 and 1.9 times higher than the values calculated by CIRIA guide [4] and ACI code [3]. However they were closely coincident with the formulas given by Paiva, Ray and Kong's [14] except for some series specimens having a larger dimension of openings beyond the geometric limits of proposed equations. Comparing with finite element analysis, it was found that shear strength, load-displacement
relationship and crack locations of deep beams could be predicted by nonlinear finite element analysis.

*Kang, et al (1999)*[21], also studied and reported size effect in reinforced concrete deep beams. A total of 12 large and medium-sized specimens with overall height ranging from (500 to 1750) mm were tested under two point symmetric loads. The beams had compressive cylinder strength of about 40 MPa. There was pronounced size effect on ultimate shear strength. The critical height beyond which they’re no significant size effect was between (500 - 1000 mm), however, the size effect seems relatively independent of [a/h] ratio.

*Lee, et al, (2000)*[22] reported their investigation of the structural behavior of indirectly loaded deep beam. They carried out some tests under different structural parameters such as shear span, web reinforcement ratio and boundary condition. Experimental investigation could be summarized as follows:

- Investigate the effect of shear span variation of directly loaded beam.
- Examine the effect of shear reinforcement at directly and indirectly loaded deep beam.
- Compare the behavior of edge and continuous boundary condition.
- Test program, a total of 5 deep beams were tested as shown Fig (2.1).

![Fig (2.1), Specimens shape and loading arrangement.](image)
Shear span ratio of loading beam was varied from (0.5 to 1.5) the compressive strength of concrete was designed to 25 MPa and measured average compressive strength at tests was 28.2 MPa. The test specimens were loaded by point concentrated loads according to the loading condition. 

Lee. Test can be summarized as follows:

- The diagonal cracking shear force was decreased slightly as loading point moved from top to bottom.
- There was no significant difference of ultimate shear strength and fail mode between direct loading and indirect loading deep beam that have more than three times of minimum web reinforcement by ACI code provision.
- Bottom loaded specimen failed at 42.6 % of shear strength of top loaded beam.

Fig (2.2), Lee. [22] Test results, showing shear force versus deflections and shear span (a/d).
2.2 Design Recommendations of Reinforced Concrete Deep Flexural Members:

2.2.1 Portland Cement Association (1946) [1]:

This document proposed a design procedure applicable to reinforced concrete deep beams with:

<table>
<thead>
<tr>
<th>$H/L &gt; 2/5$</th>
<th>For continuous beam.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H/L &gt; 4/5$</td>
<td>For single span beam.</td>
</tr>
</tbody>
</table>

There are two essential ratios when using this procedure, the height/span ratio, $\frac{H}{L}$, denoted as $B$ and the width of support span ratio, $\frac{W}{L}$, denoted as $E^1$. The design method is as follows:

The stress coefficients can be selected from charts. A coefficient is obtained to calculate the resultant of all concrete tensile stresses, $T$. The area of reinforcement ($A_{sl}$) given by:

$$A_{sl} = \frac{T}{f_s}$$

(2.1)

where:

$f_s$, is the allowable working stress of the steel.

Suggestions were given for verification of shear strength. The shear stress $v$ is computed as:

$$v = \frac{8V}{7bd}$$

(2.2)

And the permissible shear stress of the concrete deep beams could be considered equal to:

$$v_c \left(1 + \frac{5H}{L}\right)/3$$

where:
\( \nu_c \) is the permissible shear stress for shallow beams.

The tensile steel, \( A_{s1} \), equation (2.1) was modified as calculated by equation (2.3) given below:

\[
A_{s1} = \frac{1.5T}{f_s} 
\]

(2.3)

They also advised to distribute the area of steel within the whole of the tension zone, by spreading half of the area of steel uniformly throughout the tension zone and the other half should have a progressively linear distribution with increasing distance from the neutral axis.

2.2.2 Uhlman (1952) [5]

Uhlman provided some recommendations for the design of reinforcement in deep beams. The minimum width of the section of simply supported beam and loaded in its own plane is:

\[
b = \frac{0.06L}{\sqrt{K}} 
\]

(2.4)

Where:

- \( L \) = span of beam.
- \( K \) = a coefficient in tabular form in Uhlman’s report which is a function of \( \frac{H}{L} \).

\( H \) = overall depth of the beam section.

The area of the main reinforcement given by:

\[
A_{s1} = \frac{M}{f_s z} 
\]

(2.5)
where:

\( M \) = Bending moment at mid-span.

\( f_s \) = Permissible steel stress.

\( z \) = Lever arm.

The lever arm value obtained from graphs for different loading conditions is a function of the overall length and the height of the deep beam.

In the case of deep beam with loading along the lower edge, the required area of hanging steel is provided by:

\[
A_{hs} = \frac{W}{f_s} \quad \ldots
\]

(2.6)

where:

\( W \) = applied load between the supports.

In the case of a combination of loading, superposition of the reinforcement calculated for each case is advised.

2.2.3 Schutt (1956)\(^{[6]}\)

In Schutt’s report, the following procedure was recommended for the safe design of deep flexural elements under top and lower edges loading. The area of reinforcement due to bending is given by:

\[
A_s = \frac{M}{f_s z} = \frac{qL^2}{8 f_s z} \quad \ldots
\]

(2.7)

where:

\( f_s \) = allowable working stress of steel, kg/cm\(^2\).

\( z \) = internal lever arm, cm.
$L = $ effective span, cm.
$q = $ load per unit length, kg/cm.

For deep beams with $\frac{\text{height}}{\text{span}}$ ratios less than 1, the lever arm value used is calculated as for normal slender beams. In the case of walls with $\frac{\text{height}}{\text{span}}$ ratios between 1 and 2 the following lever arm value was proposed was:

$$ Z = 0.09 L \sqrt{\frac{H}{L}} $$

(2.8)

where:

$H = $ total height of wall, cm

And in walls with $\frac{\text{height}}{\text{span}}$ ratios larger than 2,

$$ z = \frac{L}{8} $$

(2.9)

For equations (2.8), (2.9) it was assumed that the main reinforcement was distributed over a height equal to $0.1L$.

Considering that $\frac{1}{2}$ to $2/3$ of the main flexural reinforcement is bent near support as inclined web reinforcement, the ultimate shear capacity of the section can be predicted from:

$$ Vu = 0.54 f_{cb} b^2 \sqrt{\frac{H}{b}} $$

(2.10)

where:

$f_{cb} = $ strength of concrete, kg/cm$^2$.

$b = $ width of beam, cm.

A safe limit for the shear capacity of the beam was considered as $1/3 V_u$, given by:
\[ V_{gr} = 0.18 f_{cb} b^2 \sqrt{\frac{H}{b}} \]  

(2.11)

Then the maximum allowable load on the top edge is:

\[ w'^{o}_{gr} = \left( \frac{0.36 f_{cb}}{L} b^2 \right) \sqrt{\frac{H}{b}} \]  

(2.12)

A limit to the load hanging capacity is given by:

\[ w'^{u}_{gr} = \left( \frac{0.30 f_{cb}}{L} b^2 \right) \sqrt{\frac{H}{b}} \]  

(2.13)

Where a wall is loaded simultaneously from the top and bottom, the total load is given by:

\[ w_{gr} = w'^{o}_{gr} w'^{o} / (w'^{o} + w'^{u}) + w'^{u}_{gr} w'^{u} / (w'^{o} + w'^{u}) \]  

(2.14)

where:

\[ w'^{o} = \text{load per unit length applied on top.} \]

\[ w'^{u} = \text{load per unit length applied on the soffit.} \]

It should be noted that the vertical reinforcement for both top and bottom loads is as follows:

For \( \frac{H}{L} < 1.0 \)

\[ A_{sv} = \frac{V}{f_s \sqrt{2}} \]

For \( 1.0 < \frac{H}{L} < 2.0 \)

\[ A_{sv} = \frac{V}{f_s \sqrt{2} \frac{H}{L}} \]

For \( \frac{H}{L} > 2.0 \)

\[ A_{sv} = \frac{V}{2 f_s} \]

In the case of specimen under bottom load, the vertical reinforcement could be increased by the factor \( \sqrt{w'^{u} \times w'^{u}_{gr}} \)
2.2.4 De Paiva and Siess (1965)[7]

After performing the experimental work, De Paiva and Siess described three modes of failure called “flexture”, “flexture-shear” and “shear-proper”.

Then they developed an expression for shear strength as follows:

\[ \nu = \frac{V}{bH} = 200 + 0.188 f'_c + 21300 p_t \]

(2.15)

where:

- \( V \) = shear force.
- \( f'_c \) = cylinder compressive strength of concrete, psi.
- \( \nu \) = nominal shear stress.
- \( H \) = depth of beam.
- \( b \) = width of beam.

\[ P_t = \frac{A_{sl}}{bH} (1 + \sin \alpha) \]

In which:

- \( A_{sl} \) = area of steel crossing a vertical section between the load point and support.
- \( \alpha \) = Angle of inclination of reinforcement to the axis of the beam.

In beams tested by De Paiva and Siess the load at failure in shear proper is given by:

\[ \frac{P_s}{Ib} = 2vbH \]

(2.16)

And the shear strength \( P''_s \) (lb) given by:

\[ p''_s = 0.8 \left( 1 - 0.6 \frac{X_e}{H} \right) p'_s \]

(2.17)

where:
\[ \frac{X_c}{H} = \text{Shear span-overall depth ratio.} \]

The above expression is valid for values of \( \frac{X_c}{H} \) between (0 - 1).

2.2.5 Ramakrishnan and Ananthanarayana (1968)\textsuperscript{[9]}

Based on experimental results, Ramakrishnan and Ananthanarayana believed that shear failure in a deep beam is essentially a diagonal tension failure and that the ultimate shear strength of the beam could be taken as the load producing a diagonal tension failure. Therefore, they developed equations that calculate the ultimate shear strength on the basis of the splitting strength of concrete.

In indirect tension test the splitting strength of concrete \((f_t)\) can be expressed as:

\[ f_t = \frac{\text{maximum splitting force}}{K \text{ (area resisting the splitting force)}} \] \hspace{1cm} (2.18)

where:

\[ K = \text{a coefficient equal to } \frac{\pi}{2} \text{ for a cylinder.} \]

For a deep beam under two-point load on the top the splitting force \(P\) is:

\[ P = W \csc \theta \] \hspace{1cm} (2.19)

Substitution of this equation into equation (2.18) gives:

\[ W = K f_t b H \] \hspace{1cm} (2.20)

And the ultimate load \(P_c\) on the beam is:
\[ P_c = 2W = 2Kf_i bH \]  
(2.21)

The failure plane is inclined at an angle (\( \theta \)) to the beam axis where:
\[ \theta = \tan^{-1}(H/X_s). \]

The same procedure is used to predict the ultimate load for an eccentric force, as follows:
\[ P_c = K (1 + \tan \theta \cot \varnothing) f_i bH \]  
(2.22)

where:

\( \varnothing \geq \theta \), The failure plane in this case is given by:
\[ \varnothing = \tan^{-1} (H/X_s). \]

\( \theta = \varnothing \), For a central concentrated force and \( X_s = L/2 \) and the ultimate load is given by:
\[ P_c = 2Kf_i bH \]  
(2.23)

And the failure plane: \( \varnothing = \tan^{-1}\left(\frac{2H}{L}\right) \)

In the uniformly distributed load, it was found that the splitting force, \( P \), reached a maximum when failure plane is fixed at: \( \varnothing = \tan^{-1} (3H/L) \).

The ultimate load \( P_c \) is given by
\[ P_c = qL = 2Kf_i bH \]  
(2.24)

### 2.2.6 Kong and Robins (1971) [8]

Kong and Robins proposed a formula for predicting the ultimate shear strength of deep beams for both normal weight and lightweight concrete. Their formula was based on experimental results that they carried out:
where:

\[ V_u = C_1 f_c h + C_2 \sum_{i=1}^{n} A_i \left( \frac{Y_i}{H} \right) \sin \alpha_i \]

\[ (2.25) \]

Later, Kong et al (1972) \[^{13,14}\] modified equation (2.25) by including \( X_e/H \) ratio explicitly and using the cylinder splitting strength instead of the cube strength. The modified formula is:
\[ V_u = C_1 (1 - 0.35Xe/H) f_t bH + C_2 \sum_{i=1}^{n} A_i \left( \frac{Y_i}{H} \right) \sin^2 \alpha_i \] 

(2.26)

where:

\( C_1 = \) coefficient equal to 1.4 for normal weight concrete and 1.0 for lightweight concrete.

\( C_2 = \) coefficient equal to 130 \( N/mm^2 \) for plain round bars and 300 \( N/mm^2 \) for deformed bars.

\( f_t = \) cylinder splitting strength, \( N/mm^2 \). All other variables are as explained previously.

2.2.7 Prakash (1999)[25]

Parakash proposed a method for determining the ultimate shear strength for beams with \( a/d < 1.0 \). He assumed the shear failure of the beam due to splitting in a similar mode to that in the cylinder-splitting test.

2.2.7.1 Beam without web reinforcement:

The ultimate shear strength is given by:

\[ V_u = \frac{\pi}{2} b df \csc(\theta) \] 

(2.27)

where:

\( f_t = \) splitting strength of cylinder.

\( \theta = \) inclination of diagonal crack to the beam axis = \( \tan^{-1}(d/a) \).

\( b = \) width of beam.

\( d = \) effective depth.

\( a = \) shear span.

2.2.7.2 Beam with web reinforcement:
He assumed that, at the time of splitting, the strain of concrete and steel perpendicular to the crack are equal. Hence the ultimate shear strength for beams with web reinforcement is given by:

\[
V_u = f_y bd \left[ 1 + \left( \frac{a}{d} \right)^2 \right] \left[ 1.57 + (\alpha_e - 1) \left( \rho_h + \frac{d}{a} \rho_v \right) \right]
\]

...(2.28)

where:

\( \alpha_e = \) modular ratio \( E_s/E_c \).

\( \rho_h = A_h/bd \), where \( A_h \) is the area of reinforcement crossing the crack in the direction of the axis of the beam.

\( \rho_v = A_v/bd \), where \( A_v \) is the area of vertical reinforcement crossing the crack.

2.2.8 Euro-International Concrete Committee (CEB),1970\[2\]

*CEB* Has defined a deep beam as a straight beam, generally of constant cross-section with a span depth ratio \((L/H)\) less than 2 for simply supported beams and 2.5 for continuous beams.

2.2.8.1 Design for flexure:

The area of main reinforcement in tension is calculated as for normal beam, but the lever arm \( z \) given by:

\[
z = 0.2(L+2H) \quad 1 \leq L/H \leq 2.0
\]

...(2.29)

or

\[
z = 0.6L \quad L/H < 1.0
\]

...(2.30)

where:

\[ H = \text{height of beam}, H \leq L \]
\[ L = \text{span of beam.} \]

The tensile reinforcement should be extended throughout the span and uniformly distributed over a depth equal to (0.25\(H\) to 0.05\(L\)) from the bottom.

For continuous beams the area of main reinforcement for both positive and negative moments is calculated as above with the lever arm given by:

\[
z = 0.2(L+1.5H) \quad \text{if } 1 \leq L/H \leq 2.5 \quad \ldots \quad (2.31)
\]

\[
z = 0.5L \quad \text{if } L/H < 1.0 \quad \ldots \quad (2.32)
\]

2.2.8.2. Design for shear:

The shear strength of a section is given by:

\[
V_{\text{max}} = 0.1 \ bH \ f_c \quad \text{if } H \leq L \quad \ldots \quad (2.33)
\]

where:

\[ f_c = \text{cylinder compressive strength, N/mm}^2. \]

2.2.8.3. Web reinforcement:

For beam loaded on top, CEB recommends to use orthogonal reinforcement in the web on both faces. The area of reinforcement is given by:

\[
A_{sw} = 0.0025bs \quad \text{for smooth round bars} \quad \ldots \quad (2.34)
\]

\[
A_{sw} = 0.002bs \quad \text{for high-bond bars} \quad \ldots \quad (2.35)
\]

where:

\[ b = \text{the thickness of the beam.} \]

\[ s = \text{the spacing between bars.} \]
When the load is applied to the lower portion of the beam, the vertical stirrups should be designed to transmit the total load to the upper portion of the beam. Spacing should not exceed 150 mm.

2.2.9 CIRIA Guide-2, 1977[4]

The CIRIA Guide applies to single-span deep beams with an effective span to overall depth ratio \( L_e/h \) of less than 2.0 (see Fig (2.2)), and the Guide is recommended for \( span/depth \) ratio up to 2.5 for continuous deep beams.

The guide defines the active height, \( h_a \), of a deep beam as the lesser of, \( L_e \) and \( h \). The shear strength formula is essentially the Kong et al equation and is given by:

\[
V_n = V_c + V_s = \lambda_1 \left[ 1 - 0.35 \frac{X}{h_a} \right] \sqrt{f_{cu} b h_a} + \lambda_2 \sum_{i=1}^n \frac{100A_i y_i \sin^2 \alpha_i}{h_a} \]

(2.36)

Where:

\[
\lambda_1 = \frac{(0.7 \times 0.52 \times C_1)}{\gamma_{mc}} = 0.44, \text{ for normal weight aggregates and equal } 0.32 \text{ for lightweight aggregate.}
\]

\[
\lambda_2 = 1.95 \text{ MPa, for deformed bars, and equal } 0.85 \text{ MPa, for plain round bars.}
\]

In addition:

\[
V_n < 1.3 \lambda_1 \sqrt{f_{ch} b h_a}
\]

(2.37)

- CIRIA Guide-2 as points:

  - **CIRIA Guide 2** is based on semi-empirical rules and it is not enough for a whole range of deep beams with various geometry and reinforcement content.
The Guide does not predict the mode of failure for a given set of parameters in deep beams. In practice it should be possible to predict the mode of failure and ultimate strength for any deep beam.

The Guide assumes that the contribution of the horizontal bars, including the main reinforcement, to the ultimate strength, depends on the position of the bar with respect to top of the beam. This is unacceptable.

The Guide is unclear with regard to the contribution of the vertical reinforcement in the beam to the ultimate strength. Within the past decade or so there have been further studies in the behavior of reinforced concrete deep beams.

2.2.10 American Building Code (ACI 318 –1999)[3]

The design equations for deep beams in ACI code are applicable to beams with \( L_n/d \) less than 5.0 and subjected to top loading. The nominal shear strength of deep beam, \( V_n \), is given by:

\[
V_n = V_c + V_s
\]

Where:

\( V_c \) = nominal shear strength provided by concrete
\( V_s \) = nominal shear strength provided by shear reinforcement.

Shear strength provided by concrete \( V_c \) shall be computed by:

\[
V_c = \left[ 3.5 - \frac{2.5}{M_{u}} \frac{V_{u}}{V_{c}} \right] 1.9 \sqrt{\frac{f_c'}{2500}} + 2500 \rho_w \frac{V_{u}}{M_{u}} bd \leq 6 \sqrt{\frac{f_c'}{b_w d}}
\]

(2.39)

where:

\( \rho_w \) = the main longitudinal reinforcement ratio, \( A_s/bd \).
\( M_a \) = the factored moment at the critical sections, \( lb-in \).
\( V_u \) = the factored shear force at the critical section, \( lb \).
\( f_c' \) = cylinder compressive strength, psi
The multiplier term in equation (2.39) i.e. \([3.5 \text{ to } 2.5 \ M_u/V_u] \) takes account of the shear strength reserve of deep beams after diagonal cracking has occurred and this term shall not exceed 2.5.

Shear strength provided by shear reinforcement \(V_s\) may be computed from:

\[
V_s = \left[ \frac{A_v}{S_v} \left( \frac{1+Ln/d}{12} \right) + \frac{A_{vh}}{S_h} \left( \frac{11-L_n/d}{12} \right) \right] f_y d
\]

(2.40)

where:

- \(A_v\) = total area of vertical stirrups spaced at \(s_v\) in the horizontal direction at both faces of the deep beam, and \(s_v\) (in²)
- \(A_{vh}\) = total area of horizontal stirrups spaced at \(s_h\) in the vertical direction at both faces of the deep beam and, \(s_h\) (in²)
- \(f_y\) = the specified yield strength of shear reinforcement, psi.

Depending on the \(Ln/d\) ratio, the final value of \(V_n\) is limited by the following expressions:

\[
\begin{cases}
V_n \leq 8\sqrt{f'c b_n d} \Rightarrow \frac{l_n}{d} < 2.0 \\
V_n < 2\left( \frac{10 + \frac{Ln}{d}}{3} \right)^{1/2} f'c b d \Rightarrow 2.0 \leq \frac{l_n}{d} \leq 5.0
\end{cases}
\]

... (2.41)

For design purposes, the ultimate shear strength of the section \(V_u\) is given by:

\[
V_u \leq \Theta V_n
\]

... (2.42)

where:

- \(\Theta = 0.85\) is the strength reduction factor for shear.
2.3 Conclusions of Literature Review

Experimental investigation of deep beam was reviewed and comparison of test results was given as well as the proposed equations. In addition, design recommendation of reinforced concrete deep beam flexural members were presented, showing the wide variation of methods used in designing deep beams.
CHAPTER [3]

STRUT-TIE MODEL METHOD
CHAPTER (3)

STRUT-TIE MODEL METHOD

3.1. Introduction

The idea of the strut-and-tie method came from the truss analogy method; the truss analogy method has been validated and improved considerably in the form of full member or sectional design procedures. The truss model has also been used as the design basis for torsion.

3.2. Strut-Tie Models

The strut-and-tie (STM) is based on the lower-bound theory of limit analysis. In the STM, the complex flow of internal forces in the discontinuity region under consideration is idealized as a truss carrying the imposed loading through the region to its supports. This truss is called strut-and-tie model and is a statically admissible stress field in lower-bound (static) solutions. Like a real truss, a strut-and-tie model consists of struts and ties interconnected at nodes (also referred to as nodal zones or nodal regions). A selection of strut-and-tie models for a few typical 2-D, regions is illustrated in Figure (3.1). As shown in the figure, struts are usually symbolized using broken lines, and ties are usually denoted using solid lines.

3.2.1 Strut-tie model components

Struts are the compression members of a strut-and-tie model and represent concrete stress fields whose principal compressive stresses are predominantly along the centerline of the strut. The idealized shape of concrete stress field surrounding a strut in a plane (2-D) member, however, can be prismatic (Figure 3.2(a)), bottle-shaped (Figure 3.2(b)), or fan-shaped (Figure 3.2(c)). Struts can be strengthened by steel reinforcement, and if so, they are termed reinforced struts.

Ties are the tension members of a strut-and-tie model. Ties mostly represent reinforcing steel, but they can occasionally represent prestressing steel or concrete stress fields with principal tension predominant in the tie direction.
Figure (3.1) Examples of Strut-and-Tie Models for Common Structural Concrete Members

Figure (3.2): Basic Type of Struts in a 2-D Member: (a) Prismatic (b) Bottle-Shaped (c) Fan-Shaped
Nodes are analogous to joints in a truss and are where forces are transferred between struts and ties. As a result, these regions are subject to a multidirectional state of stress. The types of forces being connected classify nodes. Figure (3.3) shows basic types of nodes in a (2-D) member; C is used to denote compression and (T) is used to denote tension.

![Figure (3.3): Basic Type of Nodes: (a) CCC (b) CCT (c) CTT (d) TTT](image)

### 3.2.2 Uniqueness of strut-and-tie models

As a statically admissible stress field, a strut-and-tie model has to be in equilibrium externally with the applied loading and reactions (the boundary forces) and internally at each node. In addition, reinforcing or prestressing steel is selected to serve as the ties, the effective width of each strut is selected, and the shape of each nodal zone is constructed such that the strength is sufficient. Therefore, only equilibrium and yield criterion need to be fulfilled for an admissible strut-and-tie model. The third requirement in solid mechanics framework, namely the strain compatibility, is not considered.

As a result of these relaxed requirements, there is no unique strut-and-tie model for a given problem. In other words, more than one admissible strut-and-tie model may be developed for each load case as long as the selected truss is in equilibrium with the boundary forces and the stresses in the struts, ties, and nodes are within the acceptable limits. The lower-bound theorem guarantees that the capacity obtained from all statically admissible stress fields is lower than or equal to the actual collapse load. However, as a result of limited ductility in the structural concrete, there are only a small number of viable solutions for each design region. Figure (3.4) illustrates an example in which one solution is preferable to another. Due to the point load at the tip of the cantilever portion, the upper part of the beam is likely to develop horizontal tensile stresses along the beam. Therefore, the model with the upper horizontal tie (Figure 3.4(a)) is preferable to that shown in Figure 3.4(b). The latter
only effectively resists the tension in the upper region near the middle support.

Figure (3.4) Two statically admissible strut-and-tie models for a cantilevered deep beam under vertical loading: (a) Workable truss (b) Less favorable truss due to excessive ductility demands

3.3 The Strut and Tie Model Method Design

The Strut and tie model method (STM) is a powerful tool for the design of what is known as 'discontinuity' or 'disturbed' regions in reinforced and prestressed concrete structures. These regions are normally referred to as the D-regions. These are regions where a complex state of stress and strain develops. Examples of D-regions include corbels, deep beams, joints, and walls with openings, anchorage zones and so on, see Figure (3.1).

The method idealizes the D-region by a system of truss members that serve to carry the load to the boundaries of the D-region. The truss model consists of compression struts (concrete) and tension ties (reinforcing bars). The proportioning of the sizes of the compression struts and the truss nodes (joints) are based on satisfying certain stress limits. It is considered as a lower bound plasticity method because it relies on assuming certain distribution of stress and load path that satisfy equilibrium and maximum stress conditions. The load capacity calculated from this state will always be less than or equal to the true ultimate load.

3.3.1 The structure's B- and D-regions

In using the strut-and-tie model approach, the first step is to subdivide the structure into its B- and D-regions. Those regions of a structure in which linear strain distribution (the Bernoulli-Navier
(hypothesis) is appropriate are referred to as B-regions. These regions of a structure are usually designed with high accuracy. Their internal forces or stresses can be obtained from moment and shear diagrams, analyzed by means of the statical system of beams. For uncracked B-regions, these stresses are calculated using bending theory for linear elastic material. For cracked B-regions, the truss models or the standard methods of Codes apply.

However, those regions of a structure where the strain distribution is significantly nonlinear, e.g., near corners, joints, corbels and other discontinuities, and the standard methods of Codes fail to apply in these areas will be called D-regions (Figure 3.5). The internal flow of forces in D-regions can be reasonably well described by strut-and-tie models.

In B-regions, the stresses and stress trajectories are quite smooth as compared to the turbulent pattern near D-regions. Stress intensities

\[ \text{Figure (3.5): D-regions (shaded areas) with nonlinear strain distribution due to (a) Geometrical discontinuities. (b) Statical and/or geometrical discontinuities.} \]
decrease rapidly with the distance from the location of the concentrated load, as shown in Figs. (3.6) and (3.7). This behavior helps to identify the separation of B- and D-regions in a structure.

![Figure (3.6) Stress trajectories in a D-region, maximum principal stress](image)

![Figure (3.7) Stress trajectories in a D-region, minimum principal stress](image)

3.3.2 Essential principles of the strut-and-tie model design

In a strut-and-tie model, the struts represent concrete stress fields with prevailing compression in the direction of the strut and the ties normally represent one or several layers of tensile reinforcement. Occasionally model ties can also stand for concrete tensile stress fields.

Strut-and-tie models provide the designer with considerable insight into the flow of forces in D-regions. It is well understood that cracked
reinforced concrete carries load principally by compressive stresses in the concrete and tensile stresses in the reinforcement. After significant cracking has occurred, the principal compressive stress trajectories in the concrete tend towards straight lines. Hence, straight compressive struts can approximate those compressive stress trajectories.

The internal flow of forces in D-regions can be modeled using concrete struts for principal compression stress fields, ties for the principal tensile reinforcement and nodal zones or nodes for the regions of concrete subjected to multi-directional stresses where the struts and ties meet (Figs. (3.8) and (3.9)).

When a suitable model of a D-region is known, the forces of the struts and ties will be calculated, thereby satisfying equilibrium between applied loads and inner forces. The struts, ties and their nodes will be dimensioned and checked to carry the inner forces.

Fig (3.8) Strut-and-tie model for corbel of Figure (3.1)
3.3.3 The strut-and-tie method (S.T.M) for the design of D-regions

An emerging methodology for the design of all types of $D$-Regions is to envision and design an internal truss, consisting of concrete compressive struts and steel tension ties that are interconnected at nodes, to support the imposed loading through the boundaries of the discontinuity region. This design methodology is called the Strut-and-Tie Method (STM). The design process involves the steps described below. These steps are illustrated using a variety of $D$-Region design examples including a corbel, a corner joint, a dapped-ended beam, and a deep beam.

- Define the boundaries of the $D$-Region and determine the imposed local and sectional forces.
- Sketch the internal supporting truss, determine equivalent loadings, and solve for truss member forces.
- Select reinforcing or prestressing steel to provide the necessary tie capacity and ensure that this reinforcement is properly anchored in the nodal zone (joint of the truss).
- Evaluate the dimensions of the struts and nodes, such that the capacity of these components (struts and nodes) is sufficient to carry the design forces values.
- Provide distributed reinforcement to ensure ductile behavior of the $D$-Region.

All the moments, shear and axial forces and reactions acting on the D-region must be known before modeling of $D$-regions can commence (Fig. 3.10a).
**Figure (3.10): The load path method.** (a) The structure and its loads. (b) The load paths through the structure. (c) The corresponding strut-and-tie model.

Usually load path method can be used to systematically develop strut-and-tie models by tracing flow of forces through the structure.

The S.T.M is based on the lower bound theory of plasticity. Therefore, the actual capacity of the structure is considered to be equal to or greater than that of the idealized truss. This suggests that if truss A (Cut-Away Truss shown in Figure (3.11) can support a load of $P_A$, then the capacity $P_B$ of deep beam B (equivalent to Truss A + three concrete fills) is at least equal to $P_A$. This statement is almost true. In the “filled-in” structure, the forces may spread out along the length of the strut resulting in the strut failing by splitting at a lower load than it would have failed by crushing had the stress trajectories been parallel. Such effects can, however, be easily accounted for by reducing ultimate stress limit values.

**Figure (3.11): Illustrations of “Cut-Away” and “Filled-In” Truss**
3.4. **Design Procedures of the Strut-and-Tie Model**

The following design procedure is used to construct the strut-and-tie model:

1. Draw the strut-and-tie models to scale and with the help of the finite element analysis; sketch the flow path of the forces.
2. Develop the strut-and-tie-model. The struts and ties condense the real stress fields by resultant straight lines and concentrate their curvature in nodes.
3. Determine the geometry of the strut-and-tie model. The nodes of the strut-and-tie model are located at the points of intersection of the forces at the nodal zones. With the geometry of the strut-and-tie model determined, the forces in the struts and the ties of the model can be found from statics. These are the inner forces generated to resist the external applied loads.
4. Dimension the concrete compressive struts, and the distribution and details of the reinforcement are determined based on consistent equilibrium and ultimate strength considerations. The cross-sectional area of a compressive strut is determined by the dimensions of the nodal zones at the ends of the struts. The nodal zones must be chosen large enough to ensure that the nodal zone stresses are less than the limits specified in the Code. But, the resultant dimensions of struts and nodes should be compatible with the geometric constraints of the D-regions.

3.5 **Dimensioning the Struts, Ties and Nodes**

The nodes should be dimensioned so that the strength of the struts bearing on them can be fully developed and ties, which are anchored in them, should prevent anchorage failure.

3.5.1 **Ties**

Normally tie forces are carried by reinforcement. Its cross section follows from the tie force in the ultimate limit state and the design yield strength of the steel.

3.5.2 **Concrete struts or compression stress fields**

To cover all cases of compression stress fields, three typical configurations are sufficient.

(a) The fan-shaped stress field is an idealized stress field with no (negligible) curvature and it does not develop transverse stresses (Fig. 3.12a).
Figure (3.12) The basic compression fields. (a) the 'fan', (b) the' bottle', (c) the 'prism'

(b) The bottle-shaped stress field with its bulging stress trajectories develops considerable transverse stresses i.e., compression in the bottleneck and tension further away. The transverse tension can initiate longitudinal cracks and cause an early failure. Therefore, it is essential to reinforce the stress field in the transverse direction. The transverse tension can be determined from a strut-and-tie model of the stress field (Fig. 3.12b).

(c) The prismatic stress fields is a frequent special case of the two preceding two stress fields in which the transverse stress and curvature are zero (Fig. 3.12c).

3.5.3 The nodal zones or nodes

The nodes of the model are defined as the intersection points of three or more straight struts or ties, which themselves represent either straight or curved stress fields or reinforcing bars. In actual reinforced concrete structure, a node is introduced to indicate an abrupt change of direction of forces. In reality, the node usually occurs over a certain length and width.

Fig. (3.13) shows two typical nodes encountered in the strut-and-tie model. The 'smeared' nodes (Node B - consisting of three compressive struts) represent the intersection point where wide concrete stress fields join each other or with closely distributed reinforcing bars. These types of nodes are normally not critical. When sufficient anchorage of the reinforcing bars in the smeared node is ensured, and sufficient reinforcement is provided to 'catch' the outermost fibers of the deviated compressive stress field, then the node is considered safe.

On the other hand, the singular nodes (Node A - consisting of two struts and one tie) occur where concentrated forces are applied. These
nodes have to be carefully detailed in order to prevent excessive deformations to the structure.

Figure (3.13): 'Singular nodes' A and 'smeared nodes' B of strut-and-tie model, their stress fields, nodes and corresponding reinforcement.

These nodes or nodal zones must be chosen large enough to ensure that the nodal zone stresses are less than the nodal zone stress limits. The geometry of the node region and the arrangement of reinforcement in it should be consistent with the model on which the design of the structure is based and with the applied forces. Thereby the equilibrium condition should be satisfied.

3.5.4 The nodal zone stress limit

The average compressive stresses in the node region boundaries have to be checked to be less than the limits stated. The following simplified strength value, $f_{bl}$ are proposed for dimensioning all types of struts and nodes and is taken from the CEB-FIP Model Code 1990\[27\].

$$f_{bl} = \alpha f_{cd}$$  \( \ldots \)  

(3.1)

where:

- $\alpha = 1.0$
- For an undisturbed and uniaxial state of compressive stress.
- For node regions where only compression struts meet, it could be taken a 1.1 thus creating a 2-dimensional or 3-dimensional state of compressive stresses in the node region.

$\alpha = 0.8$
• For compression fields with cracks parallel to the compressive stresses.
• For nodes where main tensile bars are anchored.

Note that $f_{cd}$ denotes the concrete compressive design strength for uniaxial compression, which is related to the specified compressive strength $f'_c$ and which in turn depends on the safety factor of the designated Code of practice. $f_{cd}$ maybe determined by:

$$f_{cd} = \frac{0.85 f'_c}{\gamma_m}$$

...(3.2)

where:

- $f_{cd}$ = concrete compressive design strength.
- $\gamma_m$ = material safety factor for the concrete in compression
  = 1. (in this case)

Coefficient 0.85 accounts for sustained loading.

### 3.6 Code Provisions S.T.M Design

STM design provisions consist of rules for defining the maximum dimensions and ultimate stress limit capacities of struts and nodes, as well as reinforcement anchorage and distribution requirements. Existing and proposed code provisions differ substantially due to uncertainties in what these rules should be. This situation is created by a lack of sufficient and detailed experimental research. Guidelines for design by the STM have been developed in the AASHTO LRFD [29] code in 1999.

Table (3.1) and Table (3.2) show examples of stress limits and strength reduction factors defined in ACI Code and AASHTO LRFD, respectively. As shown in the tables, there are substantial differences in the rules used in these provisions and guidelines because of uncertainties associated with defining the characteristics of an idealized truss within a continuum of structural concrete.
Table (3.1) Stress Limits and Strength Reduction Factors
According to ACI 318-02 1999 [28]

<table>
<thead>
<tr>
<th>Stress Limits, $f_{cu}$ struts:</th>
<th>$\beta_s = 0.85 \beta_x f'_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_s$</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>For prismatic struts in uncracked compression zones</td>
</tr>
<tr>
<td>0.40</td>
<td>For struts in tension members</td>
</tr>
<tr>
<td>0.75</td>
<td>Struts may be bottle shaped and crack control reinforcement is included</td>
</tr>
<tr>
<td>0.60</td>
<td>Struts may be bottle shaped and crack control reinforcement is not included</td>
</tr>
<tr>
<td>0.60</td>
<td>For all other cases</td>
</tr>
</tbody>
</table>

$\beta_c = \frac{f'_c}{f_c}$ = specified concrete compressive strength

Notes:
Crack control reinforcement requirement is $\Sigma \rho_{vi} \sin \gamma_i \leq 0.003$, where $\rho_{vi}$ = steel ratio of the $i$-th layer of reinforcement crossing the strut under review, and $\gamma_i$ = angle between the axis of the strut and the bars.

Nodes:
$\beta_n = 0.85 \beta_n f'_c$

where:
$\beta_n = 1.00$ when nodes are bounded by struts and/or bearing areas.
$\beta_n = 0.80$ when nodes anchor only one tie.
$\beta_n = 0.60$ when nodes anchor more than one tie.

Strength Reduction Factors, $\varphi$
$\varphi = 0.75$ for struts, ties, and nodes
Table (3.2) Stress Limits and Strength Reduction Factors According to AASHTO LRFD 1999 [29]

<table>
<thead>
<tr>
<th>Stress Limits, $f_{cu}$: struts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{cu} = \frac{f'_c}{0.80 + 170 \varepsilon_i} \leq 0.85 f'_c$</td>
</tr>
<tr>
<td>where: $\varepsilon_i = \varepsilon_s + (\varepsilon_s + 0.002) \cot 2\theta_s$</td>
</tr>
<tr>
<td>$\theta_s$ = smallest angle between the strut under review and the adjoining ties.</td>
</tr>
<tr>
<td>$\varepsilon_s$ = average tensile strain in the tie direction.</td>
</tr>
<tr>
<td>$f'_c = $ specified concrete compressive strength.</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
</tr>
<tr>
<td>The stress limit assumes a minimum distributed reinforcement of $0.003$ in each direction is provided.</td>
</tr>
<tr>
<td><strong>Nodes:</strong></td>
</tr>
<tr>
<td>$f_{cu} = v f'_c$</td>
</tr>
<tr>
<td>$v = 0.85$ when nodes are bounded by struts and/or bearing areas</td>
</tr>
<tr>
<td>$v = 0.75$ when nodes anchor only one tie</td>
</tr>
<tr>
<td>$v = 0.65$ when nodes anchor more than one tie</td>
</tr>
<tr>
<td><strong>Resistance Factors, $\varphi$</strong></td>
</tr>
<tr>
<td>$\varphi = 0.7$ for struts and nodes</td>
</tr>
<tr>
<td>$\varphi = 0.9$ for ties</td>
</tr>
</tbody>
</table>
CHAPTER (4)

PLASTIC TRUSS MODEL OF DEEP BEAMS
4.1 Introduction:

The plastic truss model consists of compression struts inclined at an angle, $\theta$, to the horizontal, where $\theta$ was between (25° and 65°), stirrups, and longitudinal chords. The tension chord comprised the longitudinal the tension reinforcement and the concrete compression zone of deep beam provided the compression chord provided the compression chord. The concentrated loads and reactions were transmitted to a number of stirrups by compression struts radiating from the load point. These struts are referred to as a compression fan. The compression fans were a compression field of uniformly sloped compressive struts.

In this section the plastic truss model is extended to include two new components:

- The major compression diagonal.
- The truss node.

In Fig (4.1), two major inclined compression struts resist the concentrated load, $P$; they are shown by light shaded area. A tension tie force equilibrates the horizontal component of the force in struts, $T$. The size of compression struts is selected such that they are stressed to:

$$f_{ce} = \nu f'_{c}$$

where:

$\nu$ is an efficiency factor, between 0 and 1.0.
Table (4.1) Recommendation Values of Effective Compressive Strength, $f_{ce}$:

<table>
<thead>
<tr>
<th>Structural Member</th>
<th>$f_{ce}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truss node:</td>
<td></td>
</tr>
<tr>
<td>Joints bounded by compressive struts and bearing areas</td>
<td>$0.80\ f_c$</td>
</tr>
<tr>
<td>Joints anchoring one tension tie</td>
<td>$0.65\ f_c$</td>
</tr>
<tr>
<td>Joints anchoring tension ties in more than one direction</td>
<td>$0.50\ f_c$</td>
</tr>
<tr>
<td>Isolated compression struts in deep beam or D-regions</td>
<td>$0.50\ f_c$</td>
</tr>
<tr>
<td>Severely cracked web of slender beams: $(\theta = 30^\circ)$</td>
<td>$0.25\ f_c$</td>
</tr>
<tr>
<td>Severely cracked web of slender beams: $(\theta = 45^\circ)$</td>
<td>$0.45\ f_c$</td>
</tr>
</tbody>
</table>

Generally speaking, major compression struts will occur if the compression fans regions overlap so that no compression field can exist.

The three triangular shaded areas in the Fig (4.1) represent at the truss nodes. There are wedges of concrete loaded on all sides except those at the supports. For deep beam with an equal compressive stress, under such a loading, both principal stresses in the plane of loading are equal, and Mohr’s circle of stress in this plane reduces to a point. For this reason truss nodes are sometimes referred to as hydrostatic elements.

Fig (4.1), Plastic truss models of the deep beam.
The load, reactions, struts, and ties in Fig (4.1) are all laid out such that centroids of each truss member and lines of action of externally applied load coincide at each joint, as shown in Fig (4.2). This is necessary for joint equilibrium.

As illustrated on the Fig (4.1) and Fig (4.2) the bar is shown with external end anchors. In reinforced concrete deep beam, the anchorage would be accomplished with horizontal or vertical hooks, or in extreme cases, with an anchor plate.

The plastic truss model can fail in one of three ways:

- The tie could yield
- One of the struts could crush when the stress in the strut exceeded $f_{ce}$.
- A node could fail by being stressed greater than its effective compressive strength.

Frequently, this involves a bearing failure at the loads reactions. Since a tension failure of steel will be more ductile than either a strut failure or a node failure, the beam should be proportioned so that the strength of steel governs.
The requirement that the centroids of the members meet at point may limit the size of members, particularly the compression strut. The joint shown in Fig (4.2a) has been redrawn in Fig (4.2b) with the reinforcement moved closer to the bottom of beam. For axes of members to meet, the compression strut must be smaller in Fig (4.2b). As a result, the compressive force it can resist drops.

4.2. **Truss Modeling of Simple Span Deep Beams**

A simple concrete deep beam with vertical stirrups subjected to a concentrated load at mid-span is shown in Fig (4.3). Several struts are:

- One strut is used as a direct compression strut running from the load to support. This truss a carried a shear $V_c$.

- Another strut used the stirrup as vertical tension members and has compression fans under the load and reaction.

The vertical force in each stirrup is computed assuming that stirrup has yielded. The vertical force component in each of the small compression struts must be equal to yield strength of the stirrup, for joint equilibrium.

The farthest left stirrup is not used, since one cannot draw compression diagonal from the load point to bottom of this stirrup without encroaching on the direct compression strut.
Fig (4.3) Plastic truss models for simple deep beam with stirrups.
The compression diagonals radiating from the load point intersect the stirrups at the level of the centroid of the bottom steel, because a change in force in the bottom steel is required to equilibrate the horizontal component of the stirrup force by horizontal component of compression diagonal intersecting at that point.

The illustration in Fig (4.3b) shows a stepped line resulting from tensile force in the bottom steel. The tensile force computed from beam theory, $\frac{M}{j_d}$ is shown by dash line in the same figure.

### 4.3 Truss Modeling of Continuous Deep Beams:

Plastic truss models of continuous deep beams are shown in Fig (4.4). At the interior support, two trusses carry the load. The upper truss was shown in Fig (4.4b) utilizes the top reinforcement with a tie force, $T_2$ and lower truss shown in Fig (4.4c) uses the bottom reinforcement which has a force, $T_1$.

The capacity of each truss can be computed from the geometry of triangles and the $A_s.f_y$ of the tension chord. The capacity of beam is found by adding them together. The forces $T_2$ and $T_1$ are shown anchored at the load points and at the support.
Fig (4.4), Plastic truss models for a continuous deep beam.

(a) Complete plastic truss

(b) Negative moment truss

(c) Positive moment truss
4.4 Validity of the Plastic Truss Theory:

The validity of plastic truss model for a given beam depends on whether the truss model represents the true situation. Concrete deep beams can undergo a limited amount of distribution of internal forces as internal forces change from elastic pre-cracked state, through the elastic cracked state to plastic cracked state. If the truss that is chosen requires excessive deformation to reach the fully plastic state, it may fail prematurely.

The Fig (4.5) shows that plastic truss-model for beam with horizontal web reinforcement is an unsuitable truss, one half of simply supported with flexural steel and one layer of “Horizontal Web Reinforcement” at mid-depth. A possible plastic truss model for this beam consists of two trusses:

- One utilizing the lower steel as a tension tie.
- Other using the upper steel as compression struts.

For an ideally plastic martial, the capacity would be the sum of shear transmitted by the two trusses \([V_1 + V_2]\).

However, that the upper layer of steel has little, if any, effect on strength. When this beam is loaded, the bottom tie yields first. Large deformations are required before the upper tie can yield. Before this can fully develop, the lower truss will normally fail.

A similar problem may occur if the deformations required to yield the top tie in Fig (4.4) for the plastic truss model of a continuous deep beams, greatly exceed those required to yield the bottom ties. If extensive redistribution could occur, the ratio \(\frac{V_1}{V_2}\) in this deep beam could vary from close zero to one, [0 to 1]. Because only limited redistribution can...
occur, however, the ratio $\frac{V_1}{V_2}$ or $\frac{T_1}{T_2}$ should approach that obtained from an elastic analysis.

Fig (4.5) Plastic truss model for deep beam with horizontal web reinforcement

4.5 Major Factors Affecting the Concrete Strength:

The major factors affecting the effective compressive strength are:

- The gross tensile strain perpendicular to the strut or direction of the principal compressive stress in deep beam web.
- The direction of the cracking, whether parallel to the strut or inclined to its axis.
- The uniformity of the state of strain. The crushing strength of the members with highly localized strain conditions such as the truss nodes and the struts in a beam tends to be higher than in the more
uniformly stressed web. This is because the concrete adjacent to the struts is less disturbed and hence stronger than that in the struts.

5.6 Conclusion of Plastic Truss Model of Deep Beam

The plastic truss models of deep beams as core of this study, was described intensively. Two cores of deep beams using the truss model were explained, one case of a simply supported reinforced concrete deep beam and the other for a continuous reinforced concrete deep beam. The validity of the plastic truss theory was thoroughly discussed and the major factors affecting the concrete strength were elaborated.
CHAPTER (5)

PROGRAM MODEL
APPLICATION AND
RESULTS & DISCUSSION
5.1. Introduction

A computer-based system that evolves a solution to a problem by simulating processes found in nature and the behavior of an engineering system, an important goal of the designer to improve and to optimize its performance. The task of design optimization is to support an engineer in searching for the best possible design. The "best possible" or "optimal" design is a system that highly corresponds to the designer's desired concepts and at the same time satisfies all the functional, manufacturing and market requirements.

In this research, a computer program (PROSTM) was developed for strut-tie model method for the analysis and design of simply supported reinforced concrete deep beams applying (AASHTO LRFD 1999)

5.2 Problems in Struts and Ties Applications:

1. How to construct a strut-tie model?
2. If a truss can be formulated, is it adequate?
3. If there are two or more trusses for the same structure, which one is better?

From these points, any program of strut-tie method needs a number of models.
5.3 S.T.M, Model Design Concept:

1. The successful use of the S.T.M requires an understanding of basic member behavior and informed engineering judgment.
2. In reality, there is almost an art to the appropriate use of this technique.
3. The S.T.M is definitely a design tool for thinking of engineers.
4. The process of developing an S.T.M for a member is basically an iterative graphical procedure.

5.4 Model of the Program Used:

The algorithm of selected model, strut and tie model for deep beams, was prepared as a computer program code shown below in Fig (5.1). The program is mainly analysis and design of simply deep beams. The strut and tie program model mentioned before, contains plastic truss, strut-tie, and the applied load at specific point loads and distributed loads over span of the beam, plastic truss and loading and nodal (1, 2, 3, 4, 6, and 8). The plastic truss consists of compression struts inclined at an angle, $\theta$, to the horizontal, where $\theta$ is between (25$^\circ$ and 65$^\circ$), stirrups, longitudinal chords and nodes (1, 2, 3, 4, 6, and 8). All these constitute members of the plastic truss.

Accordingly, the plastic truss was analyzed based on strut and tie analysis concept. The stirrups were considered as vertical tension members, and chords are considered as compression members. The steps of the analysis and design program for the model are shown in the flow chart of that program is shown in Fig (5.2).
5.5 Program Assumptions:

The determination of the required forces in the members of plastic truss is based on the following assumptions:

1. The vertical Tie between node (2) and node (3) takes 50% of external force.
2. Remaining forces are taking by other members of model.
3. Minimum angle of Vertical struts is 25°
4. Maximum angle of Vertical struts is 65°.

5.6 Code of Program:

A soft or code development of the computer program (PROSTM) used Turbo Pascal language.
5.7 Flow Chart of Program

The program is stepped according to flow chart in Fig (5.2).

![Flow Chart](image)

**Fig (5.2)** Flow chart for struts and tie program

5.8 Determination of the Required Truss Forces:

Since the truss shown in Fig (5.1) is statically indeterminate, it is necessary first to select the amount and position of the vertical tie (2-3) (stirrups) by determining the point loads, and assuming that the stirrups have yielded. The truss then becomes statically determinate and all the member forces can be found easily by statics. Thus the required forces
and slopes in all the members of the truss are determined. Note that positive indicates tension and negative indicates compression.

5.9 Steel Reinforcement for the Ties

5.9.1 Vertical reinforcement

Try to use legged stirrup reinforcement for the vertical tie (2-3). This corresponds to a capacity of reinforcement, $C_{Rein}$:

$$C_{Rein} = \varphi A_v f_y$$

(5.1)

Where:

- $\varphi$ is the reduction factor:
  - $\varphi = 0.7$ for struts and nodes
  - $\varphi = 0.9$ for ties

- $A_v$ is area of legged stirrups reinforcement.

- $f_y$ is strength of reinforcement.

The capacity of reinforcement should be clear to the assumed load.

5.9.2 Horizontal reinforcement

The area of steel reinforcement for horizontal tie, bending reinforcement ($A_{req}$) is calculated from equation:

$$A_{req} = N_{ij}/ (\varphi f_y)$$

(5.2)

Where:

- $N_{ij}$ is the forces on the horizontal ties, tie (1-3) and tie (3-6).
- $\varphi$ is reduction factor taking 0.9 for tie.
- $f_y$ is strength of reinforcement.

The area of reinforcement for horizontal tie compared with minimum area of reinforcement, (AASHTO LRFD 1999)\textsuperscript{[29]}, $A_{min}$:

$$A_{min} = 0.03 \left(f'/c/fy\right)bh$$

(5.3)

5.10 Check the Struts:

The struts will be checked by computing the strut widths and checked whether they will fit in the space available.
By neglecting the tensioning effects, the average tensile strain, \( \varepsilon_{s23} \), in tie(2-3) can be estimated as:

\[
\varepsilon_{s23} = \frac{N_{23}}{(A_{s23} \cdot E_s)} < \frac{f_y}{E_s} \tag{5.4}
\]

Similarly, the average tensile, \( \varepsilon_{s13} \), in tie (2-3) can be estimated as:

\[
\varepsilon_{s13} = \frac{N_{13}}{(A_{s13} \cdot E_s)} < \frac{f_y}{E_s} \tag{5.5}
\]

The bottom part of strut (1-2) is crossed by tie(1-3). The tensile strain perpendicular to strut (1-3) due to tensile strain in this tie (1-2) is:

\[
\varepsilon_l = \varepsilon_s + (\varepsilon_s + 0.002) \cot (2\theta_s) \tag{5.6}
\]

\( \theta_s \) = smallest angle between the strut under review and the adjoining ties.
\( \varepsilon_s \) = average tensile strain in the tie direction, and take minimum value of, \( \varepsilon_{s13} \) or \( \varepsilon_{s23} \).
\( f'_{c} \) = specified concrete compressive strength.
Thus, the stress limit, \( S_{tL} \), at the bottom of strut (1-3) takes by:

\[
S_{tL} = \varphi f_{cu} \tag{5.7}
\]

where:

\[
f_{cu} = \frac{f'_{c}}{0.80 + 170\varepsilon_i} \leq 0.85 f'_{c} \tag{5.8}
\]

The top part of strut (1-3) is crossed by tie (2-3). Thus similar the strain perpendicular to strut (1-3) due to tie (2-3) is calculated according stress limits for this case.

By taking the smaller stress limits from the two cases, the required width of strut (1-3), \( w_s \) is:

\[
w_s = \frac{N_{ij}}{(S_{tL} \cdot b)} \tag{5.9}
\]
where:

\[ N_{ij}, \text{ is force in strut and tie.} \]
\[ \text{St}_{\text{L}}, \text{ is the smaller stress limits.} \]
\[ b, \text{ is width of deep beams.} \]

Similarly, the width of strut (1-4) is calculated and the required short struts widths for strut transmitting the applied load to node (4) and strut width for short strut transmitting the force meeting at node (1) to support.

Thus, are it is also calculated and checked that strut width fits into the beam region. And ensuring that stresses are not exceeded stress limits.

5.11 Design the Node Zones and Check the Anchorages:

The nodes are designed and checked according to the following:

- The width of the strut (4-8) in nodal zone (4) was chosen to satisfy the stress limit on that nodal zone.

- The stresses of the nodal zone (1) and (3) are limited to \((0.75\Phi f'_c \text{ and } 0.65\Phi f'_c)\) respectively. To satisfy the stress limit of nodal zone (3), the tie reinforcement must engage an effective depth of concrete.

5.12 Applications of Program

A first and second application of program used is shown in Table (5.0).
<table>
<thead>
<tr>
<th>Details</th>
<th>First Applications</th>
<th>Second Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied load ((P))</td>
<td>10 - 300 kips</td>
<td>10 - 300 kips</td>
</tr>
<tr>
<td></td>
<td>44.48 – 1334.49 kN</td>
<td>44.48 – 1334.49 kN</td>
</tr>
<tr>
<td>Span/Depth ratio ((l_e/d))</td>
<td>3 const</td>
<td>3 const</td>
</tr>
<tr>
<td></td>
<td>3, 3.5, 4, 4.5 and 5</td>
<td>3, 3.5, 4, 4.5 and 5</td>
</tr>
<tr>
<td>Shear /clear span ((a/l_e))</td>
<td>0.25 - 0.5 period 0.05</td>
<td>0.25 - 0.5 period 0.05</td>
</tr>
<tr>
<td></td>
<td>0.35 const</td>
<td>0.35 const</td>
</tr>
<tr>
<td>Clear span ((l_e))</td>
<td>144 in</td>
<td>144 in</td>
</tr>
<tr>
<td></td>
<td>3657.6 mm</td>
<td>3657.6 mm</td>
</tr>
<tr>
<td>Deep Beam width ((b))</td>
<td>14 in</td>
<td>14 in</td>
</tr>
<tr>
<td></td>
<td>355.6 mm</td>
<td>355.6 mm</td>
</tr>
<tr>
<td>Over all Depth ((H))</td>
<td>48 in</td>
<td>48 in</td>
</tr>
<tr>
<td></td>
<td>1219.2 mm</td>
<td>1219.2 mm</td>
</tr>
<tr>
<td>Concrete cover ((c))</td>
<td>4 in</td>
<td>4 in</td>
</tr>
<tr>
<td></td>
<td>101.6 mm</td>
<td>101.6 mm</td>
</tr>
<tr>
<td>Concrete strength ((f_c))</td>
<td>4 ksi</td>
<td>4 ksi</td>
</tr>
<tr>
<td></td>
<td>27.58 MPa</td>
<td>27.58 MPa</td>
</tr>
<tr>
<td>Reinforcement strength ((f_y))</td>
<td>60 ksi</td>
<td>60 ksi</td>
</tr>
<tr>
<td></td>
<td>413.68 MPa</td>
<td>413.68 MPa</td>
</tr>
<tr>
<td>Steel modulus ((E_s))</td>
<td>29000 ksi</td>
<td>29000 ksi</td>
</tr>
<tr>
<td></td>
<td>200 kN/mm²</td>
<td>200 kN/mm²</td>
</tr>
</tbody>
</table>
5.13 Results of Program

5.13.1 The Results of Program for first application used, see Table (5.0) and Fig (5.1):

➢ Table (5.1): Force in Diagonal Strut (1-4), (kips).

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>19.21</td>
<td>14.46</td>
<td>11.52</td>
<td>9.55</td>
<td>8.15</td>
<td>7.11</td>
</tr>
<tr>
<td>30</td>
<td>57.12</td>
<td>42.95</td>
<td>34.18</td>
<td>28.3</td>
<td>24.13</td>
<td>21.02</td>
</tr>
<tr>
<td>40</td>
<td>75.82</td>
<td>56.97</td>
<td>45.31</td>
<td>37.5</td>
<td>31.95</td>
<td>27.82</td>
</tr>
<tr>
<td>50</td>
<td>94.34</td>
<td>70.83</td>
<td>56.3</td>
<td>46.57</td>
<td>39.66</td>
<td>34.51</td>
</tr>
<tr>
<td>60</td>
<td>112.68</td>
<td>84.55</td>
<td>67.16</td>
<td>55.52</td>
<td>47.25</td>
<td>41.09</td>
</tr>
<tr>
<td>70</td>
<td>130.84</td>
<td>98.11</td>
<td>77.89</td>
<td>64.35</td>
<td>54.73</td>
<td>47.57</td>
</tr>
<tr>
<td>80</td>
<td>148.83</td>
<td>111.52</td>
<td>88.48</td>
<td>73.05</td>
<td>62.09</td>
<td>53.93</td>
</tr>
<tr>
<td>90</td>
<td>166.63</td>
<td>124.78</td>
<td>98.93</td>
<td>81.62</td>
<td>69.33</td>
<td>60.18</td>
</tr>
<tr>
<td>100</td>
<td>184.26</td>
<td>137.88</td>
<td>109.24</td>
<td>90.07</td>
<td>76.44</td>
<td>66.31</td>
</tr>
<tr>
<td>110</td>
<td>201.7</td>
<td>150.82</td>
<td>119.4</td>
<td>98.38</td>
<td>83.44</td>
<td>72.32</td>
</tr>
<tr>
<td>120</td>
<td>218.97</td>
<td>163.61</td>
<td>129.43</td>
<td>106.56</td>
<td>90.31</td>
<td>78.22</td>
</tr>
<tr>
<td>130</td>
<td>236.05</td>
<td>176.23</td>
<td>139.31</td>
<td>114.61</td>
<td>97.06</td>
<td>83.99</td>
</tr>
<tr>
<td>140</td>
<td>252.94</td>
<td>188.70</td>
<td>149.05</td>
<td>122.53</td>
<td>103.68</td>
<td>89.64</td>
</tr>
<tr>
<td>150</td>
<td>269.65</td>
<td>201.00</td>
<td>158.64</td>
<td>130.31</td>
<td>110.17</td>
<td>95.16</td>
</tr>
<tr>
<td>160</td>
<td>286.17</td>
<td>213.14</td>
<td>168.09</td>
<td>137.95</td>
<td>116.52</td>
<td>100.55</td>
</tr>
<tr>
<td>170</td>
<td>302.51</td>
<td>225.12</td>
<td>177.38</td>
<td>145.45</td>
<td>122.74</td>
<td>105.81</td>
</tr>
<tr>
<td>180</td>
<td>318.66</td>
<td>236.93</td>
<td>186.52</td>
<td>152.8</td>
<td>128.82</td>
<td>110.94</td>
</tr>
<tr>
<td>190</td>
<td>334.61</td>
<td>248.57</td>
<td>195.51</td>
<td>160.01</td>
<td>134.76</td>
<td>115.92</td>
</tr>
<tr>
<td>200</td>
<td>350.38</td>
<td>260.04</td>
<td>204.34</td>
<td>167.08</td>
<td>140.56</td>
<td>120.77</td>
</tr>
<tr>
<td>210</td>
<td>365.95</td>
<td>289.49</td>
<td>213.02</td>
<td>173.99</td>
<td>146.21</td>
<td>125.46</td>
</tr>
<tr>
<td>220</td>
<td>381.32</td>
<td>301.43</td>
<td>221.54</td>
<td>180.75</td>
<td>151.71</td>
<td>130.01</td>
</tr>
<tr>
<td>230</td>
<td>396.51</td>
<td>313.20</td>
<td>229.89</td>
<td>187.36</td>
<td>157.06</td>
<td>134.39</td>
</tr>
<tr>
<td>240</td>
<td>411.49</td>
<td>324.79</td>
<td>238.08</td>
<td>193.81</td>
<td>162.25</td>
<td>138.62</td>
</tr>
<tr>
<td>250</td>
<td>426.28</td>
<td>336.19</td>
<td>246.1</td>
<td>200.09</td>
<td>167.27</td>
<td>142.68</td>
</tr>
<tr>
<td>260</td>
<td>440.86</td>
<td>347.48</td>
<td>253.96</td>
<td>206.21</td>
<td>172.13</td>
<td>146.56</td>
</tr>
<tr>
<td>270</td>
<td>455.25</td>
<td>358.45</td>
<td>261.64</td>
<td>212.16</td>
<td>176.82</td>
<td>150.26</td>
</tr>
<tr>
<td>280</td>
<td>469.43</td>
<td>369.29</td>
<td>269.15</td>
<td>217.94</td>
<td>181.33</td>
<td>153.78</td>
</tr>
<tr>
<td>290</td>
<td>483.4</td>
<td>374.96</td>
<td>276.48</td>
<td>223.54</td>
<td>185.65</td>
<td>157.09</td>
</tr>
<tr>
<td>300</td>
<td>497.17</td>
<td>390.40</td>
<td>283.63</td>
<td>228.96</td>
<td>189.79</td>
<td>160.19</td>
</tr>
</tbody>
</table>

where:

- P load = applied load
- a/le = shear span/ clear span ratio
Table (5.2): Force in Tie (3-6), (kips)

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8.2</td>
<td>9.85</td>
<td>11.5</td>
<td>13.15</td>
<td>14.8</td>
<td>16.46</td>
</tr>
<tr>
<td>20</td>
<td>16.46</td>
<td>19.77</td>
<td>23.09</td>
<td>26.42</td>
<td>29.76</td>
<td>33.1</td>
</tr>
<tr>
<td>30</td>
<td>24.75</td>
<td>29.76</td>
<td>34.78</td>
<td>39.81</td>
<td>44.87</td>
<td>49.94</td>
</tr>
<tr>
<td>40</td>
<td>33.1</td>
<td>39.81</td>
<td>46.56</td>
<td>53.33</td>
<td>60.14</td>
<td>66.98</td>
</tr>
<tr>
<td>50</td>
<td>41.5</td>
<td>49.94</td>
<td>58.44</td>
<td>66.98</td>
<td>75.58</td>
<td>84.24</td>
</tr>
<tr>
<td>60</td>
<td>49.94</td>
<td>60.14</td>
<td>70.42</td>
<td>80.77</td>
<td>91.2</td>
<td>101.71</td>
</tr>
<tr>
<td>70</td>
<td>58.44</td>
<td>70.42</td>
<td>82.5</td>
<td>94.69</td>
<td>107</td>
<td>119.41</td>
</tr>
<tr>
<td>80</td>
<td>66.98</td>
<td>80.77</td>
<td>94.69</td>
<td>108.76</td>
<td>122.98</td>
<td>137.34</td>
</tr>
<tr>
<td>90</td>
<td>75.58</td>
<td>91.2</td>
<td>107</td>
<td>122.98</td>
<td>139.15</td>
<td>155.52</td>
</tr>
<tr>
<td>100</td>
<td>84.24</td>
<td>101.71</td>
<td>119.41</td>
<td>137.34</td>
<td>155.52</td>
<td>173.96</td>
</tr>
<tr>
<td>110</td>
<td>92.95</td>
<td>112.3</td>
<td>131.94</td>
<td>151.87</td>
<td>172.1</td>
<td>192.66</td>
</tr>
<tr>
<td>120</td>
<td>101.71</td>
<td>122.98</td>
<td>144.58</td>
<td>166.55</td>
<td>188.9</td>
<td>211.64</td>
</tr>
<tr>
<td>130</td>
<td>110.53</td>
<td>133.74</td>
<td>157.35</td>
<td>181.4</td>
<td>205.92</td>
<td>230.91</td>
</tr>
<tr>
<td>140</td>
<td>119.41</td>
<td>144.58</td>
<td>170.25</td>
<td>196.43</td>
<td>223.17</td>
<td>250.49</td>
</tr>
<tr>
<td>150</td>
<td>128.35</td>
<td>155.52</td>
<td>183.27</td>
<td>211.64</td>
<td>240.66</td>
<td>270.39</td>
</tr>
<tr>
<td>160</td>
<td>137.34</td>
<td>166.55</td>
<td>196.43</td>
<td>227.03</td>
<td>258.41</td>
<td>290.62</td>
</tr>
<tr>
<td>170</td>
<td>146.4</td>
<td>177.68</td>
<td>209.73</td>
<td>242.62</td>
<td>276.42</td>
<td>311.21</td>
</tr>
<tr>
<td>180</td>
<td>155.52</td>
<td>188.9</td>
<td>223.17</td>
<td>258.41</td>
<td>294.71</td>
<td>332.18</td>
</tr>
<tr>
<td>190</td>
<td>164.71</td>
<td>200.22</td>
<td>236.75</td>
<td>274.41</td>
<td>313.29</td>
<td>353.54</td>
</tr>
<tr>
<td>200</td>
<td>173.96</td>
<td>211.64</td>
<td>250.49</td>
<td>290.62</td>
<td>332.18</td>
<td>375.31</td>
</tr>
<tr>
<td>210</td>
<td>183.27</td>
<td>223.17</td>
<td>264.38</td>
<td>307.07</td>
<td>351.38</td>
<td>397.53</td>
</tr>
<tr>
<td>220</td>
<td>192.66</td>
<td>234.8</td>
<td>278.44</td>
<td>323.75</td>
<td>370.92</td>
<td>420.22</td>
</tr>
<tr>
<td>230</td>
<td>202.11</td>
<td>246.55</td>
<td>292.67</td>
<td>340.67</td>
<td>390.82</td>
<td>443.42</td>
</tr>
<tr>
<td>240</td>
<td>211.64</td>
<td>258.41</td>
<td>307.07</td>
<td>357.86</td>
<td>411.09</td>
<td>467.15</td>
</tr>
<tr>
<td>250</td>
<td>221.24</td>
<td>270.39</td>
<td>321.65</td>
<td>375.31</td>
<td>431.76</td>
<td>491.47</td>
</tr>
<tr>
<td>260</td>
<td>230.91</td>
<td>282.49</td>
<td>336.42</td>
<td>393.05</td>
<td>452.85</td>
<td>516.4</td>
</tr>
<tr>
<td>270</td>
<td>240.66</td>
<td>294.71</td>
<td>351.38</td>
<td>411.09</td>
<td>474.39</td>
<td>542.01</td>
</tr>
<tr>
<td>280</td>
<td>250.49</td>
<td>307.07</td>
<td>366.55</td>
<td>429.44</td>
<td>496.4</td>
<td>568.34</td>
</tr>
<tr>
<td>290</td>
<td>260.4</td>
<td>319.55</td>
<td>381.93</td>
<td>448.12</td>
<td>518.93</td>
<td>595.48</td>
</tr>
<tr>
<td>300</td>
<td>270.39</td>
<td>332.18</td>
<td>397.53</td>
<td>467.15</td>
<td>542.01</td>
<td>623.48</td>
</tr>
</tbody>
</table>

where:
- \( P \text{ load} = \text{applied load} \)
- \( a/le = \text{shear span/clear span ratio} \)
Table (5.3): Required Tie (1-3) Reinforcement, (\(in^2\))

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.26</td>
<td>0.23</td>
<td>0.21</td>
<td>0.2</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>20</td>
<td>0.53</td>
<td>0.47</td>
<td>0.43</td>
<td>0.4</td>
<td>0.39</td>
<td>0.38</td>
</tr>
<tr>
<td>30</td>
<td>0.79</td>
<td>0.7</td>
<td>0.64</td>
<td>0.6</td>
<td>0.58</td>
<td>0.56</td>
</tr>
<tr>
<td>40</td>
<td>1.05</td>
<td>0.93</td>
<td>0.85</td>
<td>0.8</td>
<td>0.77</td>
<td>0.75</td>
</tr>
<tr>
<td>50</td>
<td>1.31</td>
<td>1.16</td>
<td>1.06</td>
<td>1</td>
<td>0.96</td>
<td>0.94</td>
</tr>
<tr>
<td>60</td>
<td>1.57</td>
<td>1.39</td>
<td>1.27</td>
<td>1.2</td>
<td>1.15</td>
<td>1.13</td>
</tr>
<tr>
<td>70</td>
<td>1.82</td>
<td>1.61</td>
<td>1.48</td>
<td>1.4</td>
<td>1.34</td>
<td>1.31</td>
</tr>
<tr>
<td>80</td>
<td>2.08</td>
<td>1.84</td>
<td>1.69</td>
<td>1.59</td>
<td>1.53</td>
<td>1.5</td>
</tr>
<tr>
<td>90</td>
<td>2.33</td>
<td>2.07</td>
<td>1.9</td>
<td>1.79</td>
<td>1.72</td>
<td>1.68</td>
</tr>
<tr>
<td>100</td>
<td>2.59</td>
<td>2.29</td>
<td>2.1</td>
<td>1.98</td>
<td>1.91</td>
<td>1.87</td>
</tr>
<tr>
<td>110</td>
<td>2.84</td>
<td>2.52</td>
<td>2.31</td>
<td>2.18</td>
<td>2.1</td>
<td>2.06</td>
</tr>
<tr>
<td>120</td>
<td>3.09</td>
<td>2.74</td>
<td>2.51</td>
<td>2.37</td>
<td>2.29</td>
<td>2.24</td>
</tr>
<tr>
<td>130</td>
<td>3.34</td>
<td>2.96</td>
<td>2.72</td>
<td>2.57</td>
<td>2.47</td>
<td>2.42</td>
</tr>
<tr>
<td>140</td>
<td>3.59</td>
<td>3.18</td>
<td>2.92</td>
<td>2.76</td>
<td>2.66</td>
<td>2.61</td>
</tr>
<tr>
<td>150</td>
<td>3.84</td>
<td>3.4</td>
<td>3.12</td>
<td>2.95</td>
<td>2.85</td>
<td>2.79</td>
</tr>
<tr>
<td>160</td>
<td>4.09</td>
<td>3.62</td>
<td>3.32</td>
<td>3.14</td>
<td>3.03</td>
<td>2.98</td>
</tr>
<tr>
<td>170</td>
<td>4.33</td>
<td>3.83</td>
<td>3.52</td>
<td>3.33</td>
<td>3.22</td>
<td>3.16</td>
</tr>
<tr>
<td>180</td>
<td>4.58</td>
<td>4.05</td>
<td>3.72</td>
<td>3.52</td>
<td>3.4</td>
<td>3.34</td>
</tr>
<tr>
<td>190</td>
<td>4.82</td>
<td>4.27</td>
<td>3.92</td>
<td>3.71</td>
<td>3.58</td>
<td>3.53</td>
</tr>
<tr>
<td>200</td>
<td>5.06</td>
<td>4.48</td>
<td>4.12</td>
<td>3.89</td>
<td>3.77</td>
<td>3.71</td>
</tr>
<tr>
<td>210</td>
<td>5.3</td>
<td>4.69</td>
<td>4.31</td>
<td>4.08</td>
<td>3.95</td>
<td>3.89</td>
</tr>
<tr>
<td>220</td>
<td>5.54</td>
<td>5.03</td>
<td>4.51</td>
<td>4.27</td>
<td>4.13</td>
<td>4.08</td>
</tr>
<tr>
<td>230</td>
<td>5.78</td>
<td>5.24</td>
<td>4.7</td>
<td>4.45</td>
<td>4.32</td>
<td>4.26</td>
</tr>
<tr>
<td>240</td>
<td>6.02</td>
<td>5.46</td>
<td>4.9</td>
<td>4.64</td>
<td>4.5</td>
<td>4.45</td>
</tr>
<tr>
<td>250</td>
<td>6.26</td>
<td>5.18</td>
<td>5.09</td>
<td>4.82</td>
<td>4.68</td>
<td>4.63</td>
</tr>
<tr>
<td>260</td>
<td>6.49</td>
<td>5.39</td>
<td>5.28</td>
<td>5</td>
<td>4.86</td>
<td>4.81</td>
</tr>
<tr>
<td>270</td>
<td>6.72</td>
<td>5.60</td>
<td>5.47</td>
<td>5.19</td>
<td>5.04</td>
<td>5</td>
</tr>
<tr>
<td>280</td>
<td>6.96</td>
<td>6.31</td>
<td>5.66</td>
<td>5.37</td>
<td>5.22</td>
<td>5.19</td>
</tr>
<tr>
<td>290</td>
<td>7.19</td>
<td>6.52</td>
<td>5.85</td>
<td>5.55</td>
<td>5.4</td>
<td>5.37</td>
</tr>
<tr>
<td>300</td>
<td>7.42</td>
<td>6.73</td>
<td>6.03</td>
<td>5.73</td>
<td>5.58</td>
<td>5.56</td>
</tr>
</tbody>
</table>

where:

- \(P\) load = applied load
- \(a/le\) = shear span/ clear span ratio
Table (5.4): Required Tie (3-6) Reinforcement, ($in^2$)

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.15</td>
<td>0.18</td>
<td>0.21</td>
<td>0.24</td>
<td>0.27</td>
<td>0.3</td>
</tr>
<tr>
<td>20</td>
<td>0.3</td>
<td>0.37</td>
<td>0.43</td>
<td>0.49</td>
<td>0.55</td>
<td>0.61</td>
</tr>
<tr>
<td>30</td>
<td>0.46</td>
<td>0.55</td>
<td>0.64</td>
<td>0.74</td>
<td>0.83</td>
<td>0.92</td>
</tr>
<tr>
<td>40</td>
<td>0.61</td>
<td>0.74</td>
<td>0.86</td>
<td>0.99</td>
<td>1.11</td>
<td>1.24</td>
</tr>
<tr>
<td>50</td>
<td>0.77</td>
<td>0.92</td>
<td>1.08</td>
<td>1.24</td>
<td>1.4</td>
<td>1.56</td>
</tr>
<tr>
<td>60</td>
<td>0.92</td>
<td>1.11</td>
<td>1.3</td>
<td>1.5</td>
<td>1.69</td>
<td>1.88</td>
</tr>
<tr>
<td>70</td>
<td>1.08</td>
<td>1.3</td>
<td>1.53</td>
<td>1.75</td>
<td>1.98</td>
<td>2.21</td>
</tr>
<tr>
<td>80</td>
<td>1.24</td>
<td>1.5</td>
<td>1.75</td>
<td>2.01</td>
<td>2.28</td>
<td>2.54</td>
</tr>
<tr>
<td>90</td>
<td>1.4</td>
<td>1.69</td>
<td>1.98</td>
<td>2.28</td>
<td>2.58</td>
<td>2.88</td>
</tr>
<tr>
<td>100</td>
<td>1.56</td>
<td>1.88</td>
<td>2.21</td>
<td>2.54</td>
<td>2.88</td>
<td>3.22</td>
</tr>
<tr>
<td>110</td>
<td>1.72</td>
<td>2.08</td>
<td>2.44</td>
<td>2.81</td>
<td>3.19</td>
<td>3.57</td>
</tr>
<tr>
<td>120</td>
<td>1.88</td>
<td>2.28</td>
<td>2.68</td>
<td>3.08</td>
<td>3.5</td>
<td>3.92</td>
</tr>
<tr>
<td>130</td>
<td>2.05</td>
<td>2.48</td>
<td>2.91</td>
<td>3.36</td>
<td>3.81</td>
<td>4.28</td>
</tr>
<tr>
<td>140</td>
<td>2.21</td>
<td>2.68</td>
<td>3.15</td>
<td>3.64</td>
<td>4.13</td>
<td>4.64</td>
</tr>
<tr>
<td>150</td>
<td>2.38</td>
<td>2.88</td>
<td>3.39</td>
<td>3.92</td>
<td>4.46</td>
<td>5.01</td>
</tr>
<tr>
<td>160</td>
<td>2.54</td>
<td>3.08</td>
<td>3.64</td>
<td>4.2</td>
<td>4.79</td>
<td>5.38</td>
</tr>
<tr>
<td>170</td>
<td>2.71</td>
<td>3.29</td>
<td>3.88</td>
<td>4.49</td>
<td>5.12</td>
<td>5.76</td>
</tr>
<tr>
<td>180</td>
<td>2.88</td>
<td>3.5</td>
<td>4.13</td>
<td>4.79</td>
<td>5.46</td>
<td>6.15</td>
</tr>
<tr>
<td>190</td>
<td>3.05</td>
<td>3.71</td>
<td>4.38</td>
<td>5.08</td>
<td>5.8</td>
<td>6.55</td>
</tr>
<tr>
<td>200</td>
<td>3.22</td>
<td>3.92</td>
<td>4.64</td>
<td>5.38</td>
<td>6.15</td>
<td>6.95</td>
</tr>
<tr>
<td>210</td>
<td>3.39</td>
<td>4.15</td>
<td>4.9</td>
<td>5.69</td>
<td>6.51</td>
<td>7.36</td>
</tr>
<tr>
<td>220</td>
<td>3.57</td>
<td>4.37</td>
<td>5.16</td>
<td>6</td>
<td>6.87</td>
<td>7.78</td>
</tr>
<tr>
<td>230</td>
<td>3.74</td>
<td>4.58</td>
<td>5.42</td>
<td>6.31</td>
<td>7.24</td>
<td>8.21</td>
</tr>
<tr>
<td>240</td>
<td>3.92</td>
<td>4.81</td>
<td>5.69</td>
<td>6.63</td>
<td>7.61</td>
<td>8.65</td>
</tr>
<tr>
<td>250</td>
<td>4.1</td>
<td>5.03</td>
<td>5.96</td>
<td>6.95</td>
<td>8</td>
<td>9.1</td>
</tr>
<tr>
<td>260</td>
<td>4.28</td>
<td>5.26</td>
<td>6.23</td>
<td>7.28</td>
<td>8.39</td>
<td>9.56</td>
</tr>
<tr>
<td>270</td>
<td>4.46</td>
<td>5.49</td>
<td>6.51</td>
<td>7.61</td>
<td>8.78</td>
<td>10.04</td>
</tr>
<tr>
<td>280</td>
<td>4.64</td>
<td>5.72</td>
<td>6.79</td>
<td>7.95</td>
<td>9.19</td>
<td>10.52</td>
</tr>
<tr>
<td>290</td>
<td>4.82</td>
<td>5.95</td>
<td>7.07</td>
<td>8.3</td>
<td>9.61</td>
<td>11.03</td>
</tr>
<tr>
<td>300</td>
<td>5.01</td>
<td>6.19</td>
<td>7.36</td>
<td>8.65</td>
<td>10.04</td>
<td>11.55</td>
</tr>
</tbody>
</table>

where:

- $P_{load}$ = applied load
- $a/le$ = shear span/ clear span ratio
Fig (5.3): From table (5.1), forces in diagonal strut (1-4) against applied load, kips, using first application.
**Fig (5.4):** From table (5.1), forces in diagonal strut (3-6) against applied load, *kips*, using first application.
Fig (5.5): Required area of tie (3-6) reinforcement, $in^2$, against applied load, using first application.
Fig (5.6): Required area of tie (1-3) reinforcement, \( \text{in}^2 \), against applied load, using first application
Table (5.5): Strain in Strut (1-2)

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.01493</td>
<td>0.01049</td>
<td>0.00782</td>
<td>0.006081</td>
<td>0.004892</td>
<td>0.00404</td>
</tr>
<tr>
<td>20</td>
<td>0.01788</td>
<td>0.01266</td>
<td>0.00952</td>
<td>0.007475</td>
<td>0.006079</td>
<td>0.00508</td>
</tr>
<tr>
<td>30</td>
<td>0.02081</td>
<td>0.0148</td>
<td>0.01119</td>
<td>0.008851</td>
<td>0.007249</td>
<td>0.00611</td>
</tr>
<tr>
<td>40</td>
<td>0.0237</td>
<td>0.01692</td>
<td>0.01285</td>
<td>0.010207</td>
<td>0.008402</td>
<td>0.00711</td>
</tr>
<tr>
<td>50</td>
<td>0.01909</td>
<td>0.01352</td>
<td>0.01017</td>
<td>0.008001</td>
<td>0.00652</td>
<td>0.00546</td>
</tr>
<tr>
<td>60</td>
<td>0.02047</td>
<td>0.01452</td>
<td>0.01095</td>
<td>0.008639</td>
<td>0.00706</td>
<td>0.00594</td>
</tr>
<tr>
<td>70</td>
<td>0.02184</td>
<td>0.01552</td>
<td>0.01172</td>
<td>0.009267</td>
<td>0.007592</td>
<td>0.0064</td>
</tr>
<tr>
<td>80</td>
<td>0.02319</td>
<td>0.0165</td>
<td>0.01248</td>
<td>0.009885</td>
<td>0.008115</td>
<td>0.00685</td>
</tr>
<tr>
<td>90</td>
<td>0.02013</td>
<td>0.01424</td>
<td>0.01071</td>
<td>0.008424</td>
<td>0.006868</td>
<td>0.00576</td>
</tr>
<tr>
<td>100</td>
<td>0.02099</td>
<td>0.01486</td>
<td>0.01118</td>
<td>0.008808</td>
<td>0.007191</td>
<td>0.00604</td>
</tr>
<tr>
<td>110</td>
<td>0.02183</td>
<td>0.01546</td>
<td>0.01165</td>
<td>0.009185</td>
<td>0.007509</td>
<td>0.00632</td>
</tr>
<tr>
<td>120</td>
<td>0.02267</td>
<td>0.01606</td>
<td>0.01211</td>
<td>0.009556</td>
<td>0.00782</td>
<td>0.00659</td>
</tr>
<tr>
<td>130</td>
<td>0.02039</td>
<td>0.01438</td>
<td>0.01078</td>
<td>0.008467</td>
<td>0.00689</td>
<td>0.00577</td>
</tr>
<tr>
<td>140</td>
<td>0.02098</td>
<td>0.0148</td>
<td>0.01111</td>
<td>0.008723</td>
<td>0.007104</td>
<td>0.00596</td>
</tr>
<tr>
<td>150</td>
<td>0.02157</td>
<td>0.01522</td>
<td>0.01142</td>
<td>0.008973</td>
<td>0.007313</td>
<td>0.00614</td>
</tr>
<tr>
<td>160</td>
<td>0.02215</td>
<td>0.01562</td>
<td>0.01173</td>
<td>0.009218</td>
<td>0.007516</td>
<td>0.00631</td>
</tr>
<tr>
<td>170</td>
<td>0.02033</td>
<td>0.01428</td>
<td>0.01067</td>
<td>0.008352</td>
<td>0.006777</td>
<td>0.00566</td>
</tr>
<tr>
<td>180</td>
<td>0.02077</td>
<td>0.01459</td>
<td>0.0109</td>
<td>0.00853</td>
<td>0.006923</td>
<td>0.00579</td>
</tr>
<tr>
<td>190</td>
<td>0.0212</td>
<td>0.01488</td>
<td>0.01112</td>
<td>0.008703</td>
<td>0.007065</td>
<td>0.00591</td>
</tr>
<tr>
<td>200</td>
<td>0.02162</td>
<td>0.01517</td>
<td>0.01133</td>
<td>0.008872</td>
<td>0.007203</td>
<td>0.00602</td>
</tr>
<tr>
<td>210</td>
<td>0.02203</td>
<td>0.01546</td>
<td>0.01155</td>
<td>0.009035</td>
<td>0.007336</td>
<td>0.00614</td>
</tr>
<tr>
<td>220</td>
<td>0.02044</td>
<td>0.01429</td>
<td>0.01062</td>
<td>0.008278</td>
<td>0.006689</td>
<td>0.00557</td>
</tr>
<tr>
<td>230</td>
<td>0.02076</td>
<td>0.0145</td>
<td>0.01078</td>
<td>0.008398</td>
<td>0.006785</td>
<td>0.00565</td>
</tr>
<tr>
<td>240</td>
<td>0.02108</td>
<td>0.01472</td>
<td>0.01094</td>
<td>0.008514</td>
<td>0.006877</td>
<td>0.00572</td>
</tr>
<tr>
<td>250</td>
<td>0.02139</td>
<td>0.01492</td>
<td>0.01108</td>
<td>0.008626</td>
<td>0.006965</td>
<td>0.00579</td>
</tr>
<tr>
<td>260</td>
<td>0.02004</td>
<td>0.01393</td>
<td>0.01031</td>
<td>0.007986</td>
<td>0.006418</td>
<td>0.00546</td>
</tr>
<tr>
<td>270</td>
<td>0.02029</td>
<td>0.01409</td>
<td>0.01042</td>
<td>0.008067</td>
<td>0.006479</td>
<td>0.00568</td>
</tr>
<tr>
<td>280</td>
<td>0.02053</td>
<td>0.01425</td>
<td>0.01052</td>
<td>0.008143</td>
<td>0.006537</td>
<td>0.00563</td>
</tr>
<tr>
<td>290</td>
<td>0.02077</td>
<td>0.01444</td>
<td>0.01063</td>
<td>0.008216</td>
<td>0.00659</td>
<td>0.00585</td>
</tr>
<tr>
<td>300</td>
<td>0.0196</td>
<td>0.01354</td>
<td>0.00995</td>
<td>0.007662</td>
<td>0.006115</td>
<td>0.00582</td>
</tr>
</tbody>
</table>

where:
- P load = applied load
- a/le = shear span/ clear span
Table (5.6): Strain in Diagonal Strut (1-4)

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.00239</td>
<td>0.003032</td>
<td>0.00383</td>
<td>0.004764</td>
<td>0.005847</td>
<td>0.00708</td>
</tr>
<tr>
<td>20</td>
<td>0.00345</td>
<td>0.00414</td>
<td>0.00503</td>
<td>0.006111</td>
<td>0.007374</td>
<td>0.00882</td>
</tr>
<tr>
<td>30</td>
<td>0.00346</td>
<td>0.00525</td>
<td>0.00625</td>
<td>0.00747</td>
<td>0.008918</td>
<td>0.01059</td>
</tr>
<tr>
<td>40</td>
<td>0.00416</td>
<td>0.004903</td>
<td>0.00588</td>
<td>0.007079</td>
<td>0.010483</td>
<td>0.0124</td>
</tr>
<tr>
<td>50</td>
<td>0.004</td>
<td>0.005652</td>
<td>0.00671</td>
<td>0.008013</td>
<td>0.009568</td>
<td>0.01138</td>
</tr>
<tr>
<td>60</td>
<td>0.00453</td>
<td>0.005306</td>
<td>0.00634</td>
<td>0.007622</td>
<td>0.010655</td>
<td>0.01264</td>
</tr>
<tr>
<td>70</td>
<td>0.00433</td>
<td>0.005105</td>
<td>0.00698</td>
<td>0.008345</td>
<td>0.009986</td>
<td>0.0119</td>
</tr>
<tr>
<td>80</td>
<td>0.0042</td>
<td>0.005565</td>
<td>0.00665</td>
<td>0.008</td>
<td>0.010838</td>
<td>0.01291</td>
</tr>
<tr>
<td>90</td>
<td>0.00456</td>
<td>0.005365</td>
<td>0.00717</td>
<td>0.008599</td>
<td>0.010318</td>
<td>0.01234</td>
</tr>
<tr>
<td>100</td>
<td>0.00442</td>
<td>0.005753</td>
<td>0.00689</td>
<td>0.008299</td>
<td>0.011032</td>
<td>0.01319</td>
</tr>
<tr>
<td>110</td>
<td>0.00431</td>
<td>0.005564</td>
<td>0.00733</td>
<td>0.008815</td>
<td>0.010614</td>
<td>0.01274</td>
</tr>
<tr>
<td>120</td>
<td>0.00459</td>
<td>0.005903</td>
<td>0.00708</td>
<td>0.008555</td>
<td>0.01124</td>
<td>0.0135</td>
</tr>
<tr>
<td>130</td>
<td>0.00448</td>
<td>0.005727</td>
<td>0.00747</td>
<td>0.009015</td>
<td>0.010896</td>
<td>0.01313</td>
</tr>
<tr>
<td>140</td>
<td>0.0044</td>
<td>0.005595</td>
<td>0.00725</td>
<td>0.008789</td>
<td>0.011461</td>
<td>0.01383</td>
</tr>
<tr>
<td>150</td>
<td>0.00462</td>
<td>0.005866</td>
<td>0.0076</td>
<td>0.009208</td>
<td>0.011716</td>
<td>0.01353</td>
</tr>
<tr>
<td>160</td>
<td>0.00453</td>
<td>0.005741</td>
<td>0.0074</td>
<td>0.009634</td>
<td>0.011699</td>
<td>0.01418</td>
</tr>
<tr>
<td>170</td>
<td>0.00447</td>
<td>0.005989</td>
<td>0.00773</td>
<td>0.0094</td>
<td>0.011462</td>
<td>0.01395</td>
</tr>
<tr>
<td>180</td>
<td>0.00465</td>
<td>0.005872</td>
<td>0.00755</td>
<td>0.009796</td>
<td>0.011955</td>
<td>0.01457</td>
</tr>
<tr>
<td>190</td>
<td>0.00458</td>
<td>0.006102</td>
<td>0.00785</td>
<td>0.009595</td>
<td>0.011758</td>
<td>0.01522</td>
</tr>
<tr>
<td>200</td>
<td>0.00476</td>
<td>0.005992</td>
<td>0.0077</td>
<td>0.009969</td>
<td>0.012232</td>
<td>0.015</td>
</tr>
<tr>
<td>210</td>
<td>0.00469</td>
<td>0.006207</td>
<td>0.00798</td>
<td>0.009797</td>
<td>0.012071</td>
<td>0.01563</td>
</tr>
<tr>
<td>220</td>
<td>0.00463</td>
<td>0.006105</td>
<td>0.00784</td>
<td>0.010154</td>
<td>0.012532</td>
<td>0.01547</td>
</tr>
<tr>
<td>230</td>
<td>0.00478</td>
<td>0.006021</td>
<td>0.00811</td>
<td>0.010007</td>
<td>0.013007</td>
<td>0.0161</td>
</tr>
<tr>
<td>240</td>
<td>0.00473</td>
<td>0.006212</td>
<td>0.00798</td>
<td>0.010353</td>
<td>0.01286</td>
<td>0.01599</td>
</tr>
<tr>
<td>250</td>
<td>0.00487</td>
<td>0.006134</td>
<td>0.00824</td>
<td>0.01023</td>
<td>0.01333</td>
<td>0.01663</td>
</tr>
<tr>
<td>260</td>
<td>0.00482</td>
<td>0.006317</td>
<td>0.00813</td>
<td>0.010568</td>
<td>0.013219</td>
<td>0.01657</td>
</tr>
<tr>
<td>270</td>
<td>0.00477</td>
<td>0.006244</td>
<td>0.00838</td>
<td>0.010466</td>
<td>0.01369</td>
<td>0.01723</td>
</tr>
<tr>
<td>280</td>
<td>0.00449</td>
<td>0.00642</td>
<td>0.00828</td>
<td>0.0108</td>
<td>0.013615</td>
<td>0.01723</td>
</tr>
<tr>
<td>290</td>
<td>0.00485</td>
<td>0.006352</td>
<td>0.00852</td>
<td>0.010719</td>
<td>0.014094</td>
<td>0.01792</td>
</tr>
<tr>
<td>300</td>
<td>0.00498</td>
<td>0.006522</td>
<td>0.00844</td>
<td>0.011054</td>
<td>0.014056</td>
<td>0.01799</td>
</tr>
</tbody>
</table>

where:

- P load = applied load
- a/le= shear span/ clear span
Table (5.7): Stress in Diagonal Strut (1-4), (psi)

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2320.37</td>
<td>2128.51</td>
<td>1930.78</td>
<td>1739.35</td>
<td>1560.78</td>
<td>1398.07</td>
</tr>
<tr>
<td>20</td>
<td>2020.31</td>
<td>1862.05</td>
<td>1691.46</td>
<td>1522.71</td>
<td>1363.53</td>
<td>1217.64</td>
</tr>
<tr>
<td>30</td>
<td>1988.82</td>
<td>1654.36</td>
<td>1504.01</td>
<td>1352.77</td>
<td>1208.91</td>
<td>1076.53</td>
</tr>
<tr>
<td>40</td>
<td>1823.12</td>
<td>1617.41</td>
<td>1425.93</td>
<td>1253.48</td>
<td>1084.42</td>
<td>963.12</td>
</tr>
<tr>
<td>50</td>
<td>1892.84</td>
<td>1590.1</td>
<td>1443.25</td>
<td>1295.02</td>
<td>1153.9</td>
<td>1024.09</td>
</tr>
<tr>
<td>60</td>
<td>1783.64</td>
<td>1645.18</td>
<td>1490.87</td>
<td>1335.99</td>
<td>1072.25</td>
<td>949.37</td>
</tr>
<tr>
<td>70</td>
<td>1823.19</td>
<td>1676.97</td>
<td>1410.05</td>
<td>1261.98</td>
<td>1121.08</td>
<td>991.61</td>
</tr>
<tr>
<td>80</td>
<td>1810.85</td>
<td>1600.49</td>
<td>1404.75</td>
<td>1228.73</td>
<td>1059.64</td>
<td>935.1</td>
</tr>
<tr>
<td>90</td>
<td>1778.18</td>
<td>1635.54</td>
<td>1387.02</td>
<td>1237.98</td>
<td>1096.28</td>
<td>966.26</td>
</tr>
<tr>
<td>100</td>
<td>1805.48</td>
<td>1574.72</td>
<td>1421.04</td>
<td>1266.54</td>
<td>1046.54</td>
<td>920.27</td>
</tr>
<tr>
<td>110</td>
<td>1825.99</td>
<td>1603.76</td>
<td>1368.74</td>
<td>1218.12</td>
<td>1075.09</td>
<td>944.04</td>
</tr>
<tr>
<td>120</td>
<td>1772.43</td>
<td>1552.58</td>
<td>1382.35</td>
<td>1202.43</td>
<td>1032.93</td>
<td>904.83</td>
</tr>
<tr>
<td>130</td>
<td>1792.94</td>
<td>1578.73</td>
<td>1352.97</td>
<td>1200.38</td>
<td>1055.65</td>
<td>923.26</td>
</tr>
<tr>
<td>140</td>
<td>1809.26</td>
<td>1598.92</td>
<td>1377.85</td>
<td>1220.53</td>
<td>1018.76</td>
<td>888.74</td>
</tr>
<tr>
<td>150</td>
<td>1766.38</td>
<td>1557.97</td>
<td>1338.59</td>
<td>1183.73</td>
<td>1037.05</td>
<td>903.06</td>
</tr>
<tr>
<td>160</td>
<td>1782.55</td>
<td>1563.84</td>
<td>1358.56</td>
<td>1148.6</td>
<td>1003.99</td>
<td>871.93</td>
</tr>
<tr>
<td>170</td>
<td>1795.87</td>
<td>1540.01</td>
<td>1324.99</td>
<td>1167.62</td>
<td>1018.74</td>
<td>882.95</td>
</tr>
<tr>
<td>180</td>
<td>1760</td>
<td>1557.1</td>
<td>1343.7</td>
<td>1135.77</td>
<td>988.56</td>
<td>854.32</td>
</tr>
<tr>
<td>190</td>
<td>1773.14</td>
<td>1523.98</td>
<td>1311.79</td>
<td>1151.69</td>
<td>1000.39</td>
<td>826.68</td>
</tr>
<tr>
<td>200</td>
<td>1740.51</td>
<td>1539.62</td>
<td>1328.11</td>
<td>1122.38</td>
<td>972.41</td>
<td>835.84</td>
</tr>
<tr>
<td>210</td>
<td>1737.82</td>
<td>1509.28</td>
<td>1298.75</td>
<td>1115.24</td>
<td>951.39</td>
<td>809.86</td>
</tr>
<tr>
<td>220</td>
<td>1764.14</td>
<td>1523.57</td>
<td>1312.99</td>
<td>1108.39</td>
<td>955.47</td>
<td>816.37</td>
</tr>
<tr>
<td>230</td>
<td>1735.6</td>
<td>1535.43</td>
<td>1285.69</td>
<td>1119.44</td>
<td>929.87</td>
<td>791.64</td>
</tr>
<tr>
<td>240</td>
<td>1746.16</td>
<td>1508.54</td>
<td>1298.09</td>
<td>1093.74</td>
<td>937.66</td>
<td>795.81</td>
</tr>
<tr>
<td>250</td>
<td>1719.63</td>
<td>1495.33</td>
<td>1272.47</td>
<td>1086.04</td>
<td>913.23</td>
<td>771.97</td>
</tr>
<tr>
<td>260</td>
<td>1729.8</td>
<td>1494.23</td>
<td>1283.22</td>
<td>1078.36</td>
<td>918.88</td>
<td>774</td>
</tr>
<tr>
<td>270</td>
<td>1738.64</td>
<td>1504.19</td>
<td>1258.98</td>
<td>1085.61</td>
<td>895.33</td>
<td>750.76</td>
</tr>
<tr>
<td>280</td>
<td>1714.74</td>
<td>1480.42</td>
<td>1268.23</td>
<td>1062.18</td>
<td>899</td>
<td>750.75</td>
</tr>
<tr>
<td>290</td>
<td>1715</td>
<td>1475.63</td>
<td>1245.12</td>
<td>1052.86</td>
<td>876.08</td>
<td>727.82</td>
</tr>
<tr>
<td>300</td>
<td>1700.69</td>
<td>1466.92</td>
<td>1252.99</td>
<td>1045.12</td>
<td>877.89</td>
<td>725.8</td>
</tr>
</tbody>
</table>

where:
- P load = applied load
- a/le= shear span/clear span
Table (5.8): Stress in Strut (1-2), (psi)

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>838.73</td>
<td>1083.74</td>
<td>1315.28</td>
<td>1526.9</td>
<td>1716.08</td>
<td>1882.86</td>
</tr>
<tr>
<td>20</td>
<td>729.14</td>
<td>948.43</td>
<td>1158.22</td>
<td>1352.13</td>
<td>1527.22</td>
<td>1682.93</td>
</tr>
<tr>
<td>30</td>
<td>645.63</td>
<td>844.23</td>
<td>1036.06</td>
<td>1214.94</td>
<td>1377.74</td>
<td>1523.52</td>
</tr>
<tr>
<td>40</td>
<td>579.9</td>
<td>761.54</td>
<td>938.36</td>
<td>1104.42</td>
<td>1256.52</td>
<td>1393.48</td>
</tr>
<tr>
<td>50</td>
<td>692.26</td>
<td>903.83</td>
<td>1107.32</td>
<td>1296.17</td>
<td>1467.25</td>
<td>1619.73</td>
</tr>
<tr>
<td>60</td>
<td>654.26</td>
<td>856.56</td>
<td>1052.04</td>
<td>1234.22</td>
<td>1399.85</td>
<td>1547.92</td>
</tr>
<tr>
<td>70</td>
<td>620.56</td>
<td>814.5</td>
<td>1002.7</td>
<td>1178.75</td>
<td>1339.33</td>
<td>1483.28</td>
</tr>
<tr>
<td>80</td>
<td>590.5</td>
<td>776.86</td>
<td>958.39</td>
<td>1128.81</td>
<td>1284.71</td>
<td>1424.81</td>
</tr>
<tr>
<td>90</td>
<td>663.19</td>
<td>869.41</td>
<td>1068.74</td>
<td>1254.45</td>
<td>1423.1</td>
<td>1573.64</td>
</tr>
<tr>
<td>100</td>
<td>641.06</td>
<td>841.99</td>
<td>1036.81</td>
<td>1218.78</td>
<td>1384.4</td>
<td>1532.5</td>
</tr>
<tr>
<td>110</td>
<td>620.6</td>
<td>816.61</td>
<td>1007.21</td>
<td>1185.68</td>
<td>1348.44</td>
<td>1494.22</td>
</tr>
<tr>
<td>120</td>
<td>601.63</td>
<td>793.06</td>
<td>979.7</td>
<td>1154.88</td>
<td>1314.96</td>
<td>1458.55</td>
</tr>
<tr>
<td>130</td>
<td>656.33</td>
<td>863</td>
<td>1063.38</td>
<td>1250.38</td>
<td>1420.33</td>
<td>1572</td>
</tr>
<tr>
<td>140</td>
<td>641.15</td>
<td>844.37</td>
<td>1041.86</td>
<td>1226.54</td>
<td>1394.64</td>
<td>1544.85</td>
</tr>
<tr>
<td>150</td>
<td>626.85</td>
<td>826.81</td>
<td>1021.58</td>
<td>1204.06</td>
<td>1370.43</td>
<td>1519.26</td>
</tr>
<tr>
<td>160</td>
<td>613.36</td>
<td>810.24</td>
<td>1002.45</td>
<td>1182.87</td>
<td>1347.6</td>
<td>1495.15</td>
</tr>
<tr>
<td>170</td>
<td>657.85</td>
<td>867.39</td>
<td>1071.05</td>
<td>1261.36</td>
<td>1434.36</td>
<td>1588.68</td>
</tr>
<tr>
<td>180</td>
<td>646.61</td>
<td>853.78</td>
<td>1055.54</td>
<td>1244.4</td>
<td>1416.32</td>
<td>1569.83</td>
</tr>
<tr>
<td>190</td>
<td>632.92</td>
<td>840.83</td>
<td>1040.81</td>
<td>1228.32</td>
<td>1399.24</td>
<td>1552.01</td>
</tr>
<tr>
<td>200</td>
<td>625.73</td>
<td>828.51</td>
<td>1026.82</td>
<td>1213.07</td>
<td>1383.07</td>
<td>1535.19</td>
</tr>
<tr>
<td>210</td>
<td>616.01</td>
<td>816.79</td>
<td>1013.53</td>
<td>1198.61</td>
<td>1367.78</td>
<td>1519.33</td>
</tr>
<tr>
<td>220</td>
<td>655.04</td>
<td>867.24</td>
<td>1074.41</td>
<td>1268.57</td>
<td>1445.38</td>
<td>1603.24</td>
</tr>
<tr>
<td>230</td>
<td>646.75</td>
<td>857.41</td>
<td>1063.48</td>
<td>1256.92</td>
<td>1433.32</td>
<td>1590.98</td>
</tr>
<tr>
<td>240</td>
<td>638.81</td>
<td>848.03</td>
<td>1053.08</td>
<td>1245.89</td>
<td>1421.95</td>
<td>1579.51</td>
</tr>
<tr>
<td>250</td>
<td>631.2</td>
<td>839.06</td>
<td>1043.18</td>
<td>1235.45</td>
<td>1411.27</td>
<td>1568.81</td>
</tr>
<tr>
<td>260</td>
<td>665.5</td>
<td>883.64</td>
<td>1097.22</td>
<td>1297.77</td>
<td>1480.63</td>
<td>1620.08</td>
</tr>
<tr>
<td>270</td>
<td>658.96</td>
<td>876.12</td>
<td>1089.16</td>
<td>1289.54</td>
<td>1472.53</td>
<td>1586.48</td>
</tr>
<tr>
<td>280</td>
<td>652.68</td>
<td>868.94</td>
<td>1081.51</td>
<td>1281.82</td>
<td>1465.04</td>
<td>1594.22</td>
</tr>
<tr>
<td>290</td>
<td>646.64</td>
<td>862.08</td>
<td>1074.28</td>
<td>1274.6</td>
<td>1458.16</td>
<td>1560.96</td>
</tr>
<tr>
<td>300</td>
<td>677.59</td>
<td>902.54</td>
<td>1123.59</td>
<td>1331.76</td>
<td>1522.13</td>
<td>1565.53</td>
</tr>
</tbody>
</table>

where:
- P load = applied load
- a/le= shear span/ clear span
Table (5.9): Stress in Short Strut Node Directly under Point of Applied Load, \((\text{psi})\)

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5006.75</td>
<td>5014.42</td>
<td>5019.66</td>
<td>5023.21</td>
<td>5025.55</td>
<td>5027</td>
</tr>
<tr>
<td>20</td>
<td>1912.66</td>
<td>4970.83</td>
<td>4975.59</td>
<td>4979.2</td>
<td>4981.72</td>
<td>4983.32</td>
</tr>
<tr>
<td>30</td>
<td>3613.29</td>
<td>3621.1</td>
<td>1921.78</td>
<td>1918.46</td>
<td>1916.51</td>
<td>1915.41</td>
</tr>
<tr>
<td>40</td>
<td>2823.01</td>
<td>1904.08</td>
<td>1897.06</td>
<td>3612.38</td>
<td>3614.46</td>
<td>3615.92</td>
</tr>
<tr>
<td>50</td>
<td>1885.47</td>
<td>2823.21</td>
<td>1919.44</td>
<td>1911.92</td>
<td>1907.59</td>
<td>1905.19</td>
</tr>
<tr>
<td>60</td>
<td>1844.63</td>
<td>1895.92</td>
<td>1881.23</td>
<td>1939.01</td>
<td>1931.96</td>
<td>1928.06</td>
</tr>
<tr>
<td>70</td>
<td>1991.46</td>
<td>2336.01</td>
<td>1910.03</td>
<td>1897.29</td>
<td>1890.02</td>
<td>1886.08</td>
</tr>
<tr>
<td>80</td>
<td>1748.64</td>
<td>1885.23</td>
<td>1861.31</td>
<td>1928.76</td>
<td>1918.37</td>
<td>1912.74</td>
</tr>
<tr>
<td>90</td>
<td>1785.08</td>
<td>1927.76</td>
<td>1895.03</td>
<td>1967.11</td>
<td>1953.25</td>
<td>1945.78</td>
</tr>
<tr>
<td>100</td>
<td>1566.68</td>
<td>1872.78</td>
<td>1935.43</td>
<td>1911.24</td>
<td>1897.46</td>
<td>1984.9</td>
</tr>
<tr>
<td>110</td>
<td>1540.91</td>
<td>1815.97</td>
<td>1876.18</td>
<td>1951.69</td>
<td>1934.39</td>
<td>1925.31</td>
</tr>
<tr>
<td>120</td>
<td>1426.37</td>
<td>1596.39</td>
<td>1918.79</td>
<td>1888.73</td>
<td>1976.5</td>
<td>1965.6</td>
</tr>
<tr>
<td>130</td>
<td>1395.51</td>
<td>1644.24</td>
<td>1673.52</td>
<td>1930.31</td>
<td>2023.48</td>
<td>2010.75</td>
</tr>
<tr>
<td>140</td>
<td>1381.4</td>
<td>1512.14</td>
<td>1635.46</td>
<td>1976.25</td>
<td>1660</td>
<td>1648.39</td>
</tr>
<tr>
<td>150</td>
<td>1306.33</td>
<td>1406.62</td>
<td>1575.16</td>
<td>1641.82</td>
<td>1704.65</td>
<td>1691.64</td>
</tr>
<tr>
<td>160</td>
<td>1297.5</td>
<td>1451.75</td>
<td>1543.16</td>
<td>1579.22</td>
<td>1554.12</td>
<td>1620.39</td>
</tr>
<tr>
<td>170</td>
<td>1346.02</td>
<td>1427.03</td>
<td>1501.68</td>
<td>1625.44</td>
<td>1597.55</td>
<td>1668.56</td>
</tr>
<tr>
<td>180</td>
<td>1287.9</td>
<td>1408</td>
<td>1548.8</td>
<td>1500.63</td>
<td>1547.63</td>
<td>1533.74</td>
</tr>
<tr>
<td>190</td>
<td>1238.94</td>
<td>1393.01</td>
<td>1446.01</td>
<td>1545.13</td>
<td>1515.99</td>
<td>1579.96</td>
</tr>
<tr>
<td>200</td>
<td>1197.27</td>
<td>1376</td>
<td>1422.03</td>
<td>1440.28</td>
<td>1480.67</td>
<td>1467.18</td>
</tr>
<tr>
<td>210</td>
<td>1193.98</td>
<td>1310.19</td>
<td>1403.27</td>
<td>1483</td>
<td>1525.56</td>
<td>1511.6</td>
</tr>
<tr>
<td>220</td>
<td>1249.15</td>
<td>1306.71</td>
<td>1446.73</td>
<td>1459.67</td>
<td>1498.32</td>
<td>1484.39</td>
</tr>
<tr>
<td>230</td>
<td>1213.13</td>
<td>1349.41</td>
<td>1433.32</td>
<td>1504.36</td>
<td>1471.25</td>
<td>1531.3</td>
</tr>
<tr>
<td>240</td>
<td>1209.91</td>
<td>1294.48</td>
<td>1411.57</td>
<td>1418.52</td>
<td>1452.53</td>
<td>1440.05</td>
</tr>
<tr>
<td>250</td>
<td>1179.38</td>
<td>1335.48</td>
<td>1403.62</td>
<td>1460.95</td>
<td>1428.13</td>
<td>1426.31</td>
</tr>
<tr>
<td>260</td>
<td>1192.39</td>
<td>1338.26</td>
<td>1446.31</td>
<td>1449.38</td>
<td>1415.84</td>
<td>1471.63</td>
</tr>
<tr>
<td>270</td>
<td>1231.39</td>
<td>1324.9</td>
<td>1379.58</td>
<td>1425.75</td>
<td>1458.21</td>
<td>1397.22</td>
</tr>
<tr>
<td>280</td>
<td>1203.28</td>
<td>1329.86</td>
<td>1420.06</td>
<td>1418.81</td>
<td>1449.55</td>
<td>1440.72</td>
</tr>
<tr>
<td>290</td>
<td>1199.67</td>
<td>1285.7</td>
<td>1359.82</td>
<td>1396.88</td>
<td>1426.63</td>
<td>1374.57</td>
</tr>
<tr>
<td>300</td>
<td>1213.96</td>
<td>1323.28</td>
<td>1398.21</td>
<td>1455.54</td>
<td>1422.11</td>
<td>1416.53</td>
</tr>
</tbody>
</table>

where:

- \( P \text{ load} \) = applied load
- \( a/le \) = shear span/ clear span
Table (5.10): Stress in Short Strut at Centerline at Support, (psi)

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>a/le 0.25</th>
<th>a/le 0.30</th>
<th>a/le 0.35</th>
<th>a/le 0.40</th>
<th>a/le 0.45</th>
<th>a/le 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>73.76</td>
<td>86.4</td>
<td>101.17</td>
<td>118.01</td>
<td>136.83</td>
<td>157.53</td>
</tr>
<tr>
<td>20</td>
<td>146.02</td>
<td>170.28</td>
<td>198.38</td>
<td>230.03</td>
<td>264.93</td>
<td>302.75</td>
</tr>
<tr>
<td>30</td>
<td>216.81</td>
<td>251.75</td>
<td>291.83</td>
<td>336.46</td>
<td>385.04</td>
<td>436.94</td>
</tr>
<tr>
<td>40</td>
<td>286.15</td>
<td>330.88</td>
<td>381.69</td>
<td>437.66</td>
<td>497.83</td>
<td>561.25</td>
</tr>
<tr>
<td>50</td>
<td>354.09</td>
<td>407.75</td>
<td>468.14</td>
<td>533.96</td>
<td>603.88</td>
<td>676.66</td>
</tr>
<tr>
<td>60</td>
<td>420.64</td>
<td>482.44</td>
<td>551.34</td>
<td>625.66</td>
<td>703.73</td>
<td>784.01</td>
</tr>
<tr>
<td>70</td>
<td>485.83</td>
<td>555</td>
<td>631.43</td>
<td>713.04</td>
<td>797.85</td>
<td>884.06</td>
</tr>
<tr>
<td>80</td>
<td>549.7</td>
<td>625.52</td>
<td>708.56</td>
<td>796.37</td>
<td>886.66</td>
<td>977.45</td>
</tr>
<tr>
<td>90</td>
<td>612.27</td>
<td>694.05</td>
<td>782.86</td>
<td>875.87</td>
<td>970.56</td>
<td>1064.78</td>
</tr>
<tr>
<td>100</td>
<td>673.56</td>
<td>760.65</td>
<td>854.44</td>
<td>951.77</td>
<td>1049.88</td>
<td>1146.56</td>
</tr>
<tr>
<td>110</td>
<td>733.61</td>
<td>825.4</td>
<td>923.43</td>
<td>1024.26</td>
<td>1124.96</td>
<td>1223.23</td>
</tr>
<tr>
<td>120</td>
<td>792.43</td>
<td>888.33</td>
<td>989.94</td>
<td>1093.53</td>
<td>1196.06</td>
<td>1295.22</td>
</tr>
<tr>
<td>130</td>
<td>850.05</td>
<td>949.52</td>
<td>1054.06</td>
<td>1159.75</td>
<td>1263.46</td>
<td>1362.88</td>
</tr>
<tr>
<td>140</td>
<td>906.49</td>
<td>1009</td>
<td>1115.9</td>
<td>1223.09</td>
<td>1327.39</td>
<td>1426.54</td>
</tr>
<tr>
<td>150</td>
<td>961.78</td>
<td>1066.82</td>
<td>1175.55</td>
<td>1283.7</td>
<td>1388.07</td>
<td>1486.51</td>
</tr>
<tr>
<td>160</td>
<td>1015.93</td>
<td>1123.05</td>
<td>1233.09</td>
<td>1341.7</td>
<td>1445.7</td>
<td>1543.04</td>
</tr>
<tr>
<td>170</td>
<td>1068.97</td>
<td>1177.71</td>
<td>1288.62</td>
<td>1397.24</td>
<td>1500.46</td>
<td>1596.37</td>
</tr>
<tr>
<td>180</td>
<td>1120.92</td>
<td>1230.86</td>
<td>1342.19</td>
<td>1450.42</td>
<td>1552.52</td>
<td>1646.73</td>
</tr>
<tr>
<td>190</td>
<td>1171.8</td>
<td>1282.54</td>
<td>1393.89</td>
<td>1501.37</td>
<td>1602.05</td>
<td>1694.31</td>
</tr>
<tr>
<td>200</td>
<td>1221.62</td>
<td>1332.78</td>
<td>1443.79</td>
<td>1550.19</td>
<td>1649.17</td>
<td>1739.29</td>
</tr>
<tr>
<td>210</td>
<td>1270.4</td>
<td>1381.63</td>
<td>1491.95</td>
<td>1596.97</td>
<td>1694.02</td>
<td>1781.84</td>
</tr>
<tr>
<td>220</td>
<td>1318.18</td>
<td>1429.12</td>
<td>1538.44</td>
<td>1641.81</td>
<td>1736.73</td>
<td>1822.11</td>
</tr>
<tr>
<td>230</td>
<td>1364.95</td>
<td>1475.29</td>
<td>1583.31</td>
<td>1684.8</td>
<td>1777.41</td>
<td>1860.24</td>
</tr>
<tr>
<td>240</td>
<td>1410.74</td>
<td>1520.17</td>
<td>1626.62</td>
<td>1726</td>
<td>1816.15</td>
<td>1896.35</td>
</tr>
<tr>
<td>250</td>
<td>1455.57</td>
<td>1563.8</td>
<td>1668.42</td>
<td>1765.51</td>
<td>1853.07</td>
<td>1930.57</td>
</tr>
<tr>
<td>260</td>
<td>1499.44</td>
<td>1606.2</td>
<td>1708.77</td>
<td>1803.38</td>
<td>1888.25</td>
<td>1962.99</td>
</tr>
<tr>
<td>270</td>
<td>1542.39</td>
<td>1647.41</td>
<td>1747.71</td>
<td>1839.7</td>
<td>1921.77</td>
<td>1993.72</td>
</tr>
<tr>
<td>280</td>
<td>1584.41</td>
<td>1687.45</td>
<td>1785.29</td>
<td>1874.51</td>
<td>1953.71</td>
<td>2022.85</td>
</tr>
<tr>
<td>290</td>
<td>1625.54</td>
<td>1726.36</td>
<td>1821.55</td>
<td>1907.88</td>
<td>1984.14</td>
<td>2050.46</td>
</tr>
<tr>
<td>300</td>
<td>1665.77</td>
<td>1764.16</td>
<td>1856.53</td>
<td>1939.86</td>
<td>2013.14</td>
<td>2076.63</td>
</tr>
</tbody>
</table>

where:

- P load = applied load
- a/le= shear span/ clear span
Fig (5.7): Strain in tie (1-2) against applied load, using first application
Fig (5.8): Strain in diagonal strut (1-4) against applied load, using first application.
Fig (5.9): **Stress in diagonal Strut (1-4), in, (psi) against applied load in (kips) using first application.**

**Note:** The stresses in strut (1-4) relation-ship are nonlinear and shaped is zigzag line and here in fig (5.10) nonlinear soft line because used to study the shape of relation-ship of this stress.
Fig (5.10): Stress in strut (1-2) in, (psi) against applied load in (kips) using first application.

Note: The stress in strut (1-2) relation-ship is nonlinear and shaped is zigzag line and here in fig (5.11) nonlinear soft line because used to study the shape of relation-ship of this stress
Fig (5.11): Stress in short strut directly under point of applied load in, \((psi)\) against applied load in \((kips)\) using first application.

Note: The stress in short Strut relationship is nonlinear and shaped is zigzag line and here in fig (5.11) nonlinear soft line because used to study the shape of relation-ship of this stress.
Fig (5.12): **Stress in short Strut at Centerline support in, (psi) against applied load in (kips)** using first application.

Note: The stress in short Strut at Centerline support in Fig (5.13), relation-ship is nonlinear and real shaped
5.13.2 The results of program for first application used, see Table (5.0)

➢ Table (5.11): Force in Diagonal Strut (1-4), (in²)

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>Le/d 3</th>
<th>Le/d 3.5</th>
<th>Le/d 4</th>
<th>Le/d 4.5</th>
<th>Le/d 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>24</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>48</td>
<td>29</td>
<td>23</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>30</td>
<td>71</td>
<td>44</td>
<td>35</td>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>40</td>
<td>95</td>
<td>58</td>
<td>46</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td>50</td>
<td>118</td>
<td>72</td>
<td>57</td>
<td>47</td>
<td>39</td>
</tr>
<tr>
<td>60</td>
<td>141</td>
<td>86</td>
<td>68</td>
<td>56</td>
<td>47</td>
</tr>
<tr>
<td>70</td>
<td>164</td>
<td>99</td>
<td>79</td>
<td>64</td>
<td>54</td>
</tr>
<tr>
<td>80</td>
<td>187</td>
<td>113</td>
<td>89</td>
<td>73</td>
<td>60</td>
</tr>
<tr>
<td>90</td>
<td>210</td>
<td>126</td>
<td>99</td>
<td>81</td>
<td>67</td>
</tr>
<tr>
<td>100</td>
<td>232</td>
<td>139</td>
<td>110</td>
<td>89</td>
<td>73</td>
</tr>
<tr>
<td>110</td>
<td>255</td>
<td>152</td>
<td>119</td>
<td>96</td>
<td>79</td>
</tr>
<tr>
<td>120</td>
<td>277</td>
<td>165</td>
<td>129</td>
<td>104</td>
<td>85</td>
</tr>
<tr>
<td>130</td>
<td>299</td>
<td>177</td>
<td>139</td>
<td>111</td>
<td>91</td>
</tr>
<tr>
<td>140</td>
<td>320</td>
<td>190</td>
<td>148</td>
<td>118</td>
<td>96</td>
</tr>
<tr>
<td>150</td>
<td>342</td>
<td>202</td>
<td>157</td>
<td>125</td>
<td>101</td>
</tr>
<tr>
<td>160</td>
<td>363</td>
<td>214</td>
<td>166</td>
<td>131</td>
<td>106</td>
</tr>
<tr>
<td>170</td>
<td>384</td>
<td>225</td>
<td>174</td>
<td>138</td>
<td>110</td>
</tr>
<tr>
<td>180</td>
<td>405</td>
<td>237</td>
<td>183</td>
<td>144</td>
<td>114</td>
</tr>
<tr>
<td>190</td>
<td>426</td>
<td>248</td>
<td>191</td>
<td>149</td>
<td>117</td>
</tr>
<tr>
<td>200</td>
<td>447</td>
<td>259</td>
<td>199</td>
<td>155</td>
<td>121</td>
</tr>
<tr>
<td>210</td>
<td>467</td>
<td>270</td>
<td>206</td>
<td>160</td>
<td>123</td>
</tr>
<tr>
<td>220</td>
<td>488</td>
<td>281</td>
<td>214</td>
<td>165</td>
<td>126</td>
</tr>
<tr>
<td>230</td>
<td>508</td>
<td>291</td>
<td>221</td>
<td>169</td>
<td>127</td>
</tr>
<tr>
<td>240</td>
<td>528</td>
<td>302</td>
<td>228</td>
<td>173</td>
<td>128</td>
</tr>
<tr>
<td>250</td>
<td>547</td>
<td>312</td>
<td>234</td>
<td>177</td>
<td>128</td>
</tr>
<tr>
<td>260</td>
<td>567</td>
<td>321</td>
<td>241</td>
<td>180</td>
<td>127</td>
</tr>
<tr>
<td>270</td>
<td>586</td>
<td>331</td>
<td>247</td>
<td>183</td>
<td>124</td>
</tr>
<tr>
<td>280</td>
<td>605</td>
<td>340</td>
<td>252</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>624</td>
<td>349</td>
<td>258</td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>643</td>
<td>358</td>
<td>263</td>
<td>189</td>
<td></td>
</tr>
</tbody>
</table>

where: P load = applied load    Le/d= span depth ratio
Table (5.12): Force in Tie (1-3), *(kips)*

<table>
<thead>
<tr>
<th>P Load (kips)</th>
<th>Le/d 3</th>
<th>Le/d 3.5</th>
<th>Le/d 4</th>
<th>Le/d 4.5</th>
<th>Le/d 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.31</td>
<td>5.56</td>
<td>5.74</td>
<td>5.96</td>
<td>6.2</td>
</tr>
<tr>
<td>20</td>
<td>10.62</td>
<td>11.13</td>
<td>11.5</td>
<td>11.94</td>
<td>12.43</td>
</tr>
<tr>
<td>30</td>
<td>15.94</td>
<td>16.71</td>
<td>17.28</td>
<td>17.95</td>
<td>18.71</td>
</tr>
<tr>
<td>40</td>
<td>21.26</td>
<td>22.29</td>
<td>23.07</td>
<td>23.98</td>
<td>25.04</td>
</tr>
<tr>
<td>50</td>
<td>26.58</td>
<td>27.89</td>
<td>28.88</td>
<td>30.05</td>
<td>31.41</td>
</tr>
<tr>
<td>60</td>
<td>31.9</td>
<td>33.5</td>
<td>34.7</td>
<td>36.14</td>
<td>37.84</td>
</tr>
<tr>
<td>70</td>
<td>37.23</td>
<td>39.11</td>
<td>40.55</td>
<td>42.27</td>
<td>44.32</td>
</tr>
<tr>
<td>80</td>
<td>42.56</td>
<td>44.74</td>
<td>46.41</td>
<td>48.44</td>
<td>50.87</td>
</tr>
<tr>
<td>90</td>
<td>47.89</td>
<td>50.37</td>
<td>52.3</td>
<td>54.64</td>
<td>57.48</td>
</tr>
<tr>
<td>100</td>
<td>53.23</td>
<td>56.02</td>
<td>58.2</td>
<td>60.88</td>
<td>64.16</td>
</tr>
<tr>
<td>110</td>
<td>58.57</td>
<td>61.68</td>
<td>64.13</td>
<td>67.16</td>
<td>70.92</td>
</tr>
<tr>
<td>120</td>
<td>63.91</td>
<td>67.35</td>
<td>70.08</td>
<td>73.49</td>
<td>77.77</td>
</tr>
<tr>
<td>130</td>
<td>69.25</td>
<td>73.03</td>
<td>76.05</td>
<td>79.86</td>
<td>84.71</td>
</tr>
<tr>
<td>140</td>
<td>74.6</td>
<td>78.73</td>
<td>82.05</td>
<td>86.29</td>
<td>91.76</td>
</tr>
<tr>
<td>150</td>
<td>79.95</td>
<td>84.43</td>
<td>88.08</td>
<td>92.77</td>
<td>98.92</td>
</tr>
<tr>
<td>160</td>
<td>85.31</td>
<td>90.15</td>
<td>94.14</td>
<td>99.32</td>
<td>106.23</td>
</tr>
<tr>
<td>170</td>
<td>90.66</td>
<td>95.89</td>
<td>100.22</td>
<td>105.93</td>
<td>113.68</td>
</tr>
<tr>
<td>180</td>
<td>96.02</td>
<td>101.64</td>
<td>106.34</td>
<td>112.61</td>
<td>121.31</td>
</tr>
<tr>
<td>190</td>
<td>101.39</td>
<td>107.4</td>
<td>112.49</td>
<td>119.36</td>
<td>129.14</td>
</tr>
<tr>
<td>200</td>
<td>106.76</td>
<td>113.18</td>
<td>118.68</td>
<td>126.21</td>
<td>137.2</td>
</tr>
<tr>
<td>210</td>
<td>112.13</td>
<td>118.98</td>
<td>124.9</td>
<td>133.14</td>
<td>145.56</td>
</tr>
<tr>
<td>220</td>
<td>117.5</td>
<td>124.79</td>
<td>131.17</td>
<td>140.19</td>
<td>154.26</td>
</tr>
<tr>
<td>230</td>
<td>122.88</td>
<td>130.62</td>
<td>137.48</td>
<td>147.35</td>
<td>163.4</td>
</tr>
<tr>
<td>240</td>
<td>128.27</td>
<td>136.47</td>
<td>143.83</td>
<td>154.64</td>
<td>173.12</td>
</tr>
<tr>
<td>250</td>
<td>133.65</td>
<td>142.33</td>
<td>150.24</td>
<td>162.08</td>
<td>183.64</td>
</tr>
<tr>
<td>260</td>
<td>139.04</td>
<td>148.22</td>
<td>156.69</td>
<td>169.7</td>
<td>195.35</td>
</tr>
<tr>
<td>270</td>
<td>144.44</td>
<td>154.13</td>
<td>163.21</td>
<td>177.52</td>
<td>209.16</td>
</tr>
<tr>
<td>280</td>
<td>149.84</td>
<td>160.06</td>
<td>169.79</td>
<td>185.57</td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>155.24</td>
<td>166.01</td>
<td>176.43</td>
<td>193.91</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>160.65</td>
<td>171.99</td>
<td>183.15</td>
<td>202.6</td>
<td></td>
</tr>
</tbody>
</table>

where:

- \( p \) load = applied load
- \( Le/d \) = span depth ratio
Table (5.13): Area of Reinforcement of Tie(1-3), \( \text{in}^2 \)

<table>
<thead>
<tr>
<th>Load ( (\text{kips}) )</th>
<th>( \frac{L_e}{d} ) 3</th>
<th>( \frac{L_e}{d} ) 3.5</th>
<th>( \frac{L_e}{d} ) 4</th>
<th>( \frac{L_e}{d} ) 4.5</th>
<th>( \frac{L_e}{d} ) 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.29</td>
<td>0.24</td>
<td>0.22</td>
<td>0.2</td>
<td>0.19</td>
</tr>
<tr>
<td>20</td>
<td>0.58</td>
<td>0.47</td>
<td>0.43</td>
<td>0.4</td>
<td>0.39</td>
</tr>
<tr>
<td>30</td>
<td>0.87</td>
<td>0.7</td>
<td>0.64</td>
<td>0.61</td>
<td>0.58</td>
</tr>
<tr>
<td>40</td>
<td>1.16</td>
<td>0.93</td>
<td>0.86</td>
<td>0.8</td>
<td>0.77</td>
</tr>
<tr>
<td>50</td>
<td>1.45</td>
<td>1.17</td>
<td>1.07</td>
<td>1</td>
<td>0.96</td>
</tr>
<tr>
<td>60</td>
<td>1.74</td>
<td>1.39</td>
<td>1.28</td>
<td>1.2</td>
<td>1.15</td>
</tr>
<tr>
<td>70</td>
<td>2.02</td>
<td>1.62</td>
<td>1.49</td>
<td>1.4</td>
<td>1.34</td>
</tr>
<tr>
<td>80</td>
<td>2.31</td>
<td>1.85</td>
<td>1.69</td>
<td>1.59</td>
<td>1.52</td>
</tr>
<tr>
<td>90</td>
<td>2.59</td>
<td>2.08</td>
<td>1.9</td>
<td>1.78</td>
<td>1.71</td>
</tr>
<tr>
<td>100</td>
<td>2.87</td>
<td>2.3</td>
<td>2.11</td>
<td>1.98</td>
<td>1.9</td>
</tr>
<tr>
<td>110</td>
<td>3.16</td>
<td>2.52</td>
<td>2.31</td>
<td>2.17</td>
<td>2.08</td>
</tr>
<tr>
<td>120</td>
<td>3.44</td>
<td>2.75</td>
<td>2.51</td>
<td>2.36</td>
<td>2.26</td>
</tr>
<tr>
<td>130</td>
<td>3.72</td>
<td>2.97</td>
<td>2.71</td>
<td>2.55</td>
<td>2.45</td>
</tr>
<tr>
<td>140</td>
<td>4</td>
<td>3.19</td>
<td>2.91</td>
<td>2.73</td>
<td>2.63</td>
</tr>
<tr>
<td>150</td>
<td>4.27</td>
<td>3.4</td>
<td>3.11</td>
<td>2.92</td>
<td>2.81</td>
</tr>
<tr>
<td>160</td>
<td>4.55</td>
<td>3.62</td>
<td>3.31</td>
<td>3.1</td>
<td>2.99</td>
</tr>
<tr>
<td>170</td>
<td>4.83</td>
<td>3.84</td>
<td>3.5</td>
<td>3.29</td>
<td>3.17</td>
</tr>
<tr>
<td>180</td>
<td>5.1</td>
<td>4.05</td>
<td>3.7</td>
<td>3.47</td>
<td>3.35</td>
</tr>
<tr>
<td>190</td>
<td>5.37</td>
<td>4.26</td>
<td>3.89</td>
<td>3.65</td>
<td>3.53</td>
</tr>
<tr>
<td>200</td>
<td>5.65</td>
<td>4.48</td>
<td>4.08</td>
<td>3.83</td>
<td>3.71</td>
</tr>
<tr>
<td>210</td>
<td>5.92</td>
<td>4.69</td>
<td>4.27</td>
<td>4.01</td>
<td>3.89</td>
</tr>
<tr>
<td>220</td>
<td>6.19</td>
<td>4.89</td>
<td>4.46</td>
<td>4.19</td>
<td>4.07</td>
</tr>
<tr>
<td>230</td>
<td>6.46</td>
<td>5.1</td>
<td>4.65</td>
<td>4.36</td>
<td>4.26</td>
</tr>
<tr>
<td>240</td>
<td>6.73</td>
<td>5.31</td>
<td>4.83</td>
<td>4.54</td>
<td>4.45</td>
</tr>
<tr>
<td>250</td>
<td>6.99</td>
<td>5.51</td>
<td>5.02</td>
<td>4.72</td>
<td>4.64</td>
</tr>
<tr>
<td>260</td>
<td>7.26</td>
<td>5.71</td>
<td>5.2</td>
<td>4.89</td>
<td>4.85</td>
</tr>
<tr>
<td>270</td>
<td>7.52</td>
<td>5.92</td>
<td>5.38</td>
<td>5.06</td>
<td>5.07</td>
</tr>
<tr>
<td>280</td>
<td>7.79</td>
<td>6.12</td>
<td>5.56</td>
<td>5.24</td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>8.05</td>
<td>6.31</td>
<td>5.74</td>
<td>5.41</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>8.31</td>
<td>6.51</td>
<td>5.91</td>
<td>5.58</td>
<td></td>
</tr>
</tbody>
</table>

where:

\( P \text{ load} = \text{applied load} \)

\( \frac{L_e}{d} = \text{span depth ratio} \)
Table (5.14): Area of Reinforcement of Tie (3-6), \((in^2)\).

<table>
<thead>
<tr>
<th>(P) Load (kips)</th>
<th>(Le/d) 3</th>
<th>(Le/d) 3.5</th>
<th>(Le/d) 4</th>
<th>(Le/d) 4.5</th>
<th>(Le/d) 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.13</td>
<td>0.18</td>
<td>0.21</td>
<td>0.24</td>
<td>0.27</td>
</tr>
<tr>
<td>20</td>
<td>0.27</td>
<td>0.36</td>
<td>0.42</td>
<td>0.48</td>
<td>0.55</td>
</tr>
<tr>
<td>30</td>
<td>0.4</td>
<td>0.54</td>
<td>0.64</td>
<td>0.73</td>
<td>0.83</td>
</tr>
<tr>
<td>40</td>
<td>0.53</td>
<td>0.73</td>
<td>0.85</td>
<td>0.98</td>
<td>1.12</td>
</tr>
<tr>
<td>50</td>
<td>0.67</td>
<td>0.92</td>
<td>1.07</td>
<td>1.23</td>
<td>1.41</td>
</tr>
<tr>
<td>60</td>
<td>0.8</td>
<td>1.1</td>
<td>1.29</td>
<td>1.49</td>
<td>1.71</td>
</tr>
<tr>
<td>70</td>
<td>0.94</td>
<td>1.29</td>
<td>1.52</td>
<td>1.76</td>
<td>2.01</td>
</tr>
<tr>
<td>80</td>
<td>1.08</td>
<td>1.48</td>
<td>1.74</td>
<td>2.02</td>
<td>2.33</td>
</tr>
<tr>
<td>90</td>
<td>1.21</td>
<td>1.68</td>
<td>1.97</td>
<td>2.3</td>
<td>2.65</td>
</tr>
<tr>
<td>100</td>
<td>1.35</td>
<td>1.87</td>
<td>2.21</td>
<td>2.57</td>
<td>2.98</td>
</tr>
<tr>
<td>110</td>
<td>1.49</td>
<td>2.07</td>
<td>2.44</td>
<td>2.85</td>
<td>3.32</td>
</tr>
<tr>
<td>120</td>
<td>1.63</td>
<td>2.27</td>
<td>2.68</td>
<td>3.14</td>
<td>3.66</td>
</tr>
<tr>
<td>130</td>
<td>1.77</td>
<td>2.47</td>
<td>2.92</td>
<td>3.44</td>
<td>4.02</td>
</tr>
<tr>
<td>140</td>
<td>1.91</td>
<td>2.67</td>
<td>3.17</td>
<td>3.74</td>
<td>4.39</td>
</tr>
<tr>
<td>150</td>
<td>2.05</td>
<td>2.87</td>
<td>3.42</td>
<td>4.04</td>
<td>4.78</td>
</tr>
<tr>
<td>160</td>
<td>2.19</td>
<td>3.08</td>
<td>3.68</td>
<td>4.36</td>
<td>5.18</td>
</tr>
<tr>
<td>170</td>
<td>2.34</td>
<td>3.29</td>
<td>3.93</td>
<td>4.68</td>
<td>5.59</td>
</tr>
<tr>
<td>180</td>
<td>2.48</td>
<td>3.5</td>
<td>4.2</td>
<td>5.01</td>
<td>6.02</td>
</tr>
<tr>
<td>190</td>
<td>2.62</td>
<td>3.71</td>
<td>4.46</td>
<td>5.35</td>
<td>6.48</td>
</tr>
<tr>
<td>200</td>
<td>2.77</td>
<td>3.93</td>
<td>4.73</td>
<td>5.7</td>
<td>6.96</td>
</tr>
<tr>
<td>210</td>
<td>2.91</td>
<td>4.14</td>
<td>5.01</td>
<td>6.06</td>
<td>7.47</td>
</tr>
<tr>
<td>220</td>
<td>3.06</td>
<td>4.36</td>
<td>5.29</td>
<td>6.44</td>
<td>8.01</td>
</tr>
<tr>
<td>230</td>
<td>3.21</td>
<td>4.59</td>
<td>5.58</td>
<td>6.82</td>
<td>8.6</td>
</tr>
<tr>
<td>240</td>
<td>3.36</td>
<td>4.81</td>
<td>5.87</td>
<td>7.22</td>
<td>9.24</td>
</tr>
<tr>
<td>250</td>
<td>3.5</td>
<td>5.04</td>
<td>6.17</td>
<td>7.64</td>
<td>9.97</td>
</tr>
<tr>
<td>260</td>
<td>3.65</td>
<td>5.27</td>
<td>6.48</td>
<td>8.08</td>
<td>10.8</td>
</tr>
<tr>
<td>270</td>
<td>3.8</td>
<td>5.51</td>
<td>6.79</td>
<td>8.54</td>
<td>11.83</td>
</tr>
<tr>
<td>280</td>
<td>3.96</td>
<td>5.75</td>
<td>7.12</td>
<td>9.02</td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>4.11</td>
<td>5.99</td>
<td>7.45</td>
<td>9.54</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>4.26</td>
<td>6.23</td>
<td>7.78</td>
<td>10.09</td>
<td></td>
</tr>
</tbody>
</table>

where:

\(P\) load = applied load \quad Le/d = \text{span depth ratio}
Fig (5.13): Forces in diagonal strut (1-4) against applied load, *kips*, using second application.
Fig (5.14): Forces in strut (1-3) against applied load, kips, using second application.
Fig (5.15): Area of reinforcement for tie (1-3), in² against applied load, kips, using second application
Fig (5.16): Area of reinforcement for tie (3-6), in² against applied load, kips, using second application
5.13 Discussion of the Results

For discussion of the results see the modeling of strut-tie used in the program shown in Fig (5.1):

5.13.1 Discussion of the Results for first applications:

1. Fig (5.3) shows that the force in diagonal strut (1-4) increase when applied load increases. The force in that strut is affected by changing values of shear span-clear span ratio \((a/le)\), if the applied load is constant and the factor \((a/le)\) ratio increases the force in diagonal strut is decreased.

2. Fig (5.4) also shows that the force in tie (3-6) increases when applied load is increased and decreases when shear span-clear span ratio \((a/le)\) is increased.

3. Fig (5.5), shows that the area of main longitudinal steel for tie (3-6) increases by the following factors:
   - When the applied load increases
   - When the shear span-clear span ratio, \((a/le)\) decreases.

4. Fig (5.6) shows that the area of steel for tie (1-3) increases by applied load or shear span-clear span ratio increases.

5. Fig (5.7) shows that the strain in strut (1-2) is a nonlinear relationship against applied load. The strain in that strut increases when applied load is increased or the shear span-clear span ratio is decreased.
6. Fig (5.8) shows that the strain in diagonal strut (1-4) is a nonlinear relation-ship against applied load. The strain in that strut increases when applied load is increased or the shear span-clear span ratio is increased.

7. Fig (5.9) shows that the stress in diagonal strut (1-4) is a nonlinear relation-ship against applied load. The stresses in that strut increases when applied load is decreased or the shear span-clear span ratio is decreased.

8. Fig (5.10) shows that the stress in strut (1-2) is a nonlinear relation-ship against applied load. The stress in that strut increases when applied load decreases or shear span-clear span ratio is increased.

9. Fig (5.11) shows that the stress in short struts directly under point of applied load. The limit stress in that strut increases by decreasing the applied load or by decreasing the shear span to clear span ratio.

10. Fig (5.12) shows that the stress limits in short strut at centerline of supports. The limit stress in this strut increases by increasing the applied load or by increasing the shear span-clear span.

5.13.2 Discussion of the Results for second applications:

1. Fig (5.13) shows that the force in diagonal strut (1-4) increases when applied load is increased, and the force in that strut is affected by changing values of clear span-effective depth ratio \((le/d)\). If the applied load is constant and the factor \((le/d)\) ratio increases the force in diagonal strut is decreased.
2. Fig (5.14) shows that the force in diagonal tie (1-3) increases when both applied load or clear span-effective depth ratio \((le/d)\) are increased.

3. Fig (5.15) shows that the areas of steel for tie (1-3) increased when the applied load is increased or span-effective depth ratio \((le/d)\) is decreased.

4. Fig (5.16) shows that the area of main longitudinal steel for tie (3-6) increases by the following factors:
   - When the applied load is increased
   - When span-effective depth ratio \((le/d)\) is increased.

### 5.13.3 Comparison results between program results output and model manual solution.

Results of output of the program developed for this research for analysis and design of reinforced concrete simply supported deep beams using strut-tie model method is shown in appendix-B, and manual solution analysis and design is shown in appendix-A.

These results of output program and manual solution are compared in the following, Table (5.15)
Table (5.15) Comparison of results between program results output and model manual solution.

<table>
<thead>
<tr>
<th>Variables in strut-Tie method model</th>
<th>Program Model</th>
<th>Manual solution Using AASHTO LRFD</th>
<th>Percentage Program/manual %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forces in struts and ties, \textit{kips}:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Member (AB) or (1-2)</td>
<td>-131.0015</td>
<td>-131</td>
<td>100.001</td>
</tr>
<tr>
<td>Member (BD) or (1-4)</td>
<td>-75.9924</td>
<td>-76.0</td>
<td>99.99</td>
</tr>
<tr>
<td>Member (CC/) or (3-6)</td>
<td>304.056</td>
<td>+304</td>
<td>100.001</td>
</tr>
<tr>
<td>Member (AC) or (1-3)</td>
<td>227.956</td>
<td>+228</td>
<td>99.98</td>
</tr>
<tr>
<td>Reinforcement: \textit{(in}^2\text{)}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area of horizontal Rein As \textit{3,6}</td>
<td>5.375</td>
<td>5.63</td>
<td>94.5</td>
</tr>
<tr>
<td>Area of horizontal Rein As \textit{1,3}</td>
<td>4.85</td>
<td>4.22</td>
<td>96.81</td>
</tr>
<tr>
<td>Strain in struts and ties:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strain in Strut AB (1-2)</td>
<td>0.00945</td>
<td>0.00944</td>
<td>100.001</td>
</tr>
<tr>
<td>Strain in strut AD (1-4)</td>
<td>0.00378</td>
<td>0.00375</td>
<td>100.009</td>
</tr>
<tr>
<td>Stresses in struts and ties: \textit{(psi)}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress in Strut AB (1-2)</td>
<td>1175.76</td>
<td>1176</td>
<td>99.98</td>
</tr>
<tr>
<td>Stress in strut AD (1-4)</td>
<td>1931.38</td>
<td>1960</td>
<td>98.55</td>
</tr>
</tbody>
</table>

The plastic truss model can fail following either by:

- Yielding of the tie.

or

- Crushing of one of the struts when the stress in that strut exceeds \( f_{ce} \).
CHAPTER (6)

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY
CHAPTER (6)

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

6.1 Conclusions

6.1.1 Forces in struts and ties

The magnitudes of forces in models of reinforced concrete deep beams affected by factors such as applied load, position of the load, depth and width of the beam. Furthermore they are affected by variations of the effective span-effective depth ratio; (le/d).

The program of strut-tie model developed in this research, PROSTM, the results of the were compared with those obtained by manual solutions using AASHTO LRFD 1999 [29]. The result of comparison where no difference between values obtained by two solutions (Program and Manul).

6.1.2 Main longitudinal reinforcement:

The main longitudinal reinforcement depends on the tension forces in the horizontal ties. Thus the area of reinforcement is increased when applied load, shear span-clear span ratio (a/le) or clear span-effective depth ratio are increased.

When the results of the area of steel reinforcement obtained from (PROSTM) program and manual solution were compared, it was observed that variations existed. Thus maybe eliminated by the
developed program being able to select suitable cross-section for the bars. This one is actually one of the program facilities

6.1.3 Strain in struts
Strain in struts depend on the area of horizontal and vertical reinforcement, shear span-clear span ratio (a/le), applied load and clear span-effective depth ratio
Vaules for strain obetained form manual solution were compared with these of the program output. It has been seen that no differences existed in the two resultes of the (Program and Manul).

6.1.4 Stress in struts
The stress in struts depend on the values of strut’s strains. The output values of strut stress form the developed program (PROSTM) were compared with manual solution values and it has been seen that no differences existed methods in the two resultes of the (Program and Manul).

6.2 Recommendations

1. The developed program for strut and tie, PROSTM, is limited to simply suported deep beams using AASHTO LRFD 1999 [29] code gesign . it can modified to include model for hollow concrete deep beams section, continuos deep beams and prestress concrete deep beams
2. In this work the AASHTO LRFD 1999, code is used. The program can be extended to include other codes.
REFERENCES:

1. Portland Cement Association “design of deep girders” Concrete information, 1946


28. ACI Committee 318 E (Shear and Torsion), Appendix X and CE49: Strut-and-Tie, 2002

29. AASHTO LRFD, American Association of State Highway and Transportation Officials, LRFD Bridge Design Specification a1999
The manual solution’s are taking from side/ http://www.cee.uiuc.edu/kuchma/strut_and_tie/STM/examples/dbeam/dbeam2.htm

2- Select and Establish the Strut-and-Tie Model:

Assume that a strut-and-tie model consisting of two trusses carries the loads. One truss uses a direct strut running from the load to the support. The other truss uses stirrups as vertical ties. The geometry of the assumed truss is shown in Figure 2.

\[ d = 48 - 4 = 44 \text{ in.} \]
3- Obtain the strut width \(a\) as follows:

\[
\phi f_{yw} - \phi f'_{yw} - 0.70(0.85(4000)) = 2380 \text{ psi}
\]

\[
N_{CD} = \phi f_{yw}ba = 2380(14)a/1000 = 33.32a
\]

\[
j'd = d - \frac{a}{2} = 44 - \frac{a}{2}
\]

\[
\sum M_d = 0 \Rightarrow N_{per} j'd = P_0 \text{ (56)}
\]

\[
33.32a \left(44 - \frac{a}{2}\right) = 214 \text{ (56)}
\]

\[
16.66a^2 - 1466.08a + 11984 = 0
\]

\[
a = 9.12 \text{ in.}
\]

\[
 j'd = 44 - \frac{9.12}{2} = 39.44 \text{ in.}
\]

4- Determine the Required Truss Forces:

Assume that 50 % of the loads, \(N_{bc}=214/2 = 107\) kips, is transmitted by the stirrups at yield

The required forces in all the members of the truss are given in the following table.

<table>
<thead>
<tr>
<th>Member</th>
<th>(AB)</th>
<th>(AC)</th>
<th>(AD)</th>
<th>(CC')</th>
<th>(CD)</th>
<th>(BC)</th>
<th>(BD)</th>
<th>(DD')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (kips)</td>
<td>-131</td>
<td>+228</td>
<td>-186</td>
<td>+304</td>
<td>-131</td>
<td>+107</td>
<td>-76.0</td>
<td>-304</td>
</tr>
<tr>
<td>Slope (deg)</td>
<td>54.6</td>
<td>0.0</td>
<td>35.2</td>
<td>0.0</td>
<td>54.6</td>
<td>90</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Positive indicates tension and negative indicates compression.
5- Select the Steel Reinforcement for the Ties:

Try to use 5 #4 two-legged stirrups at 6 in. o.c. for the vertical tie BC
Capacity of

\[
\phi A_v f_y = 0.9(2)(5)(0.2)(60) = 108 \text{ kips}
\]

Very close to the assumed load.

Hence provide 5 #4 two-legged stirrups at 6 in., \( A_{v, bc} = 2 \times 5 \times 0.2 = 2 \text{ in}^2 \)
According to the AASHTO LRFD, the minimum reinforcement \( A_{s, \text{min}} \) for horizontal tie \( CC' \) and \( AC \) is:

\[
A_{s, \text{min}} = 0.03 \frac{f_c}{f_y} b \cdot h = \frac{4000}{60000} \times 0.002 \times 14 \times 48 = 1.34 \text{ in}^2
\]

The required area of steel reinforcement for tie \( CC \), \( A_{s, CC} \) is

\[
A_{s, CC} = \frac{N_{cc}}{\phi_0 f_y} = \frac{304}{0.9 \times 60} = 5.63 \text{ in}^2
\]

\[
A_{s, AC} = \frac{N_{AC}}{\phi_0 f_y} = \frac{228}{0.9 \times 60} = 4.22 \text{ in}^2
\]

Choose 2 layers of 4 #8 bars for tie \( CC' \) and choose 2 layers of 3 #8 bars for tie \( AC \),
6- Check the Struts:

The struts will be checked by computing the strut widths and checked whether they will fit in the space available.

Strain in tie $BC$ can be estimated as

$$
\varepsilon_s = \frac{N_{BC}}{A_{BC}E_s} = \frac{107}{2(29000)} = 0.00184 < \frac{f_y}{E_s} = \frac{60}{29000} = 0.002.
$$

Strain in tie $AC$ can be taken as

$$
\varepsilon_s = \frac{N_{AC}}{A_{AC}E_s} = \frac{228}{4.74(29000)} = 0.00166.
$$

The bottom part of strut $AB$ is crossed by tie $AC$. The tensile strain perpendicular to strut $AB$ due to tensile strain in this tie $AC$ is

$$
\varepsilon_1 = \varepsilon_s + (\varepsilon_s + 0.002)\cot^2 54.6^\circ = 0.00351.
$$

Stress limit at the bottom of strut $AB$ is

$$
\phi f_y = \phi \frac{f_y}{0.8 + 170\varepsilon_1} = \phi \frac{f_y}{0.8 + 170(0.00351)} = 0.72\phi f_y = 0.72(0.70)(4000) = 2016\text{ psi}.
$$

The top part of strut $AB$ is crossed by tie $BC$ and the tensile strain perpendicular to strut $AB$ due to tie $BC$ is

$$
\varepsilon_t = 0.00184 + (0.00184 + 0.002)\cot^2 (90 - 54.6)^\circ = 0.00944.
$$

Stress limit at the top of strut $AB$ becomes

$$
\phi f_y = \phi \frac{f_y}{0.8 + 170(0.00944)} = 0.42\phi f_y = 0.42(0.70)(4000) = 1176\text{ psi}.
$$

Required width for strut $AB$, $W_{SAB}$ is

$$
W_{SAB} = \frac{N_{AB}}{\phi f_y b} = \frac{131(1000)}{1176(14)} = 7.96\text{ in}.
$$

$W_{SAB} = 7.96\text{ in}$. Take 8 in.
The bottom of strut $AD$ is crossed by tie $AC$ and the tensile strain perpendicular to strut $AD$ due to tensile strain in tie $AC$ is

$$
\varepsilon_1 = 0.00166 + (0.00166 + 0.002)\cot^2 35.2^\circ = 0.00901. 
$$

Stress limit at the bottom of strut $AD$ is

$$
\phi f_{w} = \frac{f_{e}}{0.8 + 170(0.00901)} = 0.43f_{c} = 0.43(0.70)(4000) = 1204 \text{ psi.}
$$

Middle part of strut $AD$ is crossed by tie $BC$ and the tensile strain perpendicular to strut $AD$ due to tie $BC$ is

$$
\varepsilon_2 = 0.00184 + (0.00184 + 0.002)\cot^2(90 - 35.2)^\circ = 0.00375. 
$$

Stress limit at the middle of strut $AD$ is

$$
\phi f_{w} = \frac{f_{e}}{0.8 + 170(0.00375)} = 0.70f_{c} = 0.70(0.70)(4000) = 1960 \text{ psi.}
$$

Required width for strut $AD$, $W_{s,AD}$ is

$$
W_{s,AD} = \frac{\frac{N_{w}}{\phi f_{w} b}}{1204(14)} = 11.03 \text{ in.}
$$

$W_{s,AD} = 11.03$ in. Take $11$ in.

The bottom part of strut $CD$ is mostly influenced by tie $BC$ and can be assumed to be the same as the top part of strut $AB$. Thus, the stress limit and the required width for strut $CD$ are 1176 psi and 7.96 in. respectively. Choose also a width of 8 in. for strut $CD$.

Strut $BD$ is mostly crossed by tie $BC$ and the tensile strain perpendicular to strut $BD$ due to tensile strain in tie $BC$ is

$$
\varepsilon_3 = \varepsilon_2 = 0.00184. 
$$

Stress limit for strut $BD$ is

$$
\phi f_{w} = \frac{f_{e}}{0.8 + 170(0.00184)} = 0.90f_{c} > 0.85f_{c},
$$

$\phi f_{w} = 0.85f_{c} = 0.85(0.70)(4000) = 2380 \text{ psi.}$
The required width for short strut transmitting the applied load to node D is \( \frac{214(1000)}{2380(14)} = 6.42 \text{ in} \). Choose a width equal to the bearing plate width for this strut, i.e. 16 in.

The required width for short strut transmitting the force meeting at node A to the support is \( \frac{214(1000)}{2100(14)} = 7.28 \text{ in} \). Choose a width of 13 in. for this short strut.

The stress demands, stress limits, and the widths of the struts are summarized in Figure 3. As shown in Figure 3, most of the strut widths fit into the outline of the beam region except that struts AB and AD near node A overlap and struts BD, AD, and CD near node D overlap. To ensure that the overlapping struts in those regions do not exceed the stress limit, the stresses due to the force resultant are checked against the corresponding stress limit. The force resultant of struts AB and AD is \( \sqrt{214^2 + 228^2} = 313 \text{ kips} \) with a slope of \( \arctan \frac{214}{228} = 43.2^\circ \) and the available width is \( 8\cos 43.2^\circ + 13\sin 43.2^\circ = 14.73 \text{ in} \) (Figure 4(a)). The stress due to this force resultant is then \( \frac{313(1000)}{14.73(14)} = 1518 \text{ psi} \). This force resultant zone crosses both ties AC and BC. The tensile strain perpendicular to this force resultant due to tensile strain in tie AC is \( e_t = 0.00186 + (0.00166 + 0.002) \cot^2 43.2^\circ = 0.00581 \) while the tensile strain perpendicular to the force resultant due to tie BC is \( e_t = 0.00184 + (0.00184 + 0.002) \cot^2 (90 - 43.2)^\circ = 0.00523 \). By taking the larger tensile strain, it gives the lower stress limit of

\[
\phi f_w = \frac{f_c}{0.8 + 170(0.00581)} = 0.56 \phi f'_c = 0.56(0.70)(4000) = 1568\text{ psi}
\]

which is greater than the stress demand, i.e. 1518 psi.

Similarly, the force resultant of struts BD, AD, and CD is \( \sqrt{214^2 + 304^2} = 372 \text{ kips} \) with a slope of \( \arctan \frac{214}{304} = 35.1^\circ \) and the available width is \( 9.12\cos 35.1^\circ + 16\sin 35.1^\circ = 16.67 \text{ in} \) (Figure 4(b)). The stress due to this force resultant is \( \frac{372(1000)}{16.67(14)} = 1594 \text{ psi} \). Part of force resultant zone crosses the BC. The tensile strain perpendicular to this force resultant due to tensile strain in tie BC is \( e_t = 0.00184 + (0.00184 + 0.002) \cot^2 (90 - 35.1)^\circ = 0.00374 \). This gives a stress limit of \( \phi f_w = \frac{f_c}{0.8 + 170(0.00374)} = 0.70 \phi f'_c = 0.70(0.70)(4000) = 1960\text{ psi} \) which is greater than the stress demand, i.e. 1594 psi.

7 - Design the Nodal Zone and Check the Anchorages:

The width \( a \) of nodal zone D was chosen to satisfy the stress limit on that nodal zone. The stresses of the nodal zone A and C are limited to \( 0.75 \phi f_w = 0.75(0.70)(4000) = 2100 \text{ psi} \) and \( 0.63 \phi f_w = 0.63(0.70)(4000) = 1820 \text{ psi} \) respectively. To satisfy the stress limit of nodal zones A and C, the tie reinforcement must engage an effective depth of concrete at least equal to:

\[
\frac{N_{Ac}}{0.65 \phi f_w} = \frac{204 - 228(1000)}{1820(14)} = 2.98 \text{ in}
\]

To satisfy the stress limit of nodal zone A, the tie reinforcement must engage an effective depth of concrete at least equal to...
\[
\frac{N_{ec}}{0.75f'_{cb}} = \frac{228(1000)}{(2100)(14)} = 7.76 \text{ in.}
\]
These limits are easily satisfied since the nodal zone available is 8 in.

Figure 3

\[
P_r = 214 \text{ kips}
\]

Figure 4
The required anchorage length for tie $AC$ is $L_a = \frac{1200d^2}{f'y} = 0.7 \frac{1200(1)}{\sqrt{4000}} = 13.28$ in. Since this is less than the available length, i.e. $16 - 2.5 = 13.5$ in, then anchorage length is adequate.

8.- Calculate the Minimum Reinforcement Required for Crack Control:

According AASHTO LRFD, a uniformly distributed reinforcement in vertical and horizontal directions near each face must be provided with minimum of volumetric ratio of 0.003 in each direction and the minimum bar spacing for each direction is 12 in.

Try pairs of #4 bars with spacing of 9 in. for both vertical and horizontal reinforcement. The reinforcement ratio is $\frac{2(0.2)}{14(9)} = 0.00317$. The ratio is greater than 0.003. Hence use pairs of #4 bars @ 9 in. o.c. in each direction.

9.- Summary of the Design:

The reinforcement details for the deep beam designed using the strut-and-tie model according to AASHTO LRFD are shown in Figure 5.
program strut_Tie;
uses crt,dos,graph;
var
     xn,n, fac,g1,x1,x2,y1,y2,x3,x4,x5,y3,y4,y5,X6,Y6,nn,sup,i,j,s,ss,Nload,
     ff,ill:integer;
     jd,Spacesstir,Suportp,Suportl,nostir,nustir,width,cover,loadu,depth,bb,cc,
     phicu,clearSP,suported,bartie,Nobartieprov,diabar,areabar,Nola,E1,E11,
     ebs, Nobartie,span,oversp,wload,tieprovper,tiespace,Asmintie,x,y:
array[1..15]of real;
Asprov,Asreq,force,ws,bearingP,Ac,Ac1,lengths,shearSP,pload,React,wsp,
magam,slop, sita,stress,stress1,plwidth,ref:
array[1..10,1..10]of real;
phiAvfy,phifcload,phifcsupp,fcbar,fy,jo,supportSp,striyield,Es,ratiotrans,
ephi,Key3:real;
unt1,unt2,unt3,unt4,unt5:string;
emaddo,emaddol: string[20];
unity,Key1: char;
fi:text;
const
     phi=.7;
     phi2=.75;
     phi1=.85;
     phi3=.9;
procedure Jointequ;
begin
   X1:=100;y1:=350;
   X2:=X1+TRUNC(FAC*(Span[SS]/2+SUPORTP[ll]));
   y2:=y1-TRUNC(FAC*(y[2]+ws[4,8]/2)); {J1}
   X3:=X1+TRUNC(FAC*(SUPORTP[ll]/2)); {J1}
   Y3:=Y1-TRUNC(FAC*(COVER[SS])); {J1}
   X4:=X3+ TRUNC(FAC*SHEARSP[SS,FF]/2); {J2}
   Y4:=Y2+TRUNC(FAC*(ws[4,8]/2)); {J2}
   X5:=X4; {J3}
   Y5:=Y3; {J3}
   X6:= X3+TRUNC(FAC*SHEARSP[SS,FF]); {J4}
   Y6:=Y4; {J4} end;
procedure dimline;
begin
   Setcolor(10);
   LINE(X2,Y1+40,X2,Y1+70) ; {CENTER}
   LINE(X5,Y1+40,X5,Y1+55) ; {CENTER}
   LINE(X6,Y1+40,X6,Y1+55) ; {CENTER}
   LINE(X1,Y1+40,X1,Y1+55) ; {CENTER}
   LINE(X1,Y1+48,X6,Y1+48) ; {CENTER}
   LINE(X3,Y2-40,X6,Y2-40) ; {CENTER}
   LINE(X1-15,Y1,X1-15,Y2) ; {CENTER}
LINE(X1-20,Y1,X1-10,Y1) ; {CENTER}
LINE(X1-20,Y2,X1-10,Y2) ; {CENTER}
LINE(X1+trunc(FAC*(suportp[ll])),Y1+65,X2,Y1+65) ; {CENTER}
LINE(X1+trunc(FAC*(suportp[ll])),Y1+40,X1+trunc(FAC*(suportp[ll])),Y1+70);
SetLineStyle(1, 1, 1);
LINE(X3,Y1+32,X3,Y2-50) ; SetLineStyle(0, 0, 0);
end;
procedure trussline;
begin
Setcolor(14);
LINE(X3,Y3,X4,Y4) ; {1,2}
LINE(X4,Y4,X6,Y6) ; {2,4}
LINE(X3,Y3,X6,Y6) ; {1,4}
LINE(X3,Y3,X5,Y5) ; {1,3}
LINE(X4,Y4,X5,Y5) ; {2,3}
LINE(X5,Y5,X6,Y6) ; {3,5}
LINE(X4,Y6,X2,Y6) ; {3,5}
LINE(X5,Y5,X2,Y5) ; {2,3}
{Joint Point}
FOR I:=0 TO 2 DO BEGIN setcolor(4);
CIRCLE(X3,Y3,I);CIRCLE(X4,Y4,I); CIRCLE(X5,Y5,I);CIRCLE(X6,Y6,I);
END;
end;
procedure window1andTopicName;
begin
setcolor(1);
setbkcolor(8); SetLineStyle(0, 0, 0);
RECTANGLE(0,0,getmaxx,getmaxy);
FOR I:=17 TO 50 DO  RECTANGLE(i,i-40,getmaxx+40-i,getmaxy-i);
settextstyle(2,1,7);setcolor(15); outtextxy(-5,235,'Deep Beam Using STM');
settextstyle(2,0,7); outtextxy(12,460,'TRUSS MODEL CASE-{1}');
settextstyle(2,0,6);outtextxy(380,460,' Press Enter to Continuous');
end;
procedure outwordline;
begin
setcolor(15);
outtextxy(X3-TRUNC(FAC*3),Y3,'1');
outtextxy(X4-TRUNC(FAC*3),Y4,'2');
outtextxy(X5+TRUNC(FAC*3),Y5,'3');
outtextxy(X6+TRUNC(FAC*3),Y6,'4');
outtextxy(TRUNC(X1+(X6-X1)/2),Y2-50,'a');
outtextxy(X6+5,Y2-60,'P');
outtextxy(X1+TRUNC((X2-X1-FAC*suportp[ll])/2),Y1+55,'Ln/2');
outtextxy(X1-30,TRUNC(Y1+(Y2-Y1)/2)-15,'H');
setcolor(4);
outtextxy(X1+TRUNC((X2-X1-FAC*suportp[ll])/2)-15,Y1+70,'Clear Span/2');
outtextxy(TRUNC(X1+(X6-X1)/2)-30,Y2-35,'Shear Span');
outtextxy(X1-45,TRUNC(Y1+(Y2-Y1)/2)-15,'Hight');
outtextxy (X5-30,Y1+40,'a/2') ; {CENTER}
outtextxy (X5+30,Y1+40,'a/2') ; {CENTER}
end;
procedure frameline;
begin
  for i:=0 to 2 do BEGIN
    setcolor(15);
    rectangle(X1+i,Y1+i,X2-i,Y2-i);
    RECTANGLE(X1+i,Y1+i,X1+trunc(FAC*(suportp[I]))+i,Y1+30-i);
    setcolor(2);
    LINE(X6+i,Y2-3,X6+i,Y2-50);
    LINE(X6+i,Y2-3,X6-3+i,Y2-7);
    LINE(X6+i,Y2-3,X6+3+i,Y2-7); {FORCE}
  END;
Setcolor(8);SetLineStyle(1, 1, 1);
for i:=0 to 1 do LINE(X2-I,Y1,X2-I,Y2) ;
end;

procedure Section1;
{main section drow } Begin
SS:=1;FF:=1; LL:=1;n:=4;
Jointequ;
outwrordline;
trussline;
dimline;
frameline;
window1andTopicName;
end;

procedure BearingPlate;
label 100;
begin
writeln('CHECK BEARING STRESS AT POINTS OF LOADING AND
SUPPORTS');
  for ss:=1 to s do begin  for ff:=1 to Nload do
    begin
      Ac[ss,ff]:=width[ss]*lengths[ss,ff];
      if Ac[ss,ff]=0 then Ac[ss,ff]=1;
      bearingP[ss,ff]:=Pload[ss,ff]/Ac[ss,ff];
      phifcload:=phi*phi1*fcbar*1000;
      phifcsupp:=phi2*phi1*fcbar*1000;
      if bearingP[ss,ff] < phifcload then begin
        writeln('For Span [' ,ss,' ] :');
        writeln(' Bearing At Points of Loading is: < OK >'); end;
      if bearingP[ss,ff] >= phifcload then begin
        writeln(' Bearing At Points of Loading is: < NOT OK >');
      end;
  end;
end;
writeln('  And then increasing one of:');
writeln('  POINTS OF LOADING PLATE.');
writeln('  OR STRENGTH OF CONCRETE.'); goto 100;
end;
end;
end;
100:end;

procedure datacase1;
begin
  DEPTH[ss]:=OVERSP[ss]-cover[ss];
  bb[ss]:=2*DEPTH[ss];
  phi[ss]:=phi*phi1*fcbar*1000;
  cc[ss]:=2000*pload[ss,ff]*shearSp[ss,ff]/(phi[ss]*width[ss]);
  ws[4,8]:=abs(-bb[ss]/2+sqrt(sqr(bb[ss])-4*cc[ss])/2);
  jd[ss]:=depth[ss]-ws[4,8]/2;
  x[1]:=(span[ss]-clearsp[ss])/2;
  y[1]:=cover[ss];
  x[2]:=(span[ss]-clearsp[ss])/2+shearSp[ss,ff]/2;
  y[2]:=cover[ss];
  x[3]:=(span[ss]-clearsp[ss])/2+shearSp[ss,ff]/2;
  y[3]:=cover[ss];
  x[4]:=(span[ss]-clearsp[ss])/2+shearSp[ss,ff];
  y[4]:=cover[ss];
end;

procedure analysiscase1;
begin
  force[4,8]:=-phi[ss]*width[ss]*ws[4,8]/1000;
  force[8,4]:=force[4,8];
  force[3,6]:=-force[4,8];
  force[6,3]:=force[3,6];
  striyield:=ratiotrans*Pload[ss,ff]/100;
  force[2,3]:=striyield;
  force[3,2]:=force[2,3];
  force[1,2]:=-force[2,3]/sin(pi/180*sita[1,2]);
  force[2,1]:=-force[1,2];
  force[2,4]:=-force[1,2]*cos(pi/180*sita[1,2]);
  force[4,2]:=force[2,4];
  force[3,4]:=-force[2,3]/sin(pi/180*sita[3,4]);
  force[4,3]:=force[3,4];
  force[1,3]:=-force[3,4]/cos(pi/180*sita[3,4]);
  force[3,1]:=-force[1,3];
  force[1,4]:=-force[1,2]*cos(pi/180*sita[1,2])/cos(pi/180*sita[1,4]);
  force[4,1]:=force[1,4];
end;

procedure slopcase1;
begin
for i:=1 to s do begin
for j:=i to s do begin
magam[i,j]:=x[i]-x[j];
if (magam[i,j]=0) or (i<>j) then begin
sita[i,j]:= 90; sita[j,i]:= 90;
end else begin
slop[i,j]:=(y[i]-y[j])/(x[i]-x[j]);
sita[i,j]:=180/pi*arctan(slop[i,j]);
sita[j,i]:= sita[i,j];
end;
end;
end;

procedure outputForce;
begin
writeln;
textcolor(4);
write('':15,'Joint':10); write('Force':14); writeln('Slope':12);textcolor(15);
writeln('':15,'':15,':',178,':');
for i:=1 to s do begin
for j:=i to s do
if (i=j) then begin end else
writeln('':15,'³':4,'J(':3,i,'-',j,')','³':3,force[i,j]:10:2,'³':5,sita[i,j]:7:2,'³':7);
end;
writeln('':15,'³':4,'J(':3,3,'-',6,')','³':3,force[3,6]:10:2,'³':5,0.00:7:2,'³':7);
writeln('':15,':',178,':');
end;

procedure StrutCheck;
begin

Ebs[1]:=force[2,3]/(Asprov[2,3]*Es);
Ebs[2]:=force[1,3]/(Asprov[1,3]*Es);
if (Ebs[1] >= fy/Es) or ((Ebs[2] >= fy/Es) ) then begin
writeln('The Stress Exceed the range.');
end else begin
key3:=1;
E1[1]:=Ebs[2]+(Ebs[2]+0.002)*SQR(cos(pi/180*(sita[1,2]-sita[3,1]))/sin(pi/180*(sita[1,2]-sita[3,1])));
ephi:= 1/(0.8+170*E1[1]);
if ephi>= 0.85 then ephi:=0.85;
Stress[1,2]:=ephi*phi*fcbar*1000;
E1[2]:=Ebs[1]+(Ebs[1]+0.002)*SQR(cos(pi/180*(sita[3,2]-sita[1,2]))/sin(pi/180*(sita[3,2]-sita[1,2])));
ephi:= 1/(0.8+170*E1[2]);
if ephi>= 0.85 then ephi:=0.85;
Stress1[1,2]:=ephi*phi*fcbar*1000;
if stress1[1,2] < stress[1,2] then
begin

128
\[ e_{11}[1] := e_{1}[2]; \text{stress}[1,2] := \text{stress}[1,2]; \text{end}; \]
\[ Ws[1,2] := \text{Abs}(\text{force}[1,2]*1000)/\text{stress}[1,2]*\text{width}[ss]; \]
\[ \text{wsp}[1,2] := \text{trunc}(ws[1,2]+0.8); \]
\[ E[1][3] := Ebs[2]+(Ebs[2]+0.002)*SQR(\cos(pi/180*(\text{sita}[1,4]-\text{sita}[3,1])))/\sin(pi/180*(\text{sita}[1,4]-\text{sita}[3,1])); \]
\[ e_{11}[2] := e_{1}[3]; \text{ephi} := 1/(0.8+170*E[1][3]); \]
if ephi >= 0.85 then ephi := 0.85;
\[ \text{Stress}[1,4] := \text{ephi} * \text{phi} * \text{fcbar} * 1000; \]
\[ E[1][4] := Ebs[1]+(Ebs[1]+0.002)*SQR(\cos(pi/180*(\text{sita}[1,4]-\text{sita}[3,1])))/\sin(pi/180*(\text{sita}[1,4]-\text{sita}[3,1])); \]
\[ \text{ephi} := 1/(0.8+170*E[1][4]); \]
if ephi >= 0.85 then ephi := 0.85;
\[ \text{Stress}[1,1] := \text{ephi} * \text{phi} * \text{fcbar} * 1000; \]
if stress[1,4] < stress[1,4] then begin
\[ e_{11}[2] := e_{1}[3]; \]
\[ \text{stress}[1,4] := \text{stress}[1,4]; \text{end}; \]
\[ Ws[1,4] := \text{Abs}(\text{force}[1,4]*1000)/\text{stress}[1,4]*\text{width}[ss]; \]
\[ \text{wsp}[1,4] := \text{trunc}(ws[1,4]+0.8); \text{stress}[3,4] := \text{stress}[1,2]; \]
\[ ws[3,4] := ws[1,2]; \]
\[ \text{wsp}[3,4] := \text{trunc}(ws[3,4]+0.8); \]
\[ e_{1}[5] := ebs[1]; \]
\[ \text{ephi} := 1/(0.8+170*E[1][5]); \]
if ephi >= 0.85 then ephi := 0.85;
\[ \text{Stress}[2,4] := \text{ephi} * \text{phi} * \text{fcbar} * 1000; \]
\[ Ws[2,4] := \text{Abs}(\text{force}[2,4]*1000)/\text{stress}[2,4]*\text{width}[ss]; \]
\[ \text{wsp}[2,4] := \text{trunc}(ws[2,4]+0.8); \text{stress}[4,4] := 0.85*\text{phi} * \text{fcbar} * 1000; \]
\[ \text{Stress}[1,1] := 0.75*\text{phi} * \text{fcbar} * 1000; \]
\[ Ws[4,4] := \text{Abs}(\text{pload}[ss,ff]*1000)/\text{stress}[4,4]*\text{width}[ss]; \]
\[ Ws[1,1] := \text{Abs}(\text{React}[1,1]*1000)/\text{stress}[1,1]*\text{width}[ss]; \]
if Ws[4,4] < pload[ss,ff] then \text{wsp}[4,4] := pload[ss,ff];
if wsp[1,4] > wsp[1,2] then begin \text{wsp}[1,1] := wsp[1,4]+2;
if wsp[1,4] <= ws[1,1] then \text{wsp}[1,1] := \text{Trunc} (ws[1,1]+0.8);
end else \text{wsp}[1,1] := wsp[1,2]+2;
\]
\[ \text{ReF}[10,10] := \sqrt{\text{sqr}(\text{react}[1,1]) + \text{sqr}(\text{force}[1,3])}; \]
\[ \text{Slop}[10,10] := \text{React}[1,1]/\text{force}[1,3]; \]
\[ \text{sita}[10,10] := 180/\pi*\arctan(slop[10,10]); \]
\[ \text{wp}[10,10] := \text{ws}[1,2]*\cos(pi/180*\text{sita}[10,10])+\text{wsp}[1,1]*\sin(pi/180*\text{sita}[10,10]); \]
\[ \text{stress}[10,10] := \text{Abs}(\text{ReF}[10,10]*1000)/\text{Wsp}[10,10]*\text{width}[ss]; \]
\[ \text{E}[1][10] := \text{Ebs}[1]+(\text{Ebs}[1]+0.002)*\text{SQR}(\cos(pi/180*(90-\text{sita}[10,10])))/\sin(pi/180*(90-\text{sita}[10,10])); \]
\[ \text{E}[1][11] := \text{Ebs}[2]+(\text{Ebs}[2]+0.002)*\text{SQR}(\cos(pi/180*(\text{sita}[10,10])))/\sin(pi/180*(\text{sita}[10,10])); \]
if E[1][11] > E[1][10] then \text{e}[1][10] := e[1][11];
\[ \text{ephi} := 1/(0.8+170*E[1][10]); \]
if ephi >= 0.85 then ephi := 0.85;
\[ \text{Stress}[10,10] := \text{ephi} * \text{phi} * \text{fcbar} * 1000; \]
\[ \text{ReF}[9,9] := \sqrt{\text{sqr}(\text{pload}[ss,ff]) + \text{sqr}(\text{force}[4,8])}; \]
\[ \text{Slop}[9,9] := \text{Pload}[ss,ff]/\text{force}[4,8]; \]
\[ \text{sita}[9,9] := 180/\pi*\arctan(slop[9,9]); \]
wsp[9,9] := ws[4,8]*cos(pi/180*sita[9,9])+wsp[4,4]*sin(pi/180*sita[9,9]);
stress[9,9] := Abs(ReF[9,9]*1000)/(Wsp[9,9]*width[ss]);
ephi := 1/(0.8+170*E1[9]); if ephi >= 0.85 then ephi := 0.85;
Stress1[9,9] := ephi*phi*fcbar*1000;
end;
end;

procedure outstrut;
begin
clrscr;
Writeln;
readln;
Writeln('        Table No {1}        Details Of Struts');
writeln('
---------------------------------------------------------------------------------------------------------------');
write('Strut ':15,'Stress' :15,'Strain':12,' Width  ':15,'   Width of   ':20);
writeln('limits':33,'of Strut':27,'Strut Choosing':20);
writeln('Strut[1-2]':17,Stress[1,2]:13:2,E11[1]:13:6,Ws[1,2]:13:2,Wsp[1,2]:17:2);
writeln('Strut[1-4]':17,Stress[1,4]:13:2,E11[2]:13:6,Ws[1,4]:13:2,Wsp[1,4]:17:2);
writeln('Strut[2-4]':17,Stress[2,4]:13:2,E1[1]:13:6,Ws[2,4]:13:2,Wsp[2,4]:17:2);
writeln('Strut[3-4]':17,Stress[3,4]:13:2,E1[1]:13:6,Ws[3,4]:13:2,Wsp[3,4]:17:2);
writeln('Strut[4-8]':17,Stress[4,8]:13:2,E1[1]:13:6,Ws[4,8]:13:2,Wsp[4,8]:17:2);
 writeln('---------------------------------------------------------------------------------------------------------------');
writeln('- Press Key Enter-');
writeln('---------------------------------------------------------------------------------------------------------------');
Writeln('');
writeln('        Table No {2}        Details Of Short Struts');
writeln('---------------------------------------------------------------------------------------------------------------');
writeln('Column [1]':48,'Column [2]':18);
writeln('Required Width Short Strut ³',ws[4,4]:14:2,ws[1,1]:18:2);
writeln('Choose a Width Short Strut ³',wsp[4,4]:14:2,wsp[1,1]:18:2);
writeln('Resultant Force at Nodal ³',ReF[10,10]:14:2,ReF[9,9]:18:2);
writeln('Slope Of The Resultant ³',Sita[10,10]:14:2,Sita[9,9]:18:2);
writeln('Available Width due Resulant³',wsp[10,10]:14:2,wsp[9,9]:18:2);
writeln('Stress Demand due Resulant³',Stress[10,10]:14:2,Stress[9,9]:18:2);
writeln('Stress Limits³',Stress1[10,10]:14:2,Stress1[9,9]:18:2);
writeln('Tensile Strain due Resultant³',E1[10]:14:6,E1[9]:18:6);
 writeln('---------------------------------------------------------------------------------------------------------------');
writeln('Note:    Column [1]:  Transmitting Applied load');
writeln('            Column [2]:  Transmiting Nodal[1]');
if (Stress[10,10] < Stress1[10,10] and Stress[9,9] < Stress1[9,9]) then begin
Writeln(' Note:     The Stress limit greater than Stress demand that: ');
Writeln('On the Transmitting Applied load.');
Writeln('On the Transmitting Nodal{1}.');
Writeln('              Check Struts and Struts width is <<<<<<< OK >>>>>> ');
end else begin
end;
Writeln(' Note: The Stress limit lesser than Stress demand And then: ');
Writeln(' Correction of the stress that by:');
Writeln(' - Increasing overall depth.');
Writeln(' - Increasing Width of deep beam.');
Writeln(' Check Struts and Struts width is <<<<< Not OK >>>>>');
end;
end;

procedure outsteel;
Begin
clrscr;
writeln(' Details of Steel Reinforcement For Tie:');
writeln(' - Frist Vertical Steel Reinforcement For Tie{2-3}:');
Writeln('  ³ Hence Provid ',Nobartieprov[1]:0:0,'#',bartie[1]:0:0,' Two-Legged Stirrups at ','tiespace[1]:0:0,' in ');
writeln('  ³ Requird Area of steel = ',Asreq[2,3]:9:2,' in^2 ³');
writeln('  ³ Provid Area of steel    = ',Asprov[2,3]:9:2,' in^2 ³');
writeln('  ³ Precentage Area of steel= ',tieprovper[1]:9:2 ,' ³');
writeln('  ³  Thus Provid ³
');
writeln('  ³ Secand Horizontal Steel Reinforcement For Tie{1-3} and Tie{3-6}:');
writeln('   ³         Details         ³','Tie {1-3}':15,'Tie {3-6}':12,'³':3);
writeln('   ³ Bar Size #              ³',bartie[2]:10:0,bartie[3]:12:0,'³':8);
writeln('   ³ No of Bar Provid        ³',Nobartieprov[2]:10:0,Nobartieprov[3]:12:0,'³':8);
writeln('   ³ No of Bar Layer         ³',Nola[2]:10:0,Nola[3]:12:0,'³':8);
writeln('   ³ Requird Area of steel   ³',Asreq[1,3]:10:2,Asreq[3,6]:12:2,' in^2³':8);
writeln('   ³ Provid Area of steel    ³',Asprov[1,3]:10:2,Asprov[3,6]:12:2,' in^2³':8);
writeln('   ³ Precentage Area of steel³',tieprovper[2]:10:2 ,tieprovper[3]:12:2 ,'³':8);
Writeln('  ³ Details ³
');
Key1:='Y';
repeat
Writeln(' Message ³
');
Writeln('  ³ For Depending the data of Selecting and Trying Steel    ³');
Writeln('  ³ Details Enter Char < Y >, For Try Again Enter Char < N >³');
Write('  ³ Y or N ?
');
{readln(Key1)}    Until (Key1='Y') or (Key1='y')or(Key1='N') or (Key1='n');
end;

procedure inputdata;
label 10;
begin
write('   Project Name                                     :'); readln(emaddo1);
write('   Designer Engineer Name                           :');readln(emaddo);
if jo=5 then goto 10;
if jo=5 then goto 10;
}
INPUT
DATA

writeln('MATERIALS:');
 writeln;
 writeln('Concrete strength fc~ ',unt1:7,' = ') ;readln(fcbar);
 writeln('Steel strength fy ',unt1:7,' = ') ;readln(fy);
 writeln('GEOMETRY:');
 writeln('Project Name                                     :',emaddo1);
 writeln('Designer Engineer Name                           :',emaddo);
 writeln('MATERIALS:');
 writeln('Concrete strength   fc~   = ',fcbar:10:2,unt1:6);
 writeln('Steel    strength   fy    = ',fy:10:2,unt1:6);
 writeln('GEOMETRY:');
 write('Enter No of Span                      = ') ;   readln(s);
 for ss:=1 to s do begin
  writeln('Clear span           Ln[',ss,']        ',unt3:7,' = ') ;readln(ClearSP[ss]);
  writeln('Span                 L[',ss,']         ',unt3:7,' = ') ;readln(Span[ss]);
  writeln('Over all Span        H[',ss,']         ',unt3:7,' = '); readln(overSP[ss]);
  writeln('Span Width           b[',ss,']         ',unt3:7,' = '); readln(width[ss]);
  writeln('Span Steel Cover     c[',ss,']         ',unt3:7,' = '); readln(cover[ss]);
  writeln('Clear span           Ln[',ss,']    = ',ClearSP[ss]:10:2,unt3:6);
  writeln('Span                 L[',ss,']     = ',Span[ss]:10:2,unt3:6);
  writeln('Over all Span        H[',ss,']     = ',overSP[ss]:10:2,unt3:6);
  writeln('Span Width           b[',ss,']     = ',width[ss]:10:2,unt3:6);
  writeln('Span Steel Cover     c[',ss,']     = ',cover[ss]:10:2,unt3:6);
 writeln('Points Load At span No[',ss,']:' );
 writeln('Points Loads At span No[',ss,']:' );
 write('Enter No of concentrated load for span[',ss,'] = ') ;readln(Nload);
 write('Enter No of concentrated load for span[',ss,'] = ',Nload:2);
 for ff:=1 to Nload do begin
  writeln('Point Load   P[',ff,'] Load at  Span[',ss,']       ',unt4:7,' = ');readln(Pload[ss,ff]);
  writeln('Shear span a[',ff,'] For Point Load   P[',ff,'] from left       ',unt3:7,' = ');
  writeln('Point Load Plate Width For P[',ff,'] ',unt3:7,' = ');readln(plwidth[ss,ff]);
  writeln('Point Load Plate Length For P[',ff,'] ',unt3:7,' = ');
 end;}
writeln(' Point Load \[',ff,']\ Load at Span[',ss,'] = ',Pload[ss,ff]:10:2,unt4:6);
writeln(' Shear span a[',ff,'] For Point Load \[',ff,'] from left =
','shearSP[ss,ff]:10:2,unt3:6);
{writeln(' Point Load Plate Width For P[',ff,'] =','plwidth[ss,ff]:10:2,unt3:6);
writeln(' Point Load Plate Length For P[',ff,'] =','lengths[ss,ff]:10:2,unt3:6);
end;
write(' Distribution Load w[',ss,'] at Span[',ss,'] = ',unt5:7,' = ');read(wload[ss]);
writeln(' Distribution Load w[',ss,'] at Span[',ss,'] =
','wload[ss]:10:2,unt5:9);
end;

10:end;
procedure SteelDesign;
begin
  textbackground(0);
  writeln(' Select Steel Reinforcement For Tie:');
  writeln('');
  repeat
    writeln(' Vertical Tie \{2-3\}:');writeln('');
    write(' Try Tie\{2-3\} Enter Size paris #');{readln(bartie[1]);}bartie[1]:=4;
    diabar[1]:= bartie[1]/8; areabar[1]:=pi*sqr(diabar[1])/4;
    Asreq[2,3]:=force[2,3]/(phi3*fy);
    Nobartie[1]:=force[2,3]/(2*phi3*fy*areabar[1]);
    Nobartieprov[1]:=trunc(Nobartie[1]+1);
    tieprovper[1]:= 100*Nobartie[1]/Nobartieprov[1];
    tiespace[1]:=trunc((shearSP[ss,ff]/2)/Nobartieprov[1]+1;
    Asprov[2,3]:=2*Nobartieprov[1]*areabar[1];
    Asmintie[2]:=0.03*fcbar*width[ss]*overSP[ss]/fy;
    writeln(' Horizontal Tie:'); writeln('');
    write(' Try Tie\{3-6\} Enter Size paris #');{readln(bartie[2]);}bartie[2]:=4;
    Nola[2]:=2;
    write(' Try Tie\{3-6\} Enter No. Layer='); { readln(Nola[2]);}
    Asreq[3,6]:=force[3,6]/(phi3*fy);     diabar[2]:= bartie[2]/8;
    areabar[2]:=pi*sqr(diabar[2])/4;
    Nobartie[2]:=force[3,6]/(Nola[2]*phi3*fy*areabar[2]);
      Writeln(' The Area of Reinforcement for Tie \{3-6\} less Than minimum
reinforcement\.');
      Writeln(' for Horizont According the AASHTOLRFD\');
    Nobartieprov[2]:=trunc(Nobartie[2]+1);
    Asprov[3,6]:=Nola[2]*Nobartieprov[2]*areabar[2];
    tieprovper[2]:= 100*Asreq[3,6]/Asprov[3,6];
    write(' Try Tie\{1-3\} Enter Size paris #');{readln(bartie[3]);}bartie[3]:=4;
    Nola[3]:=2;
    write(' Try Tie\{1-3\} Enter No. Layer='); { readln(Nola[3]);}
    Asreq[1,3]:=force[1,3]/(phi3*fy);     diabar[3]:= bartie[3]/8;
    areabar[3]:=pi*sqr(diabar[3])/4;
    Nobartie[3]:=force[1,3]/(Nola[3]*phi3*fy*areabar[3]);

The Area of Reinforcement for Tie {1-3} less Than minimum reinforcement;

for Horizont According the AASHTO LRFD

\[ \text{Nobartie}[3] := \text{Asmintie}[2] \text{ end; } \]
\[ \text{Nobartieprov}[3] := \text{trunc}(\text{Nobartie}[3] + 1); \]
\[ \text{Asprov}[1,3] := \text{Nola}[3] \times \text{Nobartieprov}[3] \times \text{areabar}[3]; \]
\[ \text{tieprovper}[3] := 100 \times \text{Asreq}[1,3] / \text{Asprov}[1,3]; \]

repeat

\[ \text{Minimum Reinforcement for Crack Control Enter Size paris #}; \]
\[ \{\text{read(bartie}[4]);\} \]
\[ \text{bartie}[4] := 4; \]
\[ \text{diabar}[4] := \text{bartie}[4] / 8; \]
\[ \text{areabar}[4] := \pi \times \text{sqr}(\text{diabar}[4]) / 4; \]
\[ \text{tiespace}[4] := \text{Trunc}(2 \times \text{areabar}[4] / (\text{width}[ss] \times 0.003)); \]

if \[ \text{tiespace}[4] \geq 12 \] then

\[ \text{write(' The Space is greater than 12 in Pease Change size bar again');} \]

Until \[ \text{tiespace}[4] < 12; \]

\[ \text{outsteel; Key1 := 'Y';} \]

Until \[ \text{(Key1 = 'Y') or (Key1 = 'y');} \]

end,

procedure windeep;

begin

\[ \text{setcolor}(12); \]
\[ \text{settextstyle}(1,0,5); \text{setbkcolor}(4); \]
\[ \text{rectangle}(0,0,\text{getmaxx},\text{getmaxy}); \text{rectangle}(1,1,\text{getmaxx}-1,\text{getmaxy}-1); \]
\[ \text{setcolor}(1); \text{for i:=1 to 200 do line}(100+i,100-i,200-i,200-i); \]
\[ \text{setcolor}(17); \text{for i:=1 to 200 do line}(400+i,500-i,\text{getmaxx}-i,200-i); \]
\[ \text{settextstyle}(7,0,1); \text{setcolor}(4); \text{outtextxy}(20,10,\text{'University Of Khartoum'}); \]
\[ \text{setcolor}(15); \text{outtextxy}(16,12,\text{'University Of Khartoum'}); \text{setcolor}(62); \]
\[ \text{settextstyle}(2,0,5); \text{setcolor}(15); \text{outtextxy}(16,30,\text{'Engineering college'}); \]
\[ \text{outtextxy}(16,40,\text{'Civil Department'}); \]
\[ \text{settextstyle}(7,0,3); \text{setcolor}(15); \text{outtextxy}(120,80,\text{'Reinforcement Concrete Design'}); \]
\[ \text{outtextxy}(290,110,\text{'OF'}); \text{setcolor}(14); \text{settextstyle}(7,0,5); \text{outtextxy}(160,135,\text{'Deep Beams'}); \]
\[ \text{settextstyle}(2,0,6); \text{outtextxy}(380,460,\text{'Press Enter to Continuous'}); \]

end;

procedure Summary;

begin

\[ \text{writeln(tiespace}[4]:10:0); \]

end;

begin

\[ \text{assign(fi,'deep.doc'); rewrite(fi);} \]
\[ \text{s} := 4; \]
\[ \text{writeln(fi,'Stress\{4-8\}':15,'Stress\{1-4\}':15,'stress\{1-2\}':15,'Stress\{2-4\}':15);} \]
\[ \text{pload}[ss,ff] := 90; \]
\[ \text{nload} := 10; \]

\[ \{\text{repeat} \]
\[ \text{ss} := 1; \text{ff} := 1; \text{ll} := 1; \]
\[ \text{ratiotrans} := 50; \]

134
ss:=1;ff:=1;
overSP[ss]:=48;
shearSP[ss,ff]:=72;
width[ss]:=14;
cover[ss]:=4;
fbar:=4;
{pload[ss]:=214;
span[ss]:=160;
clearsp[ss]:=144; ...}
es:=29000; fy:=60; react[1,1]:=214; plwidth[ss,ff]:=16;
fcbar:=4;
for i:=1 to 11 do begin
for j:=1 to 11 do force[i,j]:= abs(force[i,j]);
end;
SteelDesign;
StrutCheck;
if key3=1 then
outstrut;
summary;
{until nload> 300 ; }

readln;
closegraph;

close(fi);
end.