The Effect of Initial Out-of-Straightness and Taper on the Strength of Small, Round-Timber Poles

by

Kris J. Dick, P.Eng.

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

Department of Civil and Geological Engineering
University of Manitoba
Winnipeg, Manitoba, Canada

ISBN 0-612-16124-2

Name KRIS DICK

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

WOOD TECHNOLOGY — SUBJECT TERM

0746 — SUBJECT CODE

U·M·I

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION
General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523
Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
Language
- General 0679
- Ancient 0289
- Linguistics 0290
- Modern 0291

Literature
- General 0401
- Classical 0294
- Comparative 0295
- Medieval 0297
- Modern 0298
- African 0316
- American 0591
- Asian 0305
- Canadian (English) 0352
- Canadian (French) 0355
- English 0593
- Germanic 0311
- Latin American 0312
- Middle Eastern 0315
- Romance 0313
- Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
Philosophy 0422
Religion
- General 0318
- Biblical Studies 0321
- Clergy 0319
- History of 0320
- Philosophy of 0322

Theology 0469

SOCIAL SCIENCES
American Studies 0323
Anthropology
- Archaeology 0324
- Cultural 0326
- Physical 0327

Business Administration
- General 0310
- Accounting 0272
- Banking 0770
- Management 0454
- Marketing 0338

Canadian Studies 0385
Economics
- General 0501
- Agricultural 0503
- Commerce-Business 0505
- Finance 0508
- History 0509
- Labor 0510
- Theory 0511

Folklore 0358
Geography 0366
Gerontology 0351
History
- General 0578
- Ancient 0579
- Medieval 0581
- Modern 0582
- Black 0328
- African 0331
- Asia, Australia and Oceania 0332
- Canadian 0334
- European 0335
- Latin American 0336
- Middle Eastern 0333
- United States 0337

History of Science 0585
Law 0398
Political Science
- General 0615
- International Law and Relations 0616
- Public Administration 0617

Recreation 0814
Social Work 0452
Sociology
- General 0626
- Criminology and Penology 0627
- Demography 0938
- Ethnic and Racial Studies 0631
- Individual and Family Studies 0628
- Industrial and Labor Relations 0629
- Public and Social Welfare 0630
- Social Structure and Development 0700
- Theory and Methods 0344

Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
Agriculture
- General 0473
- Agronomy 0285
- Animal Culture and Nutrition 0475
- Animal Pathology 0476
- Food Science and Technology 0359
- Forestry and Wildlife 0478
- Plant Culture 0479
- Plant Pathology 0480
- Plant Physiology 0817
- Range Management 0777
- Wood Technology ....0746 —

Biology
- General 0306
- Anatomy 0287
- Biostatistics 0308
- Botany 0309
- Cell 0379
- Ecology 0329
- Entomology 0353
- Genetics 0369
- Limnology 0793
- Microbiology 0410
- Molecular 0307
- Neuroscience 0317
- Oceanography 0416
- Physiology 0433
- Radiation 0821
- Veterinary Science 0778
- Zoology 0472

Biophysics
- General 0786
- Medical 0760

EARTH SCIENCES
Biogeochemistry 0425
Geochemistry 0996
Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palynology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
Environmental Sciences 0768
Health Sciences
- General 0566
- Audiology 0300
- Chemotherapy 0992
- Dentistry 0567
- Education 0350
- Hospital Management 0769
- Human Development 0758
- Immunology 0982
- Medicine and Surgery 0564
- Mental Health 0347
- Nursing 0569
- Nutrition 0570
- Obstetrics and Gynecology 0380
- Occupational Health and Therapy 0354
- Ophthalmology 0381
- Pathology 0571
- Pharmacology 0419
- Pharmacy 0572
- Physical Therapy 0382
- Public Health 0573
- Radiology 0574
- Recreation 0575
- Speech Pathology 0460
- Toxicology 0383

Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences

Chemistry
- General 0485
- Agricultural 0749
- Analytical 0486
- Biochemistry 0487
- Inorganic 0488
- Nuclear 0738
- Organic 0490
- Pharmaceutical 0491
- Physical 0494
- Polymer 0495
- Radiation 0754

Mathematics 0405
Physics
- General 0605
- Acoustics 0986
- Astronomy and Astrophysics 0606
- Atmospheric Science 0608
- Atomic 0748
- Electronics and Electricity 0607
- Elementary Particles and High Energy 0798
- Fluid and Plasma 0759
- Molecular 0609
- Nuclear 0610
- Optics 0752
- Radiation 0756
- Solid State 0611

Statistics 0463

Applied Sciences

Applied Mechanics 0346
Computer Science 0984
Engineering
- General 0537
- Aerospace 0538
- Agricultural 0539
- Automotive 0540
- Biomedical 0541
- Chemical 0542
- Civil 0543
- Electronics and Electrical 0544
- Heat and Thermodynamics 0348
- Hydraulic 0545
- Industrial 0546
- Marine 0547
- Materials Science 0794
- Mechanical 0548
- Metallurgy 0743
- Mining 0551
- Nuclear 0552
- Packaging 0549
- Petroleum 0765
- Sanitary and Municipal 0554
- System Science 0790

Geotechnology 0428
Operations Research 0796
Plastics Technology 0795
Textile Technology 0994

PSYCHOLOGY
General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

THE EFFECT OF INITIAL OUT-OF-STRAIGHTNESS AND TAPER ON THE STRENGTH OF SMALL, ROUND-TIMBER POLES

BY

KRIS J. DICK

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

Abstract

An experimental test programme was conducted on small, round, white-spruce poles. The effect of taper and initial out-of-straightness on the performance of these poles as structural members was investigated. A total of 102 specimens were tested and measured. The specimens were 2110 mm in length with a diameter range of 45 to 94 mm. A design model was developed for use with this size and species of timber pole. A modification factor $\mathbf{K}_{TO}$ was defined to be used in a limit states design approach in determining the specified compressive strength parallel to the grain, f_c. A second, but no less important aspect of this research, was the design and fabrication of the laboratory equipment used in the testing programme. This component of the work provided valuable insight into the feasibility of constructing practical test equipment from locally-available resources.

Preface

This thesis chronicles approximately four years of thought, study, speculation, research, fabrication and physical testing related to small, round, white-spruce poles. There are principally two main components to the work discussed in this document: (i) the design and fabrication of laboratory test equipment used for the research ; and (ii) the testing of the poles to investigate what relationship, if any, exists between the initial out-of-straightness and taper of a pole and its performance as a structural member.

The thesis has been arranged in the following manner: Chapter One provides the setting for the research. The impetus for this work is presented, along with a review of others efforts in this field. Chapter Two discusses the philosophy, design, fabrication and application of the test equipment used in this research. Chapter Three outlines the test programme itself, what was measured, why and how. In Chapter Four, the data that emerged from the test programme is discussed and analysed, culminating in a proposed design tool or model. The relationship established between the initial out-of-straightness and taper on the performance of a small, round, white-spruce pole is expressed in a mathematical and a graphical form. How this model could be applied in a limit states approach to timber design for small poles is the focus of Chapter Five.

During the course of this research some issues and questions have emerged that, while interesting, would have sidetracked the focus of the discussion. Chapter Six provides an opportunity to briefly discuss these issues.

When research of this nature is undertaken, there are some fundamental questions in search of illumination. In the process of seeking answers other queries tend to emerge. Chapter Seven makes some suggestions for further research to both expand this work and also to look at other, but no less important aspects, of timber design. Chapter Eight sums up the research with general comments and conclusions.

Much information has been gathered during this research. The rationale and design processes involved in test equipment fabrication combined with choices made along the way, require a fair amount of documentation. Inclusion of this material in the main body of the thesis was not considered a satisfactory approach for presentation. Thus, seven appendices have been included within this thesis. Although they are all self-explanatory, a comment on Appendix A - Specimen-Specific Data, is felt to be warranted. The author was concerned that often raw data becomes separated from the original document unless a perfect archival system exists. It was decided, therefore, that the raw data be presented with the thesis for the use of any interested individual in the future.

This research has been a challenging learning experience within a continuum of work with timber that the author hopes with continue for a long time to come.

Kris J. Dick, P.Eng.

Anola, Manitoba, Canada

Desktop publishing, graphics and layout by the author.

Acknowledgements

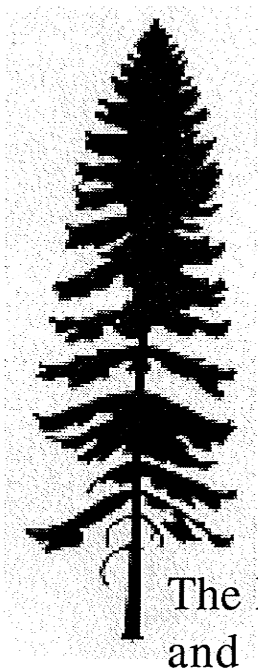
Although research may be primarily a solitary endeavour, it is not done without support which contributes to the greater whole. The author takes this opportunity to thank the following for their contribution:

The University of Manitoba Graduate Fellowship Awards for financial support for the past three and a half years;

To the author's PhD. committee: Dr. M. Britton; Dr. D. Polyzois, and; Prof. J.Glanville for supporting a research project a little out of the ordinary. A special thanks to Dr. A.M. Lansdown, P.Eng. , PhD. advisor, for unselfish sharing of his particular brand of knowledge and concern for those things natural;

The Engineering Structures Lab at the University of Manitoba for the loan of two proving rings, and;

Last, but by no means least, the author's family Suzanne, Graham, Colin and Rebecca who have not seen husband and father as much as they might have liked over the past while. Also, to Jean Dick for looking after children to free up time for testing and writing.



The Effect of Initial Out-of-Straightness and Taper on the Strength of Small, Round-Timber Poles

To know a tree's name is the beginning of aquaintance - not an end in itself. There is all the rest of one's life in which to follow it up.
Julia Rogers, The Tree Book, 1905

K.J. Dick

Table of Contents

Page

Table of Contents

Page

Table of Contents

List of Figures

List of Figures

Page

List of Figures

Page

List of Figures

Page

List of Figures

Page

List of Tables

Page

Abbreviations and Symbols

A	- cross-sectional area
ASTM	- American Society for Testing and Materials
C	- compression
CW	- clockwise
CCW	- counter-clockwise
CSA	- Canadian Standards Association
CWC	- Canadian Wood Council
cm	- centimeters
DOM	- drawn over mandrel
E	- modulus of elasticity
E_{05}	- modulus of elasticity for design of compression members
GF	- gauge factor
gst	- goods and services tax, Canadain federal tax
I	- moment of inertia
in	- inches
in^2	- square inches
f_c	- specified compressive stress parallel to the grain
F_C	- $f_c(K_D K_H K_{Sc} K_T)$, modified compressive resistance parallel to grain
FSP	- fibre saturation point
ft	- foot, or feet
K_C	- slenderness factor
K_D	- load duration factor
K_H	- system factor
K_{Sc}	- service condition factor
K_T	- treatment factor
K_{TO}	- taper and intial out-of-straightness factor

Abbreviations and Symbols

K_{Zc}	- size factor for sawn lumber
kN	- kilonewton(s)
kPa	- kilopascals(s)
L	- length of specimen
lbs	- pounds weight
lbf	- pounds force
LH	- left-handed
LSD	- limit states design
MC	- moisture content
min	- minute
mm	- millimeter(s)
mm^2	- square millimeter(s)
MOE	- modulus of elasticity
Mpa	- megapascal(s)
MS	- mild steel
MSR	- machine stress rated
mV	- millivolt(s) ($1x10^{-3}$ volt)
n	- number of active arms in Wheatstone bridge
OS	- initial out-of-straightness
P	- load
Pr	- factored compressive resistance;
psf	- pounds per square foot
psi	- pounds per square inch
pst	- provincial sales tax, Manitoba
r,R	- correlation coefficient
RH	- right-handed

Abbreviations and Symbols

SC	- straight crack
SD	- standard deviation
S-P-F	- spruce-pine-fur species group
SS	- select structural
T	- tension
TR	- taper ratio
typ.	- typical
U	- strain energy
V	- voltage
V_o	- excitation voltage
V_{in}	- input voltage in bridge
V_{out}	- output voltage from bridge
ΔV	- change in voltage
vs	- versus
°	- degrees
Δ	- deflection
δ	- deflection
"	- inch(es)
'	- foot or feet
ϕ	- diameter
ϕ	- 0.8, resistance factor in limit states design
ε	- strain
σ	- stress
μ	- sample mean
μV	- microvolt(s) ($1x10^{-6}$ volt)
ν	- Poisson's ratio
π	- constant, 3.1416
%	- percent
$\cong$	- approximately equal to

1

Introduction

1.0 Introduction

1.1 Background:

The structural use of round timber is not a new phenomenon. The ability to use round timber, harvested from forests adjacent to their communities for building construction, was a skill many people had. For centuries, housing, agricultural, and commercial structures were built using round timber construction. As hand-sawing and hand-hewing gave way to advances in mechanized sawing, the ability to produce regular, square-cornered timbers was enhanced. The use of dimensional timber products became more practical. The creation of an industry with a vested interest in maintaining the use of dimensional timber products occurred coincidentally. Of course this is understandable, but as a consequence, interest in research surrounding the structural use of round timber appears to have waned substantially over the past three decades.

In many regions of the world the use of round timber for construction purposes is still commonplace. Figure 1.1 illustrates a traditional housing structure in the south of Sierra Leone, West Africa. The timber stands that are used for house construction are also used as firewood for cooking fires. In a region with a dwindling timber-resource base, conflicts can emerge.

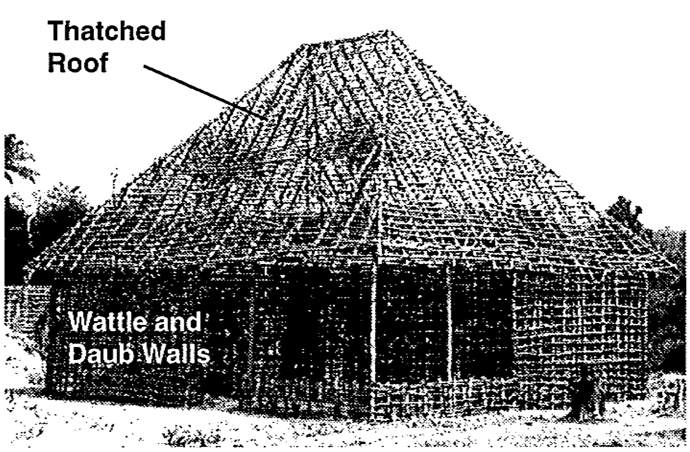


Fig. 1.1: Traditional Structure in Sierra Leone.

The author became interested in the use of timber for these structures while living and working in Sierra Leone. Of particular interest were the diameter, amount, and structural integrity of the round-timber poles that were being used. The development of a metal-connecting system for the fabrication of round-timber trusses (Dick, 1989) and subsequent testing of the system both in Canada and Sierra Leone (Dick, 1992) provided the impetus for more focused work with respect to the behaviour of round-timber poles.

The original work on pole trusses (Dick, 1989) used poles of poplar, or trembling aspen, for the truss members. It was always of interest to the author to fabricate trusses using spruce poles. Being both a softwood and inherently straighter than poplar it was felt that spruce would work well with the connecting system.

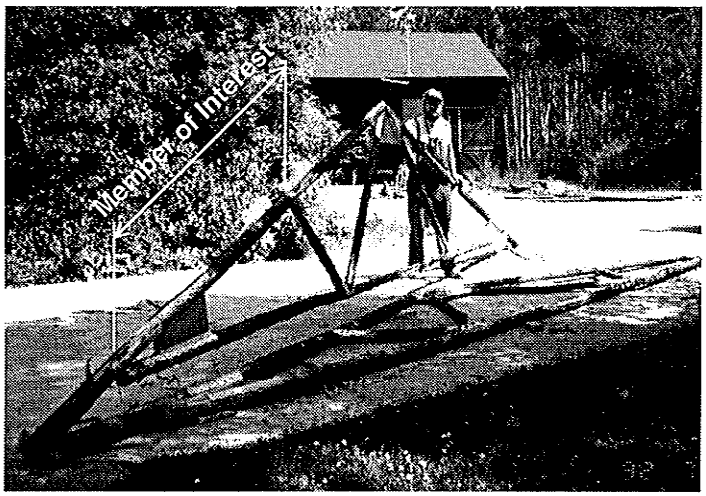


Fig.1.2: One of the trusses used in July, 1992 test.

In July of 1992, a full-scale truss test was conducted on a pair of 7.3m (24 ft.) span, 1/6 pitch, W-trusses,(Fig.1.2) in accordance with CSA Standard S307-M1980 (CSA, 1980) . This test was carried out at the author's facilities to observe the behaviour of white-spruce poles when used with the connecting system developed. As anticipated, (Dick, 1989, 1992) the trusses performed well, sustaining a load in excess of 2.3 kPa (48 psf). What emerged from this test, combined with considerable thought and discussion was *"I wonder what the actual behaviour of the pole members is like?"* and *"If I were to pick one member of the truss to examine closer which one would I choose?"* The choice of which member to look at more closely was quite apparent: that running from the heel joint to the first panel point of the top chord – the member that most often has to resist a higher compressive load than any other member in the truss (see Fig.1.2). An answer to the first question forms the basis of this thesis.

1.2 Focus of Thesis

This research encompasses two overarching goals - the development of testing facilities and physical testing of pole specimens. Three objectives emerge from these goals:

1. To examine the feasibility of fabricating all test equipment to simulate conditions in a developing region where test facilities may not exist;
2. To investigate the effect of initial out-of-straightness and taper on the strength of small-diameter white-spruce poles by a process of physical testing; and
3. To develop a design tool that could be used in the design process of small-diameter, white-spruce pole compression members.

This, more-focused work on timber poles, is in keeping with an underlying theme of previous work: that of sustainable technology (Dick, 1989, 1992). The application of the technology presented in this thesis will likely be most appropriate in developing regions, although by no means exclusively so. The essential equipment to conduct precise scientific work must also be portable to the same geographical locations, enabling communities to investigate solutions to construction issues using locally-available resources. This is, in essence, the rationale behind building all of the test equipment for this experimental investigation. A detailed discussion of the design considerations, fabrication processes, and use of the test equipment forms Chapter 2 of this thesis.

The decision to investigate the effect that initial out-of-straightness and taper have on the strength of small, round-timber poles emerged for a variety of reasons. Observations made by the author while fabricating trusses in Sierra Leone; a lack of specific literature on the subject; how crooked can a pole be before it is not usable; combined with considerable reflection and an over-arching personal *need to know*, led to the research presented and discussed in Chapters 3 through 5.

The adjective *small* has been used in conjunction with these poles as a means of differentiating them from the typical pole size used for piles and power, or hydro, poles. The mean diameter at mid-height of the test specimens in this research was approximately

70mm (2.75 in.). The length of the test specimens corresponded to the distance from the heel joint to the first panel point of a 7315 mm- (24ft-) span truss, or, 2108 mm(83 in.). A total of 102 specimens were tested and measured. The data from complete measurement and compression testing of 58 specimens were used to formulate a proposed design tool. Three specimens were used to test the model. These specimens were measured and tested with the results compared with the proposed design tool. The remaining 41 specimens were measured only to provide additional information for the database on this particular selection of pole specimens. Each completely tested specimen yielded the following information for the database:

- Dimensions of pole specimen at 0, L/4, L/2, 3L/4 and L, measured from the butt end;
- Pole taper and initial out of straightness;
- Specimen-specific stiffness;
- Load versus lateral deflection at L/4, L/2, 5L/8 and 3L/4;
- Angle of twist ;
- Moisture content; and
- Tension and compression zones at final breakage location of pole.

It is considered important at this juncture of the thesis to state briefly the perceived contribution of this work to the field of timber technology is. In other words, what is the gap or seam that this work addresses? There has been much research done into the behaviour of compression members, in steel, concrete, and timber. When dealing with timber that is to be used in its natural state there exist many variables in the geometry of the pole. Although the author was cognizant of current design approaches, there was still a reticence to use the assumptions in design equations as a starting point. In particular, the design of wood poles is based on information derived from poles with diameters considerably in excess of the specimens of interest in this research. To affect any comparison of these specimens it was felt that the most valid way to approach design with these poles was to base a design aid or model on experimental data obtained from actually working with the poles. Once this was done and a model or design tool established, then, and only then, could a meaningful comparison be made with existing column design formulae that have been developed primarily from experimentation with sawn, dimensional timber.

1.3 Pole Specimens used for Testing:

The white-spruce poles used in the testing programme, shown in Figure1.3, were purchased locally in Anola, Manitoba. The original source of the poles was the Duck Mountain region of west-central Manitoba where they are generally cut in January or February. The bundle of 100 poles cost $289.00 , or $2.89 per pole (see also Sec.6.5). Each pole was approximately 4878 mm (16 ft.) in length. Two specimens were cut from each pole(see Fig.3.1). Specimens were selected from the bundle based on their suitability for an end use of truss fabrication. Some poles, however, were selected for as much out-of-straightness as possible since one of the parameters to be investigated was to determine an out-of-straightness limit beyond which a pole would be considered unacceptable. The testing programme was conducted from November, 1993 through to June, 1994. All research work was conducted at shop facilities near Anola, Manitoba.

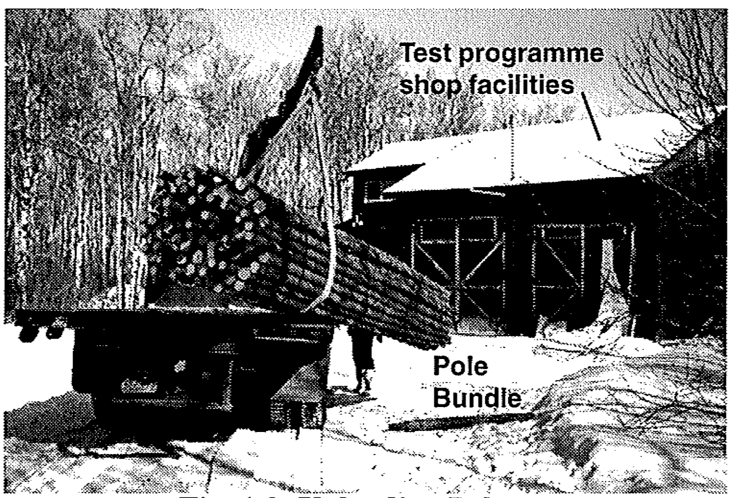


Fig. 1.3: Unloading Poles

1.4 Timber Terminology

The purpose of this section is to clarify how certain terms related to timber are within this document. Likely the most confusing issue is what is the difference between "timber", "wood", and "lumber". There are several approaches used by various authors, however, this author puts forth his version as follows: **Timber** - a useable section of a tree in its natural state, that is, round; **Lumber** - timber that has been converted to dimensional sizes by sawing; and, **Wood** - a clear, defect-free piece of timber, usually quite small.

The remainder of the list of timber terms is in point form for the sake of brevity.

Anisotropy: the properties of timber differ depending upon from which direction they are measured. (see Fig 1.4)

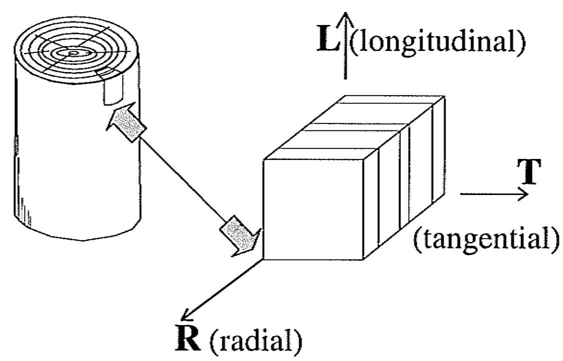


Fig. 1.4: Anisotropic Timber Axes

Pole: a round timber

Spiral grain: direction of the grain as it twists around a tree. In a round timber, direction from the butt end up to the top. (See Fig.1.5, and also Sec.6.7)

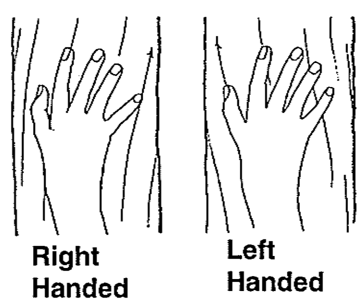


Fig.1.5: Spiral Grain
(source: Phleps, 1982)

1.5 Literature Related to Timber as a Structural Element

Information directly relating to the structural behaviour of small-diameter, round-timber poles is limited at best. The majority of the literature specific to the use of round timber deals primarily with timber piles, large-frame pole structures, and hydro or power pole structures.

The American Society for Testing and Materials(ASTM) Standards D25 and D2899 are specific to round timber piles. Although ASTM Standard D3200 deals with design stresses for round timber construction poles, there is a loop back to D25 and D2899 when the reader is directed to use the methods presented in D2899 to establish design stresses. Albeit most useful information, two concerns emerge. First, the minimum pole size discussed in the standards was far in excess of the maximum poles that would be used for truss construction within the context of this work. Minimum circumference for a 3048mm (10 ft.) pole in the standard is 406 mm (16 in.). (Equivalent to a 129 mm (5 in.) diameter pole.) (ASTM - D3200 -74) The second, and perhaps more important concern, is that the design stresses in the specifications are based on tests on clear wood samples as contained in ASTM-D2555. It was felt that to gain insight into the behaviour of small, round, white-spruce poles, full-scale tests had to be carried out.

In Canada, the Canadian Standards Association (CSA) produces the National Standard of Canada for Engineering Design in Wood, CAN/CSA-086.1-M89. In addition to three pages on pole construction in this standard, there is also CAN3-015 which deals specifically with pole-type structures. Again, as with ASTM, the size of poles discussed are much larger than the poles of interest in this research.

In two papers by Huybers (1984 and 1985) the use of round timber for the construction of dome structures is discussed. A total of 9 tests were performed on 10 cm (4 in.) diameter poles. These tests were conducted, however, to examine the behaviour of a connection system designed for the dome. They were conducted on 80 cm (32 in.) poles in tension.

A very interesting report was produced by G.B. Walford of New Zealand in 1981. In his report, *The Effect of Mechanical Debarking on the Strength of Corsican Pine Poles*, Walford discusses bending tests that were conducted. Although the size of the poles tested were a minimum of 150 mm (6 in.) in diameter, the report provides valuable insight into the differences in pole strength with respect to mechanical, versus hand, debarking.

Studies at the University of Manitoba on hydro poles (Savic, 1991) information on some of the issues surrounding the testing of large-diameter poles was provided.

There exist a few publications that fall under what one might call "appropriate solutions in building construction". In a publication entitled *Shanty Upgrading*, J.P.M. Parry(1987) briefly discusses the use of unsawn poles for low-cost structures. There is, however, no indication of size, species or design guidelines. Similarly in their book, *Building Materials in Developing Countries*, Spence and Cook(1983) briefly discuss pole structures. One caveat they cite is not to use timber that may have been damaged from felling operations or that constrained any localized defects that may adversely affect the performance of the pole when subjected to compression forces. Again, there are no specific design guidelines. A resource guide put out SKAT - Swedish Center for Appropriate Technology (1988) has a brief section on the use of poles in construction. Various jointing techniques are described, but once again no design guidelines are included.

While living and working in Sierra Leone, the author came across a paper by A.M. Iscandari (1988) in which a test that was carried out at Fourah Bay College in Freetown on a single scissor truss with a span 6098 mm (20 ft.) is discussed. Load-deflection curves were determined for the truss. Although this author did see the setup for the test in person, he was unable to find Mr Iscandari to discuss his work further. Suffice it to say, the experience did provide corroboration that the use of round timber for truss construction was potentially feasible.

For many years timber design in North America and elsewhere in the world was, and still is in some cases, based on information about timber material properties obtained from small, clear wood specimens. As Madsen (1992) points out: " The two products – wood, in the sense of clear, defect-free wood and timber, in the sense of commercial timber – have to be considered as two different materials and that must be respected when strength properties are developed for engineering purposes." The testing of small, clear wood specimens as outlined in ASTM 2555 for use in engineering design has its origins in the 1920's. The behaviour of clear-wood specimens in failure may not reflect what happens with timber in structural sizes however. As the Western Wood Products Association (WWPA, 1991) states : "History shows that existing design values based on the clear wood approach (ASTM D2555/D245) are adequate and conservative.... design values are at the core of structural lumber safety and associated liabilities." The mounting concern about predicting timber performance based on clear-wood samples led to testing programs in both Canada and the United States in the 1970's. In addition, in Canada the move towards Limit States Design, based on statistical probability of material properties, puts timber at a distinct disadvantage due to the inherent uncertainty related to the use of clear wood specimens to predict structural timber performance (after Madsen, 1992) *In-Grade Testing Programs* (Madsen, 1983, 1992; Buchanan, 1984, 1985; WWPA, 1991) investigated the behaviour of timber in dimensional sizes used in the construction industry. Tests on full-scale specimens have become more commonplace.

At a microscopic level wood is "a complex chemical material"(Wangaard, 1981) composed of many tube-like cell structures call tracheids, for the most part running in a longitudinal direction, all glued together with lignin and a combination of other chemicals, depending upon the species. These tube-like elements afford the timber member a fairly high degree of flexural rigidity, while at the same time providing a high stiffness-weight ratio (after Silvester, 1967). The ability of timber to sustain a certain amount of permanent deformation without appreciable loss of strength identifies it as a material that exhibits *plastic* characteristics. The significant non-linear behaviour of the cellulose content of the wood under loading, as Silvester (1961) points out, accounts for timber's ability to sustain permanent set.

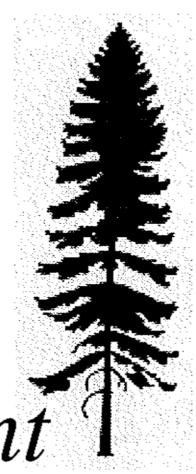
The application of fracture mechanics as a design approach used by Valentin(1991), Bostrom (1991) and Nielsen (1992) views wood as a visco-elastic material. Whether the choice of terminology is *visco-elastic*, *quasi-plastic* or *glass-like,* there is an implicit "time-dependent" characteristic to timber that is reflected in its response to *rate of loading* and the *duration of load.*

It has been known for more than 200 years (Booth, 1964), that timber reacts in different ways based on the length of time it has to sustain a load. This is reflected in CAN/CSA 086.1-M89, (National Standard of Canada, 1989) in clause 4.3.1 where the Load Duration Factor - K_D is discussed. For a so-called permanent load there is a 35% reduction factor, drawing attention to this important property of timber. Publications by J. Liska (1950), L. Wood(1960), K. Johns(1982), Madsen and Johns (1982a, 1982b), Glos(1986), United States Department of Agriculture(USDA, 1987) and Madsen (1992) chronicle the discussion regarding the effect of the duration of load and the rate of loading on timber behaviour. Generally speaking, higher values of strength are obtained for wood loaded at more rapid rates and lower values are obtained at slower rates (USDA, 1987).

Hoadley, in , *Understanding Wood*, (1980) and *Identifying Wood*, (1990) presents detailed information about the nature, composition and behaviour of wood, which provides the reader with valuable insight into the character of wood. When discussing the strength properties of wood, however, the discourse is restricted to ASTM clear wood standards.

Clearly, testing of full-scale specimens has been seen by many timber researchers as valuable to increasing the database of timber knowledge. It appears, however, that the vast proportion of research attention has gone to sawn lumber, and that attention paid to round-timber has gone to large-diameter poles.

2



Test Equipment

2.0 Test Equipment

2.1 Introduction

The ability to transfer technology is considered by the author to be a very important component of what we do as engineers. Previous work in developing a connecting system for round timber poles (Dick, 1989, 1992) had a strong thread of sustainable technology running through it. It was mandatory, as far as the author was concerned, that this sentiment carry on into this research. It was not sufficient to simply test indigenous material. The research also had to incorporate a component that would address the need to be able to do precise scientific work without a dependence on capital-intensive laboratory facilities. The equipment used for this experimental programme had to be low-cost and portable. The term low-cost is self-evident. The concept of portable, however, within this context deserves a bit of discussion. By portability, what is meant is not that the entire ensemble of equipment is to be shipped to another location. It implies rather, that the key physical components of the test facility can be easily transported along with the understanding of why the various pieces of equipment have been fabricated the way they have been. In this particular case, all of the key components could be put in a suitcase. Of equal importance would be a set of notes to accompany the key pieces, clearly illustrating the rationale behind the test equipment construction. The reason for fabricating the test equipment was, therefore, to simulate conditions that might be encountered in a developing region where this type of facility may not exist. It was important to demonstrate and document that precision equipment could be manufactured at low cost. If a facility of this nature was established in region where none existed previously, it could be used for a wide variety of research. Once operational, this type of laboratory could assist in the setup of other facilities in a region by providing the means to standardize equipment for example.

Within this chapter the four main components of the test facility are discussed within the context of design rationale, fabrication, and cost. Basic illustrations of the equipment are included in this chapter for discussion purposes. Detailed design drawings are contained in Appendix B.

2.2 Background and Fabrication Considerations

Four main pieces of equipment were fabricated for the research work.

Measuring Apparatus: Used to define the initial out-of-straightness of the test poles and to provide information about the varying diameters and taper of the poles.

Bending Test Apparatus: An apparatus used for determining modulus of elasticity of the pole specimens.

Column Test Frame: A large rectangular frame used in conjunction with a load cell and hydraulic cylinder for testing pole specimens in compression.

Load Cell: A device to enable precise measurement of load.

The site of the test facility is located at the residence of the author, just east of Winnipeg, Manitoba. Fabrication of the test equipment was done exclusively by the author who is a Journeyman Boilermaker.

The criteria used to assess the design and fabrication of the test equipment developed were as follows:

1. **Availability** - What kinds of material available locally related to the type of equipment to be fabricated?

2. **Workability** - Could the material be handled within the context of a small welding and carpentry shop environment? In other words, could the fabrication be done with the available technology and tools owned by the author?

3. **Appropriateness** - Was the material something that could reasonably be found most anywhere or was it very task specific? and

4. **Cost** - Was the capital cost of the material within the limited budget available?

Material used in the construction of the test equipment was reclaimed. This helped to reduce capital cost while at the same time addressed the issue of sustainability. Ease of use was another important design criterion. Since all of the tests were to be conducted by a single person, careful consideration had to be given as to how each apparatus would be used. Fabricating all of the major components within this environment provided valuable insight into the ability to replicate this type of equipment in developing regions, where elaborate shop facilities are unlikely to be available, but the ability to perform precise scientific work is required. It was within these parameters that the rationale for the design and construction of the test equipment was formulated. There were many lessons learned during the design, fabrication and use of the equipment. If one were to make an overall comment it would be that – *What the apparatus is made of is often not as critical as the understanding behind why it should be constructed in a certain way.* A clear vision of what the researcher wants the apparatus to do, combined with a firm grasp of the underlying concepts, translates into a useful piece of equipment.

2.3 Measuring Apparatus

One of the parameters to be investigated in the experimental programme was the effect that the initial out-of-straightness of the pole had on its resistance to axial compressive load. How to define pole out-of-straightness was one of the first issues to be clarified.

2.3.1 Fabrication Details:

The apparatus illustrated in Figure 2.1 was designed to allow the pole to remain stationary while measurements were taken. The bed of the apparatus was fabricated out of 127 mm (5 in.) channel iron, 2210 mm (87 in.) long. The end plates, 10mm (3/8 in.) mild steel(MS) plate, were welded onto the ends of the channel-iron bed using lowhydrogen, 48018 (7018) welding rod. The four wire references lines were fixed a set distance in space relative to the centreline of the pole (See Fig. 2.2). Each wire passed through a longitudinal hole drilled in a 10mm- (3/8"-) diameter bolt screwed into a threaded hole in each end plate. The wire was attached to the head of the bolt. To keep the wire taut, the bolts could be turned counter-clockwise, or backed-off, which applied tension to the wire. At the centreline of each end a 13 mm- (1/2"-) diameter bolt ran through the end plate. Once the specimen was in place the bolt was tightened at each end to hold the specimen firmly in position. (see detail Fig. 2.1)

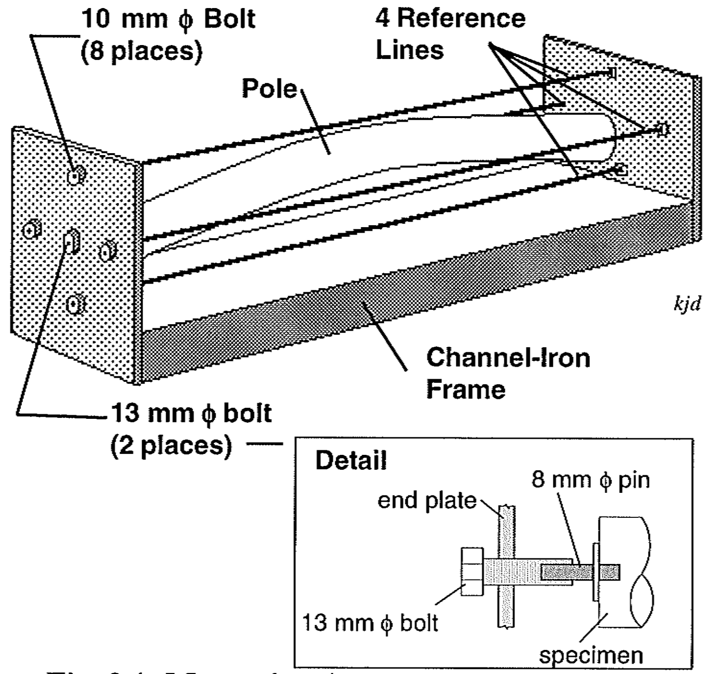


Fig. 2.1: Measuring Apparatus

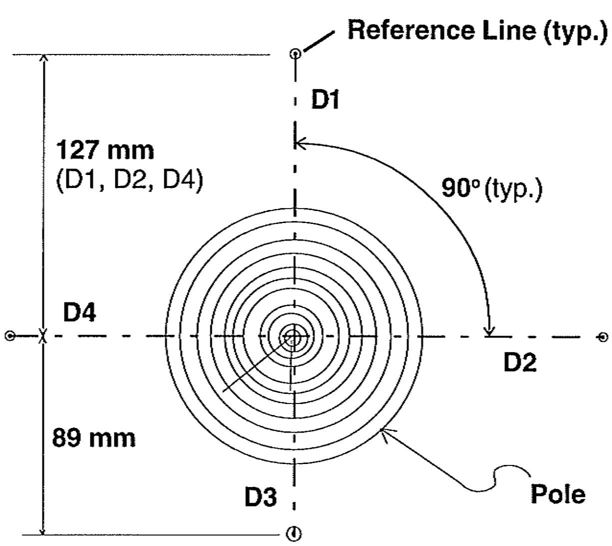


Fig. 2.2: Reference line location

2.3.2 Application:

When the specimen was first placed in the apparatus it was rotated to position any bow in the pole upward. The specimen was then clamped tight by means of bolts that ran in threaded holes in the end plate. A lumber crayon was used to mark the *bow-up* side of the pole. Using the reference lines, a line normal to the bow was scribed at each end of the specimen(see Fig. 2.3). These lines assisted in correct placement of the specimen in the column test frame.

Before a specimen was placed in the apparatus, the ends were checked for squareness. If required, a belt sander was used to square the ends. A centre gauge was then used to locate the centre of the pole. At this location, an 8 mm-(5/16"-) diameter hole was drilled into each end of the pole, approximately 25 mm (1") deep. The specimen was then placed into the apparatus and the 13 mm- (1/2"-) diameter bolt / 8 mm-(5/16"-) diameter pin tail-piece was turned into the hole.(see detail Fig. 2.1.) The pole specimen could now rotate freely on this arrangement to facilitate locating the bow-up position. Once in place, the tailpiece was tightened.

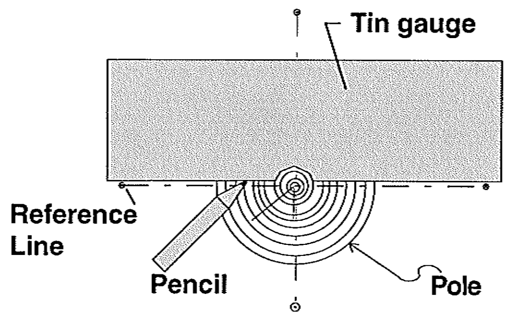


Fig. 2.3: Marking Normal Line

Measurements were taken from the four reference lines as indicated in Fig. 2.2. D1 and D3 were measured from the top and bottom reference lines respectively, to the pole. This yielded the vertical dimension at the chosen location. D2 and D4 were measured horizontally from their respective reference lines. Only at the ends of the pole, where the specimen was affixed to the tailpiece, could this measurement be considered a true horizontal dimension. At all other locations these dimensions assisted in determining the out-of-straightness of the pole. The distance from any one of the four reference lines to the pole was measured in five locations: 0; L/4; L/2; 3L/4; and L from the butt end of the specimen, where L was the specimen length. A total of 20 data points were collected for each pole. (see Appendix A data sheets) Using this information the relative locations of the five cross-sections could be plotted for every pole, as illustrated in Figure 2.4., as if viewed straight on from the end. The two solid, concentric circles represent the end diameters of the pole, while the remaining three broken circles show the relative locations of L/4, L/2 and 3L/4 with respect to the end diameters.

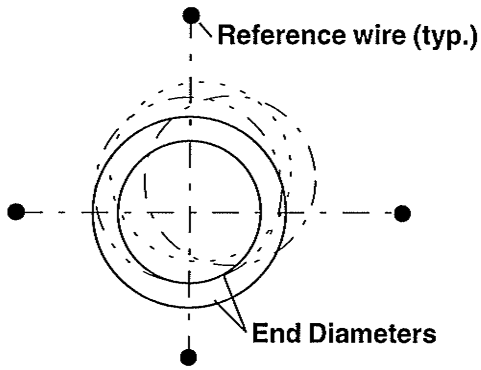


Fig. 2.4 Cross-Sectional View

Measurements D1, D2, and D4 were made using a dial depth-gauge. D3 was determined with inside callipers which were then measured with dial callipers.

Knowing the orientation of the wires the vertical and horizontal components could easily be determined using the following relationships:

Vertical Dimension = 216 mm - (D1 + D3) ; [8.5" - (D1+D3)] ; and

Horizontal Dimension = 254 mm - (D2 + D4) ; [10" - (D2+D4)] .

2.4 Bending Test Apparatus

The bending test apparatus was used to obtain information about the apparent stiffness of the pole to be used in the characterization of each pole specimen.

2.4.1 Fabrication Details:

Figure 2.5 illustrates the test set-up. The supports at either end were fabricated from 150 mm- (6"-) diameter pipe, approximately 200 mm (8") long, cut in half lengthways with an oxy-acetylene cutting torch to form a U-shape trough. One support was pinned, while the other was free to move longitudinally on roller bearings. The entire apparatus is supported on 150 mm- (6"-) I-beam trestles. Loading was affected with the use of a 1.15tonne- (2 ton-) hydraulic floor jack , running in an angle-iron track to keep it centred

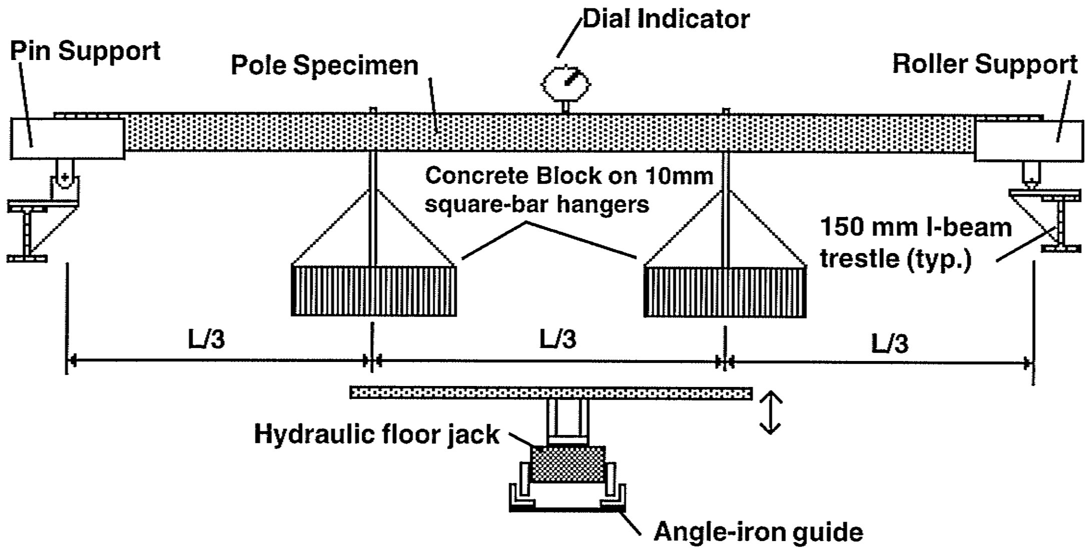


Fig. 2.5: Bending Test Apparatus

on the span. A dial indicator was attached to a bracket with a magnetic base. The bracket was welded to the channel-iron bed of the measuring apparatus that was behind the bending-test apparatus.

2.4.2 Application:

After measurement details were recorded, the pole was placed in the bending-test apparatus with the bow down. The rationale for this orientation stemmed from the fact that the pole would be placed in the column-test frame in such a way as to pre-dispose the specimen to deflect in the direction of the bow. An indication of the bending stiffness in this orientation related to the remainder of the test procedure. Load was applied to the specimen at the third points of the span. This loading corresponded to ASTM Standard D198.(1984) Point loads at L/3 from each end were provided by concrete blocks suspended on hangers fabricated from 10mm (3/8") MS square bar. Each block weighed 21.8 kg (48 lbs.). The specimen modulus of elasticity was back-calculated from the relationship for mid-span deflection with loading as shown in Figure 2.5.(Timoshenko, 1972)

$$\delta = 23\,PL^3 \,/\, 648\,EI \quad \text{, which yields,}$$

$$E = 23\,PL^3 \,/\, 648\,\delta I\,, \qquad \text{where:}$$

δ = deflection at mid span ;
P = point load;
L = span between support points;
E = specimen modulus of elasticity; and
I = specimen moment of inertia at midspan cross-section.

Appendix A contains the specimen-specific modulus of elasticity (determined in the bending test) as a part of each specimen data sheet.

The bending-test process was as follows:

1. The point load assembly was raised using the hydraulic jack;
2. The pole was set in position;
3. The dial indicator was clamped to the bracket and the dial zeroed;
4. The load assembly was slowly lowered onto the pole. At the instant the load was hanging free a stopwatch was started.
5. The deflections at 20 seconds, 1 minute and 5 minutes were recorded; and.
6. The load assembly was removed.

2.5 Column Test Frame

The most challenging piece of equipment to build, strictly from a size point of view, was the column test frame. The constructed frame weighed approximately 1 tonne (2200 lbs) and stood over 3 metres (10') high.

2.5.1 Design and Fabrication:

The main concern in the design was with the amount of strain energy stored in the frame compared with that stored in the specimen. The goal was to keep the former as low as possible. Discussions at this stage of design indicated that if the strain energy stored in the frame could be kept at approximately 1% of that in the specimen then the frame could be considered *infinitely stiff* (Lansdown, 1992). It was felt that if the test frame was very stiff the specimen would likely fail in a quite controlled manner. This would allow for good observation of specimen behaviour even after initial timber-fibre splitting had occurred. If the column test frame was made too soft, that is allowed for too much deflection in its component parts, then once cracking started in the specimen, all of the stored energy in the frame would rush to get out through the failure zone. The result would probably be a violent failure of the specimen and loss of valuable behaviour observations. Furthermore, stored energy in equipment may yield pole strengths different from those tested in a stiff system (after Madsen, 1986). Hognestad(1955) comments that: "It has been shown that sudden failures in compression tests are related to the sudden release of energy stored in the testing machine." The parameter of 1% stored strain energy was set as an initial design goal for the frame.

Figure 2.6 illustrates the basic configuration of the test frame as fabricated. Detailed construction drawings are contained in Appendix B. The main frame weldment was constructed of reclaimed W14 x 84 (similar to metric designation W360x122) with a cross-sectional area of 15,942 mm^2 (24.71 in^2). The main frame was fabricated in a horizontal position, and took approximately 3 hours using a front-end-loader tractor, heavy jacks, and chains to stand up safely. Once in an upright position, 150mm- (6"-) I-beam feet were attached to the uprights.

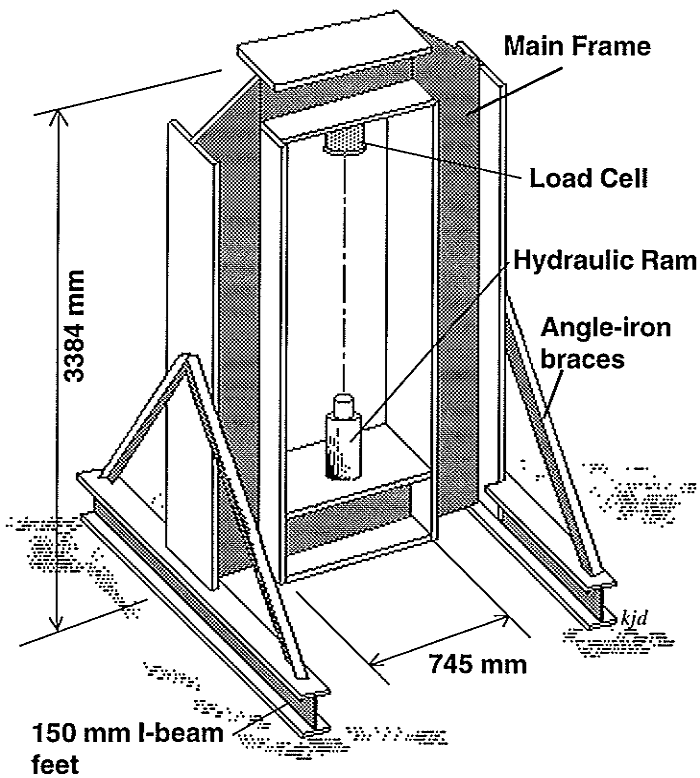


Fig. 2.6 Column Test Frame

The test frame, as constructed, has a stored energy ratio of approximately 2% of the energy stored in the specimen under load. (A detailed calculation of the strain energy in the frame can be found in Appendix C.) The test frame was indeed quite *stiff.* The implications of low strain energy storage in the frame were most evident when used for testing the poles. The specimens failed in a slow, controlled manner. Long after a peak load was reached it was possible to observe very sizeable lateral deflections, while feeling safe in the process. Although not a focus of the work contained in this document, another benefit of the low strain energy storage in the frame is that it allows the researcher to obtain data points far along the load-deflection curve. This issue will be discussed later in this thesis. The significance of these extended load-deflection curves in the energy-absorbing capacity of timber and in potential load sharing in practical structures (see Sec.6.4).

2.5.2 Application:

Figure 2.7 shows a pole specimen, butt end down, in the test frame. After the specimen was measured and put through the bending test it was placed into the test frame for the final phase of the test sequence. Angle iron shoes (see Fig. 2.8 and Appendix B) were affixed to both ends of the pole to simulate pinned-pinned end conditions. The bow, or initial out-of-straightness of the pole, as shown in Figure 2.7, was oriented away from the meter box that contained a digital voltmeter used in conjunction with a load cell. (Load measurement is discussed in the next section.) Load was applied at the bottom by means of a 89 kN- (10ton-) hydraulic ram and hand pump system.(see Fig.2.8)

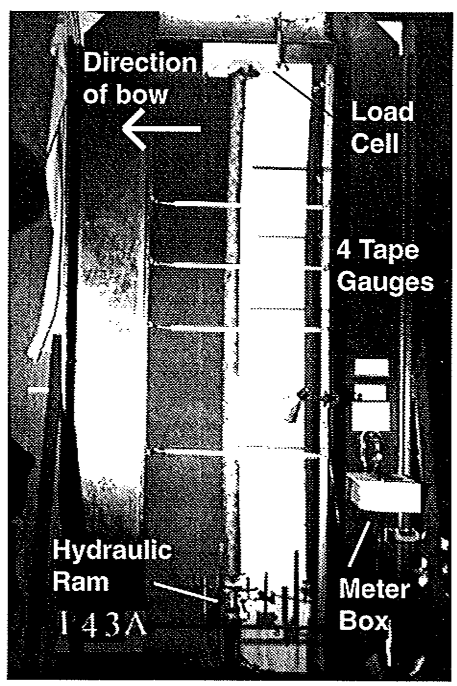


Fig. 2.7: Specimen in Test Frame

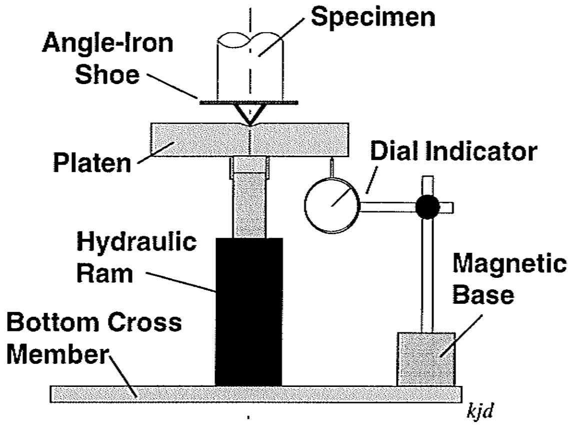


Fig.2.8: Ram Arrangement

Axial deflection was measured by a dial indicator under the platen (see Fig.2.8) Lateral deflection was measured by means of 4 sections of metallic, measuring-tape gauges that were attached to the inside of the test frame(see Fig.2.7). These were located at L/4, L/2, 5L/8 and 3L/4 measured from the bottom up on the pole. For the purposes of this test programme, it was felt that the critical section of the majority of specimens would fall somewhere between L/2 and 5L/8. Having gauges in these locations would allow for a more complete definition of pole sections at extreme lateral deflections (see Fig. 2.9). [A more detailed rationale for selecting these locations is contained in Appendix E.]

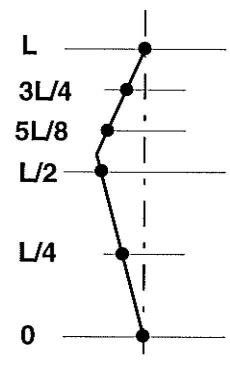


Fig.2.9: Locations

Since all measurements were being recorded by a single person a quick, but precise way to obtain deflection readings was needed. A simple solution was developed for this and is illustrated in Figure 2.10. A piece of 2mm ϕ (1/16") welding rod was formed into a hanger with a weight soldered to the end, hanging freely, from an angle hook screwed into the neutral axis of the pole. The lateral deflection could be read at a glance. An additional benefit was that this arrangement also provided an indication of any out-of-plane bending. Out-of-plane bending was

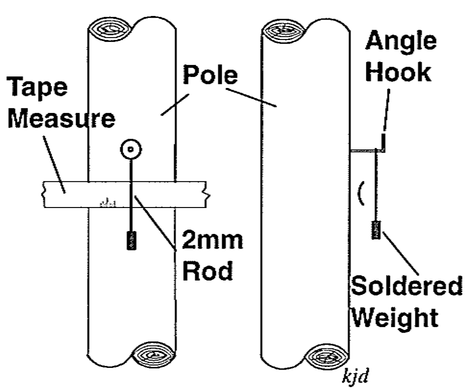


Fig. 2.10 Hanger

monitored from reference wires attached to the back of the test frame .

During the first few column tests it was noticed that some specimens exhibited pronounced twist, due most likely to spiral grain in the pole. It was decided to monitor this twist. A device was designed,(see Fig.2.11), to get an approximate idea what angle of twist, left or right of centre, was occurring. This extra piece of information added to the overall database. The gauge was mounted at the bottom with a pointer affixed to the platen. When an axial deflection reading was taken from the dial indicator it was a simple task to quickly check the angle gauge and record any movement.

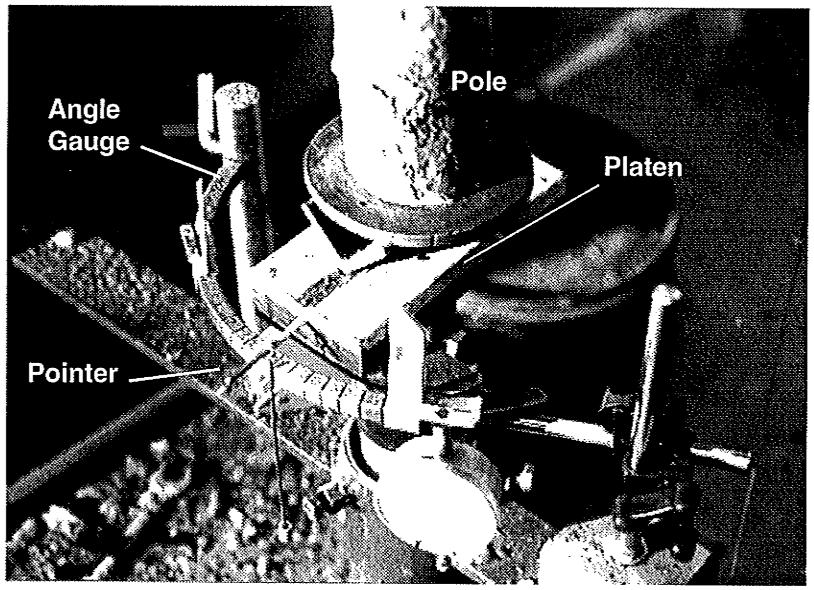


Fig. 2.11: Angle of Twist Gauge

2.6 Load Measurement

Within this section three topics are discussed: (i) design and fabrication of a temperature-compensated load cell; (ii) digital voltmeter apparatus and setup; and (iii) calibration of the load cell / voltmeter combination.

2.6.1 Load Cell:

Although commercial load cells are available, it was in keeping with the philosophy of the test programme that a load cell should be built from scratch. The initial objective was to find tubing that would form the body of the load cell. Ideally, it was thought, if a material with a high yield stress and corresponding low modulus of elasticity could be found, that would be the answer. A high yield stress would ensure that at the maximum applied load, 89 kN (20,000 lbf), then the material would most certainly be within the elastic range, thus providing a linear relationship in the loading of the tubing during a load test . Also, with a low modulus of elasticity, a fair amount of deformation could be expected. Either phosphur bronze or titanium seemed to fit the bill, both of which the author could weld in his shop. Phosphur bronze was quickly written off as an option, in spite of Winnipeg being a fairly large centre, none was available. After much searching, a piece of titanium tubing was sourced. Only one problem; it was going to cost at least $200.00 per inch, plus shipping costs from Toronto! This was not an option. A little more thought and discussion led to a most workable compromise. After looking at the loading and tubing material readily available in the Winnipeg marketplace, a piece of 76 mm- (3"-) diameter, Drawn Over Mandrel (DOM) tubing was purchased for $6.00 per foot. At this price the fabricator could even afford to make a mistake. Six feet were purchased.

An illustration of the load cell and corresponding Wheatstone Bridge circuit that was used appears in Figure 2.12. The DOM tubing was welded to a 10 mm (3/8") MS base plate, 230 mm (9") square. This plate was bolted to the top cross member of the

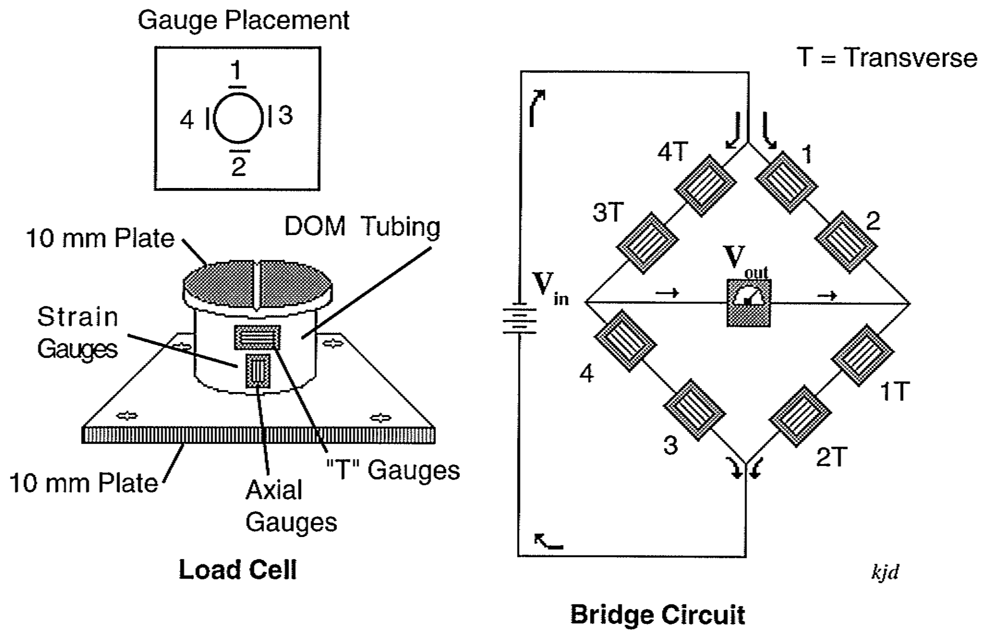


Fig. 2.12: Load Cell and Wheatstone Bridge Circuit

frame. On the opposite end of the DOM tubing a piece a 10mm (3/8") MS plate was cut to suit the diameter of the tube. A groove was cut into the plate for the angle-iron shoe to pivot in. A 10mm (3/8") diameter, threaded hole was located at the centre of this end-plate. This assisted in fastening the cell to a jig that was used when applying strain gauges. The threaded hole also provided a means to screw in a hook onto which a known weight could be attached. Periodically during testing, (the author being concerned that the cell was functioning properly), a weight was hung from the hook and the digital readout on the meter was checked to see if it corresponded to calibrated values.

A total of 8 Omega SG-7/350-LY11 , Constantan foil strain gauges(Omega, 1992) were affixed to the DOM tubing. With all of the strain gauges on the steel tubing, the load cell became temperature-compensated. Four gauges were aligned with the vertical axis of the tube, while the remaining four were placed normal to the first set, to respond to cross-strains (Poisson's effect). The load cell was used in conjunction with an Omega DP205 Digital Indicator to measure voltage changes in the Wheatstone bridge. A detailed discussion of the load cell fabrication and design calculations is contained in Appendix D.

2.6.2 Digital Meter:

The changes in voltage across the bridge were monitored with an Omega DP205-S digital indicator with excitation (Omega, 1992 p.D-21). A minimum resolution of 5 μV (5 microvolts, or 5 x 10^{-6} volt) was used in conjunction with the load cell. The digital indicator was housed in a wooden case and mounted on one of the uprights (see Fig.2.7). In addition to being a sensitive voltmeter, the DP205-S also provided the source of constant excitation voltage needed for the Wheatstone Bridge circuit (V_{in} in Fig. 2.12). A more detailed discussion of the digital indicator setup is contained in Appendix D.

2.6.3 Calibration of Load Cell:

The last task to be completed before testing could commence was to calibrate the load cell. This represented the penultimate step in terms of portability of the technology. The load cell could have been taken to the University of Manitoba, for example, and calibrated there. This would not always be possible, however, within the context of a developing region where this type of calibration facility may not exist. In other words, if the load cell could not go to the standard, then the standard must come to the load cell. While mounted in the test frame, the load cell was calibrated using a Morehouse 0-5000 lb (0-22kN) proving ring and a Morehouse 0-20000 lb (0-89kN) proving ring, as shown in Figure 2.13. Calibration curves were determined for the load

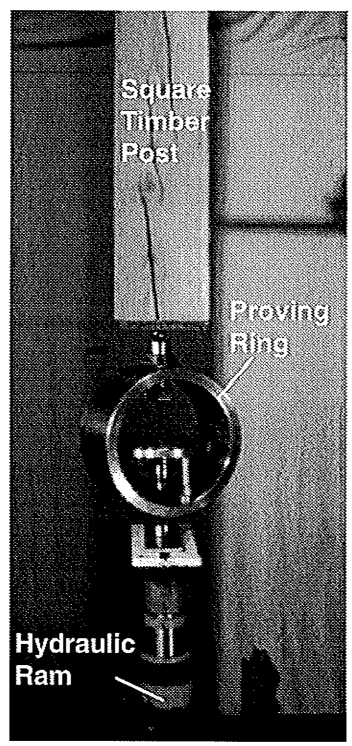


Fig.2.13: Proving Ring

cell / digital voltmeter combination. With a minimum meter resolution of 5 μV, the minimum increment of load that could be obtained precisely from the system is 0.061 kN (13.74 lbf). This value represented 0.069% of the total capacity of the test frame. The calibration curves and further discussion can be found in Appendix D.

2.7 Cost of Test Equipment

A value of approximately CDN $1400.00 covers the cost of the materials used to fabricate the measuring apparatus, bending test apparatus, load cell and column test frame. This does not include the cost of labour which would vary from place to place. A total of approximately 120 hours was required by one person to construct the equipment, excluding the time required to source materials. The following, Table 2.1, provides a breakdown of costs for the equipment.

ITEM	$CDN (1)
Pump/Ram/Gauge	213.14
Press Frame Steel(2100 lbs)	469.68
DOM Tubing	46.80
Miscellaneous Steel Pieces	100.00
Welding Rod (48018)	21.49
Strain Gauges/Meter/Adhesives	390.74
Dial Indicators/ Magnetic Base	75.00
Wire/Barrier Strips/Electricals	50.00
TOTAL	$1366.85

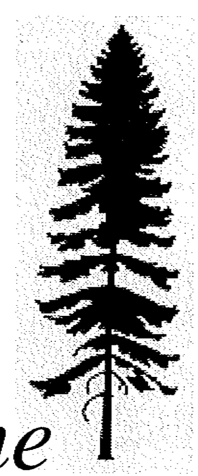
Note: 1. Includes all taxes PST and GST

Table 2.1: Equipment Costs

The above costs do not include things like a wage, shop overhead costs, and tools that the author already owned. It does indicate, however, that it is possible to set up a small lab for relatively low capital expenditure.

3

Test Programme



3.0 The Test Programme

3.1 Introduction:

Corral rails or fence posts are uses that frequently spring to mind when considering applications for spruce poles with diameters less than 90 mm (3.5"). Anecdotal evidence, coupled with experience in West Africa and rural Canada, suggests that this material should be considered as a valuable structural resource in its natural state. The traditions of the pole building and log house attest to the viability of large-diameter pole structures. Less evidence, however, exists of the structural use of smaller-diameter poles. The essence of the testing programme was seen as a first step at bridging the gap between anecdotal and scientific evidence of small-diameter, spruce-pole behaviour. While working with round-timber trusses in Sierra Leone and rural Manitoba there were two questions that kept coming to mind: *How out-of-straight does a pole initially have to be before it is unusable at a given length?* ; and *How much effect does the taper have on the strength of a round-timber pole?* Attempting to shed light on these two questions forms the basis of the test programme.

As mentioned earlier, all of the literature relates to the structural use of poles deals with pole diameters greater than the poles of interest in this research (CAN-O15-M83, 1983; Wolfe, 1980; Hoyle and Woeste, 1989; Faherty and Williamson, 1989). This chapter contains a discussion of the test programme itself, the rationale behind choices made, and the way in which the database was developed.

3.2 Testing Processes and Procedures:

The focus of this section is to discuss the pole specimen itself, and the parameters that were used as the basis for describing pole behaviour.

3.2.1 Specimen Description:

Specimens were selected at random from a bundle of 100 poles. Each pole was 4878 mm (16') long. This length allowed for two specimens, A and B, to be cut from each pole (see Fig.3.1). The specimen length was 2108 mm (83"). This length corresponds to an average distance between the first panel point and heel joint for a truss with a span range from 6706 mm (22') to 9144 mm (30'). All specimens were tested with their bark left on.

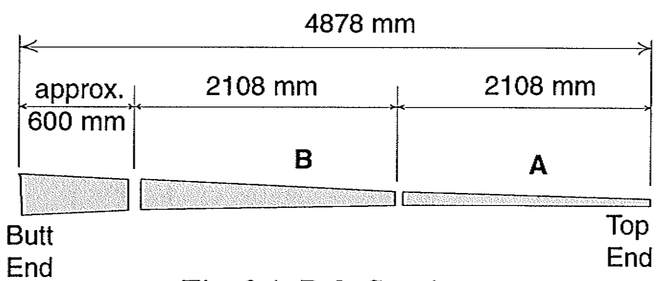


Fig. 3.1: Pole Specimens

3.2.2 Pole Out-of-Straightness (OS):

Considerable thought was given as to how the initial OS of the pole should be defined. The reduced measuring-apparatus data (Appendix A) provides information about the initial OS of the specimen at 5 locations(Sec. 2.3.). It was decided to define the initial OS as a non-dimensional ratio of the OS divided by the diameter at the location where the OS was measured(see Fig.3.2). The ratio is defined as: **OS / D.**

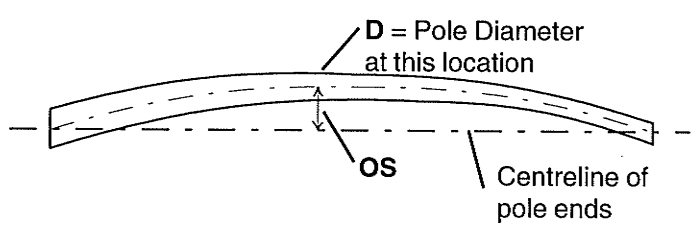


Fig. 3.2: Out-of-Straightness (OS)

The basis for this decision was twofold: (i) it was considered advantageous, whenever possible, to define parameters in a non-dimensional way; and (ii) from a brief conversation the author had (Madsen, May, 1993) the effect of out-of-straightness was discussed within the context of "number of diameters". This approach seemed to provide an easily-understandable concept.

3.2.3 Pole Taper:

As with OS, it was also desirable to have a definition of pole taper that was both non-dimensional and easily understandable. Taper, (see Fig.3.3) within the context of this research, has been defined as the taper ratio (TR):

$$\frac{\text{Diameter of small end (D1)}}{\text{Diameter of large end (D2)}} = \textbf{TR}$$

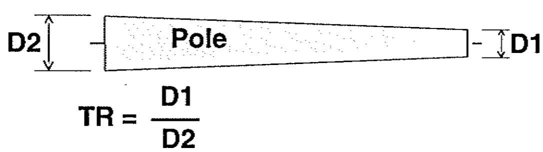


Fig. 3.3(a): Taper Ratio (TR)

The rationale for this is that the maximum the ratio can be is unity, which would indicate a cylindrical pole, one with no taper. Figure 3.4 illustrates, graphically, the taper ratio.

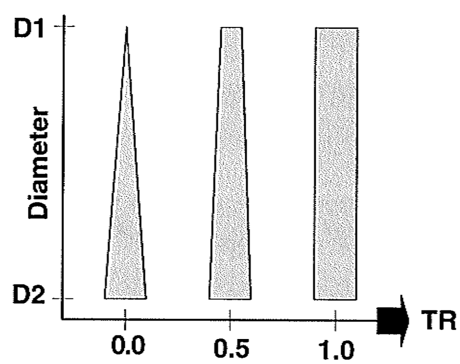


Fig. 3.3(b): Graphic of Taper Ratio

3.2.4 Moisture Content (MC):

The moisture content (MC) of every specimen was checked with a Protometer™ electrical-conductance meter. Hammer-type electrodes were used, driven to a depth of half the radius of the pole. The moisture content was tested after all other tests in the series were complete. This was done so as not to disturb the timber fibres and potentially affecting other test results. It was recognized that the MC determined with a hand-held meter was likely not as accurate as that obtained with direct methods such contained in ASTM - D4442-92, 1992. Since the MC was only checked at one or two points the value that was obtained was merely an indication of the amount of seasoning that had taken place. It was anticipated that most of the timber tested would probably be close to, or above, the fibre saturation point (FSP). In fact, this was found to be the case. It was important to simulate the actual conditions under which the timber would likely be used. High initial moisture contents would not be unexpected in this type of construction. Although the author is cognisant of the effect of moisture on the strength properties of timber, the definition of failure used within the context of this thesis suggests that the timber poles were less sensitive to moisture than they were to geometry. (See Appendix H for further discussion.)

3.2.5 Compression and Tension Zones:

After the poles were completely tested, that portion of the pole that had cracked or otherwise broken was cut out. This piece was sawn in half longitudinally as shown in Fig.3.4. Careful inspection of the zones of compression (C) and tension (T) was made and related to the diameter at that location. These values have been tabulated in Appendix A as C/D and T/D.

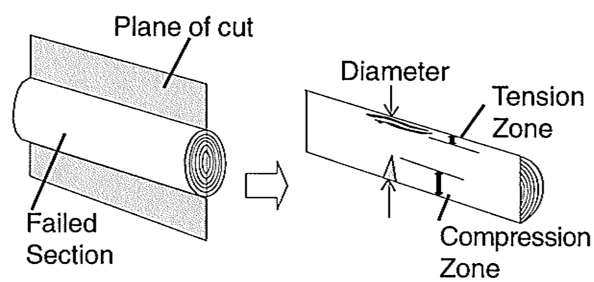


Fig.3.4 Compression and Tension

3.3 Test Procedure:

After the pole specimen had been measured and bending test performed, the pole was placed into the column test frame. The primary focus of this section is to discuss the procedure developed for the column, or compression test portion of the pole testing programme. The initial tests performed on specimens using the column test frame, combined with some early analysis, shaped the remainder of the test programme.

The following five plots, Figures 3.5 to 3.9, illustrate the relationship between the applied column-test load and time-specific readings of lateral deflection. The purpose of this at the beginning of the test programme was to gain some insight into the behaviour of the pole after a load had been applied. There was an important decision to be made: *At what time should a deflection reading be taken after the application of a load increment?* It was considered that an initial time-specific look at the first five specimens would, therefore, be crucial in the development of a column-test procedure. (A further discussion of the plots is contained in Appendix H.)

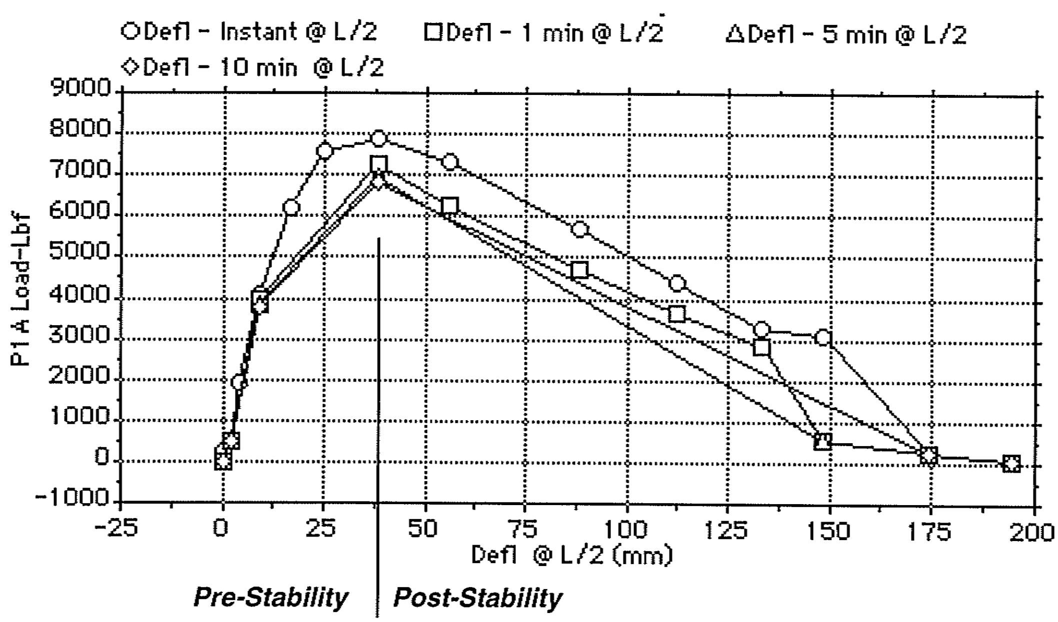


Fig. 3.5: Load vs Lateral Deflection at L/2 for Specimen # P1A

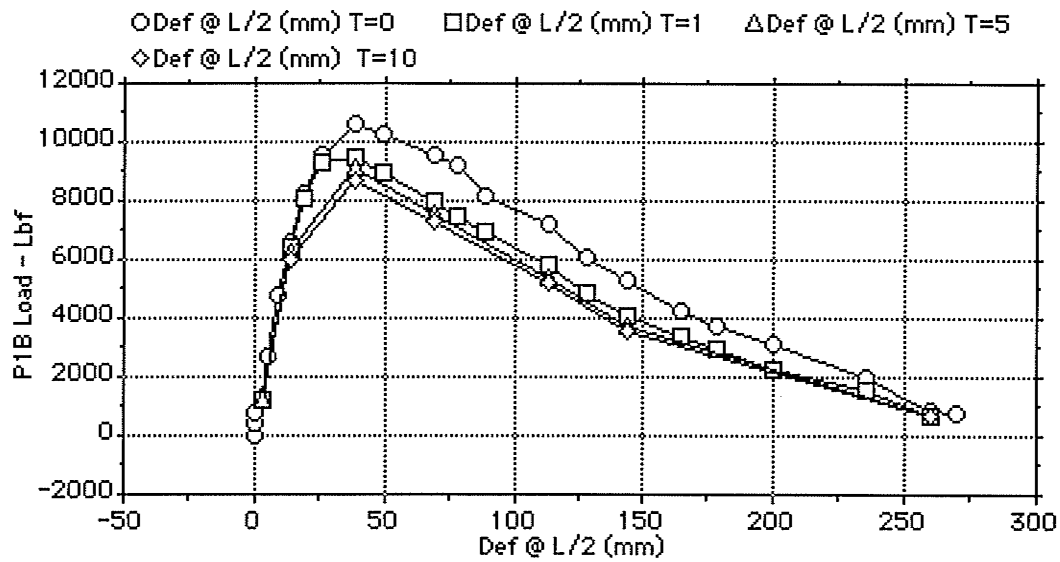


Fig. 3.6: Load vs Lateral Deflection at L/2 for Specimen # P1B

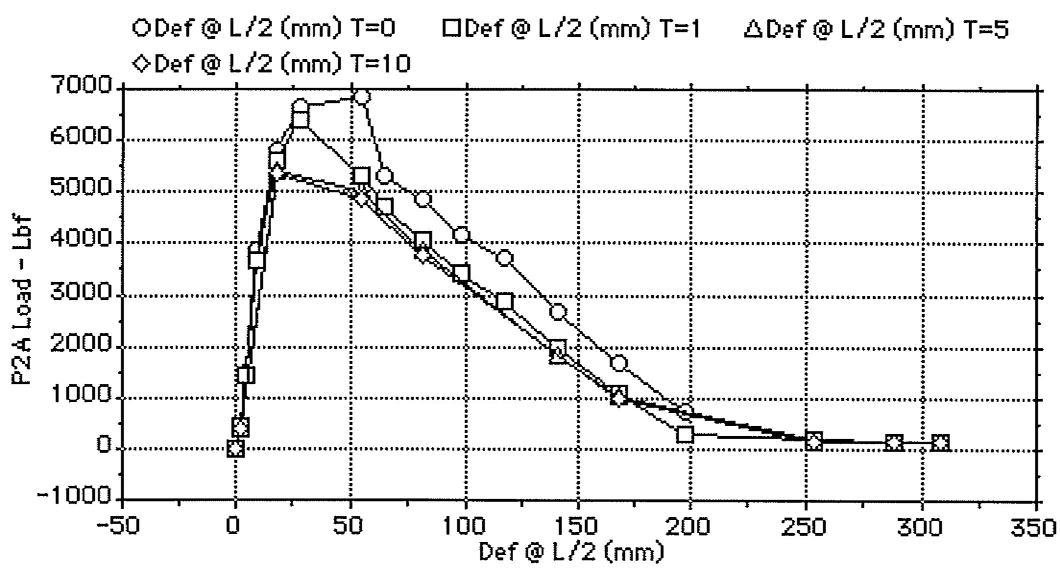


Fig. 3.7: Load vs Lateral Deflection at L/2 for Specimen # P2A

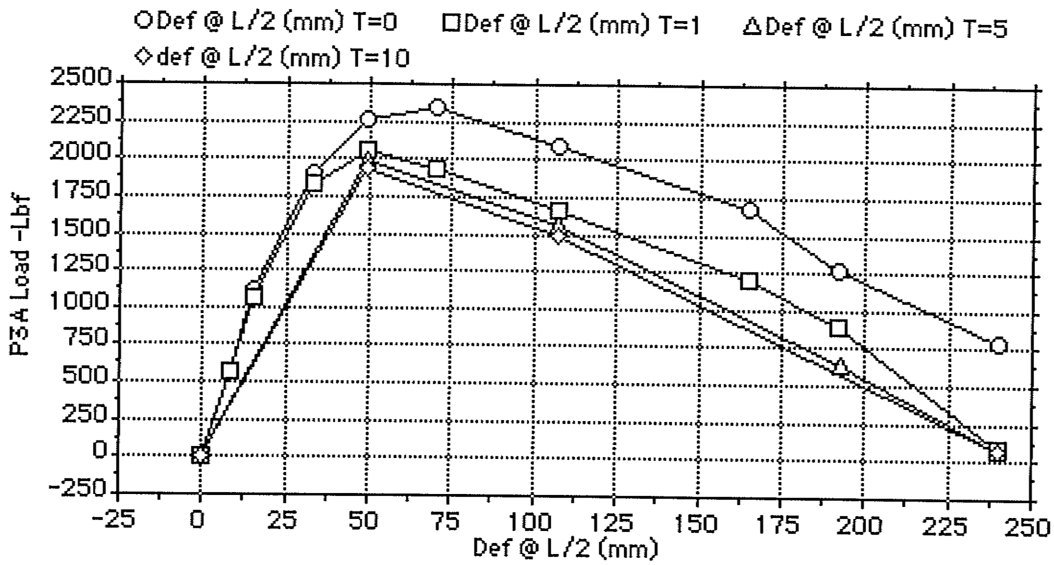


Fig. 3.8: Load vs Lateral Deflection at L/2 for Specimen # P3A

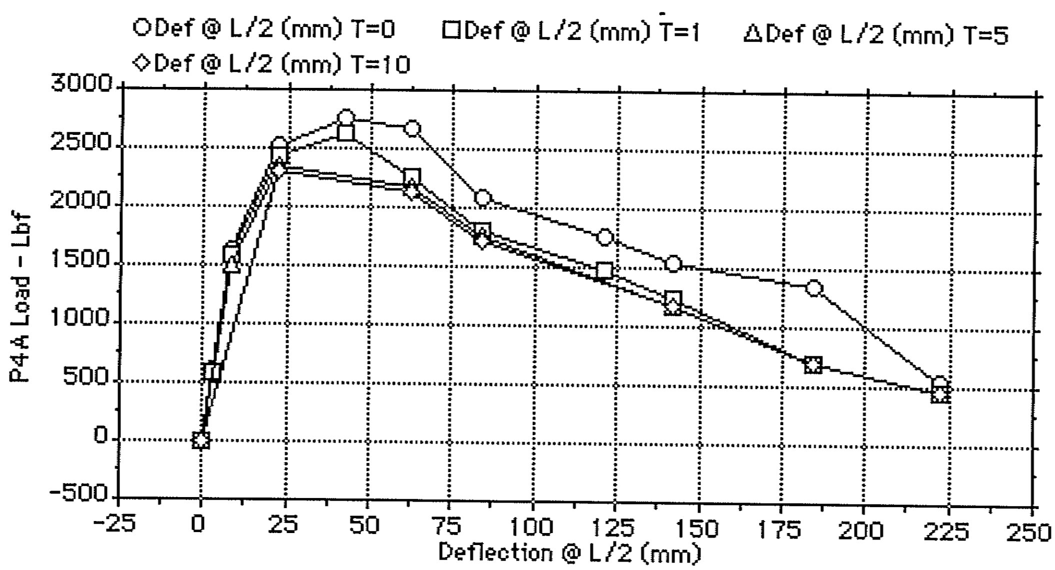


Fig. 3.9: Load vs Lateral Deflection at L/2 for Specimen # P4A

It is important at this juncture to look some apparent anomalies that appear in the 5 preceeding plots. This is done in point form.

1. Readings at 0, 1, 5 and 10 minutes were not taken in every case during what has been called the *pre-stability* portion of the plot(Shown in Fig.3.5). It was important to determine a load-deflection trend. Absence of a complete set of 10 minute measurements accounts for the straight-line portions on some graphs.

2. In Figure 3.5 (at deflection = 148 mm) and Figure 3.7 (at deflection = 55 mm) there is a marked difference between the 0 and 1 minute readings. These correspond to pronounced cracking which occurred just after the load increment was applied.

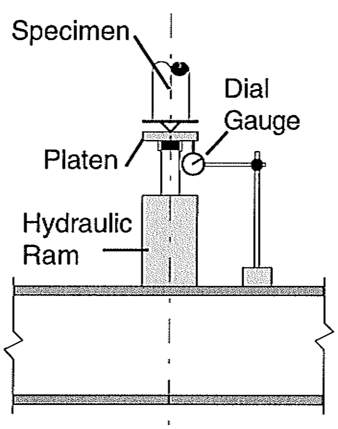


Fig. 3.10: Test for Ram Creep

3. An initial concern with the decreasing load with respect to time was: *Is the hydraulic pump losing pressure and causing a decrease in load?* To investigate this the dial gauge under the platen was monitored (Fig. 3.10) after a load increment was applied. It was found that no ram creep was present.

It was felt, therefore, that the slowly-decreasing load was likely due to such things as microcracking and the squashing of moist cell walls within the specimen. It was interesting to note that the initial drop-off from a given load increment was most rapid for about the first 30 seconds. The rate of load drop-off decreased substantially from that time on, except in cases of sudden material breakdown. This was a trend that continued for the remainder of the specimens in the programme. In the five specimens investigated, the difference between the 1-minute load and the 10-minute load at the peak load was quite small, with deflection readings converging at large lateral deflections. The relationship between the duration of load and timber strength has been the topic of discussion from the 18th century and earlier (Booth, 1964) and continues (Wood, 1960; Glos, 1986; and Madsen, 1992).

The concern at this stage was to decide on a meaningful time to record deflection measurements. It appeared that the amount of additional information that would be gained from recording deflections past the 1-minute load was small. There was also a concern for the overall time for the column test. Although ASTM D198 (1984) does not discuss round timber, Clause 25.3 states that compressive tests should not be less than 5 minutes nor more than 20 minutes. Tempering this was evidence coming out of the in-grade testing programme that the rate-of-loading does not affect the strength of compression parallel to the grain (Madsen, 1992) It was judged, therefore, that using a 1-minute load reading would be acceptable for the purposes of this testing programme.

Based on this evaluation, the following was adopted as the specimen test procedure for the column-test portion of the programme.

Step 1. Apply an increment of load;
Step 2. Note the meter reading and start a stop watch at cessation of pumping;
Step 3. Record pole deflection, call this Deflection at Time = 0;
Step 4. Wait for 1 minute from step 2;
Step 5. Record pole deflection, call this Deflection at Time=1; and
Step 6. Repeat steps 1 through 5 until test is completed.

The pole was loaded using an hydraulic hand-pump and ram combination. A ramp-loading approach was employed because of the nature of the equipment. The rate of loading was based on the movement of the ram/platen assembly. Prior to the maximum load, an axial deflection rate of approximately 1 mm per load increment was employed. After the maximum load was surpassed, the rate was increased to approximately 3 mm per load increment.

3.4 Summary of Data Collected:

The data collected about each specimen has been summarized below, in point form, according to each apparatus. Appendix A catalogues the specimen-specific data sheets that contain this detailed information.

Measuring Apparatus-

Dimensions of pole at 0, L/4, L/2, 3L/4, and L, measured from 0 at the butt end. Raw data reduced to provide initial out-of-straightness, taper and pole diameters.

Bending Test Apparatus-

Determination of the specimen MOE based on a reading of mid-span deflection at 1-minute. MOE backcalculated from theoretical relationship between load configuration and deflection.

Column Test Frame-

Load vs. lateral deflection at L/4, L/2, 5L/8, 3L/4 (0 = butt end). Load vs. axial deflection (vertical-up movement of platen). Amount of pole twist at butt end(degrees left or right). Weight of the specimen. Observations related to things such as: first cracking sounds, bark spalling, and specimen-specific issues not covered in measurements. A minimum of one photograph was taken of every pole. Using a quartz-halogen lamp, a shadow was cast against the wall behind the test frame that aligned with the centreline of the pole. At a glance, a sense of the amount of deflection can be seen in the photos(Fig.3.11).

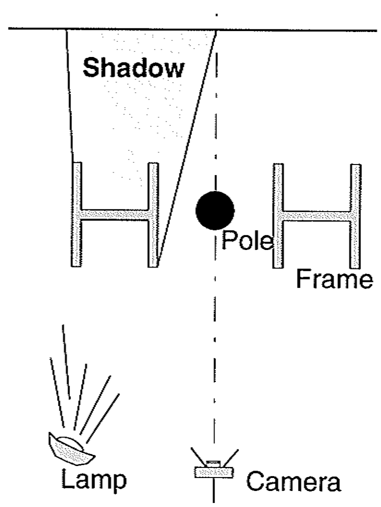
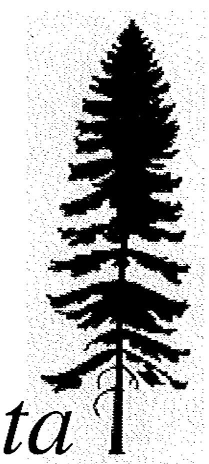


Fig.3.11: Use of Shadow for Observation of Deformation

Post-Column Test Procedures-

Moisture content measurement; examination of the failure zone; cutting of specimen longitudinally and measurement of tension-compression zones; counting of growth rings.

4



Analysis of Data

4.0 Analysis of Data

What constituted the maximum load, or, stated in another way, what would be the definition of pole failure for the purposes of this research, was an initial, fundamental question that had to be answered. Previous discussion in Section 3.3 focused on the decision to use the 1-minute load value during the column-test portion of the programme. Once this point on the load-deflection curve was passed, the pole was considered to have failed. Figure 4.1 illustrates what was used as a failure definition within the context of this research. Testing of the specimen did not cease at this point, however. With a stiff testing machine valuable information could be gained about the ability of the pole to sustain load at large lateral deflections.

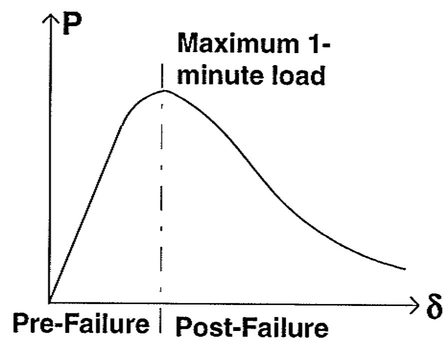


Fig. 4.1: Failure Definition

The main objective of this testing programme was to investigate what, if any, relationship exists between the load-carrying capacity of a round, white-spruce pole and its initial out-of-straightness and taper. The goal of the programme was to develop a set of design guidelines for the structural use of these poles based on the experimental data collected. A guiding parameter implicit in the development of such a design tool was: whatever the tool turned out to be, it should be useable by both the experienced engineer and the craftsperson. This chapter will discuss the rationale and steps that led up to the creation of a proposed design tool for the structural use of small, round, white-spruce poles.

4.1 A Proposed Approach:

Working with a natural material presents many challenges, not the least of which was deciding on how to evaluate the behaviour of these white-spruce pole specimens. After considerable thought, reading and reflection it was concluded that, compared with dimensional lumber, there were too many variables in the geometry of the pole to start with assumptions in current design equations, for example: Hoyle (1989); Faherty (1989); Buchanan (1984); Neubauer (1966,1969,1972, 1973); and Zahn (1986). To affect any comparison between the specimens in this research it appeared that the only valid way to approach design was to base the design aid or model on the experimental data obtained from actually working with these poles. After testing of these poles was completed and a proposed approach developed, then, and only then, could a meaningful comparison be made with existing design guidelines that have been developed primarily from experimentation with sawn, dimensional lumber.

Given the nature of the poles, it was impossible to isolate test specimens that were either straight with no taper, or, tapered with no initial out-of-straightness. Every specimen had to be tested with varying degrees of taper and out-of-straightness. The model had to address these conditions and their relationship to strength at the same time.

The opportunity to observe timber-pole behaviour in a very quiet laboratory has proven to be beneficial. The first faint crack, internal creaking and bark movement were all recorded along with loads and deflections. It became evident that it was possible to develop a feel for the material behaviour beyond quantitative parameters. It was believed that this more intimate relationship would be an asset in the interpretation of information coming out of the column tests. After approximately 25 specimens had been tested the data was reduced and an initial, cursory analysis performed. Three main parameters were initially examined: (i) the diameter; (ii) taper ratio;and (iii) the initial out-of-straightness.

Figure 4.2 illustrates the general trends of the maximum load versus these three parameters from the data that emerged at this juncture in the testing. The relationship between the

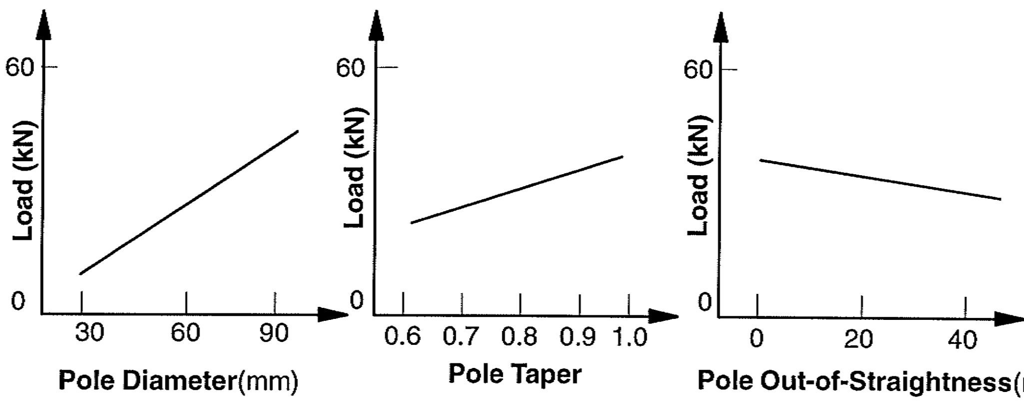


Fig. 4.2: Data Trends

maximum load and the taper ratio was fairly well defined. As expected, there was a strong effect of the diameter on the maximum load. The relationship with the initial out-of-straightness, however, was much less defined. It was apparent that it would be important to have as broad a range as practicable for the taper ratio and out-of-straightness data, to provide as good an indication as possible of the trend of these relationships. Stopping along the way to examine what was happening, as opposed to pressing on, amassing a lot of data, proved to be quite advantageous. This was especially true of the relationship with the out-of-straightness. If an effort had not been made to select some specimens that had OS/D ratios greater than 0.5 the data would have been clustered without providing any indication of what the trend may have been.

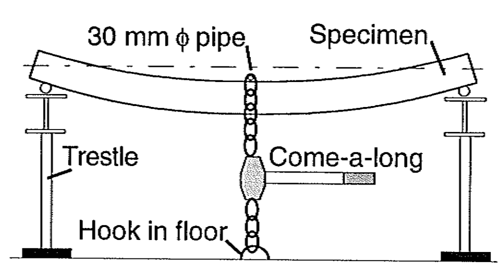


Fig. 4.3 Increasing Initial OS

To simulate poles stored in less than ideal conditions some of the specimens had the out-of-straightness artificially increased as shown in Fig. 4.3. A come-a-long, one end hooked into the shop floor, the other attached to a 30mm diameter pipe lying normal to the length of the pole, was used to give some specimens an initial out-of straightness greater than OS/D = 0.5. Poles were held in this position for one week and allowed to settle for two days prior to testing. These poles were used to provide the broader range mentioned earlier in the discussion.

A total of 58 specimens were tested before the main analysis of the data was performed. Since it had been decided to relate the maximum load sustained by the pole to the initial out-of-straightness and taper, an appropriate way of doing this was crucial. The following is a detailed discussion of the development of a proposed design approach.

At the point of imminent instability there is a combination of axial and flexural stress in the pole, as shown in Figure 4.4. In deciding how to define the strength parameter, this relationship had to be incorporated. Considering a *typical* specimen (for example 19B with an L/2 diameter of 75.95 mm), the 1-minute failure load was 13.68 kN (3077.76 lbf). The axial-compressive stress was determined to be 3.03 MPa (440 psi) while the flexural stress was 11.82 MPa (1714 psi). Using these values a theoretical shift in the neutral axis was calculated. Based on these figures, the compressive stress acted on approximately 2/3 of the total pole cross-sectional area. It is clear that both compressive and tensile stresses were present at failure. In terms of the design model it was desirous to equate pole

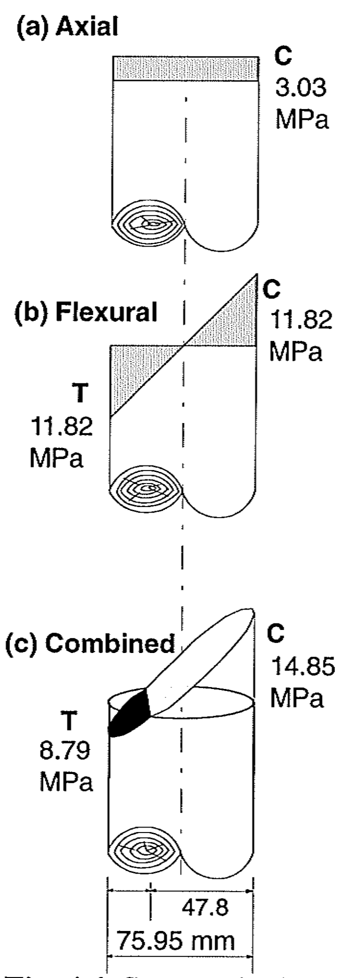


Fig. 4.4 Stresses in Axial and Bending Load

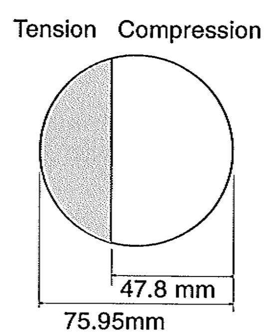


Fig. 4.5: Areas of Tension and Compression

strength with axial, compressive stress. This would account for size effects and represent a fairly straight-forward, simple calculation based on the cross-sectional area at a given location in the pole. It was decided to standardize the failure-load data based on a standard pole. This presents a problem when dealing with a natural material. Ultimately, the design model must reflect a Limit States Design (LSD) approach. With in-grade testing (Madsen, 1992), ranking specimens on a cumulative percentile basis allows the researcher to select the 5th percentile quite conveniently. Unlike dimensional lumber, that is consistent in size, natural poles are not geometrically consistent. To standardize the load data it was necessary to decide what represents a standard pole within the test sample. The first step in model development was to look at the sample distribution of pole diameters. Fig. 4.6 contains a histogram of the test-sample pole diameter at L/2. The data in the histogram indicates a slightly negative skew, thus both the mean and the median were investigated before deciding on which one to use as a measure of central tendency. It was found that there was only a 2% difference between the mean (71.32 mm, 2.808 ") and the median (72.87 mm, 2.869 "). The mean was then chosen as the central-tendency parameter to use in the normalizing process.

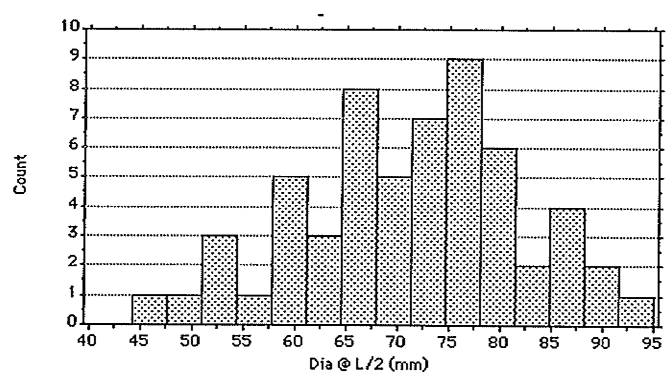


Fig. 4.6: Histogram of Pole Diameters at L/2

As discussed on page 40 , both axial and flexural stresses are present at failure. To standardize the sample pole data it was decided that a correction to the bending component would be done using the cube of the diameter (d^3) at L/2 of the sample poles. The relationship between the poles and bending stress in this respect is not linear. Since the flexural stress is dependent upon the section modulus of the pole, this flexural correction was considered to be appropriate . The size correction of the axial component had already been done through the choice of axial stress as a principle parameter.

The next step in the development of the theoretical model was to decide what would be the standard axial stress used in the correction process. Again, two views were taken of the data at the maximum 1-minute load: (i) the mean of the axial stress at L/2 on those poles 0.5 standard deviations (SD) either side of the mean diameter; and (ii) the mean and median axial stress at L/2 of the entire test sample. Table 4.1 below summarizes the results of these two views of the data.

	Mean Stress-MPa (psi)	SD-MPa (psi)	SE-MPa (psi)	#Specimens
Approach (i)	5.55 (805.43)	1.70 (247.05)	0.37 (53.911)	21
Approach (ii)	5.17 (749.70)	1.74 (252.89)	0.23 (33.21)	58

SD = standard deviation
SE = standard error

Table 4.1: Comparison of Sample Axial Stresses at L/2 at the Maximum 1-minute Load

It was decided to use the more conservative value of 5.17 MPa (749.7 psi) as the standard stress.

Data obtained from the bending apparatus provided information about the specimen-specific stiffness. Since not all of the specimens exhibited the same stiffness a final adjustment in this standardization process was to adjust each specimen for stiffness. In a similar process as for the diameter and axial stress, the mean value for the sample modulus of elasticity (MOE) was used in a linear correction to the standard stress.

The chart in Figure 4.7 illustrates the adjustment process that was used to create a set of stress values for the specimens based on a sample standard pole. A table containing values for all specimens is contained in Appendix A.

Step 1: Flexural Correction

$$\text{Standard Stress} \times \frac{d_i^3}{\left[\text{Mean Sample L/2 Diameter } (d_0)\right]^3} = \text{Flexural-Corrected Standard Stress}$$

Step 2: Stiffness Correction

$$\text{Flexural-Corrected Standard Stress} \times \frac{E_i}{\text{Mean MOE } (E_0)} = \text{E-Corrected, Flexural-Corrected Standard Stress @ L/2 (Corrected Stress)}$$

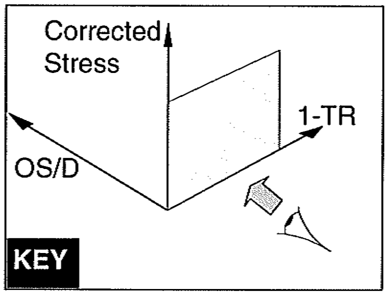
d_i^3 = Pole Specific Diameter @ L/2

E_i = Pole Specific MOE

Fig. 4.7: Standardizing Process

Once all of the data was adjusted the relationship between the taper ratio (TR) and the initial out-of-straightness ratio (OS/D) was analysed. Although the TR was discussed previously, a modification was performed on it for plotting purposes The TR was plotted as 1-TR. This was done so that taper would range from "0" for a perfectly straight pole to "1" for a cone. Intuitively, this made more sense, as straight implies zero taper. (**Note**: For an expanded discussion of what constitutes a "standard pole" see Appendix H.)

In Figures 4.8, 4.9 and 4.10 the Corrected Stress vs 1-Taper Ratio [ie. Cor Stress vs 1-TR] has been plotted. In these figures increasing levels of regression analysis were



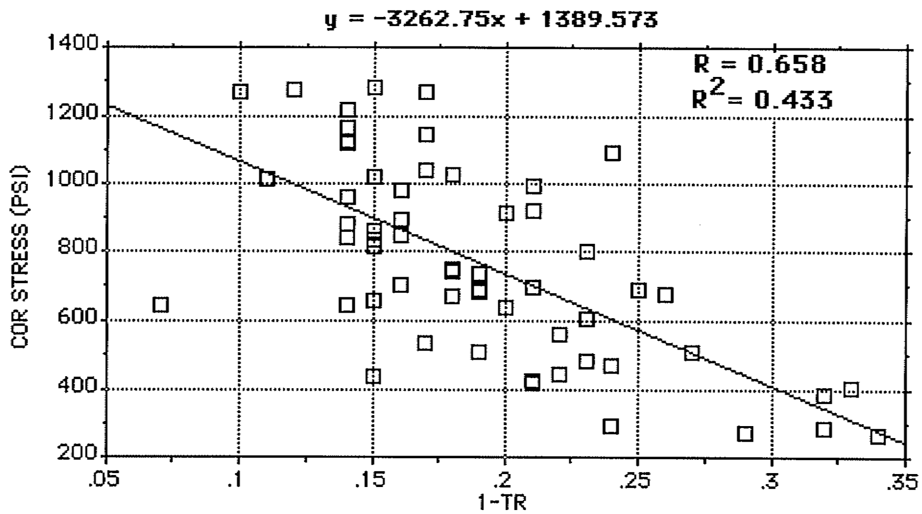


Fig. 4.8: Simple Regression of Corrected Stress vs 1- Taper Ratio

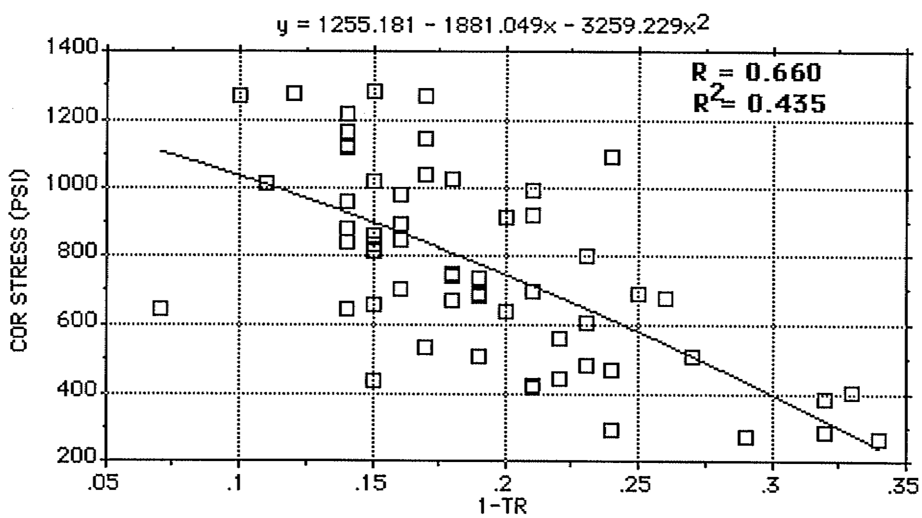


Fig. 4.9: Quadratic Regression of Corrected Stress vs 1-Taper Ratio

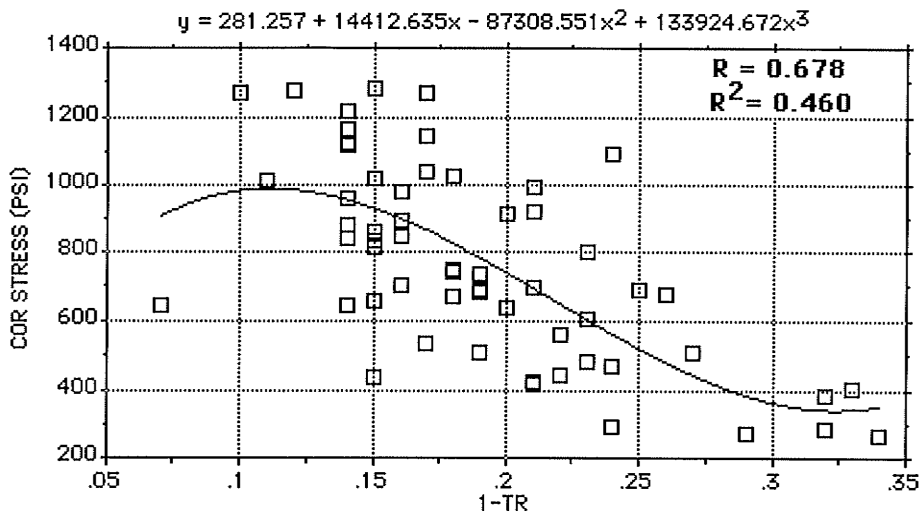
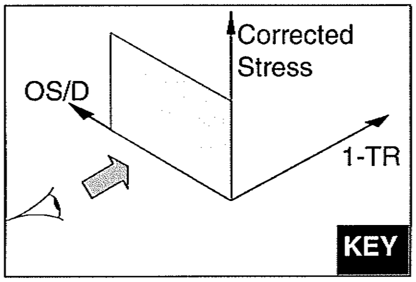


Fig. 4.10: Cubic Regression of Corrected Stress vs 1-Taper Ratio

Examination of the three plots led to the choice of simple regression to describe the relationship between the Corrected Stress and 1-TR. There is virtually no difference in the degree of correlation between simple and quadratic regression, while cubic regression begins to "chase points". It should be noted, however, that in all cases the level of correlation does appear significant. With a sample of this size the critical correlation value of **r** for 95% confidence limits is considered to be 0.250 (Hassard, 1991). The linear regression in Fig. 4.8 appears to not have happened by chance. Based on this analysis of the test sample, the use of simple, or linear regression to describe this relationship was chosen.

Similarly, the relationship between the Cor Stress and the OS/D ratio at L/2 was investigated in the same manner. Figures 4.11, 4.12, and 4.13 contain plots of the data. Again, a key has been provided for orientation.



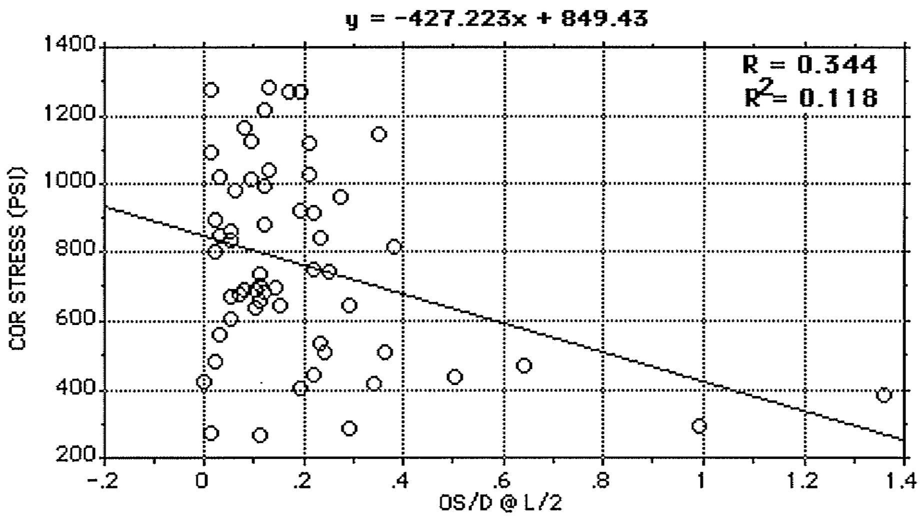


Fig. 4.11: Simple Regression of Corrected Stress vs Out-of Straightness Ratio at L/2

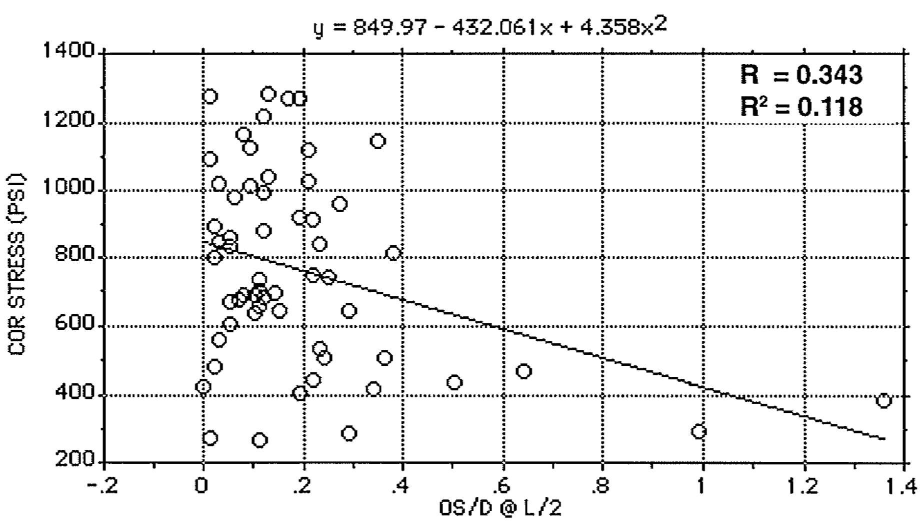


Fig. 4.12: Quadratic Regression of Corrected Stress vs Out-of-Straightness Ratio at L/2

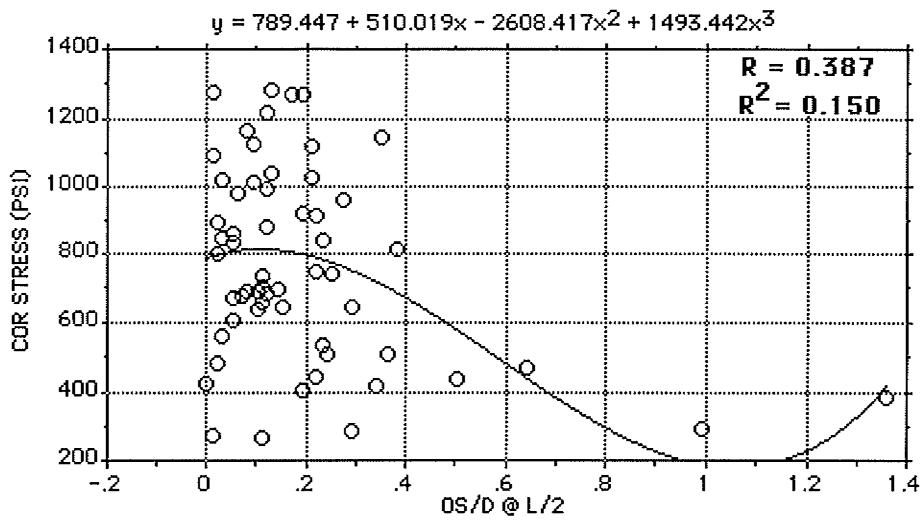


Fig. 4.13: Cubic Regression of Corrected Stress vs Out-of Straightness Ratio at L/2

As was seen in the relationship with 1-TR, the difference in degree of correlation between simple and quadratic is small. This led again to the choice of a linear relationship for development of the model. What is interesting to note in the plots of OS/D is that in the absence of very out-of-straight specimen data, (OS/D > 0.5), there is quite a large cluster of data between 0 to 0.4 that could have a line drawn through it in almost any direction. The trend of the data is much clearer with these additional data points.

In addition to the preceeding plots, the data was examined in slices along each axis as illustrated in Fig. 4.14, to get a sense of whether the use of linear relationships appeared to be appropriate. It was found that, although the number of data points per slice was low, the same type correlation emerged with the slices as had emerged with the preceeding plots.

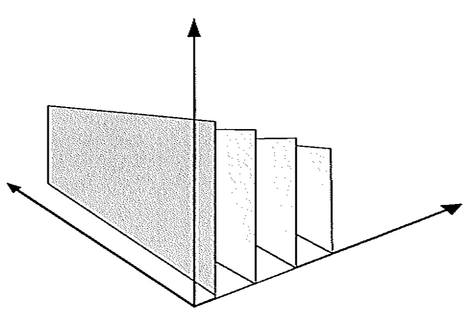


Fig. 4.14: Slices of Data

Figure 4.15 illustrates the concept of the design model that was used to relate the parameters of strength, taper and initial out-of-straightness. The 3-dimensional surface was created using multiple linear regression. Based on a Limit States Design approach this surface is used for modifying the compressive resistance of the pole with respect to taper and initial out-of-straightness.

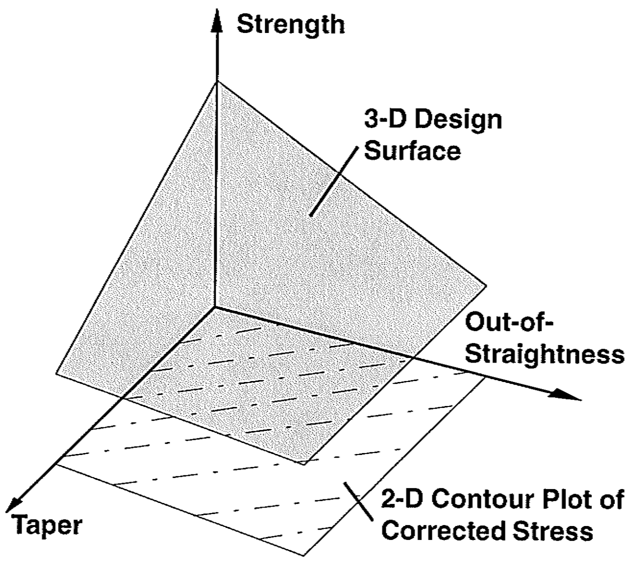


Fig. 4.15: Conceptual Model for Modified Pole Strength

The modification of the pole compressive resistance can be done in two ways: (i) using the equation of the design surface;or (ii) using the 2-dimensional contour, or topographic, plot created from the 3-dimensional surface.

Figure 4.16 shows the relationship between the surface created by multiple regression and the surface to be used in the design process. The LSD design surface represents the 5th percentile of the sample cumulative corrected stress. This 5th percentile, or LSD surface, value has been illustrated in Figure 4.16.

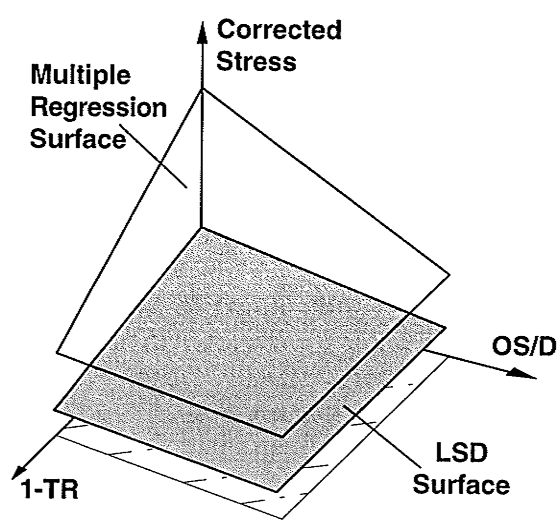


Fig. 4.16: LSD Design Surface

4.2 Testing the Model:

The equation for the surface based on multiple regression was determined to be:

$$y_{(MPa)} = 9.56 - 20.85(1\text{-}TR) - 1.55(OS/D) \text{, or}$$

$$y_{(psi)} = 1386.79 - 3023.46\,(1\text{-}TR) - 224.47\,(OS/D)\,.$$

It was important that a few specimens be tested to see how well the model would predict their behaviour. Three additional specimens were selected. The maximum 1-minute load was predicted, and then compared with the surface already obtained. Table 4.2 below contains the predicted and actual values for the three additional specimens.

Specimen Number	Predicted Value MPa (psi)	Actual Value MPa (psi)	95% Confidence Limits[1] Lower MPa (psi)	Upper MPa (psi)
36A	5.69 (824.47)	2.36 (342.52)	3.94 (571.96)	7.43 (1076.99)
40A	4.23 (612.97)	4.51 (654.14)	2.33 (337.75)	6.13 (888.19)
43A	4.96 (719.25)	3.81 (552.35)	3.06 (443.86)	6.86 (994.63)

Notes: 1. Based on Gaussian distribution. Relates the 95% confidence limits, or upper and lower bounds of the multiple regression surface, 19 times out of 20.
t-value OS/D = 1.76 , Standard Error (SE) of slope = 0.880 MPa (127.528 psi)
t-value 1-TR = 5.946, Standard Error (SE) of slope = 3.507 MPa (508.462 psi)
95% limits = +/- 2.00 x SE
R = 0.681

Table 4.2: Predicted vs Actual Values from Model Test

It can be seen from Table 4.2 that Specimens 40A and 43A have values that fall within the 95% confidence limits of the model, while Specimen 36A falls below. In one respect it would have been desirous to have all three specimens within the 95% limits, however, what this test does point to is the very nature of the material that is being modelled. Based on the *t*-value, tabulated values for *t* (Hassard, 1991), and overall correlation for a sample with 57 degrees of freedom (df), the following inferences have been made about model performance with respect to OS/D and 1-TR versus the corrected stress(see Note Table 4.2):

1. Given the scatter pattern of the data for OS/D vs stress in Figs. 4.11 to 4.13, it would not be unexpected to find a low *t*-value. The importance of the range in the data again emerges as significant since it does indicate a trend. The value of $t = 1.76$ corresponds to confidence limits of approximately 97%. Thus, the experimental value is not completely out of the realm of probability given the nature of the material;

2. The overall correlation of the model, R = 0.681, is significantly larger than the critical value of R for a 95% confidence limits and (df) = 57 which is 0.250. (Hassard, 1991) Although not too much weight should be put on the value of R, it does appear to indicate, in this instance, that there exists a significant degree of relationship between the three parameters: OS/D; 1-TR; and strength; and

3. With these preliminary findings it is felt that there is potential for this model to be useful in the design process with small, round-timber poles.

4.3 Determination of Specified Compressive Strength:

In Fig.4.17 a cumulative plot of the compressive stress is shown. The value obtained from this plot became the maximum value, or the intercept, of the 3-D design surface with

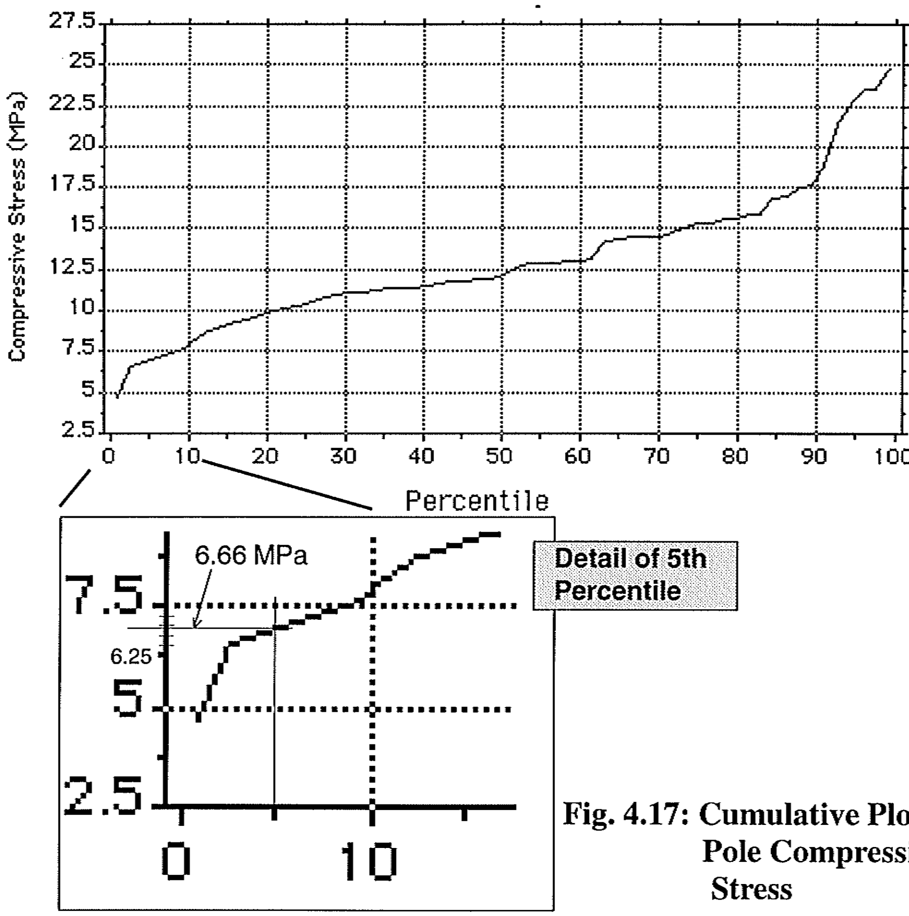


Fig. 4.17: Cumulative Plot of Pole Compressive Stress

respect to the strength axis. This maximum stress is based on the 5th percentile of the average, combined compressive stress, as shown in Fig. 4.5 and tabulated in Appendix G. This value, called the *specified strength in compression parallel to the grain* (f_c) (CAN086.1-M89, 1989), forms the foundation of the compressive-member design process.

In determining f_c it is recognised that the distribution of the data may not follow a Gaussian or normal distribution. Fig. 4.18 contains a histogram of the data used to create the cumulative plot in Fig. 4.17. It can be seen that the data has a positive skew. The suitability of using a Gaussian distribution to describe timber strength data is discussed by Madsen, (1992). Madsen suggests that using a Gaussian distribution tends to underestimate the 5th percentile. The use of a Weibull distribution (Madsen, 1992, and 1972) tends to approximate the data more closely. In the present investigation, it was decided that a normal distribution would be used, resulting in a more conservative value for f_c .

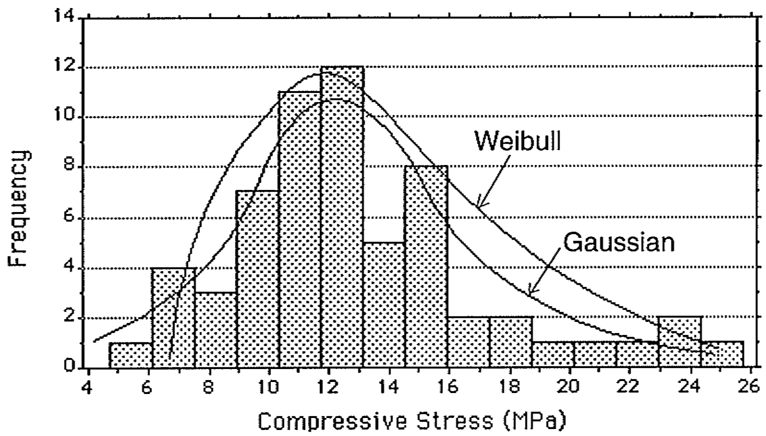


Fig. 4.18: Histogram of Compressive Stress

The value determined from the plot in Fig.4.17 was f_c = 6.66 MPa (966 psi). Using the standard deviation for a sample size of 61 the 5th percentile was calculated as:

$$\mu - (1.67 \times SD) = 13.075 - (1.67 \times 4.261) = 5.959 \text{, say } 6 \text{ MPa } (870 \text{ psi}),$$

where:

μ = sample mean, and;

SD = sample standard deviation.

It was decided that a value of f_c = 6.66 MPa would be used in the proposed design model. This decision was based mainly on two criteria:

(i) When compared with CAN3-086.1-M89, Clause 12.3 recommendation to use 80% of the Select Structural (SS) strength for round poles (80% of SS for S-P-F group = 7.6 MPa), a value of 6.66 MPa was reasonable; and

(ii) Based on research by Madsen (1992) mentioned earlier in this section, using the higher of these values was considered acceptable.

Again, until the database is increased for these poles, it was viewed as prudent to recommend a value of f_c = 6.66 MPa for the proposed design model at this juncture.

4.4 A Proposed Design Tool

Based on the discussion in the previous sections of this chapter, a design tool is proposed which relates strength, the initial out-of-straightness ratio (OS/D) and 1-taper ratio(1-TR) for use in the design of small, round, white-spruce poles as structural elements.

As alluded to earlier, it was stated that the designer could either use the equation generated from multiple regression, or, use a topographic/contour surface to decide what the reduction in the specified compressive strength f_c should be due to OS/D and 1-TR.

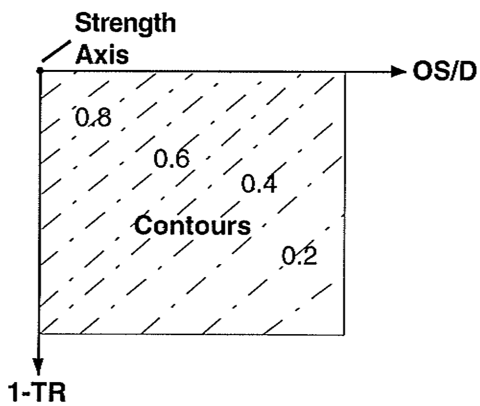


Fig. 4.19 Contour Concept

The 2-D contour surface is generated from the 3-D design surface and is simply a topographic map of the peaks and valleys in that surface. Since the surface is linear in both directions, the contours on the 2-D surface will translate into straight lines from the 1-TR axis across to the OS/D axis. Figure 4.19 illustrates the concept behind the contour plot. Each contour line represents a reduction factor to be applied to the value of f_c based on 1-TR and OS/D. Figure 4.20 shows the relationship between the multiple-regression surface, the design surface, and the contour plot.

The design process for compression members, based on the approach in CAN3-086.1-M89, uses an initial value for the specified strength and then modifies this value by a series of linear modifications. In keeping

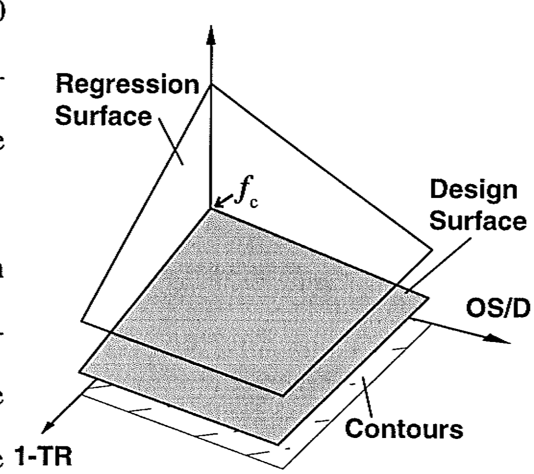


Fig. 4.20: Relationship of Contour Plot to Design Surface

with this method the design equation has been modified to create a *modification factor* to be known as K_{TO} – taper and initial out-of-straightness factor. Using the specified compressive strength determined earlier:

$$K_{TO} = \frac{f_c - 20.85\,(1\text{-TR}) - 1.55\,(OS/D)}{f_c} \qquad \textbf{EQN. 4.1},$$

where:

K_{TO} = taper and initial out-of-straightness factor;
f_c = specified compressive strength parallel to the grain;
1-TR = 1 - the taper ratio, and;
OS/D = initial out-of-straightness at L/2 divided by the diameter at L/2.

Using the above relationship a 2-D contour plot was created as shown in Figs 4.19 and 4.20. A full-page version of this plot for use in the design process, is contained in Appendix "F". Figure 4.21 illustrates the derivation of the contour design surface.

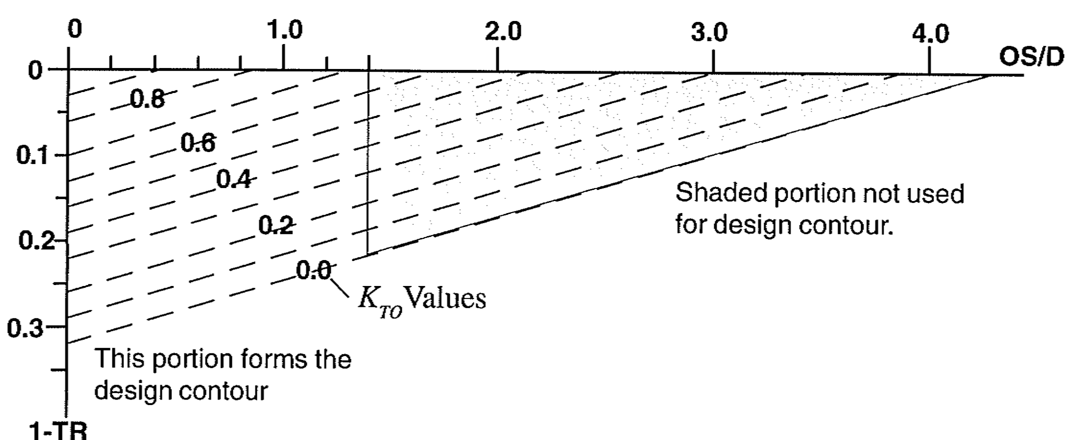


Fig. 4.21: Derivation of Contour Design Surface

Although the maximum OS/D ratio tested was 1.36, it is apparent from Fig. 4.21 that values of OS/D greater than 1.0, even without any taper, yield a reduction of more than 30%. From a design point of view, it would likely be prudent to avoid using poles of this nature in an actual design. The shaded portion in Fig. 4.21 is not included in the design contour, as shown in Fig.4.22. The maximum value of 1.4 for OS/D has been included within the plot to reflect the experimental data range.

Using either Eqn. 4.1, or the plot contained in Appendix "F" (shown scaled-down in Fig. 4.22), the modification factor K_{TO} can be determined. Once a value for K_{TO} has been obtained the design process continues based on CAN3-086.1-M89. The following chapter presents a design example using the proposed model.

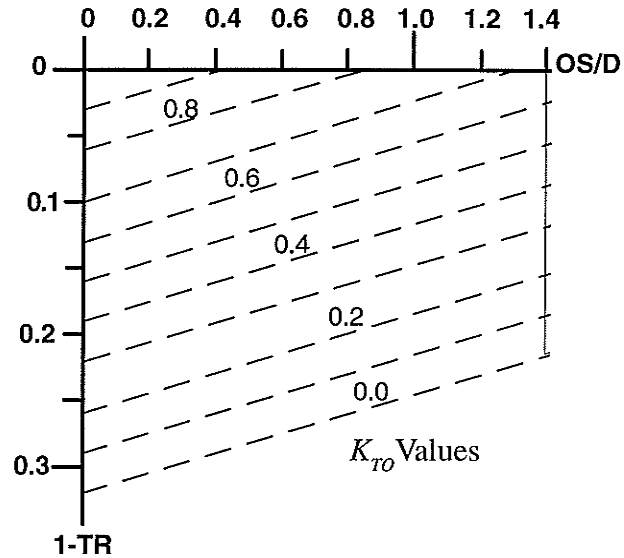


Fig.4.22: 2-D Design Contour Plot

5

Design Example

5.0 Design Example

The following is a proposed application of the design equation or surface in assessing the capacity of a round, white-spruce pole used in compression. Figure 5.1 illustrates a pole that is to be assessed for its use in a structure.

The taper ratio (TR) is calculated to be:

64 / 75 = 0.85.   1-TR is then 1 - 0.85 = 0.15.

The OS/D ratio is determined to be:

15.4 / 70 = 0.22 .

CAN/CSA O86.1-M89 (1989) is used as the basis of the design process. The following relationship from clause 5.5.6:

$$P_r = \phi\, F_c A\, K_{Zc} K_C \qquad \text{EQN 5.1,}$$

where:

Pr	= factored compressive resistance;
ϕ	= 0.8;
A	= cross-sectional area;
F_c	= $f_c (K_D K_H K_{Sc} K_T)$;
f_c	= specified compressive resistance parallel to the grain;
K_{Zc}	= size factor for sawn lumber;
K_C	= slenderness factor;
K_D	= load duration factor;
K_H	= system factor;
K_{Sc}	= service condition factor, and;
K_T	= treatment factor.

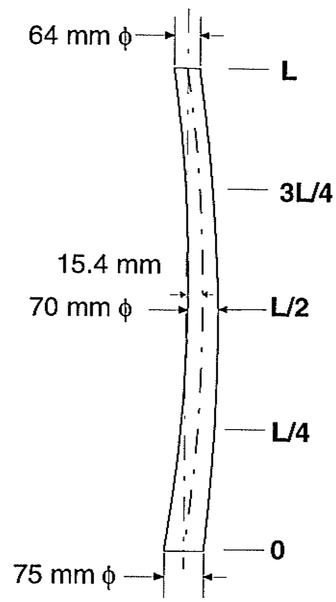


Fig. 5.1: Spruce Pole Design Example
(Length = 2110 mm)

The guidelines contained in CAN/CSA O86.1-M89, clause 12.5.2 - (Poles as Compression members) - states that poles shall be designed: "... in accordance with the appropriate provisions of Clause 5." In keeping with the spirit of the code, the slenderness ratio - C_C, is also checked for the poles.   It is envisaged that lateral bracing would be used on the top chord in a truss system at a spacing of not less than 1200 mm (4'). This length has been used for checking the value of C_C in this particular example.

C_C = effective length / member width = 1200/70 = 17 < 50 , therefore satisfactory.

Before proceeding with the rest of the design process, the use of other modifying factors in the design equation 5.1 on the previous page need to be clarfied within the context of this example based on the discussion in foregoing chapters of this thesis.

The value of K_{Zc}, the size factor, is taken to be 1.0. Although this value can be as high as 1.3, based on the relationship given in Clause 5.5.6.2.2, it was felt that using a value of unity was conservative at this point in the research. Inputting the values for the pole in this example, (length(L) = 2110 mm and dimension in buckling direction (d) = 70 mm), the calculated value of $K_{Zc} = 6.3(dL)^{-0.13} = 6.3(70 \times 2110)^{-0.13} = 1.34$. As this value is not less than unity, the approach taken was considered acceptable.

The new K_{TO}, taper and initial out-of-straightness factor, discussed in Chapter 4, must be included in the expression for F_c. The expression now becomes:

$$F_c = f_c(K_D K_H K_{Sc} K_T \mathbf{K}_{TO}) \qquad \text{EQN 5.2.}$$

The values for the modification factors, other than K_{TO}, have been summarized below in point form:

K_D = 1.00 Clause 4.3.1, standard term loading.

K_H = 1.00 Clause 4.3.4, taken as 1.00, but could be 1.10 for Case 1.

K_{Sc} = 1.00 Clause 5.4.1, dry service conditions.

K_T = 1.00 Clause 5.4.3, untreated.

The relationship developed in Section 4.4 of this thesis and the contour plot contained in Appendix F are now used to determine the value for K_{TO}. Using the relationship from equation 4.1 the value for K_{TO} is determined to be:

$$K_{TO} = (6.66 - (20.85 \times 0.15) - (1.55 \times 0.22)) / 6.66 = 0.479 \cong 0.48 .$$

If the contour plot from Appendix F were to be used, the value for K_{TO} would be read off the plot as shown in Figure 5.2. With OS/D = 0.22 and with 1-TR = 0.15 the value of K_{TO} is determined to be somewhere between 0.47 and 0.48. The designer can now make a judgement as to what value to use. Also, by using the contour plot the designer can see at a glance that the strength reduction for this pole is substantial and may chose not to use this pole at all.

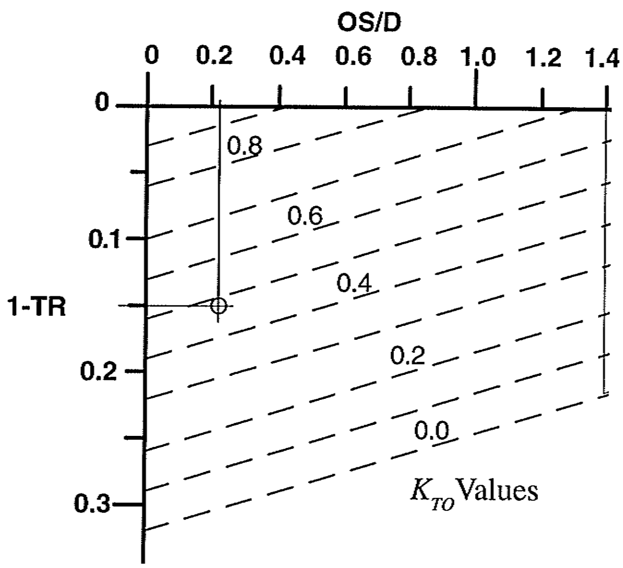


Fig.5.2: Determination of K_{TO} Using Contour Plot

Having determined the value for K_{TO} the specified strength of the pole is determined to be:

$$F_c = 6.66\ (1.00 \times 1.00 \times 1.00 \times 1.00 \times 1.00 \times 0.48) = 3.2 \text{ MPa}.$$

The slenderness factor, K_C was given a value of 1.0 for the purposes of this example. This decision was based on the fact that the new factor K_{TO} incorporates pole strength, geometry, material properties and has been derived for a specific length based on the test programme results. K_C was calculated, however, based on the relationship in Clause 5.5.6.2.3 as a check of this assumption. The modulus of elasticity used for the determination of K_c is the 5th percentile , E_{05}. The value for the sample modulus of elasticity was determined to be 7850 MPa , based on the cumulative plot as shown in Figure 5.3.

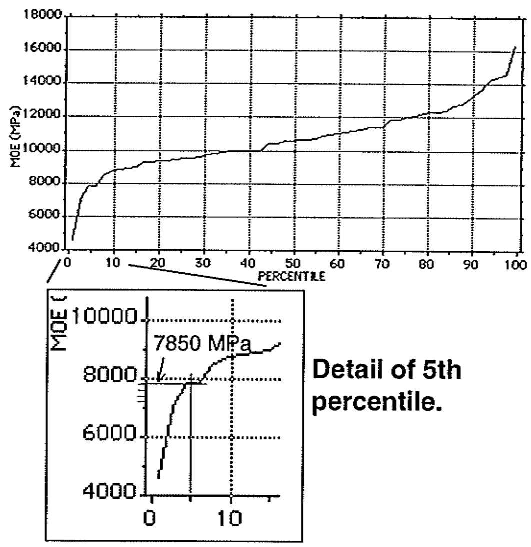


Fig. 5.3: Determination of Sample E_{05} from Cumulative Plot

Substituting this value into the relationhip in Clause 5.5.6.2.3 yielded a value for K_c of 0.95. If this value of K_c is combined with the value for K_H, which in a truss situation could be 1.1, and K_{Zc} which could be 1.3 in this situation, the result is greater than 1.0. It was felt, therefore that using a value of 1.0 for K_c was acceptable for this example.

The Factored Compressive Resistance Parallel to the Grain - P_r can be calculated using equation 5.1 and the cross-sectional area of the pole at the desired location.

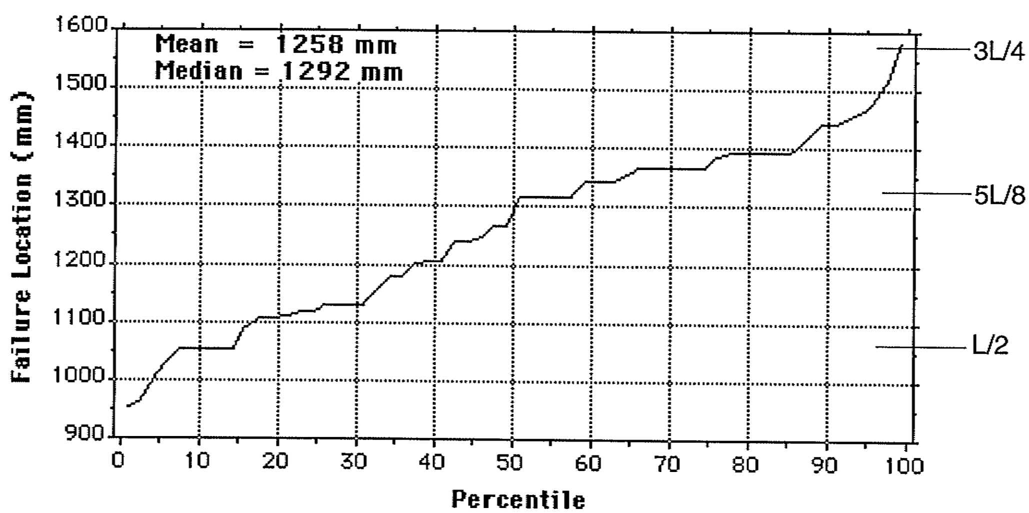


Fig. 5.4: Cumulative Plot of Failure Location Measured from Butt End (mm)

The cross-sectional area used in this example was that at 3L/4. The rationale for using the cross-sectional area at 3L/4 was based on test observations, illustrated in Fig.5.4, that indicate that more than 95% of the specimens *ultimately* failed at a location less than 3L/4 measured from the butt end. This rationale may appear incongruous given the fact that all of the poles were characterized about their diameter at L/2. The choice of 3L/4 in this example is more give the reader a sense of the inherent strength of these poles. This choice also represents a calculated value that would err on the conservative side. It may, with further research however, emerge that the use of the cross-sectional area at L/2 becomes appropriate. At that time the recommended design loads would increase as a result.

The cross-sectional area at 3L/4 is calculated as:

$$\pi d^2/4 = \pi(67)^2/4 = 3525 \text{ mm2}.$$

Thus,

$$P_r = \phi F_c A K_{Zc} K_C = (0.8)(3.2 \text{ N/mm}^2)(3525 \text{ mm}^2)(1.00)(1.00)$$

$$P_r = 9024 \text{ N} \quad (2029 \text{ lbf}) \quad .$$

6

Related Topics

6.0 Discussion of Related Topics:

6.1 Introduction:

During the course of the test programme some questions arose that begged further discussion. These issues, had they been included in the previous chapters, could have unecessarily clouded the primary focus of this thesis. They do, nevertheless, fall within the broader purview of this research work and were thought to be of sufficient interest that a separate chapter be included to provide for a comment on each. The discussion in this chapter is based on observations made during the test programme and is not intended as an in-depth analysis of the issues raised.

6.2 How many trees make a roof?

It is of interest to compare what amount of natural timber resource would be used to construct a truss roof using dimensional lumber versus round-timber poles. If, just a basis for comparion, a single 38 x 89 mm stud (2"x4") were cut from a single tree (as shown in Fig. 6.1), what would be the relative volume of timber in each case.

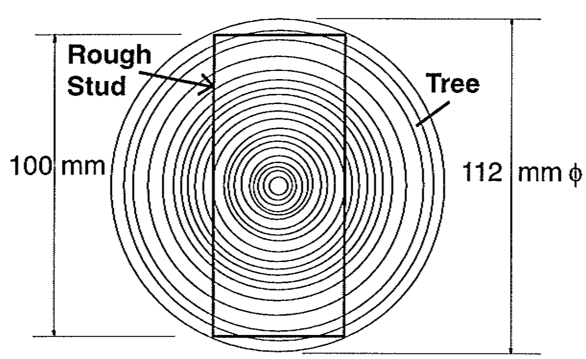


Fig. 6.1: Circumscribed Rough Stud

Consider a roof with 7320 mm (24') span trusses as shown in Fig. 6.2, at a spacing of 600 mm (24") on centres, on a structure 8530 mm (26') long. Assuming the relationship in Fig.6.1 for the dimensional lumber, and an average diameter of 64 mm (2.5") for round poles, the respective volumes of timber have been calculated for a total of 14 trusses using these two materials.

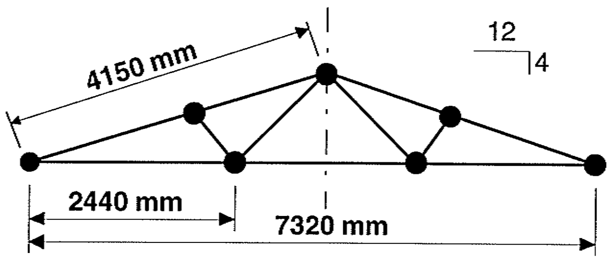


Fig.6.2: Truss Detail

The total volume of timber required to build the trusses with 2x4's is 2.38 m³. Using round poles requires 0.98 m³ of timber. This represents a saving in timber resource of 59%. Recognizing that this is only a estimation, this comparison does, however, indicate that small, white-spruce poles should be thought of in a different light. Poles removed in pre-commercial thinning operations, for example, could be considered for structural uses as opposed to just corral rails.

6.3 Size and Shape Effects in Round Poles:

The whole issue of size effects came to light with in-grade testing (e.g.Madsen, 1992; WWPA, 1991) where it was found that design strengths for smaller dimension lumber could be increased. That is, the 5th percentile strengths for 2x4's was much greater than the 5th percentile for 2x10's.

During routine testing, it was observed that some specimens did not reach the maximum load until rather large lateral deflections had taken place. (For example see specimen 24A and 37A in Appendix A.) Typically, the maximum load was observed to occur at a lateral deflection at L/2 of about 40 mm (1.6"). Once the L/2 diameter had decreased to 50mm (2") or less and the OS/D ratio was greater than 0.75 there was a change in pole behaviour with respect to maximum load:

1. The *drop-off* between the instantaneous and 1-minute load was much less, 1-2 voltmeter increments as opposed to 5-6 for a more *typical* pole; and
2. Secondly, the maximum load occurred at lateral deflections in some cases over 100mm.

A postulation of what was felt to be occurring is offered. With the *larger-diameter, straighter* pole, it resists the imposed loading (axial and flexural) until the fibres on the compression side of the pole begin to collapse. These collapsing fibres then have essentially zero stiffness (EI≅0) and are, therefore, incapable of sustaining any increased load. This zone of collapse results in an effective reduced cross-sectional area in the zone where, based on laboratory observations, ultimate failure of the pole occurs. This reduced cross-section causes the neutral axis of the pole to shift toward the tension side. Finally, when there was sufficient lateral deflection, the fibres can no longer maintain continuity and fail. The observation of the voltmeter *drop-off* between 0-1 minute readings prior to maximum load seem to imply that there was some fibre crushing, or fibre realignment, taking place within the pole that was not visible on the outside. Once maximum load had been reached, there was, however, a not-unexpected visible zone of crushing on the compression side.

In the case of *smaller-diameter, high out-of straightness* poles it is postulated that this fibre collapse on the compression side is put off until the pole has laterally deflected significantly more than the larger pole discussed above. If the pole is either thinner, more out-of -straight , or a combination of the two, its initial resistance to buckling is reduced as compared to a pole without these inherent disadvantages. The pole is predisposed to buckle. As the load is increased the pole takes a path of least resistance. It exhibits a tendency to bend more than it does to resist the load increment. The fibres conform to an ever-increasing bow of the pole until they buckle themselves, due more to the extreme geometry than their ability to resist the imposed loading. Inspection of the failure zones indicated that with these specimens the amount of buckled fibres was much less than with larger-diameter, straighter poles. (These data are contained in Appendix A.)

If a discussion by Neubaurer (1961) is considered in conjunction with the concept of *stress gradient* (Freudenthal, 1964), clues emerge that may explain this dissimilar behaviour. Fig. 6.3 illustrates the stress distribution in two poles subjected to loads that create exactly the same maximum stress σ_t in both poles. What Neubaurer refers to as a *supporting-action theory* occurs between the fibres of the timber. The distances **a** and **b** in Fig. 6.3 at the location of the arrow, correspond to some stress within the timber. What is of interest here is that the rate-of-change of stress is greater in the smaller pole. In other words, at the same location, indicated by the arrows in Fig. 6.3, the stress in the large ϕ pole is greater than in the small ϕ pole. As wood fibres fail, either in tension or compression, they get *support* from the neighbouring unfailed fibres. As Neubaurer points out, "*...it appears that the less-stressed fibres are capable of lending consderable supporting action, and that those which are close to the failing fibres are the most effective.*"

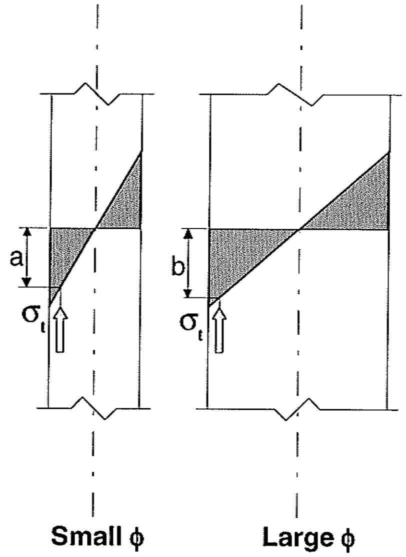


Fig.6.3: Supporting Action Theory

This would seem to validate what was observed in the lab. The fact that smaller ϕ poles sustained larger lateral deflections before maximum load was reached could be due to the support the outer fibres obtained from less-stressed adjacent fibres. The outer fibres of larger poles did not benefit from the adjacent fibres as much since these fibres were much higher stressed, and could not be of as much support.

The purpose of this discussion was to give the reader more of a macro-view of the behaviour of these two types of poles. This information about their performance within the context of these tests provides insight into how these poles would function within a structure such as a timber-pole roof.

6.4 Load sharing with round-timber trusses:

While watching pole behaviour in the column test frame, one thing became apparent – these poles appeared to absorb a considerable amount of energy before they break. Even though the load they carried at large lateral deflectctions was substantially less than their maximum capacity, they did exhibit a high degree of toughness. Toughness is defined for this discussion as the capability of a material to undergo large deflections prior to fracture (after Bauld, 1982). Fig. 6.4 illustrates the load vs lateral deflection curve for specimen 38A. The actual values are less important in this discussion than the area under the curve, which gives an indication of the amount of energy absorbed by the specimen. What is of interest here is how this relates to pole performance within a roof structure. Even at a lateral deflection of 190 mm (7.5") the pole still sustained an axial load of 3 kN (700 lbf). The implication of this is seen as the ability of round-timber trusses to absorb, or take on load that is being shed from a neighbouring truss in distress within a roof system. Since any given member within the framework should be designed using a value of f_c considerably lower than the maximum capacity of the pole, there would still be energy absorbing capacity in the neighbouring trusses. Although this is not a new concept (CAN3-089.1-M89, Clause 5.4.4, 1989), using round timber may allow for a higher value of K_H, the system factor.

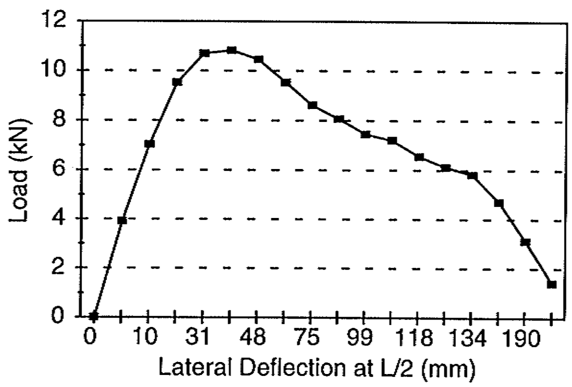


Fig. 6.4: Load-Deflection Curve -Specimen 38A

In addition, the geometry of round timber provides the same moment of inertia regardless of which axis it is taken about (see Fig.6.5). The resistance to out-of-plane buckling with round-timber trusses should be superior to that of conventional 2x4 construction.

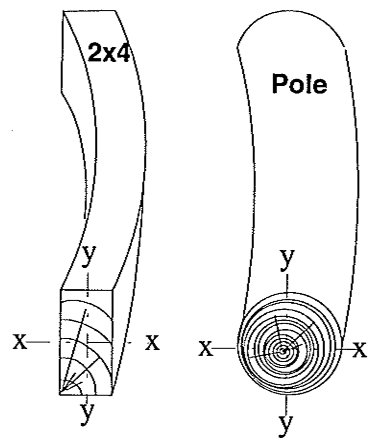


Fig. 6.5: Moments of Inertia: Sawn Timber vs Pole

A final observation that could come under this topic is how to answer the question - *If a pole has shifted in the truss member at the wall plate by 3/8", should I be worried?* Based on the data contained in Appendix A, it has been observed that the axial deflection of many members was quite considerable. The median platen movement to maximum load for the test sample was 6.2 mm (1/4"). While the load-carrying capacity of the member would be reduced beyond this point for half of the specimens, the pole's capacity to absorb energy would render this situation less of a material-failure problem than the resulting cracking of ceiling finishing due to geometry changes. The important point for illustration here is that timber is fairly *forgiving*. If a sense of the material's servicability limits are understood than this will most certainly help in making judgements about in-situ problems.

6.5 A typical white-spruce pole:

A total of 102 specimens were measured to provide a characterization of the poles contained in the initial bundle. The test specimens were included within this sample. Figures 6.6 to 6.8 illustrate the distribution of: diameter at L/2; OS/D ratios; and Taper Ratios for the sample. Poles were selected at random with an approximate diameter range that would be suitable for truss construction. Pole diameter exhibited a fairly *normal* distribution.

Approximately 95% of the taper ratios measured in this sample were tested within the model development phase. What is interesting is that the OS/D ratio still remained clustered. Fig 6.7 indicates that over 90% of the specimens fall within the range 0 to 0.4. This again indicates the importance of having a broad range in the OS/D data to get more information about the what the performance limit of a pole might be.

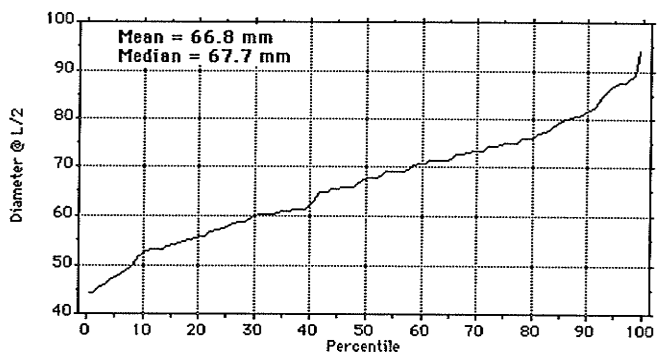


Fig.6.6: Cumulative Plot of Pole Diameter at L/2

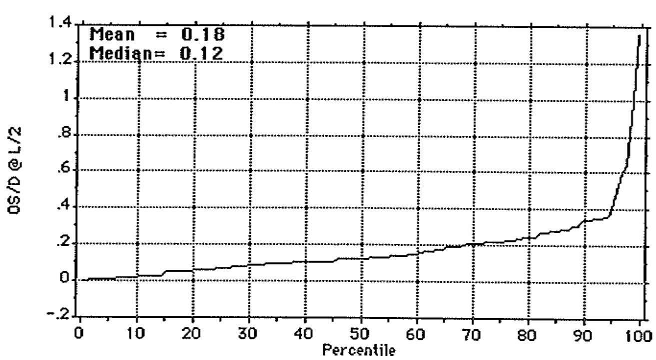


Fig.6.7: Cumulative Plot of Out-of Straightness Ratio at L/2

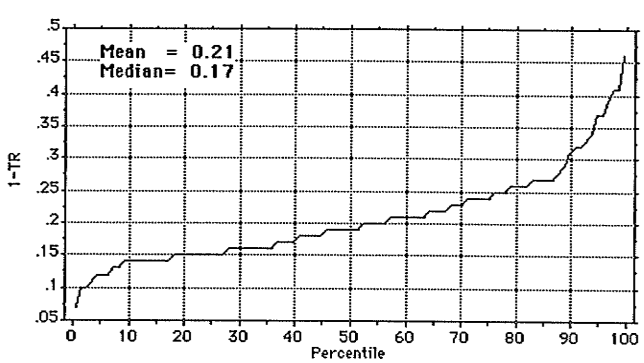


Fig.6.8: Cumulative Plot of 1-Taper Ratio

6.6 A proposed failure mechanism for round timber:

Observations made during testing have given some clues as to the flexural-compressive failure mechanism in the poles. It was noted that after the maximum load was reached, the majority of poles began to *kink* at the critical cross-section (usually between L/2 and 5L/8) as the bending deformation became concentrated in a *hinge-like* zone. In spite of this kinking the load-carrying capacity of the pole was not severely impaired. Although timber is not generally considered to be a plastic material, like structural steel for example, the deformation behaviour beyond the point of maximum load was reminiscent of the quasi-plastic behaviour of lightly-reinforced concrete members in bending, in that a hinge is formed(after Hognestad, 1955,1957). In a timber section one could postulate this quasi-plastic hinge zone if one were to recognise the strain-softening nature of the timber in compression (see Fig. 6.9(a)). The curve shown in Fig. 6.9(a) is typical for the specimens

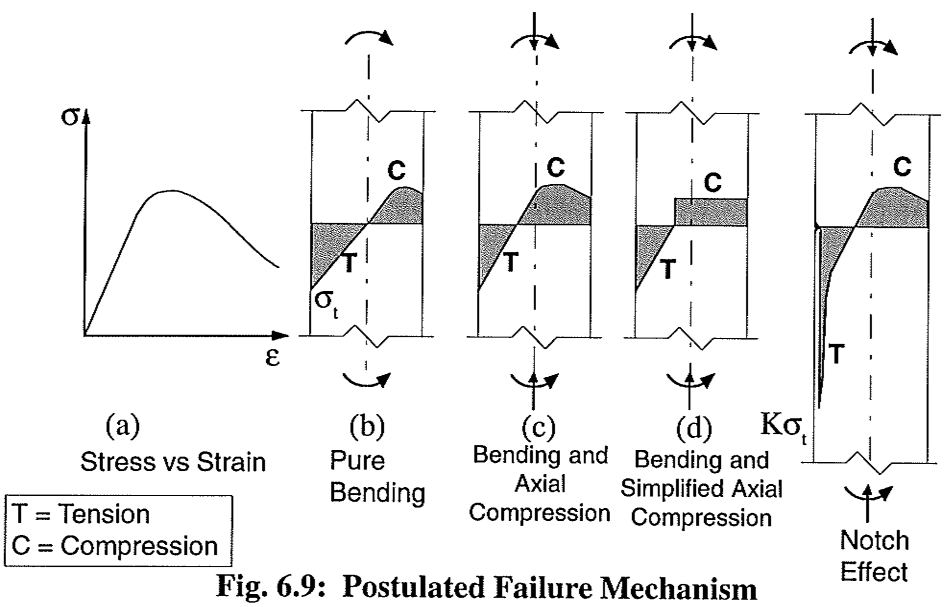


Fig. 6.9: Postulated Failure Mechanism

tested, and typical of a column of elastic-plastic material as discussed by Bleich (1952, Fig.14) When observed in a stiff testing apparatus the post-maximum-stress behaviour could be thought of as being governed by the micro-delamination of the wood fibres and their slow, restrained buckling, leading to a gradual, controlled drop in compressive strength. If compressive behaviour is coupled with a near-linear stress-strain behaviour on the tensile side of the bending member, and linear strain behaviour is assumed at the critical bending section (the hinge), the stress diagram becomes that of Figure 6.9(b).

When combined bending and axial compression are considered, the stress diagram changes to that in Fig. 6.9(c), which in turn can be approximated by that shown in Fig. 6.9(d). In each case the maximum tensile stress is assumed to be less than the maximum clear tensile strength of the timber. Finally, if a notch or discontinuity occurs on the tensile side of the hinge point, then the effect of the stress raiser must be considered. The corresponding stress diagram becomes somewhat of the form shown in Fig. 6.7(e). In this figure, the tensile stress σ_t is magnified by a factor, K, to become $K\sigma_t$. This localized, but very high, tensile stress may lead to failure on the tensile side of the specimen causing the load-carrying capacity to drop suddenly. This phenomenon was observed in the lab. Where a notch or a knot was present at the critical section of the pole.

What is considered to be the essence of this postulated failure mechanism is the forming of the kink – or hinge – zone. Linking this discussion with that of Section 6.3, the supporting-action theory, the next step may be to postulate that pole performance is suggestive of confined plastic behaviour. Although only conjecture at this stage, the application of plastic design techniques may be possible for timber structures.

6.7 Spiral Grain:

An old Bavarian dictum goes that if the twist in the tree runs counter to *(opposite to)* the direction of the sun then, this wood will retain its shape. (Phleps, 1982)(italics added by author). This was determined by using the right hand placed up against the tree. Fig. 6.10 (and Fig.1.4 showing the hand) illustrate this concept. If the timber was right-handed(RH), the twist running the direction of the little finger of the right hand, then it was considered usable for building A left-handed(LH) twist was not recommended for use. A question arises - From which side of the tree is the person determining left and right. Since the theory is Bavarian in origin the sun would be in the south, thus, one presumes, the twist is found by standing on the north side of the tree looking south. Aside from being an interesting aside, the author came across this anecdotal evidence early in the research and decided that if the opportunity arose during testing, he would keep note of it. Specimens 27A, 27B, and 28B provided a glimpse into this issue. Table 6.1 below summarizes their behaviour.

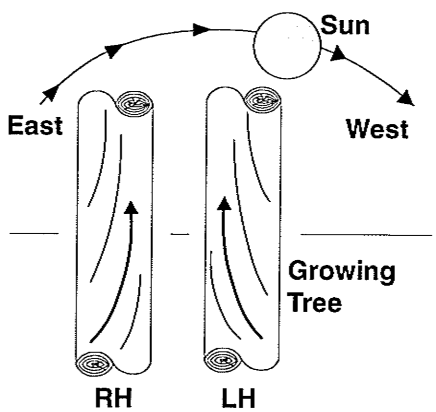


Fig. 6.10: Twist in the Tree

Specimen	Spiral Type	Maximum Axial Twist	Type of Failure	Maximum Lateral Δ @ L/2 (mm)	Maximum Axial Δ @ L/2 (mm)
27 A	LH	2.5° CCW	Controlled,slow	176	46.83
27 B	SC	5°CW	Controlled, sudden	165	30.16
28 B	RH	10°CW	Sudden, dramatic	114	14.35

Note: CW = clockwise, CCW = counterclockwise, SC = straight crack, longitudinal

Table 6.1: Comparison of 3 Specimens Relating to Grain Direction

While this is by no means conclusive evidence about the behaviour of spiral-grained poles, it was interesting nevertheless. Poles 27A and 27B both failed in a controlled manner. As the pole got closer to finally breaking, sharp cracking sounds could be heard from within the pole, then quite quickly, the pole broke. These failures were not violent. Within the stiff machine they were controlled. Specimen 28B however, was a different matter. Out of the 61 specimens tested it was the only one that gave the author a bit of a surprise, although nothing dangerous occurred. Specimen 28B had a strong *feel* to it while being tested. It held and held with very faint cracking sounds. Suddenly, it let go with a loud report and dropped out of the test rig. It fell against the test frame in the direction it was bending. In retrospect, it reminded the author of what a miner had once told him, *"You always want to here the mine talking to you."* In other words, the stored energy is being relased. In this case all of the stored energy all went at the same time.

Whether the behaviour of these poles was a result of their spiral grain, or lack thereof, is open to conjecture at this point. It is likely that the reference to spiral grain within the Bavarian context is related more the soundness of a log and dimensional changes in the log as it dries. The importance of spiral grain within the context of round-timber trusses would be less from a strength concern than it would be from a change in geometry once the pole was in place within the structure. In many cases the poles will be used with moisture contents not that far below their fibre saturation point. Once in dry structure it would likely be prudent to use RH spiral poles in locations where changes in geometry are most critical.

7

Further Research

7.0 Suggestions for Further Research

While conducting this research there were instances when one was tempted to venture off in various directions to examine issues that arose out of the testing programme. While these issues may be relevant to broader timber research, each could easily constitute a separate piece of work. This chapter presents some suggestions for further research.

7.1 Increase Database:

As with many research situations it would always be comforting to have a larger database of information to analyse. Confidence in the correlation of the data discussed in Chapter 4, although seen to be significant for this sample size, would be further tested with a larger sample. It is recommended that a total of 200 specimens be examined from this species, that is, white-spruce from the Duck Mountain region of Manitoba.

7.2 Other Species Testing:

The results obtained from the this testing programme can only be considered valid for white-spruce poles. Just as an example, tamarack is available in many regions of the Canada (Hosie, 1990) and is often a first choice of people for fence posts and rails. Living in wet areas tamarack is more resistant to decay than spruce (Hoadley, 1980) and tends to be stronger in compression (Mullins, 1981). The results obtained from these tests on white-spruce poles could be modified based on material properties of the tamarack derived from small specimens. There would be no assurance that some peculiarity of tamarack might not affect its performance. Testing of other species is considered important as the results of these tests are species-specific and not necessarily directly transferable.

7.3 Tests With Flat Ends:

In a 1972 publication, Neubaurer discusses strength differences with respect to end conditions, pinned versus flat. It would be interesting to observe pole behaviour with this type of end condition. Although it is not expected that the results would be substantially different from Neubauer's work, before recommendations for the use of small-diameter, round poles as wall studs could be made some indication of their performance in this manner would be valuable.

7.4 Machine Stress-Rated Poles:

Having a sense of the stiffness of a pole prior to its use in a structure would be valuable for timber utilization in a structure. This would be particularly true in situations where the ability to choose *good* round-timber poles is limited (Dick, 1992). A simple, hand-operated device for doing a type of machine-stress-rating (MSR) of poles could be easily fabricated (see Fig. 7.1). A pole would be placed in a frame with uprights a set distance apart. A load would be applied at A causing a set deflection at B. The load at A would be recorded. Knowing the load, span, and deflection, the value for EI could be calculated for the pole. Having an indication of the pole's apparent stiffness would allow the builder to place a pole in a structure more knowledgably.

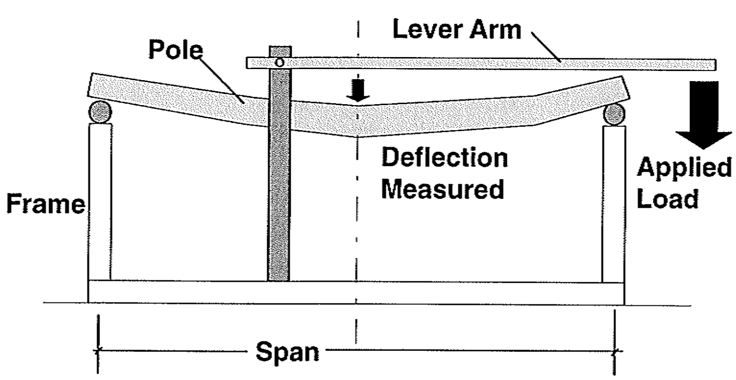


Fig.7.1: Machine Stress Rating Machine

7.4 Comparison of Surface Technique:

As alluded to in previous sections of this thesis, there exist other column design formulae for timber structures (Neubaurer, 1973; Buchanan, 1984; Hoyle, 1989; and Zahn, 1986) When a larger database has been established for small-diameter, round-timber poles, the test results should be compared to these, and other approaches, to column design. As discussed in section 4.1, once this testing has been completed then a meaningful comparison of the various techniques can be undertaken.

7.5 Plastic Design:

The proposed failure mechanism discussed in section 6.6 suggests that the exhibited behaviour of the round poles appears plastic in some respects. Investigation of the possibility of applying plastic-design techniques to timber structures should be undertaken.

7.6 Application of Weibull Distribution to Round-Pole Data:

As discussed in Chapter 4, using a Weibull distribution on lumber strength data is an alternate approach for determining the 5th percentile compressive resistance. Once a larger database has been established for small, round-timber poles, investigation of the application of the Weibull distribution should be undertaken.

7.7 Investigation of Limit States Design (LSD) Resistance Factor of $\phi = 0.8$

Within the context of this research the modification to the specified strength F_c is quite considerable. For instance in the design example in Chapter 5 of this thesis K_{TO} equalled 0.48, representing a 52% reduction in F_c. The use of a resistance factor ϕ of 0.8 may be unduly penalizing the pole. It is recommended, therefore, that further refinement of the proposed design tool discussed in this thesis must include investigation into the suitability of this factor.

8

Closing Remarks

8.0 Closing Remarks:

8.1 General Comment:

This research has provided the author with an increased depth of understanding of both test equipment design and timber behaviour. This thesis represents a slice of time along a continuum of acquiring a better grasp of the behaviour of a natural material that does not always follow man's rules. This continuum started before this body of work, and will continue, the author hopes, for a long time yet. The completion of this writing represents the honing of old tools and the acquisition of some new ones that can now be applied.

Both this and previous experience with timber emphasize that working with a natural material requires vigilance at all stages of construction if optimum use of resources are to be realized. In other words, a *continuity of care* has to exist from design through to installation. Each individual involved in the process of timber construction must exhibit the same level of concern for the material, otherwise it becomes a *weakest-link* scenario. All the best intentions of research and understanding design concepts will be negated if a timber member is placed with a knot in the wrong place.

8.2 Conclusions:

The research presented in this thesis can be considered under two separate but mutually-supporting themes – test equipment and pole design model. Conclusions emerge for both and are presented independently for clarity.

Test Equipment:

It was demonstrated that it is possible to design and fabricate precision test equipment that is low-cost. The entire test programme was conducted using equipment that had a total out-of-pocket cost of less than CDN$2000.00. This is considered to be a most important accomplishment in a time of dwindling resources. The implication is that equipment costs do not have to be as much of a deterrent to scientific research as one might think. A main message that emerged from this portion of the work was that a grasp of underlying principles and a clear understanding of what it is you want the equipment to do are critical. Once these conditions have been satisfied, then materials can be knowledgably sourced. Albeit an often lengthy process, utilizing reclaimed material can sometimes lead to more inventive solutions.

Design Model:

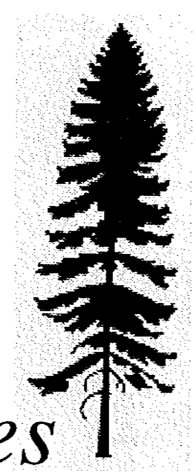
The main focus of the thesis was to investigate the effect that initial out-of-straightness and taper have on the strength of round, white-spruce poles used in a column loading situation. A total of 61 specimens, 2110 mm in length were tested. It has been demonstrated that the initial out-of-straightness does not appear to have a significantly adverse affect on pole performance until this initial out-of-straightness is greater than 0.5 diameter when measured at mid-height of the pole. Pole taper, measured as the ratio of top diameter divided by butt diameter, exhibited a fairly strong relationship with pole strength. Taper ratios in excess of 0.3 showed a marked decrease in pole strength. Generally, there was a stronger correlation between taper and strength than there was between initial out-of-straightness and pole strength.

A design model was developed that related the strength, taper and initial out-of-straightness of the pole. A modification factor called K_{TO} - taper and initial out-of-straightness factor, was developed to be used in conjunction with the limit states design of compression members in CAN/CSA 086.1-M89(1989). The design model was tested. Results of the test indicated that there is potential for its use within the design process for small, round, white-spruce poles. An example of the design process using round timber was presented using the design model. It was demonstrated that the modification factor K_{TO} could be determined from a mathematical formula, or, from a two-dimensional plot.

Overall Conclusion:

The main goals of this research programme, it is felt, have been achieved. That is, to fabricate affordable test equipment and to attempt to quantify the relationship between strength, taper and initial-out-of-straightness of small, round, white-spruce poles. In addition, this work indicates that it is not unrealistic to consider these poles for use as something other than fencing. This piece of research has provided a systematic insight into the behaviour of poles of this size. Perhaps the use of these rediscovered structural elements may not find their way into building practices of the southern urbanized corridor of Canada. Having some scientific background to their performance, however, may lend credibility to the use of small, round-timber poles as structural elements. This would be of particular importance for individuals pursuing a more economically-sustainable lifestyle, as well as for communities that cannot afford to pay the value-added costs of material that originated in their own backyard, but is marketed via southern corporate interests.

REF



References

References

ASTM D9-87 (reapproved 1992). Standard Teminology Relating to Wood

ASTM D25-91. (last 2 digits imply date)Standard Specification for Round Timber Piles

ASTM D143-83. Standard Methods of Testing Small Clear Specimens of Timber

ASTM D198-84. Standard Methods of Static Tests of Timber in Structural Sizes.

ASTM D2555-88. Standard Test Methods for Establishing Clear Wood Strength Values.

ASTM D2899-86. Standard method for Establishing Design Stresses for Round Timber Piles

ASTM D3200-74. (Reapproved 1986) Standard Specifications and Methods for Establishing Recommended Design Stresses for Round Timber Construction Poles.

ASTM D4442-92. Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-base Materials.

ASTM D4444-92. Standard Test Methods for Use and Calibration of Hand-Held Moisture Meters.

Bauld, N.R. 1982. Mechanics of Materials. Brooks/Cole Engineering Division, Division of Wadsworth, Inc. Monterey California. ISBN 0-8185-0495-1

Beckwith, T.G. and Marangoni, R.D. 1990. Mechanical Measurements. 4th Ed., Addision-Wesley Pub. Co., Reading, Mass., USA. ISBN 0-201-17866-4

Bleich, F. 1952. Buckling Strength of Metal Structures.McGraw-Hill Bo. Co., New York, USA.

Booth, L.G. 1964. *The Strength Testing of Timber During the 17th and 18th Centuries*, Institute of Wood Science Journal No. 13, November 1964, pp.5-30.

Bostrom, L. 1992. Method for Determination of the softening behaviour of wood and the applicability of a nonlinear fracture mechanics model. Doctoral Thesis, Report TVBM-1012, Lund Institute of Technology, Lund, Sweden.

Buchanan, A.H. 1984. Strength Model and Design Methods for Bending and Axial Load Interaction in Timber Members. Ph.D. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

CAN3-015-M83, 1983. (last 2 digits imply date)Wood Utility Poles and Reinforcing Stubs. Canadian Standards Association, Rexdale, Ontario, Canada.

References

CAN/CSA-086.1-M89, 1989. Engineering Design in Wood (Limit States Design). Canadian Standards Association, Rexdale, Ontario, Canada.

Cook, N.H. and Rabinowicz, E. 1963. Physical Measurements and Analysis, Addison-Wesley Pub. Co. Inc., Reading, Mass. USA.

CSA Standard S307-M1980, 1980. Load Test Procedure for Wood Roof Trusses for Houses and Small Buildings. Canadian Standards Association, Rexdale, Ontario, Canada.

CWC Canadian Wood Council, 1990, Wood Design Manual, Canadian Wood Council. Ottawa, Ontario, Canada. ISBN 0-921628-04-8

CWC Canadian Wood Council, 1991, Introduction to Design in Wood, Canadian Wood Council, Ottawa, Ontario, Canada. ISBN 0-921628-11-0

Dean, M. and Douglas, R.D. 1962. Semiconductor and Conventional Strain Gages. Academic Press, New York, USA

Dick, K.J. 1989. A Metal Connecting System for Bush-Pole Trusses. M.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Dick, K.J. 1992. *Field Testing of a Metal Connecting System for 'Bush-Pole' Trusses in Sierra Leone, West Africa.* Applied Engineering in Agriculture, American Society of Agricultural Engineers, St. Joseph, MI., USA,Vol. 8, No.5, September, 1992

Dove, R.C. and Adams, P.H. 1964. Experimental Stress Analysis and Motion Measurement. Charles E. Merrill Books, Inc., Columbus, Ohio, USA.

Faherty, K.1989. Wood Engineering and Construction Handbook. McGraw-Hill Pub. Co., New York, USA. ISBN 0-07-019895-0

Freudenthal, A.M. 1950. The Inelastic Behaviour of Engineering Materials and Structures. John Wiley and Sons, Inc., New York (third printing 1964).

Glos, P. 1986. *Rate of Loading and Duration of Load Tests in Tension and Compression.* International Workshop on Duration of Load in Lumber and Wood Products, Forintek Canada Corp., Special Publication No.SP27, March 1986.

Hoadley, R.B. 1980. Understanding Wood, A craftman's guide to wood technology. The Taunton Press Inc., 63 Main Street, Newtown, Connecticut, USA. ISBN 0-918804-05-1

References

Hoadley, R.B. 1990. Identifying Wood, Accurate results with simple tools. The Taunton Press Inc., 63 Main Street, Newtown, Connecticut, USA. ISBN 0-918804-05-1

Hognestad, E.; Hanson, N.W. and McHenry, D. 1955. Concrete Stress Distribution in Ultimate Strength Design. Bulletin D6, Portland Cement Association, Authorized reprint from Journal of the American Concrete Institute, December 1955, Proceedings Vol. 52, p.455. (see also companion document D6A containing commentary on D6)

Hognestad, E. 1957. Confirmation of Inelastic Stress Distribution in Concrete. Bulletin D15, Portland Cement Association. reprint from the Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Proc. Paper 1189, Vol.83 No.ST2, March, 1957.

Holman, J.P. 1971. Experimental Methods for Engineers. 2nd ed. McGraw-Hill Bo. Co., New York, USA.

Hosie, R.C. 1990. Native Trees of Canada. 8th ed. Minister of Supply and Services Canada, Pub. by Fitzhenry and Whiteside Ltd. Markham, Ontario, Canada. ISBN 0-88902-558-4

Hoyle, R.J. and Woeste, F.E. 1989. Wood Technology in the Design of Structures. 5th ed., Iowa State University Press, Ames Iowa, USA. ISBN 0-8138-1975-x

Huybers, P. 1984. *A Timber Pole Structure.* 3rd International Conference on Space Structures, Ed. H. Nooshin, Elsevier Applied Science Pub., pp.896-900. ISBN 0-085334-309-8

Huybers, P. 1985. *Space Structures Made of Timber Poles.* International Assoc. for Shell and Spatial Structures, Conference Proceedings, Moscow, Sept. 23-28, 1985.

Iscandari, Jr. A.M. 1988. Investigation Into The Suitability of Using Pole Type (Bush Sticks) Trusses in Low Cost Housing Roof Construction. Graduation project, Fourah Bay College, University of Sierra Leone.

Johns, K.and Madsen, B. 1982. *Duration of Load Effects in Lumber. Part 1. Fracture Mechanics Approach.* Canadian Journal of Civil Engineering, Vol. 9, No. 3, pp.502-514.

Lansdown, A.M. 1964. An Inexpensive Demountable Electric Strain Transducer. Department of Civil Engineering Report, University of Southampton, Southampton, U.K.

References

Lansdown, A.M. 1992. Personal conversation between author and Dr. Lansdown, September, 1992.

Liska, J.D. 1950. Effect of Rapid Loading on Compressive and Flexural Strength of Wood. Forest Products Laboratory report No.1769.

Madsen, B, 1972. An Engineering Approach to Estimating the 5th Percentile Levels for Structural Properties of Wood. Structural Research Series, Rep. No. 8, University of British Columbia, Vancouver, BC., Canada.

Madsen, B.; Janzen, W. and Zwaagstra, J. 1980. Moisture Effects in Lumber. Structural Research Series Report #27, ISSN 0318-3378, Dept. of Civil Engineering, University of British Columbia, Vancouver, Canada.

Madsen, B. and Johns, K. 1982a. Duration of Load effects in lumber, Part II: Experimental Results. Canadian Journal of Civil Engineering, Vol. 9, No.3, pp. 515-525.

Madsen, B. and Johns, K. 1982b. Duration of Load effects in lumber, Part III: Code Considerations. Canadian Journal of Civil Engineering, Vol. 9, No.3, pp. 526-536.

Madsen, B. ; Sexsmith, R.1983. Recent developments in timber engineering. Canadian Journal of Civil Engineering, Vol. 10, pp.722-739.

Madsen, B. 1992. Structural Behaviour of Timber. Timber Engineering Ltd. 575 Alpine Court, North Vancouver, BC, Canada. ISBN 0-9696162-0-1

Madsen, B. 1993. Personal conversation author had with Dr. Madsen in May, 1993.

Miller, F.E. and Doeringsfield, H.A. 1963. Mechanics of Materials. 2nd ed., International Textbook Co. Scranton, Pennsyvania, USA.

Mullins, E.J. and McKnight, T.S. 1981. Canadian Woods, Their Properties and Uses. Ministry of Supply and Services, Canada. ISBN 0-8020-2430-0. (note: not currently in print)

Neubauer, L.W. and Tekinel, O. 1966. A More Efficient Column Formula for the Design of Wooden Posts and Studs. Transactions of the ASAE, Vol. 9, No.6

Neubauer, L.W. 1969. Proposed CRG Generalized Column Formula for Studs and Poles. Transactions of the ASAE, Vol.12, No.5.

Neubauer, L.W. 1972. Full-Size Tests Confirm Superior Strength of Square-End Wood Columns. Transactions of the ASAE, Vol. 15, No.2.

References

Neubauer, L.W. 1973. A Realistic and Continuous Wood Column Formula. Forest Products Journal, Vol. 23, No.3, March 1973.

Neubauer, L.W. and Walker, H.B. 1961. Farm Building Design. Prentice-Hall, Inc., Englewood Cliffs, N.J., USA.

Omega, 1992. The Pressure Strain and Force Handbook, Vol.28. Omega Engineering, Inc., P.O.Box 4047 Stamford, Connecticut, USA.

Parry, J.P.M. 1987. Shanty Upgrading. Intermediate Technology Workshops, Cradley Heath, U.K. B64 7DD.

Phleps, H. 1982. The Craft of Log Building. Lee Valley Tools Inc., 1080 Morrison Dr., Ottawa, Ontario, Canada, K2H 8K7. Reprint of original publication in German - *Der Blockbau.*

Protimeter, Instruction Book for Protimeter Timbermaster Moisture Meter, Model 71T/ D375T , Marlow, Bucks, England

Savic, J. 1991. Buckling Behaviour of Wooden Poles. Master of Science Thesis, University of Manitoba, Winnipeg, Manitoba, Canada, April 1991.

SKAT, 1988. Appropriate Building Materials, A catalogue of potential solutions. SKAT, Swiss Center for Appropriate Technology, St. Gallen, Switzerland. ISBN 3-908001-09-9.

Silvester, F.D. 1967. Timber, *Its Mechanical Properties and Factors Affecting its Structural Use*. Pergamon Press, Oxford, U.K. Pergamon Series of Monographs on Furniture and Timber, Vol. 8.

Statview,1991. Statview Student, The Affordable Data Analysis Solution for Students. Software for Macintosh computer. Abacus Concepts, Inc., Berkeley CA, USA.

Timoshenko, S.P. and Gere, J.M. 1972. Mechanics of Materials. D.Van Nostrand Co., New York, USA, ISBN 0-442-22637-3

(USDA)United States Department of Agriculture, Forest Service, 1989. The Encyclopedia of Wood, Revised Edition. Sterling Pub. Co. Inc., New York, USA. Reprint of 1987 revised edition of "Wood Handbook: Wood as an Engineering Material." issued by US Gov't Office. ISBN 0-8069-6994-6

Valentin, G.H., Bostrom, L., Gustafsson, P.J., Ranta-Maunus, A., and Gowda, S. 1991. Applicaton of fracture mechanics to timber structures. RILEM state-of-the-art report, Technical Research Centre of Finland, Espoo, Finland, Research Notes, 1262 (Note: cost CDN$48.00)

References

Wangaard, F.F. 1981. WOOD, Its Structure and Properties. Forest Products Laboratory, Forest Service, USDA, in cooperation with The University of Wisconsin-Extension. Published by EMMSE Pennsylvania State University, Pa.

Wolfe, R. 1980. Low-Cost Pole Building Construction. Garden Way Publishing, Pownal, Vermont, USA. ISBN 0-88266-170-1

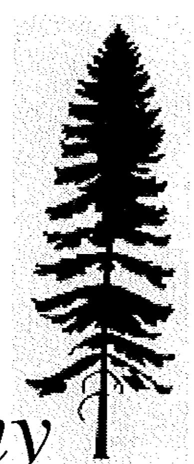
Wood, L.W. 1960. *Relation of Strength of Wood to Duration of Load,* Forest Products Laboratory Forest Service, U.S. Department of Agriculture Report #1916, December 1951, reprinted 1962.

Western Wood Products Association (WWPA), 1991a. IN-GRADE, What it means. Information brochure by WWPA, Yeon Building, 522 SW Fifth Ave. Portland, OR., USA.

Western Wood Products Association (WWPA), 1991b. Results of the In-Grade Testing Program, 20 minute VHS video. Yeon Building, 522 SW Fifth Ave. Portland, OR., USA.

Zahn, J.J. 1986. *Design of Wood Members under Combined Load.* ASCE Journal of Structural Engineering, Vol. 112, No. 9, pp.2109-2126.

B
I
B



Bibliography

Bibliography

In addition to referenced materials in the previous section, the following publications were referred to during the course of research. They are included as further sources of information related to this document and timber research.

ASAE , 1982. *Design Properties of Round , Sawn and laminated Preservatively Treated Construction Poles*, ASAE Engineering Practice: ASAE EP388, ASAE Agricultural Engineers Handbook.

ANSI, 1972. *Specifications and Dimensions for Wood Poles*. American National Standards Institute, Ic. 1430 Broadway, New York, New York, USA.

Boyd, J.D. 1964. *The Strength of Australian Pole Timbers, IV. Radiata Pine Poles*. Division of Forest Products Technological Paper No.32. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

Constantine, A. 1975. Know Your Woods, A complete guide to Trees, Woods and Veneers, Revised Edition. Charles Scribner's Sons, New York. ISBN 0-684-18778-7

Harmon, R.F.S. 1961. An Introduction to Applied Anisotropic Elasticity. Oxford University Press, London, UK.

Hoffman, O and Sachs, G. 1953. Introduction To The Theory of Plasticity for Engineers. McGraw-Hill Bo. Co., New York.

Horne, M.R. and Merchant, W. 1965. The Stability of Frames. Pergamon Press Ltd. Oxford, U.K.

Jayanetti, L. 1990. Timber Pole Construction. Published by Intermediate Technology Publications, 103/105 Southhampton Row, London, in conjunction with TRADA - Timber Research and Development Association. UK. ISBN 1-85339-068-2

Keenan, F.J. 1986. Limit States Design of Wood Structures. Published by Morrison Hershfield Ltd., Consulting Engineers. ISBN 0-9692725-0-2

Mackie, B.A.; Read, N.A.; Hahney, T.M. and Canadian Logbuilders Association, Int'l. 1993, Log Span Tables, 3rd ed. Canadian Log Builders Assoc., 7928 Lynwood Dr., Ferndale, Washington, USA. ISBN 0-9636902-0-5

Pinnel, G.C. 1978. *Selecting Poles for Farm Structures*. New Zealand Journal of Agriculture, April, 1978.

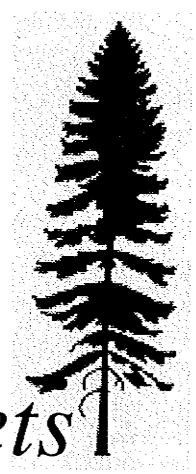
Bibliography

Platt, R.H. 1987. 1001 Questions Answered About Trees. Dover Publications Inc. Mineola, NY, USA. ISBN 0-486-27038-6

Timoshenko, S.P. and Gere, J.M. 1961. Theory of Elastic Stability. 2nd ed.,McGraw-Hill Bo. Co., New York.

Weibull, W. 1939. *A statistical theory of the strength of materials.* Royal Swedish Institute for Engineering Research, Stockholm, Sweden.

A



Data Sheets

Appendix - A:

Specimen Specific Data

This appendix contains data collected specific to each specimen: measuring; bending; load-deflection; location of ultimate failure; compression and tension zones, and; twist. To facilitate use of these data contained herein, the following generic explanation has been provided.

Load Deflection Data:

The first page of each specimen-specific data contains the load-deflection readings. All equipment used had been calibrated using imperial units, to minimize conversion errors only main results have been tabulated in metric and imperial units. The header from the data sheet is reproduced below in Fig. A-1 to assist in explanation

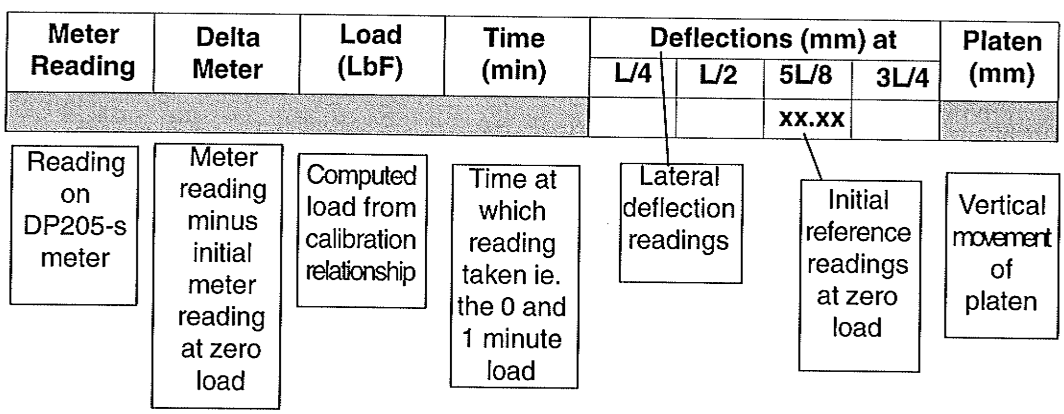


Fig. A-1: Explanation of Load-Deflection Data Sheet

Measuring Data:

The location of the pole relative to the measuring apparatus is tabulated in a data-sheet table entitled Measuring Apparatus Data for each specimen. Fig A-2 illustrates what

Specimen No. P25A

Location	Vertical (in.)	End Dia. (in.)	D3 (in.)	D3 + Vert (in.)	D4 (in.)	D4 + Hor (in.)
0	3.00	3.13	2.02	5.02	3.41	6.54
L/4	2.79		2.34	5.14	3.43	6.52
L/2	2.79		2.32	5.11	3.49	6.43
3L/4	2.48		2.47	4.95	3.66	6.40
L	2.15	2.38	2.42	4.58	3.81	6.18
Mean	2.64	2.75				
Taper Ratio		0.74				

Fig. A-2: Measuring Apparatus Data

information is contained in each section of the table. The location is where along the pole the measurement was taken. The Vertical column is the calculated diameter in the vertical direction as discussed in Section 2.3. End Dia. is the calculated horizontal diameter at the location as given in Section 2.3. The remaining columns assist in plotting the cross-section shape at each location as shown in Figure A-3 for Specimen P25A diameter at L/2. All of the diameters can be plotted with this information to obtain an end-on view as outlined in Section 2.3, Fig.2.4.

The taper ratio is calculated from the average end-diameter values at 0 and L. Thus for the pole in Fig. A-2 : TR = [(2.15+2.38)/2] / [(3.00+3.13)/2] = 0.74 .

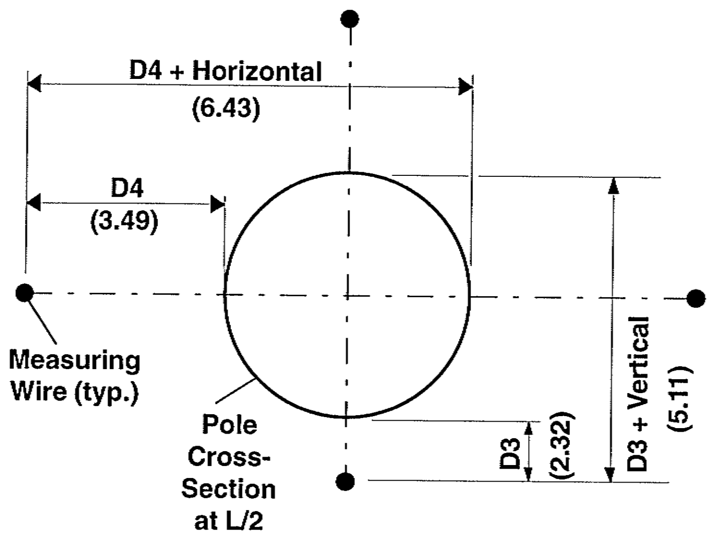


Fig. A-3: Application of Measuring Data

Bending Stiffness:

The table of values for bending stiffness indicate the load that was used, the time at which the deflection was read and, the back-calculated MOE for the member as discussed in Section 2.4.

Compression and Tension Zones:

These values indicate the amount of the specimen that was in compression or tension at the time of ultimate failure. The depth of compression or tension has been divided by the diameter at the failure location resulting in either a C/D or T/D ratio respectively. Section 3.2.5 discusses these zones.

Location of Fracture from Butt End:

This measurement provides information about where the pole ultimately broke. Figure A-4 illustrates the major divisions of the pole for reference.

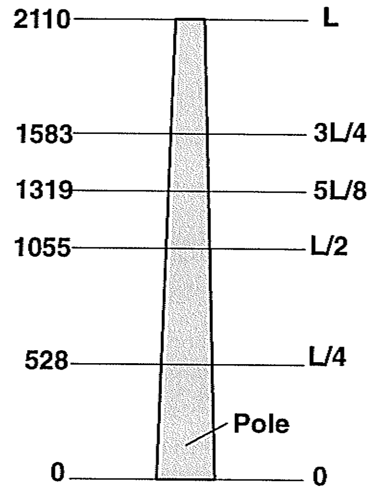


Fig. A-4: Location of Fracture from Butt End(mm)

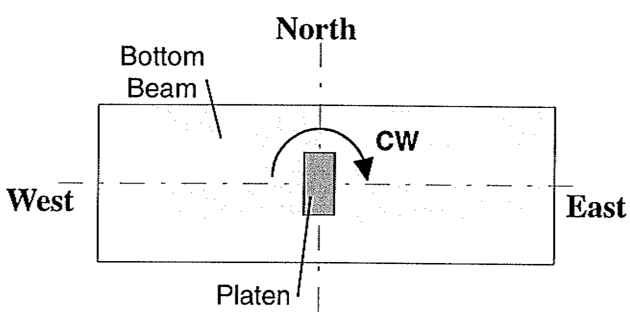


Fig.A-5: Clockwise Twist

Twist:

The amount of twist of the pole has been tabulated based on degrees clockwise (CW) or degrees counter-clockwise (CCW) Figure A-5 shows a plan view of the platen and bottom beam. The relationship between clockwise and the relative location of the test frame in the laboratory has been indicated on the sketch.

Selective Summary of Test Specimen Results ~

Ct.	Spec No.	Load @ 1 min. (lbF)	Δ @ L/4 (mm)	Δ @ L/2 (mm)	Δ @ 5L/8 (mm)	Δ @ 3L/4 (mm)	Δ Platen (mm)	ϕ @ L/2 (mm)	O.O.S. @ L/2 (mm)	OS/D @ L/2	TR	1-TR	Axial Stress @ L/2 (psi)	Standard Stress (psi)	M.O.E. of Specimen (psi) (x 10^6)	Ei / En	E-cor Stress (psi)	E-cor Stress (Mpa)	% Red. 0 min to 1 min.
1	1A	7254.72	25	38	36	28	6.35	77.22	17.1	0.22	0.82	0.18	999.40	953.18	1.23	0.79	752.03	5.19	8.17
2	1B	9508.08	27	38	32	25	6.86	87.63	30.9	0.35	0.83	0.17	1017.10	1392.97	1.28	0.82	1143.69	7.89	10.48
3	2A	5303.64	35	54	50	45	6.35	69.34	7.3	0.11	0.81	0.19	906.12	690.14	1.66	1.06	734.85	5.07	22.49
4	2B	7707.17	18	27	25	23	7.94	80.01	6.6	0.08	0.86	0.14	988.97	1060.27	1.72	1.10	1169.77	8.07	n.a.
5	3A	1937.34	44	70	66	53	14.99	58.67	29.5	0.50	0.85	0.15	462.33	418.05	1.63	1.05	437.09	3.01	17.54
6	3B	5142.21	26	35	34	26	n.a.	68.33	10.0	0.15	0.93	0.07	904.70	660.42	1.53	0.98	648.13	4.47	n.a.
7	4A	2624.34	28	42	45	37	8.64	66.80	7.6	0.11	0.66	0.34	483.11	617.04	0.67	0.43	265.18	1.83	4.98
8	4B	5056.30	14	22	21	16	n.a.	81.03	17.7	0.22	0.80	0.20	632.58	1101.34	1.30	0.83	918.37	6.33	n.a.
9	5B	6265.44	23	31	30	25	4.40	76.20	16.2	0.21	0.82	0.18	886.38	915.90	1.74	1.12	1022.24	7.05	8.43
10	6B	5825.76	23	36	36	27	5.71	74.42	3.9	0.05	0.85	0.15	864.07	853.21	1.53	0.98	837.33	5.77	14.00
11	8A	3366.30	29	36	41	34	5.00	65.79	3.3	0.05	0.82	0.18	638.87	589.47	1.78	1.14	673.04	4.64	14.93
12	8B	7625.70	17	40	38	28	4.94	76.96	9.9	0.13	0.85	0.15	1057.61	943.58	2.12	1.36	1283.13	8.85	16.42
13	9A	4534.20	23	37	37	30	4.45	71.63	6.9	0.10	0.75	0.25	725.92	760.80	1.42	0.91	692.97	4.78	11.05
14	9B	9466.86	23	35	33	27	4.75	86.87	7.9	0.09	0.86	0.14	1030.49	1357.04	1.29	0.83	1122.89	7.74	21.97
15	10A	7886.76	20	32	34	28	4.89	74.93	1.5	0.02	0.84	0.16	1153.89	870.87	1.60	1.03	893.77	6.16	6.06
16	10B	9219.54	19	27	24	20	4.35	88.65	17.0	0.19	0.90	0.10	963.67	1442.18	1.37	0.88	1267.35	8.74	10.17
17	11B	6677.64	25	40	35	30	4.88	80.52	9.7	0.12	0.79	0.21	846.04	1080.68	1.43	0.92	991.26	6.84	17.77
18	12A	5496.00	17	30	28	23	4.78	84.84	16.1	0.19	0.79	0.21	627.22	1264.11	1.14	0.73	924.37	6.37	11.50
19	14B	3998.34	28	39	33	26	6.34	74.68	18.5	0.25	0.82	0.18	588.91	862.18	1.34	0.86	741.06	5.11	10.19
20	15B	4451.76	24	36	33	26	3.99	72.64	8.4	0.12	0.81	0.19	693.04	793.44	1.34	0.86	681.98	4.70	8.73
21	16B	6636.42	19	32	34	31	5.36	83.06	0.8	0.01	0.76	0.24	790.18	1186.21	1.44	0.92	1095.66	7.56	24.53
22	18A	1415.22	39	60	55	45	10.26	57.40	36.6	0.64	0.76	0.24	352.84	391.49	1.86	1.19	467.08	3.22	3.74
23	18B	4039.56	30	41	39	29	6.35	73.41	28.2	0.38	0.85	0.15	615.75	818.94	1.56	1.00	819.46	5.65	13.78
24	19B	3077.76	22	37	35	32	6.35	75.95	17.6	0.23	0.86	0.14	438.29	906.92	1.45	0.93	843.51	5.82	19.42
25	20A	3146.46	19	17	26	22	3.26	61.21	1.5	0.02	0.77	0.23	689.85	474.74	1.59	1.02	484.18	3.34	2.55
26	20B	4685.34	22	38	20	17	6.35	75.95	9.3	0.12	0.86	0.14	667.21	906.92	1.51	0.97	878.41	6.06	19.39
27	21A	1264.08	22	34	35	30	4.09	44.20	0.4	0.01	0.71	0.29	531.51	178.75	2.37	1.52	271.74	1.87	1.09
28	21B	2473.20	35	49	44	35	6.87	58.67	13.6	0.23	0.83	0.17	590.21	418.05	2.00	1.28	536.31	3.70	2.70
29	22A	2665.56	27	39	35	30	5.54	65.53	15.8	0.24	0.73	0.27	509.90	582.51	1.36	0.87	508.16	3.50	5.83
30	22B	4025.82	24	41	45	35	8.73	80.26	21.4	0.27	0.86	0.14	513.37	1070.24	1.41	0.90	967.95	6.68	17.23
31	23A	3902.16	23	33	33	26	3.18	65.65	7.4	0.11	0.85	0.15	743.73	585.72	1.76	1.13	661.23	4.56	7.79
32	23B	10442.40	22	33	30	23	6.35	75.18	6.5	0.09	0.89	0.11	1517.66	879.61	1.79	1.15	1009.95	6.97	11.94
33	24A	1071.72	54	88	84	66	23.88	53.85	73.4	1.36	0.68	0.32	303.59	323.25	1.84	1.18	381.52	2.63	2.50
34	24B	6141.78	10	15	25	14	7.94	78.74	4.6	0.06	0.84	0.16	813.73	1010.58	1.51	0.97	978.82	6.75	7.07
35	25A	3118.98	25	38	36	25	6.35	70.87	5.2	0.07	0.74	0.26	510.11	736.84	1.44	0.92	680.59	4.69	21.45
36	25B	10469.88	0	3	4	2	6.35	89.15	0.8	0.01	0.88	0.12	1082.12	1466.72	1.36	0.87	1279.50	8.82	19.19
37	27A	1909.86	50	79	77	63	13.97	53.09	17.8	0.34	0.79	0.21	556.61	309.76	2.10	1.35	417.25	2.88	4.14
38	27B	6183.00	38	51	42	37	6.88	73.41	2.3	0.03	0.84	0.16	942.47	818.94	1.62	1.04	850.98	5.87	6.05
39	28A	4190.70	24	39	39	30	4.94	63.25	8.7	0.14	0.79	0.21	860.48	523.80	2.08	1.33	698.85	4.82	6.15
40	28B	8271.48	39	53	48	35	7.8	79.50	13.6	0.17	0.83	0.17	1075.04	1040.13	1.90	1.22	1267.63	8.74	13.01

Selective Summary of Test Specimen Results ~

Ct.	Spec No.	Load @ 1 min. (lbF)	Δ @ L/4 (mm)	Δ @ L/2 (mm)	Δ @ 5L/8 (mm)	Δ @ 3L/4 (mm)	Δ Platen (mm)	ϕ @ L/2 (mm)	O.O.S. @ L/2 (mm)	OS/D @ L/2	TR	1-TR	Axial Stress @ L/2 (psi)	Standard Stress (psi)	M.O.E. of Specimen (psi) (x 10^6)	Ei / En	E-cor Stress (psi)	E-cor Stress (Mpa)	% Red. 0 min to 1 min.
41	33A	1085.46	30	46	47	49	5.85	49.02	14.2	0.29	0.68	0.32	371.06	243.84	1.80	1.16	282.85	1.95	3.66
42	33B	5289.90	25	33	31	25	4.37	67.82	5.5	0.08	0.81	0.19	944.73	645.74	1.66	1.07	690.94	4.77	5.64
43	37A	1057.00	58	95	84	64	20.07	54.10	53.7	0.99	0.76	0.24	296.66	327.78	1.39	0.89	292.24	2.02	2.53
44	38A	2431.98	26	39	36	29	4.12	59.94	13.1	0.22	0.78	0.22	556.04	445.79	1.54	0.99	440.36	3.04	4.84
45	39B	5660.88	20	32	31	25	4.89	74.42	3.8	0.05	0.85	0.15	839.62	853.21	1.58	1.01	864.70	5.96	17.60
46	41A	2088.48	22	38	39	34	4.83	60.45	0.0	0.00	0.79	0.21	469.48	457.27	1.45	0.93	425.30	2.93	11.63
47	42A	1593.84	18	32	35	31	4.33	60.20	11.4	0.19	0.67	0.33	361.27	451.62	1.38	0.89	399.77	2.76	5.69
48	44A	3723.54	22	34	33	27	3.71	69.09	3.3	0.05	0.77	0.23	640.77	682.70	1.38	0.89	604.31	4.17	9.97
49	44B	6004.38	19	28	29	23	5.31	81.79	10.4	0.13	0.83	0.17	737.30	1132.62	1.44	0.92	1046.17	7.21	14.15
50	45A	2431.98	19	30	28	22	4.86	61.98	22.5	0.36	0.81	0.19	520.04	492.88	1.61	1.03	509.00	3.51	3.80
51	46A	5770.80	25	34	34	27	4.42	73.15	1.5	0.02	0.77	0.23	885.90	810.27	1.55	0.99	805.59	5.56	25.80
52	46B	9975.24	20	26	24	18	5.97	93.98	19.5	0.21	0.86	0.14	927.75	1718.27	1.01	0.65	1113.18	7.68	16.07
53	47B	2954.10	28	40	39	33	8.78	64.79	19.1	0.29	0.86	0.14	578.08	563.00	1.79	1.15	646.42	4.46	5.29
54	48A	5550.96	17	26	29	22	4.01	66.80	6.7	0.10	0.80	0.20	1021.86	617.04	1.66	1.06	657.02	4.53	4.27
55	48B	7447.08	20	30	28	22	5.46	77.72	9.4	0.12	0.86	0.14	1012.74	971.81	1.95	1.25	1215.55	8.38	11.29
56	49B	4492.98	21	26	27	23	3.82	67.56	7.5	0.11	0.84	0.16	808.60	638.34	1.72	1.10	704.26	4.86	3.54
57	50A	4424.28	19	28	28	24	3.99	69.09	1.9	0.03	0.78	0.22	761.36	682.70	1.27	0.81	556.14	3.84	8.00
58	50B	10978.26	17	22	22	16	3.66	87.63	2.6	0.03	0.85	0.15	1174.37	1392.97	1.13	0.72	1009.66	6.96	9.10

Reduced Deflection Data — *Specimen No.* **P1A**

Max Load (Lbf)=	7900.50	(kN) =	35.14

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				40.5	219.4	298.8	119.8	
12.00	0.00	0.00	0	0	0	0	0	0.00
12.17	0.17	233.58	0	0	0	0	0	0.00
12.37	0.37	508.38	0	0	2	1	0	************
12.36	0.36	494.64	1	0	2	1	0	************
12.35	0.35	480.90	5	0	2	1	0	************
12.34	0.34	467.16	10	0	2	1	0	************
13.40	1.40	1923.60	0	2	4	4	3	************
14.96	2.96	4067.04	0	5	9	8	7	3.18
14.90	2.90	3984.60	1	5	9	8	7	3.18
14.82	2.82	3874.68	5	5	9	8	7	3.18
14.77	2.77	3805.98	10	5	9	8	7	3.18
16.50	4.50	6183.00	0	10	17	16	13	************
17.50	5.50	7557.00	0	15	25	24	20	6.35
17.75	5.75	7900.50	0	25	38	36	28	6.35
17.28	5.28	7254.72	1	25	38	36	28	6.35
17.07	5.07	6966.18	5	25	38	36	28	6.35
16.96	4.96	6815.04	10	25	38	36	28	************
17.32	5.32	7309.68	0	35	56	56	43	************
16.54	4.54	6237.96	1	35	56	56	43	************
16.17	4.17	5729.58	0	53	88	88	68	************
15.41	3.41	4685.34	1	53	88	88	68	************
15.20	3.20	4396.80	0	65	112	115	90	************
14.67	2.67	3668.58	1	65	112	115	90	************
14.40	2.40	3297.60	0	75	133	143	113	************
14.06	2.06	2830.44	1	75	133	143	113	************
14.26	2.26	3105.24	0	77	148	173	137	42.88
12.40	0.40	549.60	1	77	148	173	137	42.88
12.40	0.40	549.60	5	77	148	173	137	42.88
12.19	0.19	261.06	0	90	174	208	164	************
12.18	0.18	247.32	1	90	174	208	164	************
12.18	0.18	247.32	5	90	174	208	164	************
12.18	0.18	247.32	10	90	174	208	164	************
12.06	0.06	82.44	0	100	194	235	182	61.93
12.06	0.06	82.44	1	100	194	235	182	61.93
12.06	0.06	82.44	5	100	194	235	182	61.93
12.06	0.06	82.44	10	100	194	235	182	************
**********	**********	**************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P1A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.10	3.21	1.95	5.05	3.38	6.59
L/4	3.07		2.33	5.40	3.49	6.55
L/2	3.04		2.60	5.64	3.62	6.51
3L/4	2.84		2.30	5.14	3.70	6.50
L	2.58	2.57	2.11	4.69	3.74	6.31
Mean	2.93	2.89				
Taper	**Ratio:**	0.82	See Note 2	1-TR=	0.18	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.00	0.37	0.62	0.22	-0.10
Corrected	(in.)	0.00	0.42	0.67	0.27	0.00
Corrected	(mm)	0.0	10.7	17.1	6.9	0.0
OS/D				0.22		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2010	4.19	5.16	1.23

Compression and Tension Zones

C (in.)	0.87	C/D	0.31
T(in.)	1.27	T/D	0.46
D(in.)	2.78		

Location of Fracture from Butt End(mm) 1384.30 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data *Specimen No.* P1B

Max Load (Lbf)=	10621.02	**(kN) =**	47.24

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				39.30	218.00	298.70	119.20	
12.02	0.00	0.00	0	0	0	0	0	0.00
12.03	0.01	13.74	0	0	0	0	0	0.00
12.34	0.32	439.68	0	0	0	0	0	************
12.57	0.55	755.70	0	0	0	0	0	************
12.98	0.96	1319.04	0	1	3	1	1	************
12.93	0.91	1250.34	1	1	3	1	1	************
12.90	0.88	1209.12	5	1	3	1	1	************
14.00	1.98	2720.52	0	3	5	4	2	************
15.50	3.48	4781.52	0	7	9	7	6	************
16.82	4.80	6595.20	0	11	14	12	9	************
16.73	4.71	6471.54	1	11	14	12	9	************
16.57	4.55	6251.70	5	11	14	12	9	************
16.36	4.34	5963.16	10	11	14	12	9	************
18.02	6.00	8244.00	0	14	19	16	12	************
17.92	5.90	8106.60	1	14	19	16	12	************
19.00	6.98	9590.52	0	18	26	22	17	************
18.79	6.77	9301.98	1	18	26	22	17	************
19.75	7.73	10621.02	0	27	38	32	25	6.75
18.94	6.92	9508.08	1	27	38	32	25	6.75
18.65	6.63	9109.62	5	27	38	32	25	6.75
18.36	6.34	8711.16	10	27	38	32	25	6.75
19.50	7.48	10277.52	0	34	49	42	31	8.73
18.55	6.53	8972.22	1	34	49	42	31	8.73
19.01	6.99	9604.26	0	48	69	59	42	12.70
17.86	5.84	8024.16	1	48	69	59	42	12.70
17.55	5.53	7598.22	5	48	69	59	42	12.70
17.33	5.31	7295.94	10	48	69	59	42	12.70
18.70	6.68	9178.32	0	54	78	66	48	************
17.49	5.47	7515.78	1	54	78	66	48	************
18.00	5.98	8216.52	0	63	89	76	55	************
17.11	5.09	6993.66	1	63	89	76	55	************
17.27	5.25	7213.50	0	74	113	95	67	25.00
16.27	4.25	5839.50	1	74	113	95	67	25.00
15.95	3.93	5399.82	5	74	113	95	67	25.00
15.79	3.77	5179.98	10	74	113	95	67	25.00

Reduced Deflection Data   *Specimen No.* P1B

Page - 2

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
16.42	4.40	6045.60	0	88	128	106	76	************
15.55	3.53	4850.22	1	88	128	106	76	************
15.85	3.83	5262.42	0	96	144	116	82	36.51
15.00	2.98	4094.52	1	96	144	116	82	36.51
14.75	2.73	3751.02	5	96	144	116	82	36.51
14.64	2.62	3599.88	10	96	144	116	82	36.51
15.11	3.09	4245.66	0	110	164	131	92	************
14.47	2.45	3366.30	1	110	164	131	92	************
14.75	2.73	3751.02	0	117	178	141	98	************
14.19	2.17	2981.58	1	117	178	141	98	************
14.32	2.30	3160.20	0	131	200	157	110	************
13.66	1.64	2253.36	1	131	200	157	110	************
13.47	1.45	1992.30	0	151	235	181	127	80.96
13.16	1.14	1566.36	1	151	235	181	127	80.96
12.63	0.61	838.14	0	172	260	202	140	101.60
12.54	0.52	714.48	1	172	260	202	140	101.60
12.54	0.52	714.48	5	172	260	202	140	101.60
12.54	0.52	714.48	10	172	260	202	140	101.60
12.59	0.57	783.18	0	175	270	209	143	************
**********	**********	*************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data **Specimen No. P1B**

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.93	3.74	1.71	5.64	3.25	6.99
L/4	3.26		2.79	6.05	2.76	6.04
L/2	3.45		3.04	6.49	3.29	6.19
3L/4	3.24		2.34	5.59	2.81	6.10
L	3.21	3.20	1.82	5.03	3.22	6.42
Mean	3.42	3.47				
Taper	**Ratio:**	0.83	See Note 2	1-TR=	0.17	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.18	0.92	1.26	0.46	-0.08
Corrected	(in.)	0.00	0.87	1.22	0.42	0.00
Corrected	(mm)	0.0	22.1	30.9	10.5	0.0
OS/D				0.35		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1168	6.95	8.88	1.28

Compression and Tension Zones

C (in.)	1.37	C/D	0.43
T(in.)	1.14	T/D	0.36
D(in.)	3.21		

Location of Fracture from Butt End(mm) 1117.60 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P2A

Max Load (Lbf)=	6842.52	(kN) =	30.44

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.30	219.80	300.40	119.90	
12.18	0.00	0.00	0	0	0	0	0	0.00
12.50	0.32	439.68	0	2	2	2	3	0.40
12.49	0.31	425.94	1	2	2	2	3	0.40
12.47	0.29	398.46	5	2	2	2	3	0.40
12.47	0.29	398.46	10	2	2	2	3	0.40
13.26	1.08	1483.92	0	3	4	4	5	************
13.22	1.04	1428.96	1	3	4	4	5	************
14.99	2.81	3860.94	0	7	8	8	8	************
14.84	2.66	3654.84	1	7	8	8	8	************
16.40	4.22	5798.28	0	12	17	17	15	************
16.26	4.08	5605.92	1	12	17	17	15	************
16.10	3.92	5386.08	5	12	17	17	15	************
16.08	3.90	5358.60	10	12	17	17	15	************
17.03	4.85	6663.90	0	20	28	27	23	3.97
16.85	4.67	6416.58	1	20	28	27	23	3.97
17.16	4.98	6842.52	0	35	54	50	45	6.35
16.04	3.86	5303.64	1	35	54	50	45	6.35
15.83	3.65	5015.10	5	35	54	50	45	************
15.72	3.54	4863.96	10	35	54	50	45	************
16.04	3.86	5303.64	0	40	65	60	48	************
15.60	3.42	4699.08	1	40	65	60	48	************
15.73	3.55	4877.70	0	51	81	74	59	************
15.13	2.95	4053.30	1	51	81	74	59	************
15.00	2.82	3874.68	5	51	81	74	59	************
14.91	2.73	3751.02	10	51	81	74	59	************
15.20	3.02	4149.48	0	62	98	91	70	************
14.66	2.48	3407.52	1	62	98	91	70	************
14.89	2.71	3723.54	0	69	117	104	79	************
14.29	2.11	2899.14	1	69	117	104	79	************
14.13	1.95	2679.30	0	79	141	122	92	26.20
13.62	1.44	1978.56	1	79	141	122	92	26.19
13.53	1.35	1854.90	5	79	141	122	92	26.20
13.40	1.22	1676.28	0	90	168	140	99	33.34
12.98	0.80	1099.20	1	90	168	140	99	33.34
12.93	0.75	1030.50	5	90	168	140	99	33.34

Reduced Deflection Data   *Specimen No.* P2A

Page - 2

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
12.91	0.73	1003.02	10	90	168	140	99	************
12.71	0.53	728.22	0	103	197	159	112	************
12.40	0.22	302.28	1	103	197	159	112	************
12.32	0.14	192.36	0	133	253	203	141	65.09
12.31	0.13	178.62	1	133	253	203	141	57.47
12.30	0.12	164.88	5	133	253	203	141	************
12.30	0.12	164.88	10	133	253	203	141	************
12.29	0.11	151.14	0	150	288	233	159	************
12.28	0.10	137.40	1	150	288	233	159	************
12.28	0.10	137.40	5	150	288	233	159	************
12.28	0.10	137.40	10	150	288	233	159	************
12.28	0.10	137.40	0	162	308	251	174	97.63
12.27	0.09	123.66	1	162	308	251	174	97.63
12.27	0.09	123.66	5	162	308	251	174	97.63
12.27	0.09	123.66	10	162	308	251	174	97.63
**********	**********	*************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data **Specimen No. P2A**

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.96	2.93	2.05	5.01	3.49	6.42
L/4	2.79		2.41	5.20	3.45	6.26
L/2	2.73		2.44	5.16	3.45	6.26
3L/4	2.62		2.30	4.92	3.44	6.11
L	2.37	2.38	2.31	4.68	3.83	6.22
Mean	2.70	2.66				
Taper	**Ratio:**	0.81	See Note 2	1-TR=	0.19	

Out-of-Straightness

		0	**L/4**	**L/2**	**3L/4**	**L**
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.03	0.31	0.30	0.11	-0.00
Corrected	(in.)	0.00	0.29	0.29	0.09	0.00
Corrected	(mm)	0.0	7.5	7.3	2.4	0.0
OS/D				0.10		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2308	2.71	4.50	1.66

Compression and Tension Zones

C (in.)	1.26	C/D	0.49
T(in.)	1.44	T/D	0.56
D(in.)	2.56		

Location of Fracture from Butt End(mm) 1054.10 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data
Specimen No. P2B

Max Load (Lbf)=	8628.72	(kN) =	38.38

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.3	219.7	299.1	119.3	
12.02	0.00	0.00	0	0	0	0	0	0.00
12.11	0.09	123.66	0	0	0	0	0	************
12.22	0.20	274.80	0	0	0	0	0	************
12.64	0.62	851.88	0	1	1	1	2	************
13.26	1.24	1703.76	0	2	2	3	3	************
13.45	1.43	1964.82	0	2	2	3	3	************
14.16	2.14	2940.36	0	3	5	5	5	************
15.00	2.98	4094.52	0	5	7	7	7	************
15.63	3.61	4960.14	0	7	9	9	8	************
16.32	4.30	5908.20	0	8	12	11	10	************
17.32	5.30	7282.20	0	12	16	16	13	************
17.87	5.85	8037.90	0	14	21	21	18	************
18.30	6.28	8628.72	0	18	27	25	23	7.94
18.01	5.99	8230.26	0	25	41	41	35	************
16.40	4.38	6018.12	0	37	58	61	50	************
15.81	3.79	5207.46	0	46	78	85	68	************
14.75	2.73	3751.02	0	52	87	93	77	************
13.90	1.88	2583.12	0	60	107	119	94	************
13.65	1.63	2239.62	0	63	112	124	100	************
13.39	1.37	1882.38	0	67	122	141	110	************
13.18	1.16	1593.84	0	72	129	150	115	************
12.98	0.96	1319.04	0	74	138	161	123	************
12.83	0.81	1112.94	0	78	147	171	132	************
12.56	0.54	741.96	0	85	169	188	143	************
12.48	0.46	632.04	0	88	169	200	153	************
12.19	0.17	233.58	0	95	191	228	173	************
12.16	0.14	192.36	0	109	211	255	195	85.73
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P2B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.41	3.49	1.85	5.26	3.22	6.71
L/4	3.12		2.20	5.32	3.57	6.95
L/2	3.15		2.23	5.38	3.52	6.80
3L/4	3.09		2.57	5.66	3.43	6.56
L	2.92	3.04	2.08	5.00	3.49	6.53
Mean	3.14	3.27				
Taper	**Ratio:**	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.05	0.26	0.30	0.61	0.04
Corrected	(in.)	0.00	0.21	0.26	0.57	0.00
Corrected	(mm)	0.0	5.4	6.6	14.4	0.0
OS/D				0.08		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1253	4.80	8.28	1.72

Compression and Tension Zones

C (in.)	1.21	C/D	0.40
T(in.)	1.25	T/D	0.42
D(in.)	2.99		

Location of Fracture from Butt End(mm) 1393.83 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* **P3A**

Max Load (Lbf)=	2349.54	(kN) =	10.45

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				38.6	217.0	297.2	118.0	
12.29	0.00	0.00	0	0	0	0	0	0.00
12.71	0.42	577.08	0	4	8	7	5	0.79
12.70	0.41	563.34	1	4	8	7	5	0.79
13.10	0.81	1112.94	0	9	15	7	13	2.38
13.07	0.78	1071.72	1	9	15	7	13	2.38
13.67	1.38	1896.12	0	21	33	31	25	************
13.62	1.33	1827.42	1	21	33	31	25	************
13.93	1.64	2253.36	0	30	49	46	37	7.94
13.79	1.50	2061.00	1	30	49	46	37	7.94
13.74	1.45	1992.30	5	30	49	46	37	7.94
13.70	1.41	1937.34	10	30	49	46	37	7.94
14.00	1.71	2349.54	0	44	70	66	53	14.99
13.70	1.41	1937.34	1	44	70	66	53	14.99
13.81	1.52	2088.48	0	64	107	101	78	22.23
13.50	1.21	1662.54	1	64	107	101	78	22.23
13.42	1.13	1552.62	5	64	107	101	78	22.23
13.38	1.09	1497.66	10	64	107	101	78	22.23
13.51	1.22	1676.28	0	94	165	153	115	************
13.16	0.87	1195.38	1	94	165	153	115	************
13.22	0.93	1277.82	0	108	192	177	130	54.77
12.94	0.65	893.10	1	108	192	177	130	54.77
12.76	0.47	645.78	5	106	193	176	127	54.77
12.87	0.58	796.92	0	124	240	195	134	69.85
12.36	0.07	96.18	1	124	240	195	134	69.85
12.35	0.06	82.44	5	124	240	195	134	69.85
12.35	0.06	82.44	10	124	240	195	134	69.85
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P3A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.49	2.62	2.36	4.85	3.76	6.38
L/4	2.43		3.23	5.66	3.67	5.86
L/2	2.31		3.60	5.91	5.00	5.00
3L/4	2.32		3.17	5.49	3.78	6.18
L	2.12	2.22	2.52	4.64	3.88	6.10
Mean	2.33	2.42				
Taper	**Ratio:**	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.10	0.94	1.26	0.83	0.08
Corrected	(in.)	0.00	0.85	1.16	0.74	0.00
Corrected	(mm)	0.0	21.6	29.5	18.7	0.0
OS/D				0.50		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.4550	1.40	2.28	1.63

Compression and Tension Zones

C (in.)	0.69	C/D	0.31
T(in.)	0.91	T/D	0.40
D(in.)	2.26		

Location of Fracture from Butt End(mm) 1054.10 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* **P3B**

Max Load (Lbf)=	5757.06	(kN) =	25.61

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.6	219.5	300.6	120.0	
12.27	0.00	0.00	0	0	0	0	0	0.00
12.74	0.47	645.78	0	2	2	3	3	************
12.90	0.63	865.62	0	3	3	3	4	************
13.20	0.93	1277.82	0	3	4	4	4	************
13.50	1.23	1690.02	0	4	5	5	5	************
13.98	1.71	2349.54	0	5	6	6	5	************
14.47	2.20	3022.80	0	7	9	8	7	************
15.03	2.76	3792.24	0	10	12	11	10	************
15.48	3.21	4410.54	0	12	15	15	13	************
16.03	3.76	5166.24	0	16	22	21	17	************
16.46	4.19	5757.06	0	26	35	34	26	************
16.25	3.98	5468.52	0	32	47	42	34	************
16.00	3.73	5125.02	0	41	61	56	45	************
15.34	3.07	4218.18	0	51	76	70	54	************
15.01	2.74	3764.76	0	61	95	85	65	************
14.65	2.38	3270.12	0	71	110	98	75	************
14.38	2.11	2899.14	0	76	121	108	80	************
13.78	1.51	2074.74	0	86	135	116	85	************
13.48	1.21	1662.54	0	96	150	126	90	************
13.14	0.87	1195.38	0	106	167	128	100	************
12.99	0.72	989.28	0	115	185	161	105	************
12.72	0.45	618.30	0	136	215	174	120	************
12.60	0.33	453.42	0	151	245	196	130	82.55
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P3B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.64	2.85	2.25	4.88	3.62	6.47
L/4	2.67		2.51	5.18	3.80	6.61
L/2	2.69		2.61	5.30	3.63	6.27
3L/4	2.50		2.42	4.92	4.03	6.75
L	2.57	2.55	2.28	4.84	3.81	6.36
Mean	2.61	2.70				
Taper	**Ratio:**	0.93	See Note 2	1-TR=	0.07	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.35	0.45	0.17	0.06
Corrected	(in.)	0.00	0.29	0.39	0.10	0.00
Corrected	(mm)	0.0	7.3	10.0	2.7	0.0
OS/D				0.15		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2630	2.57	3.94	1.53

Compression and Tension Zones

C (in.)	1.19	C/D	0.47
T(in.)	1.01	T/D	0.40
D(in.)	2.52		

Location of Fracture from Butt End(mm) 952.50 mm

Twist (Degrees CCW or CW) n.a

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data | *Specimen No.* **P4A**

Max Load (Lbf)=	2761.74	(kN) =	12.28

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.0	220.2	300.0	120.2	
12.02	0.00	0.00	0	0	0	0	0	0.00
12.47	0.45	618.30	0	3	3	4	4	************
12.45	0.43	590.82	1	3	3	4	4	************
13.21	1.19	1635.06	0	7	8	8	8	1.59
13.18	1.16	1593.84	1	7	8	8	8	1.59
13.11	1.09	1497.66	5	7	8	8	8	1.59
13.85	1.83	2514.42	0	15	22	23	20	************
13.79	1.77	2431.98	1	15	22	23	20	************
13.73	1.71	2349.54	5	15	22	23	20	************
13.69	1.67	2294.58	10	15	22	23	20	************
14.03	2.01	2761.74	0	28	42	45	37	************
13.93	1.91	2624.34	1	28	42	45	37	************
13.96	1.94	2665.56	0	39	62	66	57	8.73
13.67	1.65	2267.10	1	39	62	66	57	8.73
13.60	1.58	2170.92	5	39	62	66	57	8.73
13.57	1.55	2129.70	10	39	62	66	57	8.73
13.54	1.52	2088.48	0	52	84	94	85	15.08
13.34	1.32	1813.68	1	52	84	94	85	15.08
13.30	1.28	1758.72	5	52	84	94	85	15.08
13.27	1.25	1717.50	10	52	84	94	85	15.08
13.30	1.28	1758.72	0	70	121	133	120	26.19
13.09	1.07	1470.18	1	70	121	133	120	26.19
13.15	1.13	1552.62	0	80	142	160	146	37.31
12.92	0.90	1236.60	1	80	142	160	146	37.31
12.88	0.86	1181.64	5	80	142	160	146	37.31
12.87	0.85	1167.90	10	80	142	160	146	37.31
13.00	0.98	1346.52	0	100	184	215	202	64.29
12.52	0.50	687.00	1	100	184	215	202	64.29
12.52	0.50	687.00	5	100	184	215	202	64.29
12.52	0.50	687.00	10	100	184	215	202	64.29
12.42	0.40	549.60	0	118	222	262	252	98.43
12.36	0.34	467.16	1	118	222	262	252	98.43
12.36	0.34	467.16	5	118	222	262	252	98.43
12.36	0.34	467.16	10	118	222	262	252	98.43
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data　　　　Specimen No. P4A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.71	2.70	2.21	4.93	3.68	6.38
L/4	2.40		2.40	4.80	3.61	6.14
L/2	2.63		2.54	5.17	3.84	6.29
3L/4	2.07		2.59	4.66	4.16	6.31
L	1.81	1.77	2.64	4.45	4.08	5.86
Mean	2.32	2.24				
Taper	**Ratio:**	0.66	See Note 2	1-TR=	0.34	

Out-of-Straightness

		0	**L/4**	**L/2**	**3L/4**	**L**
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.07	0.10	0.36	0.13	0.04
Corrected	(in.)	0.00	0.04	0.30	0.07	0.00
Corrected	(mm)	0.0	1.1	7.6	1.8	0.0
OS/D				0.11		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.6650	2.33	1.56	0.67

Compression and Tension Zones

C (in.)	0.22	C/D	0.11
T(in.)	0.52	T/D	0.27
D(in.)	1.92		

Location of Fracture from Butt End(mm)　　1479.55　mm

Twist (Degrees CCW or CW)　　n.a.

Note: 1　Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2　Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P4B

Max Load (Lbf)=	5660.88	(kN) =	25.18

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	219.0	299.1	120.0	
12.37	0.00	0.00	0	0	0	0	0	0.00
12.38	0.01	13.74	0	0	0	0	0	************
13.19	0.82	1126.68	0	0	0	0	0	************
14.19	1.82	2500.68	0	2	4	4	4	************
14.72	2.35	3228.90	0	4	6	7	5	************
15.25	2.88	3957.12	0	7	10	11	7	************
15.75	3.38	4644.12	0	10	14	14	10	************
16.49	4.12	5660.88	0	14	22	21	16	************
15.57	3.20	4396.80	0	33	56	49	34	************
14.80	2.43	3338.82	0	47	78	75	56	************
14.10	1.73	2377.02	0	60	106	101	76	************
13.71	1.34	1841.16	0	78	133	124	90	************
13.29	0.92	1264.08	0	85	151	136	100	************
13.11	0.74	1016.76	0	100	175	151	110	************
12.95	0.58	796.92	0	102	190	161	115	************
12.87	0.50	687.00	0	114	204	171	123	************
12.74	0.37	508.38	0	124	223	186	130	************
12.65	0.28	384.72	0	137	245	201	140	************
12.62	0.25	343.50	0	144	255	209	146	************
12.38	0.01	13.74	0	**********	55	**********	**********	77.79
**********	**********		**********	**********		**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P4B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.46	3.43	1.85	5.31	3.37	6.80
L/4	3.28		2.55	5.82	3.76	6.92
L/2	3.19		2.65	5.84	3.67	6.68
3L/4	2.88		2.30	5.18	3.65	6.60
L	2.74	2.79	2.15	4.89	3.63	6.41
Mean	3.11	3.11				
Taper	**Ratio:**	0.80	See Note 2	1-TR=	0.20	

Out-of-Straightness

		0	**L/4**	**L/2**	**3L/4**	**L**
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.08	0.68	0.75	0.24	0.02
Corrected	(in.)	0.00	0.64	0.70	0.19	0.00
Corrected	(mm)	0.0	16.2	17.7	4.8	0.0
OS/D				0.22		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1568	5.11	6.62	1.30

Compression and Tension Zones

C (in.)	1.19	C/D	0.38
T(in.)	0.41	T/D	0.13
D(in.)	3.12		

Location of Fracture from Butt End(mm) 1054.10 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   Specimen No. P5B

Max Load (Lbf)=	6842.52	(kN) =	30.44

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	219.3	299.5	120.0	
11.46	0.00	0.00	0	0	0	0	0	0.00
12.10	0.64	879.36	0	3	3	4	4	0.93
12.04	0.58	796.92	1	3	3	4	4	0.93
13.55	2.09	2871.66	0	5	8	9	8	1.74
13.41	1.95	2679.30	1	5	8	9	8	1.74
14.36	2.90	3984.60	0	10	12	13	8	2.24
14.25	2.79	3833.46	1	10	12	13	8	2.24
15.65	4.19	5757.06	0	15	11	20	18	3.21
15.48	4.02	5523.48	1	15	11	20	18	3.21
16.44	4.98	6842.52	0	23	31	30	25	4.40
16.02	4.56	6265.44	1	23	31	30	25	4.40
16.41	4.95	6801.30	0	30	45	44	34	6.15
15.60	4.14	5688.36	1	30	45	44	34	6.15
15.83	4.37	6004.38	0	38	57	55	43	8.08
15.19	3.73	5125.02	1	38	57	55	43	8.08
15.48	4.02	5523.48	0	45	68	65	50	10.01
14.88	3.42	4699.08	1	45	68	65	50	10.01
15.22	3.76	5166.24	0	54	82	77	60	13.22
14.45	2.99	4108.26	1	54	82	77	60	13.22
14.77	3.31	4547.94	0	60	93	88	69	16.01
14.22	2.76	3792.24	1	60	93	88	69	16.01
14.50	3.04	4176.96	0	65	103	96	74	18.58
14.01	2.55	3503.70	1	65	103	96	74	18.58
14.23	2.77	3805.98	0	70	112	104	79	20.73
13.90	2.44	3352.56	1	70	112	104	79	20.73
14.12	2.66	3654.84	0	75	121	111	84	23.38
13.71	2.25	3091.50	1	75	121	111	84	23.38
13.93	2.47	3393.78	0	78	129	118	88	25.65
13.27	1.81	2486.94	1	78	129	118	88	25.65
13.69	2.23	3064.02	0	90	157	139	100	33.34
12.88	1.42	1951.08	1	90	157	139	100	33.34
12.88	1.42	1951.08	0	98	173	154	110	41.28
12.53	1.07	1470.18	1	98	173	154	110	41.28
12.45	0.99	1360.26	0	111	206	176	128	50.80
12.06	0.60	824.40	1	111	206	176	128	50.80
11.94	0.48	659.52	0	127	233	197	140	63.50
11.85	0.39	535.86	1	127	233	197	140	63.50
11.81	0.35	480.90	0	138	257	219	153	73.03
11.77	0.31	425.94	1	138	257	219	153	73.03
**********	**********	*************	**********	**********	***********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P5B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.21	3.18	2.00	5.21	3.35	6.53
L/4	3.11		2.65	5.76	3.49	6.47
L/2	3.00		2.69	5.69	3.58	6.43
3L/4	2.84		2.39	5.23	3.51	6.39
L	2.60	2.67	2.20	4.80	3.61	6.28
Mean	2.95	2.93				
Taper	***Ratio:***	0.82	See Note 2	1-TR=	0.18	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.11	0.70	0.69	0.31	0.00
Corrected	(in.)	0.00	0.65	0.64	0.26	0.00
Corrected	(mm)	0.0	16.5	16.2	6.5	0.0
OS/D				0.21		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1510	3.95	6.87	1.74

Compression and Tension Zones

C (in.)	1.25	C/D	0.43
T(in.)	1.00	T/D	0.34
D(in.)	2.91		

Location of Fracture from Butt End(mm) 1104.90 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* **P6B**

Max Load (Lbf)=	6773.82	(kN) =	30.13

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	220.3	300.0	120.1	
11.53	0.00	0.00	0	0	0	0	0	0.00
11.61	0.08	109.92	0	0	0	0	0	1.17
11.60	0.07	96.18	1	0	0	0	0	1.17
12.44	0.91	1250.34	0	0	1	0	0	2.10
12.30	0.77	1057.98	1	0	1	0	0	2.10
14.00	2.47	3393.78	0	2	4	4	2	2.87
13.76	2.23	3064.02	1	2	4	4	2	2.87
15.19	3.66	5028.84	0	5	8	9	2	3.56
14.97	3.44	4726.56	1	5	8	9	2	3.56
16.05	4.52	6210.48	0	10	18	17	14	4.27
15.83	4.30	5908.20	1	10	18	17	14	4.27
16.46	4.93	6773.82	0	23	36	36	27	5.71
15.77	4.24	5825.76	1	23	36	36	27	5.71
15.92	4.39	6031.86	0	31	51	50	39	7.48
15.17	3.64	5001.36	1	31	51	50	39	7.48
15.38	3.85	5289.90	0	39	63	63	49	9.36
14.74	3.21	4410.54	1	39	63	63	49	9.36
14.95	3.42	4699.08	0	45	73	73	56	11.20
14.44	2.91	3998.34	1	45	73	73	56	11.20
14.62	3.09	4245.66	0	50	83	83	64	13.11
14.21	2.68	3682.32	1	50	83	83	64	13.11
14.42	2.89	3970.86	0	55	95	95	73	16.04
13.92	2.39	3283.86	1	55	95	95	73	16.04
14.10	2.57	3531.18	0	60	103	104	79	18.49
13.74	2.21	3036.54	1	60	103	104	79	18.49
13.94	2.41	3311.34	0	65	113	115	86	21.58
13.52	1.99	2734.26	1	65	113	115	86	21.58
13.72	2.19	3009.06	0	70	122	124	94	24.35
13.33	1.80	2473.20	1	70	122	124	94	24.35
13.54	2.01	2761.74	0	85	153	159	116	35.72
12.60	1.07	1470.18	1	85	153	159	116	35.72
12.43	0.90	1236.60	0	96	180	185	131	45.25
12.29	0.76	1044.24	1	96	180	185	131	45.25
12.16	0.63	865.62	0	111	213	218	153	60.33
12.03	0.50	687.00	1	111	213	218	153	60.33
11.85	0.32	439.68	0	132	253	260	181	84.14
11.78	0.25	343.50	1	132	253	260	181	84.14
**********	**********	*************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P6B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.07	3.08	2.00	5.07	3.41	6.49
L/4	2.92		2.45	5.37	3.29	6.23
L/2	2.93		2.18	5.11	3.85	6.64
3L/4	2.73		2.23	4.95	3.77	6.45
L	2.62	2.59	2.14	4.75	3.65	6.24
Mean	2.85	2.84				
Taper	*Ratio:*	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.41	0.14	0.09	-0.05
Corrected	(in.)	0.00	0.42	0.15	0.10	0.00
Corrected	(mm)	0.0	10.7	3.9	2.5	0.0
OS/D				0.05		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1872	3.61	5.54	1.53

Compression and Tension Zones

C (in.)	1.27	C/D	0.45
T(in.)	0.78	T/D	0.27
D(in.)	2.84		

Location of Fracture from Butt End(mm) 1206.50 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P8A

Max Load (Lbf)=	3957.12	(kN) =	17.60

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.1	220.2	299.8	120.0	
11.35	0.00	0.00	0	0	0	0	0	0.00
11.75	0.40	549.60	0	1	1	1	1	0.44
11.72	0.37	508.38	1	1	1	1	1	0.44
12.76	1.41	1937.34	0	4	5	5	4	1.22
12.68	1.33	1827.42	1	4	5	5	4	1.22
13.73	2.38	3270.12	0	11	14	13	10	2.18
13.61	2.26	3105.24	1	11	14	13	10	2.18
14.18	2.83	3888.42	0	19	26	26	20	3.28
14.03	2.68	3682.32	1	19	26	26	20	3.28
14.23	2.88	3957.12	0	29	36	41	34	5.00
13.80	2.45	3366.30	1	29	36	41	34	5.00
13.95	2.60	3572.40	0	36	54	54	45	6.95
13.52	2.17	2981.58	1	36	54	54	45	6.95
13.66	2.31	3173.94	0	43	63	65	52	8.55
13.35	2.00	2748.00	1	43	63	65	52	8.55
13.48	2.13	2926.62	0	47	72	73	60	10.39
13.18	1.83	2514.42	1	47	72	73	60	10.39
13.30	1.95	2679.30	0	51	81	83	67	12.29
13.06	1.71	2349.54	1	51	81	83	67	12.29
13.17	1.82	2500.68	0	56	88	92	74	14.25
12.94	1.59	2184.66	1	56	88	92	74	14.25
13.04	1.69	2322.06	0	61	99	102	80	16.80
12.82	1.47	2019.78	1	61	99	102	80	16.80
12.90	1.55	2129.70	0	64	106	107	86	18.94
12.72	1.37	1882.38	1	64	106	107	86	18.94
12.82	1.47	2019.78	0	70	115	117	96	21.89
12.62	1.27	1744.98	1	70	115	117	96	21.89
12.71	1.36	1868.64	0	72	122	126	102	24.53
12.53	1.18	1621.32	1	72	122	126	102	24.53
12.60	1.25	1717.50	0	78	135	126	102	28.58
12.38	1.03	1415.22	1	78	135	126	102	28.58
12.41	1.06	1456.44	0	90	158	168	135	39.69
12.12	0.77	1057.98	1	90	158	168	135	39.69
12.02	0.67	920.58	0	105	192	212	167	58.74
11.80	0.45	618.30	1	105	192	212	167	58.74
11.85	0.50	687.00	0	121	226	268	200	84.14
11.74	0.39	535.86	1	121	226	268	200	84.14
11.70	0.35	480.90	0	136	260	308	230	112.71
11.65	0.30	412.20	1	36	260	308	230	112.71
11.77	0.42	577.08	0	141	272	328	240	122.24
11.59	0.24	329.76	1	141	272	328	240	122.24
**********	**********	*************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P8A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.79	2.85	2.22	5.01	3.60	6.45
L/4	2.56		2.85	5.40	3.94	6.51
L/2	2.59		2.40	4.99	3.73	6.42
3L/4	2.49		2.50	4.99	3.50	6.04
L	2.31	2.34	2.36	4.67	3.85	6.19
Mean	2.55	2.60				
Taper	***Ratio:***	0.82	See Note 2	1-TR=	0.18	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.11	0.62	0.19	0.25	0.02
Corrected	(in.)	0.00	0.56	0.13	0.18	0.00
Corrected	(mm)	0.0	14.2	3.3	4.7	0.0
OS/D				0.05		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2635	2.22	3.94	1.78

Compression and Tension Zones

C (in.)	0.91	C/D	0.38
T(in.)	0.37	T/D	0.16
D(in.)	2.39		

Location of Fracture from Butt End(mm) 1317.63 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data *Specimen No* **P8B**

Max Load (Lbf)	9123.36	(kN) =	40.58

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	220.0	300.5	120.6	
11.19	0.00	0.00	0	0	0	0	0	0.00
12.27	1.08	1483.92	0	0	3	2	1	0.81
12.32	1.13	1552.62	1	0	3	2	1	0.81
14.23	3.04	4176.96	0	3	5	5	3	1.49
14.14	2.95	4053.30	1	3	5	5	3	1.49
16.39	5.20	7144.80	0	10	13	12	9	2.36
16.22	5.03	6911.22	1	10	13	12	9	2.36
17.61	6.42	8821.08	0	15	24	22	16	3.28
17.27	6.08	8353.92	1	15	24	22	16	3.28
17.83	6.64	9123.36	0	17	40	38	28	4.94
16.74	5.55	7625.70	1	17	40	38	28	4.94
17.04	5.85	8037.90	0	38	59	54	40	7.26
15.96	4.77	6553.98	1	38	59	54	40	7.26
16.32	5.13	7048.62	0	46	77	68	50	9.78
15.41	4.22	5798.28	1	46	77	68	50	9.78
15.74	4.55	6251.70	0	55	87	79	58	12.52
15.01	3.82	5248.68	1	55	87	79	58	12.52
15.28	4.09	5619.66	0	60	98	89	66	15.06
14.72	3.53	4850.22	1	60	98	89	66	15.06
14.96	3.77	5179.98	0	65	109	99	71	17.88
14.43	3.24	4451.76	1	65	109	99	71	17.88
14.67	3.48	4781.52	0	70	119	107	76	20.46
14.17	2.98	4094.52	1	70	119	107	76	20.46
14.39	3.20	4396.80	0	75	129	115	81	23.37
13.84	2.65	3641.10	1	75	129	115	81	23.37
14.02	2.83	3888.42	0	80	137	120	86	25.88
13.61	2.42	3325.08	1	80	137	120	86	25.88
13.57	2.38	3270.12	0	95	170	146	103	38.10
12.93	1.74	2390.76	1	95	170	146	103	38.10
13.15	1.96	2693.04	0	110	198	168	116	47.63
12.37	1.18	1621.32	1	110	198	168	116	47.63
12.26	1.07	1470.18	0	123	230	189	130	60.33
12.02	0.83	1140.42	1	123	230	189	130	60.33
11.89	0.70	961.80	0	137	257	210	145	73.03
11.73	0.54	741.96	1	137	257	210	145	73.03

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No **P8B**

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.30	3.34	1.94	5.24	3.32	6.66
L/4	3.27		2.20	5.47	3.49	6.73
L/2	3.03		2.39	5.41	3.64	6.62
3L/4	2.91		2.07	4.97	3.58	6.69
L	2.77	2.84	2.04	4.82	3.67	6.51
Mean	3.05	3.09				
Taper	*Ratio:*	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.33	0.40	0.02	-0.07
Corrected	(in.)	0.00	0.32	0.39	0.01	0.00
Corrected	(mm)	0.0	8.2	9.9	0.2	0.0
OS/D				0.13		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1189	4.11	8.73	2.12

Compression and Tension Zones

C (in.)	1.25	C/D	0.42
T(in.)	0.81	T/D	0.27
D(in.)	2.97		

Location of Fracture from Butt End(mm) 1111.25 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P9A

Max Load (Lbf)=	5097.54	(kN) =	22.67

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.1	219.8	299.7	120.0	
11.29	0.00	0.00	0	0	0	0	0	0.00
12.03	0.74	1016.76	0	1	2	1	1	0.71
11.97	0.68	934.32	1	1	2	1	1	0.71
13.20	1.91	2624.34	0	3	7	6	5	1.42
13.11	1.82	2500.68	1	3	7	6	5	1.42
14.32	3.03	4163.22	0	10	16	15	13	2.31
14.21	2.92	4012.08	1	10	16	15	13	2.31
14.90	3.61	4960.14	0	16	27	26	22	3.31
14.72	3.43	4712.82	1	16	27	26	22	3.31
15.00	3.71	5097.54	0	23	37	37	30	4.45
14.59	3.30	4534.20	1	23	37	37	30	4.45
14.77	3.48	4781.52	0	31	52	52	43	6.43
14.18	2.89	3970.86	1	31	52	52	43	6.43
14.37	3.08	4231.92	0	37	62	64	52	8.46
13.89	2.60	3572.40	1	37	62	64	52	8.46
14.05	2.76	3792.24	0	45	75	76	62	10.97
13.63	2.34	3215.16	1	45	75	76	62	10.97
13.75	2.46	3380.04	0	51	86	87	70	13.67
13.42	2.13	2926.62	1	51	86	87	70	13.67
13.55	2.26	3105.24	0	56	96	97	79	16.26
13.26	1.97	2706.78	1	56	96	97	79	16.26
13.37	2.08	2857.92	0	61	103	107	87	18.85
13.14	1.85	2541.90	1	61	103	107	87	18.85
13.25	1.96	2693.04	0	65	113	117	95	21.56
13.01	1.72	2363.28	1	65	113	117	95	21.56
13.12	1.83	2514.42	0	69	120	126	102	24.08
12.91	1.62	2225.88	1	69	120	126	102	24.08
13.01	1.72	2363.28	0	79	140	150	120	31.75
12.60	1.31	1799.94	1	79	140	150	120	31.75
12.47	1.18	1621.32	0	89	164	182	145	44.45
11.98	0.69	948.06	1	89	164	182	145	44.45
11.78	0.49	673.26	0	96	182	202	162	53.98
11.67	0.38	522.12	1	96	182	202	162	53.98
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P9A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.07	3.01	2.00	5.07	3.53	6.53
L/4	2.93		2.18	5.11	3.68	6.59
L/2	2.82		2.38	5.19	3.71	6.51
3L/4	2.61		2.39	5.01	3.75	6.29
L	2.34	2.23	2.32	4.66	3.97	6.20
Mean	2.75	2.62				
Taper	***Ratio:***	0.75	See Note 2	1-TR=	0.25	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.03	0.15	0.28	0.20	-0.02
Corrected	(in.)	0.00	0.14	0.27	0.19	0.00
Corrected	(mm)	0.0	3.5	6.9	4.8	0.0
OS/D				0.10		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2365	3.09	4.39	1.42

Compression and Tension Zones

C (in.)	1.03	C/D	0.39
T(in.)	0.60	T/D	0.23
D(in.)	2.66		

Location of Fracture from Butt End(mm) 1393.83 mm

Twist (Degrees CCW or CW) CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* **P9B**

Max Load (Lbf)=	12132.42	(kN) =	53.97

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.0	219.6	299.8	120.0	
11.25	0.00	0.00	0	0	0	0	0	0.00
12.73	1.48	2033.52	0	0	0	0	0	0.86
12.70	1.45	1992.30	1	0	0	0	0	0.86
14.03	2.78	3819.72	0	3	1	2	1	1.28
13.90	2.65	3641.10	1	3	1	2	1	1.28
15.91	4.66	6402.84	0	4	3	3	4	1.80
15.76	4.51	6196.74	1	4	3	3	4	1.80
17.24	5.99	8230.26	0	6	6	6	5	2.18
17.14	5.89	8092.86	1	6	6	6	5	2.18
19.68	8.43	11582.82	0	10	15	15	12	3.06
19.37	8.12	11156.88	1	10	15	15	12	3.06
20.08	8.83	12132.42	0	23	35	33	27	4.75
18.14	6.89	9466.86	1	23	35	33	27	4.75
18.44	7.19	9879.06	0	30	48	46	36	6.43
17.00	5.75	7900.50	1	30	48	46	36	6.43
17.44	6.19	8505.06	0	37	59	57	44	8.14
16.26	5.01	6883.74	1	37	59	57	44	8.14
16.69	5.44	7474.56	0	43	69	66	50	10.01
15.72	4.47	6141.78	1	43	69	66	50	10.01
16.15	4.90	6732.60	0	48	78	76	57	12.07
15.27	4.02	5523.48	1	48	78	76	57	12.07
15.68	4.43	6086.82	0	53	86	83	63	14.08
14.91	3.66	5028.84	1	53	86	83	63	14.08
15.25	4.00	5496.00	0	58	96	93	70	16.64
14.55	3.30	4534.20	1	58	96	93	70	16.64
14.85	3.60	4946.40	0	65	109	103	75	19.76
14.19	2.94	4039.56	1	65	109	103	75	19.76
14.50	3.25	4465.50	0	70	116	112	83	22.40
13.93	2.68	3682.32	1	70	116	112	83	22.40
14.22	2.97	4080.78	0	74	126	118	88	25.30
13.67	2.42	3325.08	1	74	126	118	88	25.30
13.91	2.66	3654.84	0	82	147	138	102	31.75
13.12	1.87	2569.38	1	82	147	138	102	31.75
13.46	2.21	3036.54	0	95	166	156	111	38.90
12.71	1.46	2006.04	1	95	166	156	111	38.90
13.02	1.77	2431.98	0	100	184	171	120	45.25
12.07	0.82	1132.18	1	100	184	171	120	45.25
12.29	1.04	1428.96	0	115	214	196	138	57.15
11.40	0.15	206.10	1	115	214	196	138	57.15
11.80	0.55	755.70	0	135	251	232	160	74.61
11.62	0.37	508.38	1	135	251	232	160	74.61
************	*********	**************	************	***********	************	***********	***********	**********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No P9B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.57	3.61	1.81	5.38	3.29	6.89
L/4	3.52		1.85	5.37	3.31	6.89
L/2	3.42		2.11	5.52	3.41	6.75
3L/4	3.30		2.04	5.34	3.37	6.62
L	3.11	3.07	1.86	4.97	3.56	6.63
Mean	3.38	3.34				
Taper	***Ratio:***	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.11	0.31	0.19	-0.09
Corrected	(in.)	0.00	0.10	0.31	0.19	0.00
Corrected	(mm)	0.0	2.6	7.9	4.7	0.0
OS/D				0.09		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
73	1	0.1600	6.68	8.61	1.29

Compression and Tension Zones

C (in.)	1.47	C/D	0.44
T(in.)	1.24	T/D	0.37
D(in.)	3.34		

Location of Fracture from Butt End(mm) 1130.30 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valic
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* **P10A**

Max Load (Lbf)=	8395.14	(kN) =	37.34

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.5	220.2	300.0	119.8	
11.24	0.00	0.00	0	0	0	0	0	0.00
11.79	0.55	755.70	0	0	0	0	0	0.62
11.77	0.53	728.22	1	0	0	0	0	0.62
12.57	1.33	1827.42	0	0	1	1	1	1.25
12.53	1.29	1772.46	1	0	1	1	1	1.25
13.68	2.44	3352.56	0	1	2	3	3	1.78
13.61	2.37	3256.38	1	1	2	3	3	1.78
15.20	3.96	5441.04	0	3	6	8	3	2.45
15.10	3.86	5303.64	1	3	6	8	11	2.45
16.22	4.98	6842.52	0	7	12	13	11	3.05
16.11	4.87	6691.38	1	7	12	13	11	3.05
16.94	5.70	7831.80	0	13	20	22	18	3.78
16.80	5.56	7639.44	1	13	20	22	18	3.78
17.35	6.11	8395.14	0	20	32	34	28	4.89
16.98	5.74	7886.76	1	20	32	34	28	4.89
17.20	5.96	8189.04	0	30	46	49	38	6.62
16.21	4.97	6828.78	1	30	46	49	38	6.62
16.48	5.24	7199.76	0	37	59	63	51	8.59
15.62	4.38	6018.12	1	37	59	63	51	8.59
15.81	4.57	6279.18	0	44	70	75	60	10.81
15.15	3.91	5372.34	1	44	70	75	60	10.81
15.34	4.10	5633.40	0	49	82	87	70	13.41
14.76	3.52	4836.48	1	49	82	87	70	13.41
14.93	3.69	5070.06	0	55	90	96	78	15.71
14.50	3.26	4479.24	1	55	90	96	78	15.71
14.68	3.44	4726.56	0	58	99	105	86	18.37
14.25	3.01	4135.74	1	58	99	105	86	18.37
14.40	3.16	4341.84	0	63	106	115	94	21.11
14.00	2.76	3792.24	1	63	106	115	94	21.11
14.14	2.90	3984.60	0	65	112	122	101	23.36
13.81	2.57	3531.18	1	65	112	122	101	23.36
13.60	2.36	3242.64	0	66	121	134	112	25.81
12.57	1.33	1827.42	1	66	121	134	112	25.81
12.74	1.50	2061.00	0	75	132	148	123	29.37
11.58	0.34	467.16	1	75	132	148	123	29.37

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P10A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.07	3.11	2.09	5.16	3.47	6.58
L/4	3.02		1.85	4.86	3.13	6.28
L/2	2.95		2.13	5.08	3.43	6.43
3L/4	2.86		2.35	5.21	3.68	6.43
L	2.55	2.64	2.20	4.75	3.72	6.36
Mean	2.89	2.87				
Taper	*Ratio:*	0.84	See Note 2	1-TR=	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.12	-0.15	0.11	0.28	-0.02
Corrected	(in.)	0.00	-0.20	0.06	0.23	0.00
Corrected	(mm)	0.0	-5.0	1.5	5.8	0.0
OS/D				0.02		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1745	3.72	5.95	1.60

Compression and Tension Zones

C (in.)	0.55	C/D	0.20
T(in.)	1.03	T/D	0.36
D(in.)	2.83		

Location of Fracture from Butt End(mm) 1466.85 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — Specimen No. P10B

Max Load (Lbf)=	10263.78	(kN) =	45.66

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				40.6	219.1	298.6	119.6	
11.28	0.00	0.00	0	0	0	0	0	0.00
11.33	0.05	68.70	0	0	0	0	0	0.00
11.33	0.05	68.70	1	0	0	0	0	0.00
12.91	1.63	2239.62	0	2	4	2	2	0.83
12.82	1.54	2115.96	1	2	4	2	2	0.83
14.64	3.36	4616.64	0	6	7	6	5	1.53
14.50	3.22	4424.28	1	6	7	6	5	1.53
16.54	5.26	7227.24	0	8	10	9	12	2.37
16.34	5.06	6952.44	1	8	10	9	12	2.37
17.80	6.52	8958.48	0	12	16	15	12	3.12
17.50	6.22	8546.28	1	12	16	15	12	3.12
18.75	7.47	10263.78	0	19	27	24	20	4.35
17.99	6.71	9219.54	1	19	27	24	20	4.35
18.72	7.44	10222.56	0	26	39	36	30	6.03
17.42	6.14	8436.36	1	26	39	36	30	6.03
18.06	6.78	9315.72	0	33	50	49	37	7.91
16.77	5.49	7543.26	1	33	50	49	37	7.91
17.21	5.93	8147.82	0	38	59	58	46	9.73
16.26	4.98	6842.52	1	38	59	58	46	9.73
16.62	5.34	7337.16	0	46	70	70	54	12.10
15.70	4.42	6073.08	1	46	70	70	54	12.10
15.94	4.66	6402.84	0	51	90	91	66	15.29
13.00	1.72	2363.28	1	51	90	91	66	15.29
13.01	1.73	2377.02	0	56	99	101	72	17.88
12.67	1.39	1909.86	1	56	99	101	72	17.88
12.62	1.34	1841.16	0	61	111	116	81	21.14
12.19	0.91	1250.34	1	61	111	116	81	21.14
12.25	0.97	1332.78	0	64	120	125	87	23.60
12.09	0.81	1112.94	1	64	120	125	87	23.60
12.14	0.86	1181.64	0	68	129	135	95	25.88
11.78	0.50	687.00	1	68	129	135	95	25.88
11.39	0.11	151.14	0	81	159	180	116	38.10
11.38	0.10	137.40	1	81	159	180	116	38.10
**********	**********	************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P10B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.56	3.38	1.86	5.43	3.33	6.71
L/4	3.55		2.19	5.74	3.47	6.94
L/2	3.49		2.50	5.99	3.31	6.43
3L/4	3.40		2.16	5.56	3.38	6.64
L	3.08	3.17	1.97	5.05	3.43	6.61
Mean	3.42	3.28				
Taper	***Ratio:***	0.90	See Note 2	1-TR=	0.10	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.14	0.46	0.75	0.36	0.01
Corrected	(in.)	0.00	0.39	0.67	0.28	0.00
Corrected	(mm)	0.0	9.8	17.0	7.2	0.0
OS/D				0.19		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1032	7.32	10.05	1.37

Compression and Tension Zones

C (in.)	1.73	C/D	0.52
T(in.)	1.25	T/D	0.38
D(in.)	3.33		

Location of Fracture from Butt End(mm) 1393.83 mm

Twist (Degrees CCW or CW) 3 CCW

Note: 1 Only the horizontal diameters at the ends are ture dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data ***Specimen No. P11B***

Max. Load (LbF)= 8120.34 **(kN) =** 36.12 ***Page - 1***

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Delta Platen
				40.6	219.7	300.0	120.2	(mm)
11.30	0.00	0.00	0	0	0	0	0	0.00
11.84	0.54	741.96	0	0	0	0	0	0.48
11.80	0.50	687.00	1	0	0	0	0	0.48
12.45	1.15	1580.10	0	1	2	1	1	0.84
12.38	1.08	1483.92	1	1	2	1	1	0.84
13.45	2.15	2954.10	0	3	3	2	2	1.35
13.36	2.06	2830.44	1	3	3	2	2	1.35
14.39	3.09	4245.66	0	4	6	5	4	1.78
14.28	2.98	4094.52	1	4	6	5	4	1.78
15.32	4.02	5523.48	0	6	8	8	6	2.18
15.21	3.91	5372.34	1	6	8	8	6	2.18
16.39	5.09	6993.66	0	11	15	13	11	2.71
16.26	4.96	6815.04	1	11	15	13	11	2.71
17.10	5.80	7969.20	0	16	22	20	17	3.35
16.80	5.50	7557.00	1	16	22	20	17	3.35
17.21	5.91	8120.34	0	25	40	35	30	4.88
16.16	4.86	6677.64	1	25	40	35	30	4.88
16.37	5.07	6966.18	0	34	54	50	41	6.81
15.44	4.14	5688.36	1	34	54	50	41	6.81
15.75	4.45	6114.30	0	40	66	62	50	8.78
14.97	3.67	5042.58	1	40	66	62	50	8.78
15.22	3.92	5386.08	0	46	76	72	57	10.77
14.58	3.28	4506.72	1	46	76	72	57	10.77
14.80	3.50	4809.00	0	51	87	83	66	13.30
14.23	2.93	4025.82	1	51	87	83	66	13.30
14.46	3.16	4341.84	0	58	101	94	74	16.31
13.92	2.62	3599.88	1	58	101	94	74	16.31
14.13	2.83	3888.42	0	66	111	105	81	19.20
13.65	2.35	3228.90	1	66	111	105	81	19.20
13.63	2.33	3201.42	0	69	121	113	86	21.74
13.43	2.13	2926.62	1	69	121	113	86	21.74
13.62	2.32	3187.68	0	75	133	122	92	25.10
13.08	1.78	2445.72	1	75	133	122	92	25.10
13.30	2.00	2748.00	0	84	152	138	102	30.16
12.68	1.38	1896.12	1	84	152	138	102	30.16
12.68	1.38	1896.12	0	96	177	155	113	38.10
12.04	0.74	1016.76	1	96	177	155	113	38.10
11.86	0.56	769.44	0	111	207	183	132	52.39
11.67	0.37	508.38	1	111	207	183	132	52.39
11.73	0.43	590.82	0	129	245	213	150	68.26
11.49	0.19	261.06	1	129	245	213	150	68.26
**********	**********		**********	**********	**********	**********	**********	**********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P11B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.39	3.49	1.90	5.29	3.34	6.83
L/4	3.25		2.05	5.30	3.41	6.77
L/2	3.17		2.31	5.47	3.56	6.61
3L/4	2.88		2.21	5.09	3.48	6.33
L	2.70	2.72	2.07	4.77	3.66	6.37
Mean	3.08	3.10				
Taper	***Ratio:***	0.79	See Note 2	1-TR=	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.17	0.39	0.15	-0.08
Corrected	(in.)	0.00	0.17	0.38	0.14	0.00
Corr (mm		0.0	4.3	9.7	3.7	0.0
OS/D				0.12		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1468	4.93	7.07	1.43

Compression and Tension Zones

C (in.)	1.33	C/D	0.44
T(in.)	1.20	T/D	0.40
D(in.)	2.99		

Location of Fracture from Butt End(mm) 1104.90 mm

Twist (Degress CCW or CW) 2 CW

Note: 1 Only the horizontal diameters at the ends are ture dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P12A

Max Load(Lbf)=	6210.48	(kN) =	27.63

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.0	219.0	299.0	119.3	
11.58	0.00	0.00	0	0	0	0	0	0.00
11.65	0.07	96.18	0	0	0	0	0	0.00
11.65	0.07	96.18	1	0	0	0	0	0.00
12.64	1.06	1456.44	0	1	3	2	2	0.80
12.50	0.92	1264.08	1	1	3	2	2	0.80
13.90	2.32	3187.68	0	4	6	6	2	1.68
13.64	2.06	2830.44	1	4	6	6	2	1.68
14.78	3.20	4396.80	0	7	12	10	9	2.41
14.45	2.87	3943.38	1	7	12	10	9	2.41
15.51	3.93	5399.82	0	10	19	17	14	3.38
15.34	3.76	5166.24	1	10	19	17	14	3.38
16.10	4.52	6210.48	0	17	30	28	23	4.78
15.58	4.00	5496.00	1	17	30	28	23	4.78
15.95	4.37	6004.38	0	24	42	39	33	6.29
15.26	3.68	5056.32	1	24	42	39	33	6.29
15.53	3.95	5427.30	0	36	59	56	46	9.13
14.68	3.10	4259.40	1	36	59	56	46	9.13
15.01	3.43	4712.82	0	44	74	70	57	12.04
14.28	2.70	3709.80	1	44	74	70	57	12.04
14.21	2.63	3613.62	0	60	104	94	77	19.53
13.61	2.03	2789.22	1	60	104	94	77	19.53
13.80	2.22	3050.28	0	73	129	120	93	26.20
13.10	1.52	2088.48	1	73	129	120	93	26.20
12.84	1.26	1731.24	0	87	166	155	111	36.51
11.67	0.09	123.66	1	87	166	155	111	36.51
11.72	0.14	192.36	0	103	198	187	132	49.21
11.64	0.06	82.44	1	103	198	187	132	49.21
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P12A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.52	3.46	1.84	5.36	3.29	6.75
L/4	3.30		1.92	5.22	3.04	6.35
L/2	3.34		2.51	5.85	3.66	6.76
3L/4	3.12		2.43	5.55	3.88	6.92
L	2.73	2.77	2.13	4.86	3.65	6.41
Mean	3.20	3.12				
Taper	***Ratio:***	0.79	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.10	0.07	0.68	0.49	-0.00
Corrected	(in.)	0.00	0.03	0.63	0.44	0.00
Corrected	(mm)	0.0	0.6	16.1	11.2	0.0
OS/D				0.19		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
73	1	0.1982	6.10	6.95	1.14

Compression and Tension Zones

C (in.)	1.65	C/D	0.54
T(in.)	1.21	T/D	0.40
D(in.)	3.06		

Location of Fracture from Butt End(mm) 1181.10 mm

Twist (Degrees CCW or CW) 1 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P14B

Max Load (Lbf) =	4451.76	(kN) =	19.80

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	219.0	298.6	119.6	
11.49	0.00	0.00	0	0	0	0	0	0.00
12.09	0.60	824.40	0	5	5	2	1	************
12.05	0.56	769.44	1	5	5	2	1	************
13.13	1.64	2253.36	0	7	10	6	5	1.59
13.04	1.55	2129.70	1	7	10	6	5	1.59
13.91	2.42	3325.08	0	13	18	14	11	3.18
13.84	2.35	3228.90	1	13	18	14	11	3.18
14.47	2.98	4094.52	0	20	28	23	19	4.76
14.38	2.89	3970.86	1	20	28	23	19	4.76
14.73	3.24	4451.76	0	28	39	33	26	************
14.40	2.91	3998.34	1	28	39	33	26	************
14.61	3.12	4286.88	0	40	60	55	43	9.53
14.00	2.51	3448.74	1	40	60	55	43	9.53
14.17	2.68	3682.32	0	49	75	69	54	12.70
13.73	2.24	3077.76	1	49	75	69	54	12.70
13.83	2.34	3215.16	0	60	95	89	69	16.67
13.35	1.86	2555.64	1	60	95	89	69	16.67
13.47	1.98	2720.52	0	70	116	110	84	23.02
13.03	1.54	2115.96	1	70	116	110	84	23.02
13.08	1.59	2184.66	0	85	143	139	104	33.34
11.70	0.21	288.54	1	84	154	152	110	33.34
11.81	0.32	439.68	0	96	176	176	126	42.86
11.65	0.16	219.84	1	96	176	176	126	42.86
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P14B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.08	3.21	2.00	5.08	3.39	6.60
L/4	3.11		2.63	5.74	3.54	6.60
L/2	2.94		2.78	5.73	3.77	6.46
3L/4	2.73		2.44	5.17	3.59	6.43
L	2.46	2.67	2.28	4.74	3.70	6.38
Mean	2.86	2.94				
Taper	***Ratio:***	0.82	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.68	0.75	0.31	0.01
Corrected	(in.)	0.00	0.66	0.73	0.28	0.00
Corrected	(mm)	0.0	16.7	18.5	7.1	0.0

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2098	3.69	4.94	1.34

Compression and Tension Zones

C (in.)	1.28	C/D	0.47
T(in.)	1.29	T/D	0.47
D(in.)	2.74		

Location of Fracture from Butt End(mm) 1393.83 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data Specimen No. P15B

Max Load(Lbf)=	4877.70	(kN) =	21.70

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				40.5	220.0	300.6	120.2	
11.48	0.00	0.00	0	0	0	0	0	0.00
12.47	0.99	1360.26	0	1	4	2	2	0.94
12.39	0.91	1250.34	1	1	4	2	2	0.94
13.91	2.43	3338.82	0	5	9	8	6	1.80
13.79	2.31	3173.94	1	5	9	8	6	1.80
14.72	3.24	4451.76	0	13	20	18	15	2.65
14.58	3.10	4259.40	1	13	20	18	15	2.65
15.03	3.55	4877.70	0	24	36	33	26	3.99
14.72	3.24	4451.76	1	24	36	33	26	3.99
14.85	3.37	4630.38	0	37	57	53	42	6.60
14.10	2.62	3599.88	1	37	57	53	42	6.60
14.02	2.54	3489.96	0	55	89	85	66	2.68
13.40	1.92	2638.08	1	55	89	85	66	2.68
13.58	2.10	2885.40	0	67	112	108	82	18.90
13.06	1.58	2170.92	1	67	112	108	82	18.90
13.30	1.82	2500.68	0	76	129	125	97	24.21
12.90	1.42	1951.08	1	76	129	125	97	24.21
13.11	1.63	2239.62	0	85	146	141	108	************
12.75	1.27	1744.98	1	85	146	141	108	************
12.65	1.17	1607.58	0	115	205	203	155	58.74
12.33	0.85	1167.90	1	115	205	203	155	58.74
12.49	1.01	1387.74	0	130	235	236	181	74.61
12.14	0.66	906.84	1	130	235	236	181	74.61
12.30	0.82	1126.68	0	137	256	260	197	85.73
12.03	0.55	755.70	1	137	256	260	197	85.73
11.86	0.38	522.12	0	155	290	306	232	112.71
11.85	0.37	508.38	1	155	290	306	232	112.71
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P15B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.02	3.09	2.04	5.05	3.47	6.56
L/4	2.97		2.27	5.25	3.32	6.41
L/2	2.86		2.42	5.28	3.58	6.46
3L/4	2.66		2.15	4.81	3.63	6.31
L	2.41	2.51	2.29	4.70	3.72	6.23
Mean	2.79	2.80				
Taper	*Ratio:*	0.81	See Note 2	1-TR=	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.05	0.26	0.35	-0.02	-0.01
Corrected	(in.)	0.00	0.24	0.33	-0.04	0.00
Corrected	(mm)	0.0	6.1	8.4	-1.1	0.0

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2350	3.29	4.41	1.34

Compression and Tension Zones

C (in.)	0.79	C/D	0.30
T(in.)	0.78	T/D	0.30
D(in.)	2.61		

Location of Fracture from Butt End(mm) 1393.83 mm

Twist (Degrees CCW or CW) 4 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* **P16B**

Max Load (Lbf)=	8793.60	(kN) =	39.12

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.3	220.7	300.4	120.1	
11.59	0.00	0.00	0	0	0	0	0	0.00
13.20	1.61	2212.14	0	0	0	0	0	0.99
13.03	1.44	1978.56	1	0	0	0	0	0.99
14.65	3.06	4204.44	0	3	2	2	4	1.49
14.28	2.69	3696.06	1	3	2	2	4	1.49
16.03	4.44	6100.56	0	3	4	4	6	2.17
15.47	3.88	5331.12	1	3	4	4	6	2.17
17.07	5.48	7529.52	0	6	7	8	10	2.79
16.40	4.81	6608.94	1	6	7	8	10	2.79
17.76	6.17	8477.58	0	8	13	14	15	3.56
17.30	5.71	7845.54	1	8	13	14	15	3.56
17.99	6.40	8793.60	0	19	32	34	31	5.36
16.42	4.83	6636.42	1	19	32	34	31	5.36
16.65	5.06	6952.44	0	29	50	53	47	7.92
15.46	3.87	5317.38	1	29	50	53	47	7.92
15.50	3.91	5372.34	0	42	73	79	71	13.08
14.56	2.97	4080.78	1	42	73	79	71	13.08
14.82	3.23	4438.02	0	51	87	97	86	17.25
14.14	2.55	3503.70	1	51	87	97	86	17.25
14.41	2.82	3874.68	0	54	97	107	95	19.99
13.96	2.37	3256.38	1	54	97	107	95	19.99
14.16	2.57	3531.18	0	59	107	119	105	23.66
13.71	2.12	2912.88	1	59	107	119	105	23.66
13.96	2.37	3256.38	0	66	121	136	119	28.58
13.39	1.80	2473.20	1	66	121	136	119	28.58
12.25	0.66	906.84	0	77	146	174	141	************
11.91	0.32	439.68	1	77	146	174	141	************
11.92	0.33	453.42	0	86	164	193	159	46.04
11.87	0.28	384.72	1	86	164	193	159	46.04
11.74	0.15	206.10	0	98	186	222	179	55.56
11.62	0.03	41.22	1	98	186	222	179	55.56
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P16B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.76	3.58	1.62	5.38	3.10	6.68
L/4	3.67		1.66	5.34	3.15	6.75
L/2	3.27		1.84	5.10	3.12	6.42
3L/4	3.19		1.88	5.07	3.16	6.41
L	2.78	2.84	2.11	4.89	3.40	6.24
Mean	3.33	3.21				
Taper	*Ratio:*	0.76	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.00	0.00	-0.03	-0.02	0.00
Corrected	(in.)	0.00	0.00	-0.03	-0.02	0.00
Corrected	(mm)	0.0	0.0	-0.8	-0.5	0.0
OS/D				-0.01		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
73	1	0.1710	5.60	8.05	1.44

Compression and Tension Zones

C (in.)	0.79	C/D	0.26
T(in.)	1.41	T/D	0.46
D(in.)	3.06		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 2 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P18A

Max Load (Lbf)=	1470.18	(kN) =	6.54

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				39.2	217.2	297.7	118.5	
12.12	0.00	0.00	0	0	0	0	0	0.00
12.50	0.38	522.12	0	5	7	5	5	1.28
12.46	0.34	467.16	1	5	7	5	5	1.28
12.78	0.66	906.84	0	10	16	13	12	2.54
12.73	0.61	838.14	1	10	16	13	12	2.54
12.94	0.82	1126.68	0	15	26	21	19	3.84
12.89	0.77	1057.98	1	15	26	21	19	3.84
13.03	0.91	1250.34	0	22	34	29	25	5.11
12.99	0.87	1195.38	1	22	34	29	25	5.11
13.10	0.98	1346.52	0	27	42	37	31	6.49
13.07	0.95	1305.30	1	27	42	37	31	6.49
13.14	1.02	1401.48	0	32	48	42	36	7.72
13.11	0.99	1360.26	1	32	48	42	36	7.72
13.17	1.05	1442.70	0	35	54	49	40	9.02
13.14	1.02	1401.48	1	35	54	49	40	9.02
13.19	1.07	1470.18	0	39	60	55	45	10.26
13.15	1.03	1415.22	1	39	60	55	45	10.26
13.18	1.06	1456.44	0	42	64	60	50	11.57
13.14	1.02	1401.48	1	42	64	60	50	11.57
13.16	1.04	1428.96	0	44	71	67	55	13.02
13.11	0.99	1360.26	1	44	71	67	55	13.02
13.13	1.01	1387.74	0	47	77	72	59	14.10
13.09	0.97	1332.78	1	47	77	72	59	14.10
13.11	0.99	1360.26	0	53	87	82	65	16.85
13.02	0.90	1236.60	1	53	87	82	65	16.85
13.03	0.91	1250.34	0	60	97	92	75	19.67
12.95	0.83	1140.42	1	60	97	92	75	19.67
12.94	0.82	1126.68	0	62	103	99	80	22.03
12.89	0.77	1057.98	1	62	103	99	80	22.03
12.89	0.77	1057.98	0	67	111	107	85	24.71
12.82	0.70	961.80	1	67	111	107	85	24.71
12.82	0.70	961.80	0	80	146	155	125	38.10
12.17	0.05	68.70	1	80	146	155	125	38.10
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P18A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.50	2.61	2.32	4.81	3.70	6.31
L/4	2.50		3.13	5.63	4.07	5.93
L/2	2.26		3.81	6.08	5.00	5.00
3L/4	2.18		3.26	5.44	4.15	5.88
L	1.70	2.19	2.59	4.29	3.93	6.12
Mean	2.23	2.40				
Taper	***Ratio:***	0.76	See Note 2	1-TR =	0.24	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.88	1.45	0.85	-0.06
Corrected	(in.)	0.00	0.88	1.44	0.85	0.00
Corrected	(mm)	0.0	22.3	36.6	21.6	0.0
OS/D				0.64		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.4350	1.29	2.38	1.86

Compression and Tension Zones

C (in.)	1.02	C/D	0.45
T(in.)	0.74	T/D	0.32
D(in.)	2.29		

Location of Fracture from Butt End(mm) 1317.63 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data *Specimen No.* **P18B**

Max Load (Lbf)=	4685.34	(kN) =	20.84

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at			
				L/4	L/2	5L/8	3L/4
				40.0	217.6	298.0	118.7
11.45	0.00	0.00	0	0	0	0	0
11.83	0.38	522.12	0	0	0	0	0
11.81	0.36	494.64	1	0	0	0	0
13.57	2.12	2912.88	0	9	9	9	6
13.45	2.00	2748.00	1	9	9	9	6
14.80	3.35	4602.90	0	20	29	27	20
14.57	3.12	4286.88	1	20	29	27	20
14.86	3.41	4685.34	0	30	41	39	29
14.39	2.94	4039.56	1	30	41	39	29
14.52	3.07	4218.18	0	42	63	60	44
13.89	2.44	3352.56	1	42	63	60	44
14.04	2.59	3558.66	0	53	81	77	57
13.52	2.07	2844.18	1	53	81	77	57
13.65	2.20	3022.80	0	64	103	98	71
13.16	1.71	2349.54	1	64	103	98	71
13.28	1.83	2514.42	0	78	125	116	85
12.84	1.39	1909.86	1	78	125	116	85
12.25	0.80	1099.20	0	92	159	139	97
11.91	0.46	632.04	1	92	159	139	97
11.91	0.46	632.04	0	110	194	165	117
11.73	0.28	384.72	1	110	194	165	117
**********	**********		**********	**********	**********	**********	**********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P18B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.00	3.06	1.99	4.99	3.39	6.44
L/4	2.98		2.54	5.52	3.64	6.53
L/2	2.89		3.16	6.05	3.94	6.02
3L/4	2.79		2.69	5.48	3.57	6.26
L	2.49	2.66	2.25	4.75	3.70	6.36
Mean	2.83	2.86				
Taper	***Ratio:***	0.85	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.53	1.10	0.59	-0.00
Corrected	(in.)	0.00	0.53	1.11	0.59	0.00
Corrected	(mm)	0.0	13.6	28.2	15.0	0.0

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1930	3.44	5.38	1.56

Compression and Tension Zones

C (in.)	1.04	C/D	0.38
T(in.)	1.10	T/D	0.40
D(in.)	2.76		

Location of Fracture from Butt End(mm) 1054.10 mm

Twist (Degrees CCW or CW) 1 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P19B

Max Load (Lbf)=	3819.72	(kN) =	16.99

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at			
				L/4	L/2	5L/8	3L/4
				39.8	218.3	298.5	118.5
11.97	0.00	0.00	0	0	0	0	0
12.78	0.81	1112.94	0	3	7	7	7
12.69	0.72	989.28	1	3	7	7	7
13.63	1.66	2280.84	0	8	13	13	13
13.50	1.53	2102.22	1	8	13	13	13
14.31	2.34	3215.16	0	13	22	22	20
14.15	2.18	2995.32	1	13	22	22	20
14.75	2.78	3819.72	0	22	37	35	32
14.21	2.24	3077.76	1	22	37	35	32
14.54	2.57	3531.18	0	28	48	49	43
13.98	2.01	2761.74	1	28	48	49	43
14.24	2.27	3118.98	0	40	68	71	59
13.62	1.65	2267.10	1	40	68	71	59
13.96	1.99	2734.26	0	48	87	89	74
13.43	1.46	2006.04	1	48	87	89	74
13.74	1.77	2431.98	0	60	105	111	90
13.22	1.25	1717.50	1	60	105	111	90
13.51	1.54	2115.96	0	68	123	134	108
13.05	1.08	1483.92	1	68	123	134	108
13.21	1.24	1703.76	0	80	148	160	128
12.55	0.58	796.92	1	80	148	160	128
12.70	0.73	1003.02	0	87	167	195	147
12.22	0.25	343.50	1	87	167	195	147
12.29	0.32	439.68	0	95	183	210	163
12.16	0.19	261.06	1	95	183	210	163
12.20	0.23	316.02	0	108	203	235	183
12.16	0.19	261.06	1	108	203	235	183
**********	**********		**********	**********	**********	**********	**********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P19B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.15	3.18	1.96	5.11	3.44	6.62
L/4	3.16		2.31	5.47	3.20	6.39
L/2	2.99		2.73	5.72	3.45	6.42
3L/4	2.81		2.78	5.59	3.84	6.58
L	2.70	2.73	2.18	4.87	3.68	6.41
Mean	2.96	2.95				
Taper	***Ratio:***	0.86	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.39	0.72	0.68	0.02
Corrected	(in.)	0.00	0.36	0.69	0.65	0.00
Corrected	(mm)	0.0	9.2	17.6	16.6	0.0
OS/D				0.23		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1808	3.94	5.74	1.45

Compression and Tension Zones

C (in.)	1.14	C/D	0.41
T(in.)	1.22	T/D	0.44
D(in.)	2.79		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* 20A

Max Load (Lbf)=	3228.90	(kN) =	14.36

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	220.6	300.7	120.7	
12.12	0.00	0.00	0	0	0	0	0	0.00
12.87	0.75	1030.50	0	0	1	0	0	0.76
12.79	0.67	920.58	1	0	1	0	0	0.76
13.80	1.68	2308.32	0	4	4	3	3	1.52
13.70	1.58	2170.92	1	4	4	3	3	1.52
14.39	2.27	3118.98	0	10	15	12	12	2.34
14.31	2.19	3009.06	1	10	15	12	12	2.34
14.47	2.35	3228.90	0	19	17	26	22	3.26
14.41	2.29	3146.46	1	19	17	26	22	3.26
14.45	2.33	3201.42	0	28	41	39	33	4.58
14.35	2.23	3064.02	1	28	41	39	33	4.58
14.31	2.19	3009.06	0	35	55	52	45	6.22
14.08	1.96	2693.04	1	35	55	52	45	6.22
14.03	1.91	2624.34	0	45	71	72	58	8.89
13.71	1.59	2184.66	1	45	71	72	58	8.89
13.70	1.58	2170.92	0	52	85	86	69	11.56
13.49	1.37	1882.38	1	52	85	86	69	11.56
13.50	1.38	1896.12	0	57	94	96	80	14.12
13.35	1.23	1690.02	1	57	94	96	80	14.12
13.34	1.22	1676.28	0	64	105	107	87	16.76
13.23	1.11	1525.14	1	64	105	107	87	16.76
13.22	1.10	1511.40	0	66	112	117	97	19.51
13.13	1.01	1387.74	1	66	112	117	97	19.51
13.12	1.00	1374.00	0	72	119	127	103	22.07
13.06	0.94	1291.56	1	72	119	127	103	22.07
13.03	0.91	1250.34	0	75	127	135	111	24.73
12.99	0.87	1195.38	1	75	127	135	111	24.73
12.90	0.78	1071.72	0	90	161	181	145	38.10
12.55	0.43	590.82	1	90	161	181	145	38.10
12.46	0.34	467.16	0	97	180	207	162	47.63
12.30	0.18	247.32	1	97	180	207	162	47.63
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 20A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.62	2.59	2.24	4.86	3.81	6.40
L/4	2.62		2.59	5.21	3.89	6.29
L/2	2.41		2.44	4.85	3.98	6.36
3L/4	2.18		2.55	4.73	4.09	6.31
L	2.00	2.01	2.61	4.61	4.12	6.12
Mean	2.37	2.30				
Taper	***Ratio:***	0.77	See Note 2	1-TR=	0.23	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.05	0.40	0.14	0.14	0.11
Corrected	(in.)	0.00	0.32	0.06	0.06	0.00
Corrected	(mm)	0.0	8.1	1.5	1.4	0.0
OS/D				0.02		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.3935	1.66	2.64	1.59

Compression and Tension Zones

C (in.)	0.97	C/D	0.43
T(in.)	0.46	T/D	0.20
D(in.)	2.26		

Location of Fracture from Butt End(mm) 1343.03 mm

Twist (Degrees CCW or CW) 1 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P20B

Max Load (Lbf)=	5812.02	(kN) =	25.85

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.2	219.4	299.0	119.4	
11.58	0.00	0.00	0	0	0	0	0	0.00
12.43	0.85	1167.90	0	2	1	3	2	************
12.32	0.74	1016.76	1	2	1	3	2	************
14.44	2.86	3929.64	0	6	9	10	9	2.38
14.21	2.63	3613.62	1	6	9	10	9	2.38
15.31	3.73	5125.02	0	12	18	20	17	************
15.13	3.55	4877.70	1	12	18	20	17	************
15.81	4.23	5812.02	0	22	38	20	17	6.35
14.99	3.41	4685.34	1	22	38	20	17	6.35
15.29	3.71	5097.54	0	34	55	59	47	8.73
14.48	2.90	3984.60	1	34	55	59	47	8.73
14.84	3.26	4479.24	0	41	69	72	57	************
14.14	2.56	3517.44	1	41	69	72	57	************
14.47	2.89	3970.86	0	48	82	86	67	************
13.84	2.26	3105.24	1	48	82	86	67	************
13.88	2.30	3160.20	0	62	109	115	88	22.23
13.05	1.47	2019.78	1	62	109	115	88	22.23
13.29	1.71	2349.54	0	68	124	130	99	************
12.73	1.15	1580.10	1	68	124	130	99	************
13.03	1.45	1992.30	0	77	144	152	112	34.13
12.35	0.77	1057.98	1	77	144	152	112	34.13
12.54	0.96	1319.04	0	87	163	175	128	************
12.15	0.57	783.18	1	87	163	175	128	************
12.21	0.63	865.62	0	96	183	199	143	51.59
11.78	0.20	274.80	1	96	183	199	143	51.60
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P20B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.14	3.13	1.92	5.06	3.45	6.58
L/4	3.33		1.91	5.24	3.33	6.29
L/2	2.99		2.39	5.38	3.52	6.52
3L/4	2.71		2.61	5.33	3.56	6.37
L	2.64	2.73	2.23	4.87	3.66	6.38
Mean	2.96	2.93				
Taper	*Ratio:*	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.08	0.38	0.47	0.05
Corrected	(in.)	0.00	0.06	0.36	0.45	0.00
Corrected	(mm)	0.0	1.4	9.3	11.4	0.0
OS/D				0.12		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1750	3.93	5.93	1.51

Compression and Tension Zones

C (in.)	1.02	C/D	0.35
T(in.)	0.82	T/D	0.28
D(in.)	2.91		

Location of Fracture from Butt End(mm) 1241.43 mm

Twist (Degrees CCW or CW) 2 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P21A

Max Load (Lbf)=	1264.08	(kN) =	5.62

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.2	220.5	300.2	120.3	
12.08	0.00	0.00	0	0	0	0	0	0.00
12.27	0.19	261.06	0	0	1	1	1	0.85
12.26	0.18	247.32	1	0	1	1	1	0.85
12.70	0.62	851.88	0	2	4	4	3	1.91
12.66	0.58	796.92	1	2	4	4	3	1.91
12.99	0.91	1250.34	0	12	19	20	18	2.87
12.96	0.88	1209.12	1	12	19	20	18	2.87
13.00	0.92	1264.08	0	22	34	35	30	4.09
12.99	0.91	1250.34	1	22	34	35	30	4.09
12.98	0.90	1236.60	0	32	50	51	43	5.89
12.97	0.89	1222.86	1	32	50	51	43	5.89
12.94	0.86	1181.64	0	42	65	66	56	8.28
12.93	0.85	1167.90	1	42	65	66	56	8.28
12.90	0.82	1126.68	0	52	80	80	68	10.85
12.88	0.80	1099.20	1	52	80	80	68	10.85
12.84	0.76	1044.24	0	60	100	92	78	13.49
12.82	0.74	1016.76	1	60	100	92	78	13.49
12.78	0.70	961.80	0	64	101	102	87	16.15
12.75	0.67	920.58	1	64	101	102	87	16.15
12.73	0.65	893.10	0	72	110	112	97	18.73
12.70	0.62	851.88	1	72	110	112	97	18.73
12.67	0.59	810.66	0	74	119	122	103	21.37
12.64	0.56	769.44	1	74	119	122	103	21.37
12.62	0.54	741.96	0	80	125	130	113	23.91
12.59	0.51	700.74	1	80	125	130	113	23.91
12.57	0.49	673.26	0	82	130	136	118	25.84
12.55	0.47	645.78	1	82	130	136	118	25.84
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P21A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	1.98	2.12	2.55	4.54	3.87	5.99
L/4	1.97		2.63	4.60	4.10	6.17
L/2	1.74		2.67	4.41	4.01	6.86
3L/4	1.56		2.87	4.44	4.20	5.84
L	1.39	1.54	2.81	4.20	4.28	5.82
Mean	1.73	1.83				
Taper	***Ratio:***	0.71	See Note 2	1-TR=	0.29	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.12	0.04	0.16	0.01
Corrected	(in.)	0.00	0.09	0.02	0.13	0.00
Corrected	(mm)	0.0	2.4	0.4	3.3	0.0
OS/D				0.01		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.9670	0.45	1.07	2.37

Compression and Tension Zones

C (in.)	0.00	C/D	0.00
T(in.)	0.00	T/D	0.00
D(in.)	**********		

Note: At a lateral deflection of 136 mm specimen split at top end.

Location of Fracture from Butt End(mm) ********** mm

Twist (Degrees CCW or CW) 1/2 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P22A

Max Load (Lbf)=	2830.44	(kN) =	12.59

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				39.7	219.2	298.7	119.5	
11.45	0.00	0.00	0	0	0	0	0	0.00
11.58	0.13	178.62	0	0	0	0	0	0.00
11.57	0.12	164.88	1	0	0	0	0	0.00
12.02	0.57	783.18	0	2	4	2	3	1.37
11.99	0.54	741.96	1	2	4	2	3	1.37
12.78	1.33	1827.42	0	9	12	11	10	2.57
12.73	1.28	1758.72	1	9	12	11	10	2.57
13.29	1.84	2528.16	0	17	26	23	20	3.99
13.25	1.80	2473.20	1	17	26	23	20	3.99
13.51	2.06	2830.44	0	27	39	35	30	5.54
13.39	1.94	2665.56	1	27	39	35	30	5.54
13.50	2.05	2816.70	0	37	56	52	43	8.00
13.24	1.79	2459.46	1	37	56	52	43	8.00
13.36	1.91	2624.34	0	47	72	69	56	11.25
13.08	1.63	2239.62	1	47	72	69	56	11.25
13.10	1.65	2267.10	0	65	100	97	79	17.91
12.75	1.30	1786.20	1	65	100	97	79	17.91
12.80	1.35	1854.90	0	77	122	122	98	17.91
12.51	1.06	1456.44	1	77	122	122	98	24.89
12.54	1.09	1497.66	0	89	147	152	122	24.89
12.30	0.85	1167.90	1	89	147	152	122	************
12.24	0.79	1085.46	0	102	176	191	153	************
12.05	0.60	824.40	1	102	176	191	153	************
12.00	0.55	755.70	0	107	187	204	165	************
11.90	0.45	618.30	1	107	187	204	165	************
11.86	0.41	563.34	0	107	196	225	183	66.68
11.64	0.19	261.06	1	107	196	225	183	66.68
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P22A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.82	2.72	2.20	5.02	3.55	6.27
L/4	2.59		2.94	5.54	3.94	6.49
L/2	2.58		2.88	5.45	3.99	6.44
3L/4	2.18		2.64	4.82	3.38	5.75
L	2.02	2.04	2.46	4.49	3.97	6.01
Mean	2.44	2.38				
Taper	*Ratio:*	0.73	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.11	0.74	0.66	0.22	-0.03
Corrected	(in.)	0.00	0.70	0.62	0.18	0.00
Corrected	(mm)	0.0	17.7	15.8	4.7	0.0

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.3545	2.16	2.93	1.36

Compression and Tension Zones

C (in.)	1.08	C/D	0.48
T(in.)	0.70	T/D	0.31
D(in.)	2.27		

Location of Fracture from Butt End(mm) 1419.23 mm

Twist (Degrees CCW or CW) 2.5 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P22B

Max Load (Lbf)=	4863.96	(kN) =	21.64

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	218.8	297.5	117.6	
11.72	0.00	0.00	0	0	0	0	0	0.00
11.95	0.23	316.02	0	0	2	3	1	************
11.95	0.23	316.02	1	0	2	3	1	************
12.80	1.08	1483.92	0	3	6	8	6	************
12.75	1.03	1415.22	1	3	6	8	6	************
13.69	1.97	2706.78	0	6	12	14	10	************
13.63	1.91	2624.34	1	6	12	14	10	************
14.91	3.19	4383.06	0	15	26	29	23	************
14.72	3.00	4122.00	1	15	26	29	23	************
15.26	3.54	4863.96	0	24	41	45	35	8.73
14.65	2.93	4025.82	1	24	41	45	35	8.73
14.98	3.26	4479.24	0	34	58	65	51	************
14.18	2.46	3380.04	1	34	58	65	51	************
14.41	2.69	3696.06	0	45	78	89	68	17.46
13.70	1.98	2720.52	1	45	78	89	68	17.46
13.89	2.17	2981.58	0	53	93	109	81	************
13.32	1.60	2198.40	1	53	93	109	81	************
13.30	1.58	2170.92	0	60	108	132	94	************
12.82	1.10	1511.40	1	60	108	132	94	************
12.85	1.13	1552.62	0	70	121	155	108	************
12.52	0.80	1099.20	1	70	121	155	108	************
12.18	0.46	632.04	0	80	148	187	129	49.21
12.05	0.33	453.42	1	80	148	187	129	49.21
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P22B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.11	3.38	1.89	5.00	3.32	6.70
L/4	3.19		2.55	5.74	3.04	6.23
L/2	3.16		2.74	5.90	3.28	6.33
3L/4	2.74		3.13	5.88	3.90	6.59
L	2.68	2.90	2.17	4.84	3.58	6.48
Mean	2.97	3.14				
Taper	***Ratio:***	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.06	0.64	0.82	1.00	0.01
Corrected	(in.)	0.00	0.67	0.84	1.03	0.00
Corrected	(mm)	0.0	17.0	21.4	26.2	0.0
OS/D				0.27		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.1505	4.90	6.89	1.41

Compression and Tension Zones

C (in.)	1.01	C/D	0.36
T(in.)	0.50	T/D	0.18
D(in.)	2.82		

Location of Fracture from Butt End(mm) 1343.03 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P23A

Max Load (Lbf)=	4231.92	(kN) =	18.82

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.3	219.6	299.3	119.6	
11.58	0.00	0.00	0	0	0	0	0	0.00
11.92	0.34	467.16	0	0	0	0	0	************
11.88	0.30	412.20	1	0	0	0	0	************
13.42	1.84	2528.16	0	3	5	6	4	************
13.26	1.68	2308.32	1	3	5	6	4	************
14.29	2.71	3723.54	0	8	14	15	11	1.59
14.18	2.60	3572.40	1	8	14	15	11	1.59
14.66	3.08	4231.92	0	23	33	33	26	3.18
14.42	2.84	3902.16	1	23	33	33	26	3.18
14.47	2.89	3970.86	0	33	50	50	40	************
13.95	2.37	3256.38	1	33	50	50	40	************
14.00	2.42	3325.08	0	43	66	68	53	7.94
13.52	1.94	2665.56	1	43	66	68	53	7.94
13.51	1.93	2651.82	0	58	94	96	75	14.29
13.07	1.49	2047.26	1	58	94	96	75	14.29
12.86	1.28	1758.72	0	78	134	138	106	26.99
12.62	1.04	1428.96	1	78	134	138	106	26.23
12.60	1.02	1401.48	0	90	155	160	123	34.93
12.46	0.88	1209.12	1	90	155	160	123	34.93
12.43	0.85	1167.90	0	103	179	187	138	************
12.30	0.72	989.28	1	103	179	187	138	************
12.28	0.70	961.80	0	110	196	203	150	************
12.16	0.58	796.92	1	110	196	203	150	************
12.07	0.49	673.26	0	126	236	237	173	************
11.95	0.37	508.38	1	126	236	237	173	************
11.96	0.38	522.12	0	135	250	253	186	85.73
11.87	0.29	398.46	1	135	250	253	186	85.73
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P23A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.69	2.78	2.19	4.87	3.63	6.41
L/4	2.58		2.50	5.09	4.06	6.82
L/2	2.58		2.52	5.11	3.99	6.59
3L/4	2.52		2.54	5.07	3.72	6.32
L	2.27	2.37	2.38	4.65	3.84	6.21
Mean	2.53	2.58				
Taper	*Ratio:*	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.03	0.29	0.31	0.30	0.02
Corrected	(in.)	0.00	0.27	0.29	0.28	0.00
Corrected	(mm)	0.0	6.9	7.4	7.1	0.0
OS/D				0.11		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2700	2.18	3.84	1.76

Compression and Tension Zones

C (in.)	1.20	C/D	0.48
T(in.)	0.43	T/D	0.17
D(in.)	2.51		

Location of Fracture from Butt End(mm) 1206.50 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data *Specimen No.* P23B

Max Load (Lbf)=	11857.62	(kN) =	52.75

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	220.1	300.0	120.3	
12.12	0.00	0.00	0	0	0	0	0	0.00
12.13	0.01	13.74	0	0	0	0	0	************
12.55	0.43	590.82	0	0	0	0	0	************
12.51	0.39	535.86	1	0	0	0	0	************
13.45	1.33	1827.42	0	0	0	0	0	************
13.36	1.24	1703.76	1	0	0	0	0	************
15.82	3.70	5083.80	0	2	4	4	2	************
15.59	3.47	4767.78	1	2	4	4	2	************
18.03	5.91	8120.34	0	5	9	9	7	************
17.81	5.69	7818.06	1	5	9	9	7	************
19.94	7.82	10744.68	0	11	16	16	12	************
19.65	7.53	10346.22	1	11	16	16	12	************
20.75	8.63	11857.62	0	22	33	30	23	7.94
19.72	7.60	10442.40	1	22	33	30	23	7.94
19.30	7.18	9865.32	0	35	54	50	38	************
18.18	6.06	8326.44	1	35	54	50	38	************
18.49	6.37	8752.38	0	45	71	68	49	************
17.15	5.03	6911.22	1	45	71	68	49	************
17.35	5.23	7186.02	0	55	90	87	62	************
16.30	4.18	5743.32	1	55	90	87	62	************
16.58	4.46	6128.04	0	65	109	105	73	17.46
15.67	3.55	4877.70	1	65	109	105	73	17.46
15.83	3.71	5097.54	0	75	132	127	90	************
15.06	2.94	4039.56	1	75	132	127	90	************
15.26	3.14	4314.36	0	89	159	153	108	************
14.56	2.44	3352.56	1	89	159	153	108	************
14.73	2.61	3586.14	0	100	179	169	118	************
14.11	1.99	2734.26	1	100	179	169	118	************
14.36	2.24	3077.76	0	110	201	189	131	************
13.81	1.69	2322.06	1	110	201	189	131	************
13.92	1.80	2473.20	0	123	229	215	151	************
13.54	1.42	1951.08	1	123	229	215	151	************
13.65	1.53	2102.22	0	135	249	235	161	73.03
13.28	1.16	1593.84	1	135	249	235	161	73.03
13.48	1.36	1868.64	0	144	266	250	173	************
13.11	0.99	1360.26	1	144	266	250	173	************
**********	**********	**************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P23B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.09	3.11	2.05	5.13	3.45	6.56
L/4	3.03		2.17	5.21	3.47	6.63
L/2	2.96		2.33	5.29	3.55	6.61
3L/4	3.08		2.04	5.12	3.50	6.56
L	2.70	2.84	2.17	4.87	3.59	6.43
Mean	2.97	2.98				
Taper	***Ratio:***	0.89	See Note 2	1-TR=	0.11	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.19	0.31	0.08	0.02
Corrected	(in.)	0.00	0.13	0.26	0.03	0.00
Corrected	(mm)	0.0	3.4	6.5	0.6	0.0
OS/D				0.09		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1528	3.78	6.79	1.79

Compression and Tension Zones

C (in.)	1.19	C/D	0.40
T(in.)	0.44	T/D	0.15
D(in.)	2.98		

Location of Fracture from Butt End(mm) 1054.10 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* **P24B**

Max Load (Lbf)=	**6608.94**	**(kN) =**	29.40

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.3	220.2	301.0	120.0	
12.04	0.00	0.00	0	0	0	0	0	0.00
13.04	1.00	1374.00	0	0	0	0	0	************
12.92	0.88	1209.12	1	0	0	0	0	************
14.98	2.94	4039.56	0	1	2	24	5	************
14.80	2.76	3792.24	1	1	2	24	5	************
16.85	4.81	6608.94	0	10	15	25	14	************
16.51	4.47	6141.78	1	10	15	25	14	************
16.70	4.66	6402.84	0	23	40	50	35	7.94
15.27	3.23	4438.02	1	23	40	50	35	7.94
15.30	3.26	4479.24	0	35	61	74	54	************
14.44	2.40	3297.60	1	35	61	74	54	************
14.65	2.61	3586.14	0	43	79	94	68	************
13.86	1.82	2500.68	1	43	79	94	68	************
14.06	2.02	2775.48	0	51	92	112	85	************
13.25	1.21	1662.54	1	51	92	112	85	************
14.42	2.38	3270.12	0	57	110	137	105	************
12.73	0.69	948.06	1	57	110	137	105	************
12.93	0.89	1222.86	0	70	131	168	130	38.10
12.32	0.28	384.72	1	70	131	168	130	38.10
12.47	0.43	590.82	0	78	152	195	155	************
12.10	0.06	82.44	1	78	152	195	155	************
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P24B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.21	3.20	1.95	5.16	3.47	6.67
L/4	3.22		2.20	5.41	3.23	6.41
L/2	3.10		2.17	5.27	3.42	6.43
3L/4	2.90		2.21	5.11	3.66	6.49
L	2.73	2.63	2.15	4.88	3.66	6.30
Mean	3.03	2.92				
Taper	*Ratio:*	0.84	See Note 2	1-TR=	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.30	0.22	0.16	0.01
Corrected	(in.)	0.00	0.27	0.18	0.13	0.00
Corrected	(mm)	0.0	6.8	4.6	3.2	0.0
OS/D				0.06		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1510	4.56	6.87	1.51

Compression and Tension Zones

C (in.)	1.42	C/D	0.50
T(in.)	1.03	T/D	0.36
D(in.)	2.83		

Location of Fracture from Butt End(mm) 1397.00 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P25A

Max Load (Lbf)=	3970.86	(kN) =	17.66

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.7	220.4	299.6	119.3	
11.99	0.00	0.00	0	0	0	0	0	0.00
12.41	0.42	577.08	0	0	0	0	0	************
12.35	0.36	494.64	1	0	0	0	0	************
14.10	2.11	2899.14	0	5	12	4	2	************
13.83	1.84	2528.16	1	5	12	4	2	************
14.69	2.70	3709.80	0	11	16	14	8	************
14.51	2.52	3462.48	1	11	16	14	8	************
14.88	2.89	3970.86	0	25	38	36	25	************
14.26	2.27	3118.98	1	25	38	36	25	************
14.31	2.32	3187.68	0	35	57	56	42	************
13.77	1.78	2445.72	1	35	57	56	42	************
13.80	1.81	2486.94	0	45	74	76	59	************
13.40	1.41	1937.34	1	45	74	76	59	************
13.45	1.46	2006.04	0	56	94	101	79	17.46
13.05	1.06	1456.44	1	56	94	101	79	17.46
13.10	1.11	1525.14	0	65	119	144	108	************
12.10	0.11	151.14	1	65	119	144	108	************
12.06	0.07	96.18	0	79	154	184	138	28.58
12.02	0.03	41.22	1	79	154	184	138	28.58
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P25A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.00	3.13	2.02	5.02	3.41	6.54
L/4	2.79		2.34	5.14	3.43	6.52
L/2	2.79		2.32	5.11	3.49	6.43
3L/4	2.48		2.47	4.95	3.66	6.40
L	2.15	2.38	2.42	4.58	3.81	6.18
Mean	2.64	2.75				
Taper	*Ratio:*	0.74	See Note 2	1-TR=	0.26	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.02	0.24	0.22	0.21	0.00
Corrected	(in.)	0.00	0.23	0.21	0.20	0.00
Corrected	(mm)	0.0	5.9	5.2	5.0	0.0
OS/D				0.07		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2442	2.96	4.25	1.44

Compression and Tension Zones

C (in.)	1.06	C/D	0.44
T(in.)	1.44	T/D	0.59
D(in.)	2.43		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P25B

Max Load (Lbf)=	12956.82	(kN) =	57.63

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				42.7	220.7	300.2	120.2	
11.72	0.00	0.00	0	0	0	0	0	0.00
13.65	1.93	2651.82	0	0	0	0	0	************
13.52	1.80	2473.20	1	0	0	0	0	************
16.57	4.85	6663.90	0	0	0	0	0	************
16.27	4.55	6251.70	1	0	0	0	0	************
19.10	7.38	10140.12	0	0	0	0	0	************
18.22	6.50	8931.00	1	0	0	0	0	************
21.15	9.43	12956.82	0	0	3	4	2	6.35
19.34	7.62	10469.88	1	0	3	4	2	6.35
20.71	8.99	12352.26	0	15	30	30	22	************
17.96	6.24	8573.76	1	15	30	30	22	************
18.44	6.72	9233.28	0	27	51	52	39	7.94
16.19	4.47	6141.78	1	27	51	52	39	7.94
16.71	4.99	6856.26	0	37	66	67	50	************
15.51	3.79	5207.46	1	37	66	67	50	************
16.03	4.31	5921.94	0	45	79	81	60	************
14.66	2.94	4039.56	1	45	79	81	60	************
15.00	3.28	4506.72	0	49	95	99	70	18.26
13.67	1.95	2679.30	1	49	95	99	70	18.26
13.18	1.46	2006.04	0	67	127	136	91	************
12.08	0.36	494.64	1	67	127	136	91	************
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P25B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.55	3.56	1.73	5.28	3.38	6.94
L/4	3.60		2.23	5.84	3.22	6.73
L/2	3.51		1.70	5.21	3.35	6.90
3L/4	3.36		1.55	4.91	3.49	6.65
L	3.08	3.19	1.93	5.02	3.55	6.74
Mean	3.42	3.37				
Taper	*Ratio:*	0.88	See Note 2	1-TR=	0.12	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.00	0.53	-0.04	-0.27	-0.03
Corrected	(in.)	0.00	0.55	-0.03	-0.26	0.00
Corrected	(mm)	0.0	13.8	-0.8	-6.7	0.0
OS/D				-0.01		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
73	1	0.1360	7.44	10.12	1.36

Compression and Tension Zones

C (in.)	0.48	C/D	0.14
T(in.)	0.22	T/D	0.07
D(in.)	3.33		

Location of Fracture from Butt End(mm) 1266.83 mm

Twist (Degrees CCW or CW) n.a.

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data Specimen No. P27A

Max Load (Lbf)=	1992.30	(kN) =	8.86

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	218.6	298.2	118.3	
11.13	0.00	0.00	0	0	0	0	0	0.00
11.33	0.20	274.80	0	3	4	2	3	0.66
11.33	0.20	274.80	1	3	4	2	3	0.66
11.67	0.54	741.96	0	8	11	11	9	1.75
11.65	0.52	714.48	1	8	11	11	9	1.75
11.96	0.83	1140.42	0	15	22	21	17	3.18
11.94	0.81	1112.94	1	15	22	21	17	3.18
12.16	1.03	1415.22	0	22	34	32	27	4.70
12.14	1.01	1387.74	1	22	34	32	27	4.70
12.27	1.14	1566.36	0	27	40	40	33	6.01
12.26	1.13	1552.62	1	27	40	40	33	6.01
12.39	1.26	1731.24	0	34	50	50	41	7.82
12.37	1.24	1703.76	1	34	50	50	41	7.82
12.51	1.38	1896.12	0	42	66	65	53	10.92
12.48	1.35	1854.90	1	42	66	65	53	10.92
12.58	1.45	1992.30	0	50	79	77	63	13.97
12.52	1.39	1909.86	1	50	79	77	63	13.97
12.58	1.45	1992.30	0	60	91	90	73	17.39
12.52	1.39	1909.86	1	60	91	90	73	17.39
12.53	1.40	1923.60	0	62	98	96	79	19.22
12.47	1.34	1841.16	1	62	98	96	79	19.22
12.51	1.38	1896.12	0	68	110	110	90	23.03
12.28	1.15	1580.10	1	68	110	110	90	23.03
12.31	1.18	1621.32	0	71	120	121	98	25.88
12.08	0.95	1305.30	1	71	120	121	98	25.88
12.08	0.95	1305.30	0	80	136	138	109	31.75
11.91	0.78	1071.72	1	80	136	138	109	31.75
11.89	0.76	1044.24	0	87	155	156	121	38.10
11.64	0.51	700.74	1	87	155	156	121	38.10
11.40	0.27	370.98	0	92	176	190	138	46.83
11.29	0.16	219.84	1	92	176	190	138	46.83
***********	********		********	*********	**********	*********	*********	********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P27A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.28	2.43	2.57	4.85	3.81	6.25
L/4	2.16		3.03	5.19	4.30	6.31
L/2	2.09		3.27	5.36	4.31	5.70
3L/4	2.00		3.34	5.34	4.38	5.88
L	1.80	1.93	2.62	4.42	4.07	6.00
Mean	2.07	2.18				
Taper	***Ratio:***	0.79	See Note	1-TR=	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.21	0.61	0.81	0.84	0.02
Corrected	(in.)	0.00	0.49	0.70	0.73	0.00
Corr (mm)		0.0	12.6	17.8	18.6	0.0
OS/D				0.33		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.5250	0.94	1.98	2.10

Compression and Tension Zones

C (in.)	0.41	C/D	0.20
T(in.)	0.81	T/D	0.39
D(in.)	2.08		

Location of Fracture from Butt End(mm) 1241.43 mm

Twist (Degrees CCW or CW) 2.5 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 v
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data

Specimen No. **P27B**

Max Load (Lbf)=	6581.46	(kN) =	29.28

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Delta Platen
				L/4	L/2	5L/8	3L/4	
				39.1	220.1	299.2	120.7	(mm)
11.42	0.00	0.00	0	0	0	0	0	0.00
11.68	0.26	357.24	0	0	0	0	0	0.69
11.66	0.24	329.76	1	0	0	0	0	0.69
12.44	1.02	1401.48	0	2	2	0	2	1.31
12.35	0.93	1277.82	1	2	2	0	2	1.31
13.23	1.81	2486.94	0	4	5	0	4	1.75
13.13	1.71	2349.54	1	4	5	0	4	1.75
14.11	2.69	3696.06	0	6	8	2	7	2.21
13.97	2.55	3503.70	1	6	8	2	7	2.21
14.95	3.53	4850.22	0	11	14	9	12	2.79
14.80	3.38	4644.12	1	11	14	9	12	2.79
15.58	4.16	5715.84	0	17	21	17	17	3.52
15.48	4.06	5578.44	1	17	21	17	17	3.52
16.00	4.58	6292.92	0	24	33	26	24	4.53
15.83	4.41	6059.34	1	24	33	26	24	4.53
16.13	4.71	6471.54	0	29	41	33	31	5.52
15.96	4.54	6237.96	1	29	41	33	31	5.52
16.21	4.79	6581.46	0	38	51	42	37	6.88
15.92	4.50	6183.00	1	38	51	42	37	6.88
16.10	4.68	6430.32	0	46	63	54	46	8.64
15.63	4.21	5784.54	1	46	63	54	46	8.64
15.77	4.35	5976.90	0	51	71	62	52	10.25
15.35	3.93	5399.82	1	51	71	62	52	10.25
15.48	4.06	5578.44	0	56	82	72	60	12.22
15.04	3.62	4973.88	1	56	82	72	60	12.22
15.17	3.75	5152.50	0	63	92	82	67	14.58
14.76	3.34	4589.16	1	63	92	82	67	14.58
14.91	3.49	4795.26	0	66	101	91	75	16.56
14.53	3.11	4273.14	1	66	101	91	75	16.56
14.68	3.26	4479.24	0	72	111	102	82	19.42
14.26	2.84	3902.16	1	72	111	102	82	19.42
14.41	2.99	4108.26	0	79	126	117	93	22.68
13.50	2.08	2857.92	1	79	126	117	93	21.31
13.62	2.20	3022.80	0	83	134	125	99	25.04
13.40	1.98	2720.52	1	83	134	125	99	25.04
13.01	1.59	2184.66	0	83	139	130	100	**********
12.68	1.26	1731.24	1	83	139	130	100	**********
13.06	1.64	2253.36	0	87	165	157	115	30.16
11.63	0.21	288.54	1	87	165	157	115	30.16
**********	**********	**************	**********	**********	**********	**********	**********	**********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P27B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.87	2.86	2.15	5.01	3.55	6.41
L/4	2.88		2.67	5.56	3.78	6.52
L/2	2.89		2.17	5.05	3.75	6.48
3L/4	2.67		2.31	4.98	3.52	6.27
L	2.36	2.44	2.28	4.64	3.76	6.20
Mean	2.73	2.65				
Taper	*Ratio:*	0.84	See Note 2	1-TR=	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.08	0.62	0.11	0.14	-0.04
Corrected	(in.)	0.00	0.59	0.09	0.12	0.00
Corr (mm		0.0	15.1	2.3	3.1	0.0
OS/D				0.03		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1880	3.41	5.52	1.62

Compression and Tension Zones

C (in.)	0.91	C/D	0.32
T(in.)	0.87	T/D	0.30
D(in.)	2.88		

Location of Fracture from Butt End(mm) 1181.10 mm

Twist (Degrees CCW or CW) 5 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P28A

Max Load (Lbf)=	4465.50	(kN) =	19.86

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.6	220.0	299.5	120.2	
11.43	0.00	0.00	0	0	0	0	0	0.00
11.78	0.35	480.90	0	0	0	0	0	0.86
11.75	0.32	439.68	1	1	0	0	0	0.86
12.98	1.55	2129.70	0	1	2	3	2	1.68
12.88	1.45	1992.30	1	1	2	3	2	1.68
13.82	2.39	3283.86	0	4	7	8	6	2.26
13.73	2.30	3160.20	1	4	7	8	6	2.26
14.30	2.87	3943.38	0	8	14	15	12	2.86
14.23	2.80	3847.20	1	8	14	15	12	2.86
14.63	3.20	4396.80	0	16	25	25	20	3.71
14.51	3.08	4231.92	1	16	25	25	20	3.71
14.68	3.25	4465.50	0	24	39	39	30	4.94
14.48	3.05	4190.70	1	24	39	39	30	4.94
14.52	3.09	4245.66	0	33	52	52	41	6.71
14.18	2.75	3778.50	1	33	52	52	41	6.71
14.24	2.81	3860.94	0	40	64	57	49	8.36
13.95	2.52	3462.48	1	40	64	57	49	8.36
13.94	2.51	3448.74	0	45	79	70	55	10.06
13.68	2.25	3091.50	1	45	79	70	55	10.06
13.66	2.23	3064.02	0	49	83	78	61	11.75
13.44	2.01	2761.74	1	49	83	78	61	11.75
13.42	1.99	2734.26	0	55	93	86	65	13.86
13.23	1.80	2473.20	1	55	93	86	65	13.86
12.44	1.01	1387.74	0	65	128	104	68	18.35
11.56	0.13	178.62	1	65	128	104	68	18.35
11.59	0.16	219.84	0	71	139	113	75	20.92
11.57	0.14	192.36	1	71	139	113	75	20.92
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P28A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.68	2.77	2.20	4.88	3.69	6.46
L/4	2.66		2.09	4.75	3.73	6.30
L/2	2.49		2.59	5.08	3.72	6.20
3L/4	2.28		2.56	4.84	4.14	6.43
L	2.09	2.22	2.40	4.49	3.86	6.08
Mean	2.44	2.49				
Taper	***Ratio:***	0.79	See Note 2	1-TR=	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	-0.08	0.34	0.20	-0.05
Corrected	(in.)	0.00	-0.07	0.34	0.21	0.00
Corrected	(mm)	0.0	-1.9	8.7	5.2	0.0
OS/D				0.14		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2660	1.87	3.90	2.08

Compression and Tension Zones

C (in.)	0.64	C/D	0.26
T(in.)	1.20	T/D	0.49
D(in.)	2.43		

Location of Fracture from Butt End(mm) 1092.20 mm

Twist (Degrees CCW or CW) 4 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* 28B

Max Load (Lbf)=	9508.08	(kN) =	42.29

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				39.3	219.1	299.0	119.6	
11.26	0.00	0.00	0	0	0	0	0	0.00
11.57	0.31	425.94	0	0	0	0	0	0.99
11.54	0.28	384.72	1	0	0	0	0	0.99
12.14	0.88	1209.12	0	2	1	2	1	1.70
12.08	0.82	1126.68	1	2	1	2	1	1.70
13.61	2.35	3228.90	0	5	5	5	3	2.47
13.52	2.26	3105.24	1	5	5	5	3	2.47
15.34	4.08	5605.92	0	10	11	10	6	3.23
15.22	3.96	5441.04	1	10	11	10	6	3.23
16.89	5.63	7735.62	0	15	20	20	11	4.11
16.70	5.44	7474.56	1	15	20	20	11	4.11
17.58	6.32	8683.68	0	21	28	27	18	4.88
18.14	6.88	9453.12	1	21	28	27	18	4.88
17.76	6.50	8931.00	0	29	39	38	26	6.12
18.18	6.92	9508.08	1	29	39	38	26	6.12
17.28	6.02	8271.48	0	39	53	48	35	7.80
17.56	6.30	8656.20	1	39	53	48	35	7.80
16.71	5.45	7488.30	0	48	65	58	42	9.68
16.94	5.68	7804.32	1	48	65	58	42	9.68
16.21	4.95	6801.30	0	54	75	66	48	11.56
16.40	5.14	7062.36	1	54	75	66	48	11.56
15.80	4.54	6237.96	0	61	84	74	53	13.39
15.94	4.68	6430.32	1	61	84	74	53	13.39
*********	*********	**********	*********	*********	*********	**********	*********	***********

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No 28B

Location	Vertical (in)	End Dia (in) Note	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.33	3.41	1.92	5.25	3.29	6.70
L/4	3.26		2.44	5.70	3.43	6.74
L/2	3.13		2.53	5.66	3.42	6.61
3L/4	2.92		2.34	5.26	3.48	6.51
L	2.73	2.83	2.16	4.90	3.68	6.51
Mean	3.07	3.12				
Taper	Ratio:	0.83	See Note	1-TR=	0.17431	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.08	0.57	0.59	0.30	0.03
Corrected	(in.)	0.00	0.51	0.53	0.24	0.00
Corrected	(mm)	0.0	13.0	13.6	6.2	0.0
OS/D				0.17		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.1158	4.71	8.96	1.90

Compression and Tension Zones

C (in.)	0.52	C/D	0.17
T(in.)	2.05	T/D	0.67
D(in.)	3.06		

Location of Fracture from Butt End(mm) 965.2 mm

Twist (Degrees CCW or CW) 10 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data Specimen No. P33A

Max Load (Lbf)=	1126.68	(kN) =	5.01

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.1	218.7	298.8	119.5	
11.18	0.00	0.00	0	0	0	0	0	0.00
11.50	0.32	439.68	0	5	9	8	8	1.02
11.49	0.31	425.94	1	5	9	8	8	1.02
11.70	0.52	714.48	0	11	17	18	15	1.91
11.69	0.51	700.74	1	11	17	18	15	1.91
11.88	0.70	961.80	0	17	27	28	25	3.25
11.87	0.69	948.06	1	17	27	28	25	3.25
11.97	0.79	1085.46	0	24	37	38	33	4.53
11.95	0.77	1057.98	1	24	37	38	33	4.53
12.00	0.82	1126.68	0	30	46	47	49	5.85
11.97	0.79	1085.46	1	30	46	47	49	5.85
11.99	0.81	1112.94	0	36	57	58	49	7.84
11.93	0.75	1030.50	1	36	57	58	49	7.84
11.95	0.77	1057.98	0	41	67	67	58	9.83
11.89	0.71	975.54	1	41	67	67	58	9.83
11.92	0.74	1016.76	0	46	77	79	68	12.64
11.83	0.65	893.10	1	46	77	79	68	12.64
11.86	0.68	934.32	0	51	86	88	75	15.12
11.80	0.62	851.88	1	51	86	88	75	15.12
11.81	0.63	865.62	0	56	95	98	83	17.67
11.76	0.58	796.92	1	56	95	98	83	17.67
11.75	0.57	783.18	0	60	101	108	91	20.19
11.73	0.55	755.70	1	60	101	108	91	20.19
11.74	0.56	769.44	0	63	110	116	97	22.74
11.69	0.51	700.74	1	63	110	116	97	22.74
11.70	0.52	714.48	0	66	117	123	104	25.40
11.66	0.48	659.52	1	66	117	123	104	25.40
11.65	0.47	645.78	0	76	135	143	121	31.75
11.59	0.41	563.34	1	76	135	143	121	31.75
11.56	0.38	522.12	0	100	177	198	170	56.36
11.49	0.31	425.94	1	100	177	198	170	56.36
11.46	0.28	384.72	0	129	237	273	228	101.60
11.36	0.18	247.32	1	29	237	273	228	101.60
11.35	0.17	233.58	0	139	257	308	254	125.41
11.33	0.15	206.10	1	139	257	308	254	125.41

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P33A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.28	2.21	2.53	4.81	3.99	6.20
L/4	2.24		2.80	5.03	3.97	6.04
L/2	1.93		3.19	5.12	4.02	5.72
3L/4	1.74		3.05	4.80	4.02	5.74
L	1.52	1.54	2.76	4.28	4.26	5.79
Mean	1.94	1.88				
Taper	***Ratio:***	0.68	See Note 2	1-TR=	0.32	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.17	0.41	0.65	0.43	0.02
Correcte	(in.)	0.00	0.32	0.56	0.33	0.00
Corr (mn		0.0	8.1	14.2	8.5	0.0
OS/D				0.29		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.8540	0.68	1.21	1.80

Compression and Tension Zones

C (in.)	0.78	C/D	0.44
T(in.)	0.17	T/D	0.10
D(in.)	1.75		

Location of Fracture from Butt End(mm) 1444.63 mm

Twist (Degrees CCW or CW) 6 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   Specimen No P33B

Max Load (Lbf)=	5605.92	(kN) =	24.94

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	220.2	300.1	120.7	
11.15	0.00	0.00	0	0	0	0	0	0.00
12.01	0.86	1181.64	0	1	1	1	1	1.09
11.96	0.81	1112.94	1	1	1	1	1	1.09
13.15	2.00	2748.00	0	4	3	2	2	1.75
13.10	1.95	2679.30	1	4	3	2	2	1.75
14.51	3.36	4616.64	0	10	12	10	7	2.59
14.46	3.31	4547.94	1	10	12	10	7	2.59
15.09	3.94	5413.56	0	18	24	22	17	3.49
15.04	3.89	5344.86	1	18	24	22	17	3.49
15.23	4.08	5605.92	0	25	33	31	25	4.37
15.00	3.85	5289.90	1	25	33	31	25	4.37
15.01	3.86	5303.64	0	35	49	47	37	6.12
14.48	3.33	4575.42	1	35	49	47	37	6.12
14.49	3.34	4589.16	0	42	62	61	47	8.15
14.05	2.90	3984.60	1	42	62	61	47	8.15
14.02	2.87	3943.38	0	50	77	75	57	10.62
13.65	2.50	3435.00	1	50	77	75	57	10.62
13.62	2.47	3393.78	0	55	87	86	67	13.37
13.28	2.13	2926.62	1	55	87	86	67	13.37
13.30	2.15	2954.10	0	60	97	97	74	15.86
13.07	1.92	2638.08	1	60	97	97	74	15.86
13.08	1.93	2651.82	0	65	107	106	81	18.54
12.91	1.76	2418.24	1	65	107	106	81	18.54
12.90	1.75	2404.50	0	70	117	116	87	21.45
12.75	1.60	2198.40	1	70	117	116	87	21.45
12.73	1.58	2170.92	0	75	126	125	92	24.04
12.61	1.46	2006.04	1	75	126	125	92	24.04
12.59	1.44	1978.56	0	76	131	130	97	25.84
12.51	1.36	1868.64	1	76	131	130	97	25.84
12.48	1.33	1827.42	0	88	155	156	115	33.34
12.13	0.98	1346.52	1	88	155	156	115	33.34
12.08	0.93	1277.82	0	95	177	178	129	42.07
11.81	0.66	906.84	1	95	177	178	129	42.07
11.47	0.32	439.68	0	114	214	216	152	59.53
11.41	0.26	357.24	1	114	214	216	152	59.53

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No **P33B**

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.84	2.77	2.22	5.05	3.56	6.34
L/4	2.79		2.57	5.36	3.68	6.39
L/2	2.67		2.41	5.07	3.66	6.30
3L/4	2.55		2.23	4.78	3.63	6.15
L	2.29	2.28	2.26	4.55	3.87	6.14
Mean	2.63	2.53				
Taper	*Ratio:*	0.81	See Note 2	1-TR=	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.14	0.46	0.24	0.01	-0.09
Corrected	(in.)	0.00	0.44	0.22	-0.02	0.00
Corr (mm)		0.0	11.2	5.5	-0.4	0.0
OS/D				0.08		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.2511	2.49	4.13	1.66

Compression and Tension Zones

C (in.)	1.17	C/D	0.46
T(in.)	0.70	T/D	0.27
D(in.)	2.57		

Location of Fracture from Butt End(mm) 1203.33 mm

Twist (Degrees CCW or CW) 1 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* 36A

Max Load (Lbf)=	1841.16	(kN) =	8.19

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.7	219.0	299.0	118.7	
12.71	0.00	0.00	0	0	0	0	0	0.00
12.76	0.05	68.70	0	1	0	0	0	0.98
12.75	0.04	54.96	1	1	0	0	0	0.98
12.84	0.13	178.62	0	1	0	0	0	1.88
12.82	0.11	151.14	1	1	0	0	0	1.88
13.11	0.40	549.60	0	3	4	3	2	2.60
13.06	0.35	480.90	1	3	4	3	2	2.60
13.49	0.78	1071.72	0	7	10	9	7	3.73
13.42	0.71	975.54	1	7	10	9	7	3.73
13.78	1.07	1470.18	0	12	20	20	17	4.88
13.73	1.02	1401.48	1	12	20	20	17	4.88
13.93	1.22	1676.28	0	22	34	31	26	6.25
13.90	1.19	1635.06	1	22	34	31	26	6.25
14.03	1.32	1813.68	0	31	48	45	37	8.08
13.99	1.28	1758.72	1	31	48	45	37	8.08
14.05	1.34	1841.16	0	39	60	56	47	9.94
13.99	1.28	1758.72	1	39	60	56	47	9.94
14.03	1.32	1813.68	0	46	70	67	55	11.86
13.94	1.23	1690.02	1	46	70	67	55	11.86
13.98	1.27	1744.98	0	50	79	76	62	13.82
13.89	1.18	1621.32	1	50	79	76	62	13.82
13.89	1.18	1621.32	0	65	100	99	80	19.38
13.73	1.02	1401.48	1	65	100	99	80	19.38
13.75	1.04	1428.96	0	76	123	122	97	30.48
13.60	0.89	1222.86	1	76	123	122	97	30.48
13.51	0.80	1099.20	0	91	152	158	126	38.10
13.36	0.65	893.10	1	61	152	158	126	38.10
13.28	0.57	783.18	0	108	186	199	157	56.36
13.18	0.47	645.78	1	108	186	199	157	56.36
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 36A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.35	2.52	2.31	4.66	3.70	6.22
L/4	2.38		2.63	5.00	3.82	6.22
L/2	2.20		3.14	5.33	4.03	5.81
3L/4	2.15		3.14	5.29	4.26	6.00
L	2.01	2.08	2.45	4.46	4.03	6.11
Mean	2.22	2.30				
Taper	*Ratio:*	0.84	See Note 2	1-TR=	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.02	0.32	0.73	0.71	-0.05
Corrected	(in.)	0.00	0.35	0.77	0.75	0.00
Corrected	(mm)	0.0	8.9	19.5	19.0	0.0
OS/D				0.35		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.6120	1.14	1.70	1.48

Compression and Tension Zones

C (in.)	0.85	C/D	0.40
T(in.)	1.28	T/D	0.61
D(in.)	2.12		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 5 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   Specimen No. P38A

Max Load (Lbf)= 2555.64	(kN) = 11.37

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				40.6	219.1	300.0	120.6	
11.17	0.00	0.00	0	0	0	0	0	0.00
11.83	0.66	906.84	0	3	4	3	3	0.74
11.81	0.64	879.36	1	3	4	3	3	0.74
12.34	1.17	1607.58	0	6	10	9	6	1.35
12.32	1.15	1580.10	1	6	10	9	6	1.35
12.74	1.57	2157.18	0	14	21	19	14	2.23
12.73	1.56	2143.44	1	14	21	19	14	2.23
12.97	1.80	2473.20	0	21	31	29	22	3.21
12.92	1.75	2404.50	1	21	31	29	22	3.21
13.03	1.86	2555.64	0	26	39	36	29	4.12
12.94	1.77	2431.98	1	26	39	36	29	4.12
13.02	1.85	2541.90	0	31	48	44	36	5.26
12.88	1.71	2349.54	1	31	48	44	36	5.26
12.91	1.74	2390.76	0	41	61	59	46	7.56
12.73	1.56	2143.44	1	41	61	59	46	7.56
12.74	1.57	2157.18	0	48	75	70	56	10.07
12.58	1.41	1937.34	1	48	75	70	56	10.07
12.65	1.48	2033.52	0	56	88	83	65	12.73
12.49	1.32	1813.68	1	56	88	83	65	12.73
12.52	1.35	1854.90	0	61	99	93	73	15.41
12.39	1.22	1676.28	1	61	99	93	73	15.41
12.43	1.26	1731.24	0	66	108	102	81	18.03
12.35	1.18	1621.32	1	66	108	102	81	18.03
12.35	1.18	1621.32	0	71	118	111	87	20.82
12.24	1.07	1470.18	1	71	118	111	87	20.82
12.27	1.10	1511.40	0	76	126	120	94	23.62
12.17	1.00	1374.00	1	76	126	120	94	23.62
12.18	1.01	1387.74	0	81	134	126	98	25.86
12.12	0.95	1305.30	1	81	134	126	98	25.86
12.08	0.91	1250.34	0	91	155	145	111	31.75
11.94	0.77	1057.98	1	91	155	145	111	31.75
11.93	0.76	1044.24	0	108	190	175	130	46.04
11.68	0.51	700.74	1	108	190	175	130	46.04
11.70	0.53	728.22	0	130	237	211	152	66.68
11.40	0.23	316.02	1	130	237	211	152	66.68

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **P38A**

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.48	2.52	2.33	4.81	3.85	6.37
L/4	2.45		2.59	5.04	3.97	6.44
L/2	2.36		2.89	5.25	3.91	5.81
3L/4	2.14		2.27	4.41	3.49	5.74
L	1.93	1.99	2.57	4.50	4.08	6.07
Mean	2.27	2.26				
Taper	*Ratio:*	0.78	See Note 2	1-TR=	0.22	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.07	0.31	0.57	-0.16	0.04
Corrected	(in.)	0.00	0.26	0.52	-0.21	0.00
Corrected	(mm)	0.0	6.6	13.1	-5.4	0.0
OS/D				0.22		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.4470	1.51	2.32	1.54

Compression and Tension Zones

C (in.)	0.80	C/D	0.35
T(in.)	0.74	T/D	0.33
D(in.)	2.27		

Location of Fracture from Butt End(mm) 1130.30 mm

Twist (Degrees CCW or CW) 1 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* 39B

Max Load (Lbf)=	6870.00	(kN) =	30.56

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.0	220.4	299.7	120.0	
11.44	0.00	0.00	0	0	0	0	0	0.00
12.03	0.59	810.66	0	1	1	0	0	0.53
11.95	0.51	700.74	1	1	1	0	0	0.53
12.86	1.42	1951.08	0	2	2	1	2	1.05
12.72	1.28	1758.72	1	2	2	1	2	1.05
13.94	2.50	3435.00	0	3	4	2	4	1.78
13.78	2.34	3215.16	1	3	4	2	4	1.78
14.88	3.44	4726.56	0	5	8	7	6	2.46
14.72	3.28	4506.72	1	5	8	7	6	2.46
16.11	4.67	6416.58	0	10	17	16	13	3.52
15.88	4.44	6100.56	1	10	17	16	13	3.52
16.44	5.00	6870.00	0	20	32	31	25	4.89
15.56	4.12	5660.88	1	20	32	31	25	4.89
15.75	4.31	5921.94	0	30	47	47	38	6.74
14.85	3.41	4685.34	1	30	47	47	38	6.74
15.05	3.61	4960.14	0	35	59	61	49	8.71
14.38	2.94	4039.56	1	35	59	61	49	8.71
14.57	3.13	4300.62	0	40	69	71	58	10.71
14.07	2.63	3613.62	1	40	69	71	58	10.71
14.24	2.80	3847.20	0	46	79	82	65	13.03
13.78	2.34	3215.16	1	46	79	82	65	13.03
13.95	2.51	3448.74	0	52	89	93	75	15.66
13.52	2.08	2857.92	1	52	89	93	75	15.66
13.71	2.27	3118.98	0	55	99	103	84	18.52
13.27	1.83	2514.42	1	55	99	103	84	18.52
13.41	1.97	2706.78	0	60	104	112	90	21.05
13.08	1.64	2253.36	1	60	104	112	90	21.05
13.21	1.77	2431.98	0	62	110	121	98	23.57
12.92	1.48	2033.52	1	62	110	121	98	23.57
13.00	1.56	2143.44	0	65	116	127	105	25.87
12.81	1.37	1882.38	1	65	116	127	105	25.87
12.65	1.21	1662.54	0	70	129	145	120	30.16
12.34	0.90	1236.60	1	70	129	145	120	30.16
12.35	0.91	1250.34	0	78	144	168	140	38.10
11.89	0.45	618.30	1	78	144	168	140	38.10
11.80	0.36	494.64	0	85	161	191	162	47.63
11.61	0.17	233.58	1	85	161	191	162	47.63

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 39B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.98	3.01	2.00	4.98	3.56	6.57
L/4	2.92		2.18	5.10	3.40	6.30
L/2	2.93		2.17	5.10	3.66	6.44
3L/4	2.74		2.28	5.02	3.75	6.46
L	2.55	2.54	2.21	4.76	3.83	6.37
Mean	2.82	2.77				
Taper	***Ratio:***	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.14	0.14	0.15	-0.01
Corrected	(in.)	0.00	0.15	0.15	0.16	0.00
Corrected	(mm)	0.0	3.9	3.8	4.1	0.0
OS/D				0.05		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1805	3.63	5.75	1.58

Compression and Tension Zones

C (in.)	1.07	C/D	0.41
T(in.)	1.25	T/D	0.48
D(in.)	2.61		

Location of Fracture from Butt End(mm) 1454.15 mm

Twist (Degrees CCW or CW) 2 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data

Specimen No. 40A

Max Load (Lbf)=	**5001.36**	**(kN) =**	22.25

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.6	220.1	300.5	120.7	
12.71	0.00	0.00	0	0	0	0	0	0.00
13.47	0.76	1044.24	0	1	1	0	1	0.91
13.41	0.70	961.80	1	1	1	0	1	0.91
14.40	1.69	2322.06	0	2	1	1	2	1.54
14.28	1.57	2157.18	1	2	1	1	2	1.54
15.84	3.13	4300.62	0	6	6	5	5	2.31
15.63	2.92	4012.08	1	6	6	5	5	2.31
16.35	3.64	5001.36	0	19	26	24	20	3.35
16.15	3.44	4726.56	1	19	26	24	20	3.35
16.30	3.59	4932.66	0	27	40	38	31	4.45
16.00	3.29	4520.46	1	27	40	38	31	4.45
16.04	3.33	4575.42	0	36	56	54	42	6.36
15.51	2.80	3847.20	1	36	56	54	42	6.36
15.56	2.85	3915.90	0	46	75	70	57	9.32
15.00	2.29	3146.46	1	46	75	70	57	9.32
15.17	2.46	3380.04	0	54	85	82	65	11.30
14.80	2.09	2871.66	1	54	85	82	65	11.30
14.95	2.24	3077.76	0	59	97	94	72	14.08
14.54	1.83	2514.42	1	59	97	94	72	14.08
14.72	2.01	2761.74	0	66	107	104	81	16.64
14.51	1.80	2473.20	1	66	107	104	81	16.64
14.57	1.86	2555.64	0	71	119	113	87	19.58
14.27	1.56	2143.44	1	71	119	113	87	19.58
14.47	1.76	2418.24	0	76	129	123	94	22.73
14.14	1.43	1964.82	1	76	129	123	94	22.73
14.33	1.62	2225.88	0	81	141	133	101	30.73
13.87	1.16	1593.84	1	81	141	133	101	30.73
14.04	1.33	1827.42	0	86	161	148	105	34.29
13.08	0.37	508.38	1	86	161	148	105	34.29
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 40A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.99	2.91	1.97	4.95	3.55	6.46
L/4	2.92		2.31	5.23	3.70	6.30
L/2	2.72		2.30	5.02	3.71	6.26
3L/4	2.66		2.06	4.71	3.79	6.25
L	2.28	2.15	2.27	4.55	3.96	6.11
Mean	2.71	2.53				
Taper	***Ratio:***	0.75	See Note 2	1-TR	0.25	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.04	0.27	0.16	-0.12	-0.09
Corrected	(in.)	0.00	0.33	0.22	-0.05	0.00
Corrected	(mm)	0.0	8.5	5.5	-1.4	0.0
OS/D				0.08		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2600	2.69	3.99	1.49

Compression and Tension Zones

C (in.)	0.86	C/D	0.32
T(in.)	0.91	T/D	0.34
D(in.)	2.67		

Location of Fracture from Butt End(mm) 1130.30 mm

Twist (Degrees CCW or CW) 5 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P41A

Max Load (Lbf)=	2363.28	(kN) =	10.51

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.7	220.0	299.9	119.6	
11.31	0.00	0.00	0	0	0	0	0	0.00
11.52	0.21	288.54	0	0	0	0	0	0.56
11.50	0.19	261.06	1	0	0	0	0	0.56
11.96	0.65	893.10	0	2	4	4	3	1.27
11.94	0.63	865.62	1	2	4	4	3	1.27
12.44	1.13	1552.62	0	6	10	9	8	1.88
12.38	1.07	1470.18	1	6	10	9	8	1.88
12.82	1.51	2074.74	0	12	18	19	16	2.67
12.77	1.46	2006.04	1	12	18	19	16	2.67
13.00	1.69	2322.06	0	17	28	29	24	3.56
12.92	1.61	2212.14	1	17	28	29	24	3.56
13.03	1.72	2363.28	0	22	38	39	34	4.83
12.83	1.52	2088.48	1	22	38	39	34	4.83
12.88	1.57	2157.18	0	31	53	55	47	7.11
12.64	1.33	1827.42	1	31	53	55	47	7.11
12.72	1.41	1937.34	0	37	66	70	61	9.83
12.47	1.16	1593.84	1	37	66	70	61	9.83
12.56	1.25	1717.50	0	42	76	82	71	12.34
12.35	1.04	1428.96	1	42	76	82	71	12.34
12.40	1.09	1497.66	0	47	85	92	80	14.97
12.25	0.94	1291.56	1	47	85	92	80	14.97
12.31	1.00	1374.00	0	52	93	102	89	17.45
12.18	0.87	1195.38	1	52	93	102	89	17.45
12.25	0.94	1291.56	0	55	100	109	96	20.02
12.10	0.79	1085.46	1	55	100	109	96	20.02
12.17	0.86	1181.64	0	58	106	117	104	22.65
12.04	0.73	1003.02	1	58	106	117	104	22.65
12.10	0.79	1085.46	0	61	114	129	111	25.34
11.99	0.68	934.32	1	61	114	129	111	25.34
12.01	0.70	961.80	0	69	130	149	136	33.34
11.76	0.45	618.30	1	69	130	149	136	33.34
11.77	0.46	632.04	0	67	135	166	164	41.28
11.38	0.07	96.18	1	67	135	166	164	41.28
11.39	0.08	109.92	0	78	155	193	192	53.98
11.35	0.04	54.96	1	78	155	193	192	53.98

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P41A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.61	2.74	2.29	4.90	3.72	6.47
L/4	2.54		2.32	4.86	4.02	6.61
L/2	2.38		2.41	4.79	3.88	6.46
3L/4	2.27		2.62	4.89	3.89	6.23
L	2.00	2.22	2.60	4.60	3.88	6.10
Mean	2.36	2.48				
Taper	*Ratio:*	0.79	See Note 2	1-TR=	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.09	0.10	0.26	0.10
Corrected	(in.)	0.00	-0.01	0.00	0.16	0.00
Corrected	(mm)	0.0	-0.2	0.0	4.1	0.0
OS/D				0.00		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.4570	1.57	2.27	1.45

Compression and Tension Zones

C (in.)	0.67	C/D	0.30
T(in.)	0.98	T/D	0.45
D(in.)	2.20		

Location of Fracture from Butt End(mm) 1517.65 mm

Twist (Degrees CCW or CW) 5 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No* **P42A**

Max Load (Lbf)=	1690.02	(kN) =	7.52

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				41.8	219.6	299.1	119.2	
11.36	0.00	0.00	0	0	0	0	0	0.00
11.86	0.50	687.00	0	1	4	5	5	1.07
11.80	0.44	604.56	1	1	4	5	5	1.07
12.23	0.87	1195.38	0	6	11	14	11	1.93
12.20	0.84	1154.16	1	6	11	14	11	1.93
12.52	1.16	1593.84	0	13	24	26	21	3.23
12.48	1.12	1538.88	1	13	24	26	21	3.23
12.59	1.23	1690.02	0	18	32	35	31	4.33
12.52	1.16	1593.84	1	18	32	35	31	4.33
12.59	1.23	1690.02	0	23	41	45	40	5.79
12.48	1.12	1538.88	1	23	41	45	40	5.79
12.52	1.16	1593.84	0	29	51	56	50	7.75
12.40	1.04	1428.96	1	29	51	56	50	7.75
12.42	1.06	1456.44	0	33	59	66	62	9.70
12.31	0.95	1305.30	1	33	59	66	62	9.70
12.31	0.95	1305.30	0	38	66	76	66	11.63
12.23	0.87	1195.38	1	38	66	76	66	11.63
12.22	0.86	1181.64	0	42	74	85	72	13.80
12.15	0.79	1085.46	1	42	74	85	72	13.80
12.12	0.76	1044.24	0	46	80	91	82	16.23
12.07	0.71	975.54	1	46	80	91	82	16.23
12.03	0.67	920.58	0	50	90	101	92	19.35
11.97	0.61	838.14	1	50	90	101	92	19.35
11.94	0.58	796.92	0	53	96	111	102	22.49
11.90	0.54	741.96	1	53	96	111	102	22.49
11.87	0.51	700.74	0	58	100	121	111	25.68
11.83	0.47	645.78	1	58	100	121	111	25.68
11.74	0.38	522.12	0	67	121	141	130	33.34
11.69	0.33	453.42	1	67	121	141	130	33.34
11.60	0.24	329.76	0	77	140	164	152	44.45
11.58	0.22	302.28	1	77	140	164	152	44.45
11.64	0.28	384.72	0	80	156	189	182	58.74
11.51	0.15	206.10	1	80	156	189	182	58.74
11.61	0.25	343.50	0	88	169	195	204	69.85
11.54	0.18	247.32	1	88	169	195	204	69.85

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P42A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.78	2.96	2.26	5.05	3.54	6.51
L/4	2.68		2.15	4.83	3.79	6.63
L/2	2.37		2.85	5.22	3.70	6.00
3L/4	2.12		3.07	5.19	3.74	5.70
L	1.90	1.98	2.57	4.47	3.97	5.95
Mean	2.37	2.47				
Taper	***Ratio:***	0.67	See Note 2	1-TR=	0.33	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.16	-0.01	0.53	0.63	0.02
Corrected	(in.)	0.00	-0.10	0.45	0.54	0.00
Corrected	(mm)	0.0	-2.4	11.4	13.7	0.0
OS/D				0.19		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.4895	1.54	2.12	1.38

Compression and Tension Zones

C (in.)	0.70	C/D	0.35
T(in.)	0.76	T/D	0.37
D(in.)	2.02		

Location of Fracture from Butt End(mm) 1581.15 mm

Twist (Degrees CCW or CW) 2 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data

Specimen No. P43A

Max Load (Lbf)=	2555.64	(kN) =	11.37

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				39.6	218.5	298.6	118.6	
12.78	0.00	0.00	0	0	0	0	0	0.00
12.93	0.15	206.10	0	0	0	0	0	1.04
12.90	0.12	164.88	1	0	0	0	0	1.04
13.54	0.76	1044.24	0	0	4	4	1	1.84
13.46	0.68	934.32	1	0	4	4	1	1.84
14.00	1.22	1676.28	0	6	11	11	9	2.70
13.91	1.13	1552.62	1	6	11	11	9	2.70
14.29	1.51	2074.74	0	13	20	20	15	3.66
14.22	1.44	1978.56	1	13	20	20	15	3.66
14.51	1.73	2377.02	0	18	30	30	23	4.85
14.45	1.67	2294.58	1	18	30	30	23	4.85
14.62	1.84	2528.16	0	25	39	39	30	6.10
14.52	1.74	2390.76	1	25	39	39	30	6.10
14.64	1.86	2555.64	0	31	49	50	40	7.95
14.45	1.67	2294.58	1	31	49	50	40	7.95
14.56	1.78	2445.72	0	37	60	60	46	9.88
14.34	1.56	2143.44	1	37	60	60	46	9.88
14.46	1.68	2308.32	0	46	73	72	56	12.50
14.21	1.43	1964.82	1	46	73	72	56	12.50
14.33	1.55	2129.70	0	54	84	83	66	17.70
14.11	1.33	1827.42	1	54	84	83	66	17.70
14.22	1.44	1978.56	0	56	94	94	74	17.84
14.03	1.25	1717.50	1	56	94	94	74	17.84
14.12	1.34	1841.16	0	63	103	101	81	20.40
13.96	1.18	1621.32	1	63	103	101	81	20.40
14.04	1.26	1731.24	0	66	110	111	86	22.96
13.88	1.10	1511.40	1	66	110	111	86	22.96
13.94	1.16	1593.84	0	68	117	118	94	25.53
13.81	1.03	1415.22	1	68	117	118	94	25.53
13.77	0.99	1360.26	0	86	150	152	119	38.10
13.53	0.75	1030.50	1	86	150	152	119	38.10
13.53	0.75	1030.50	0	102	182	191	147	54.77
13.34	0.56	769.44	1	102	182	191	147	54.77
13.36	0.58	796.92	0	110	200	215	163	65.09
13.19	0.41	563.34	1	110	200	215	163	65.09

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P43A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.59	2.58	2.27	4.85	3.74	6.32
L/4	2.60		2.81	5.41	3.89	6.36
L/2	2.40		3.01	5.40	3.96	6.00
3L/4	2.20		3.03	5.23	4.03	5.91
L	1.96	2.14	2.52	4.49	3.89	6.04
Mean	2.35	2.36				
Taper	*Ratio:*	0.80	See Note 2	1-TR	0.20	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.61	0.70	0.63	0.00
Corrected	(in.)	0.00	0.58	0.67	0.60	0.00
Corrected	(mm)	0.0	14.7	17.0	15.2	0.0
OS/D				0.28		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.3500	1.62	2.96	1.84

Compression and Tension Zones

C (in.)	1.05	C/D	0.45
T(in.)	0.47	T/D	0.20
D(in.)	2.33		

Location of Fracture from Butt End(mm) 1247.78 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data

Specimen No. **P44A**

Max Load (Lbf)	4135.74	(kN) =	18.40

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.1	220.0	300.0	120.5	
11.20	0.00	0.00	0	0	0	0	0	0.00
11.91	0.71	975.54	0	1	1	2	2	0.66
11.86	0.66	906.84	1	1	1	2	2	0.66
12.75	1.55	2129.70	0	5	5	5	5	1.22
12.69	1.49	2047.26	1	5	5	5	5	1.22
13.67	2.47	3391.03	0	11	14	14	12	1.97
13.59	2.39	3283.86	1	11	14	14	12	1.97
14.03	2.83	3888.42	0	16	23	22	18	2.64
13.95	2.75	3778.50	1	16	23	22	18	2.64
14.21	3.01	4135.74	0	22	34	33	27	3.71
13.91	2.71	3723.54	1	22	34	33	27	3.71
14.04	2.84	3902.16	0	29	44	44	35	4.94
13.63	2.43	3338.82	1	29	44	44	35	4.94
13.78	2.58	3544.92	0	36	58	58	46	7.01
13.31	2.11	2899.14	1	36	58	58	46	7.01
13.44	2.24	3077.76	0	44	73	72	58	9.79
13.03	1.83	2514.42	1	44	73	72	58	9.79
13.17	1.97	2706.78	0	51	84	85	69	12.58
12.85	1.65	2267.10	1	51	84	85	69	12.58
12.99	1.79	2459.46	0	56	95	95	76	15.29
12.71	1.51	2074.74	1	56	95	95	76	15.29
12.83	1.63	2239.62	0	61	104	105	85	17.84
12.60	1.40	1923.60	1	61	104	105	85	17.84
12.69	1.49	2047.26	0	65	111	115	92	20.61
12.52	1.32	1813.68	1	65	111	115	92	20.61
12.60	1.40	1923.60	0	69	120	124	99	23.32
12.43	1.23	1690.02	1	69	120	124	99	23.32
12.52	1.32	1813.68	0	72	127	130	105	25.78
12.34	1.14	1566.36	1	72	127	130	105	25.78
11.90	0.70	961.80	0	91	170	195	150	50.01
11.56	0.36	494.64	1	91	170	195	150	50.01
11.53	0.33	453.42	0	101	195	225	172	62.71
11.43	0.23	316.02	1	101	195	225	172	62.71
11.47	0.27	370.98	0	116	222	265	199	82.55
11.34	0.14	192.36	1	116	222	265	199	82.55

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **P44A**

Locatior	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.94	2.83	2.20	5.14	3.58	6.41
L/4	2.84		2.65	5.50	3.69	6.37
L/2	2.72		2.36	5.08	3.70	6.29
3L/4	2.58		2.25	4.83	3.73	6.16
L	2.21	2.25	2.40	4.61	3.86	6.11
Mean	2.66	2.54				
Taper	***Ratio:***	0.77	See Note 2			

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.17	0.57	0.22	0.04	0.01
Correctec	(in.)	0.00	0.49	0.13	-0.05	0.00
Correctec	(mm)	0.0	12.3	3.3	-1.3	0.0

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2820	2.67	3.68	1.38

Compression and Tension Zones

C (in.)	1.21	C/D	0.47
T(in.)	0.58	T/D	0.22
D(in.)	2.58		

Location of Fracture from Butt End(mm) 1343.03 mm

Twist (Degrees CCW or CW) 2 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P44B

Max Load (Lbf)=	6993.66	(kN) =	31.11

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	219.3	299.1	119.3	
11.41	0.00	0.00	0	0	0	0	0	0.00
12.03	0.62	851.88	0	0	0	0	0	0.79
11.99	0.58	796.92	1	0	0	0	0	0.79
13.15	1.74	2390.76	0	2	3	3	2	1.59
13.02	1.61	2212.14	1	2	3	3	2	1.59
14.27	2.86	3929.64	0	5	7	6	5	2.34
14.12	2.71	3723.54	1	5	7	6	5	2.34
15.26	3.85	5289.90	0	8	12	11	10	3.12
15.11	3.70	5083.80	1	8	12	11	10	3.12
16.16	4.75	6526.50	0	13	18	19	15	4.10
15.88	4.47	6141.78	1	13	18	19	15	4.10
16.50	5.09	6993.66	0	19	28	29	23	5.31
15.78	4.37	6004.38	1	19	28	29	23	5.31
16.13	4.72	6485.28	0	25	41	41	33	7.07
15.32	3.91	5372.34	1	25	41	41	33	7.07
15.71	4.30	5908.20	0	30	49	51	41	8.59
15.05	3.64	5001.36	1	30	49	51	41	8.59
15.37	3.96	5441.04	0	38	63	64	51	11.24
14.66	3.25	4465.50	1	38	63	64	51	11.24
14.99	3.58	4918.92	0	42	73	75	60	13.75
14.39	2.98	4094.52	1	42	73	75	60	13.75
14.61	3.20	4396.80	0	50	83	86	68	16.46
14.16	2.75	3778.50	1	50	83	86	68	16.46
14.40	2.99	4108.26	0	54	93	96	75	19.04
13.98	2.57	3531.18	1	54	93	96	75	19.04
14.20	2.79	3833.46	0	60	101	105	83	21.64
13.81	2.40	3297.60	1	60	101	105	83	21.64
14.00	2.59	3558.66	0	62	108	113	88	24.08
13.68	2.27	3118.98	1	62	108	113	88	24.08
13.89	2.48	3407.52	0	70	128	133	103	30.16
13.34	1.93	2651.82	1	70	128	133	103	30.16
13.50	2.09	2871.66	0	78	143	154	117	38.10
12.77	1.36	1868.64	1	78	143	154	117	38.10
12.73	1.32	1813.68	0	90	167	186	138	50.01
12.28	0.87	1195.38	1	90	167	186	138	50.01

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P44B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.55	3.50	1.75	5.30	3.40	6.89
L/4	3.51		2.26	5.77	3.23	6.61
L/2	3.22		2.34	5.56	3.31	6.46
3L/4	3.16		2.44	5.60	3.64	6.58
L	2.88	2.95	2.11	4.99	3.65	6.60
Mean	3.26	3.22				
Taper	***Ratio:***	0.83	See Note 2	1-TR=	0.17	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.02	0.51	0.45	0.52	0.05
Corrected	(in.)	0.00	0.48	0.41	0.48	0.00
Corrected	(mm)	0.0	12.1	10.4	12.2	0.0
OS/D				0.13		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1370	5.26	7.57	1.44

Compression and Tension Zones

C (in.)	1.40	C/D	0.46
T(in.)	1.03	T/D	0.34
D(in.)	3.05		

Location of Fracture from Butt End(mm) 1317.63 mm

Twist (Degrees CCW or CW) 3.5 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — Specimen No. P45A

Max Load (Lbf)=	2528.16	(kN) =	11.25

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				39.7	218.2	298.5	119.3	
11.43	0.00	0.00	0	0	0	0	1	0.00
11.65	0.22	302.28	0	1	2	3	1	0.84
11.63	0.20	274.80	1	1	2	3	1	0.84
12.25	0.82	1126.68	0	7	10	8	5	1.88
12.18	0.75	1030.50	1	7	10	8	5	1.88
12.72	1.29	1772.46	0	12	21	20	14	3.25
12.64	1.21	1662.54	1	12	21	20	14	3.25
13.27	1.84	2528.16	0	19	30	28	22	4.86
13.20	1.77	2431.98	1	19	30	28	22	4.86
13.27	1.84	2528.16	0	27	42	40	32	6.68
13.11	1.68	2308.32	1	27	42	40	32	6.68
13.13	1.70	2339.92	0	35	54	53	41	8.56
12.93	1.50	2061.00	1	35	54	53	41	8.56
12.95	1.52	2088.48	0	42	67	65	50	10.98
12.75	1.32	1813.68	1	42	67	65	50	10.98
12.78	1.35	1854.90	0	49	80	78	60	13.79
12.61	1.18	1621.32	1	49	80	78	60	13.79
12.63	1.20	1648.80	0	56	91	89	68	16.69
12.50	1.07	1470.18	1	56	91	89	68	16.69
12.52	1.09	1497.66	0	59	100	99	76	19.27
12.41	0.98	1346.52	1	59	100	99	76	19.27
12.43	1.00	1374.00	0	67	110	109	83	22.20
12.33	0.90	1236.60	1	67	110	109	83	22.20
12.34	0.91	1250.34	0	69	118	118	90	25.04
12.26	0.83	1140.42	1	69	118	118	90	25.04
12.26	0.83	1140.42	0	87	149	148	113	36.51
12.12	0.69	948.06	1	87	149	148	113	36.51
12.03	0.60	824.40	0	97	172	170	128	46.04
11.97	0.54	741.96	1	97	172	170	128	46.04
11.70	0.27	370.98	0	122	222	215	158	71.44
11.68	0.25	343.50	1	22	222	215	158	71.44
11.60	0.17	233.58	0	139	262	245	178	93.66
11.60	0.17	233.58	1	139	262	245	178	93.66
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P45A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.55	2.68	2.22	4.77	3.64	6.32
L/4	2.64		2.85	5.49	3.89	6.37
L/2	2.44		3.18	5.61	4.08	6.05
3L/4	2.22		2.81	5.03	4.16	6.29
L	2.05	2.17	2.50	4.55	3.99	6.16
Mean	2.38	2.43				
Taper	***Ratio:***	0.81	See Note 2	1-TR=	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.67	0.89	0.42	0.02
Corrected	(in.)	0.00	0.66	0.89	0.41	0.00
Corrected	(mm)	0.0	16.8	22.5	10.5	0.0
OS/D				0.36		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.3732	1.73	2.78	1.61

Compression and Tension Zones

C (in.)	0.98	C/D	0.41
T(in.)	0.29	T/D	0.12
D(in.)	2.37		

Location of Fracture from Butt End(mm) 1130.30 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data *Specimen No.* P46A

Max Load (Lbf)=	7776.84	(kN) =	34.59

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.0	220.4	300.4	120.8	
11.35	0.00	0.00	0	0	0	0	0	0.00
11.81	0.46	632.04	0	2	1	0	1	0.95
11.79	0.44	604.56	1	2	1	0	1	0.95
12.76	1.41	1937.34	0	4	2	2	1	1.71
12.67	1.32	1813.68	1	4	2	2	1	1.71
14.31	2.96	4067.04	0	5	3	2	1	2.36
14.18	2.83	3888.42	1	5	3	2	1	2.36
16.01	4.66	6402.84	0	8	8	4	3	2.97
15.84	4.49	6169.26	1	8	8	4	3	2.97
17.01	5.66	7776.84	0	25	34	34	27	4.42
15.55	4.20	5770.80	1	25	34	34	27	4.42
15.49	4.14	5688.36	0	35	52	53	42	6.35
14.53	3.18	4369.32	1	35	52	53	42	6.35
14.69	3.34	4589.16	0	40	64	67	53	8.33
13.95	2.60	3572.40	1	40	64	67	53	8.33
14.16	2.81	3860.94	0	46	77	79	63	10.62
13.56	2.21	3036.54	1	46	77	79	63	10.62
13.81	2.46	3380.04	0	48	82	87	72	13.00
13.30	1.95	2679.30	1	48	82	87	72	13.00
13.55	2.20	3022.80	0	52	93	98	82	15.83
13.11	1.76	2418.24	1	52	93	98	82	15.83
13.33	1.98	2720.52	0	57	102	108	91	18.69
12.95	1.60	2198.40	1	57	102	108	91	18.69
13.14	1.79	2459.46	0	59	110	129	114	22.20
11.63	0.28	384.72	1	59	110	129	114	22.20
11.58	0.23	316.02	0	63	118	142	125	25.12
11.54	0.19	261.06	1	63	118	142	125	25.12
11.46	0.11	151.14	0	80	149	179	158	38.10
11.43	0.08	109.92	1	80	149	179	158	38.10
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P46A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.25	3.34	1.84	5.08	3.33	6.68
L/4	3.16		1.95	5.11	3.42	6.82
L/2	2.88		2.15	5.03	3.52	6.59
3L/4	2.65		2.12	4.77	3.51	6.31
L	2.45	2.60	2.38	4.83	3.60	6.20
Mean	2.88	2.97				
Taper	***Ratio:***	0.77	See Note 2	1-TR=	0.23	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.04	0.03	0.09	-0.06	0.10
Corrected	(in.)	0.00	-0.00	0.06	-0.09	0.00
Corrected	(mm)	0.0	-0.0	1.5	-2.3	0.0
OS/D				0.02		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.1970	3.39	5.27	1.55

Compression and Tension Zones

C (in.)	1.01	C/D	0.39
T(in.)	1.33	T/D	0.51
D(in.)	2.62		

Location of Fracture from Butt End(mm) 1444.63 mm

Twist (Degrees CCW or CW) 4 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data | *Specimen No.* P46B

Max Load (Lbf)=	11885.10	(kN) =	52.87

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.0	218.8	299.6	120.0	
11.35	0.00	0.00	0	0	0	0	0	0.00
12.01	0.66	906.84	0	0	0	0	0	1.02
11.92	0.57	783.18	1	0	0	0	0	1.02
13.50	2.15	2954.10	0	1	2	1	1	1.97
13.29	1.94	2665.56	1	1	2	1	1	1.97
15.41	4.06	5578.44	0	5	5	5	3	2.87
15.19	3.84	5276.16	1	5	5	5	3	2.87
17.32	5.97	8202.78	0	8	8	9	6	3.77
16.99	5.64	7749.36	1	8	8	9	6	3.77
19.33	7.98	10964.52	0	13	17	16	12	4.93
18.63	7.28	10002.72	1	13	17	16	12	4.93
20.00	8.65	11885.10	0	20	26	24	18	5.97
18.61	7.26	9975.24	1	20	26	24	18	5.97
19.52	8.17	11225.58	0	27	37	35	26	7.48
17.87	6.52	8958.48	1	27	37	35	26	7.48
18.73	7.38	10140.12	0	32	48	45	33	9.06
17.56	6.21	8532.54	1	32	48	45	33	9.06
18.00	6.65	9137.10	0	39	58	53	40	10.81
16.79	5.44	7474.56	1	39	58	53	40	10.81
17.31	5.96	8189.04	0	45	69	63	46	13.27
16.17	4.82	6622.68	1	45	69	63	46	13.27
16.70	5.35	7350.90	0	52	82	73	54	16.05
15.60	4.25	5839.50	1	52	82	73	54	16.05
15.56	4.21	5784.54	0	67	109	90	63	19.62
12.45	1.10	1511.40	1	67	109	90	63	19.62
12.09	0.74	1016.76	0	80	136	106	74	24.66
11.73	0.38	522.12	1	80	136	106	74	24.66
11.46	0.11	151.14	0	99	165	129	88	33.34
11.45	0.10	137.40	1	99	165	129	88	33.34
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P46B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	4.02	3.79	1.60	5.62	3.11	6.90
L/4	3.94		2.23	6.17	3.36	7.10
L/2	3.70		2.46	6.16	3.39	7.04
3L/4	3.47		1.98	5.45	3.29	6.80
L	3.26	3.43	1.84	5.10	3.32	6.75
Mean	3.68	3.61				
Taper	***Ratio:***	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.11	0.70	0.81	0.22	-0.03
Corrected	(in.)	0.00	0.66	0.77	0.18	0.00
Corrected	(mm)	0.0	16.7	19.5	4.5	0.0
OS/D				0.21		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1110	9.21	9.35	1.01

Compression and Tension Zones

C (in.)	0.87	C/D	0.24
T(in.)	2.61	T/D	0.73
D(in.)	3.58		

Location of Fracture from Butt End(mm) 1003.30 mm

Twist (Degrees CCW or CW) 2 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P47B

Max Load (Lbf)=	3118.98	(kN) =	13.87

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				39.8	218.5	298.4	119.0	
11.28	0.00	0.00	0	0	0	0	0	0.00
11.43	0.15	206.10	0	0	0	0	0	0.81
11.42	0.14	192.36	1	0	0	0	0	0.81
11.80	0.52	714.48	0	3	4	4	3	2.11
11.78	0.50	687.00	1	3	4	4	3	2.11
12.05	0.77	1057.98	0	4	5	4	5	2.77
12.03	0.75	1030.50	1	4	5	4	5	2.77
12.43	1.15	1580.10	0	8	10	11	9	3.68
12.41	1.13	1552.62	1	8	10	11	9	3.68
12.82	1.54	2115.96	0	12	17	17	14	4.81
12.79	1.51	2074.74	1	12	17	17	14	4.81
13.14	1.86	2555.64	0	18	25	24	19	5.97
13.11	1.83	2514.42	1	18	25	24	19	5.97
13.39	2.11	2899.14	0	23	32	32	25	9.78
13.36	2.08	2857.92	1	23	32	32	25	9.78
13.55	2.27	3118.98	0	28	40	39	33	8.78
13.43	2.15	2954.10	1	28	40	39	33	8.78
13.54	2.26	3105.24	0	36	52	51	40	10.63
13.33	2.05	2816.70	1	36	52	51	40	10.63
13.38	2.10	2885.40	0	42	64	62	48	12.92
13.14	1.86	2555.64	1	42	64	62	48	12.92
13.18	1.90	2610.60	0	48	75	72	55	15.38
12.98	1.70	2335.80	1	48	75	72	55	15.38
13.02	1.74	2390.76	0	56	85	83	64	18.12
12.83	1.55	2129.70	1	56	85	83	64	18.12
12.84	1.56	2143.44	0	60	95	93	70	20.78
12.69	1.41	1937.34	1	60	95	93	70	20.78
12.70	1.42	1951.08	0	66	104	102	78	23.32
12.58	1.30	1786.20	1	66	104	102	78	23.32
12.57	1.29	1772.46	0	70	112	109	84	25.88
12.42	1.14	1566.36	1	70	112	109	84	25.88
12.21	0.93	1277.82	0	87	144	146	109	33.34
12.00	0.72	989.28	1	87	144	146	109	33.34
11.65	0.37	508.38	0	103	183	204	142	63.50
11.57	0.29	398.46	1	103	183	204	142	63.50
11.55	0.27	370.98	0	114	207	224	160	77.79
11.47	0.19	261.06	1	114	207	224	160	77.79
11.50	0.22	302.28	0	138	255	282	197	111.13
11.45	0.17	233.58	1	138	255	282	197	111.13
**********	**********	*************	**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P47B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.72	2.68	2.30	5.02	3.66	6.34
L/4	2.63		2.83	5.46	3.43	5.74
L/2	2.55		3.07	5.62	3.80	5.82
3L/4	2.50		2.82	5.32	3.97	6.17
L	2.39	2.24	2.32	4.72	3.93	6.17
Mean	2.56	2.46				
Taper	***Ratio:***	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.16	0.64	0.84	0.57	0.02
Corrected	(in.)	0.00	0.55	0.75	0.48	0.00
Corrected	(mm)	0.0	14.0	19.1	12.2	0.0
OS/D				0.29		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2785	2.09	3.73	1.79

Compression and Tension Zones

C (in.)	1.01	C/D	0.41
T(in.)	0.24	T/D	0.10
D(in.)	2.44		

Location of Fracture from Butt End(mm) 1266.83 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data **Specimen No. P48A**

Max Load (Lbf)=	**5798.28**	**(kN) =**	25.79	***Page - 1***

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.3	220.1	300.0	120.0	
11.36	0.00	0.00	0	0	0	0	0	0.00
11.40	0.04	54.96	0	0	0	0	0	0.00
12.36	1.00	1374.00	0	0	0	0	0	1.07
12.31	0.95	1305.30	1	0	0	0	0	1.07
13.15	1.79	2459.46	0	1	2	3	2	1.65
13.10	1.74	2390.76	1	1	2	3	2	1.65
14.10	2.74	3764.76	0	4	8	9	6	2.34
14.04	2.68	3682.32	1	4	8	9	6	2.34
14.81	3.45	4740.30	0	11	17	5	14	2.86
14.80	3.44	4726.56	1	11	17	5	14	3.11
15.58	4.22	5798.28	0	17	26	29	22	4.01
15.40	4.04	5550.96	1	17	26	29	22	4.01
15.38	4.02	5523.48	0	25	41	44	33	5.46
14.81	3.45	4740.30	1	25	41	44	33	5.46
14.86	3.50	4809.00	0	33	54	56	44	7.19
14.33	2.97	4080.78	1	33	54	56	44	7.19
14.44	3.08	4231.92	0	38	64	65	50	8.90
14.00	2.64	3627.36	1	38	64	65	50	8.90
14.10	2.74	3764.76	0	43	71	74	57	10.44
13.80	2.44	3352.56	1	43	71	74	57	10.44
13.88	2.52	3462.48	0	46	80	81	64	11.93
13.60	2.24	3077.76	1	46	80	81	64	11.93
13.66	2.30	3160.20	0	48	85	90	70	13.95
13.32	1.96	2693.04	1	48	85	90	70	13.95
13.41	2.05	2816.70	0	55	100	105	83	18.24
13.10	1.74	2390.76	1	55	100	105	83	18.24
13.19	1.83	2514.42	0	60	109	115	90	21.16
12.93	1.57	2157.18	1	55	109	115	90	21.16
12.95	1.59	2184.66	0	67	121	130	101	25.73
12.72	1.36	1868.64	1	67	121	130	101	25.73
12.75	1.39	1909.86	0	78	151	165	124	33.34
11.53	0.17	233.58	1	78	151	165	124	33.34
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P48A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.86	2.91	2.08	4.94	3.52	6.44
L/4	2.83		2.24	5.07	3.43	6.33
L/2	2.68		2.43	5.11	3.61	6.34
3L/4	2.55		2.38	4.93	3.68	6.28
L	2.28	2.37	2.36	4.64	3.84	6.21
Mean	2.64	2.64				
Taper	*Ratio:*	0.80	See Note 2	1-TR=	0.20	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.01	0.15	0.27	0.15	0.00
Corrected	(in.)	0.00	0.15	0.26	0.15	0.00
Corrected	(mm)	0.0	3.8	6.7	3.8	0.0
OS/D				0.10		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2465	2.53	4.21	1.66

Compression and Tension Zones

C (in.)	0.96	C/D	0.38
T(in.)	0.57	T/D	0.22
D(in.)	2.52		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 7 CCW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid
at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data **Specimen No. P48B**

Max Load (Lbf)=	8395.14	(kN) =	37.34

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.2	219.6	299.5	119.8	
11.41	0.00	0.00	0	0	0	0	0	0.00
11.87	0.46	632.04	0	0	0	0	0	0.66
11.80	0.39	535.86	1	0	0	0	0	0.66
12.48	1.07	1470.18	0	1	2	2	2	1.22
12.38	0.97	1332.78	1	1	2	2	2	1.22
13.45	2.04	2802.96	0	2	4	4	3	1.99
13.31	1.90	2610.60	1	2	4	4	3	1.99
14.70	3.29	4520.46	0	6	9	8	6	2.81
14.54	3.13	4300.62	1	6	9	8	6	2.81
15.92	4.51	6196.74	0	10	14	13	8	3.64
15.78	4.37	6004.38	1	10	14	13	8	3.64
16.96	5.55	7625.70	0	14	21	19	15	4.47
16.78	5.37	7378.38	1	14	21	19	15	4.47
17.52	6.11	8395.14	0	20	30	28	22	5.46
16.83	5.42	7447.08	1	20	30	28	22	5.46
17.18	5.77	7927.98	0	26	43	40	32	7.10
16.13	4.72	6485.28	1	26	43	40	32	7.10
16.44	5.03	6911.22	0	34	56	55	42	9.00
15.46	4.05	5564.70	1	34	56	55	42	9.00
15.80	4.39	6031.86	0	42	65	65	48	10.77
15.00	3.59	4932.66	1	42	65	65	48	10.77
15.25	3.84	5276.16	0	46	75	74	56	12.67
14.56	3.15	4328.10	1	46	75	74	56	12.67
14.70	3.29	4520.46	0	52	84	82	62	14.52
14.21	2.80	3847.20	1	52	84	82	62	14.52
14.46	3.05	4190.70	0	55	91	90	67	16.40
13.96	2.55	3503.70	1	55	91	90	67	16.40
14.22	2.81	3860.94	0	61	101	100	73	19.27
13.65	2.24	3077.76	1	61	101	100	73	19.27
13.11	1.70	2335.80	0	72	131	129	91	23.39
11.60	0.19	261.06	1	72	131	129	91	23.39
11.61	0.20	274.80	0	82	156	154	106	30.16
11.49	0.08	109.92	1	82	156	154	106	30.16
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P48B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.35	3.39	1.96	5.31	3.35	6.74
L/4	3.19		2.31	5.50	3.43	6.66
L/2	3.06		2.44	5.49	3.62	6.76
3L/4	3.05		2.30	5.35	3.71	6.72
L	2.86	2.92	2.12	4.98	3.66	6.58
Mean	3.10	3.15				
Taper	***Ratio:***	0.86	See Note 2	1-TR=	0.14	

Out-of-Straightness

		0	**L/4**	**L/2**	**3L/4**	**L**
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.14	0.40	0.46	0.32	0.05
Corrected	(in.)	0.00	0.31	0.37	0.23	0.00
Corrected	(mm)	0.0	7.9	9.4	5.8	0.0
OS/D				0.12		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.1240	4.29	8.37	1.95

Compression and Tension Zones

C (in.)	1.18	C/D	0.38
T(in.)	1.27	T/D	0.41
D(in.)	3.09		

Location of Fracture from Butt End(mm) 1155.70 mm

Twist (Degrees CCW or CW) 7 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data — *Specimen No.* P49B

Max Load (Lbf)=	4657.86	(kN) =	20.72

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at L/4	L/2	5L/8	3L/4	Platen (mm)
				40.6	219.6	299.8	120.0	
11.41	0.00	0.00	0	0	0	0	0	0.00
11.78	0.37	508.38	0	0	0	0	0	0.42
11.75	0.34	467.16	1	0	0	0	0	0.42
12.94	1.53	2102.22	0	3	2	3	0	1.37
12.83	1.42	1951.08	1	3	2	3	0	1.37
14.18	2.77	3805.98	0	9	11	12	10	2.46
14.09	2.68	3682.32	1	9	11	12	10	2.46
14.80	3.39	4657.86	0	21	26	27	23	3.82
14.68	3.27	4492.98	1	21	26	27	23	3.82
14.79	3.38	4644.12	0	31	44	43	35	5.68
14.33	2.92	4012.08	1	31	44	43	35	5.68
14.38	2.97	4080.78	0	40	56	56	45	7.52
13.98	2.57	3531.18	1	40	56	56	45	7.52
14.06	2.65	3641.10	0	49	74	73	59	10.60
13.61	2.20	3022.80	1	49	74	73	59	10.60
13.73	2.32	3187.68	0	56	89	88	70	13.83
13.36	1.95	2679.30	1	56	89	88	70	13.83
13.44	2.03	2789.22	0	64	100	98	79	16.75
13.18	1.77	2431.98	1	64	100	98	79	16.75
13.24	1.83	2514.42	0	70	111	112	88	20.09
13.01	1.60	2198.40	1	70	111	112	88	20.09
13.04	1.63	2239.62	0	75	121	122	96	23.19
12.87	1.46	2006.04	1	75	121	122	96	23.19
12.91	1.50	2061.00	0	77	128	128	100	25.60
12.77	1.36	1868.64	1	77	128	128	100	25.60
12.78	1.37	1882.38	0	86	149	155	118	33.34
12.47	1.06	1456.44	1	86	149	155	118	33.34
12.32	0.91	1250.34	0	101	176	191	145	48.42
12.13	0.72	989.28	1	101	176	191	145	48.42
11.96	0.55	755.70	0	116	210	132	174	68.26
11.87	0.46	632.04	1	116	210	132	174	68.26
11.85	0.44	604.56	0	126	233	252	192	84.14
11.71	0.30	412.20	1	126	233	252	192	84.14
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data — Specimen No. P49B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.85	2.96	2.02	4.88	3.55	6.51
L/4	2.77		2.37	5.14	3.72	6.61
L/2	2.66		2.43	5.08	3.58	6.36
3L/4	2.55		2.32	4.87	3.59	6.30
L	2.39	2.47	2.27	4.66	3.79	6.26
Mean	2.64	2.72				
Taper	***Ratio:***	0.84	See Note 2	1-TR=	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.05	0.26	0.25	0.10	-0.03
Corrected	(in.)	0.00	0.30	0.30	0.14	0.00
Corrected	(mm)	0.0	7.6	7.5	3.5	0.0
OS/D				0.11		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
55	1	0.2470	2.44	4.20	1.72

Compression and Tension Zones

C (in.)	1.05	C/D	0.40
T(in.)	1.06	T/D	0.40
D(in.)	2.63		

Location of Fracture from Butt End(mm) 1368.43 mm

Twist (Degrees CCW or CW) 3 CW

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* P50A

Max Load (Lbf)=	4809.00	(kN) =	21.39

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				41.4	220.3	300.1	120.0	
11.40	0.00	0.00	0	0	0	0	0	0.00
11.60	0.20	274.80	0	0	0	0	0	0.91
11.58	0.18	247.32	1	0	0	0	0	0.91
12.35	0.95	1305.30	0	0	0	0	0	1.45
12.30	0.90	1236.60	1	0	0	0	0	1.45
13.65	2.25	3091.50	0	1	2	0	0	2.12
13.55	2.15	2954.10	1	1	2	0	0	2.12
14.55	3.15	4328.10	0	6	8	7	7	2.75
14.44	3.04	4176.96	1	6	8	7	7	2.75
14.90	3.50	4809.00	0	19	28	28	24	3.99
14.62	3.22	4424.28	1	19	28	28	24	3.99
14.65	3.25	4465.50	0	31	47	46	39	5.82
13.96	2.56	3517.44	1	31	47	46	39	5.82
14.03	2.63	3613.62	0	36	58	59	50	7.52
13.62	2.22	3050.28	1	36	58	59	50	7.52
13.71	2.31	3173.94	0	43	70	71	60	9.50
13.37	1.97	2706.78	1	43	70	71	60	9.50
13.43	2.03	2789.22	0	49	82	85	70	12.19
13.14	1.74	2390.76	1	49	82	85	70	12.19
13.20	1.80	2473.20	0	54	92	96	79	14.76
12.98	1.58	2170.92	1	54	92	96	79	14.76
13.03	1.63	2239.62	0	58	102	106	88	17.53
12.85	1.45	1992.30	1	58	102	106	88	17.53
12.90	1.50	2061.00	0	64	111	116	96	20.15
12.75	1.35	1854.90	1	64	111	116	96	20.15
12.77	1.37	1882.38	0	67	120	125	103	22.99
12.65	1.25	1717.50	1	67	120	125	103	22.99
12.67	1.27	1744.98	0	72	128	135	110	25.80
12.57	1.17	1607.58	1	72	128	135	110	25.80
12.30	0.90	1236.60	0	86	158	171	140	39.69
12.22	0.82	1126.68	1	86	158	171	140	39.69
11.65	0.25	343.50	0	104	195	226	180	60.33
11.63	0.23	316.02	1	104	195	226	180	60.33
**********	**********		**********	**********	**********	**********	**********	************

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P50A

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.93	3.02	2.12	5.05	3.53	6.55
L/4	2.91		2.03	4.94	3.54	6.55
L/2	2.72		2.23	4.95	3.54	6.29
3L/4	2.55		2.40	4.95	3.69	6.31
L	2.30	2.37	2.30	4.60	3.91	6.28
Mean	2.68	2.70				
Taper	*Ratio:*	0.78	See Note 2	1-TR=	0.22	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	-0.01	0.09	0.18	-0.05
Corrected	(in.)	0.00	-0.03	0.07	0.16	0.00
Corrected	(mm)	0.0	-0.8	1.9	4.0	0.0
OS/D				0.03		

Bending Stiffness

Load	Time	Defl'n	I @ L/2	EI	E
(Lbs)	(min.)	(in.)	(in.^4)	(lb-in^2)	(lb/in^2)
		(measured)	(calc.)	(x10^6)	(x10^6)
55	1	0.3052	2.68	3.40	1.27

Compression and Tension Zones

C (in.)	0.41	C/D	0.17
T(in.)	0.66	T/D	0.27
D(in.)	2.46		

Location of Fracture from Butt End(mm) 1355.73 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Reduced Deflection Data   *Specimen No.* **P50B**

Max Load (Lbf)=	12077.46	(kN) =	53.72

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.9	220.5	300.3	120.2	
11.45	0.00	0.00	0	0	0	0	0	0.00
13.13	1.68	2308.32	0	0	0	0	0	0.91
12.99	1.54	2115.96	1	0	0	0	0	0.91
14.74	3.29	4520.46	0	3	1	2	0	1.50
14.59	3.14	4314.36	1	3	1	2	0	1.50
16.70	5.25	7213.50	0	4	3	3	1	2.11
16.49	5.04	6924.96	1	4	3	3	1	2.11
18.89	7.44	10222.56	0	8	9	8	5	2.78
18.65	7.20	9892.80	1	8	9	8	5	2.78
20.24	8.79	12077.46	0	17	22	22	16	3.66
19.44	7.99	10978.26	1	17	22	22	16	3.66
19.55	8.10	11129.40	0	32	48	46	32	5.49
17.05	5.60	7694.40	1	32	48	46	32	5.49
17.31	5.86	8051.64	0	39	60	61	45	7.21
16.15	4.70	6457.80	1	39	60	61	45	7.21
16.49	5.04	6924.96	0	49	78	77	57	10.06
15.39	3.94	5413.56	1	49	78	77	57	10.06
15.75	4.30	5908.20	0	56	90	92	67	12.90
14.91	3.46	4754.04	1	56	90	92	67	12.90
15.30	3.85	5289.90	0	62	104	103	77	16.03
14.53	3.08	4231.92	1	62	104	103	77	16.03
14.92	3.47	4767.78	0	67	110	113	86	19.00
14.27	2.82	3874.68	1	67	110	113	86	19.00
14.58	3.13	4300.62	0	70	120	123	93	22.11
14.05	2.60	3572.40	1	70	120	123	93	22.11
14.36	2.91	3998.34	0	77	130	136	102	25.53
13.83	2.38	3270.12	1	77	130	136	102	25.53
14.15	2.70	3709.80	0	85	148	156	116	32.55
13.46	2.01	2761.74	1	85	148	156	116	32.55
13.74	2.29	3146.46	0	99	169	176	132	41.28
13.05	1.60	2198.40	1	99	169	176	132	41.28
12.17	0.72	989.28	0	109	205	217	156	55.56
12.03	0.58	796.92	1	109	205	217	156	55.56
12.23	0.78	1071.72	0	115	233	247	177	68.26
11.59	0.14	192.36	1	115	233	247	177	68.26

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. P50B

Location	Vertical (in)	End Dia (in) Note 1	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.52	3.59	1.83	5.35	3.20	6.79
L/4	3.50		1.95	5.45	3.28	6.80
L/2	3.45		1.89	5.35	3.24	6.73
3L/4	3.24		1.86	5.10	3.41	6.60
L	2.97	3.06	1.96	4.93	3.45	6.51
Mean	3.33	3.33				
Taper	***Ratio:***	0.85	See Note 2	1-TR=	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.20	0.12	-0.02	-0.06
Corrected	(in.)	0.00	0.18	0.10	-0.04	0.00
Corrected	(mm)	0.0	4.6	2.6	-1.0	0.0
OS/D				0.03		

Bending Stiffness

Load (Lbs)	Time (min.)	Defl'n (in.) (measured)	I @ L/2 (in.^4) (calc.)	EI (lb-in^2) (x10^6)	E (lb/in^2) (x10^6)
73	1	0.1740	6.98	7.91	1.13

Compression and Tension Zones

C (in.)	1.10	C/D	0.35
T(in.)	1.33	T/D	0.42
D(in.)	3.19		

Location of Fracture from Butt End(mm) 1317.63 mm

Twist (Degrees CCW or CW) 0

Note: 1 Only the horizontal diameters at the ends are true dimensions
Out-of-straightness may not make horizontal difference between D2 and D4 valid at the horizontal centre line diameter at L/4, L/2, & 3L/4

Note: 2 Taper Ratio calculated as:

$$\frac{\text{Mean of Horizontal and Vertical Diameters at L=L}}{\text{Mean of Horizontal and Vertical Diameters at L=0}}$$

Maximum value TR can have is 1.0

Measurement Data Only

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 5A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.59	2.64	2.27	4.86	3.63	6.27
L/4	2.46		2.45	4.91	3.94	6.49
L/2	2.27		2.53	4.80	3.82	6.17
3L/4	2.35		2.42	4.76	3.96	6.07
L	1.81	1.78	2.58	4.39	4.10	5.88
Mean	2.29	2.21				
Taper	***Ratio:***	0.69		1-TR =	0.31	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.07	0.18	0.17	0.09	-0.02
Corrected	(in.)	0.00	0.16	0.14	0.06	0.00
Corrected	(mm)	0.0	3.9	3.6	1.6	0.0
OS/D				0.06		

Measuring Apparatus Data

Specimen No. 6A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.39	2.55	2.37	4.75	3.81	6.36
L/4	2.27		2.15	4.42	3.59	6.03
L/2	2.08		2.58	4.65	3.63	5.91
3L/4	1.98		2.29	4.27	3.79	6.03
L	1.70	1.95	2.59	4.29	4.12	6.07
Mean	2.08	2.25				
Taper	***Ratio:***	0.74		1-TR =	0.26	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	-0.21	0.11	-0.22	-0.06
Corrected	(in.)	0.00	-0.21	0.11	-0.22	0.00
Corrected	(mm)	0.0	-5.4	2.8	-5.6	0.0
OS/D				0.05		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **11A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.58	2.79	2.23	4.81	3.60	6.39
L/4	2.34		2.41	4.74	4.18	6.64
L/2	2.25		2.64	4.89	4.10	6.43
3L/4	1.95		3.04	4.99	4.16	6.10
L	1.61	1.76	2.72	4.33	4.14	5.90
Mean	2.15	2.28				
Taper	***Ratio:***	0.63		1-TR =	0.37	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.02	0.07	0.27	0.52	0.02
Corrected	(in.)	0.00	0.05	0.25	0.49	0.00
Corrected	(mm)	0.0	1.3	6.3	12.5	0.0
OS/D				0.11		

Measuring Apparatus Data

Specimen No. **13B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.39	2.55	2.30	4.69	3.75	6.30
L/4	2.41		2.48	4.89	3.59	6.13
L/2	2.41		2.80	5.22	3.72	6.02
3L/4	2.24		3.01	5.25	3.86	6.02
L	2.06	2.16	2.42	4.48	3.95	6.11
Mean	2.30	2.36				
Taper	***Ratio:***	0.85		1-TR =	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.18	0.51	0.63	-0.05
Corrected	(in.)	0.00	0.21	0.54	0.66	0.00
Corrected	(mm)	0.0	5.4	13.6	16.7	0.0
OS/D				0.22		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 13A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.08	2.17	2.61	4.69	3.93	6.09
L/4	1.93		2.54	4.47	3.81	5.95
L/2	1.91		2.63	4.55	4.11	6.17
3L/4	1.81		3.11	4.92	3.71	5.38
L	1.71	1.84	2.56	4.27	4.07	5.91
Mean	1.89	2.00				
Taper	***Ratio:***	0.84		1-TR =	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.15	0.01	0.09	0.52	-0.09
Corrected	(in.)	0.00	-0.03	0.06	0.49	0.00
Corrected	(mm)	0.0	-0.6	1.5	12.4	0.0
OS/D				0.03		

Measuring Apparatus Data

Specimen No. 15A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.31	2.46	2.41	4.73	3.75	6.21
L/4	2.35		2.65	4.99	3.91	6.28
L/2	2.14		3.17	5.31	4.17	5.78
3L/4	2.04		2.83	4.87	4.20	6.07
L	1.70	1.82	2.60	4.30	4.15	5.97
Mean	2.11	2.14				
Taper	***Ratio:***	0.74		1-TR =	0.26	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.07	0.32	0.74	0.35	-0.05
Corrected	(in.)	0.00	0.31	0.74	0.34	0.00
Corrected	(mm)	0.0	8.0	18.7	8.7	0.0
OS/D				0.34		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 16A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.73	2.82	2.21	4.94	3.73	6.55
L/4	2.37		2.38	4.75	3.91	6.53
L/2	2.18		2.41	4.59	4.13	6.48
3L/4	1.89		2.86	4.75	4.28	6.23
L	1.61	1.68	2.65	4.27	4.15	5.83
Mean	2.15	2.25				
Taper	***Ratio:***	0.59		1-TR =	0.41	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.08	0.06	-0.00	0.31	-0.04
Corrected	(in.)	0.00	0.04	-0.02	0.29	0.00
Corrected	(mm)	0.0	1.1	-0.5	7.3	0.0
OS/D				-0.01		

Measuring Apparatus Data

Specimen No. 17A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	1.99	2.08	2.50	4.49	3.91	5.99
L/4	2.00		2.57	4.57	3.91	6.01
L/2	1.86		2.76	4.61	4.19	6.05
3L/4	1.76		2.65	4.41	4.25	6.11
L	1.63	1.78	2.66	4.29	4.17	5.95
Mean	1.85	1.93				
Taper	***Ratio:***	0.84		1-TR =	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.00	0.07	0.18	0.03	-0.02
Corrected	(in.)	0.00	0.08	0.20	0.04	0.00
Corrected	(mm)	0.0	2.1	5.0	1.1	0.0
OS/D				0.11		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **17B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.28	2.38	2.45	4.73	3.85	6.23
L/4	2.30		2.78	5.08	3.87	6.18
L/2	2.16		2.85	5.01	3.96	6.22
3L/4	2.06		2.63	4.68	4.24	6.38
L	1.99	2.09	2.42	4.42	4.03	6.13
Mean	2.16	2.24				
Taper Ratio:		0.88		1-TR =	0.12	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.43	0.43	0.15	-0.08
Corrected	(in.)	0.00	0.43	0.43	0.15	0.00
Corrected	(mm)	0.0	10.8	10.8	3.8	0.0
OS/D				0.20		

Measuring Apparatus Data

Specimen No. **19A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.65	2.70	2.28	4.93	3.63	6.33
L/4	2.47		2.58	5.05	3.65	6.26
L/2	2.34		2.81	5.15	3.77	6.07
3L/4	2.16		3.17	5.33	4.11	6.09
L	1.88	2.02	2.57	4.45	4.06	6.08
Mean	2.30	2.36				
Taper Ratio:		0.73		1-TR =	0.27	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.10	0.32	0.48	0.75	0.01
Corrected	(in.)	0.00	0.26	0.42	0.69	0.00
Corrected	(mm)	0.0	6.6	10.7	17.6	0.0
OS/D				0.18		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **26A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.65	2.77	2.18	4.83	3.75	6.52
L/4	2.46		2.45	4.90	3.82	6.43
L/2	2.09		2.81	4.90	3.74	5.92
3L/4	2.01		2.89	4.90	4.11	6.04
L	1.55	1.67	2.70	4.25	4.18	5.85
Mean	2.15	2.22				
Taper	***Ratio:***	0.59		1-TR =	0.41	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.01	0.18	0.36	0.39	-0.02
Corrected	(in.)	0.00	0.18	0.37	0.40	0.00
Corrected	(mm)	0.0	4.7	9.3	10.2	0.0
OS/D				0.18		

Measuring Apparatus Data

Specimen No. **32A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.20	2.31	2.55	4.75	3.89	6.20
L/4	2.05		2.53	4.59	4.03	6.19
L/2	1.89		2.88	4.77	4.01	5.97
3L/4	1.83		2.45	4.28	4.00	5.85
L	1.41	1.44	2.72	4.13	4.31	5.75
Mean	1.88	1.87				
Taper	***Ratio:***	0.63		1-TR =	0.37	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.15	0.06	0.33	-0.14	-0.08
Corrected	(in.)	0.00	0.02	0.29	-0.18	0.00
Corrected	(mm)	0.0	0.6	7.3	-4.5	0.0
OS/D				0.15		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 30A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.83	2.85	2.25	5.08	3.51	6.36
L/4	2.74		2.69	5.43	3.55	6.22
L/2	2.67		2.61	5.27	3.48	6.18
3L/4	2.50		2.42	4.91	3.59	6.19
L	2.24	2.33	2.43	4.67	3.90	6.24
Mean	2.59	2.59				
Taper	***Ratio:***	0.81		1-TR =	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.16	0.56	0.44	0.17	0.05
Corrected	(in.)	0.00	0.45	0.33	0.06	0.00
Corrected	(mm)	0.0	11.5	8.5	1.6	0.0
OS/D				0.13		

Measuring Apparatus Data

Specimen No. 32B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.75	2.92	2.22	4.97	3.55	6.47
L/4	2.64		2.85	5.49	4.14	6.82
L/2	2.55		2.91	5.46	3.54	6.08
3L/4	2.40		2.32	4.72	3.59	6.15
L	2.13	2.35	2.41	4.54	3.84	6.19
Mean	2.49	2.64				
Taper	***Ratio:***	0.79		1-TR =	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.09	0.67	0.68	0.02	-0.03
Corrected	(in.)	0.00	0.64	0.65	-0.01	0.00
Corrected	(mm)	0.0	16.2	16.5	-0.3	0.0
OS/D				0.25		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 35A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.75	2.81	2.19	4.94	3.64	6.45
L/4	2.49		2.76	5.26	3.69	6.27
L/2	2.23		3.04	5.27	3.89	5.96
3L/4	1.90		3.28	5.18	4.01	5.72
L	1.48	1.51	2.77	4.25	4.26	5.78
Mean	2.17	2.16				
Taper	***Ratio:***	0.54		1-TR =	0.46	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.51	0.66	0.73	0.01
Corrected	(in.)	0.00	0.47	0.62	0.69	0.00
Corrected	(mm)	0.0	12.0	15.8	17.5	0.0
OS/D				0.28		

Measuring Apparatus Data

Specimen No. 35B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.68	3.83	1.57	5.25	3.04	6.87
L/4	3.54		1.67	5.21	2.98	6.69
L/2	3.24		2.05	5.29	3.19	6.59
3L/4	3.03		2.28	5.31	3.23	6.39
L	2.73	2.80	2.18	4.91	3.59	6.39
Mean	3.24	3.32				
Taper	***Ratio:***	0.74		1-TR =	0.26	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.09	-0.06	0.17	0.30	0.05
Corrected	(in.)	0.00	-0.05	0.19	0.32	0.00
Corrected	(mm)	0.0	-1.1	4.8	8.0	0.0
OS/D				0.06		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **37B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.92	2.94	1.99	4.91	3.59	6.53
L/4	2.97		2.26	5.23	3.68	6.58
L/2	2.83		2.44	5.27	4.01	6.78
3L/4	2.68		2.71	5.39	3.99	6.55
L	2.50	2.50	2.23	4.72	3.83	6.33
Mean	2.78	2.72				
Taper	***Ratio:***	0.85		1-TR =	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.05	0.24	0.36	0.55	-0.03
Corrected	(in.)	0.00	0.28	0.40	0.59	0.00
Corrected	(mm)	0.0	7.1	10.1	15.0	0.0
OS/D				0.14		

Measuring Apparatus Data

Specimen No. **38B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.90	2.95	2.11	5.01	3.60	6.55
L/4	2.91		2.09	5.00	3.44	6.46
L/2	2.74		2.42	5.16	3.61	6.42
3L/4	2.69		2.23	4.92	3.77	6.52
L	2.52	2.56	2.19	4.71	3.91	6.47
Mean	2.75	2.75				
Taper	***Ratio:***	0.87		1-TR =	0.13	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.04	0.29	0.07	-0.05
Corrected	(in.)	0.00	0.04	0.28	0.07	0.00
Corrected	(mm)	0.0	1.0	7.2	1.8	0.0
OS/D				0.10		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 43B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.98	3.02	2.11	5.09	3.55	6.57
L/4	2.92		2.45	5.37	3.88	6.89
L/2	1.82		2.79	4.62	3.95	6.57
3L/4	2.74		2.42	5.17	3.47	6.15
L	2.54	2.66	2.26	4.81	3.71	6.37
Mean	2.60	2.84				
Taper	***Ratio:***	0.87		1-TR =	0.13	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.10	0.41	0.20	0.29	0.03
Corrected	(in.)	0.00	0.34	0.14	0.23	0.00
Corrected	(mm)	0.0	8.6	3.4	5.7	0.0
OS/D				0.07		

Measuring Apparatus Data

Specimen No. 45B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.91	3.07	2.05	4.95	3.47	6.54
L/4	2.92		2.31	5.23	3.87	6.97
L/2	2.79		3.00	5.78	3.89	6.51
3L/4	2.71		2.60	5.31	3.89	6.65
L	2.58	2.66	2.24	4.81	3.77	6.43
Mean	2.78	2.87				
Taper	***Ratio:***	0.88		1-TR =	0.12	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.00	0.27	0.89	0.46	0.02
Corrected	(in.)	0.00	0.26	0.88	0.44	0.00
Corrected	(mm)	0.0	6.6	22.3	11.2	0.0
OS/D				0.31		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 47A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.32	2.28	2.50	4.82	4.00	6.28
L/4	2.21		2.74	4.96	3.93	6.13
L/2	1.98		2.79	4.77	3.84	5.83
3L/4	1.92		2.67	4.59	3.93	5.89
L	1.75	1.83	2.61	4.36	4.10	5.93
Mean	2.04	2.05				
Taper Ratio:		0.78		1-TR =	0.22	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.16	0.35	0.28	0.13	-0.02
Corrected	(in.)	0.00	0.28	0.21	0.06	0.00
Corrected	(mm)	0.0	7.1	5.3	1.5	0.0
OS/D				0.11		

Measuring Apparatus Data

Specimen No. 49A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.30	2.46	2.49	4.79	3.82	6.28
L/4	2.15		2.93	5.09	4.12	6.33
L/2	2.04		2.98	5.02	4.13	6.16
3L/4	1.85		2.76	4.61	4.19	6.05
L	1.66	1.76	2.69	4.35	4.15	5.91
Mean	2.00	2.11				
Taper Ratio:		0.72		1-TR =	0.28	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.14	0.51	0.50	0.18	0.02
Corrected	(in.)	0.00	0.43	0.42	0.11	0.00
Corrected	(mm)	0.0	10.9	10.8	2.7	0.0
OS/D				0.21		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **51A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.44	2.46	2.46	4.90	3.69	6.15
L/4	2.33		2.69	5.02	3.77	6.04
L/2	2.30		2.57	4.87	3.95	6.06
3L/4	2.16		2.60	4.75	4.05	6.25
L	1.93	1.95	2.52	4.45	4.10	6.05
Mean	2.23	2.21				
Taper	***Ratio:***	0.79		1-TR =	0.21	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.18	0.35	0.22	0.18	-0.02
Corrected	(in.)	0.00	0.27	0.14	0.09	0.00
Corrected	(mm)	0.0	6.9	3.5	2.4	0.0
OS/D				0.06		

Measuring Apparatus Data

Specimen No. **51B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.73	2.90	2.12	4.85	3.51	6.41
L/4	2.68		2.61	5.29	3.47	6.26
L/2	2.59		2.66	5.25	3.61	6.20
3L/4	2.23		2.75	4.98	3.66	6.14
L	2.36	2.48	2.39	4.75	3.65	6.13
Mean	2.52	2.69				
Taper	***Ratio:***	0.86		1-TR =	0.14	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.45	0.45	0.36	0.07
Corrected	(in.)	0.00	0.42	0.43	0.34	0.00
Corrected	(mm)	0.0	10.7	10.9	8.5	0.0
OS/D				0.17		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 52A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.41	2.57	2.27	4.68	3.83	6.40
L/4	2.26		2.51	4.77	3.85	6.29
L/2	2.14		2.67	4.81	3.85	6.09
3L/4	2.11		2.43	4.54	3.88	6.02
L	1.78	1.93	2.59	4.37	4.01	5.94
Mean	2.14	2.25				
Taper	**Ratio:**	0.75		1-TR =	0.25	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.02	0.14	0.24	-0.02	-0.02
Corrected	(in.)	0.00	0.16	0.26	0.00	0.00
Corrected	(mm)	0.0	4.1	6.7	0.1	0.0
OS/D				0.12		

Measuring Apparatus Data

Specimen No. 52B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.94	3.05	2.06	5.01	3.55	6.60
L/4	2.92		2.45	5.38	3.69	6.55
L/2	2.77		2.52	5.29	3.47	6.30
3L/4	2.53		2.20	4.73	3.50	6.20
L	2.44	2.59	2.19	4.63	3.72	6.30
Mean	2.72	2.82				
Taper	**Ratio:**	0.84		1-TR =	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.41	0.40	-0.03	-0.09
Corrected	(in.)	0.00	0.44	0.43	-0.01	0.00
Corrected	(mm)	0.0	11.2	11.0	-0.1	0.0
OS/D				0.16		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **53A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.49	2.64	2.24	4.74	3.81	6.45
L/4	2.38		2.89	5.27	4.01	6.23
L/2	2.17		2.98	5.15	4.03	6.16
3L/4	2.12		2.69	4.81	3.83	5.96
L	1.83	1.89	2.57	4.41	4.13	6.02
Mean	2.20	2.27				
Taper	***Ratio:***	0.73		1-TR =	0.27	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.01	0.58	0.57	0.25	-0.01
Corrected	(in.)	0.00	0.59	0.58	0.26	0.00
Corrected	(mm)	0.0	14.9	14.6	6.6	0.0
OS/D				0.27		

Measuring Apparatus Data

Specimen No. **53B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.00	2.99	1.99	5.00	3.48	6.47
L/4	2.90		2.62	5.51	3.25	6.18
L/2	2.81		2.37	5.18	3.59	6.32
3L/4	2.63		2.42	5.05	3.69	6.37
L	2.49	2.55	2.27	4.76	3.81	6.36
Mean	2.77	2.77				
Taper	***Ratio:***	0.84		1-TR =	0.16	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	-0.00	0.56	0.27	0.23	0.02
Corrected	(in.)	0.00	0.56	0.27	0.23	0.00
Corrected	(mm)	0.0	14.2	6.7	5.8	0.0
OS/D				0.09		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 54A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.25	2.12	2.54	4.79	4.01	6.13
L/4	2.03		3.23	5.25	4.30	5.98
L/2	1.79		3.24	5.03	4.50	6.05
3L/4	1.68		3.11	4.79	4.50	5.98
L	1.51	1.67	2.74	4.25	4.22	5.89
Mean	1.85	1.90				
Taper	***Ratio:***	0.73		1-TR =	0.27	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.16	0.74	0.64	0.45	-0.00
Corrected	(in.)	0.00	0.66	0.56	0.37	0.00
Corrected	(mm)	0.0	16.8	14.2	9.4	0.0
OS/D				0.31		

Measuring Apparatus Data

Specimen No. 54B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.74	2.75	2.25	4.99	3.67	6.42
L/4	2.57		2.65	5.21	3.84	6.49
L/2	2.39		2.69	5.08	3.90	6.31
3L/4	2.37		2.52	4.89	3.85	6.27
L	2.02	2.26	2.57	4.59	3.87	6.13
Mean	2.42	2.51				
Taper	***Ratio:***	0.78		1-TR =	0.22	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.12	0.43	0.39	0.20	0.08
Corrected	(in.)	0.00	0.33	0.29	0.10	0.00
Corrected	(mm)	0.0	8.4	7.3	2.6	0.0
OS/D				0.12		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **55A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.53	2.62	2.36	4.89	3.61	6.23
L/4	2.46		2.41	4.87	3.74	6.28
L/2	2.42		2.75	5.17	3.78	6.24
3L/4	2.31		2.53	4.84	3.93	6.27
L	2.04	2.18	2.58	4.62	3.79	5.96
Mean	2.35	2.40				
Taper	***Ratio:***	0.82		1-TR =	0.18	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.13	0.14	0.46	0.18	0.10
Corrected	(in.)	0.00	0.03	0.35	0.07	0.00
Corrected	(mm)	0.0	0.8	8.9	1.8	0.0
OS/D				0.14		

Measuring Apparatus Data

Specimen No. **55B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.18	3.15	2.05	5.23	3.56	6.71
L/4	3.04		2.15	5.19	3.26	6.36
L/2	2.89		2.28	5.17	3.46	6.40
3L/4	2.81		1.75	4.56	3.35	6.19
L	2.57	2.57	2.13	4.69	3.76	6.33
Mean	2.90	2.86				
Taper	***Ratio:***	0.81		1-TR =	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.14	0.17	0.22	-0.35	-0.09
Corrected	(in.)	0.00	0.15	0.20	-0.37	0.00
Corrected	(mm)	0.0	3.8	5.0	-9.4	0.0
OS/D				0.07		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. **56A**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.57	2.52	2.35	4.91	3.81	6.33
L/4	2.30		2.87	5.17	4.13	6.35
L/2	2.09		3.05	5.13	4.22	6.04
3L/4	1.83		3.09	4.93	4.21	5.93
L	1.51	1.61	2.73	4.24	4.22	5.83
Mean	2.06	2.07				
Taper	***Ratio:***	0.61		1-TR =	0.39	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.13	0.52	0.59	0.51	-0.02
Corrected	(in.)	0.00	0.46	0.53	0.45	0.00
Corrected	(mm)	0.0	11.7	13.5	11.5	0.0
OS/D				0.25		

Measuring Apparatus Data

Specimen No. **56B**

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.14	3.07	1.97	5.11	3.45	6.53
L/4	3.02		2.31	5.33	3.43	6.36
L/2	2.96		2.39	5.36	3.58	6.40
3L/4	2.68		2.47	5.15	3.66	6.29
L	2.53	2.51	2.26	4.80	3.65	6.17
Mean	2.87	2.79				
Taper	***Ratio:***	0.81		1-TR =	0.19	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.32	0.37	0.31	0.03
Corrected	(in.)	0.00	0.28	0.34	0.27	0.00
Corrected	(mm)	0.0	7.2	8.6	7.0	0.0
OS/D				0.11		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 57A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.62	2.58	2.23	4.85	3.69	6.28
L/4	2.44		2.89	5.32	4.11	6.35
L/2	2.38		2.71	5.09	3.92	6.18
3L/4	2.24		2.17	4.41	3.75	6.11
L	1.98	2.20	2.64	4.61	3.97	6.17
Mean	2.33	2.39				
Taper Ratio:		0.80		1-TR =	0.20	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.04	0.61	0.40	-0.21	0.12
Corrected	(in.)	0.00	0.52	0.32	-0.29	0.00
Corrected	(mm)	0.0	13.3	8.0	-7.4	0.0
OS/D				0.13		

Measuring Apparatus Data

Specimen No. 57B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.87	2.86	2.26	5.13	3.41	6.27
L/4	2.84		2.67	5.52	3.49	6.26
L/2	1.75		3.83	5.58	3.71	6.30
3L/4	2.73		2.29	5.01	3.67	6.53
L	2.56	2.58	2.34	4.90	3.73	6.31
Mean	2.55	2.72				
Taper Ratio:		0.90		1-TR =	0.10	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.19	0.59	1.20	0.15	0.12
Corrected	(in.)	0.00	0.44	1.05	-0.01	0.00
Corrected	(mm)	0.0	11.1	26.6	-0.1	0.0
OS/D				0.60		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 59A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.05	3.13	2.04	5.09	3.59	6.72
L/4	3.02		2.30	5.31	3.79	6.76
L/2	2.81		2.43	5.24	3.48	6.28
3L/4	2.71		2.30	5.01	3.47	6.07
L	2.33	2.38	2.35	4.69	3.79	6.18
Mean	2.79	2.76				
Taper	***Ratio:***	0.76		1-TR =	0.24	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.06	0.30	0.34	0.15	0.02
Corrected	(in.)	0.00	0.26	0.30	0.11	0.00
Corrected	(mm)	0.0	6.7	7.5	2.8	0.0
OS/D				0.10		

Measuring Apparatus Data

Specimen No. 59B

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.57	3.53	1.79	5.37	3.05	6.58
L/4	3.53		1.95	5.48	3.33	6.75
L/2	3.38		1.83	5.21	3.29	6.68
3L/4	3.25		1.99	5.24	3.45	6.68
L	2.99	3.07	2.09	5.08	3.60	6.67
Mean	3.35	3.30				
Taper	***Ratio:***	0.85		1-TR =	0.15	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.08	0.21	0.02	0.11	0.08
Corrected	(in.)	0.00	0.13	-0.06	0.03	0.00
Corrected	(mm)	0.0	3.3	-1.5	0.8	0.0
OS/D				-0.02		

Reduced Measuring Apparatus Data:

Measuring Apparatus Data

Specimen No. 60A

Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	2.36	2.47	2.39	4.75	3.80	6.27
L/4	2.28		2.47	4.75	3.91	6.35
L/2	2.19		2.54	4.73	3.89	6.15
3L/4	1.96		2.59	4.55	3.99	6.07
L	1.67	1.86	2.72	4.39	4.13	5.99
Mean	2.09	2.17				
Taper	***Ratio:***	0.73		1-TR =	0.27	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.07	0.11	0.14	0.07	0.06
Corrected	(in.)	0.00	0.05	0.07	0.01	0.00
Corrected	(mm)	0.0	1.2	1.9	0.2	0.0
OS/D				0.03		

Measuring Apparatus Data

Specimen No. 60B

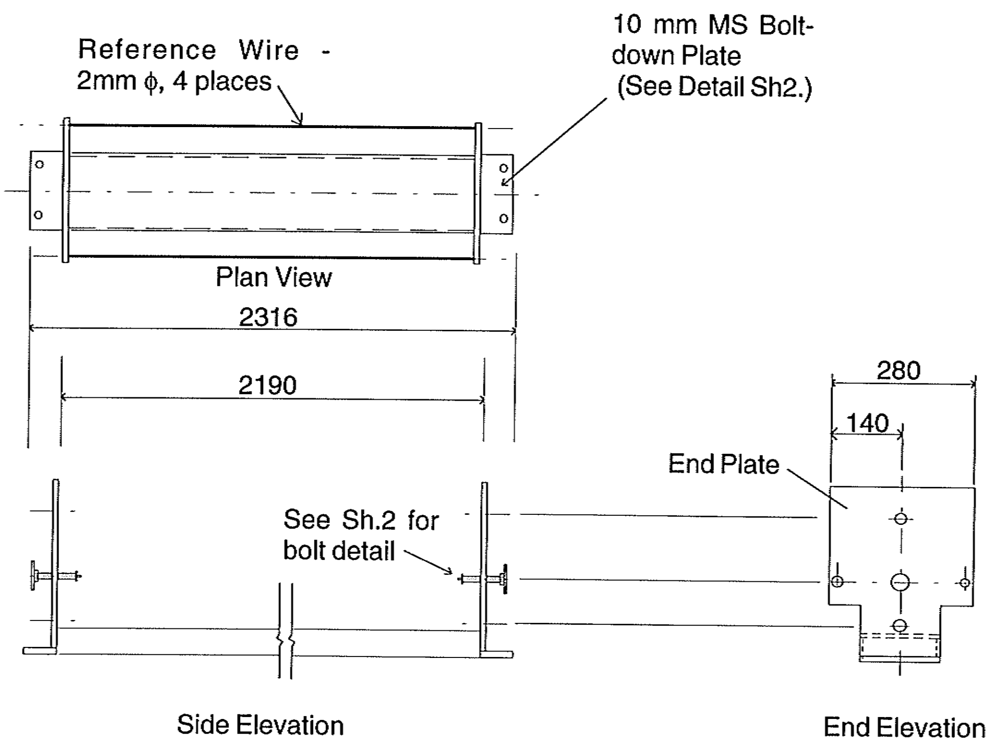
Location	Vertical (in)	End Dia (in)	D3 (in)	D3+Vert (in)	D4 (in)	D4+Hor (in)
O	3.04	3.08	2.13	5.17	3.49	6.56
L/4	3.03		2.11	5.13	3.37	6.37
L/2	2.86		2.18	5.04	3.45	6.26
3L/4	2.68		2.23	4.91	3.59	6.24
L	2.41	2.46	2.29	4.69	3.77	6.23
Mean	2.80	2.77				
Taper	***Ratio:***	0.80		1-TR =	0.20	

Out-of-Straightness

		0	L/4	L/2	3L/4	L
Location	(in.)	0.00	20.75	41.50	62.25	83.00
Variance	(in.)	0.15	0.12	0.11	0.07	-0.01
Corrected	(in.)	0.00	0.05	0.04	-0.00	0.00
Corrected	(mm)	0.0	1.2	1.0	-0.0	0.0
OS/D				0.01		

B

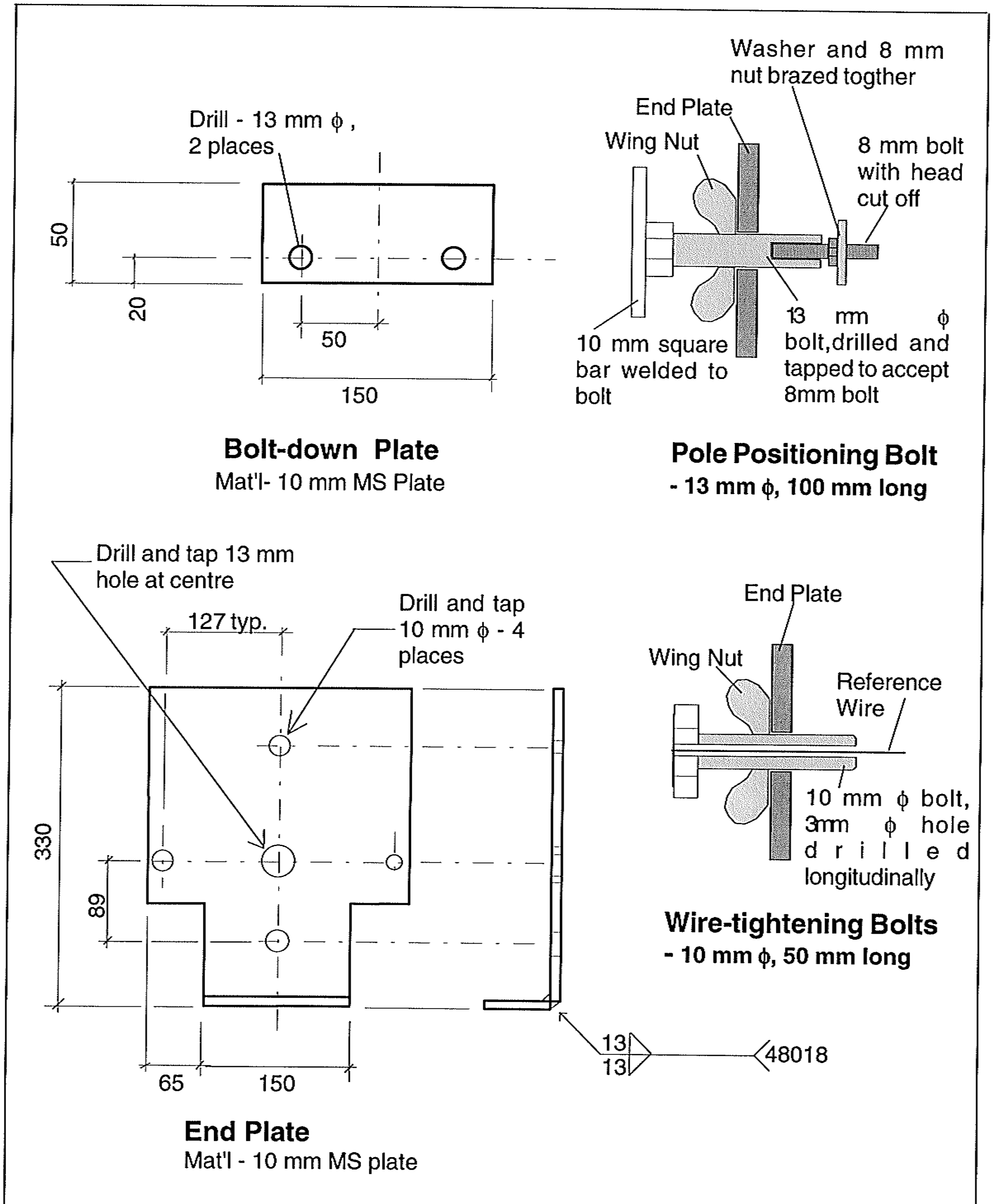
Design Drawings



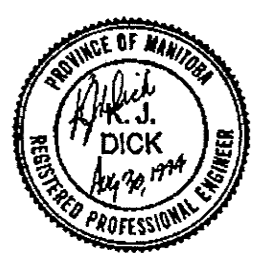
General Arrangement

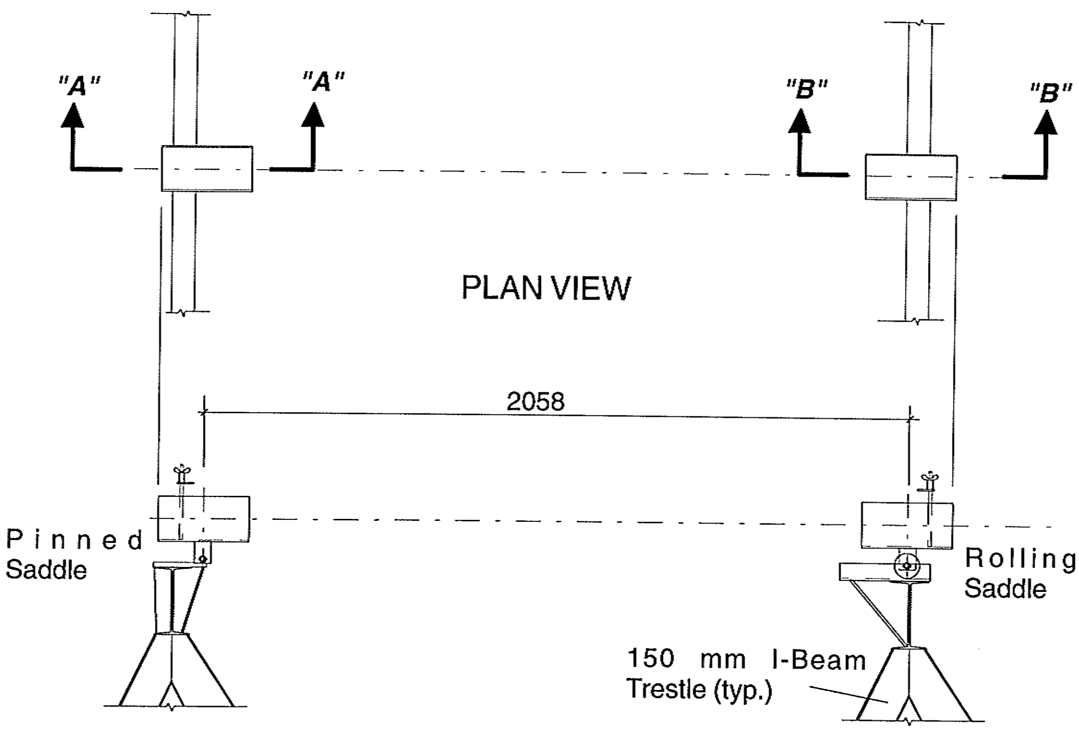
Title: **Measuring Apparatus**
General Arrangement
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. **B1** **Sh. 1 of 2**
Scale: NTS

PROVINCE OF MANITOBA
K.J. DICK
REGISTERED PROFESSIONAL ENGINEER



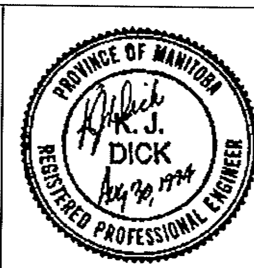
Title: Measuring Apparatus Details
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B1 **Sh. 2 of 2**
Scale: NTS

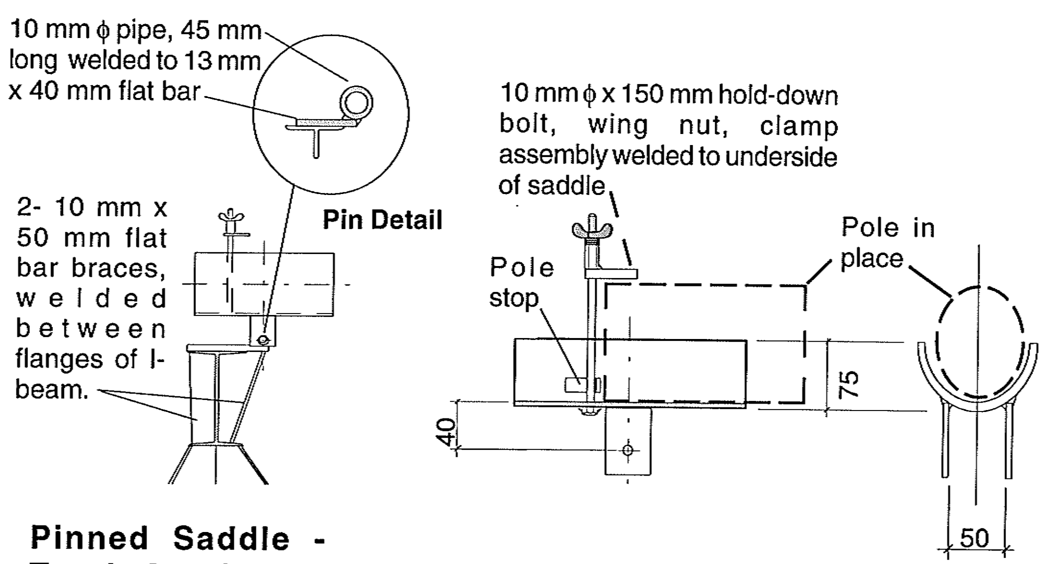




GENERAL ARRANGEMENT

Title: Bending Test Apparatus -General Arrangement
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B2 **Sh. 1 of 2**
Scale: NTS

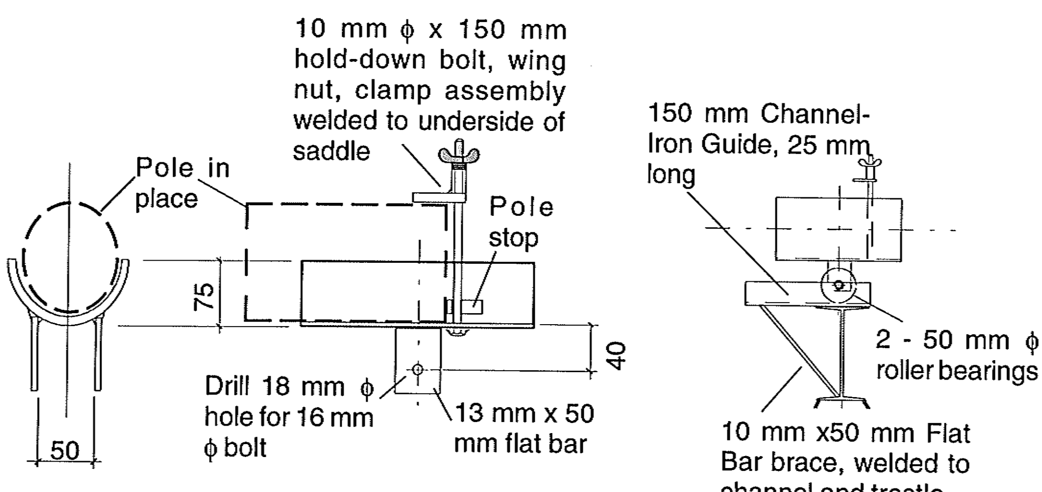




Pinned Saddle - Trestle Attachment

***Section "A-A"* - PINNED SADDLE**

PINNED SADDLE

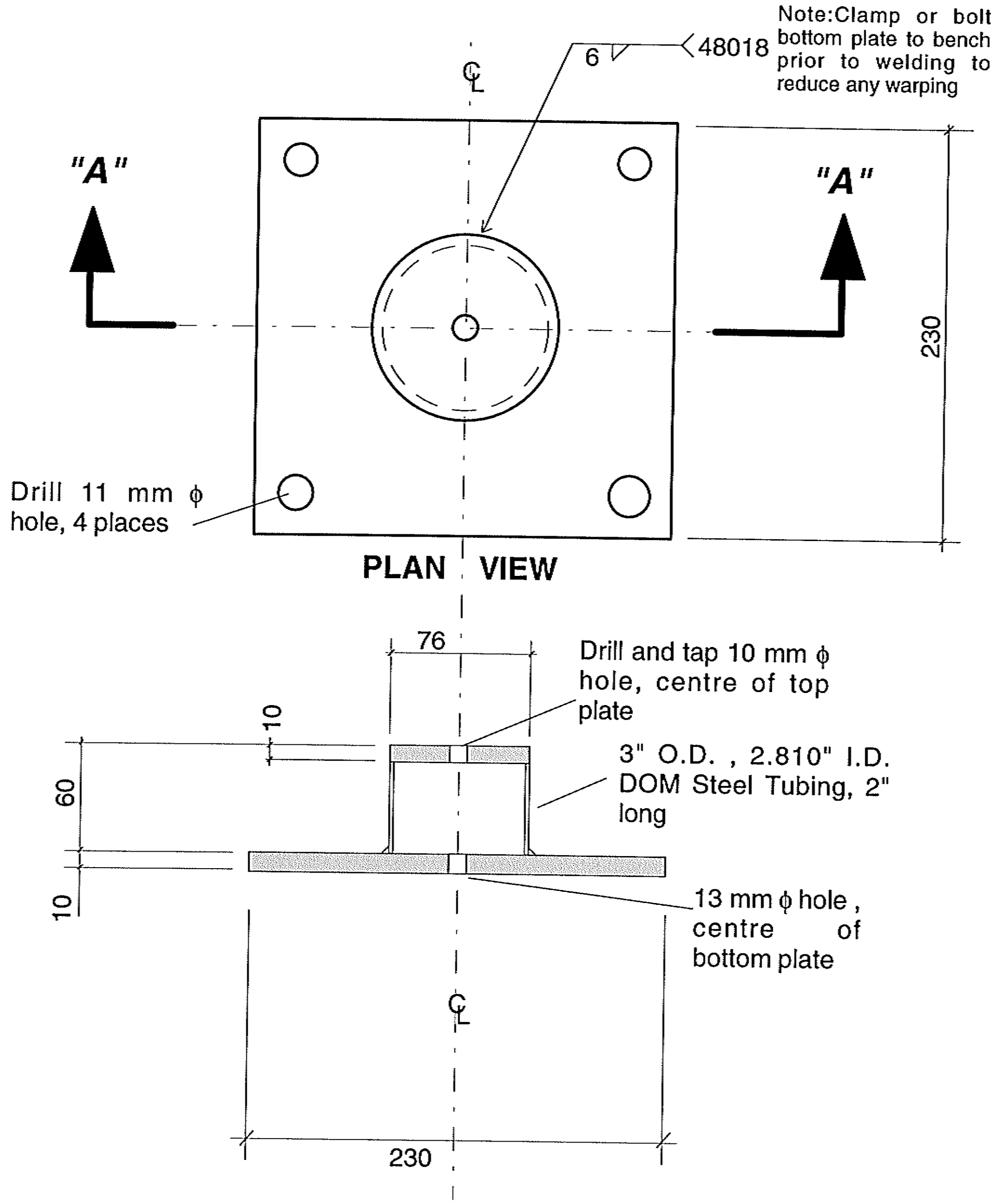


***Section "B-B"* - ROLLING SADDLE**

ROLLING SADDLE

Title: **Bending Test Apparatus - Details**
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B2 **Sh. 2 of 2**
Scale: NTS

PROVINCE OF MANITOBA REGISTERED PROFESSIONAL ENGINEER K.J. DICK Aug 30, 1994



Section "A-A"

Title: Load Cell

Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B3 **Sh. 1 of 2**
Scale: NTS

PROVINCE OF MANITOBA
K.J. DICK
REGISTERED PROFESSIONAL ENGINEER

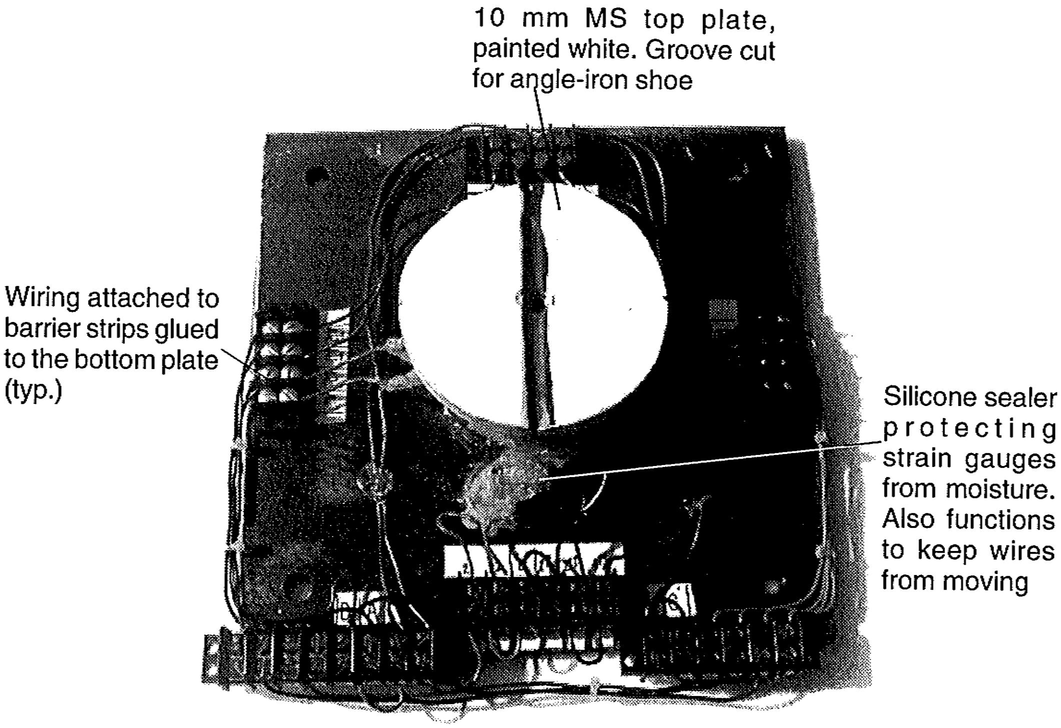


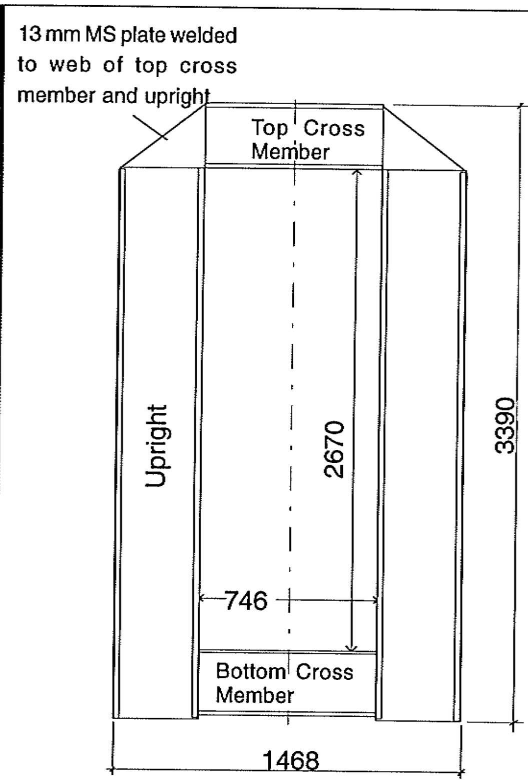
Photo of Load Cell Arrangement showing wiring.

Title: Load Cell
- As built, showing wiring

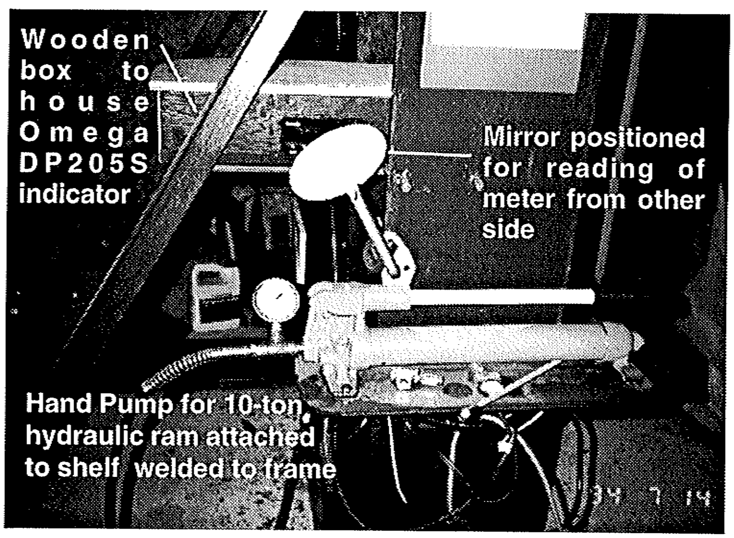
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B3 — **Sh. 2 of 2**
Scale: n.a.

PROVINCE OF MANITOBA
K.J. DICK
REGISTERED PROFESSIONAL ENGINEER

General Arrangement of Test Frame



OVERALL DIMENSIONS



Title: Column Test Frame -General Features

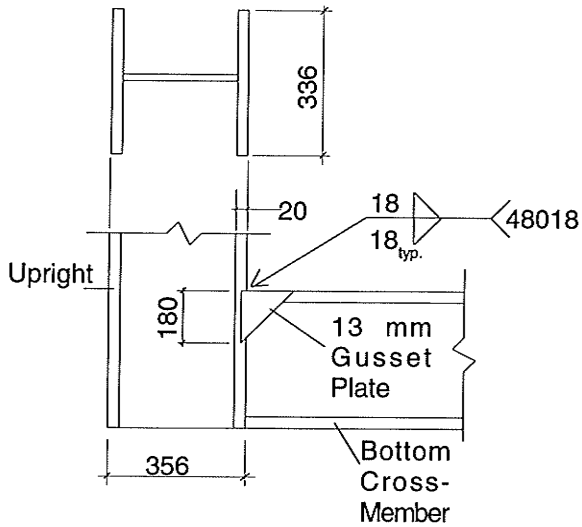
Designed By: K.J. Dick

Drawn By: K.J. Dick

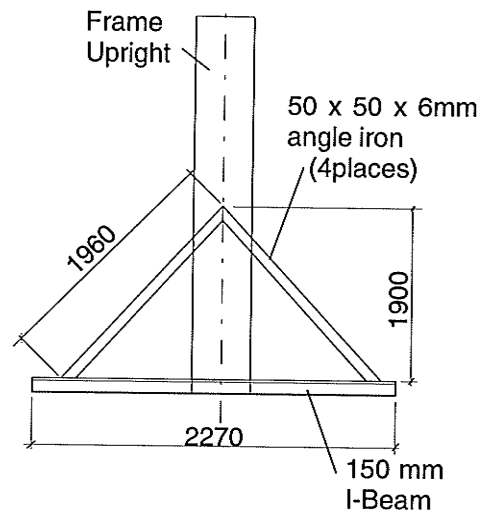
Drawing No. B4 **Sh. 1 of 2**

Scale: NTS

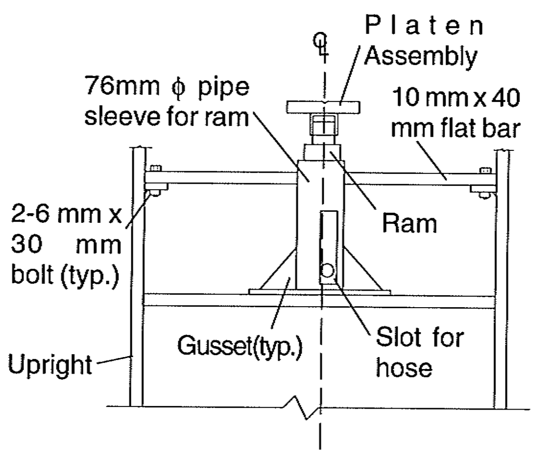
PROVINCE OF MANITOBA K.J. DICK REGISTERED PROFESSIONAL ENGINEER Aug 30, 1994



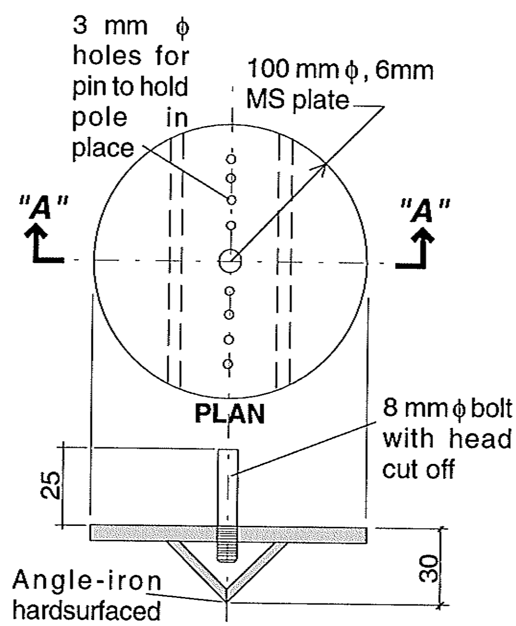
Bottom Cross-Member to Upright Connection (typ.)



Frame Braces



HYDRAULIC RAM PLACEMENT



SECTION "A-A"

ANGLE-IRON SHOE

Title: Column Test Frame -Details
Designed By: K.J. Dick
Drawn By: K.J. Dick
Drawing No. B4 **Sh. 2 of 2**
Scale: NTS

PROVINCE OF MANITOBA
K. J. DICK
REGISTERED PROFESSIONAL ENGINEER

C

Strain Energy

Appendix - C :

Strain Energy Calculations Related to Column Test Frame.

The strain energy in the frame compared with that going into the specimen is calculated below. The following calculations are based on standard references related to the strength of materials. (eg. Timoshenko, 1972; Miller, 1963)

First, the energy stored in a 3" diameter, timber pole, 84" long was determined for a load of 20,000 lbs. It was assumed that the pole was still in the elastic region at this load. The modulus of elasticity for white spruce was taken to be 1.44 x 10^6 psi based on a value put forth by Mullin and McKnight (1981) for dry white spruce. This would yield a conservative value since the specimens to be tested would have moisture contents closer to the fibre saturation point which would effectively reduce the stiffenss of the pole. The energy in the pole is determined to be:

$$U_{Timber} = \frac{P^2L}{2AE} = \frac{(20,000)^2 \times 84}{2 \times 7.1 \times (1.44 \times 10^6)} = 1643.19 \text{ lb-in}$$

The strain energy in the column test frame is stored the uprights and also in the top and bottom cross-beams. The entire frame was fabricated using reclaimed W14 x 12 (W360 x 122) beams with the following properties:

A = 24.71 in^2 (15, 942 mm^2) (Note: 2 uprights);
E = 29.5 x 10^6 psi (203 Mpa);
Lu = 105.12 in. (2670 mm)
Lb = 29.375 in. (745 mm)
Ix = 928.4 in^4 (386 x 10^6 mm^4), and;
Iy = 225.5 in^4 (93.9 x 10^6 mm^4).

Uprights:

$$U_{Uprights} = \frac{P^2L}{2AE} = \frac{(20,000)^2 \times 105.12}{2 \times (2 \times 24.71) \times (29.5 \times 10^6)} = 14.42 \text{ lb-in}$$

Beams: These are assumed to be simply supported (conservative)

$$M = PL/4 = (20,000) \times (29.375)/4 = 146,875 \text{ in-lbs.}$$

$$U_{Beams} = \frac{M^2L \times 2}{2EI} = \frac{(146,875)^2 \times 29.375}{(29.5 \times 10^6) \times (928.4)} = 23.14 \text{ lb-in}$$

The total strain energy in the frame becomes:

$$U_{FRAME} = U_{Uprights} + U_{Beams} = 14.42 + 23.14 = 37.56 \text{ lb-in.}$$

The amount of strain energy going into the frame compared with that going into the timber specimen is calculated to be:

$$\frac{U_{FRAME}}{U_{TIMBER}} = \frac{37.56}{1643.19} \times 100 = 2.29\%$$

The percentage is likely lower since the connection between the uprights and beams is not pinned but a welded, semi-rigid connection. If the average between the simply-supported moment and the fixed-end moment (PL/6) is used a rough approximation of the connection behaviour the strain energy in the beams is reduced to 10.28 lb-in. This yields a corresponding reduction in the percentage to:

$$\frac{U_{FRAME}}{U_{TIMBER}} = \frac{14.42 + 10.28}{1643.19} \times 100 = 1.5\%$$

In addition to the column frame the load cell absorbs energy within the system. Based on the same load, the strain energy going into the load cell is calculated to be:(Note: For material details of load cell see Appendix D.)

$$U_{CELL} = \frac{P2L}{2AE} = \frac{(20000^2) \times 2}{2 \times (0.867) \times (30 \times 10^6)} = 15.38 \text{ lb-in}$$

Combing the energy in the load cell with that in the frame yields:

$$\frac{U_{CELL} + U_{FRAME}}{U_{TIMBER}} = \frac{(14.42 + 10.28 + 15.38)}{1643.19} \times 100 = 2.44\%$$

Although this quite a low percentage, it is likely that for the specimens tested in this programme the relationship between the test frame and specimen is lower still. The majority of the specimens tested had a moisture content(MC) of about 20%. This MC corresponds to about a 20% reduction in the modulus of elasticity(MOE) of the specimen(CWC, 1991) If this reduction in specimen MOE is input into the previous relationships the resulting percentage reduces to 1.95%. It is recognised that this is rather a moot point, however, what did come out of this part of the equipment construction was a far better understanding of strain energy relationships.

D

Load Cell

Appendix - D:

Load Cell, Wheatstone-Bridge Circuit and Calibration Issues

Within this appendix the design rationale, fabrication and calibration of the load cell - digital indicator combination will be discussed in more detail.

Various sources of information were researched prior to construction of the load cell. (Cook and Rabinowicz, 1963; Dean, 1962; Lansdown, 1964; Omega, 1992; Dove and Adams, 1964; Scott and Owens, 19??; Beckwith and Marangoni,1990; and Holman, 1971) It should be noted that while most of these references appear dated, it was in these older references that the better discussions of strain-gauge theory and application appeared.

D.1 Behaviour of Load Cell Body:

The main component of the load cell is a tube made from Drawn Over Mandrel (DOM) steel tubing (Marmon, 1993) with an outside diameter of 76.2mm (3") and an inside diameter of 71.4 mm (2.81"). The cross-sectional area of the tube is 559 mm^2 (0.867 in^2.) Although there is10mm (3/8") MS plate on the ends of the tubing, it is assumed that their contribution to the overall deformation of the load cell would be insignificant. (This will be investigated in the next section, however, just to be sure.) The underlying concept was that the load cell would be placed in axial compression within the test frame as illustrated in Figure D-1. With the angle-iron shoe aligned with the centreline of the load cell, and free to rotate, it was assumed that there would be no moment created in the load cell. The configuration of the strain gauges, discussed later, would, however, cancel out non-axial load components.

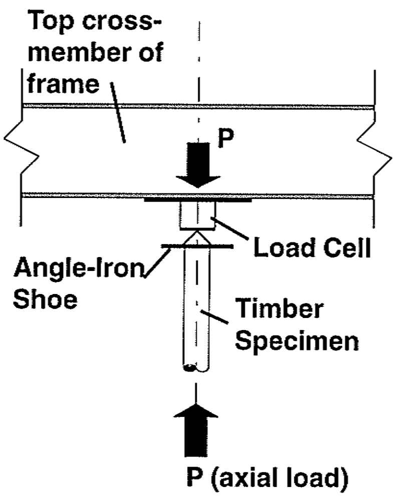


Fig.D-1: Load Cell Alignment

Presuming no flexural stress, the normal stress created in the load cell by the axial load would be comprised of:

σ_{Tube} and $\sigma_{End\ Plate}$, which would be simply calculated as,

P/A_{Tube} and P/A_{Plates}.

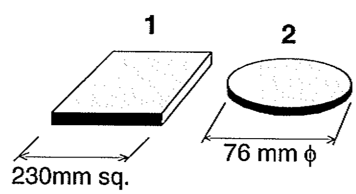
The deflection of these components would be determined using the familiar relationship; $\delta = PL/AE$ where:

δ = Axial deformation;
L = Length of component (tube or end plate);
A = Cross-sectional area of component;
E = Modulus of Elasticity of component, and;
P = Axial Load.

The total deformation of the load cell is given by:

$$\delta_{Total} = \delta_{Tube} + \delta_{End\ Plates}$$

The upper load limit of the test apparatus is based on the capacity of the hydraulic ram that was used, namely 89 kN (20,000 lbs.). Using this load the relative deformation of the end plates is compared with that of the tube.



$$\delta_{Plate1} = \frac{PL}{AE} = \frac{(89\times10^3) \times 10}{(230^2)(200\times10^3)} = 8.4 \times 10^{-5}\ mm$$

$$\delta_{Plate2} = \frac{PL}{AE} = \frac{(89\times10^3) \times 10}{(\pi\times76^2/4)(200\times10^3)} = 9.8 \times 10^{-4}\ mm$$

The deformation of the tube is now calculated based on a length of 51mm (2").

$$\delta_{Tube} = \frac{PL}{AE} = \frac{(89\times10^3) \times 51}{(559)(200\times10^3)} = 4.1 \times 10^{-2}\ mm$$

Comparing dPlates with dTube yields:

$$\%\ of\ \delta_{Tube} = (\delta_{Plates} / \delta_{Tube}) \times 100 = (0.001/0.041) \times 100 = 2.3\%.$$

It is felt, therefore, since the total deformation of the ends is relatively small compared to that of the tube, assumptions used in strain energy calculations were valid. Any deformation calculations requiring the inclusion of the load cell will only use tube deformation.

If the maximum load that this load cell will be used with is 89kN (20,000 lbs), this represents a maximum working stress on the load cell tubing of :

$$\sigma_{max} = (89 \times 10^3 \text{ N}) / 559 \text{ mm}^2 \quad = 159 \text{ N/mm}^2 \text{, or } 159 \text{ Mpa.}$$

This stress is 33% of the yield stress of 483 Mpa for the DOM tubing (Marmon-Lyman, 1993). The tubing is, therefore, well within the elastic range of the material while being used within the test frame.

D-2 Strain Gauges - Circuitry and Application:

The basic premise upon which the strain gauge is founded is that there exists a relationship between change in physical shape and electrical resistance. More specifically in relationship to this loadcell, the compressive strain is related to the electrical resistance. Figure D-2 illustrates a *bonded resistance strain gauge* of the type usesd in this research. When the grid wires in between the end loops change in length due to a compressive strain there is a corresponding change in electrical resistance in the wire grid. The relationship of strain to change in electrical resistance in a strain gauge is known as the *gauge factor (GF).* By definition, the gauge factor is the ratio of the change in resistance to the change in length over the gauge length. The significance of the GF is that it is a measure of the sensitivity of a strain gauge, or strain-gauge circuit - *the larger the GF the more sensitive the strain gauge.* Mathematically, this relationship may be stated as follows:

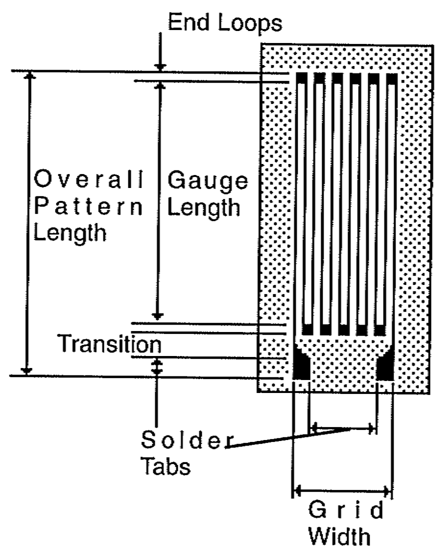


Fig. D-2: Strain Gauge
(source: after Omega, 1992)

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

The GF for constantan and nickel-chromium alloy strain gauges is nominally said to be GF = 2 (Omega, 1992) This value becomes important when determining the sensitivity of strain-gauge circuits.

Although a single strain gauge can be considered an effective measuring device, able to detect strains as small as 10^{-7} (Cook & Rabinowicz, 1963), when used in groups their combined sensitivity increases dramatically. It was decided that a Wheatstone Bridge circuit that had four active arms, as illustrated in Fig. D-3, would be used for this load cell. With this configuration of strain gauges the bridge output V_{out} was linear. In addition, with

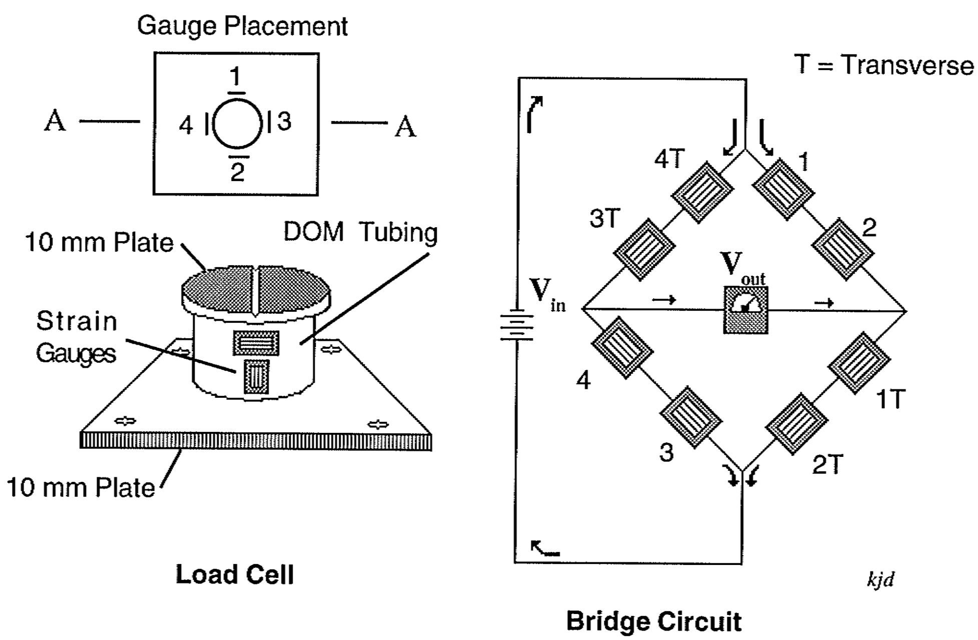


Fig. D-3: Load Cell and Wheatstone Bridge Circuit

all of the gauges affixed to the load cell it would be temperature compensated.(after Beckwith and Marangoni, 1990; and others) Temperature compensation is accomplished simply because all of the gauges are on the same material. Any change in temperature, therefore, affects all the gauges in the same manner. With the gauges placed in the configuration shown in Fig. D-3 any bending that may occur in the tube would have its effect cancelled out. Consider bending about the A-A axis in Fig D-3 for example. If gauge 1 was in tension, gauge 2 on the other side of the cell would go into compression. The opposite signs of the resulting voltage would cancel each other out since the gauges are in series within the circuit.

Cook and Rabinowicz (1963) sum up the essence of the bridge circuit within the context of strain-gauge circuit sensitivity. " Thus for maximum output two oppposite arms *(i.e. R1-R2 and R3-R4 for this load cell)* should undergo one change ΔR while the other two opposite arms *(i.e. transverse gauges)* should undergo a negative ΔR." (italics added, not a part of quote.)

A bridge with "n" active arms, the relationship of strain (ε), GF and change in voltage ΔV (V_{out}) is given by:(after Cook and Rabinowicz, 1963)

$$\Delta V/V_0 \quad = \frac{n}{4}\,(GF)\,\varepsilon \quad , \text{ where:} \qquad \textbf{Eqn. D-1}$$

ΔV = change in voltage across the bridge (V_{out});
V_0 = input or excitation voltage used for the bridge (V_{in});
n = number of active arms;
GF = strain-gauge gauge factor, and;
ε = strain in the tube.

The above relationship can now be used to determine the sensitivity of the load cell and what will be the range of voltage that the digital indicator will have to measure.

The strain will have two components, axial, and Poisson's effect (ν), which for steel is taken to be ν = 0.3. These are determined with the following relationship

$$\varepsilon_{axial} = \frac{P}{AE} \quad , \qquad \text{and} \quad \varepsilon_{Poisson} = \frac{\nu P}{AE} \quad .$$

These can be combined and Eqn D-1 rewritten as follows:

$$\Delta V = V_0 \left(\frac{n + n\nu}{4} (GF) \left(\frac{P}{AE}\right) \right). \qquad \textbf{EQN. D-2}$$

The 350 ohm strain gauges used had a GF = 2.07 (Omega, April 27, 1993, Batch No. M0675).

It is of interest to determine what the range of voltage (Vout) will be from the bridge. Using Eqn D-2, values of 89 kN (20,000 lbf) and 0.05 kN (11 lbf) have been selected to represent the range of loads for the test frame. The input voltage used for the load cell was 10V. It can be seen from Eqn. D-2 that the higher the input voltage the greater the value of ΔV will be. There is, however, a caveat that must be remembered. Too high an input voltage will cause heat in the strain gauge. Strain-gauge manufacturers publish maximum input voltages for their products. This data must be checked before a strain gauge is selected. For this bridge the term $\frac{n + n\nu}{4}$ reduces to $(4 + 4(0.3)) / 4 = 1.3$.

$$\Delta V_{(89)} = 10 \times (1.3) \times (2.07) \times (89\times10^3 / (559 \times 200\times10^3)$$
$$= 0.02142 \text{ Volts, or,}$$
$$= 21422\ \mu V \text{ (microvolts).}$$
$$\Delta V_{(0.05)} = 10 \times (1.3) \times (2.07) \times (0.05\times10^3 / (559 \times 200\times10^3)$$
$$= 0.00001203 \text{ Volts, or}$$
$$= 12.03\ \mu V \text{ (microvolts).}$$

The digital indicator, should therefore, be able to detect and display values within this range. The Omega DP205-S that was used for this work has a minimum resolution of 1 µV, which is appropriate for this voltage range.

D.3 Use of the DP205-S Meter:

It is not the intent of this section to go into great detail about the hook-up and inner workings of the DP205-S, but rather to act as a source of information for future reference about the setup of the meter for use with this test equipment.

The way the DP205-S increases or decreases its resolution is to simply multiply the input value of the voltage by an appropriate integer value, effectively increasing the deflection of the meter. With an analogue meter, this would represent a larger "sweep" of the needle. Figure D-4 illustrates this principle. By default the DP205-S is set to read with a resolution of 10 μV. If, for example, a voltage of 5.2 volts was read with the default resolution, then this would be analagous to the meter in Fig. D-4(a). If a resolution of 5 μV was desired then the sweep would be doubled and the meter would read 10.4 as in Fig. D-4(b).

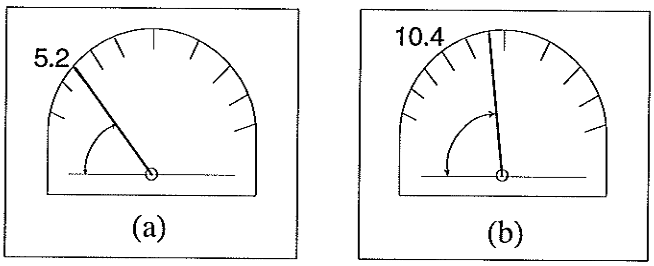


Fig. D-4: Analogue Meter

The meter was set up to have a sweep of 100 mV (millivolts). Figure D-5 illustrates what is happening with the DP205-S meter when an increment of load is applied to the load cell that is equivalent to a ΔV of 0.005 mV (or 5 μV).

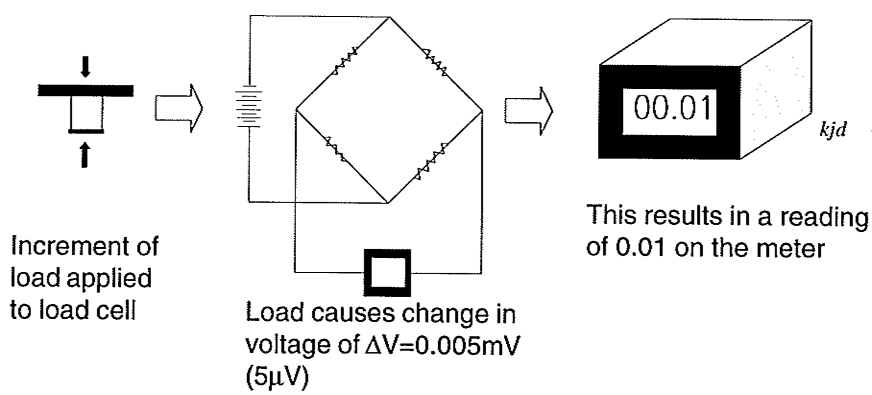
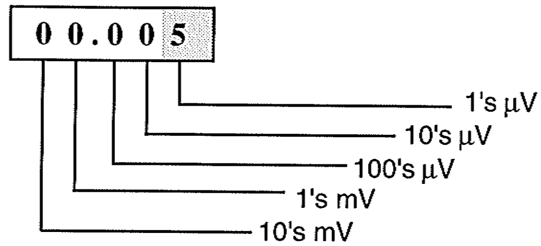


Fig. D-5: Meter Reading

Due to the configuration of this display on the meter only two decimal places can be used in order to get a range of 0 - 99 mV. The digits on the meter represent the following units:



D.4 Calibration of Load Cell:

Prior to using the Morehouse, vibrating-reed, proving rings the values in the tables accompanying the proving rings were checked for linearity. It should be noted at this juncture that the data is presented in Imperial units. The conversion of units is left to the end of calibration to reduce conversion errors from the tables supplied with the proving rings. Figures D-6 and D-7 contain plots of the tablulated load versus the proving ring micrometer divisions.

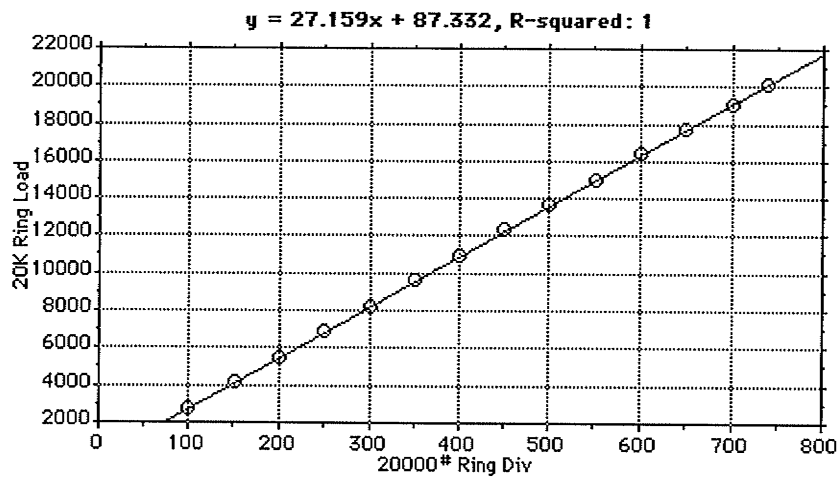


Fig. D-6: Tabulated Loads vs Ring Divisions, 20 Kilopound Proving Ring
(Morehouse 0-20000 lbf Proving Ring, Serial #4160A)

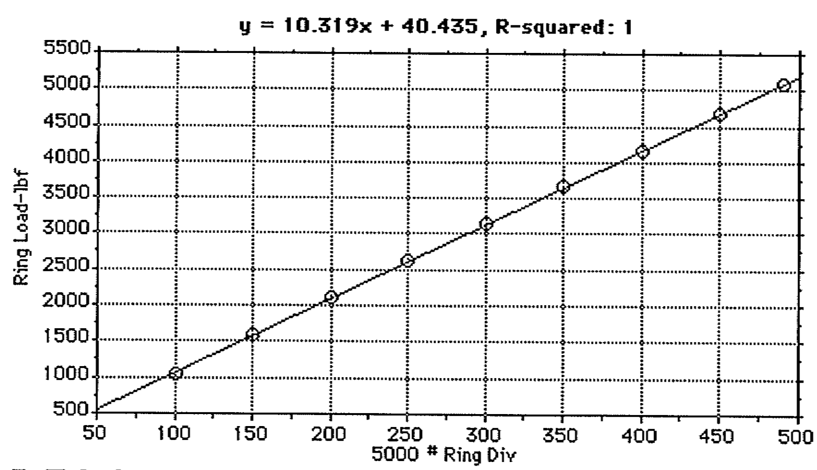


Fig. D-7: Tabulated Loads vs Ring Divisions, 5 Kilopound Proving Ring
(Morehouse 0-5000 lbf Proving Ring, Serial #4505)

The following plots , Figures D-8 and D-9, were created from the actual meter readings from the DP205-S - Load cell combination.

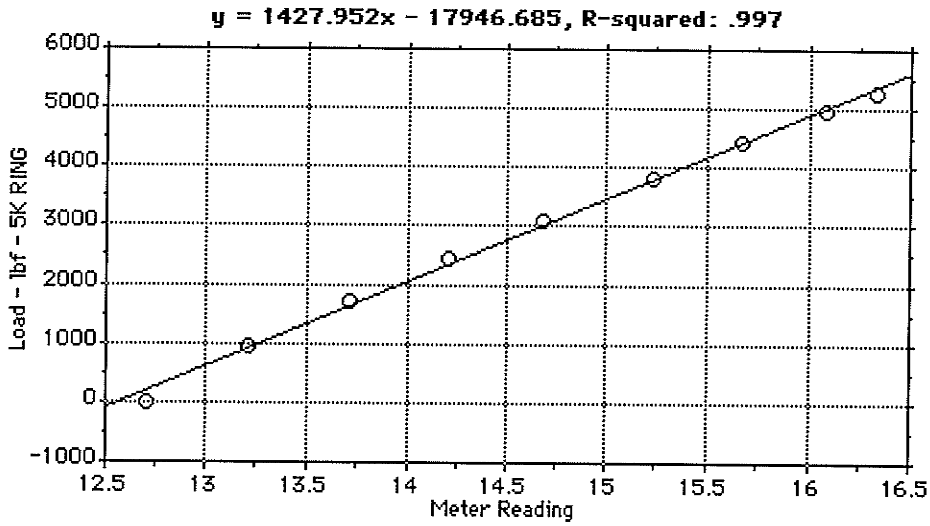


Fig. D-8: Load(lbf) vs Meter Reading(mV) for 5Kilopound proving ring
(Relationship between the load as determined by the 5K proving ring and the corresponding meter reading)

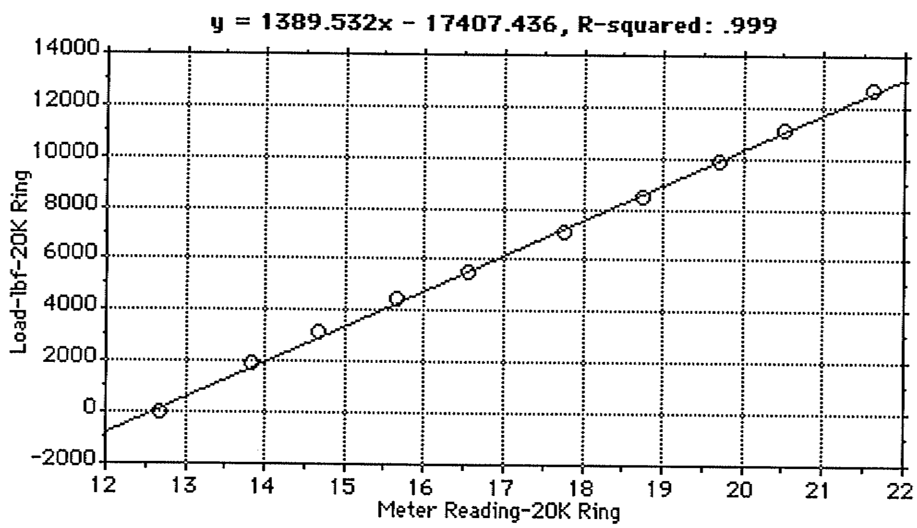


Fig. D-9: Load(lbf) vs Meter Reading(mV) for 20Kilopound proving ring
(Relationship between the load as determined by the 20K proving ring and the corresponding meter reading)

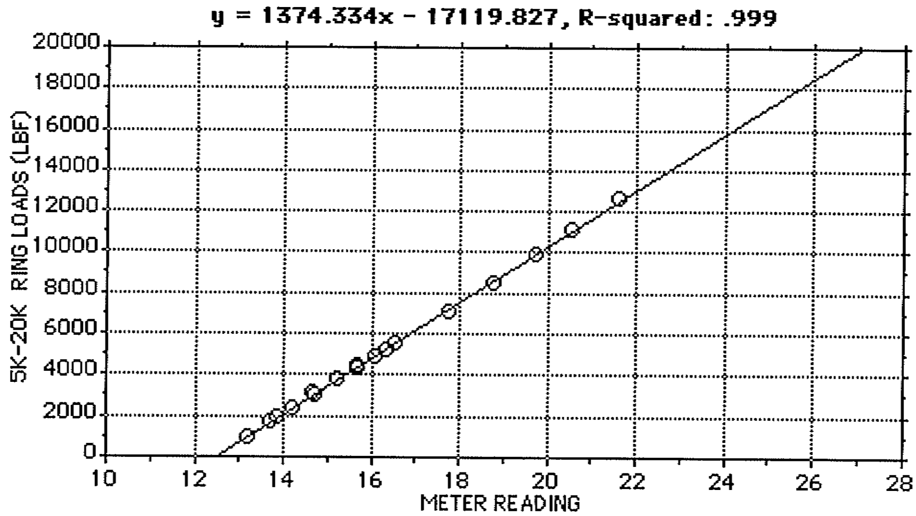
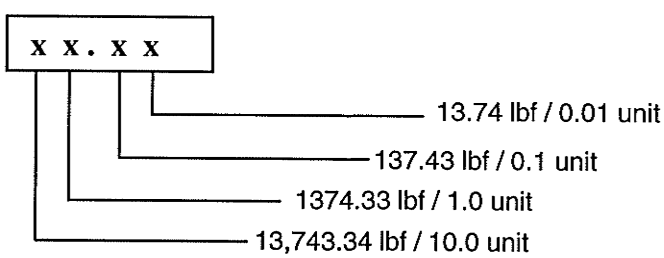


Fig.D-10: Force on Loadcell (lbf) vs Combined 5Kilopound and 20Kilopound Readings(mV)

Figure D-10 is a combination of Figures D-8 and D-9. The linear correlation between the load and meter readings was so close to unity that it was felt acceptable to combine the data from both calibrations into one plot. From this plot, D-10, the linear regression equation computed by Statview (software used for statistical analysis in this research), $y = 1374.334x - 17119.827$, was used to produce a calibration chart for use in the lab and for reduction of meter data. The linear behaviour of the proving rings coupled with the linear behaviour of the meter-load cell combination created confidence that the fabrication of the load cell was quite successful.

From the above equation the slope of the calibration curve is 1374.334 lbf / 1.0 meter unit. The resolution associated with this then becomes:



If the maximum machine load is 20,000 lbf, then the resolution of the meter provides for (13.74 / 20,000) x 100 = 0.000687 x 100 = 0.0687% of machine capacity per 0.01 meter reading. By carefully watching the "float" of the meter one may be able to predict to the 0.005 value which corresponds to 13.74/2 = 6.45 lbf.

As discussed previously, the Omega DP205-S meter increases the measurement resolution by multiplying the input voltage from the bridge by some factor. At a 1:1 resolution, the digital reading has a resolution of 10μV (microvolts). A meter reading of say 6.34 mV (millivolts) has the 4 with a resolution of 10 μV. As built there is a slight out-of-balance voltage in the bridge of 6.34 mV. This is not a problem since the meter can either be "zeroed" or all calculations take this into account. Again, it is the out-of-balance voltage of V_{out} when the cell is being loaded that is of interest. In Figure D-11 the bridge

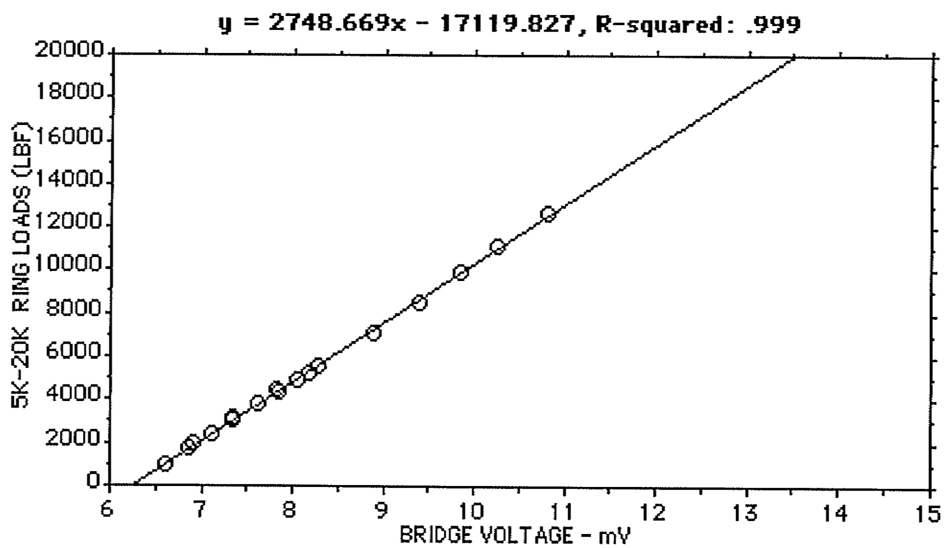


Fig. D-11: Load vs Actual Bridge Voltage

voltage shown on the x-axis is the actual V_{out} of the bridge as the load cell is compressed. In Figure D-10 the bridge voltage indicated on the x-axis is the same actual voltage only the scale of the meter has been changed to a ratio of 2:1. All readings are now doubled. An out-of-balance reading of 6.34 mV would now be seen as 12.68 mV. The difference between the two readings is that now the 8 is accurate to a resolution of 5 μV. Using the linear-regression equation from Figure D-11, the chart below helps to clarify what is going on.

1.000	mV	=	1,000 μV	=	2748.669	lbf
0.100	mV	=	100 μV	=	274.8669	lbf
0.010	mV	=	10 μV	=	27.48669	lbf
0.001	mV	=	1 μV	=	2.748669	lbf

1 μV = 1 microvolt = 1 x 10^{-6} volts
1 mV = 1 millivolt = 1 x 10^{-3} volts

If the resolution of the meter is set at 5μV , then each digit at the second place right of the decimal point will be equivalent to 5 x 2.7488669 = 13.74 lbf. The increment of load for the load cell on the column test frame is then:

13.74 lbf per 0.01 meter reading, or

0.061 kN per 0.01 meter reading.

E

Lateral Deflection

Appendix - E :

Locations for Measuring Lateral Deflection

The following process was used to investigate the behaviour of a pole with respect to the location of maximum deflection when subjected to the extremes of loading shown in Fig. E-1. It had already been decided to measure the lateral deflection of the pole at L/4, L/2 and 3L/4 measured from the butt end. The extreme cases for deflection were considered to be:

(i) As in Fig.E-1(a) a midspan load causing a maximum deflection at L/2, where a measuring device was already in place, and;

(ii) A concentrated moment at one end of the pole resulting in a maximum deflection at 0.577L. ($\delta_{max} = L(1- 3^{1/2}/3)$,

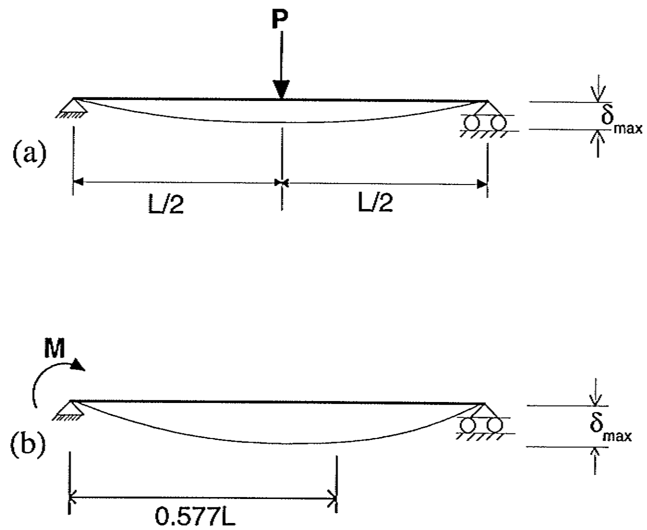


Fig.E-1: Location of Maximum Deflection

Thus, a measuring device was required somewhere between L/2 and 3L/4. Figure E-2 illustrates the locations selected for measurement of lateral deflection. Since the maximum deflection was likely to occur somewhere between L/2 and 3L/4, a distance 0.625 L or 5L/8 was selected. Even though the pole was tapered, it was felt that the above calculations indicated that these locations would provide adequate information about pole movement. As it turned out this did prove to be the case.

An additional rationale for the selection of these locations was that it takes a minumum of three points to define a line which could be accomplished as seen in Fig. E-2.

The lateral deflection of the pole was monitored at L/4, L/2, 5L/8, and 3L/4.

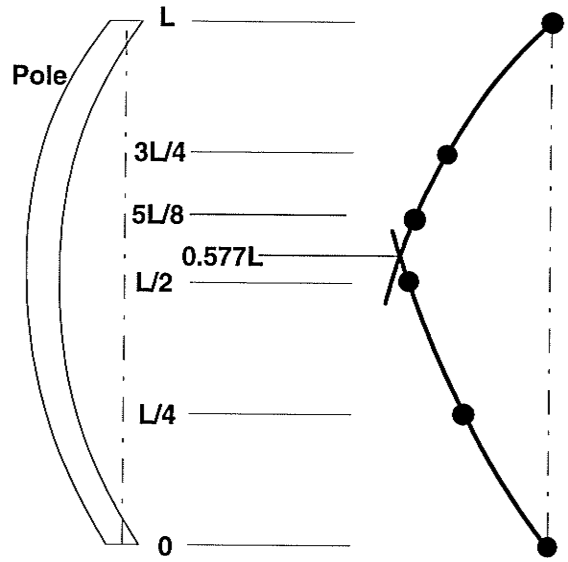
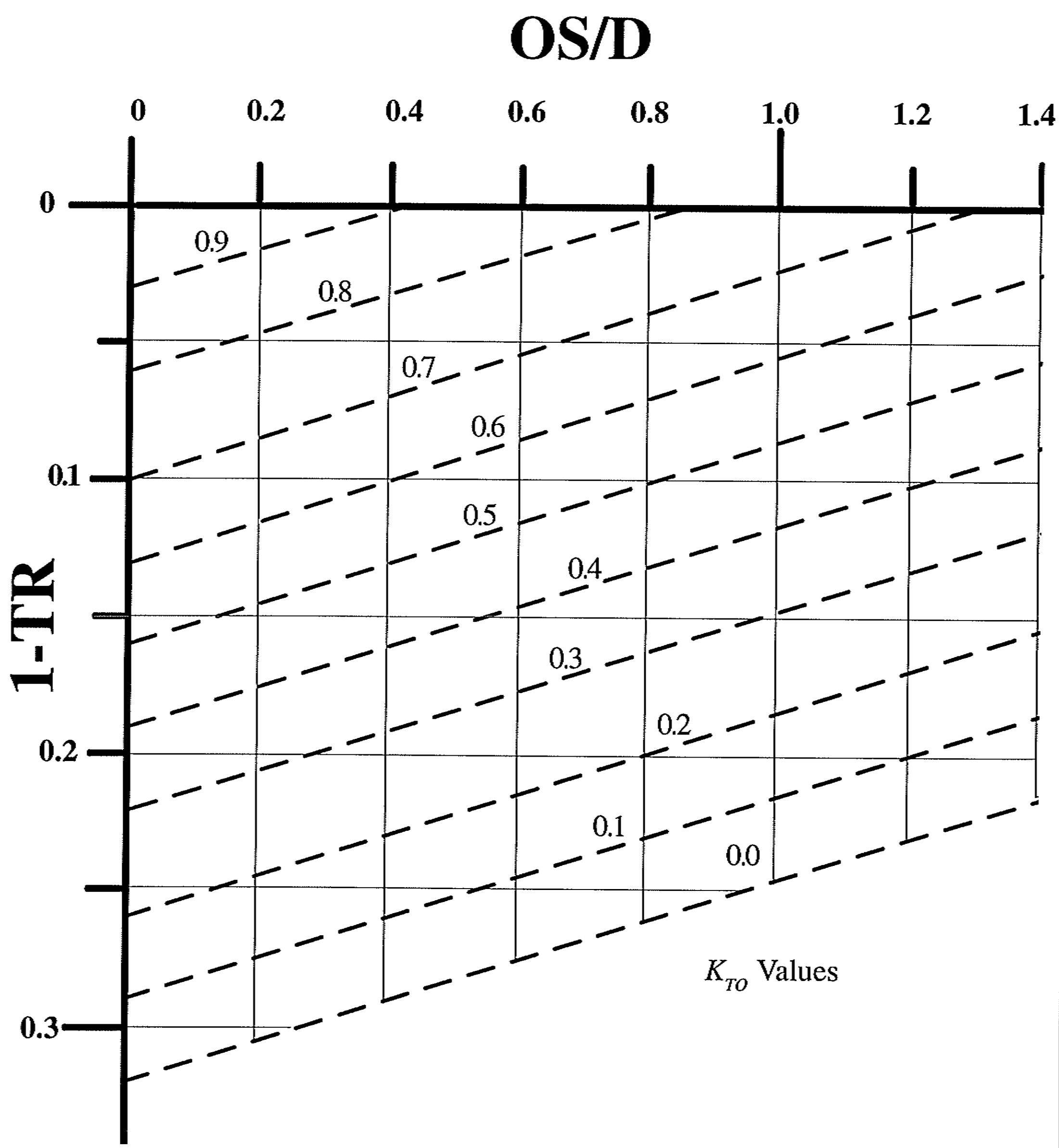


Fig. E-2: Lateral Deflection Measuring Locations

F

Contour Plot



2-D Design Contour Plot

G

Specified Strength

Appendix - G:

Specified Compressive Strength

The following table of values was used in the determination of the 5th percentile value that was used for the specified compressive strength f_c. The table summarizes the axial and flexural stress determined for the cross-section at L/2 based on the recorded 1-minute load.

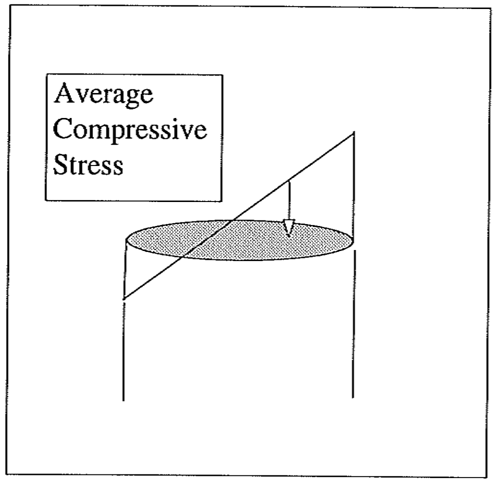
Appendix - G: Summary of Combined Axial and Flexural Stresses ~

#	Spec No.	Max. 1 min. load P (lbf)	Max. 1 min. load P (kN)	Delta at L/2 Δ (mm)	Diameter at L/2 d (mm)	X-Section Area at L/2 A (mm^2)	Moment of Inertia at L/2 I (mm^4) x10^3	Moment due to Delta P - Delta (N-mm) x 10^3	Axial Stress (comp) P/A (MPa) (N/mm^2)	Flexural Stress (comp) My/I (MPa) (N/mm^2)	Axial + Flexural (MPa) (N/mm^2)	Average of Axial + Flexural Compress (MPa) (N/mm^2)
1	1A	7254.72	32.27	38	77.22	4683.3	1745.38	1226.28	6.89	27.13	34.02	17.01
2	1B	9508.08	42.29	38	87.63	6031.1	2894.55	1607.17	7.01	24.33	31.34	15.67
3	2A	5303.64	23.59	54	69.34	3776.2	1134.76	1273.96	6.25	38.92	45.17	22.59
4	2B	7707.17	34.28	27	80.01	5027.8	2011.62	925.65	6.82	18.41	25.23	12.61
5	3A	1937.34	8.62	70	58.67	2703.5	581.61	603.24	3.19	30.43	33.61	16.81
6	3B	5142.21	22.87	35	68.33	3667.0	1070.08	800.58	6.24	25.56	31.80	15.90
7	4A	2624.34	11.67	42	66.80	3504.6	977.41	490.29	3.33	16.75	20.09	10.04
8	4B	5056.30	22.49	22	81.03	5156.8	2116.18	494.81	4.36	9.47	13.83	6.92
9	5B	6265.44	27.87	31	76.20	4560.4	1654.97	863.97	6.11	19.89	26.00	13.00
10	6B	5825.76	25.91	36	74.42	4349.8	1505.67	932.91	5.96	23.06	29.01	14.51
11	8A	3366.30	14.97	36	65.79	3399.5	919.62	539.07	4.40	19.28	23.69	11.84
12	8B	7625.70	33.92	40	76.96	4651.8	1721.99	1356.83	7.29	30.32	37.61	18.81
13	9A	4534.20	20.17	37	71.63	4029.8	1292.26	746.26	5.01	20.68	25.69	12.84
14	9B	9466.86	42.11	35	86.87	5926.9	2795.43	1473.87	7.10	22.90	30.01	15.00
15	10A	7886.76	35.08	32	74.93	4409.6	1547.37	1122.63	7.96	27.18	35.14	17.57
16	10B	9219.54	41.01	27	88.65	6172.3	3031.69	1107.28	6.64	16.19	22.83	11.42
17	11B	6677.64	29.70	40	80.52	5092.1	2063.41	1188.14	5.83	23.18	29.02	14.51
18	12A	5496.00	24.45	30	84.84	5653.2	2543.15	733.42	4.32	12.23	16.56	8.28
19	14B	3998.34	17.79	39	74.68	4380.2	1526.82	693.63	4.06	16.96	21.02	10.51
20	15B	4451.76	19.80	36	72.64	4144.2	1366.70	712.89	4.78	18.94	23.72	11.86
21	16B	6636.42	29.52	32	83.06	5418.4	2336.35	944.65	5.45	16.79	22.24	11.12
22	18A	1415.22	6.30	60	57.40	2587.7	532.87	377.71	2.43	20.34	22.78	11.39
23	18B	4039.56	17.97	41	73.41	4232.5	1425.58	736.72	4.25	18.97	23.21	11.61
24	19B	3077.76	13.69	37	75.95	4530.5	1633.36	506.55	3.02	11.78	14.80	7.40
25	20A	3146.46	14.00	17	61.21	2942.6	689.06	237.93	4.76	10.57	15.32	7.66
26	20B	4685.34	20.84	38	75.95	4530.5	1633.36	791.97	4.60	18.41	23.01	11.51
27	21A	1264.08	5.62	34	44.20	1534.4	187.35	191.18	3.66	22.55	26.22	13.11
28	21B	2473.20	11.00	49	58.67	2703.5	581.61	539.07	4.07	27.19	31.26	15.63
29	22A	2665.56	11.86	39	65.53	3372.6	905.17	462.42	3.52	16.74	20.25	10.13
30	22B	4025.82	17.91	41	80.26	5059.3	2036.89	734.22	3.54	14.47	18.00	9.00
31	23A	3902.16	17.36	33	65.65	3385.0	911.82	572.80	5.13	20.62	25.75	12.87
32	23B	10442.40	46.45	33	75.18	4439.1	1568.12	1532.85	10.46	36.74	47.21	23.60
33	24A	1071.72	4.77	88	53.85	2277.5	412.77	419.52	2.09	27.36	29.46	14.73
34	24B	6141.78	27.32	15	78.74	4869.5	1886.91	409.80	5.61	8.55	14.16	7.08
35	25A	3118.98	13.87	38	70.87	3944.7	1238.28	527.21	3.52	15.09	18.60	9.30
36	25B	10469.88	46.57	3	89.15	6242.1	3100.67	139.72	7.46	2.01	9.47	4.73
37	27A	1909.86	8.50	79	53.09	2213.7	389.96	671.14	3.84	45.69	49.52	24.76
38	27B	6183.00	27.50	51	73.41	4232.5	1425.58	1402.67	6.50	36.12	42.61	21.31
39	28A	4190.70	18.64	39	63.25	3142.0	785.62	727.01	5.93	29.27	35.20	17.60
40	28B	8271.48	36.79	53	79.50	4963.9	1960.82	1950.05	7.41	39.53	46.94	23.47
41	33A	1085.46	4.83	46	49.02	1887.3	283.44	222.10	2.56	19.21	21.76	10.88
42	33B	5289.90	23.53	33	67.82	3612.5	1038.49	776.51	6.51	25.36	31.87	15.93
43	37A	1057.00	4.70	95	54.10	2298.7	420.49	446.67	2.05	28.73	30.78	15.39
44	38A	2431.98	10.82	39	59.94	2821.8	633.63	421.90	3.83	19.96	23.79	11.89
45	39B	5660.88	25.18	32	74.42	4349.8	1505.67	805.79	5.79	19.91	25.70	12.85
46	41A	2088.48	9.29	38	60.45	2870.0	655.47	353.02	3.24	16.28	19.52	9.76
47	42A	1593.84	7.09	32	60.20	2846.3	644.70	226.87	2.49	10.59	13.08	6.54
48	44A	3723.54	16.56	34	69.09	3749.0	1118.49	563.15	4.42	17.39	21.81	10.91
49	44B	6004.38	26.71	28	81.79	5254.0	2196.70	747.85	5.08	13.92	19.01	9.50
50	45A	2431.98	10.82	30	61.98	3017.1	724.40	324.54	3.59	13.88	17.47	8.73
51	46A	5770.80	25.67	34	73.15	4202.6	1405.49	872.77	6.11	22.71	28.82	14.41
52	46B	9975.24	44.37	26	93.98	6936.8	3829.23	1153.67	6.40	14.16	20.55	10.28
53	47B	2954.10	13.14	40	64.79	3296.9	864.97	525.62	3.99	19.69	23.67	11.84
54	48A	5550.96	24.69	26	66.80	3504.6	977.41	641.99	7.05	21.94	28.98	14.49
55	48B	7447.08	33.13	30	77.72	4744.1	1791.02	993.79	6.98	21.56	28.54	14.27
56	49B	4492.98	19.99	26	67.56	3584.8	1022.65	519.63	5.58	17.16	22.74	11.37
57	50A	4424.28	19.68	28	69.09	3749.0	1118.49	551.04	5.25	17.02	22.27	11.13
58	50B	10978.26	48.83	22	87.63	6031.1	2894.55	1074.34	8.10	16.26	24.36	12.18

Appendix - G: Summary of Combined Axial and Flexural Stresses ~

#	Spec No.	Max. 1 min. load P (lbf)	Max. 1 min. load P (kN)	Delta at L/2 Δ (mm)	Diameter at L/2 d (mm)	X-Section Area at L/2 A (mm^2)	Moment of Inertia at L/2 I (mm^4) x10^3	Moment due to Delta P - Delta (N-mm) x 10^3	Axial Stress (comp) P/A (MPa) (N/mm^2)	Flexural Stress (comp) My/I (MPa) (N/mm^2)	Axial + Flexural (MPa) (N/mm^2)	Average of Axial + Flexural Compress (MPa) (N/mm^2)
59**	36A	1758.72	7.82	60	55.88	2452.5	478.63	469.39	3.19	27.40	30.59	15.30
60**	40A	4726.56	21.02	26	69.09	3749.0	1118.49	546.64	5.61	16.88	22.49	11.25
61**	43A	2294.58	10.21	49	60.96	2918.6	677.88	500.13	3.50	22.49	25.99	12.99

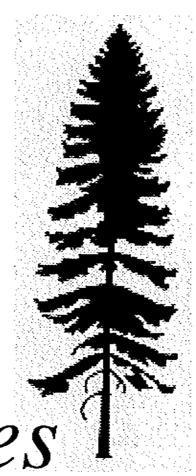
** = model test specimens



Calculation of Average Compressive Stress

Filename: d:\phd\thesis\poledata\combine.wb1

H



Selected Issues

Appendix - H :

Selected Issues for Further Discussion

The purpose of this appendix is to expand on three issues discussed earlier in the thesis. It was felt that if the expansion of these issues presented here had been incorporated within the main body of the thesis it may have been distracting, taking away from the central theme or focus of the work.

H.1 What is a *Standard* Pole?

In Chapter Four of this thesis a standardizing process is presented. Since the timber being tested was not dimensional lumber, that is having consistent dimensions (eg. 2x4 or 2x6), some way of standardizing the test poles had to be accomplished to provide for a means of comparison. By standardizing the pole about L/2 it reduced by one degree of freedom the final mathematical model. That is to say, the final design tool should be three-dimensional - taper, straightness and strength. Work by Madsen (1992), WWPA(1991) and others, has all been conducted on dimensional lumber. The issue of a non-standard geometric shape was not a concern in their work in comparison to this research. It is quite safe to assume that virtually every pole in this sample had different geometry, that is, no two poles were alike. It was this constraint or variable that was addressed by standardizing the 58-specimen sample about the mean axial, compressive stress calculated using the cross-sectional area at L/2 at the maximum 1-minute load.

Referring to Fig. 4.20 on page 53, the standard pole for this particular research would represent one that is perfectly straight with no taper, with a maximum allowable compressive stress parallel to the grain of f_c, which in this case is 6.66 MPa. This in turn corresponds to a pole with a $\mathbf{K}_{TO}$ value of 1.0. In other words, the standard or "golden pole" would be strongest a pole of this nature could be based on this species sample.

A final comment in this regard is to address why the diameter at L/2 was chosen as the location about which to standardize, or characterize, this species-specific sample. The rationale for this choice emerged for a variety of reasons.

1. Given the context within which these poles will likely be used, consistent quality control may not always be possible or practicable. Say, for example, the butt end diameter had been chosen as the basis for pole characterization, and in a field application the small-end diameter had been mistakenly used as the basis for design. The resulting product could have an inappropriate load-carrying capacity associated with it if the specified stresses had been based on another location within the pole.

2. Regardless of which end a pole is measured from, that is butt end or top end, the distance to its mid-point is the same. Use of L/2 eliminates the problem of measuring from the wrong end.

3. The first question posed that provided impetus for this research was, "How out of straight do one of these poles have to be before it is not acceptable?" Characterizing a pole about its mid-point provides a quick means of either visual inspection or a simple measurement to determine pole suitability. A straight line in the sand, or a string line from one end of a pole to the other can provide an easy way of checking the OS/D ratio at the mid-point. A specification such as: 'No pole shall be more than 0.5 diameters out at its mid-point', for example, could be easily and quickly determined for a bundle of poles.

H.2 Moisture Content and Failure Definition:

On page 30 of this thesis it was noted that, "the definition of failure used within the context of this thesis suggests that the timber poles were less sensitive to moisture than they were to geometry." In his book, Structural Behaviour of Timber (1992), Madsen describes results of in-grade testing in Spruce-Pine-Fir and Hem-Fir species groups with respect to the effect of moisture. The primary issue here with respect to the research presented in this thesis is that the poles being tested were not being taken to breakage as the main objective of the study. The test could have been stopped any time after the maximum 1-minute load had been reached. Once in the column test frame, however, continuation of the test past this point was valuable in that it would contribute information to the database that could be used for future investigations of such issues as energy absorbing capability of the pole or how extreme the geometry could be before the load-carrying capacity of the pole was significantly reduced.

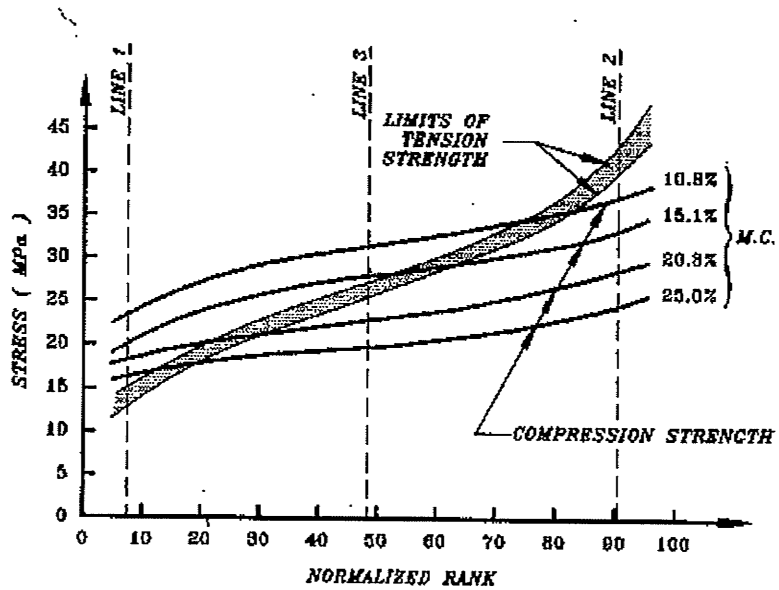


Fig. H.1: Normalized Rank Presentation for Tension and Compression Data Related to Moisture Content. (Source: Madsen, 1992, p.231)

It was considered, therefore, that it was the geometry of the pole that contributed more to its instability than the moisture content. The moisture content was high for most of the poles. As shown in Fig.H.1, at the low-strength end of the plot, left of line 1, tension failure governs. It must be emphasized again, however, that pole breakage occurred long after the maximum load had been reached in all poles within the sample. Since the design approach using LSD and CAN/CSA O86.1-M89 uses the 5th percentile of strength as the basis of design it was felt that this approach was justified.

H.3: Plot of Time-Specific Load vs Lateral Deflection Data:

In Section 3.3 of this thesis a discussion of the 1-minute load is presented. In this discussion five plots representing data obtained from the 0-, 1-, 5- and 10-minute load is illustrated. In Figs 3.5 through 3.9 the plots may give the impression that each specimen was tested 4 times, this was not the case. Each specimen was given a load increment and left for 10 minutes at this increment. At 0, 1, 5 and 10 minutes the lateral deflection was recorded and the load at that time. In all specimens the lateral deflection remained constant with only the load decreasing. The most rapid drop off was for the first 30 seconds. By the one-minute mark the load tended to stabilize. The difference between the 1-minute load and the 10 minute load was not considered enough to justify each specimen being tested in this way. In addition keeping ASTM (D198) test guidelines in mind which state that no strength test should be longer than 20 minutes, as well as in-grade testing work done by Madsen and the WWPA which brought specimens to failure in approximately one minute, this procedure was considered to be appropriate for this species-specific research. The reason for presenting the data in this way was to present the reader with a sense of what was happening to the specimen and how the load versus lateral deflection converged at high lateral deflection values. Figures H.2 and H.3 on the following page illustrate the same data only in two distinct ways. Fig. H.2 is how it was presented in Section 3.3, while Fig. H.3 shows how the data would appear if strictly plotted as it was obtained. There is no difference in the results, however, just in the manner of presentation.

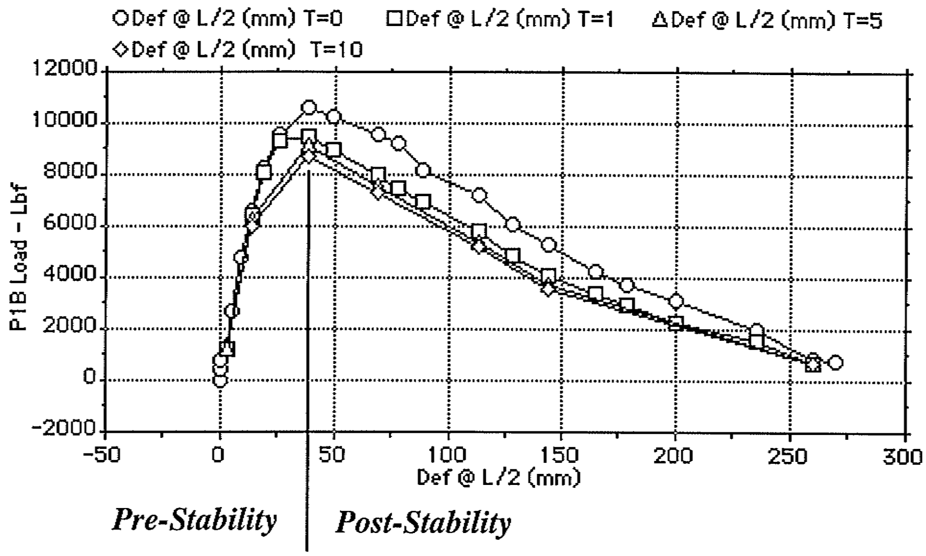


Fig. H.2: Load vs Lateral Deflection at L/2 for Specimen # P1B

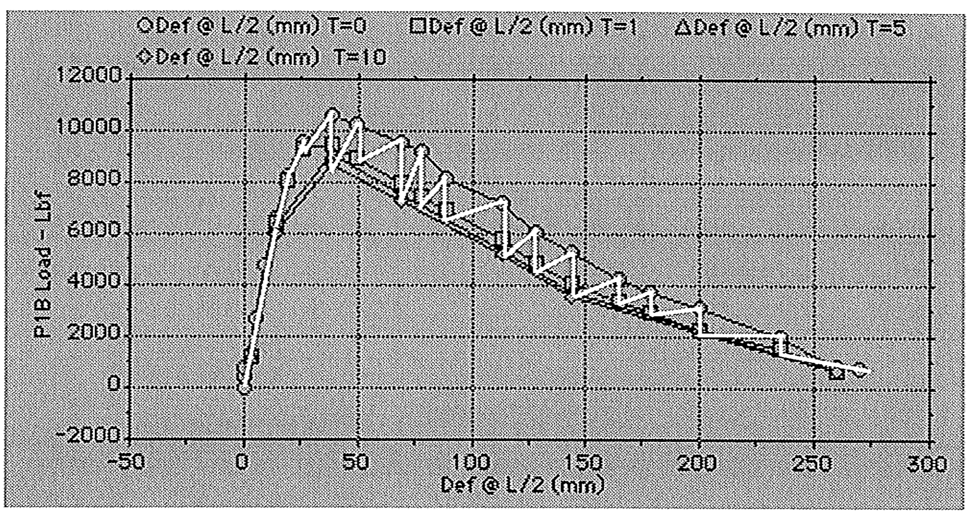


Fig. H.3:Load vs Lateral Deflection at L/2 for Specimen # P1B

Reduced Deflection Data **Specimen No. P1A**

Max Load (Lbf)=	7900.50	(kN) =	35.14

Page - 1

Meter Reading	Delta Meter	Load (LbF)	Time (min.)	Deflections (mm) at				Platen (mm)
				L/4	L/2	5L/8	3L/4	
				40.5	219.4	298.8	119.8	
12.00	0.00	0.00	0	0	0	0	0	0.00
12.17	0.17	233.58	0	0	0	0	0	0.00
12.37	0.37	508.38	0	0	2	1	0	************
12.36	0.36	494.64	1	0	2	1	0	************
12.35	0.35	480.90	5	0	2	1	0	************
12.34	0.34	467.16	10	0	2	1	0	************
13.40	1.40	1923.60	0	2	4	4	3	************
14.96	2.96	4067.04	0	5	9	8	7	3.18
14.90	2.90	3984.60	1	5	9	8	7	3.18
14.82	2.82	3874.68	5	5	9	8	7	3.18
14.77	2.77	3805.98	10	5	9	8	7	3.18
16.50	4.50	6183.00	0	10	17	16	13	************
17.50	5.50	7557.00	0	15	25	24	20	6.35
17.75	5.75	7900.50	0	25	38	36	28	6.35
17.28	5.28	7254.72	1	25	38	36	28	6.35
17.07	5.07	6966.18	5	25	38	36	28	6.35
16.96	4.96	6815.04	10	25	38	36	28	************
17.32	5.32	7309.68	0	35	56	56	43	************
16.54	4.54	6237.96	1	35	56	56	43	************
16.17	4.17	5729.58	0	53	88	88	68	************
15.41	3.41	4685.34	1	53	88	88	68	************
15.20	3.20	4396.80	0	65	112	115	90	************
14.67	2.67	3668.58	1	65	112	115	90	************
14.40	2.40	3297.60	0	75	133	143	113	************
14.06	2.06	2830.44	1	75	133	143	113	************
14.26	2.26	3105.24	0	77	148	173	137	42.88
12.40	0.40	549.60	1	77	148	173	137	42.88
12.40	0.40	549.60	5	77	148	173	137	42.88
12.19	0.19	261.06	0	90	174	208	164	************
12.18	0.18	247.32	1	90	174	208	164	************
12.18	0.18	247.32	5	90	174	208	164	************
12.18	0.18	247.32	10	90	174	208	164	************
12.06	0.06	82.44	0	100	194	235	182	61.93
12.06	0.06	82.44	1	100	194	235	182	61.93
12.06	0.06	82.44	5	100	194	235	182	61.93
12.06	0.06	82.44	10	100	194	235	182	************
**********	**********	*************	**********	**********	**********	**********	**********	************