FINAL REPORT

EXPERIMENTAL INVESTIGATION OF THE 3x10 WOOD LAGGING

SUBMITTED TO

JESUS MUSTAFA, P.E.
STRUCTURES DESIGN ENGINEER

FLORIDA DEPARTMENT OF TRANSPORTATION
STRUCTURES DESIGN OFFICE
DISTRICT 5, MS 3-545

BY

MOUSSA A. ISSA, Ph.D., P.E.
SENIOR STRUCTURAL ANALYST

FLORIDA DEPARTMENT OF TRANSPORTATION
STRUCTURAL RESEARCH CENTER, MS 80
2007 EAST PAUL DIRAC DRIVE
TALLAHASSEE, FLORIDA 32310

JULY 1996

EXPERIMENTAL INVESTIGATION THE 3x10 WOOD LAGGING

By: Moussa A. Issa, Ph.D., P.E.

EXECUTIVE SUMMARY

An experimental investigation was conducted by the Florida Department of Transportation Structural Research Center to investigate the flexural/bending stresses of a 3x10 wood lagging. A total of four(4) beams were tested. These beams were tested in a static mode in small loading increments until failure. The beams were tested in the weak axis to represent the actual field condition at one third point test (pure flexure in the middle third of the beam). Figure 1 shows the location of load for a typical test setup. The objectives of this experimental program were to investigate the bending stresses of the 3x10 in the weak axis. In addition, strains and deflections were also measured and collected at the middle location of the specimen. It is important to note that all the specimens had a fresh cut (green or wet condition). Moisture was coming out of the specimens as they were placed down on the concrete floor.

Strain gages were used to monitor the state of stress at the top and bottom of the specimen. Also, LVDT's were used to measure the deflection of the beam. Figure 2 shows the location of instrumentation for a typical test specimen. Theses gages were connected to a data acquisition system that continuously monitors and stores the data for further reduction and presentation.

The average density of the four beams was 62.4 Ibs/ft^3. This density was calculated based on the weight and cross sections of the beams after testing.

Figure 3 presents the results of the moment vs. midspan deflection for all the test beams. The plots depicted that these deflection vary from one beam to another for the same bending moment. For example, at a moment of 40 kip-in beam 1 reads 1.5" while beam 3 reads 1.03".

Figure 4 presents the results of the moment vs. top strain for all the test beams. The plots depicted that these strains are in compression and they vary from one beam to another for the same bending moment.

Figure 5 presents the results of the moment vs. bottom strain for all the test beams. The plots depicted that these strains are in tension and they vary from one beam to another for the same bending moment.

Based on the experimental results and experience it is recommended to use the lower bound of figures 3, 4 and 5. The lower bound represents the most critical deflections and stresses for the lagging design. A design moment of 41.0 kip-in will be used to calculate the allowable design stresses for the lagging. Based on the 41 kip-in. moment, beam test #1 allowable design stress will be 3,000.0 psi. This allowable design stresses should be adjusted according to the governing timber code (example NDS, AITC, ...).

Allowable (adjusted) Design Stresses = (Adjustment Factors) x (Allowable Design Stress)

or

$$F'_b = (C_D, C_M, C_t, C_L, C_F,, C_V, C_{fu}, C_r, C_f) \times (F_b)$$

Appendix A presents a design example of the existing lagging design.

Appendix B presents the same design example of Appendix A based on the recommended value of the research findings by the author.

This project is made possible by the support and cooperation of the staff at the FDOT/Structural Research Center. Special thanks are due to B. Hubbard, M. Coleman, G. Johnston, T. Beitelman. F. Cobb and A. Fishburn.

The results for the beam test specimens are discussed below: Beam Test #1:

Span Length = 7.5 ft.

Cross section: 2.875" x 9.9"

Beam weight = 90 lbs (57 Ibs/ft^3)

Section Modulus = $(b)(d)^2/6$ = 13.638 in^3.

Initial Cracking Load (P) = 2,450.0 lbs.

Maximum Moment = (30)*P = 73,500.0 lb-in.

Ultimate Load (P_{ut}) = 2,750.0 lbs.

Bending Stress (Fb) = 5,389.4 psi.

Beam Test #2:

Span Length = 6.0 ft.

Cross section: 2.875" x 9.9"

Beam weight = 82.5 lbs (60 Ibs/ft^3)

Section Modulus =$(b)(d)^2/6$ = 13.638 in^3.

Initial Cracking Load (P) = 4,500.0 lbs.

Maximum Moment = (24)*P = 108,000.0 Ib=in.

Ultimate Load ($P_{ult.}$) = 4,500.0 lbs.

Bending Stress (Fb) = 7,919.0 psi.

Beam Test #3:

Span Length = 6.0 ft.

Cross section: 2.875" x 9:9"

Beam weight = 93.5 Ibs (67.6 Ibs/ft^3)

Section Modulus = $(b)(d)^2/6$ = 13.638 in^3.

Initial Cracking Load (P) = 5,000.0 lbs.

Maximum Moment = (24)*P = 120,000.0 Ib-in.

Ultimate Load ($P_{ult..}$) = 5,000.0 Ibs.

Bending Stress (Fb) = 8,800.0 psi.

Beam Test #4:

Span Length = 6.0 ft.

Cross section: 2.563" x 9.9"

Beam weight = 80 Ibs (64.9 Ibs/ft^3)

Section Modulus = $(b)(d)^2/6$ = 10.839 in^3.

Initial Cracking Load (P) = 3,250.0 lbs.

Maximum Moment = (24)*P = 78,000.0 lb-in.

Ultimate Load ($P_{ult.}$) = 3,500.0 lbs.

Bending Stress (Fb) = 7,196.2 psi.

APPENDIX A

Design Example of the Existing Lagging Design.

LAGGING DESIGN

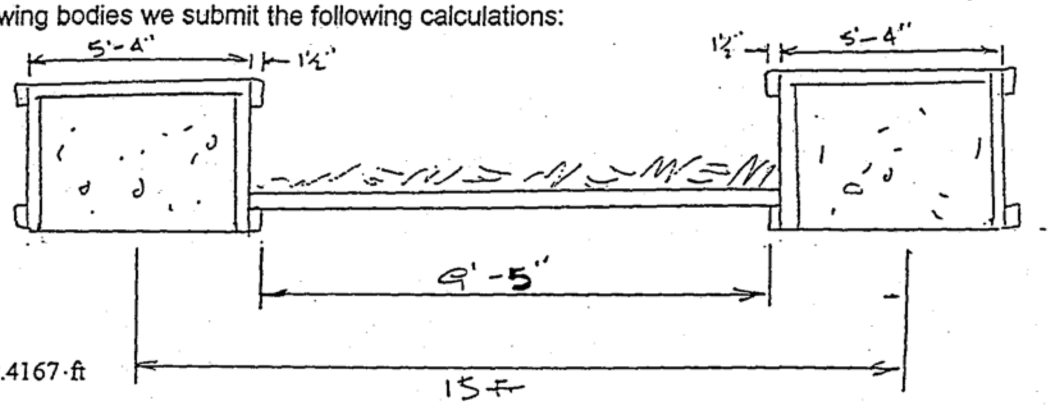
Three-inch (3") boards are used to maintain the earth between beams thereby maintaining the arching abilities of the soil to transmit the loading to the piles. To date, no authoritative design engineer has devised a theoretical method to accurately estimate the earth pressures that are applied to wood lagging. Several authors have discussed the subject; however, the most apparent factor resulting from the literature is that lagging is not designed, but the size of the boards are selected on the basis of judgment by experienced engineers and contractors. The following references are cited concerning lagging design:

a. Foundation Design, by Wayne C. Teng, 1962, Chapter 13, page 396. The most significant sentence states "lagging is seldom subject to high bending stress even if the calculated value is high."

b. Soil Mechanics in Engineering Practice, by Terzaghi & Peck, 2nd Edition, 1967, Article 38, the authors present a discussion on the theory of arching, which is the reason lagging defies analysis.

c. Foundation Engineering, by Peck, Hanson, & Thornburn, 2nd Edition, 1974, Chapter 27 applies to our discussion on pages 470-471, the authors offer a suggested method for design of lagging. However, they state that the results are likely to be overly conservative because of arching. They suggest the dimensions of the lagging should be selected on the basis of experience.

Lagging is normally sized empirically according to experience. However in order to satisfy the reviewing bodies we submit the following calculations:



$l := 9.4167 \cdot ft$

$p_a := 0.505 \cdot \frac{k}{ft}$

$F_b := 575 \cdot psi$ Appendix A for unrated mixed oak lumber- AASHTO Guide Design Specification For Bridge Temporary Works

$C_d := 1.15$

$C_m := 1$

$C_t := 1$

$C_l := 1$

$C_f := 1$

$C_{fu} := 1.2$

$C_r := 1.15$

$F_{bprime} := F_b \cdot C_d \cdot C_m \cdot C_t \cdot C_l \cdot C_f \cdot C_{fu} \cdot C_r$ per NDS

$F_{bprime} = 912.525 \cdot psi$

$M_{max} := \frac{p_a \cdot l^2}{12}$

$M_{max} = 3.732 \cdot ft \cdot k$

From experience it is known the calculated value for the maximum moment is unrealistically high. To compensate for this inoccuracy the maximum moment will be multiplied by a factor of 0.30.

$M_{max} := 0.3 \cdot M_{max}$

$M_{max} = 1.12 \cdot$ ft-k

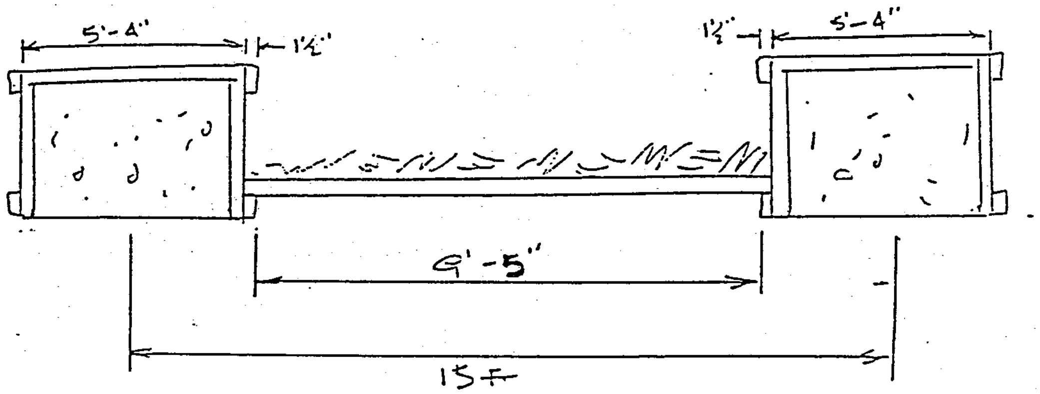
$S_{reqd} := \frac{M_{max}}{F_{bprime}}$ $S_{reqd} = 14.722 \cdot in^3$

Use 3"x 10" rough-cut mixed hardwood lagging, $S := \frac{10in(3in)^2}{6}$ $S = 15\ in^3$

APPENDIX B

Design Example of Appendix A
Based on the Recommended Value of the
Research Findings by the Author.

LAGGING DESIGN EXAMPLE



L = 9"-5"

P_a =0.505 kip/ft

F_b = 3,000.0 psi (Recommended value by Author)

C_D = 1.15

C_M = 0.85

C_t = 1.0

C_L = 1.0

C_f = 1.0

C_{fu} = 1.20

C_r = 1.15

F'_b = (C_D, C_M, C_t, C_L, C_f, C_{fu}, C_r) x (F_b) per 1991 NDS F'_b = (1.15*0.85*1 *1 *1 *1.20*1.15)*(3,000.0)

F'_b = 4,047.0 psi (Adjusted Allowable Design Stress)

$M_{max} = (Pa)(L)^2/12$; Maximum Moment

$M_{max} = (0.505)(9.4167)^2/12$

M_{max} = 3.732 kip-ft

$S_{req'd} = (M_{max})/(F'_b)$; Required Section Modulus

$S_{req'd}$ = (3.732*12,000)/(4,047.0) = 11.07 in^3.

➔$S_{req'd}$ = 11.07 in^3.

➔Use 3 x 10 rough cut mixed hardwood lagging.

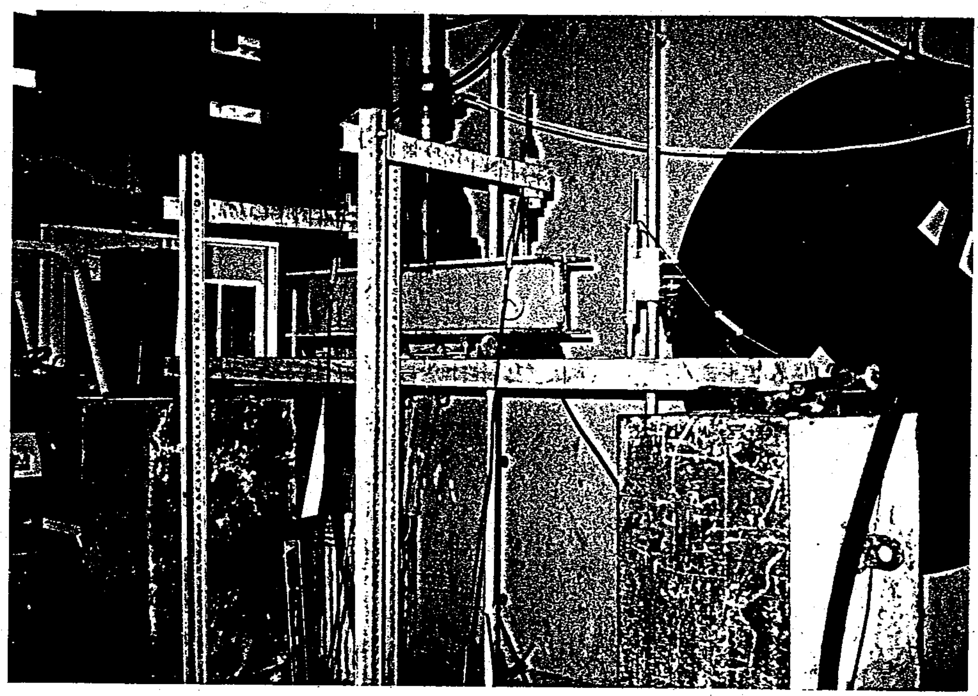


Figure 1 - Typical Test Setup and Location of Load.

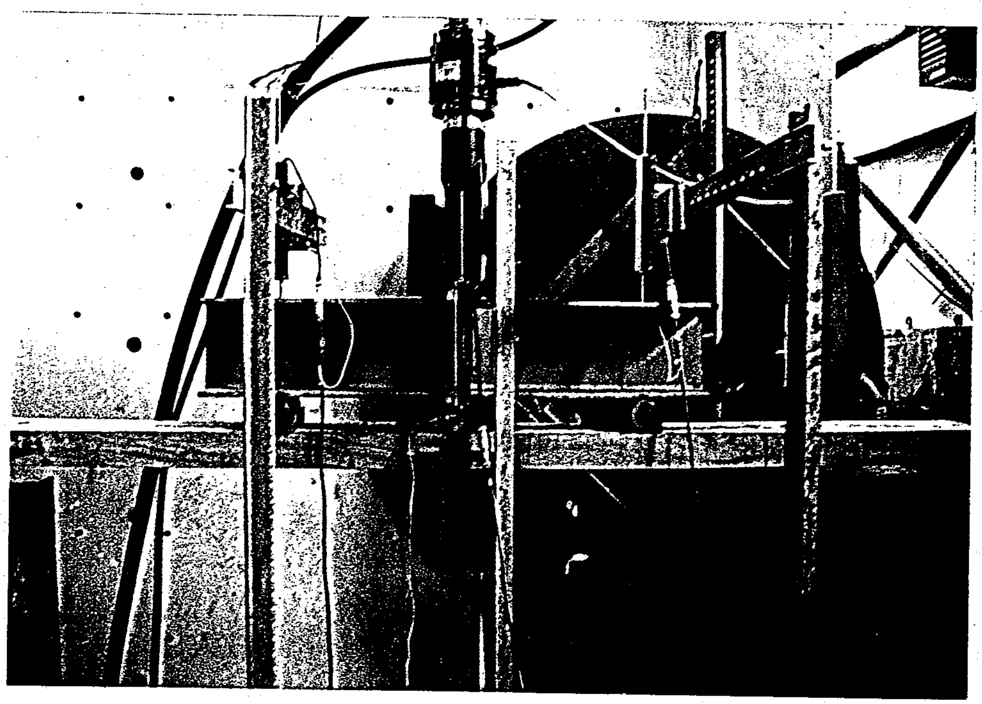


Figure 2 - Location of Instrumentation.

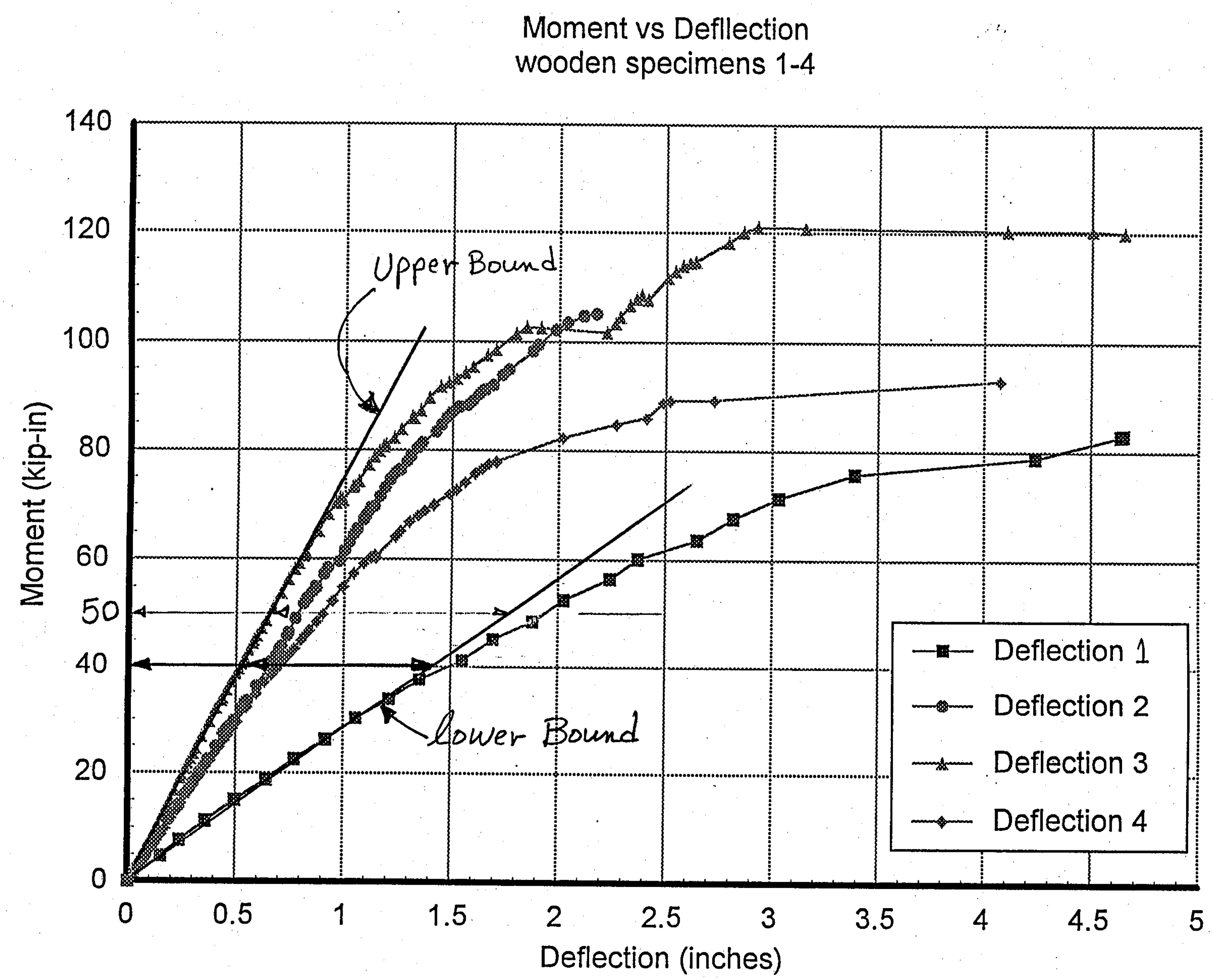

Moment vs Defllection
wooden specimens 1-4
Moment (kip-in)
140
120
100
80
60
50
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Deflection (inches)
Upper Bound
Lower Bound
Deflection 1
Deflection 2
Deflection 3
Deflection 4

Figure 3

Top Strain Comparison
Wooden specimens 1-4

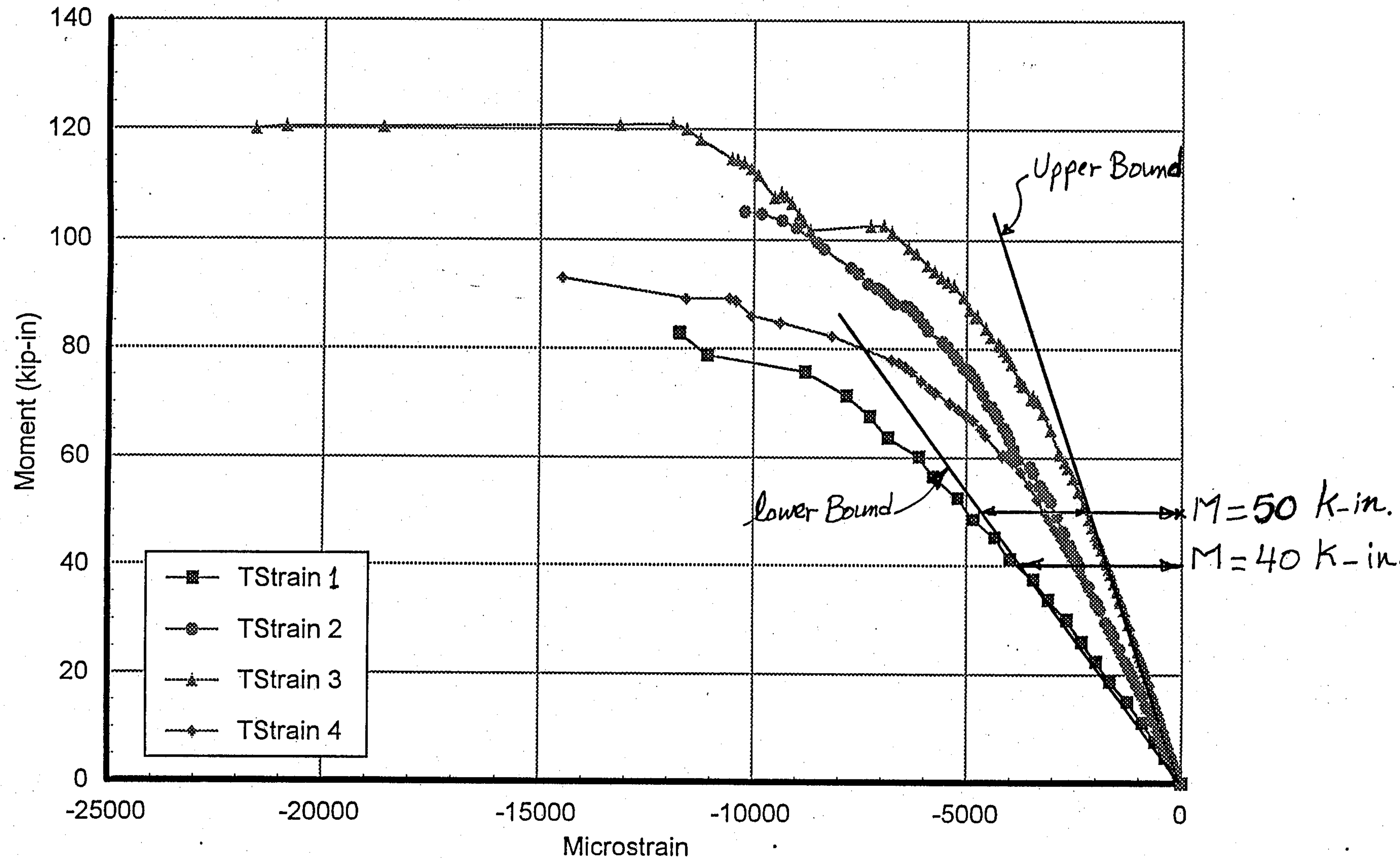


Figure 4

Bottom Strain Comparison
Wooden specimens 1-4

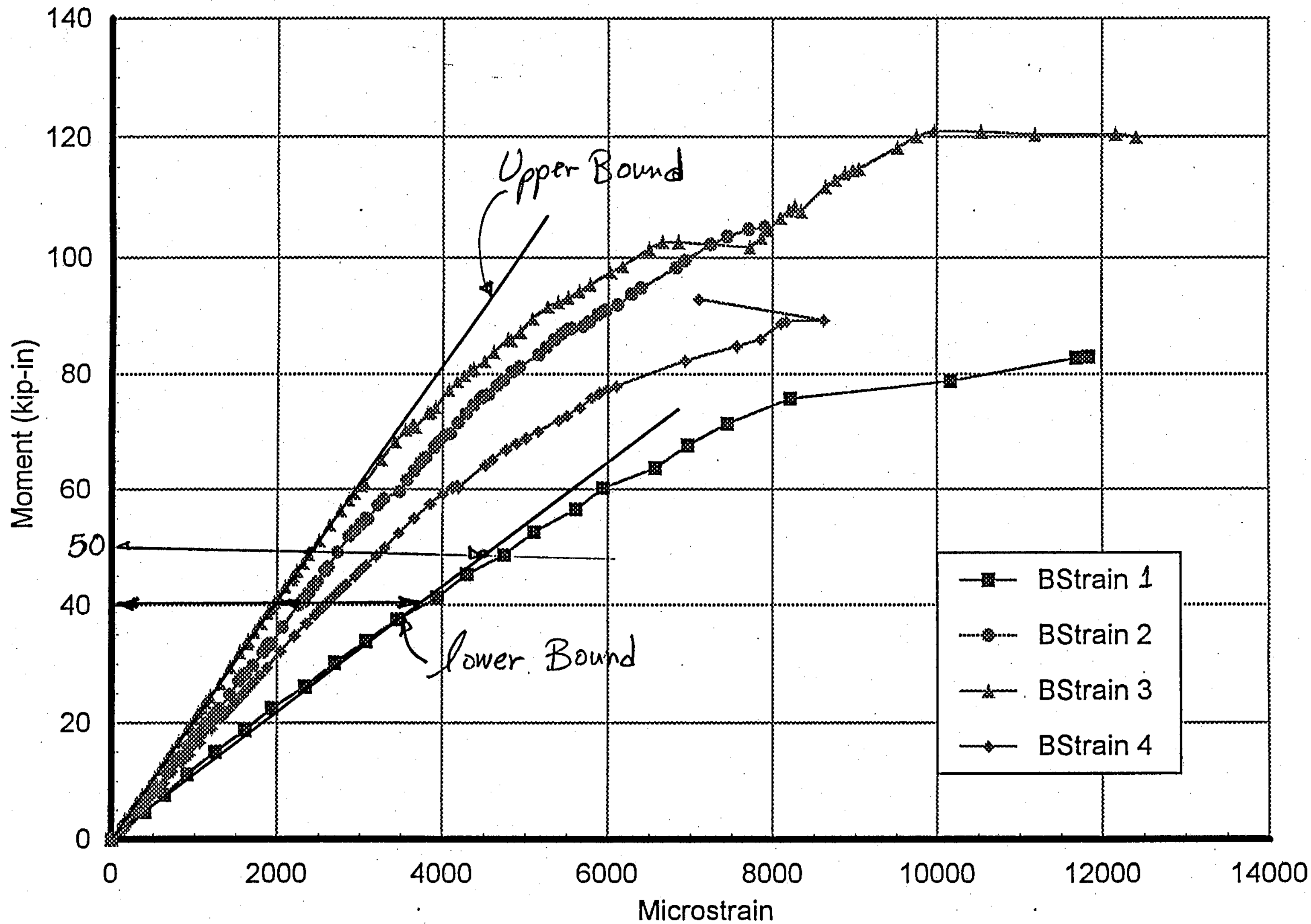


Figure 5