R. E. Abendroth, R. A. Stuart, and D. Yuan

Precast Concrete Panel Thickness for Epoxy-Coated Prestressing Strands

Final Report
Volume 2—Supplemental Report

December 1994

Sponsored by the
Iowa Department of Transportation Highway Division,
and the Iowa Highway Research Board

Iowa DOT Project HR-353
ISU-ERI-Ames-95066

Iowa Department of Transportation

report

College of Engineering
Iowa State University

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ABSTRACT

This final report for Phase 1 of the research on epoxy-coated, prestressing strands in precast prestressed concrete (PC) panels has been published in two volumes. Volume 1--Technical Report contains the problem description, literature review, and survey results; descriptions of the test specimens, experimental tests, and analytical models; discussions of the analytical and experimental results; summary, conclusions, and recommendations; list of references; and acknowledgments. Volume 2--Supplemental Report contains additional information in the form of appendix material for Volume 1 on the questionnaires, strand forces, geometry of the specimens, concrete crack patterns that formed in the strand transfer length and strand development length specimens, concrete strains in the strand transfer length specimens, and load-point deflections and strand-slip measurements for the strand development length specimens.

Appendix A contains the questionnaires that were sent to the design agencies and precast concrete producers. A summary of the results to the questions on the surveys are given as the number of respondents who provided the same answers and as paraphrased comments from the respondents. Appendix B contains graphs of strand force versus time, strand force versus temperature, and strand force versus strand cutting sequence for the concrete castings. Appendix C contains figures that show the location of each specimen in the prestress bed, the geometrical configurations for the strand transfer length (T-type) specimens and strand development length (D-type) specimens, and the concrete cracks that developed in some of the T-type specimens when they were prestressed. Appendix D contains figures that show the concrete cracks that developed in the D-type specimens during the strand development length tests. For each of these tests, the sequence of the failure for the specimen is specified. Appendix E contains graphs of concrete strain versus distance from the end of the T-type specimens that were instrumented with internal embedment strain gages. Appendix F contains graphs of load versus load-point deflection and load versus strand-slip for the strand development length tests of the D-type specimens.

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APPENDIX A: QUESTIONNAIRE RESULTS

A.1. Design Agency Questionnaire Results

In August of 1993, a questionnaire was distributed to bridge engineers in the 50 state departments of transportation; three branches of the U.S. Forest Service; nine Canadian provinces, Northwest Territories; and Puerto Rico transportation agencies; New Jersey Turnpike, New York State Bridge, and New York Thruway Authorities; and Port Authority of New York and New Jersey. The survey and a summary of the bridge engineers responses are given in this appendix. The number in the parentheses ( ) represents the number of design agencies having that particularly answer. The notes within braces [ ] are paraphrased comments from the respondents. An individual respondent's remarks are separated by a comma.

Part I. General Background.

1. Has your state or agency ever specified any type of epoxy-coated reinforcement in structures?

   (53) Yes: (Please complete the rest of the questionnaire)
   (7) No Why? [There is no local fabricator that produces the epoxy-coated reinforcement therefore it would be very expensive to use versus the regular steel reinforcement, Epoxy-coated reinforcement would require extreme care in handling and placing in order to prevent the epoxy coating from being nicked or stripped and we have rehabilitated structures that were 25 years and older and have found the regular steel reinforcement has only minor corrosion so we feel that with additional concrete cover and lower water/cement ratio the regular steel reinforcement would be just as good or better than the epoxy-coated reinforcement, Corrosion is not a problem on our bridges and we don't use salt, Salt is not used on our bridge deck and concrete deterioration is not a significant problem, Our roads and bridges are not open during winter snow conditions and no de-icing salts are used, No severe corrosion problems, We only specify AASHTO M-284.]

   Note: If you answered "No" to Question No. 1, skip the rest of the questionnaire.

2. Has your state or agency ever discontinued specifying any type of epoxy-coated reinforcement after previously permitting its usage?

   (5) Yes: When? [1987, 3 @ 1992, 07/1992]
   Why? [Inadequate performance, We have stopped using epoxy-coated rebar in substructures along the coast of our state (salt water), Test results published by different agencies challenging the benefit of epoxy coating, Benefit questionable.]

   (47) No

(1) Unknown

Note: If you answered "Yes" or "Unknown" to Question No.2, please answer the remaining questions with respect to the last time epoxy-coated reinforcement was specified.

3. Has your state's or agency's specifications or criteria for epoxy-coated reinforcement changed since December 31, 1989?

(18) Yes: Date of last change?
[10/1990, Early 1991 with subsequent revisions, 05/1991, 2 @ 1992, 01/1992, 10/1992, 12/1992, 3 @ 1992, 02/1993, 03/1993, 05/1993, 07/1993, 1993, 1991-1993, in progress as of 8/1993.]

Reason for change?
[Test results published by different agencies challenging the benefit of epoxy coating, Recent coating thickness change, AASHTO Spec. changed coating thickness and recommendation by FHWA, Development length, To match FHWA recommendation, To improve the performance of epoxy-coated reinforcement, Modify construction requirements, Rewrite of standard specifications with revision dated 3/10/93, Increase thickness of epoxy coating, Adopted change in AASHTO M284 Specification, Adopted CRSI's Certification Program for fusion bonded epoxy-coated applicator plants, Adhesion testing being added and storage requirements enhanced, Revision of standards, To reduce coating defects, To comply with 30 July 1992 FHWA Memorandom on epoxy coated reinforcing steel and to require CRSI Certification for epoxy centers, FHWA Memorandum, Increased coating thickness as recommended by FHWA, Tighten requirements.]

(30) No
(3) Unknown

Note: If you answered "Yes" or "Unknown" to Question No.3, please answer the remaining questions by applying the current specifications or criterion.

4. Is your state or agency currently specifying any type of epoxy-coated reinforcement?

(47) Yes (5) No

Part II. Types of Epoxy-Coated Reinforcement, Epoxy Coatings, and Uses.

1. What type of epoxy coating that is applied to the reinforcement type listed in the table is specified by your state or agency? (Check only those boxes that apply)

Epoxy Coating Texture	Epoxy-Coated Reinforcement Type				
	Standard Deformed Reinforcing Bars	Prestressing Bars	Prestressing Strands	Welded Wire Fabric	Other [*]
Smooth Surfaced	52	3	0	16	1
Grit Impregnated Surface	0	0	4	0	0
Other [Powder Electra-statically Sprayed]	1	0	0	1	0

*Other type of reinforcement listed by designer was smooth spirals

2. What type of reinforcement has been or is being used by your state or agency for the structural elements listed in the table? (Check only those boxes that apply)

Structural Element	Not Used	Any Type of Uncoated Reinforcement	Epoxy-Coated Reinforcement Type				
			Standard Deformed Reinforcing Bars	Prestressing Bars	Prestressing Strands	Welded Wire Fabric	Other [*]
Full-Depth Cast-In-Place Bridge Decks	0	21	51	1	1	3	0
Full-Depth Precast Concrete Bridge Decks	21	10	14	1	1	0	0
Precast Concrete Sub-Deck Panels	25	12	4	0	1	2	1
Topping Slab Over Precast Concrete Panel Subdecks	23	4	18	0	0	0	0
Prestressed Concrete Girders	1	35	20	0	2	0	0
Precast Concrete Piles	14	27	7	0	2	0	1
Precast Concrete Multi-Stemmed Bridge Units	15	20	9	0	2	1	0
Other [**]	0	5	9	0	1	2	0

* Other type of reinforcement listed by designers include smooth spirals and stirrup hoops.

** Other structural elements listed by designers include prestressed box beams, abutment caps, concrete barrier, topping over precast slabs or multi-stemmed bridge units, bridge parapets, and substructure.

Part III. Designs with Epoxy-Coated Prestressing Strands.

1. For approximately how many years (in total) has your state or agency specified epoxy-coated prestressing strands?

   (1) 0 to 2 years
   (0) 2 to 5 years
   (1) 5 to 10 years
   (0) Over 10 years
   (2) Unknown

2. What type of epoxy-coated prestressing strands have been used? (Check all that apply)

   (1) Stress-relieved
   (3) Low-relaxation
   (0) Other

3. What configuration and grade of epoxy-coated prestressing strands have been used? (Check all that apply)

   (0) Three-wire 1,720 MPa (250 ksi) prestressing strands
   (0) Four-wire 1,720 MPa (250 ksi) prestressing strands
   (0) Seven-wire 1,720 MPa (250 ksi) prestressing strands
   (4) Seven-wire 1,860 MPa (270 ksi) prestressing strands
   (0) Other

4. For an epoxy-coated prestressing strand, does the epoxy coating cover all of the individual wires in the strand? (i.e.: For a seven wire strand, is the center wire coated?)

   (0) Always (0) Sometimes (1) Never (3) Unknown

5. For an epoxy-coated prestressing strand with grit impregnated in the surface, is the grit essentially uniformly distributed along the length and around the perimeter of the reinforcement?

   (0) Grit impregnated epoxy-coated prestressing strands are not used.
   (1) Always (0) Sometimes (0) Never (3) Unknown

6. Minimum concrete cover over epoxy-coated prestressing strands in precast concrete (P/C) girders.

   (0) P/C girders are not used.
   (3) Epoxy-coated strands are not used in P/C girders.
   (0) 38 mm (1 1/2 in.)
   (1) 51 mm (2 in.)
   (0) 64 mm (2 1/2 in.)
   (0) Other

7. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C girders.

(0) P/C girders are not used.
(3) Epoxy-coated prestressing strands are not used in P/C girders.
(1) 51 mm (2 in.)
(0) 57 mm (2 1/4 in.)
(0) 64 mm (2 1/2 in.)
(0) 70 mm (2 3/4 in.)
(0) 76 mm (3 in.)
(0) Other

8. Minimum concrete cover over epoxy-coated prestressing strands in P/C slabs or panels.

(0) P/C slabs or panels are not used.
(1) Epoxy-coated strands are not used in P/C slabs or panels.
(1) 25 mm (1 in.)
(0) 32 mm (1 1/4 in.)
(1) 38 mm (1 1/2 in.)
(1) 45 mm (1 3/4 in.)
(0) 51 mm (2 in.)
(0) Other

9. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C slabs or panels.

(0) P/C slabs or panels are used.
(1) Epoxy-coated strands are not used in P/C slabs or panels.
(0) 102 mm (4 in.)
(0) 127 mm (5 in.)
(1) 152 mm (6 in.)
(0) 178 mm (7 in.)
(0) 203 mm (8 in.)
(2) Other [2 in.]

10. Minimum concrete cover over epoxy-coated prestressing strands in P/C multi-stemmed bridge units.

(0) P/C multi-stemmed bridge units are not used.
(4) Epoxy-coated prestressing strands are not used in P/C multi-stemmed bridge units
(0) 32 mm (1 1/4 in.)
(0) 38 mm (1 1/2 in.)
(0) 45 mm (1 3/4 in.)
(0) 51 mm (2 in.)
(0) Other

11. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C multi-stemmed bridge units.

(0) P/C multi-stemmed bridge units are not used.
(4) Epoxy-coated prestressing strands are not used in P/C multi-stemmed bridge units.
(0) 51 mm (2 in.)
(0) 57 mm (2 1/4 in.)
(0) 64 mm (2 1/2 in.)
(0) 70 mm (2 3/4 in.)
(0) 76 mm (3 in.)
(0) Other

12. Total nominal diameter of epoxy-coated prestressing strands specified. (Check all that apply)

(0) 6.35 mm (1/4 in.)
(0) 7.94 mm (5/16 in.)
(1) 9.53 mm (3/8 in.)
(0) 11.11 mm (7/16 in.)
(3) 12.70 mm (1/2 in.)
(0) 15.24 mm (0.6 in.)
(0) Other

13. Is confinement reinforcement provided along the epoxy-coated strand development length in P/C slabs or panels?

(0) P/C slabs or deck panels are not used.
(1) Epoxy-coated strands are not used in P/C slabs or panels.
(2) Always (0) Sometimes (0) Never
(1) Unknown

14. How is the development length for the epoxy-coated prestressing strands established? (Check all that apply)

(3) AASHTO Specification for uncoated prestressing strands
(0) ACI Specification for uncoated prestressing strands
(0) PCI Specification for uncoated prestressing strands
(0) PCI Ad-Hoc Committee on Epoxy-Coated Strand Recommendations
(0) Other technical papers or reports on epoxy-coated strands
Title:_____
(0) Other:_____
(1) Unknown

15. Bundling of epoxy-coated prestressing strands (Check all that apply):

(3) Bundling of strands is not permitted
(0) Two strand bundles may be used
(0) Three strand bundles may be used
(1) Other:[Unknown]_____

Part IV. Experiences with Epoxy-Coated Prestressing Strands.

1. Which of the following problems has your state or agency experienced with epoxy-coated prestressing strands? (Check all that apply)

   (4) Can not really comment since we have not used epoxy-coated prestressing strands often enough.
   (0) Have not experienced any problems.
   (0) Slippage of a strand has occurred at either the prestressing or anchorage end chucks which grip the strand.
   (0) After cutting the strand, removal of the chucks from the strand ends has been difficult.
   (0) Epoxy coating contained more holidays than permitted.
   (0) Epoxy coating thickness was not uniform around the strand cross section.
   (0) Epoxy coating thickness was not uniform along the strand length.
   (0) Knicks or gouges have occurred in the epoxy coating during shipment from the supplier.
   (0) Knicks or gouges have occurred in the epoxy coating during strand placement prior to concrete casting.
   (0) Repair of damaged epoxy coating areas has been difficult.
   (0) Other:_____

2. Repair philosophy for damaged epoxy coating areas on prestressing strands that would occur within a member. (Check all that apply)

   (1) Damaged epoxy coatings have not been encountered.
   (0) Discard the portion of strand containing the damage.
   (1) Always apply an epoxy material over the damaged areas.
   (0) Only apply an epoxy material over damaged areas which are of a certain size.
   (0) Repairs to damaged epoxy coatings are not made.
   (0) Other:_____
   (2) Unknown

3. Detensioning procedures for epoxy-coated prestressing strands. (Check all that apply)

   (1) Acetylene torches
   (1) Abrasive saw blades
   (0) Wire/strand cutters
   (1) Slow release of hydraulic pressure
   (0) Other:_____
   (1) Unknown

4. Which of the following problems has your state or agency experienced with prestressed concrete members reinforced with epoxy-coated prestressing strands? (Check all that apply)

   (4) Can not really comment since we have not used epoxy-coated strands often enough.
   (0) Have not experienced any problems.
   (0) Splitting of the concrete only at the ends of the member parallel to and directly along the prestressing strand(s).
   (0) Cracking parallel to the strand(s) along a significant portion of the member length.
   (0) Strand slippage at the end of the member.
   (0) Apparent creep or prestress loss beyond that associated with uncoated prestressing strands.
   (0) Other:_____

5. Are any special precautions taken to minimize cracking in members reinforced with epoxy-coated prestressing strands?

   (0) Yes, Explain:_____
   (4) No

6. Overall, how does your state or agency classify problems associated with the use of epoxy-coated prestressing strands?

   (4) Can not really comment because we have not used epoxy-coated prestressing strands often enough.

(0) Non-existent	(0) Moderate	(0) Major
(0) Minor	(0) Significant	

7. Considering all aspects of manufacturing and performance of members reinforced with epoxy-coated prestressing strands, how does your state or agency rate the usage of epoxy-coated prestressing strands?

   (4) Can not really comment since we have not used epoxy-coated prestressing strands often enough.

(0) Excellent	(0) Good	(0) Poor
(0) Very good	(0) Fair	

8. Please feel free to expand on the experiences that your state or agency has had regarding any aspect of using epoxy-coated prestressing strands. Comment on the differences between using epoxy-coated strands and uncoated strands are especially welcomed. (Quotes are respondents' comments)

   "We have only specified epoxy coated strands on one project which is currently being built. We have not yet evaluated its effectiveness; however, the extra cost will probably deter us from using on a regular basis."

"Hubbard Creek Bridge has been in service with epoxy coated 1/2" 7-wire low relaxation strands since 1985 with no strand problems."

"Will welcome the use of coated strand for prestressed girders."

"Normally, there is sufficient concrete cover to protect the strand from contaminants, such as salt, that would cause corrosion.

There are installation problems, such as anchor slippage, that make the product construction sensitive.

Material quality seems to be a problem. We are aware that epoxy coating has been installed over corroded strand."

A.2. Precaster Questionnaire Results

In August of 1993, a questionnaire was distributed to 205 precast prestressed concrete producers who are members of the Precast/Prestressed Concrete Institute Producers in the United States and Canada. The survey and a summary of the producers responses are given in this appendix. The number in the parentheses ( ) represents the number of precasters having that particularly answer. The notes within braces [ ] are paraphrased comments from the respondents. An individual respondent's remarks are separated by a comma.

Part I. General Background.

1. Has your company ever produced any type of precast concrete member that contained epoxy-coated reinforcement?

   (57) Yes: (Please complete the rest of the questionnaire)
   (19) No Why? [(9)Never specified by design professionals, Do not feel it is necessary, Not needed, No state highway work, Has not been specified, Building construction -- fire concern versus corrosion, We decline to bid work showing epoxy-coated strands due to bond problems, Not specified, Has not been required, Bid high because of epoxy coating, Epoxy-coated prestressing strands are not available at the present time from local supplier.]

Note: If you answered "No" to Question No. 1, skip the rest of the questionnaire.

2. Has your company ever stopped producing any type of precast concrete member that contained epoxy-coated reinforcement?

   (4) Yes: When? [1987, Jan. 1989, May 1993]
   Why? [Embrittlement problem with epoxy-coated hardware, Completion of job, Project completed, Project completed.]

   (51) No

   (2) Unknown

   Note: If you answered "Yes" or "Unknown" to Question No.2, please answer the remaining questions with respect to the last time a precast concrete member that contained epoxy-coated reinforcement was produced.

3. Has your company ever produced precast concrete bridge structure members, that contain epoxy-coated reinforcement, for a state department of transportation, U.S. or Canadian provinces, counties, cities, forest service, or any other agency?

   (41) Yes: Please list agencies. In the following list, repeated agency names mentioned by the producers have been eliminated.
   [AL DOT; CT DOT; DE DOT; FL DOT; IA DOT; IL DOT; KS DOT; KY DOT; MA DOT; MD DOT; MI DOT; MN DOT; MO DOT; NC DOT; ND DOT; NJ DOT; NY DOT; OR DOT; PA DOT; RI DOT; TN DOT; VA DOT; WA DOT; WI DOT; FHWA; British Columbia; Alberta; Saskatchewan; Manitoba; Vancouver Port Corp.; City of Winnipeg; Province of Manitoba bridge Dept.; Mass. DHWD; Ministry of Transportation of Ontario; IL State Toll Authority; State of Tennessee; State of Kentucky; NASA; USFS; NAVY; Berlington Northern; British Columbia Provincial Ministry of Transportation & Highways; British Columbia Provincial Ministry of Forests; States of Missouri and Kansas Cities in Montreal; Quebec; City of Calgary; Kansas Turnpike Authority.]

   (16) No

4. Is your company currently producing precast concrete members that contain any type of epoxy-coated reinforcement?

   (41) Yes (16) No

5. Please list your suppliers for the following epoxy-coated reinforcement only (If epoxy-coated reinforcement of the type listed has not been used, write "Not Used" on the corresponding line).

   Prestressing strands [Florida Wire & Cable Company]

   Welded-wire fabrics
   [Irving Wire, Calgary, Mid West , Calgary, Mid West Pipe Coating, Lane Coating, Multon Coating, E Engineered Wire Products, Durawall, National Wire Co., Ambassador Steel, Ivy Steel & Wire, Western Coatings.]

Part II. Types of Epoxy-Coated Reinforcement, Epoxy Coatings, and Uses.

1. What type of epoxy coating that is applied to the reinforcement type listed in the table is used by your company? (Check only those boxes that apply)

Epoxy Coating Texture	Epoxy-Coated Reinforcement Type				
	Standard Deformed Reinforcing Bars	Prestressing Bars	Prestressing Strands	Welded Wire Fabric	Other [*]
Smooth Surfaced	54	2	1	20	2
Grit Impregnated Surface	0	0	13	0	0
Other	0	0	0	0	0

*Other type of reinforcement listed by the precasters was spiral wire

2. What type of reinforcement has been or is being used by your company for the precast prestressed concrete structural elements listed in the table? (Check only those boxes that apply)

			Epoxy-Coated Reinforcement Type				
Structural Element	Not Cast	Any Type of Uncoated Reinforcement	Standard Deformed Reinforcing Bars	Prestressing Bars	Prestressing Strands	Welded Wire Fabric	Other [*]
Full-Depth Bridge Deck Panels	25	13	13	0	2	1	0
Bridge Sub-Deck Panels	24	13	12	0	0	1	0
Bridge Girders	13	26	37	0	3	1	0
Multi-Stemmed Bridge Units	28	10	14	0	0	1	0
Hollow Core Slabs	21	17	7	0	3	0	0
Beams	6	31	23	0	0	1	0
Columns	9	29	15	0	0	0	0
Piles	21	17	6	0	3	1	3
Single or Double Tee Sections	11	24	22	0	1	16	0
Other [**]	0	7	9	0	1	3	0

* Other type of reinforcement listed by precasters is spiral wire..

** Other structural elements listed by precasters include box beams, abutment caps, wing walls, traffic barriers, wall panels, stadium risers, floating structures, deck slabs, architectural precast panels, cooling tower parts..

Part III. Designs with Epoxy-Coated Prestressing Strands.

1. For approximately how many years (in total) has your company produced precast concrete members that contain epoxy-coated prestressing strands?

   (5) 0 to 2 years
   (2) 2 to 5 years
   (3) 5 to 10 years
   (0) Over 10 years
   (3) Unknown

2. What type of epoxy-coated prestressing strands have been used? (Check all that apply)

   (3) Stress-relieved
   (11) Low-relaxation
   (0) Other

3. What configuration and grade of epoxy-coated prestressing strands have been used? (Check all that apply)

   (0) Three-wire 1,720 MPa (250 ksi) prestressing strands
   (0) Four-wire 1,720 MPa (250 ksi) prestressing strands
   (1) Seven-wire 1,720 MPa (250 ksi) prestressing strands
   (12) Seven-wire 1,860 MPa (270 ksi) prestressing strands
   (0) Other

4. For an epoxy-coated prestressing strand, does the epoxy coating cover all of the individual wires in the strand? (i.e.:For a seven wire strand, is the center wire coated?)

   (4) Always (0) Sometimes (4) Never (5) Unknown

5. For an epoxy-coated prestressing strand with grit impregnated in the surface, is the grit essentially uniformly distributed along the length and around the perimeter of the reinforcement?

   (0) Grit impregnated epoxy-coated prestressing strands are not used.
   (8) Always (2) Sometimes (0) Never (3) Unknown

6. Minimum concrete cover over epoxy-coated prestressing strands in precast concrete (P/C) girders.

   (3) P/C girders are not produced.
   (5) Epoxy-coated strands are not used in P/C girders.
   (1) 38 mm (1 1/2 in.)
   (2) 51 mm (2 in.)
   (0) 64 mm (2 1/2 in.)
   (2) Other [1 3/4 in.]

7. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C girders.

(3) P/C girders are not produced.
(5) Epoxy-coated prestressing strands are not used in P/C girders.
(4) 51 mm (2 in.)
(0) 57 mm (2 1/4 in.)
(0) 64 mm (2 1/2 in.)
(0) 70 mm (2 3/4 in.)
(0) 76 mm (3 in.)
(0) Other

8. Minimum concrete cover over epoxy-coated prestressing strands in P/C slabs or panels.

(2) P/C slabs or panels are not produced.
(5) Epoxy-coated strands are not used in P/C slabs or panels.
(1) 25 mm (1 in.)
(1) 32 mm (1 1/4 in.)
(3) 38 mm (1 1/2 in.)
(0) 45 mm (1 3/4 in.)
(1) 51 mm (2 in.)
(0) Other

9. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C slabs or panels.

(2) P/C slabs or panels are produced.
(5) Epoxy-coated strands are not used in P/C slabs or panels.
(2) 102 mm (4 in.)
(0) 127 mm (5 in.)
(1) 152 mm (6 in.)
(0) 178 mm (7 in.)
(2) 203 mm (8 in.)
(1) Other [2 in.]

10. Minimum concrete cover over epoxy-coated prestressing strands in P/C multi-stemmed bridge units and single or double tees.

(6) P/C multi-stemmed bridge units and single or double tees are not produced.
(5) Epoxy-coated prestressing strands are not used in P/C multi-stemmed bridge units and single or double tees.
(0) 32 mm (1 1/4 in.)
(1) 38 mm (1 1/2 in.)
(0) 45 mm (1 3/4 in.)
(1) 51 mm (2 in.)
(0) Other

11. Minimum center-line spacing between individual epoxy-coated prestressing strands in P/C multi-stemmed bridge units and single or double tees.

(6) P/C multi-stemmed bridge units and single or double tees are not produced.
(5) Epoxy-coated prestressing strands are not used in P/C multi-stemmed bridge units and single or double tees.
(2) 51 mm (2 in.)
(0) 70 mm (2 3/4 in.)

(0) 57 mm (2 1/4 in.)
(0) 64 mm (2 1/2 in.)
(0) 76 mm (3 in.)
(0) Other

12. Total nominal diameter of epoxy-coated prestressing strands specified. (Check all that apply)

(0) 6.35 mm (1/4 in.)
(1) 7.94 mm (5/16 in.)
(1) 9.53 mm (3/8 in.)
(0) 11.11 mm (7/16 in.)
(12) 12.70 mm (1/2 in.)
(0) 15.24 mm (0.6 in.)
(0) Other

13. Is confinement reinforcement provided along the epoxy-coated strand development length in P/C slabs or panels?

(3) P/C slabs or deck panels are not produced.
(5) Epoxy-coated strands are not used in P/C slabs or panels.
(0) Always
(4) Sometimes
(0) Never
(1) Unknown

14. How is the development length for the epoxy-coated prestressing strands established? (Check all that apply)

(8) Our company does not design the P/C member.
(1) AASHTO Specification for uncoated prestressing strands
(1) ACI Specification for uncoated prestressing strands
(1) PCI Specification for uncoated prestressing strands
(0) PCI Ad-Hoc Committee on Epoxy-Coated Strand Recommendations
(0) Other technical papers or reports on epoxy-coated strands
Title:_____
(1) Other:[Supplier]_____
(2) Unknown

15. Bundling of epoxy-coated prestressing strands (Check all that apply):

(9) Bundling of strands is not done
(0) Two strand bundles have been used
(0) Three strand bundles have been used
(1) Other:[Bundled numerous strands at harp down.]

Part IV. Experiences with Epoxy-Coated Prestressing Strands.

1. Which of the following problems has your company experienced with epoxy-coated prestressing strands? (Check all that apply)

   (3) Can not really comment since we have not used epoxy-coated prestressing strands often enough.
   (1) Have not experienced any problems.
   (7) Slippage of a strand has occurred at either the prestressing or anchorage end chucks which grip the strand.
   (7) After cutting the strand, removal of the chucks from the strand ends has been difficult.
   (0) Epoxy coating contained more holidays than permitted.
   (0) Epoxy coating thickness was not uniform around the strand cross section.
   (1) Epoxy coating thickness was not uniform along the strand length.
   (1) Knicks or gouges have occurred in the epoxy coating during shipment from the supplier.
   (1) Knicks or gouges have occurred in the epoxy coating during strand placement prior to concrete casting.
   (0) Repair of damaged epoxy coating areas has been difficult
   (7) Epoxy-coated strands are more difficult to handle than uncoated strands.
   (3) Other:[Bursting force at release of prestress force caused cracking problem, Experienced cracking of strand use jaws, During the stringing operation the strand being pulled down bed will gouge through coating and cut steel if allowed to make contact.]

2. Repair philosophy for damaged epoxy coating areas on prestressing strands that would occur within a member. (Check all that apply)

   (3) Damaged epoxy coatings have not been encountered.
   (1) Discard the portion of strand containing the damage.
   (6) Always apply an epoxy material over the damaged areas.
   (2) Only apply an epoxy material over damaged areas which are of a certain size.
   (1) Repairs to damaged epoxy coatings are not made.
   (0) Other:_____
   (1) Unknown

3. Detensioning procedures for epoxy-coated prestressing strands. (Check all that apply)

   (10) Acetylene torches
   (6) Abrasive saw blades
   (0) Wire/strand cutters
   (5) Slow release of hydraulic pressure
   (0) Other:_____
   (0) Unknown

4. Which of the following problems has your company experienced with prestressed concrete members reinforced with epoxy-coated prestressing strands? (Check all that apply)

   (7) Can not really comment since we have not used epoxy-coated strands often enough.
   (4) Have not experienced any problems.
   (0) Splitting of the concrete only at the ends of the member parallel to and directly along the prestressing strand(s).
   (1) Cracking parallel to the strand(s) along a significant portion of the member length.
   (0) Strand slippage at the end of the member.
   (0) Apparent creep or prestress loss beyond that associated with uncoated prestressing strands.
   (1) Other:[None of the above.]

5. Are any special precautions taken to minimize cracking in members reinforced with epoxy-coated prestressing strands?

   (1) Yes, Explain:[In hollow core plank solids must be added.]
   (11) No

6. Overall, how does your company classify problems associated with the use of epoxy-coated prestressing strands?

   (5) Can not really comment because we have not used epoxy-coated prestressing strands often enough.

(0) Non-existent	(6) Moderate	(0) Major
(1) Minor	(1) Significant	

7. Considering all aspects of manufacturing and performance of members reinforced with epoxy-coated prestressing strands, how does your company rate the usage of epoxy-coated prestressing strands?

   (6) Can not really comment since we have not used epoxy-coated prestressing strands often enough.

(0) Excellent	(1) Good	(0) Poor
(1) Very good	(5) Fair	

8. Please feel free to expand on the experiences that your company has had regarding any aspect of using epoxy-coated prestressing strands. Comments on the differences between using epoxy-coated strands and uncoated strands are especially welcomed. (Quotes are respondents' comments)

   "We have mainly seen specification require epoxy coated reinforcement, not strands."

   "Above is based on experience with one P/S pile project. Prefer not to use it."

"Must handle completely different, much more difficult to string bed, chuck seating is 300% compared to uncoated strand, epoxy-coated strands are not necessary for P/C beams/piles."

"We have had only one job using epoxy-coated strand. Although the job was successful, we found epoxy-coated strand difficult to work with. The epoxy coating will soften at approximate 150F which will result in the debonding of a bonded stressed strand. This temperature constraints should be considered during production due to accelerated curing procedures and during design if the structure must have some fire resistance."

"Epoxy-coated strands are more difficult to handle. Consequently more labor intensive."

"We built one of the first test bridges in U.S. using epoxy-coated strand and will be producing another large project which will have cathodic protection in addition to epoxy-coated strand and rebar."

"Feel that steam curing can be a problem with epoxy-coated strands. This is our typical curing procedure."

"Our largest problem was with the chucks. Even new ones would not always hold. This was solved by removing the coating in the chuck area."

APPENDIX B. STRAND FORCES

For each of the 17 concrete castings, the strand forces at the prestressing end of the prestress bed were recorded at regular time intervals during the strand tensioning procedure, concrete casting and curing periods, and strand cutting sequence. The force in a strand was obtained fromthe measured strains in a calibrated, high-strength, post-tensioning bar that was used to pull the strand. Figures B.1-B.17 show graphs of the strand force versus time along with notations for specific events that occurred during the entire monitoring range for Cast Nos. 1-17, respectively. After observing changes in the strand forces during the concrete curing period for some of the initial concrete castings, thermocouples and resistance temperature devices were installed to measure the temperatures of the air, the steel prestressing frame, a prestressing strand, and the concrete within a specimen. The four temperatures that were recorded at regular time intervals during the strand tensioning procedure and the concrete casting and curing periods for Cast Nos. 8-12 and 14-17 are shown in Figs. B.8-B.12 and B.14-B.17, respectively. The forces in the prestressing strands changed during the strand cutting sequence. Figures B.18-B.34 show alll of the strand forces just prior to making each cut of a particular strand at a specific header location in the prestressing frame for Cast Nos. 1-17, respectively. Figures B.1, B.6, B.7, B.10, B.11, B.15, B.16, B.18, B.23, B.24, B.27, B.28, B.32, and B.33 show the strand forces in the uncoated strands; and Figs. B.2-B.5, B.8, B.9, B.12-B.14, B.17, B.19-B.22, B.25, B.26, B.29-B.31, and B.34 show the strand forces in the coated strands.

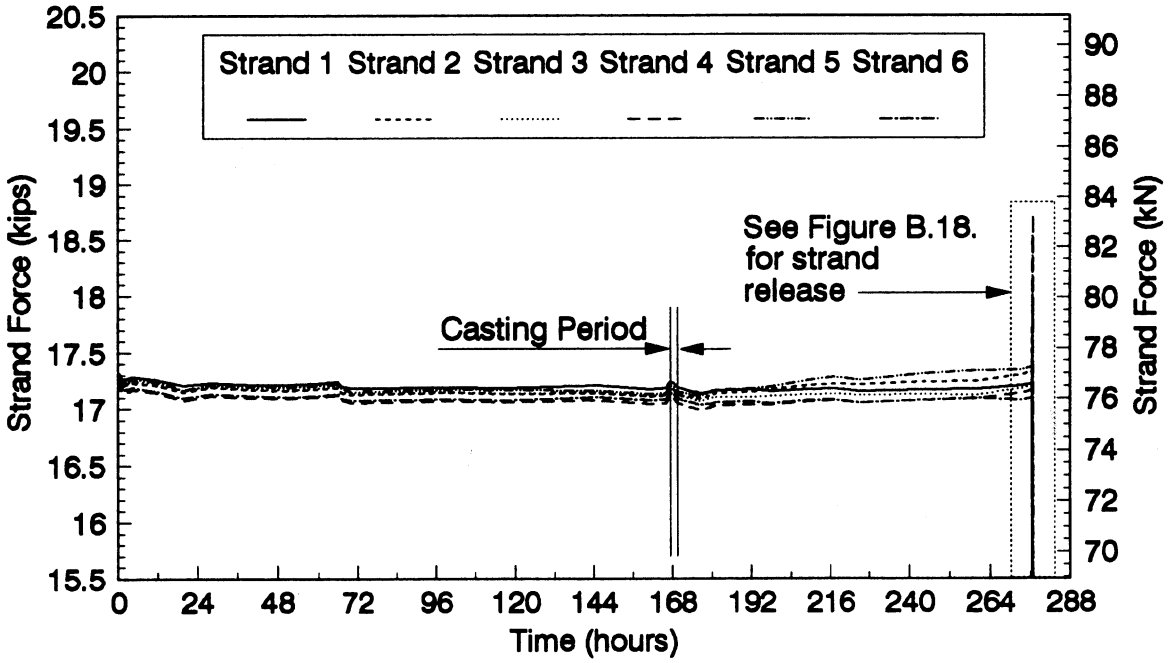


Figure B.1. Strand force versus time for Cast No. 1

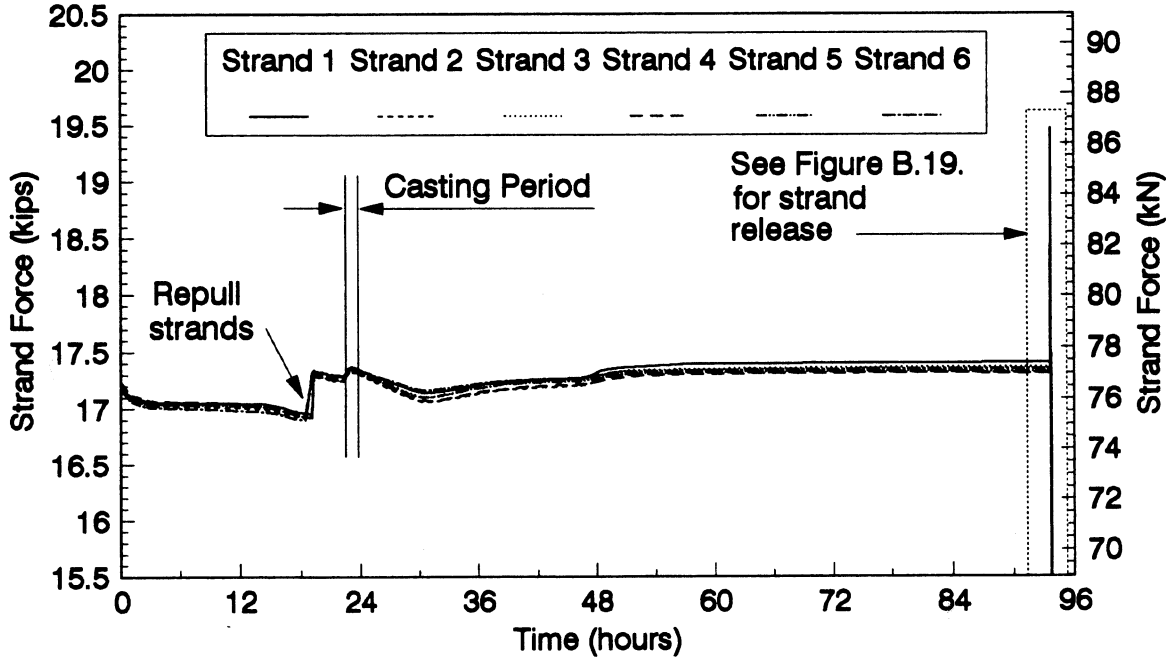


Figure B.2. Strand force versus time for Cast No. 2

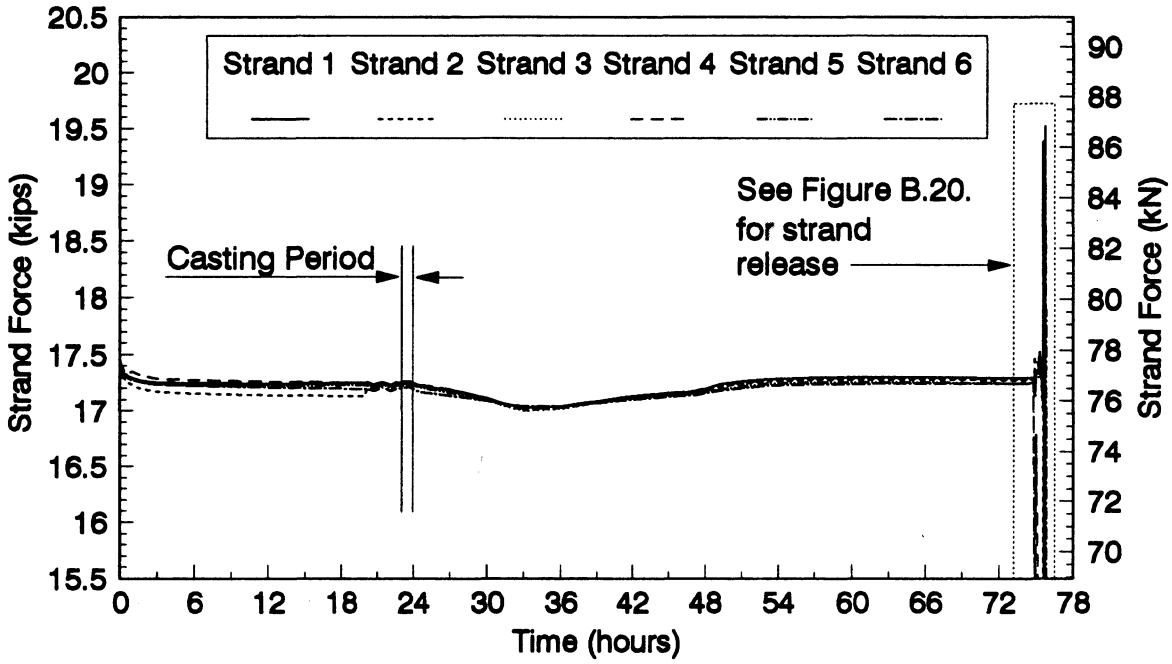


Figure B.3. Strand force versus time for Cast No. 3

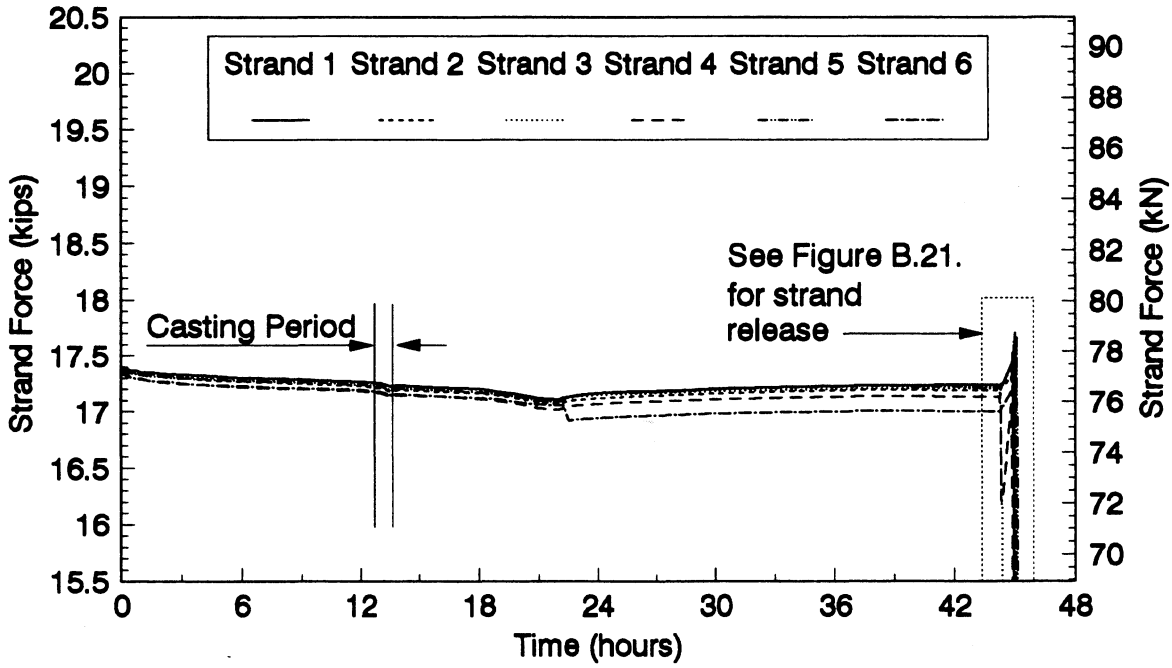


Figure B.4. Strand force versus time for Cast No. 4

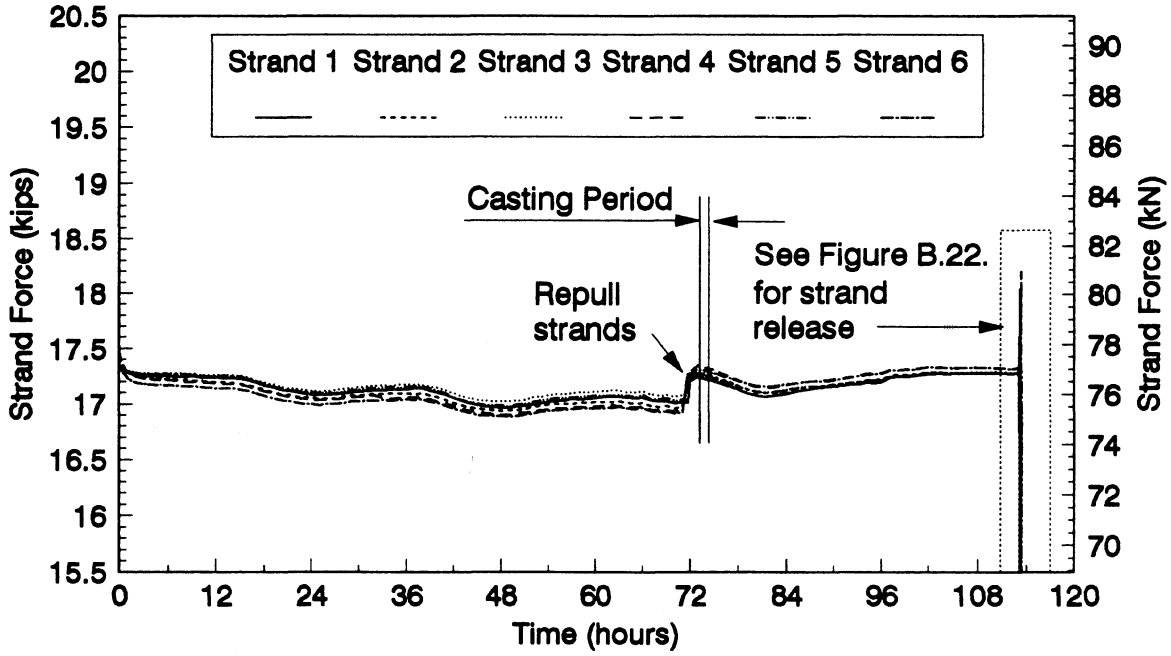


Figure B.5. Strand force versus time for Cast No. 5

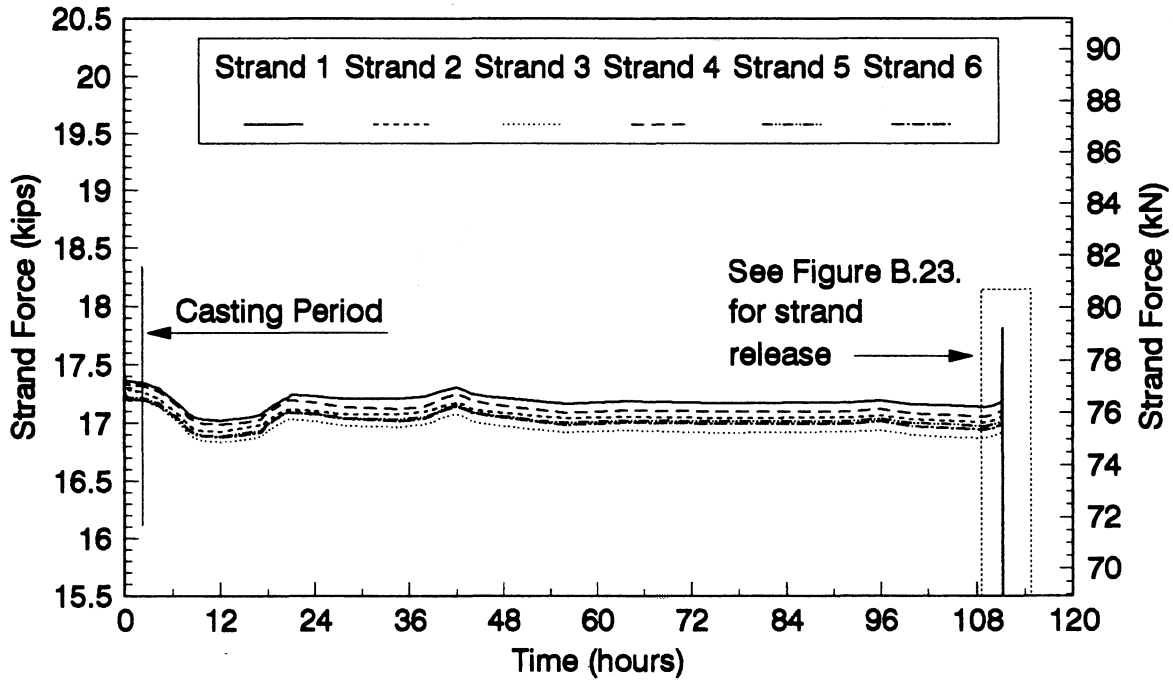


Figure B.6. Strand force versus time for Cast No. 6

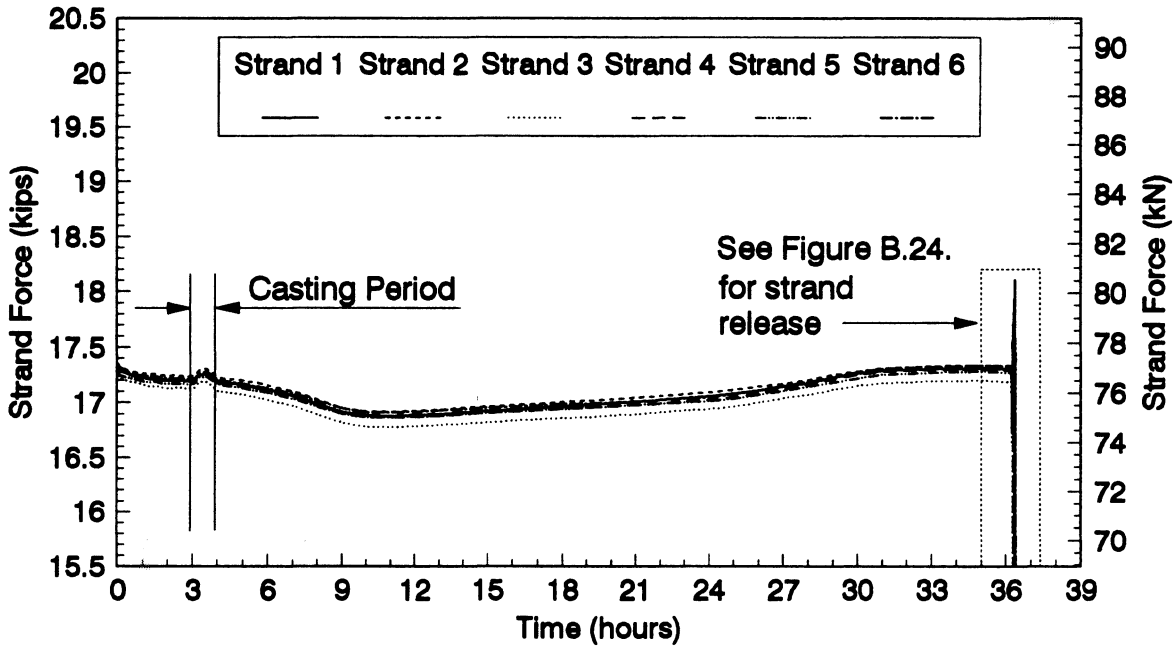


Figure B.7. Strand force versus time for Cast No. 7

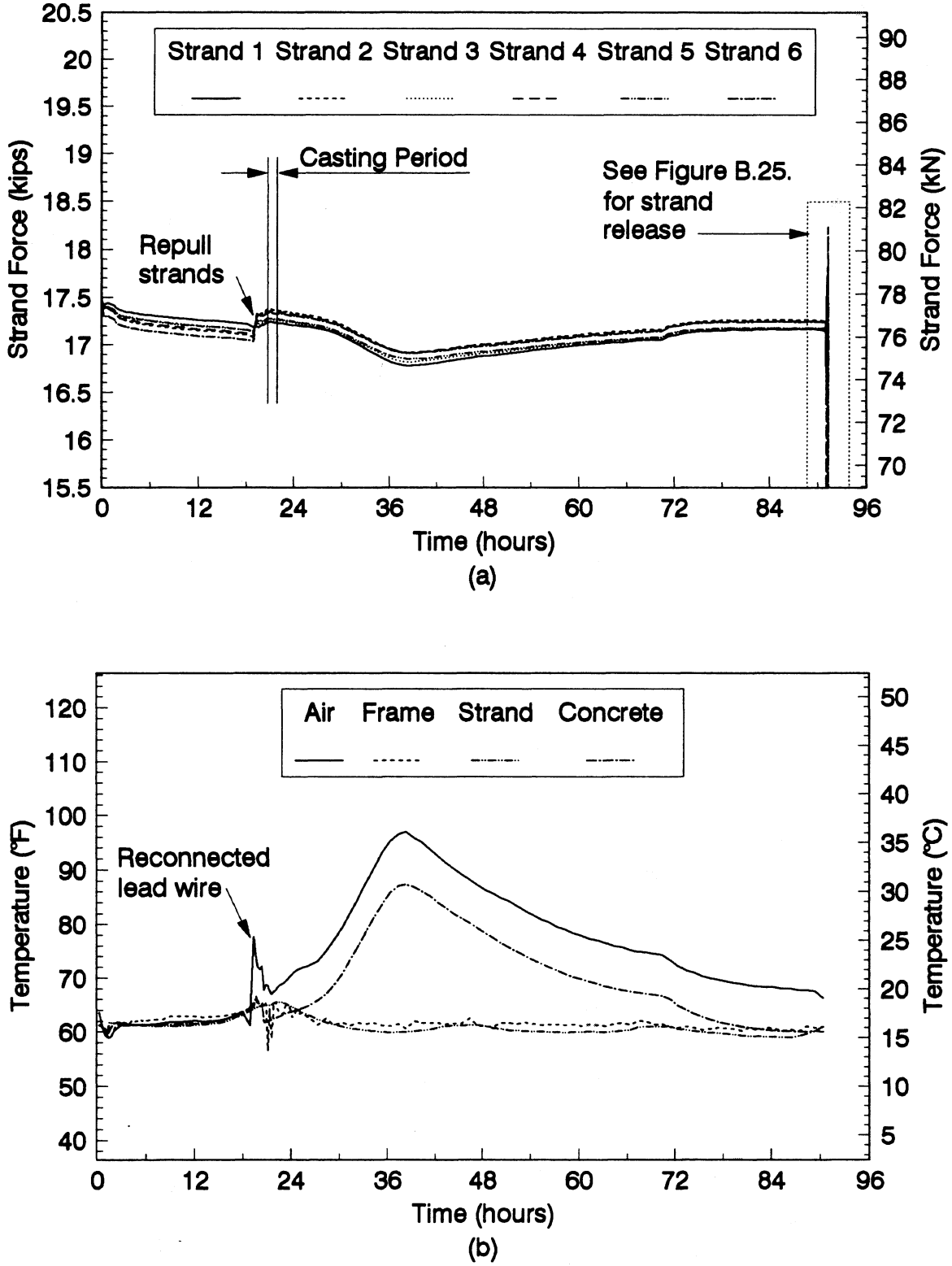


Figure B.8. Strand force and temperature variation for Cast No. 8: (a) strand force versus time; (b) temperature versus time

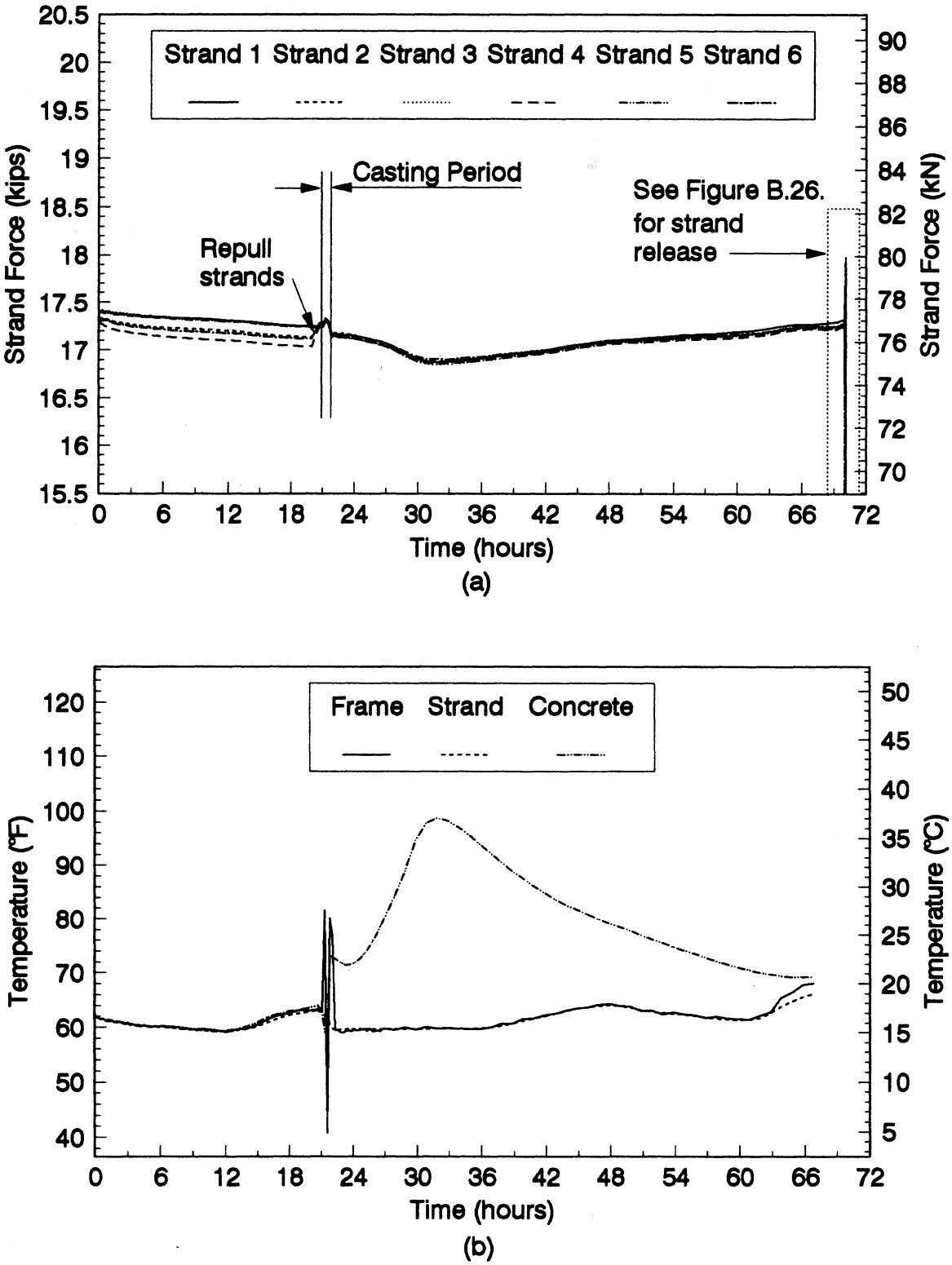


Figure B.9. Strand force and temperature variation for Cast No. 9: (a) strand force versus time; (b) temperature versus time

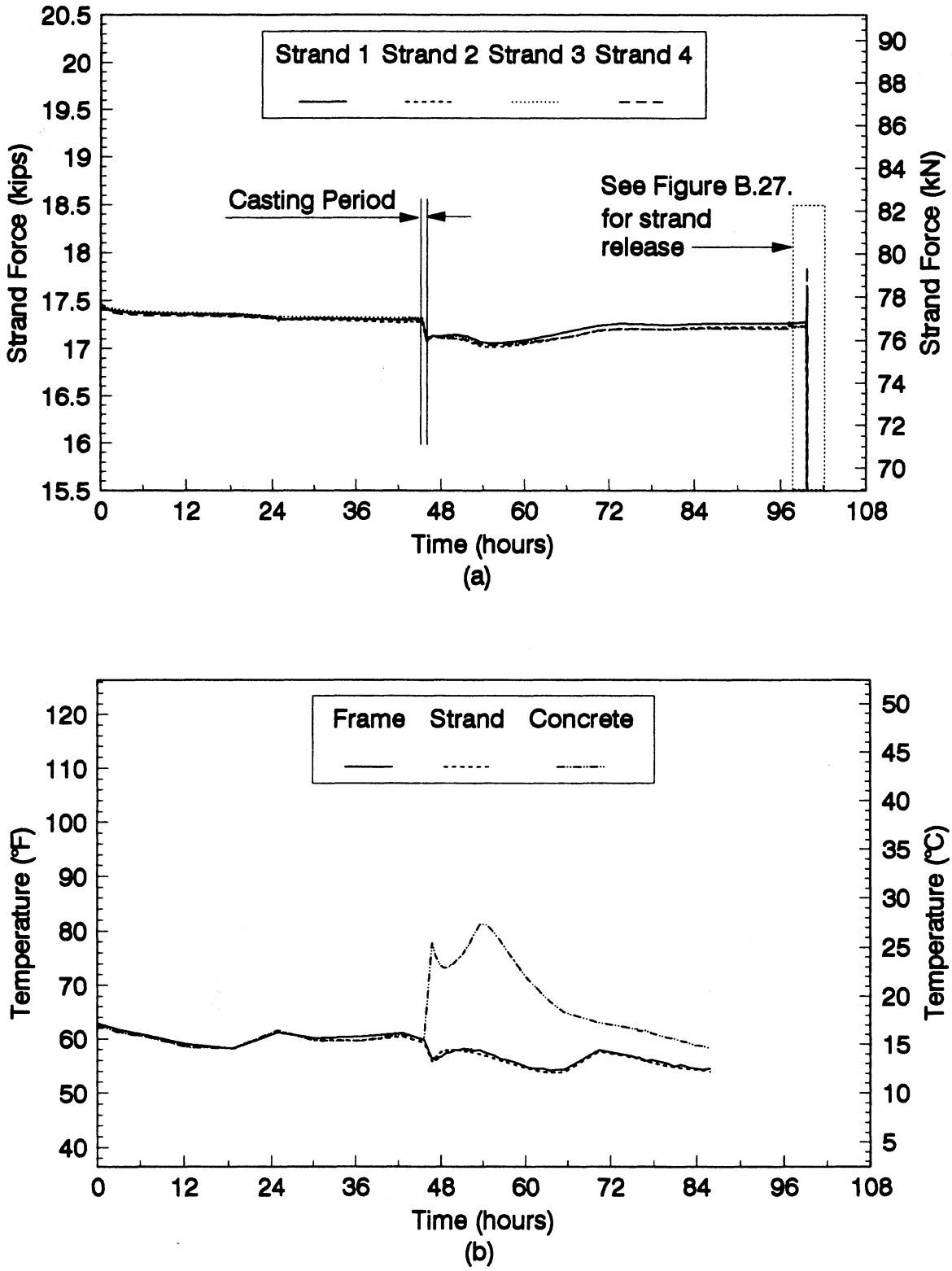


Figure B.10. Strand force and temperature variation for Cast No. 10: (a) strand force versus time; (b) temperature versus time

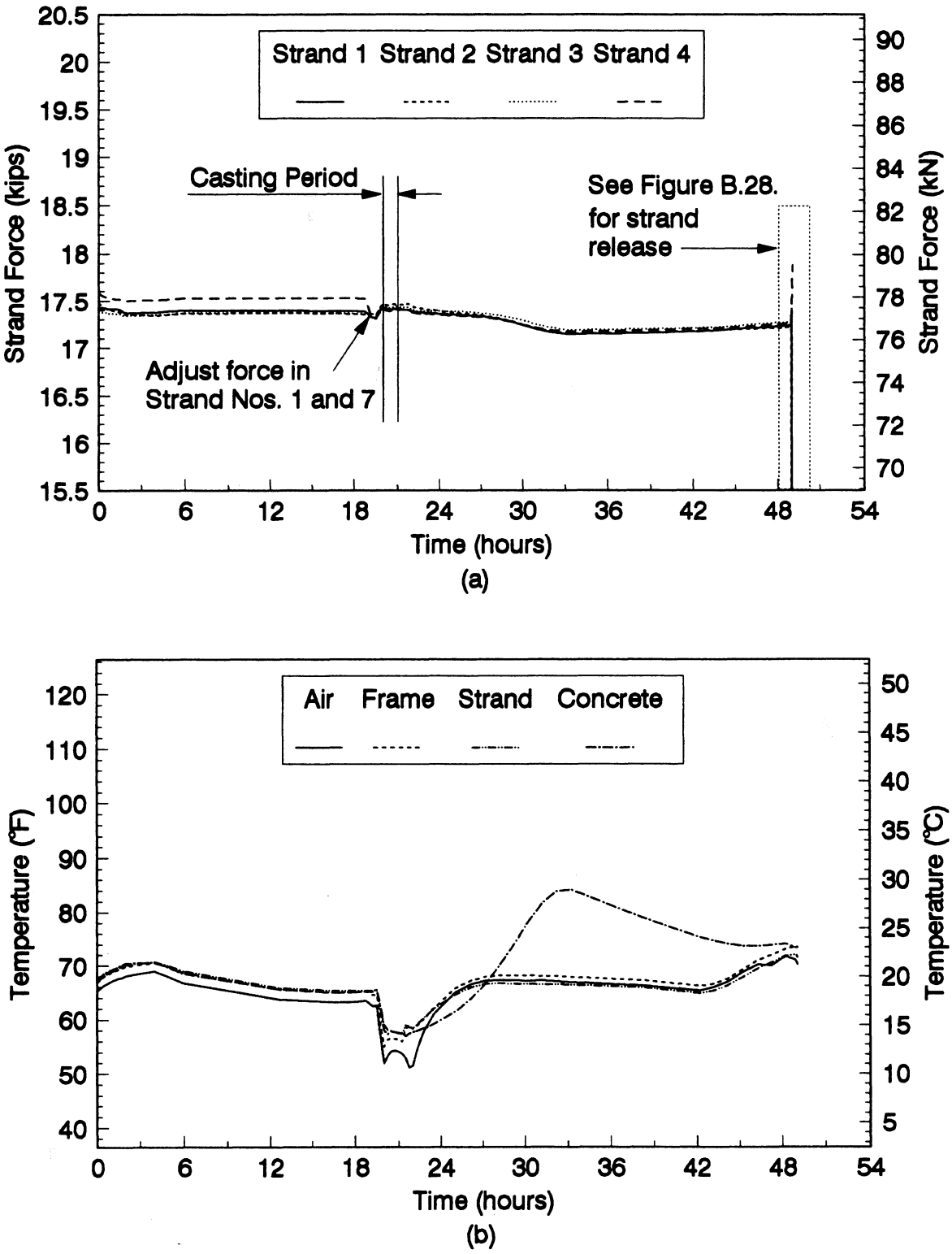


Figure B.11. Strand force and temperature variation for Cast No. 11: (a) strand force versus time; (b) temperature versus time

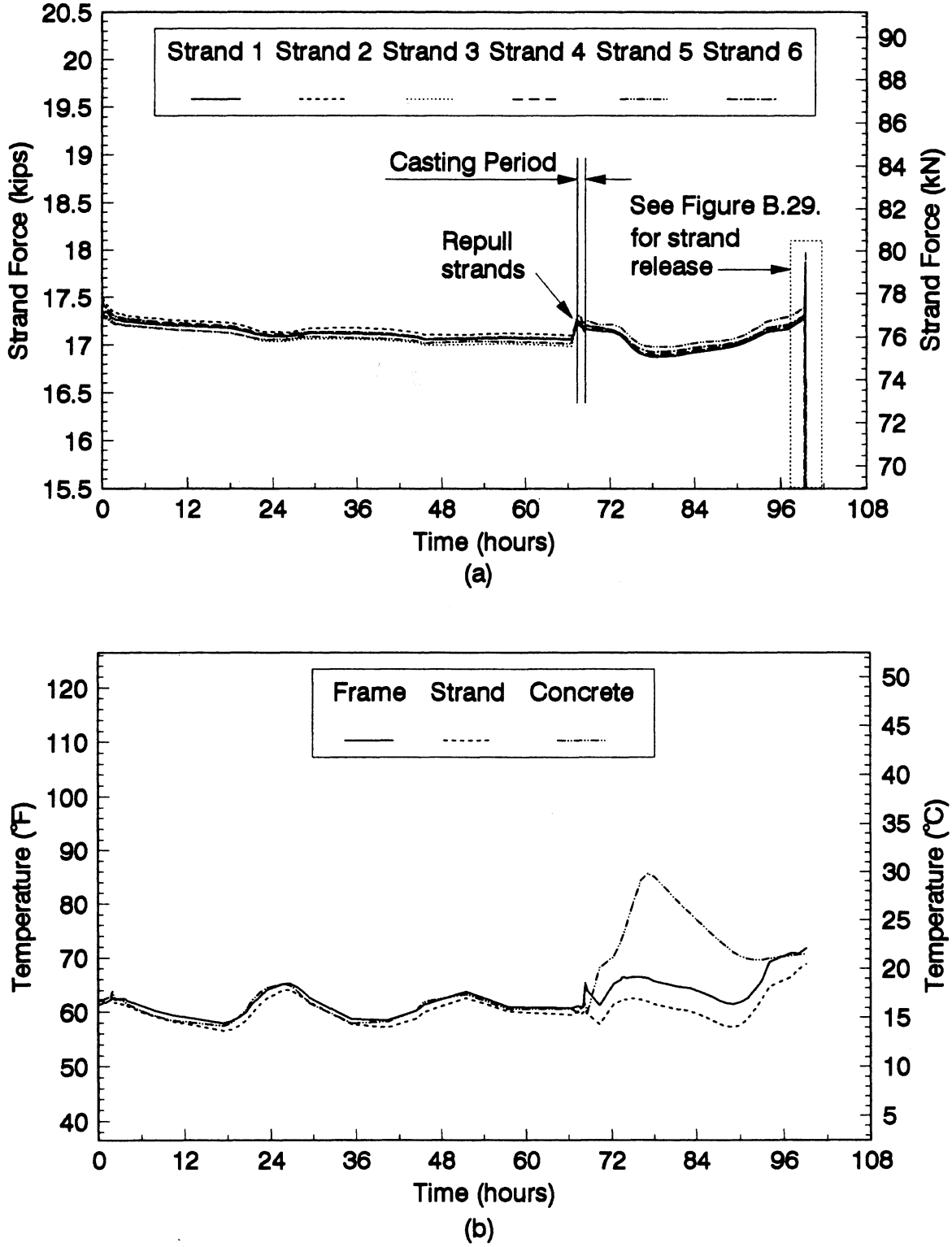


Figure B.12. Strand force and temperature variation for Cast No. 12: (a) strand force versus time; (b) temperature versus time

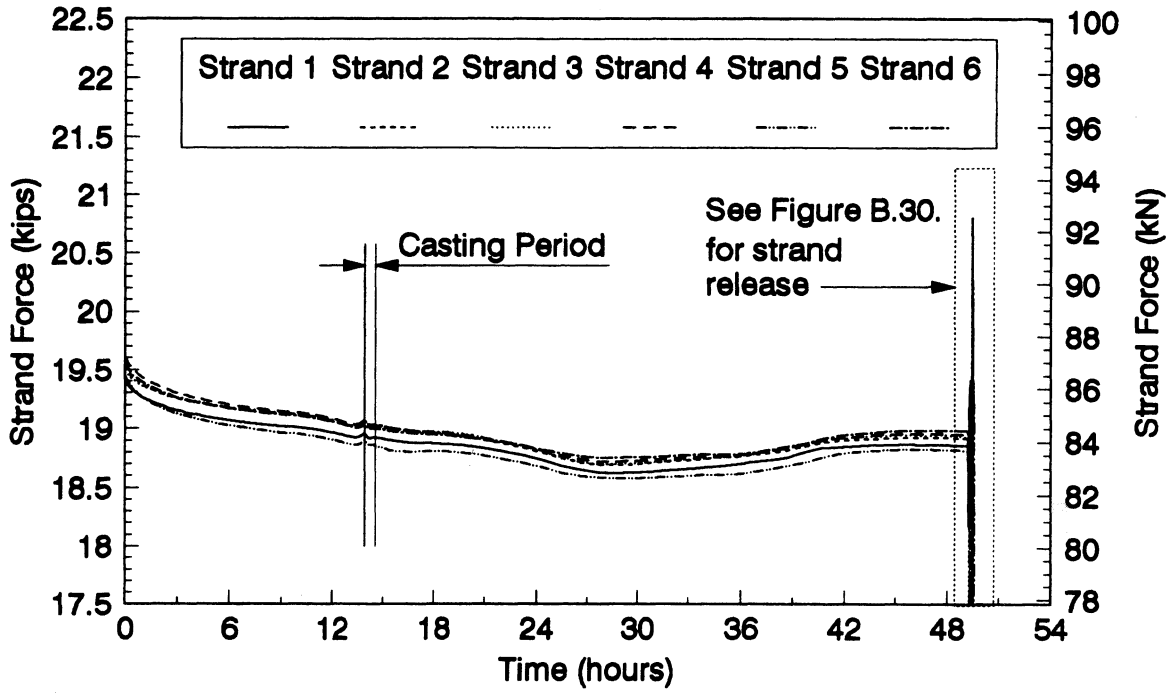


Figure B.13. Strand force versus time for Cast No. 13
(Strands intentionally overstressed)

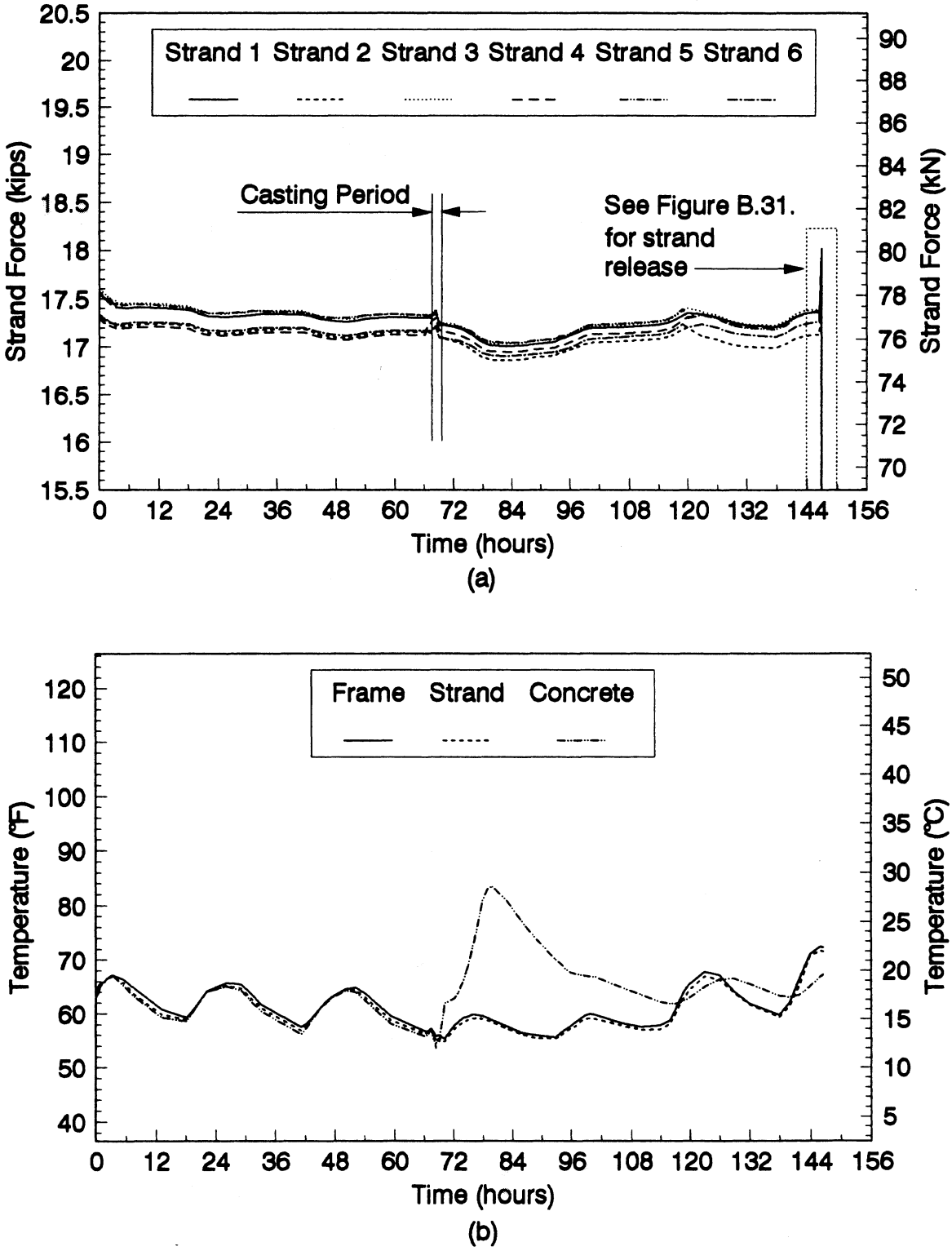


Figure B.14. Strand force and temperature variation for Cast No. 14: (a) strand force versus time; (b) temperature versus time

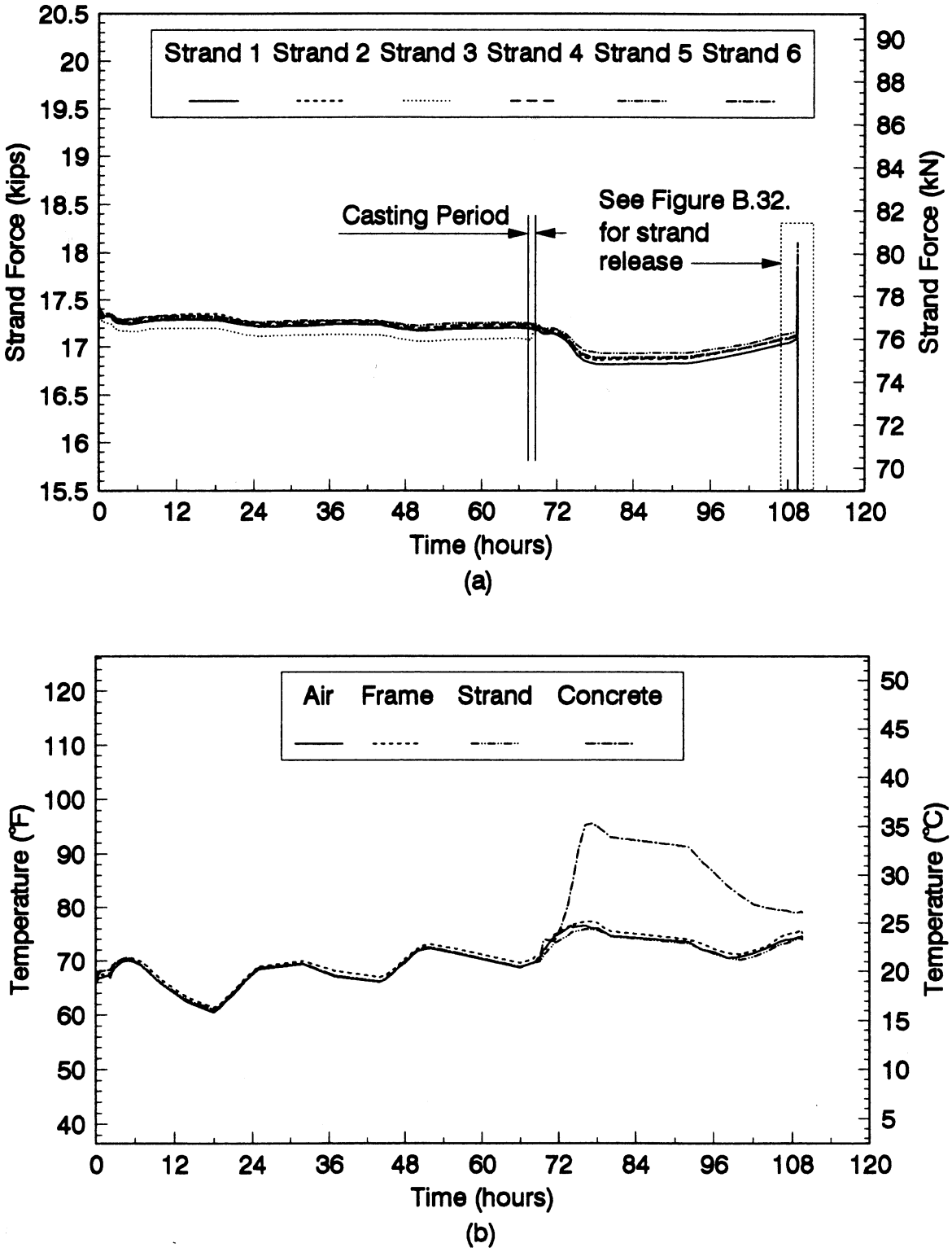


Figure B.15. Strand force and temperature variation for Cast No. 15: (a) strand force versus time; (b) temperature versus time

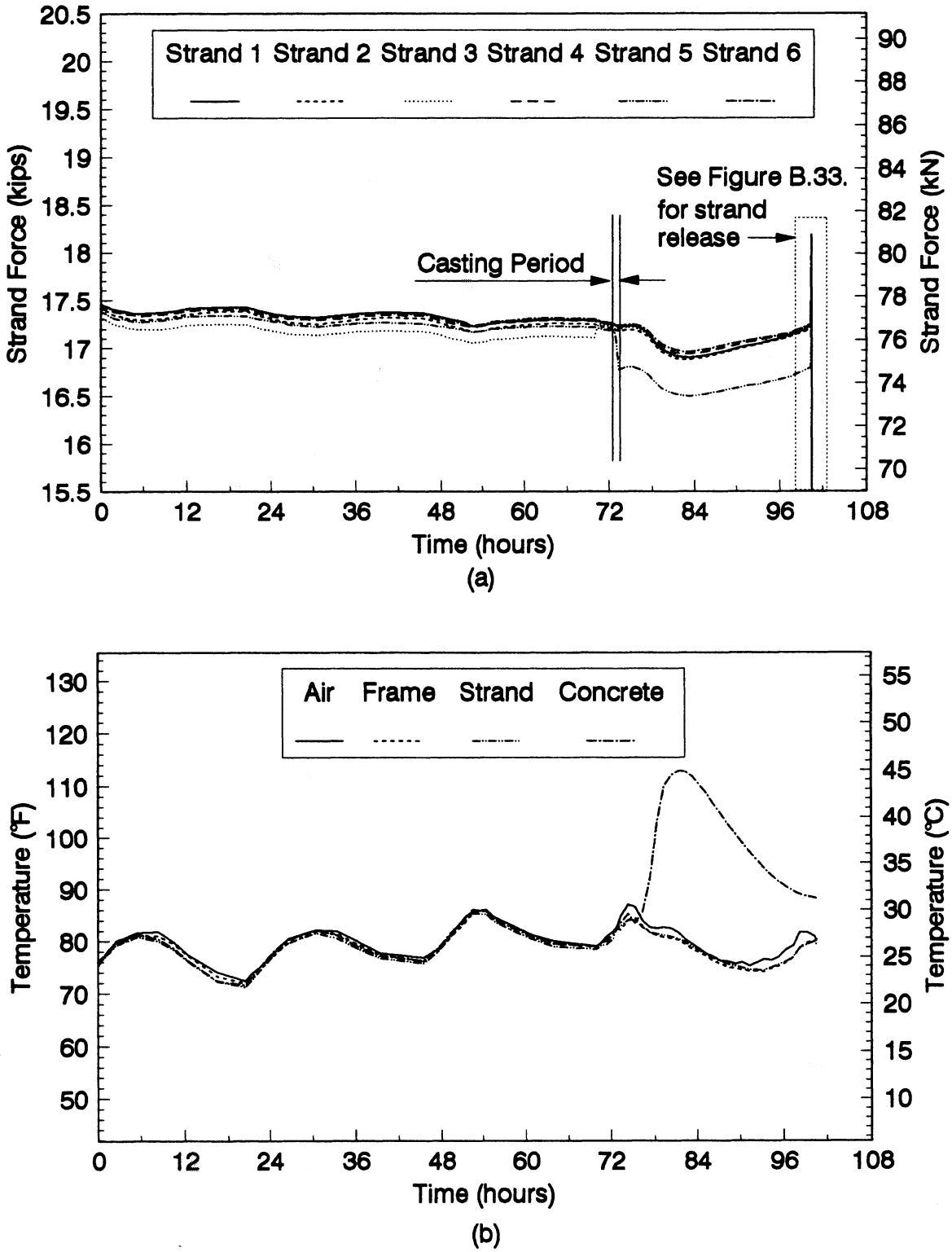


Figure B.16. Strand force and temperature variation for Cast No. 16: (a) strand force versus time; (b) temperature versus time

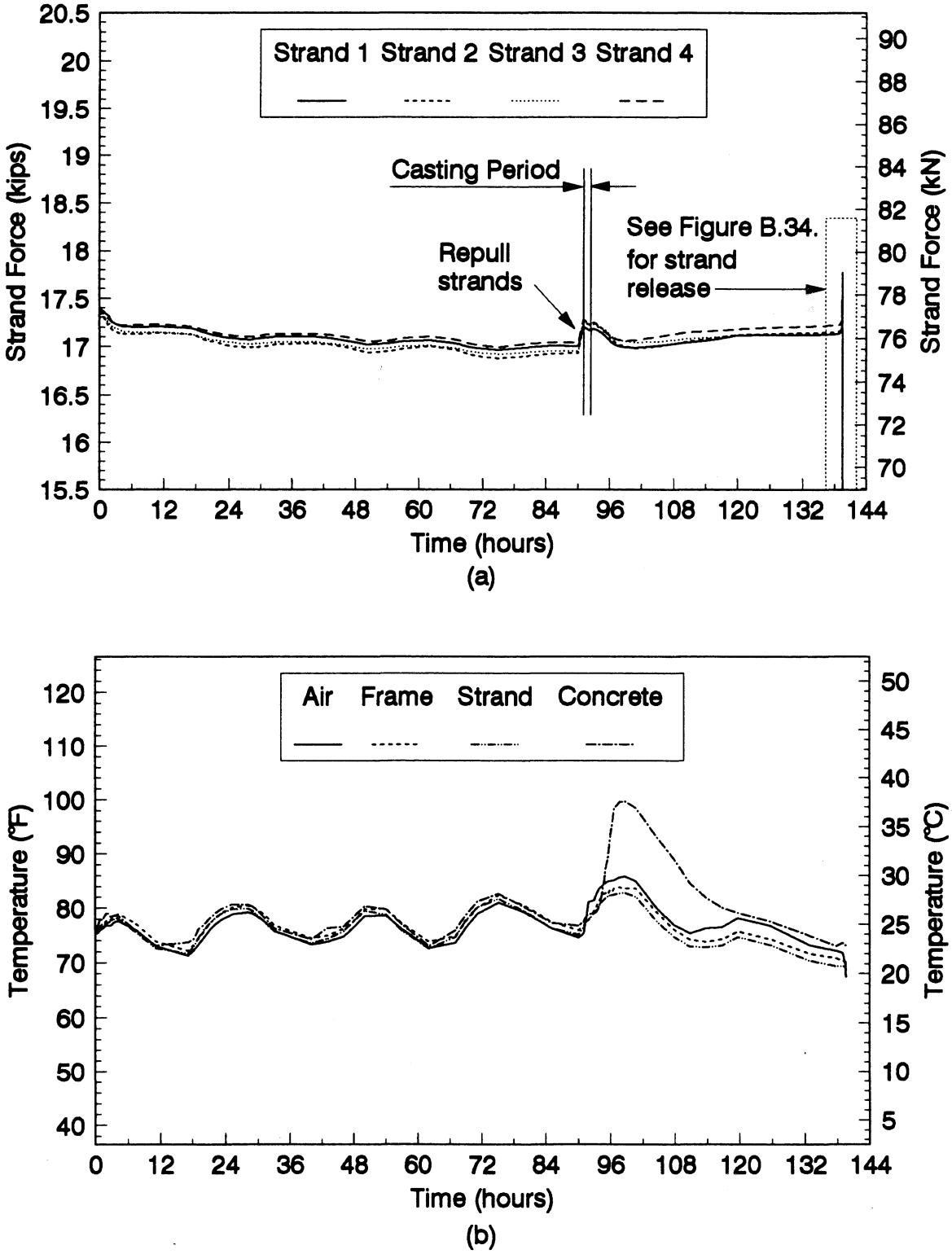


Figure B.17. Strand force and temperature variation for Cast No. 17: (a) strand force versus time; (b) temperature versus time

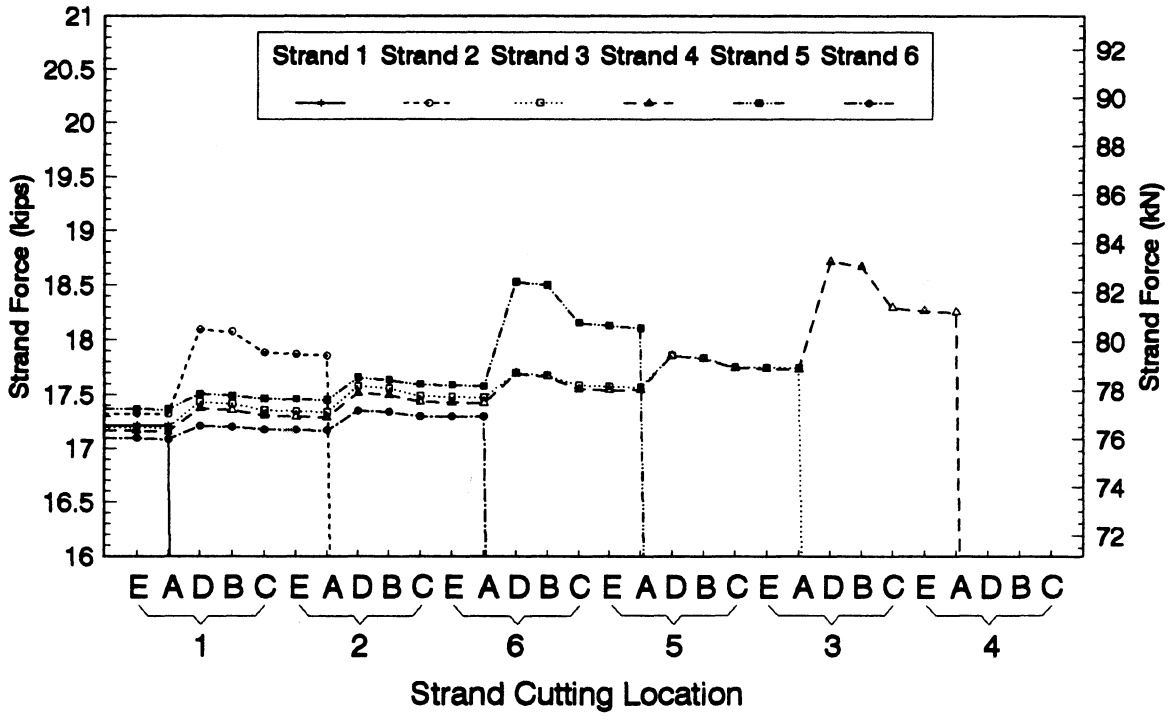


Figure B.18. Strand force during cutting sequences for Cast No. 1

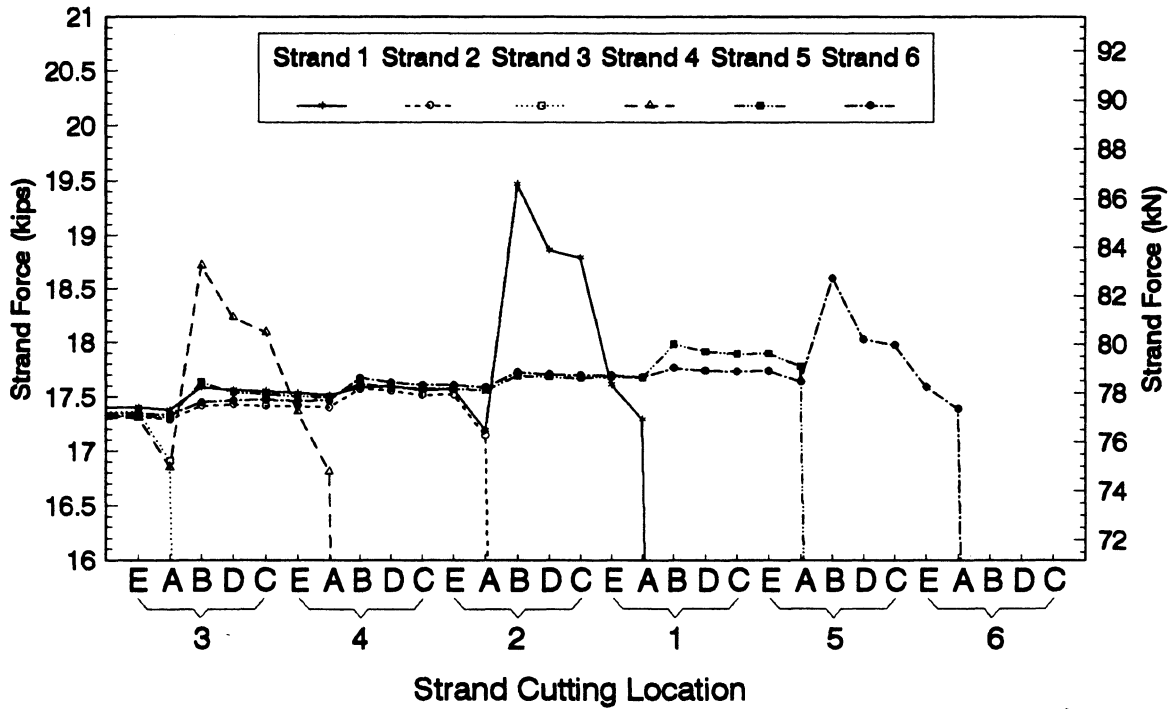


Figure B.19. Strand force during cutting sequences for Cast No. 2

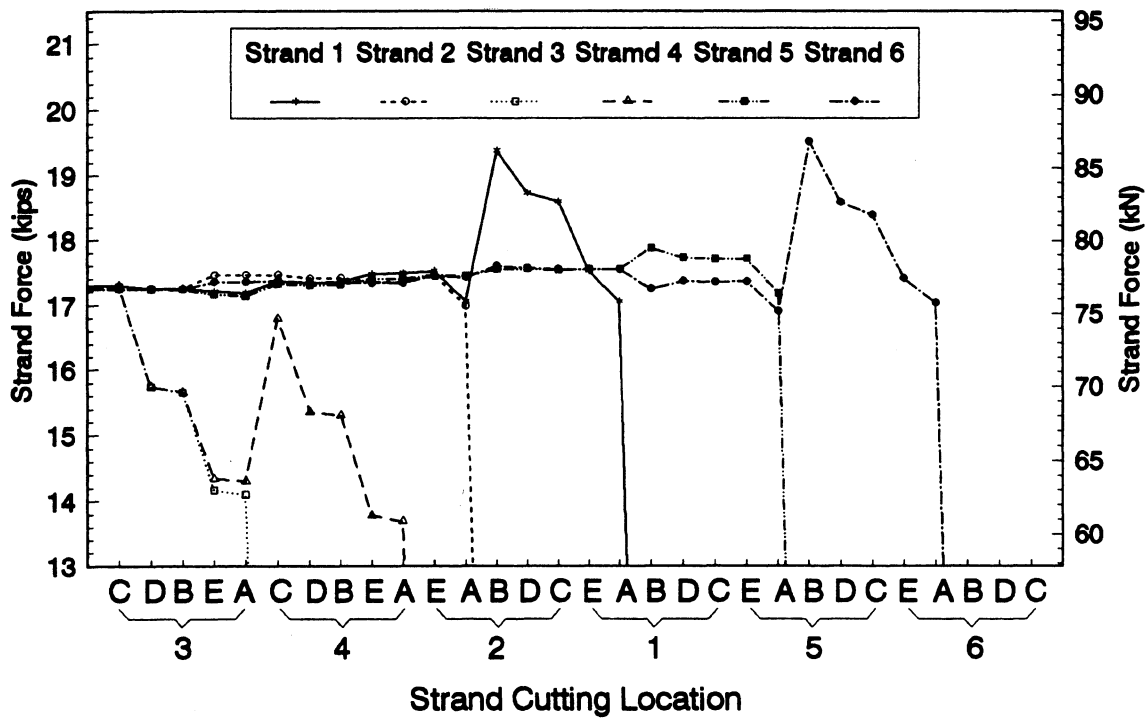


Figure B.20. Strand force during cutting sequences for Cast No. 3 (Expanded ordinate range)

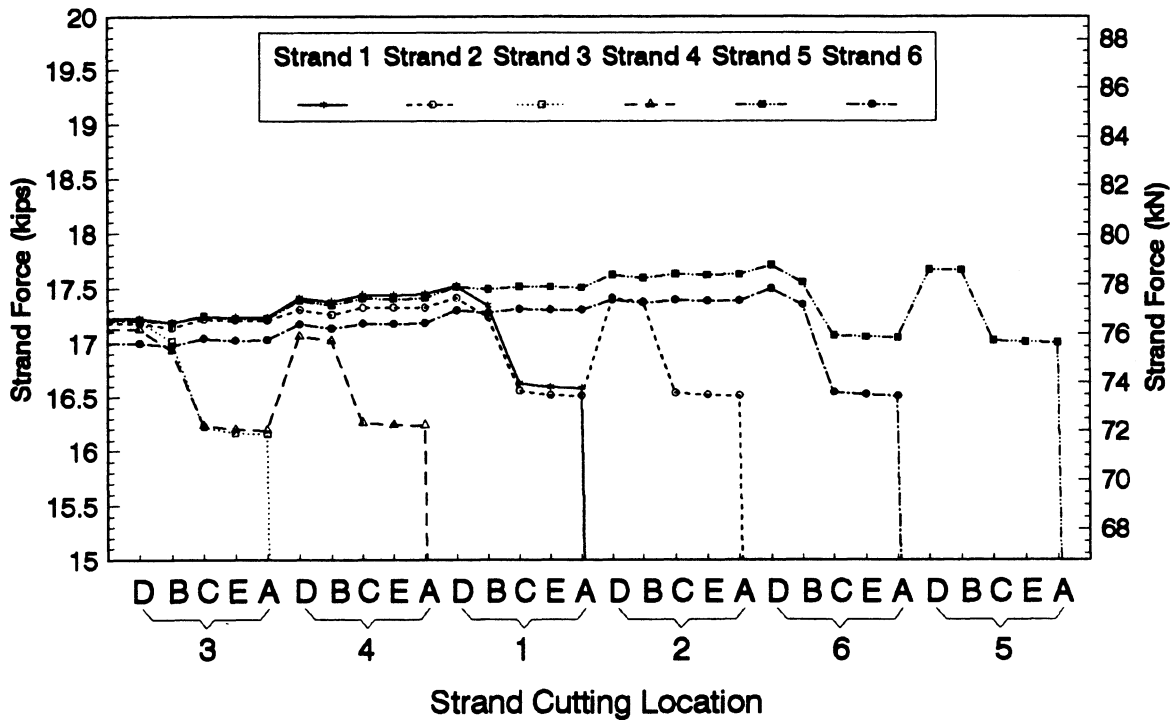


Figure B.21. Strand force during cutting sequences for Cast No. 4

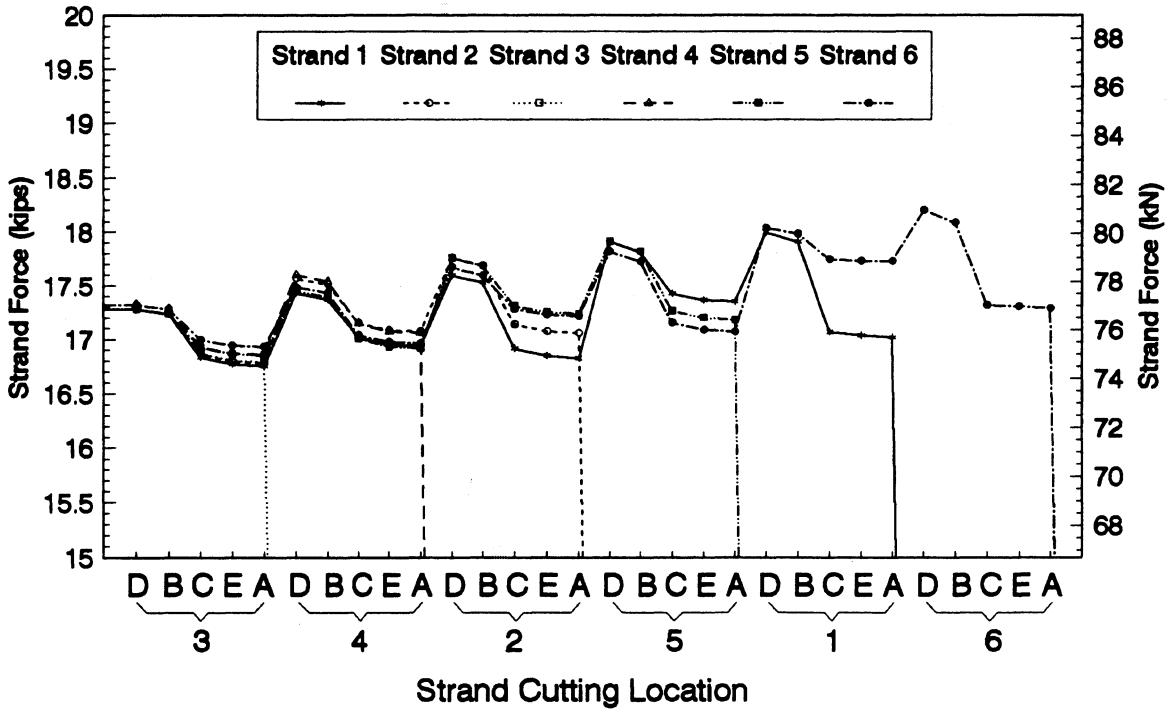


Figure B.22. Strand force during cutting sequences for Cast No. 5

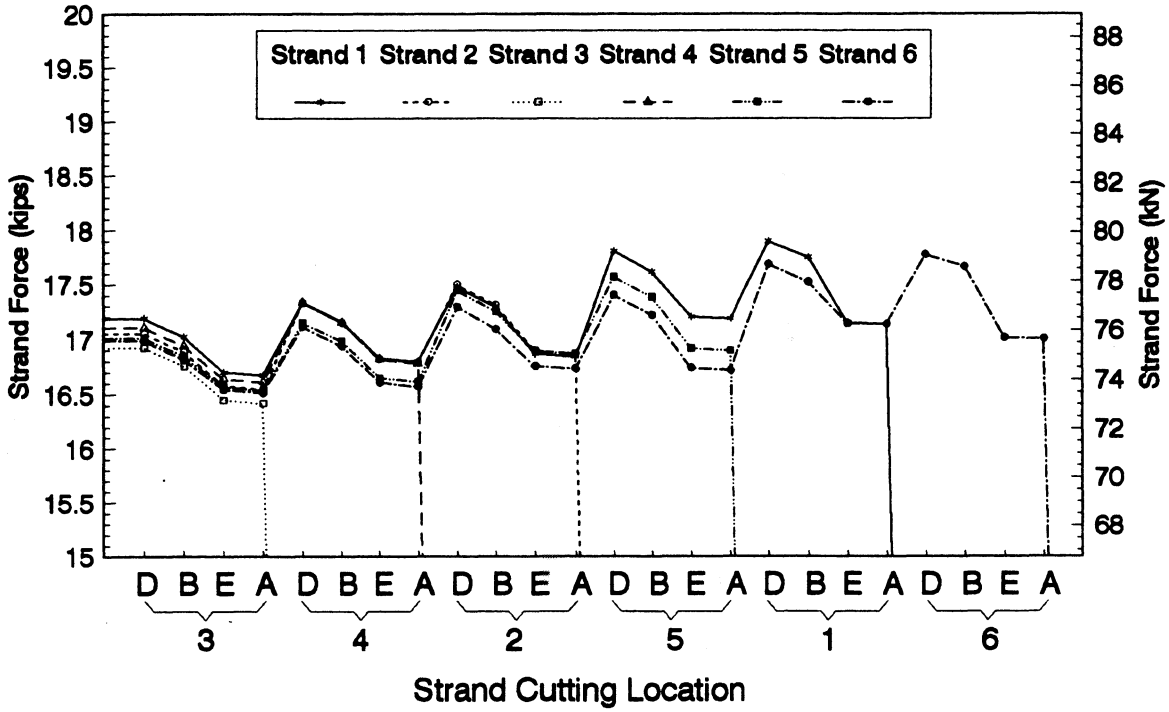


Figure B.23. Strand force during cutting sequences for Cast No. 6

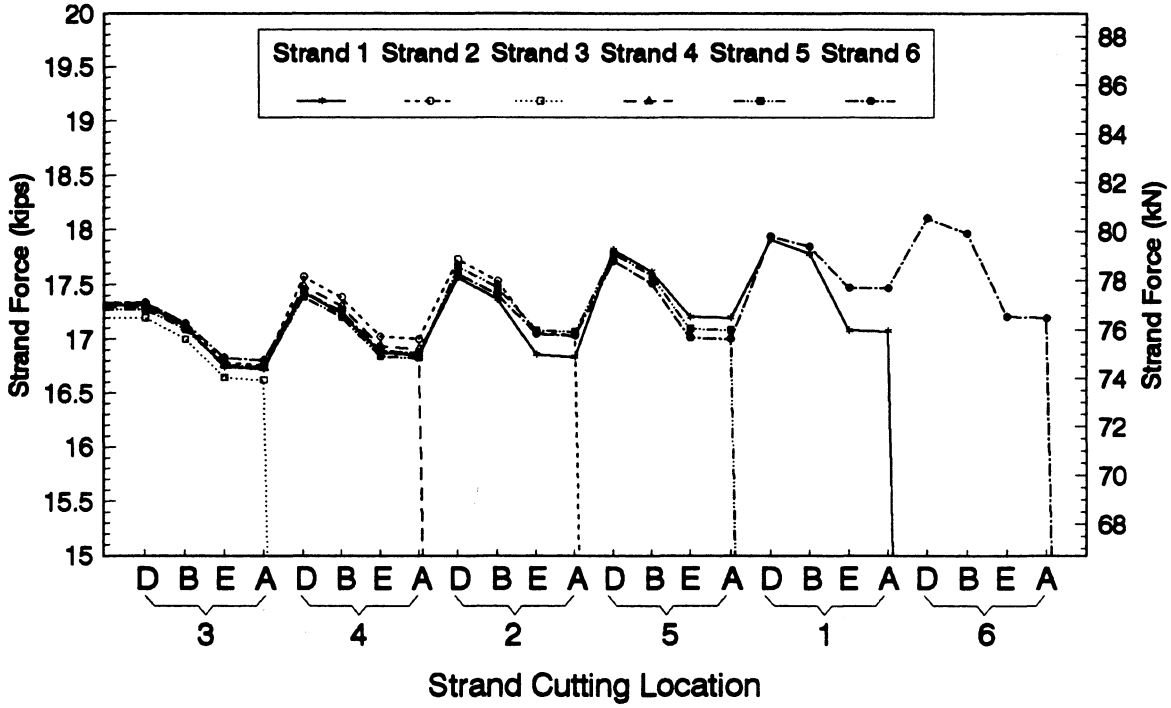


Figure B.24. Strand force during cutting sequences for Cast No. 7

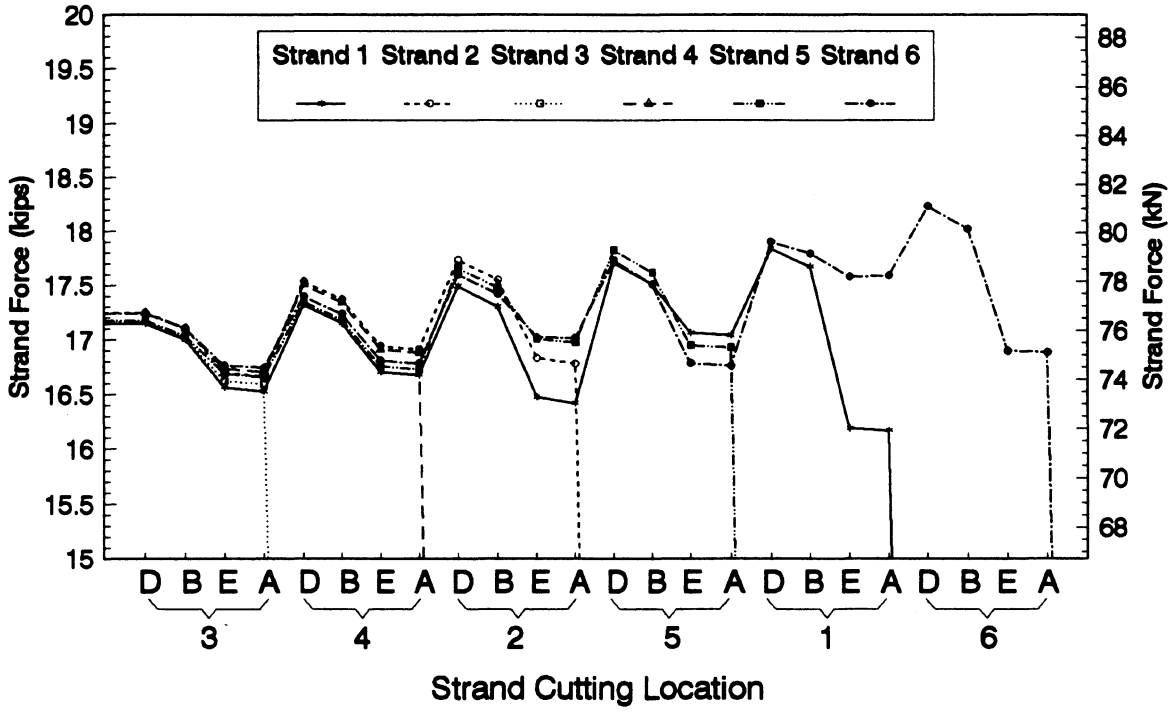


Figure B.25. Strand force during cutting sequences for Cast No. 8

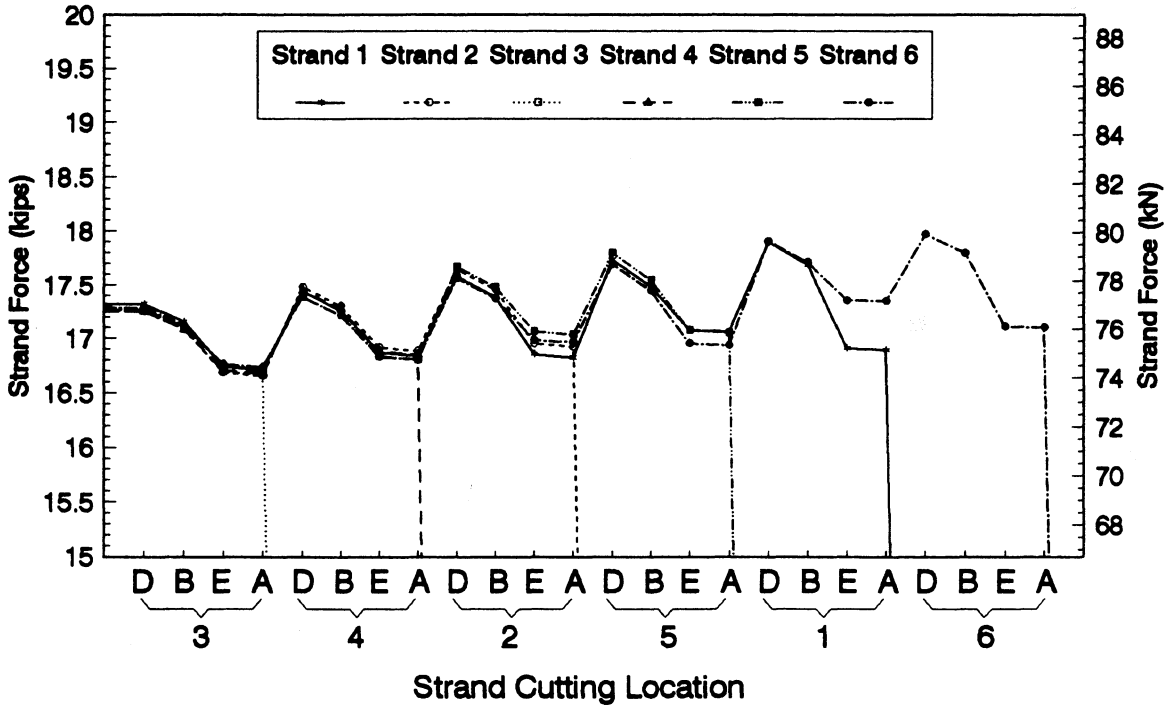


Figure B.26. Strand force during cutting sequences for Cast No. 9

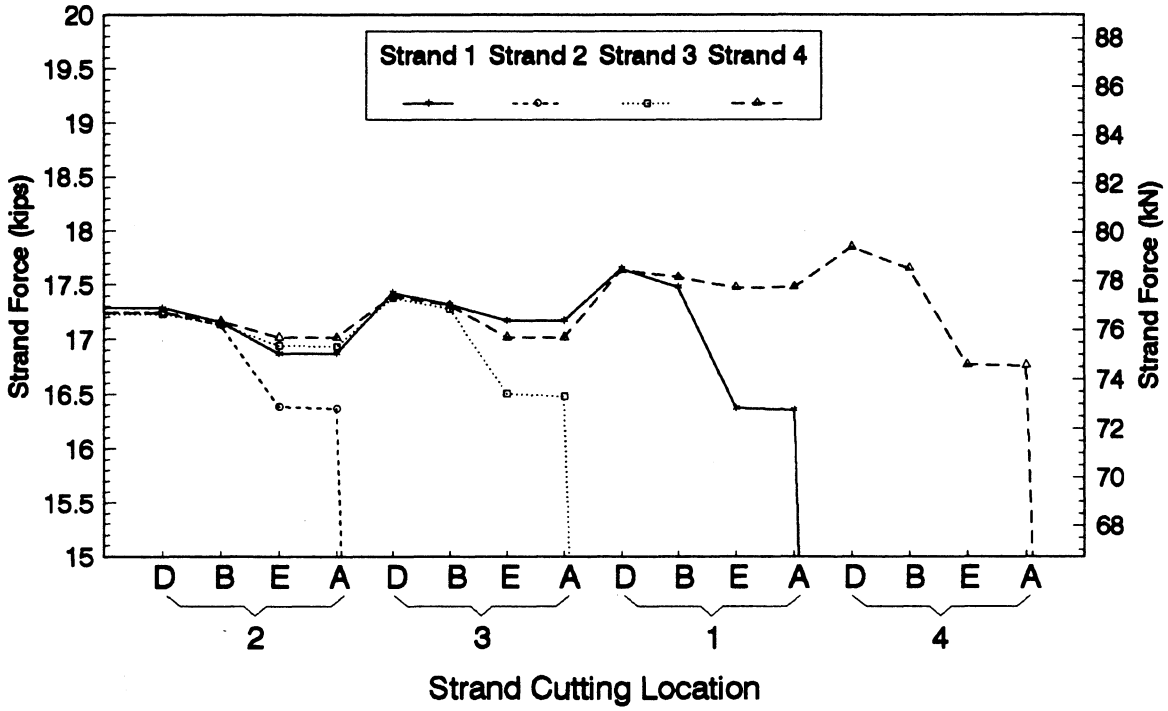


Figure B.27. Strand force during cutting sequences for Cast No. 10

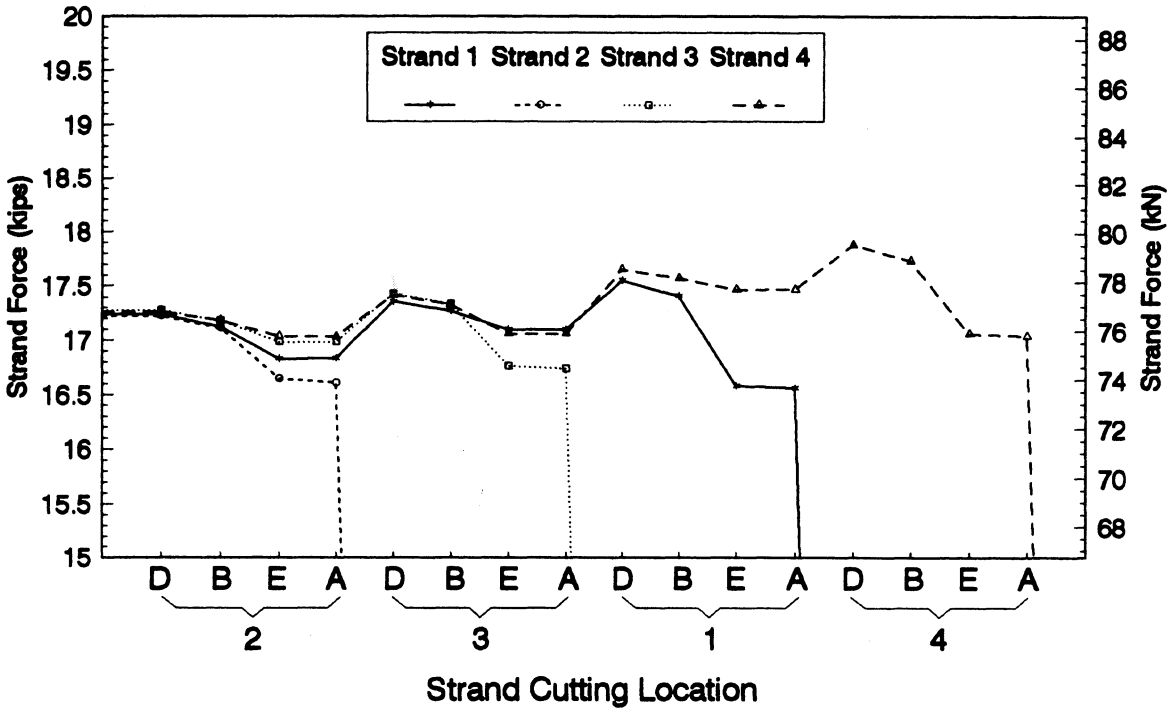


Figure B.28. Strand force during cutting sequences for Cast No. 11

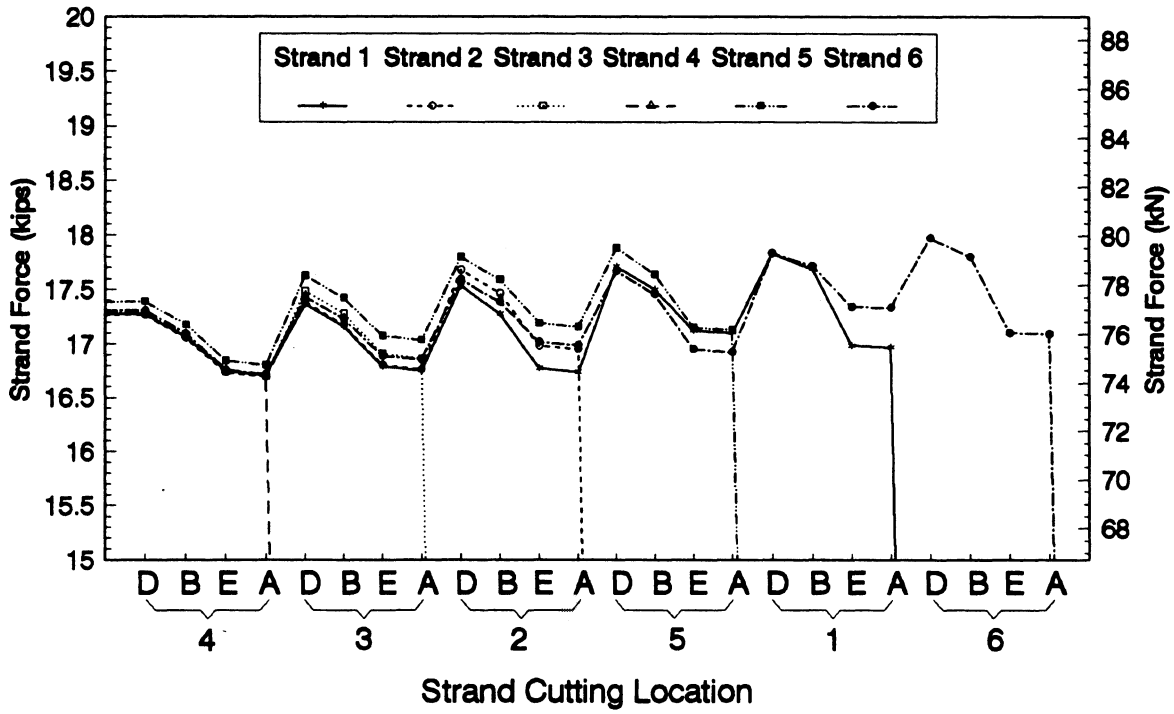


Figure B.29. Strand force during cutting sequences for Cast No. 12

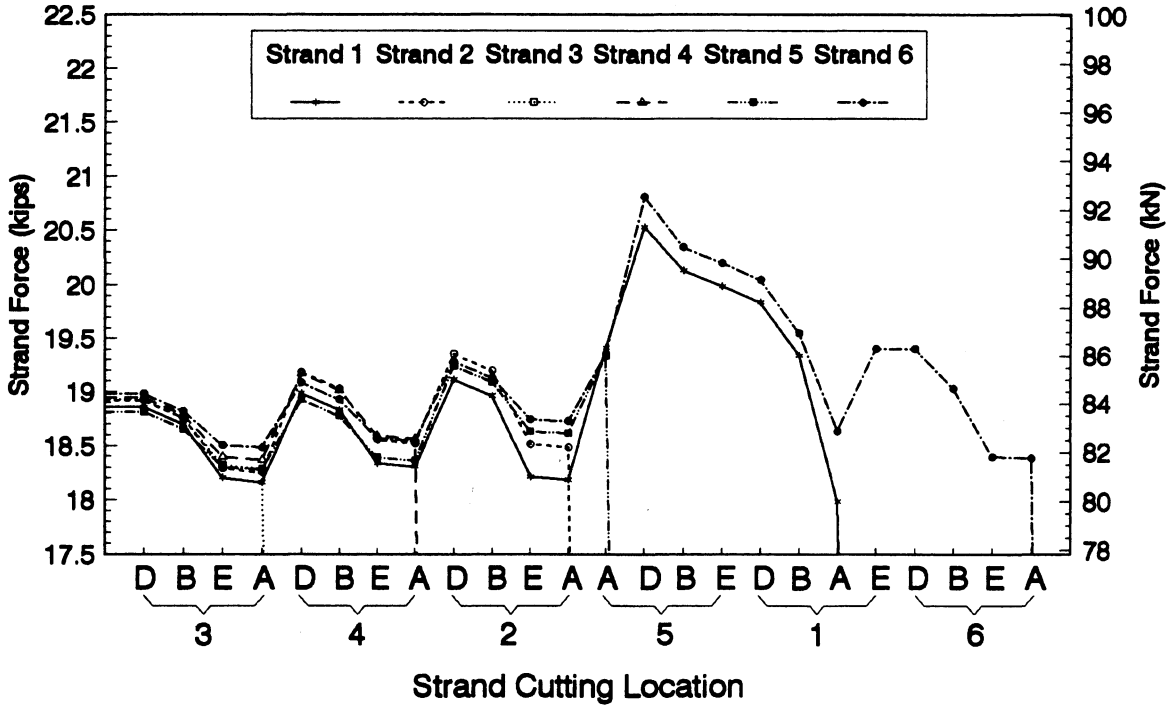


Figure B.30. Strand force during cutting sequences for Cast No. 13
(Strands intentionally overstressed)

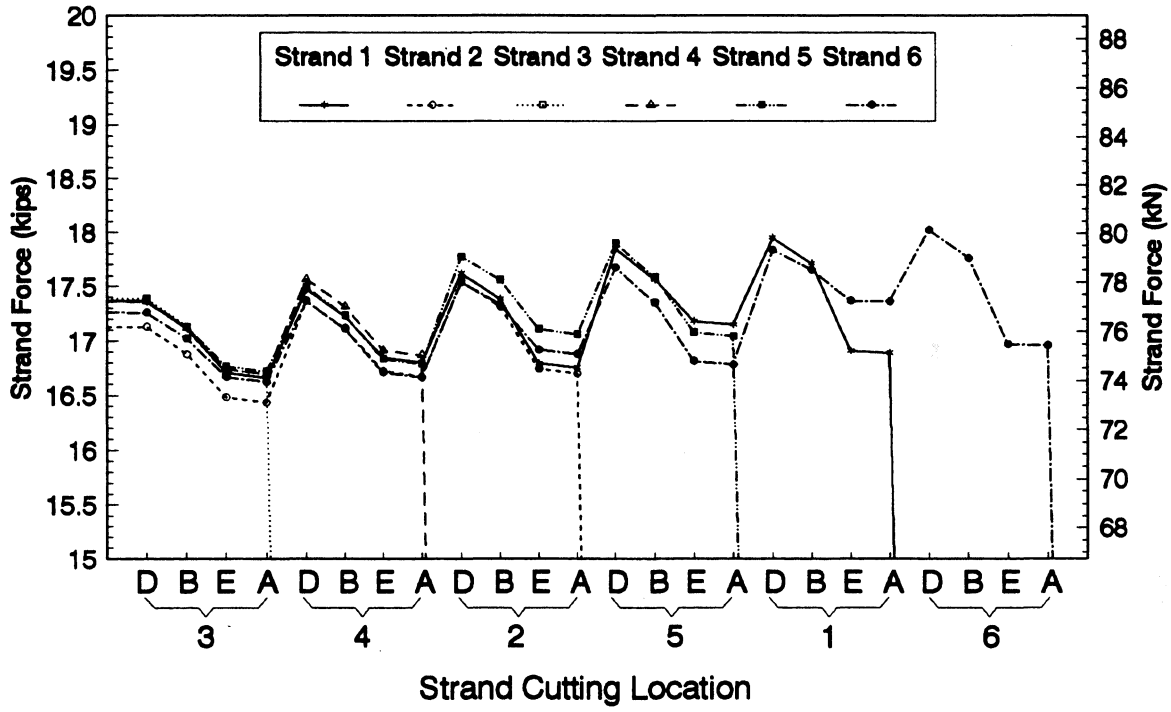


Figure B.31. Strand force during cutting sequences for Cast No. 14

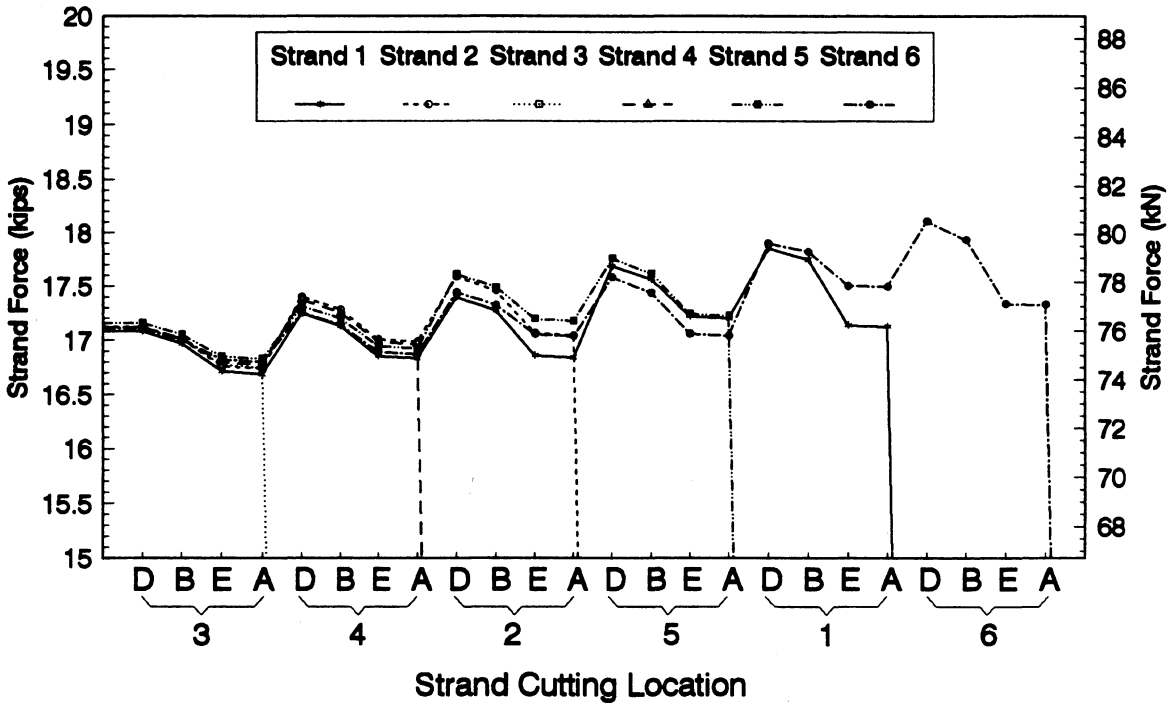


Figure B.32. Strand force during cutting sequences for Cast No. 15

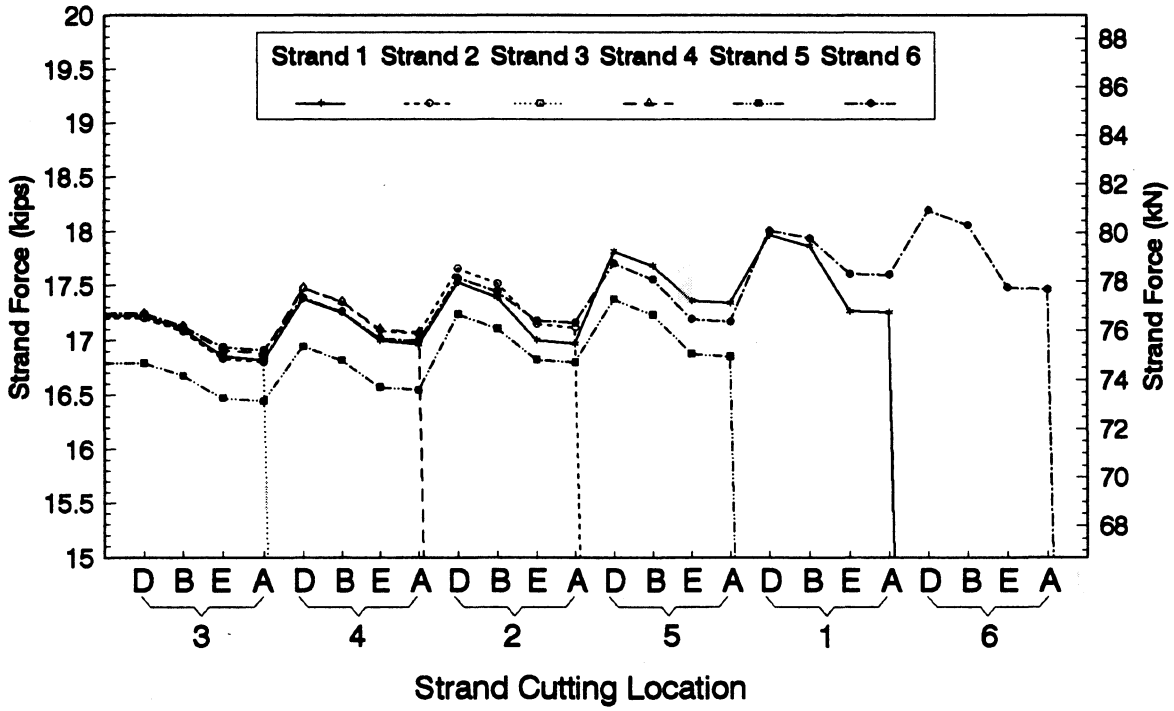


Figure B.33. Strand force during cutting sequences for Cast No. 16

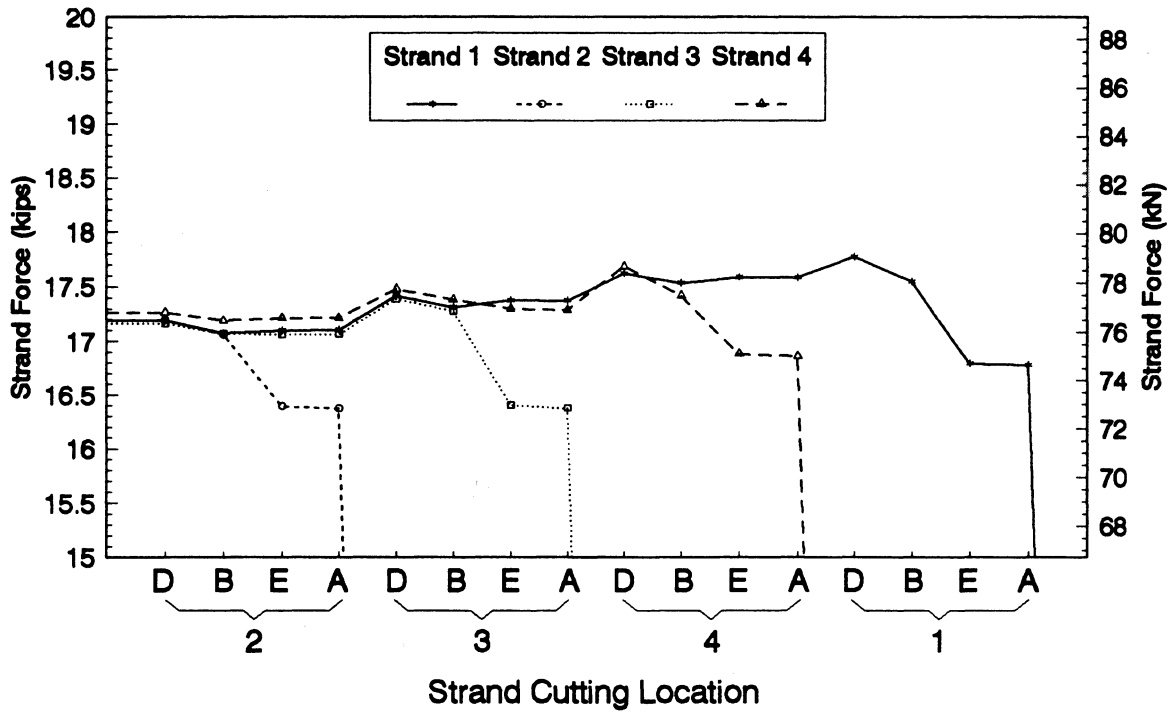


Figure B.34. Strand force during cutting sequences for Cast No. 17

APPENDIX C: SPECIMEN IDENTIFICATION AND SPECIMEN DIMENSIONS AND CONCRETE CRACK PATTERNS FOR THE T-TYPE SPECIMENS

The location for each of the strand transfer length (T-type) specimens and strand development length (D-type) specimens within the prestressing frame are shown in Figs. C1, C2, C3, and C4 for Cast Nos. 1-4; 5; 6-9 and 12-16; and 10, 11, and 17, respectively. The plan view of the prestressing frame shown in these figures illustrates the number of specimens within each bay of the frame and gives the steel header identification letters. The header letters were used to identify each end of a particular specimen. The tables shown in Figs. C1, C3 and C4 correlates each specimen of a concrete casting with the specimen outline shown in the figure of the prestressing frame.

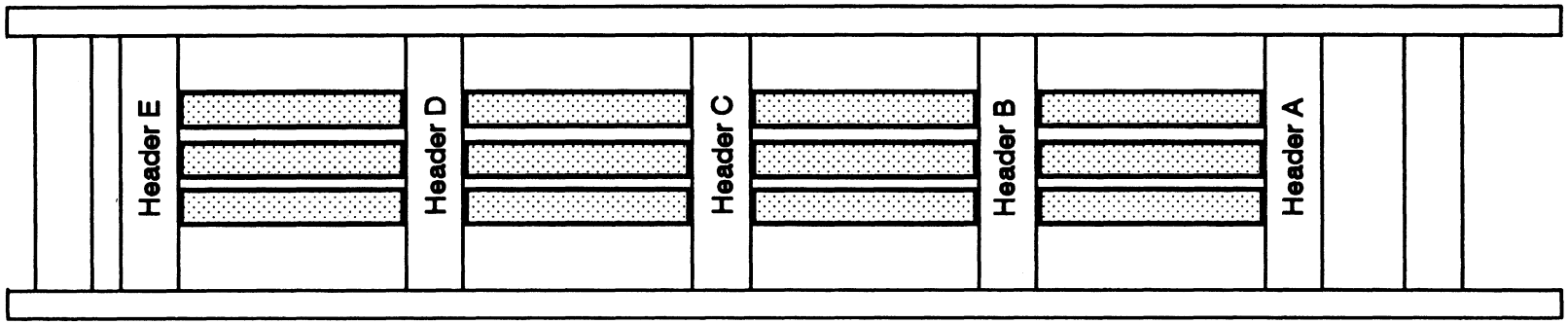
Figures C.5-C.107 show the plan view and the end views (corresponding to the steel header designations) of each specimen from Cast Nos. 2-17. The 12 specimens from Cast No. 1 were not measured after strand detensioning, since they were cast primarily to evaluate the construction methods and instrumentation system. Figures C.5-C.44, C.52, C.55, C.82, C.84-C.86, C.88, and C.100-C.103 show the coated-strand T-type specimens; and Figs. C.46, C.49, C.61-C.64, C.73-C.76, C.91, and C.94 show the uncoated-strand T-type specimens. Figures C.51, C.53, C.54, C.56, C.81, C.83, C.87, C.89, C.96-C.99, and C.104-C.107 show the coated-strand D-type specimens; and Figs. C.45, C.47, C.48, C.50, C.57-C.60, C.65-C.72, C.77-C.80, C.90, C.92, C.93, and C.95 show the uncoated-strand D-type specimens. All of the dimensions given in these figures are in units of inches. The edge distance of a prestressing strand was measured from the center of the strand to the face of the concrete. The spacing between strands was measured between the center of each adjacent strand. All of the dimensions that locate a strand were measured to the nearest 1/16 in. and the length of a

specimen was measured to the nearest inch. A strand number shown for a particular specimen corresponds to the strand numbering system that was used for the prestressing frame.

Eleven of the T-type specimens contained polyester-mold, encapsulated strain gages that were cast within the specimens. Figures C.62, C.63, C.74, C.75, C.82, C.88, C.91, C.94, and C.101-C.103 show the locations of the center of each gage length along the length of a particular specimen. Each gage was positioned at the middepth of a specimen. These gages were used to establish the strand transfer lengths.

The 4 and 6-in. wide, D-type specimens contained a single No. 4 reinforcing bar, and the 36-in. wide, D-type specimens contained four No. 4 bars. These bars were located near the top of the specimens to prevent flexural tension cracks from occurring when the specimens were moved. For the 36-in. wide, D-type specimens, transverse No. 4 reinforcing bars that were supported by bar chairs were provided to hold the longitudinal bars in position. For dimensional clarity, the end views for the D-type specimens do not show the No. 4 bars.

After prestressing some of the T-type specimens that were reinforced with coated strands, concrete cracks formed directly above and/or below a prestressing strand. These concrete splitting failures have been shown and their lengths have been dimensioned on the figures of the corresponding specimens. If a concrete crack was not visually detected in a T-type specimen, the notation "No visible cracks" has been written on the plan view of the specimen.



Cast No.	Specimen Identification Numbers								
1	Header E	1 - 4.0 TU - 12 1 - 4.0 TU - 11 1 - 4.0 TU - 10	Header D	1 - 3.5 TU - 9 1 - 3.5 TU - 8 1 - 3.5 TU - 7	Header C	1 - 3.0 TU - 6 1 - 3.0 TU - 5 1 - 3.0 TU - 4	Header B	1 - 2.5 TU - 3 1 - 2.5 TU - 2 1 - 2.5 TU - 1	Header A
2		2 - 2.5 TC - 12 2 - 2.5 TC - 11 2 - 2.5 TC - 10		2 - 3.0 TC - 9 2 - 3.0 TC - 8 2 - 3.0 TC - 7		2 - 3.0 TC - 6 2 - 3.0 TC - 5 2 - 3.0 TC - 4		2 - 2.5 TC - 3 2 - 2.5 TC - 2 2 - 2.5 TC - 1	
3		3 - 2.5 TC - 12 3 - 2.5 TC - 11 3 - 2.5 TC - 10		3 - 3.0 TC - 9 3 - 3.0 TC - 8 3 - 3.0 TC - 7		3 - 3.0 TC - 6 3 - 3.0 TC - 5 3 - 3.0 TC - 4		3 - 2.5 TC - 3 3 - 2.5 TC - 2 3 - 2.5 TC - 1	
4		4 - 3.0 TC - 12 4 - 3.0 TC - 11 4 - 3.0 TC - 10		4 - 3.0 TC - 9 4 - 3.0 TC - 8 4 - 3.0 TC - 7		4 - 3.0 TC - 6 4 - 3.0 TC - 5 4 - 3.0 TC - 4		4 - 3.0 TC - 3 4 - 3.0 TC - 2 4 - 3.0 TC - 1	

Figure C.1. Specimens for Cast Nos. 1, 2, 3, and 4

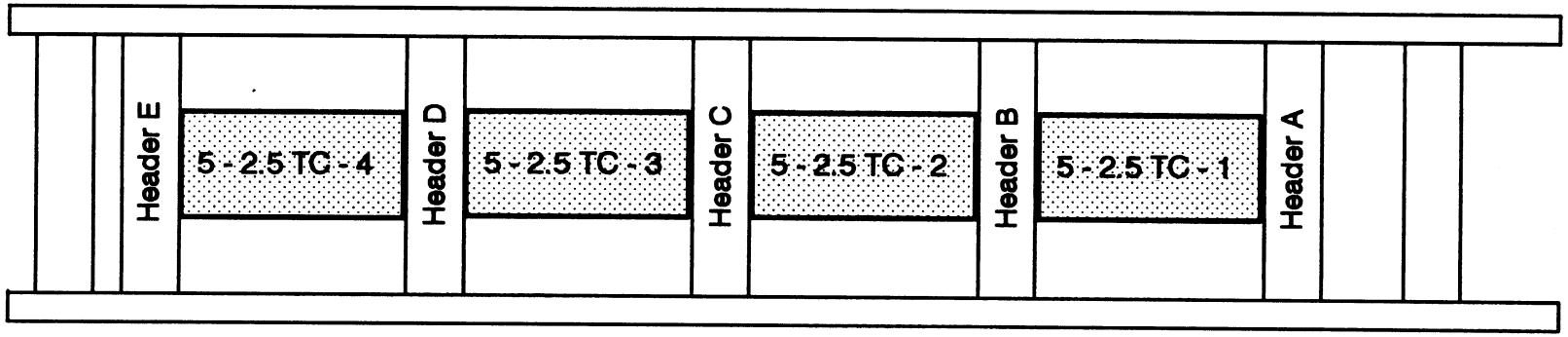
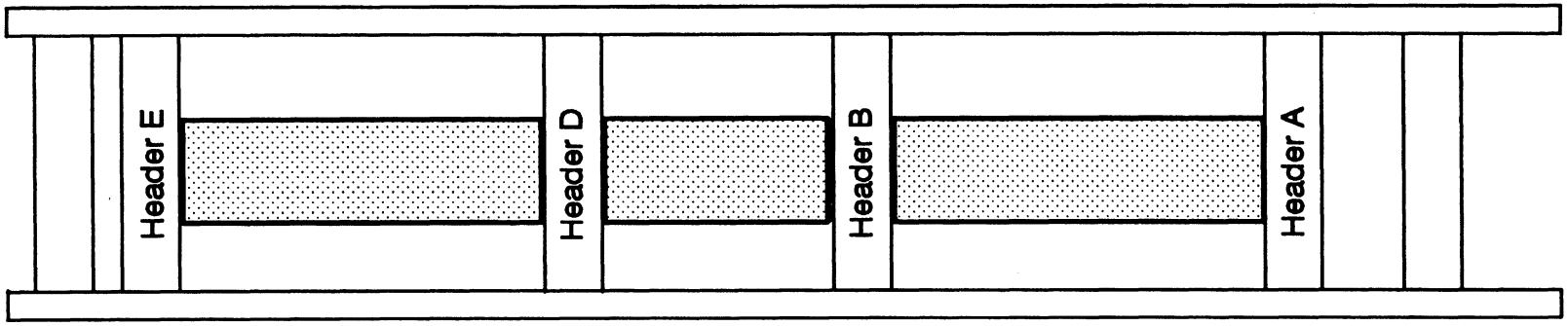
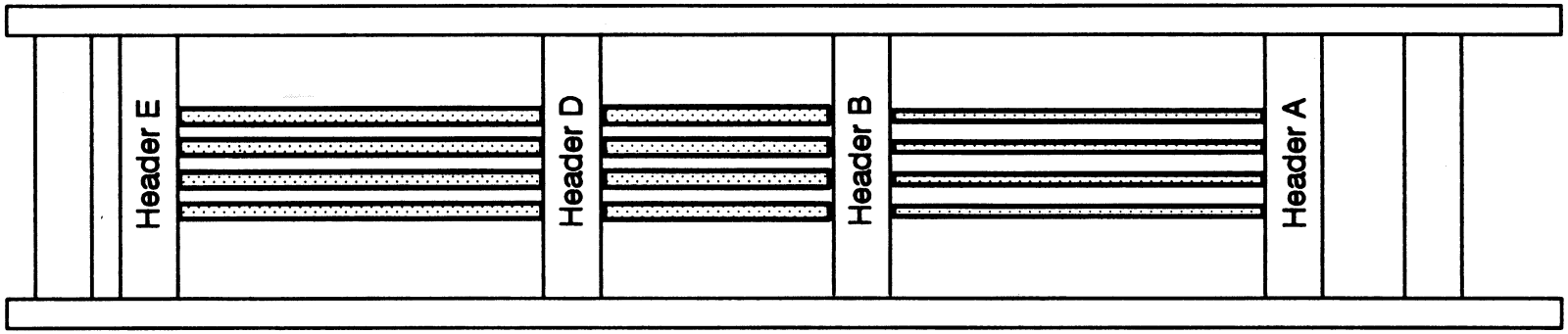


Figure C.2. Specimens for Cast No. 5



Cast No.	Specimen Identification Numbers						
6	Header E	6 - 6.0 DU - 3	Header D	6 - 3.0 TU - 2	Header B	6 - 6.0 DU - 1	Header A
7		7 - 6.0 DU - 3		7 - 3.0 TU - 2		7 - 6.0 DU - 1	
8		8 - 6.0 DC - 3		8 - 3.0 TC - 2		8 - 6.0 DC - 1	
9		9 - 6.0 DC - 3		9 - 3.0 TC - 2		9 - 6.0 DC - 1	
12		12 - 6.0 DC - 3		12 - 3.0 TC - 2		12 - 6.0 DC - 1	
13		13 - 3.0 TC - 3		13 - 3.0 TC - 2		13 - 3.0 TC - 1	
14		14 - 6.0 DC - 3		14 - 3.0 TC - 2		14 - 6.0 DC - 1	
15		15 - 6.0 DU - 3		15 - 3.0 TU - 2		15 - 6.0 DU - 1	
16		16 - 6.0 DU - 3		16 - 3.0 TU - 2		16 - 6.0 DU - 1	

Figure C.3. Specimens for Cast Nos. 6, 7, 8, 9, 12, 13, 14, 15, and 16



Cast No.	Specimen Identification Numbers						
10	Header E	10 - 6.0 DU - 12 10 - 6.0 DU - 11 10 - 6.0 DU - 10 10 - 6.0 DU - 9	Header D	10 - 3.5 TU - 8 10 - 3.5 TU - 7 10 - 3.5 TU - 6 10 - 3.5 TU - 5	Header B	10 - 6.0 DU - 4 10 - 6.0 DU - 3 10 - 6.0 DU - 2 10 - 6.0 DU - 1	Header A
11		11 - 6.0 DU - 12 11 - 6.0 DU - 11 11 - 6.0 DU - 10 11 - 6.0 DU - 9		11 - 3.0 TU - 8 11 - 3.0 TU - 7 11 - 3.0 TU - 6 11 - 3.0 TU - 5		11 - 6.0 DU - 4 11 - 6.0 DU - 3 11 - 6.0 DU - 2 11 - 6.0 DU - 1	
17		17 - 6.0 DC - 12 17 - 6.0 DC - 11 17 - 6.0 DC - 10 17 - 6.0 DC - 9		17 - 3.0 TC - 8 17 - 3.0 TC - 7 17 - 3.0 TC - 6 17 - 3.0 TC - 5		17 - 6.0 DC - 4 17 - 6.0 DC - 3 17 - 6.0 DC - 2 17 - 6.0 DC - 1	

Figure C.4. Specimens for Cast Nos. 10, 11, and 17

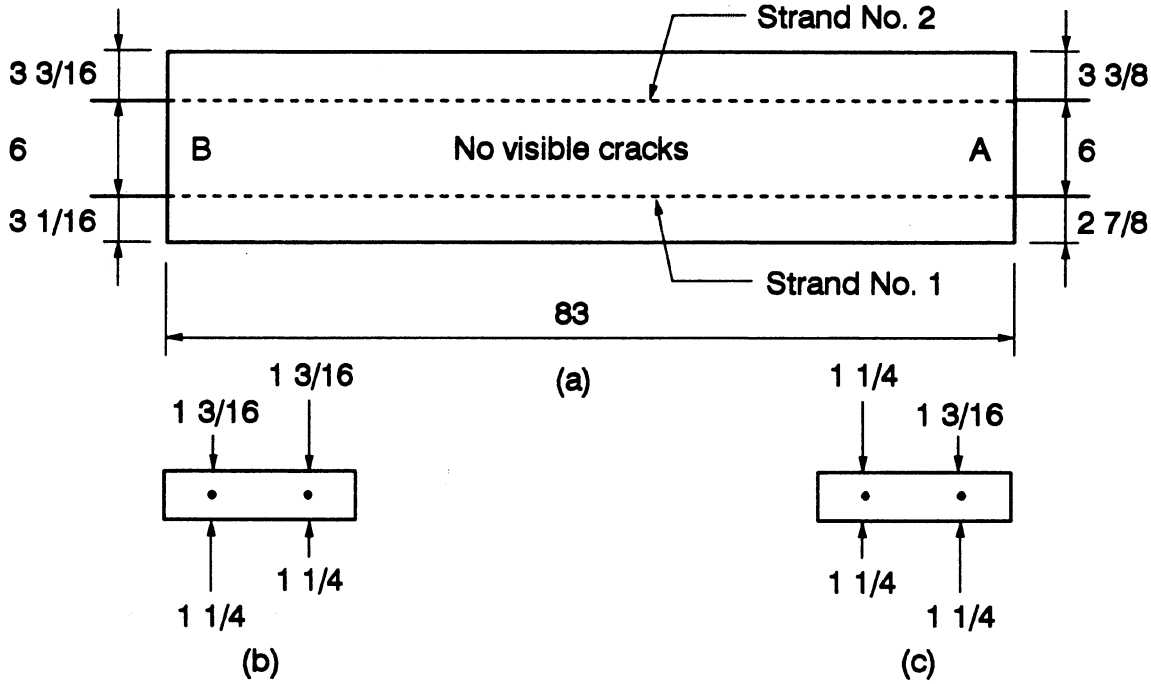


Figure C.5. Specimen No. 2-2.5TC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

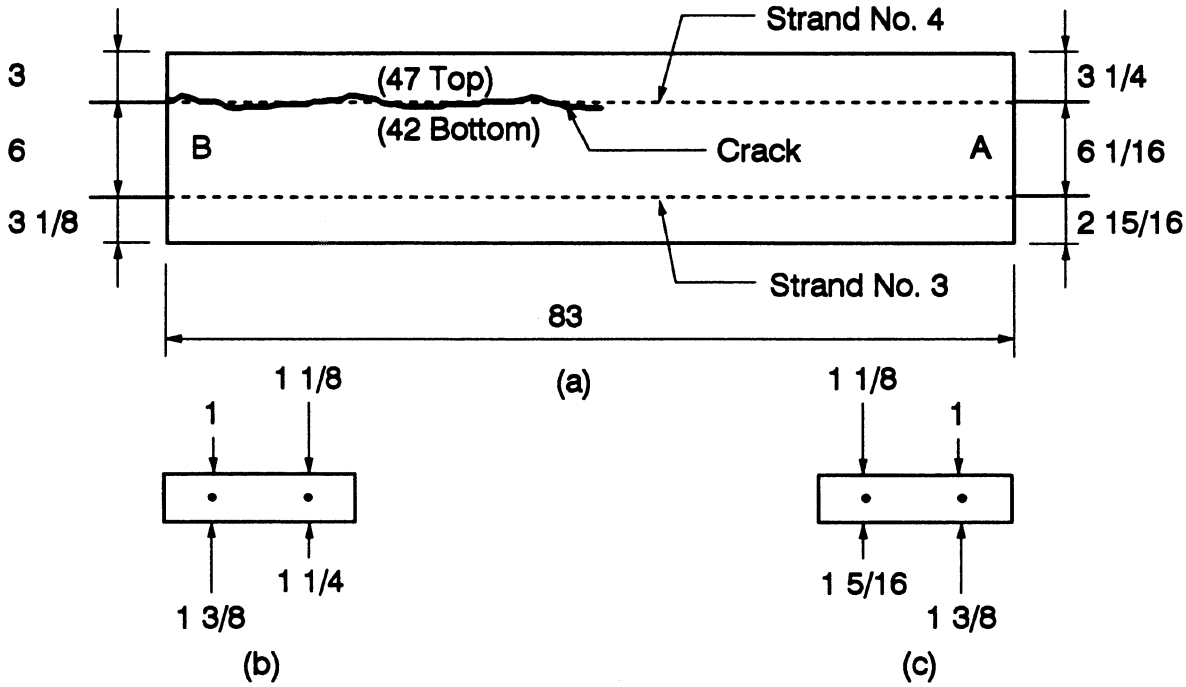


Figure C.6. Specimen No. 2-2.5TC-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

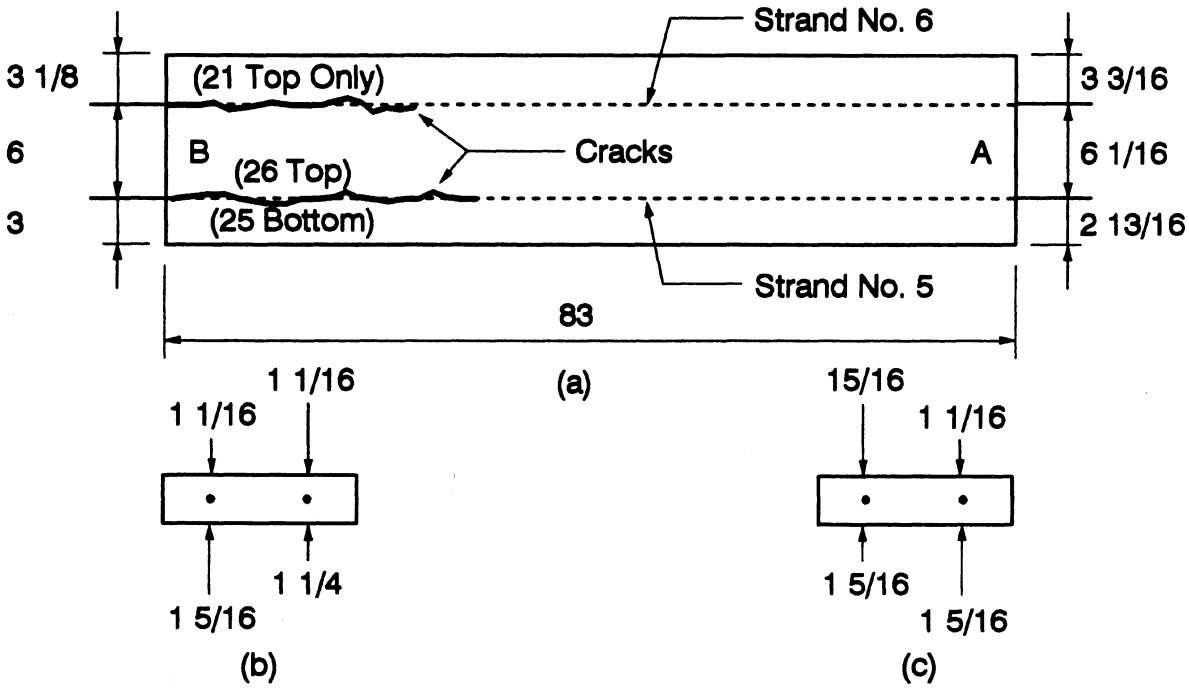


Figure C.7. Specimen No. 2-2.5TC-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

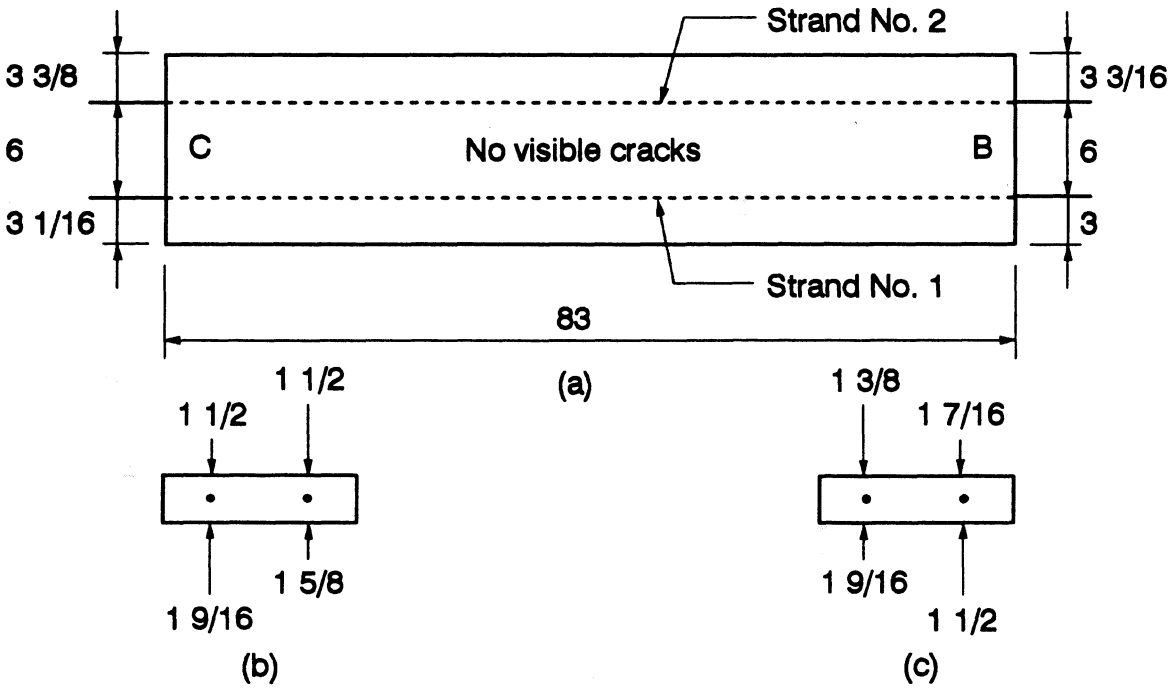


Figure C.8. Specimen No. 2-3.0TC-4 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

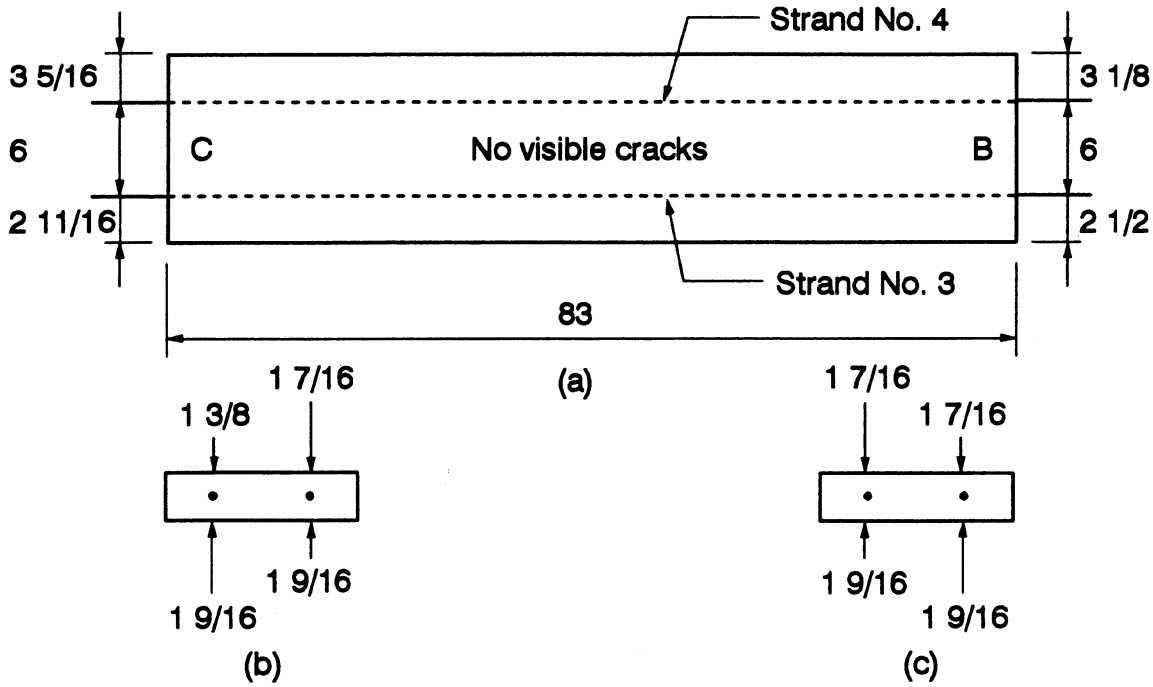


Figure C.9. Specimen No. 2-3.0TC-5 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

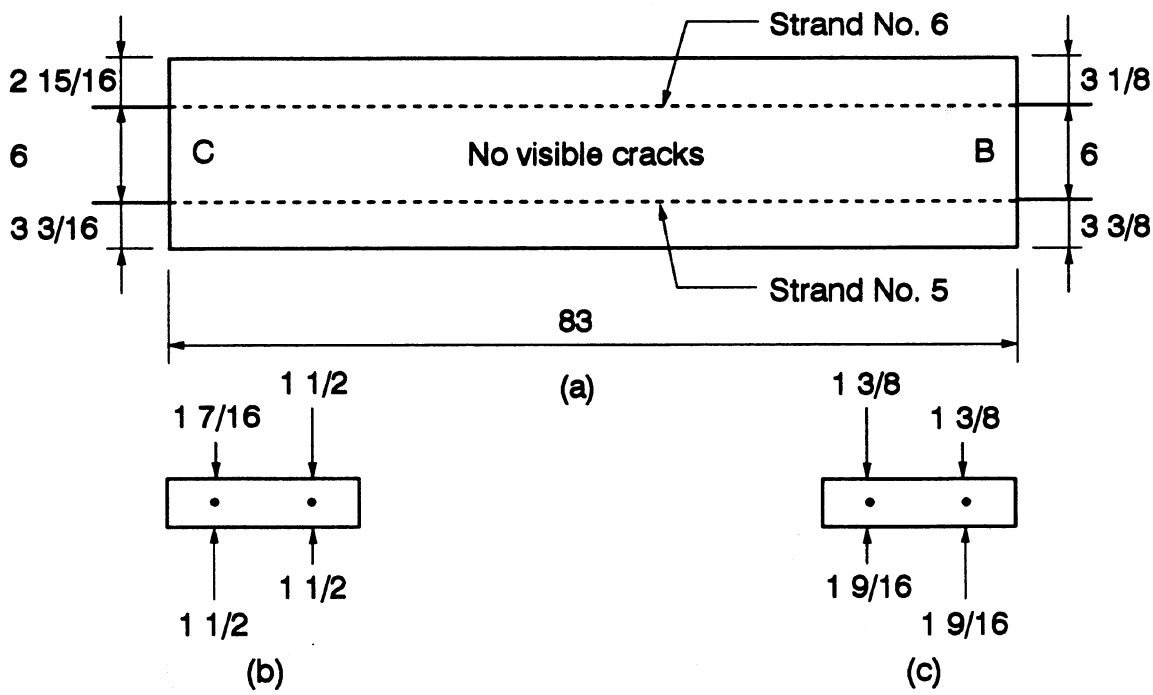


Figure C.10. Specimen No. 2-3.0TC-6 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

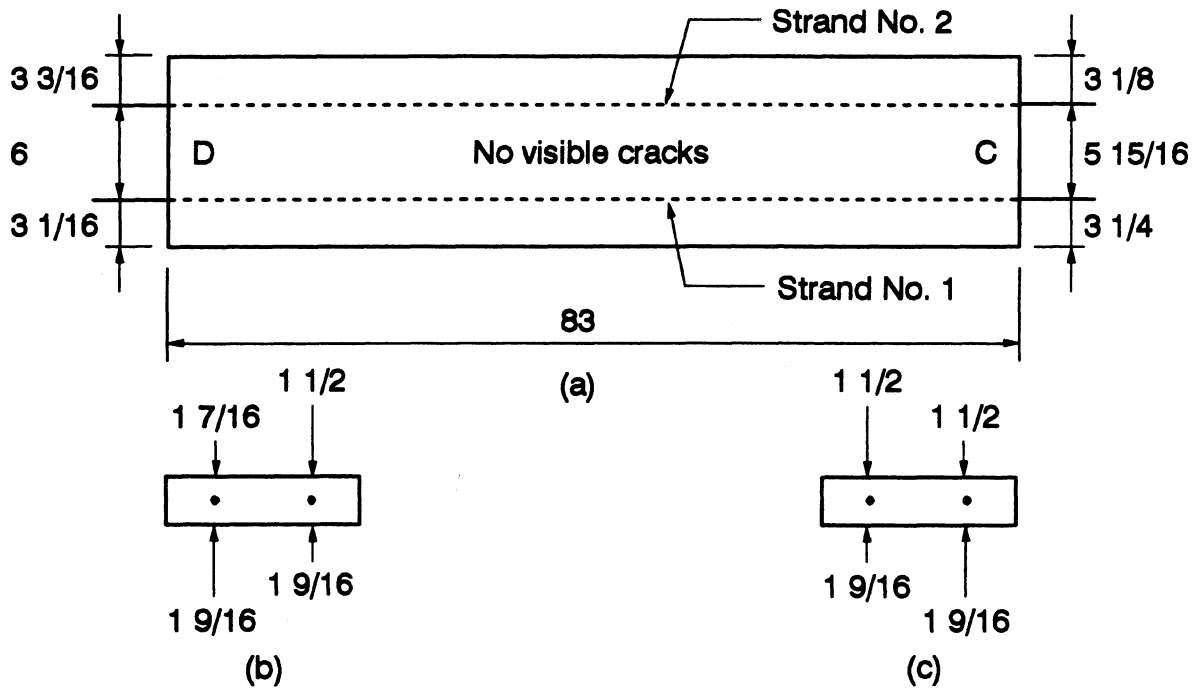


Figure C.11. Specimen No. 2-3.0TC-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

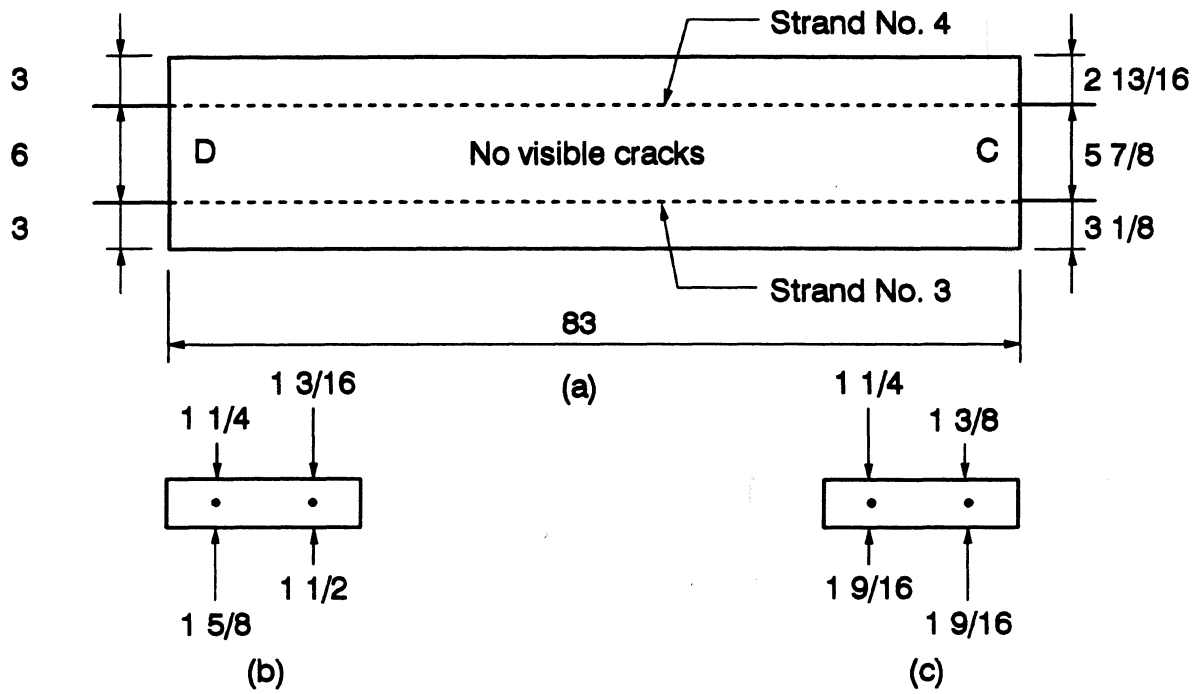


Figure C.12. Specimen No. 2-3.0TC-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

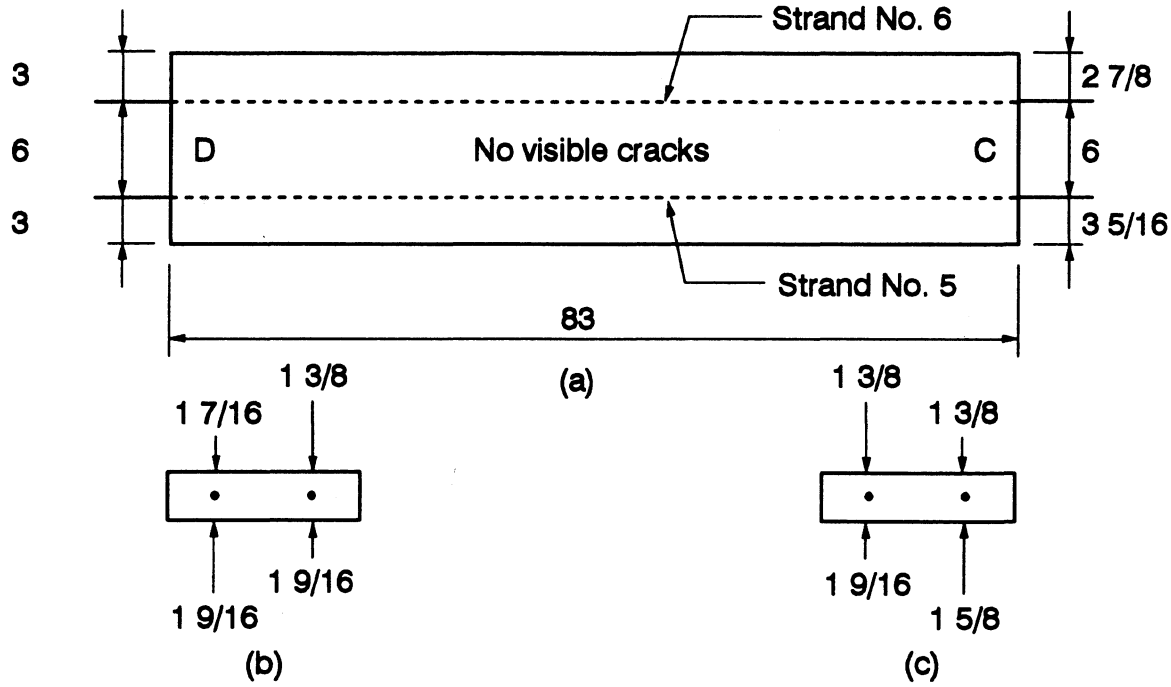


Figure C.13. Specimen No. 2-3.0TC-9 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

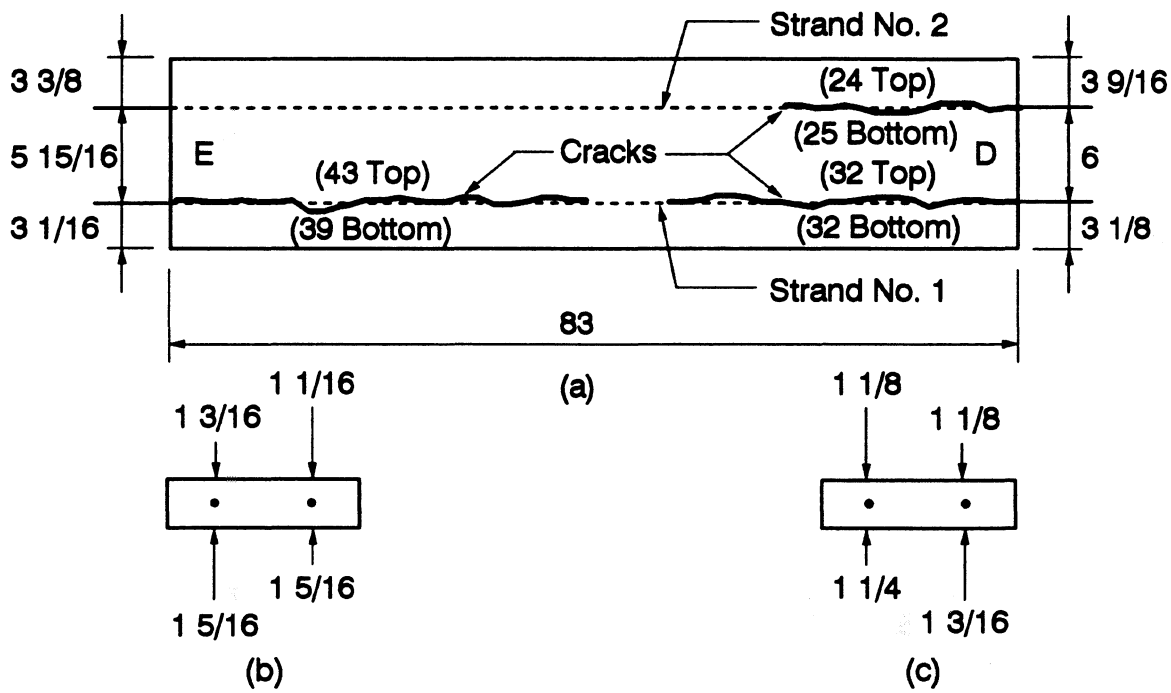


Figure C.14. Specimen No. 2-2.5TC-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

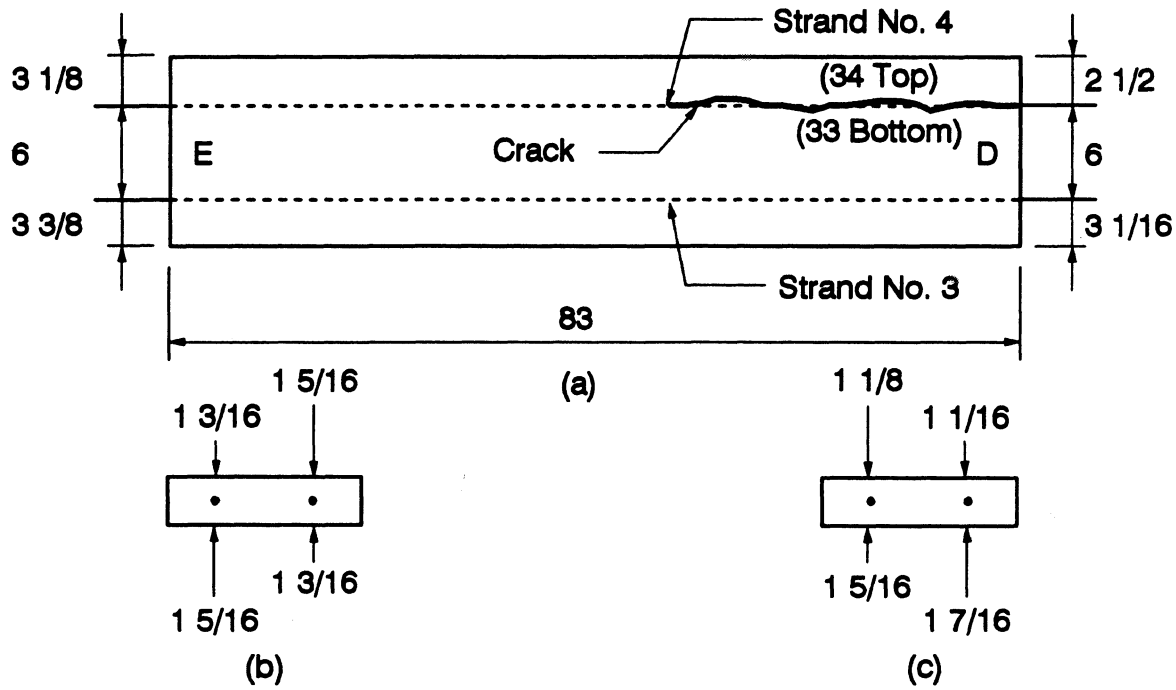


Figure C.15. Specimen No. 2-2.5TC-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

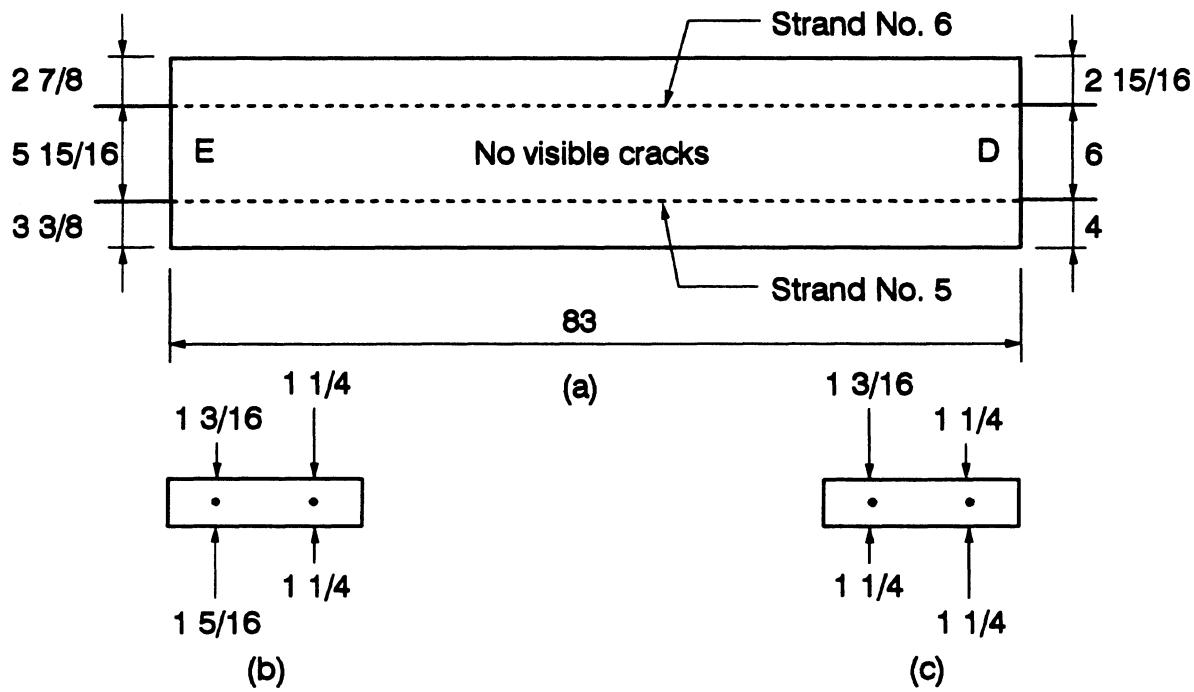


Figure C.16. Specimen No. 2-2.5TC-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

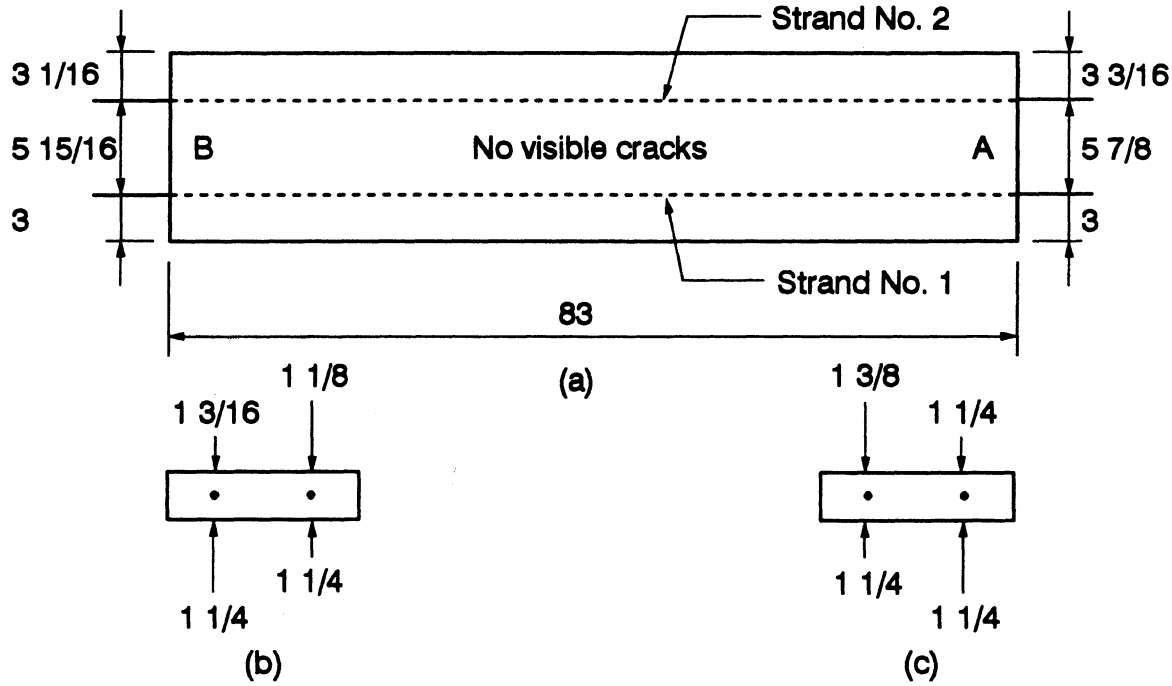


Figure C.17. Specimen No. 3-2.5TC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

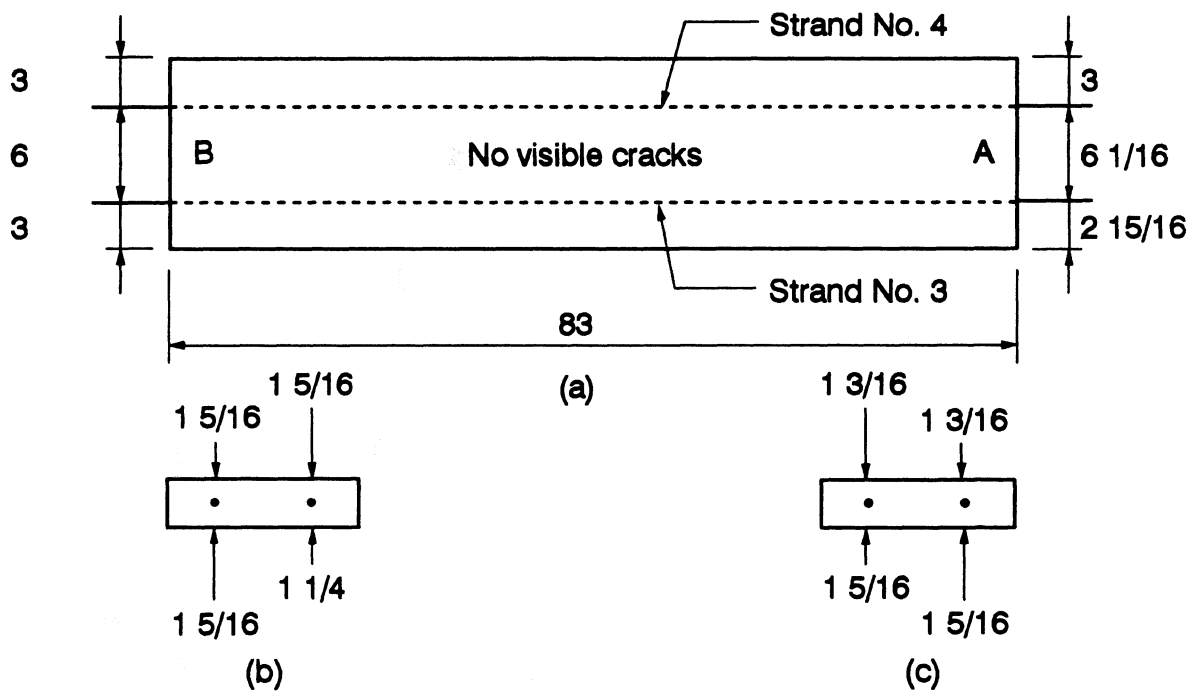


Figure C.18. Specimen No. 3-2.5TC-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

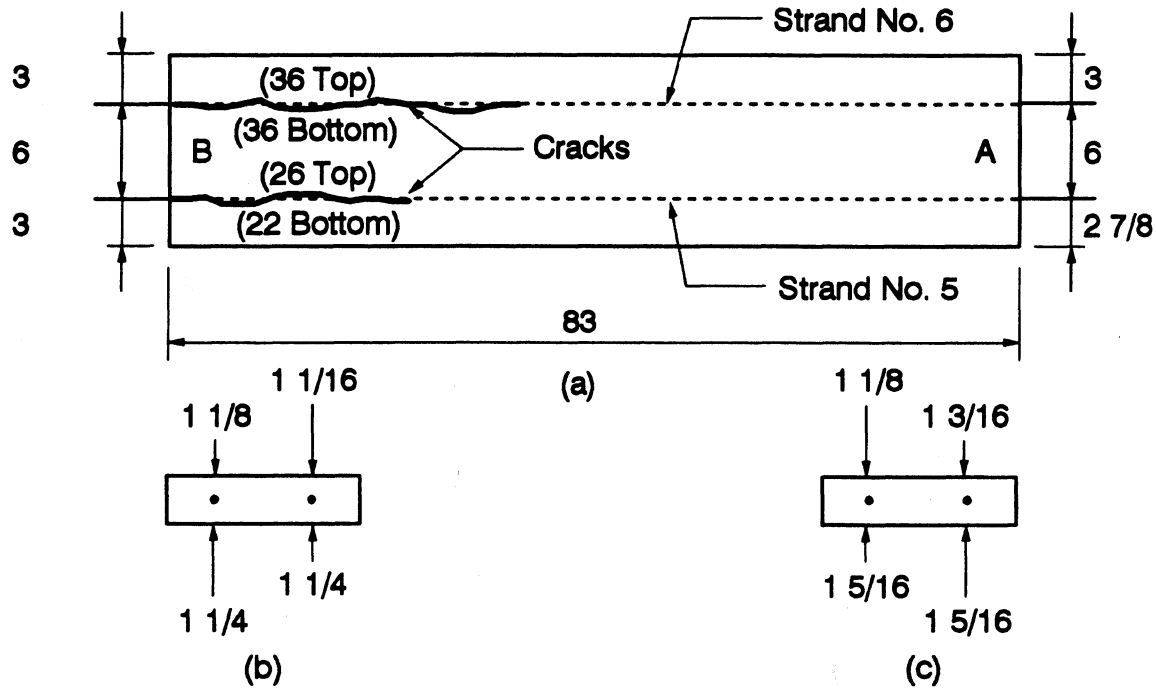


Figure C.19. Specimen No. 3-2.5TC-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

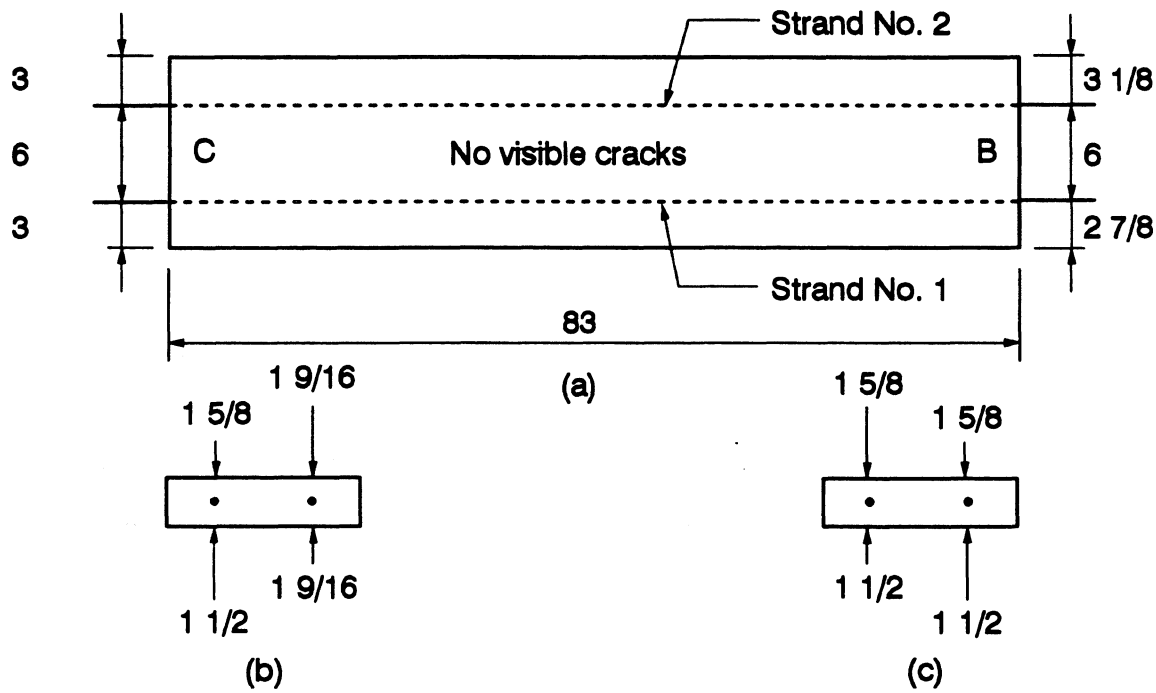


Figure C.20. Specimen No. 3-3.0TC-4 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

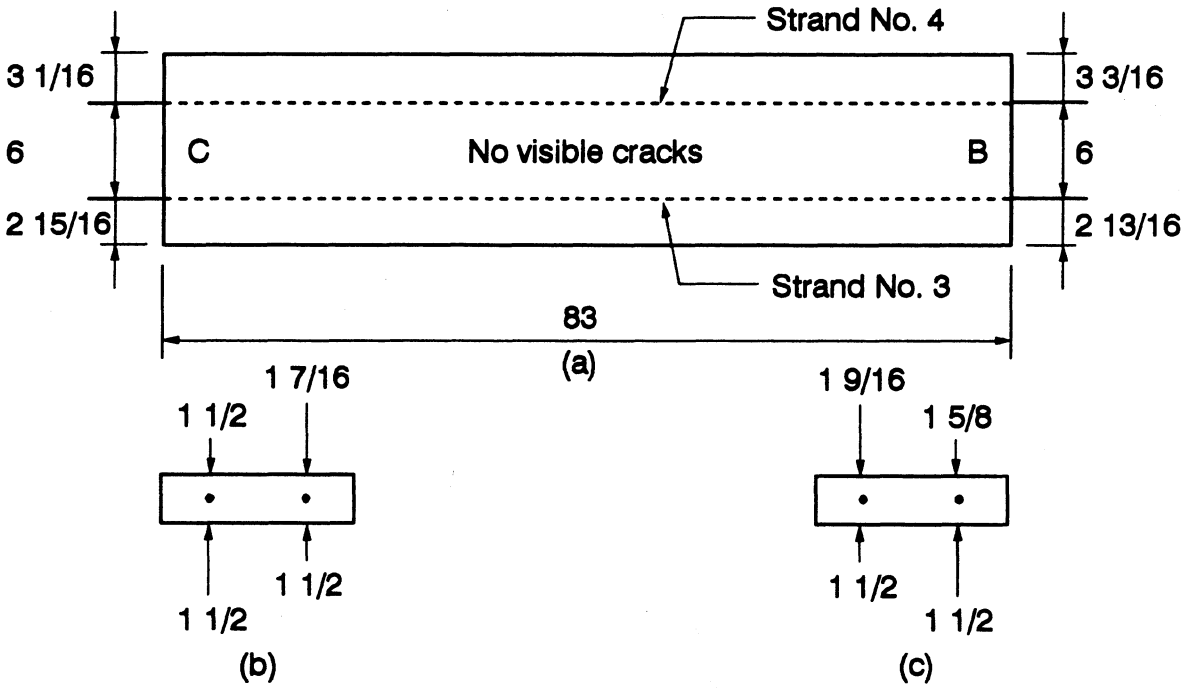


Figure C.21. Specimen No. 3-3.0TC-5 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

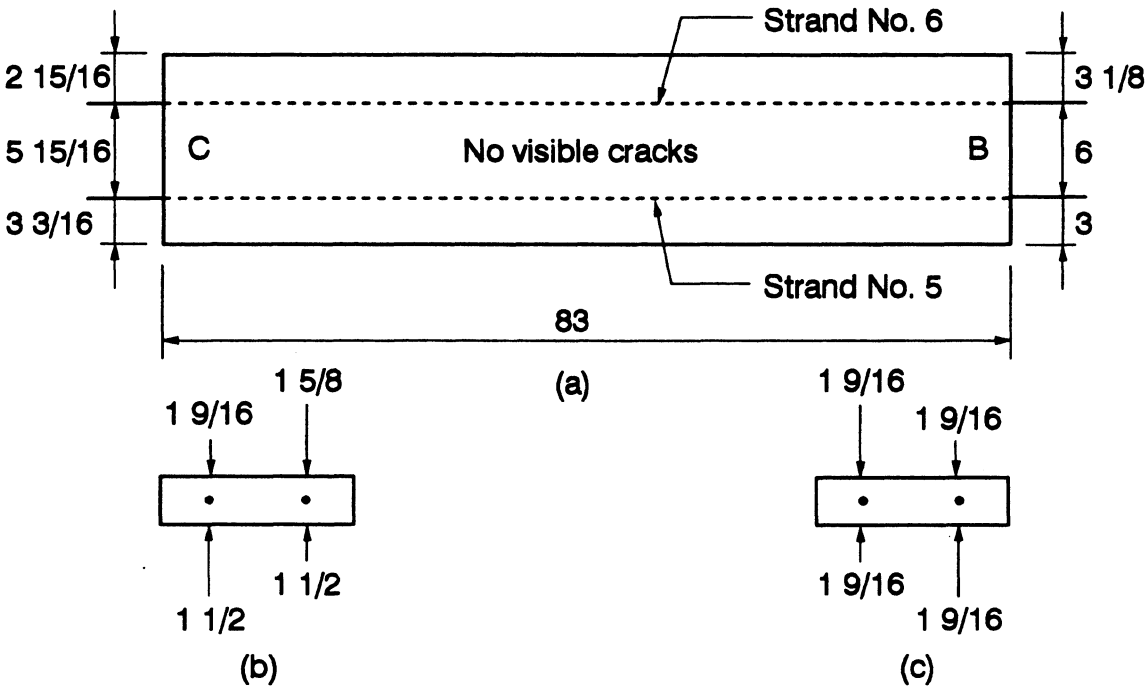


Figure C.22. Specimen No. 3-3.0TC-6 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

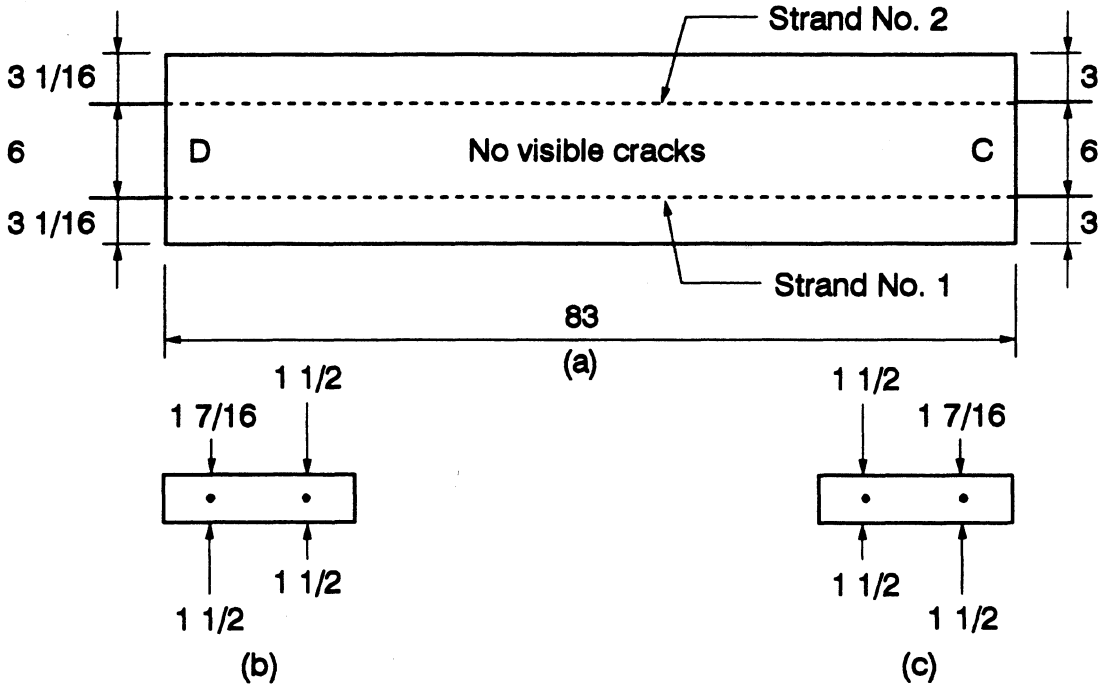


Figure C.23. Specimen No. 3-3.0TC-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

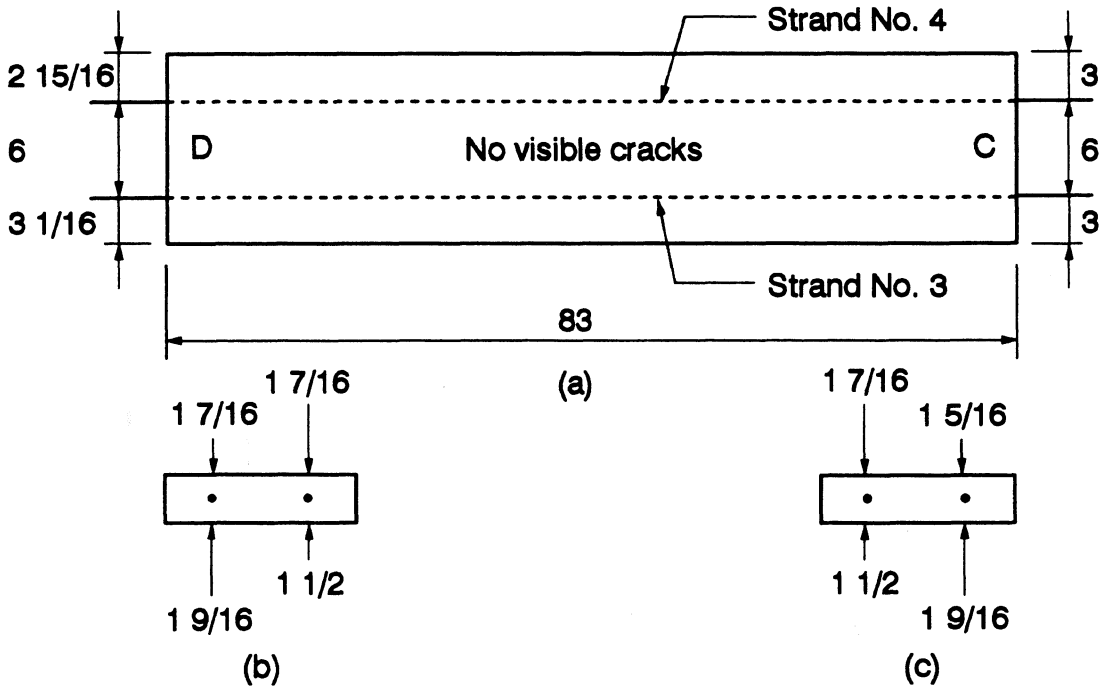


Figure C.24. Specimen No. 3-3.0TC-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

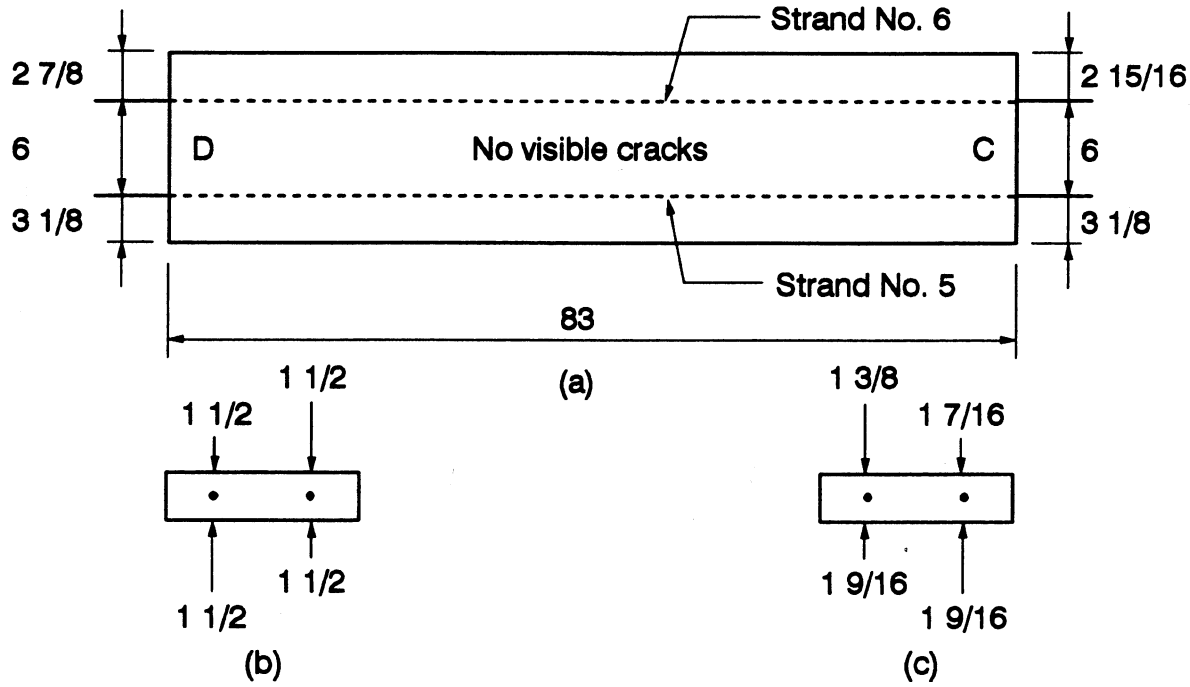


Figure C.25. Specimen No. 3-3.0TC-9 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

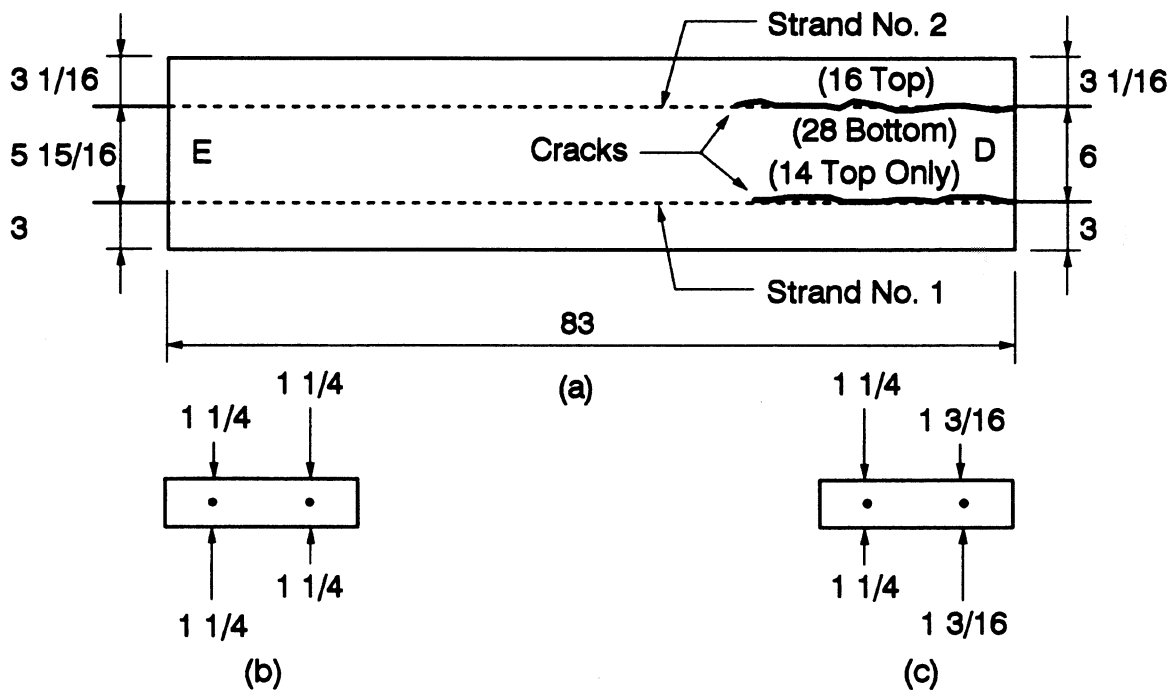


Figure C.26. Specimen No. 3-2.5TC-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

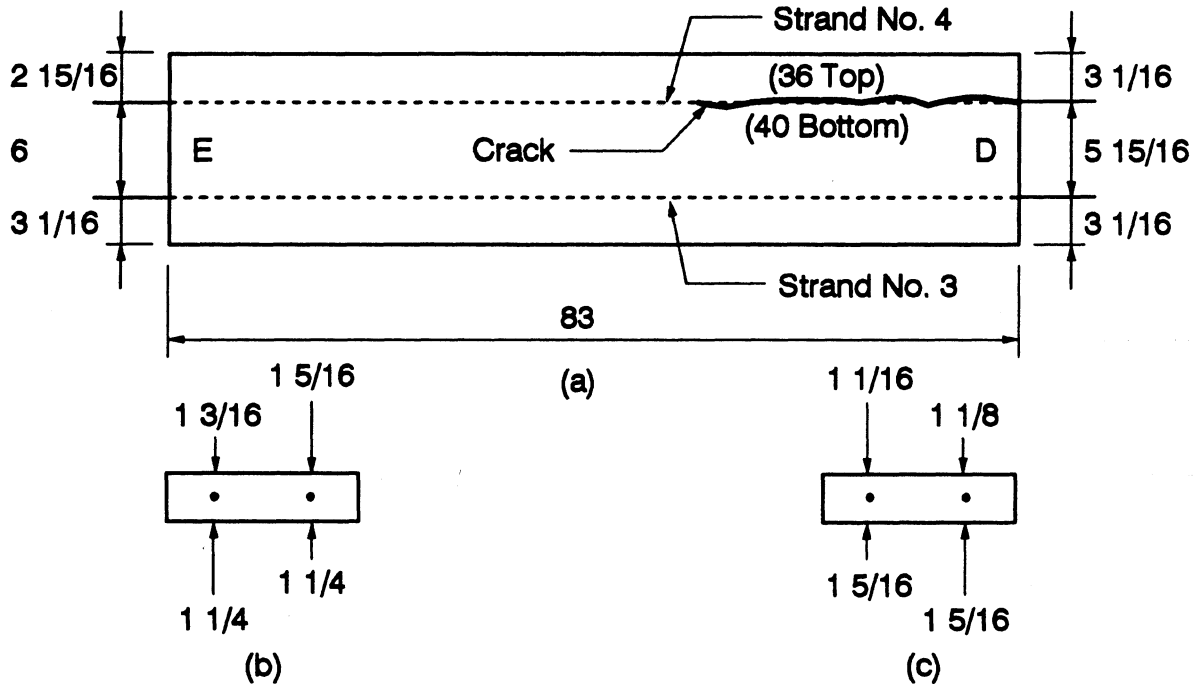


Figure C.27. Specimen No. 3-2.5TC-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

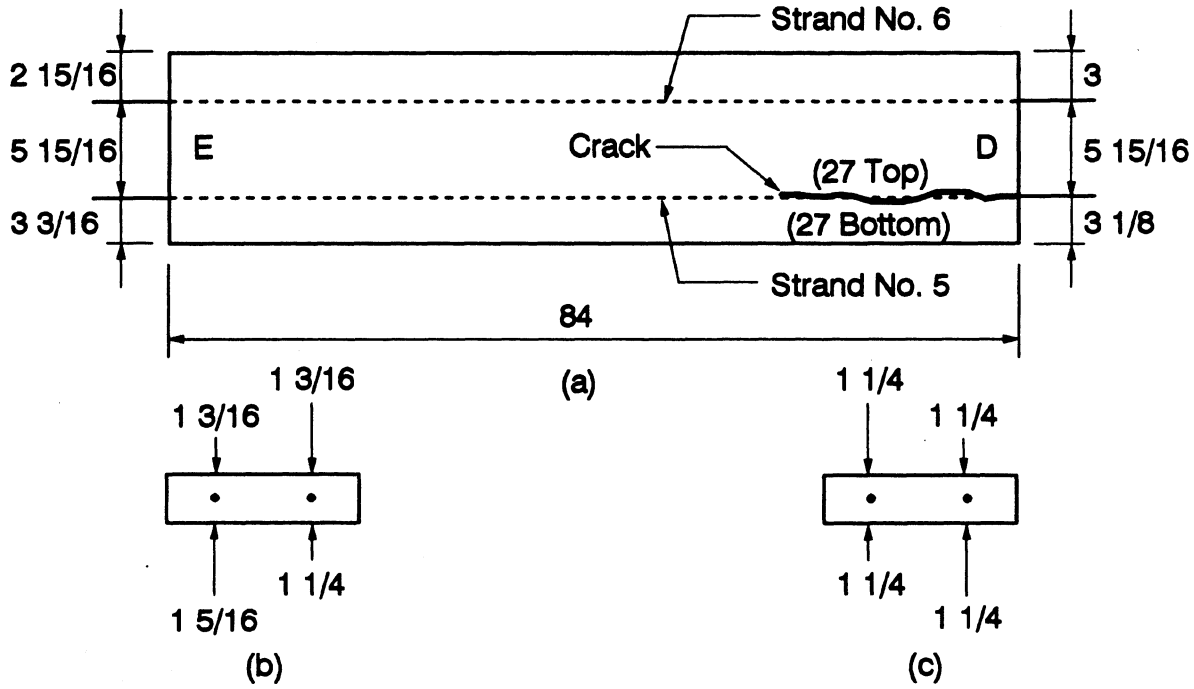


Figure C.28. Specimen No. 3-2.5TC-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

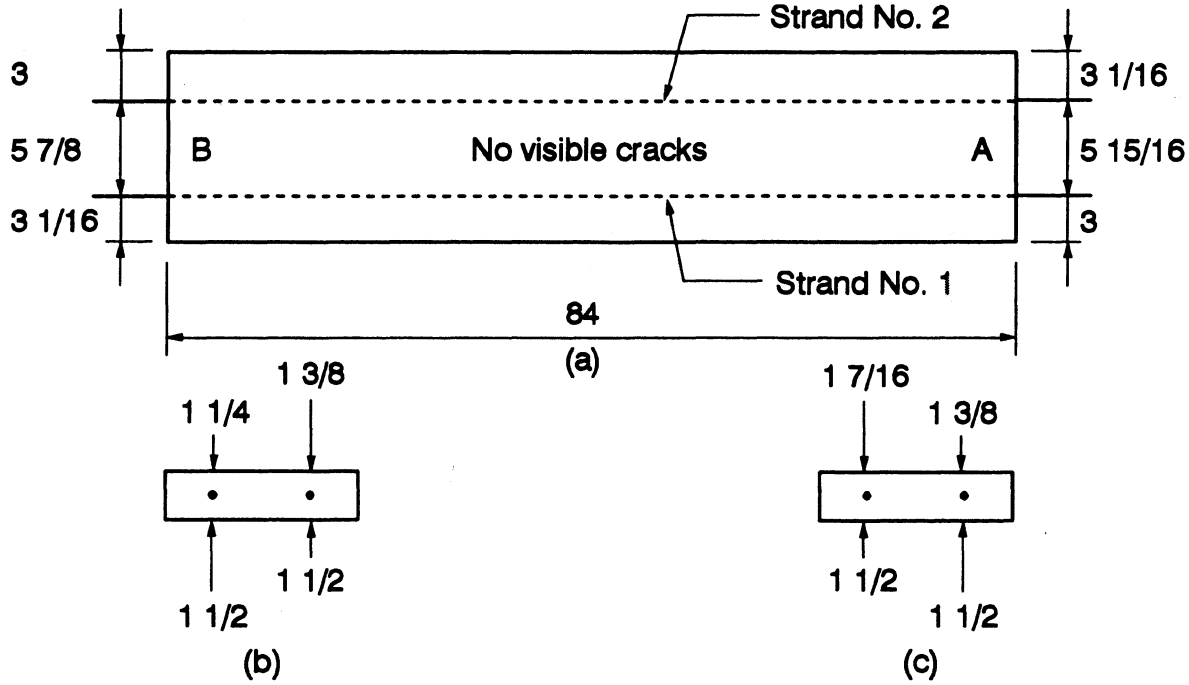


Figure C.29. Specimen No. 4-3.0TC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

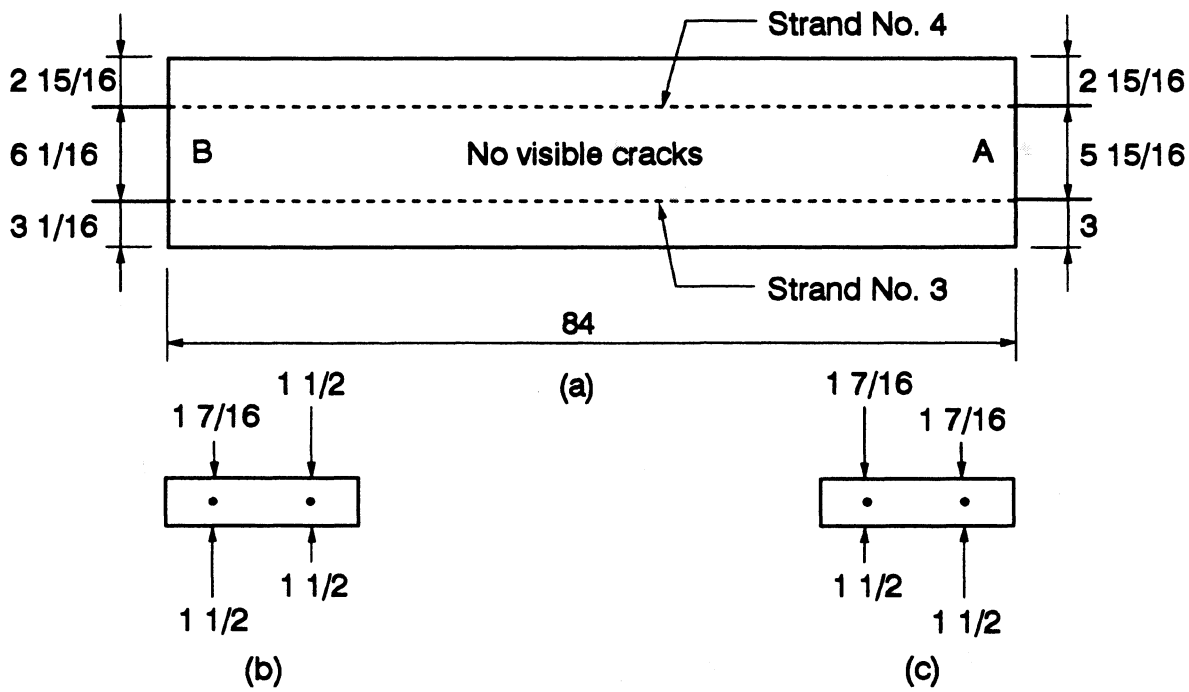


Figure C.30. Specimen No. 4-3.0TC-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

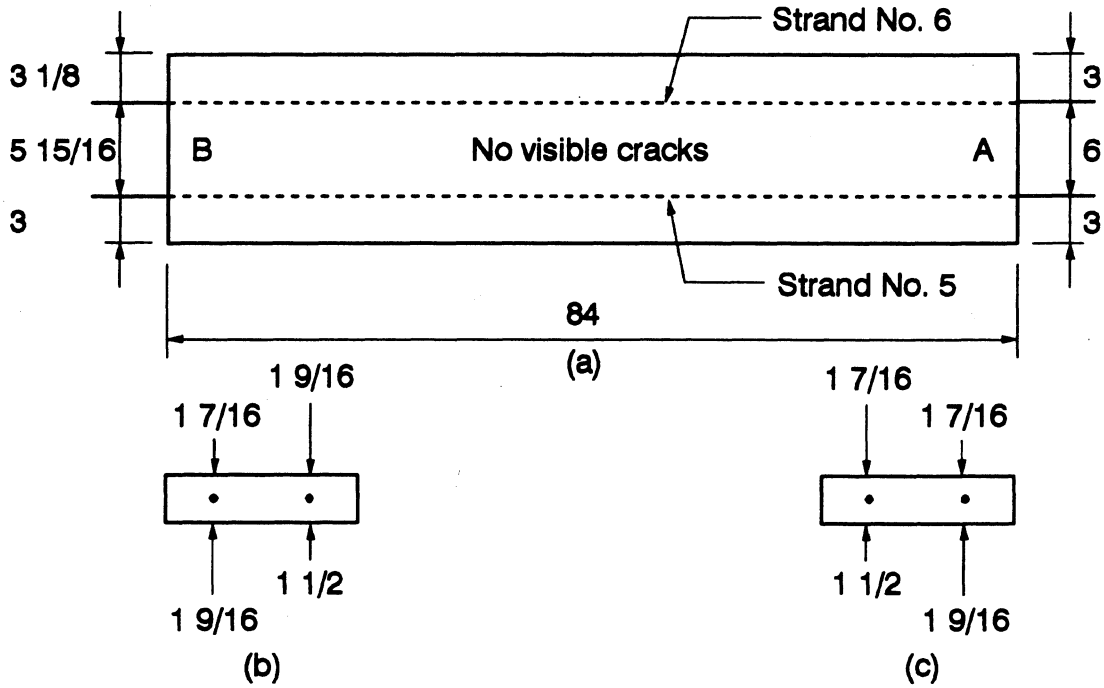


Figure C.31. Specimen No. 4-3.0TC-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

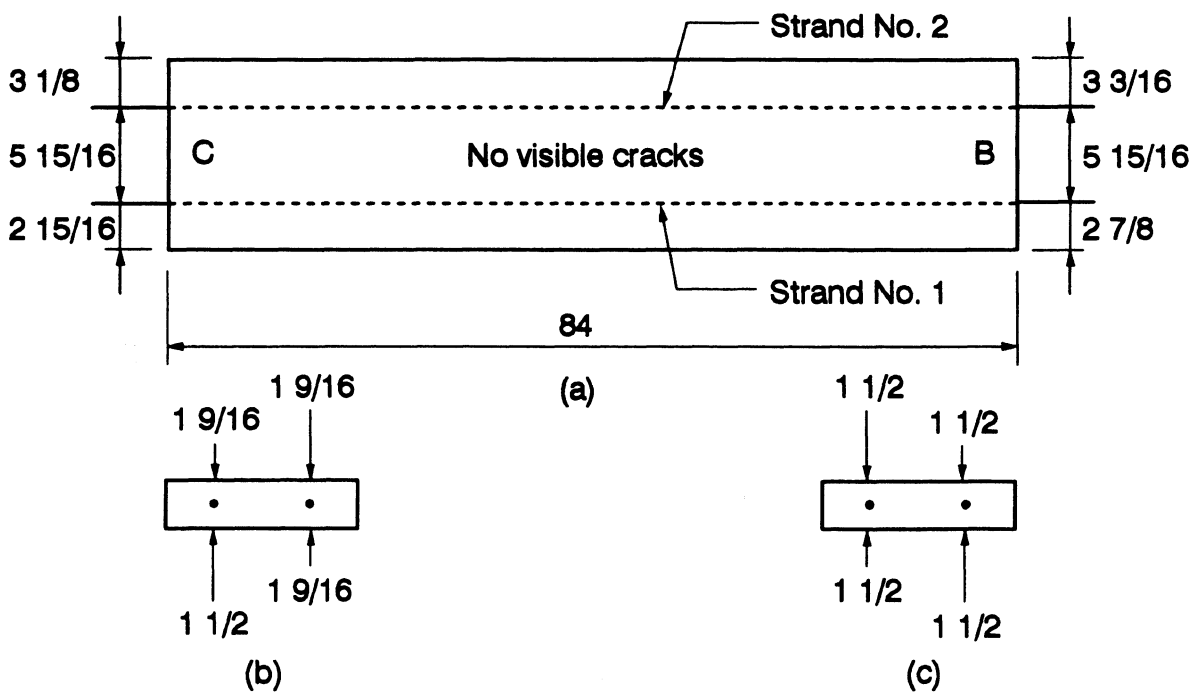


Figure C.32. Specimen No. 4-3.0TC-4 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

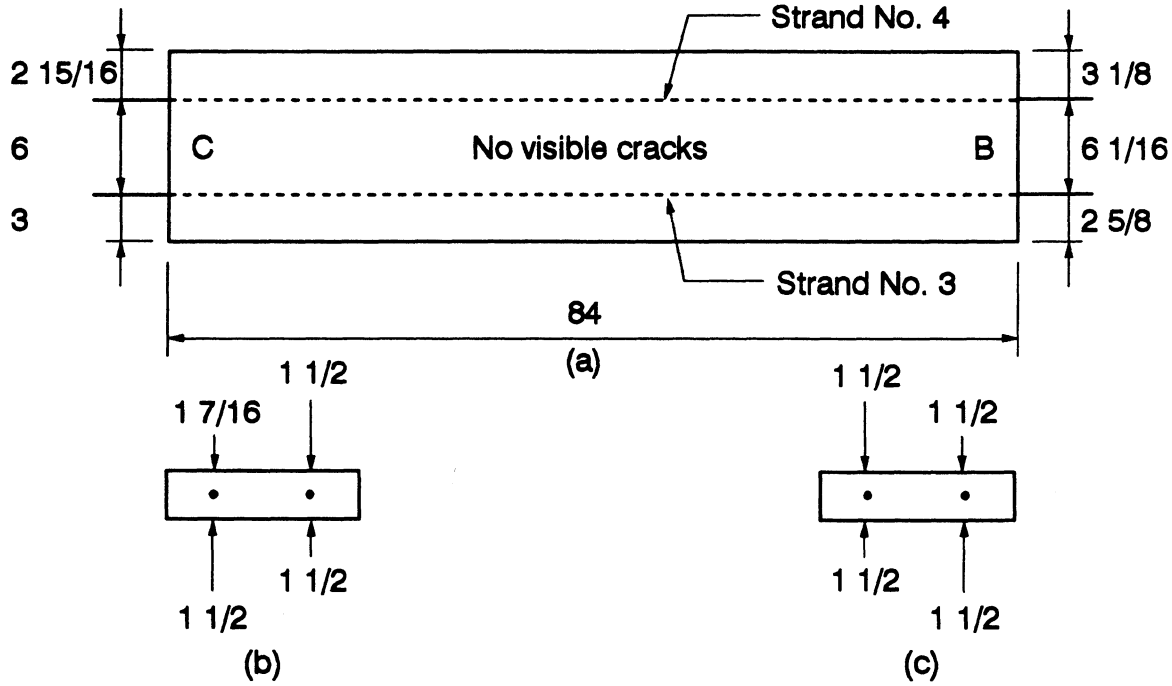


Figure C.33. Specimen No. 4-3.0TC-5 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

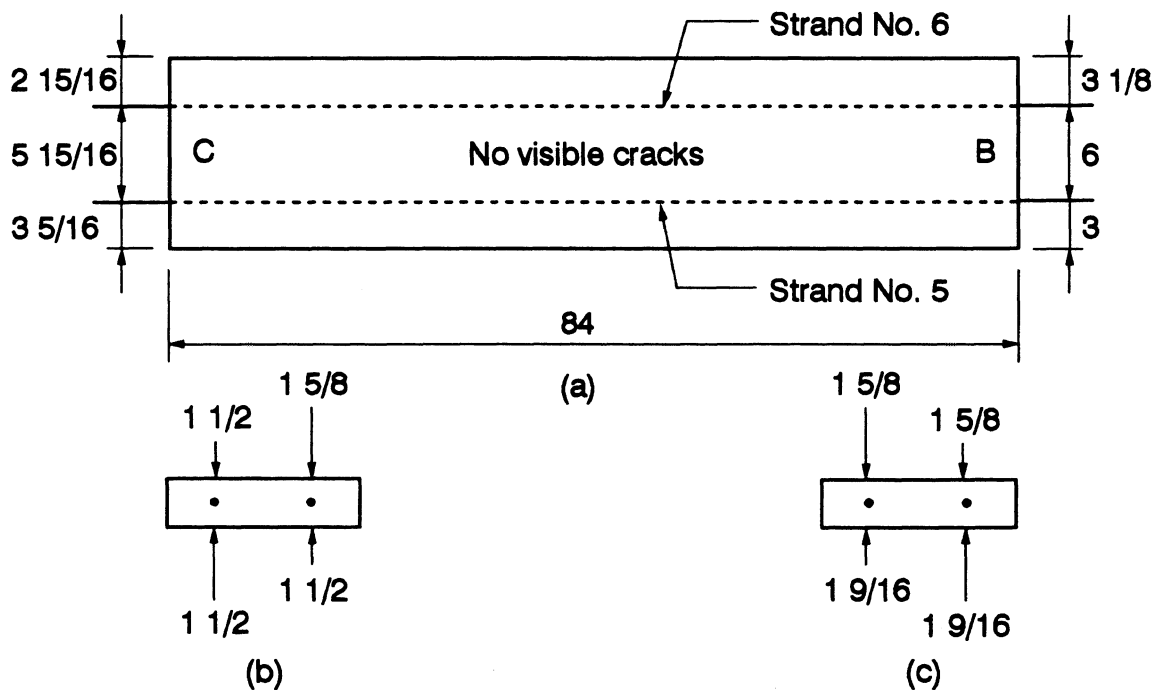


Figure C.34. Specimen No. 4-3.0TC-6 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

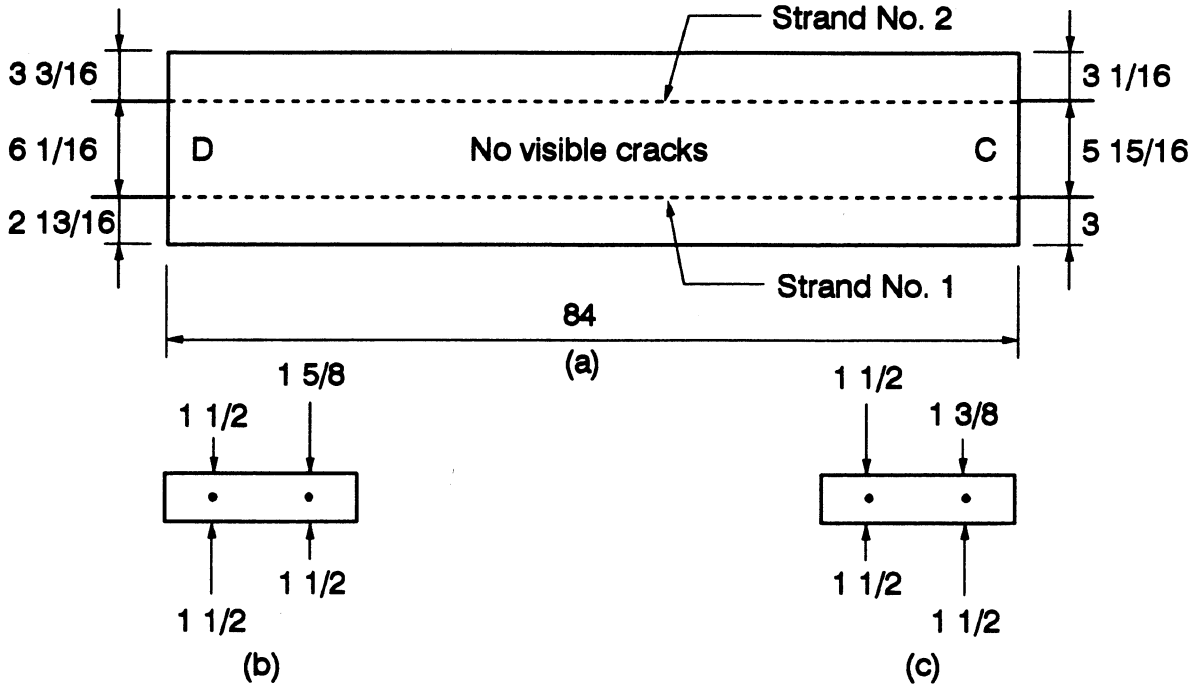


Figure C.35. Specimen No. 4-3.0TC-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

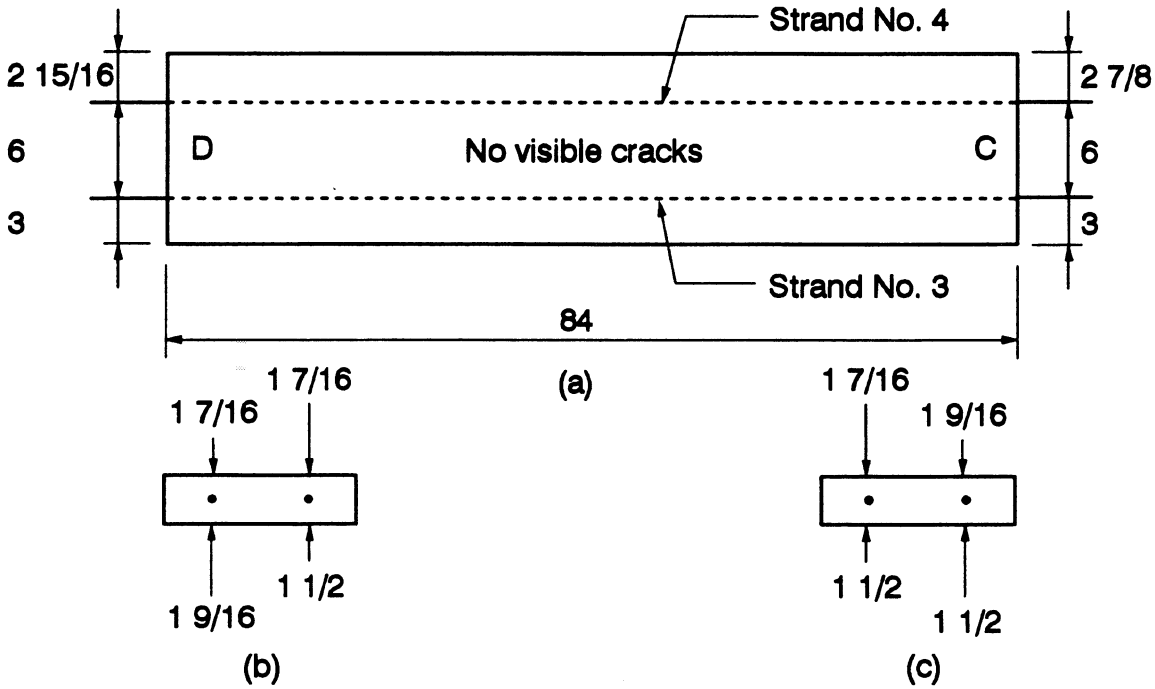


Figure C.36. Specimen No. 4-3.0TC-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

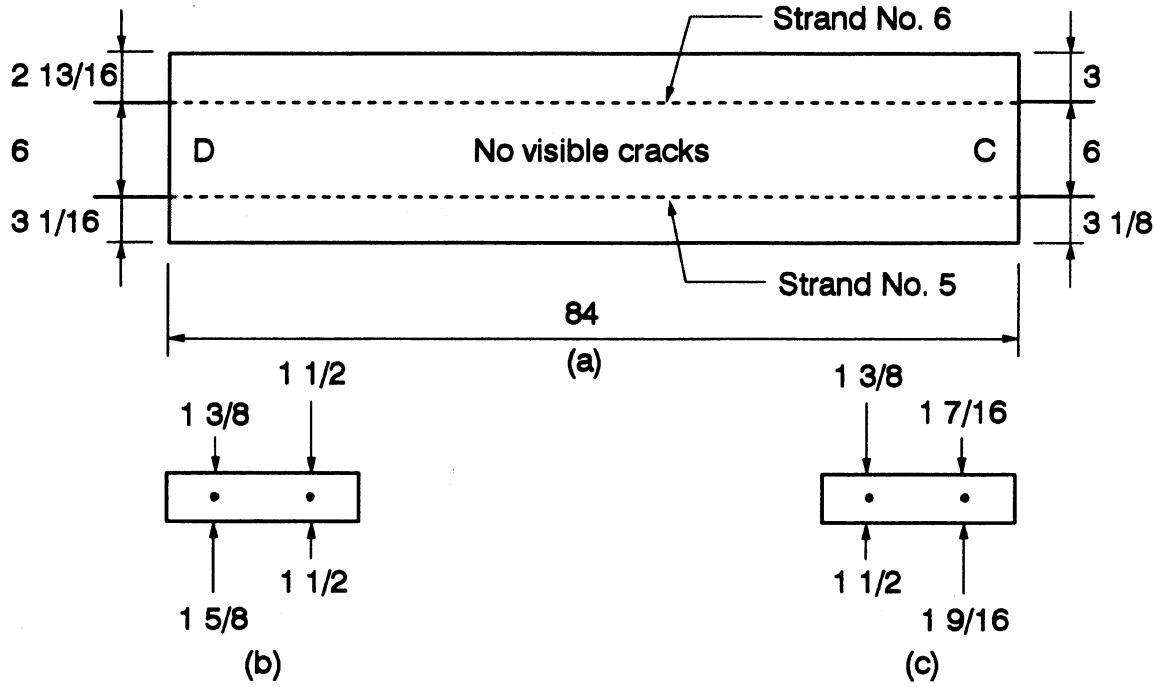


Figure C.37. Specimen No. 4-3.0TC-9 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

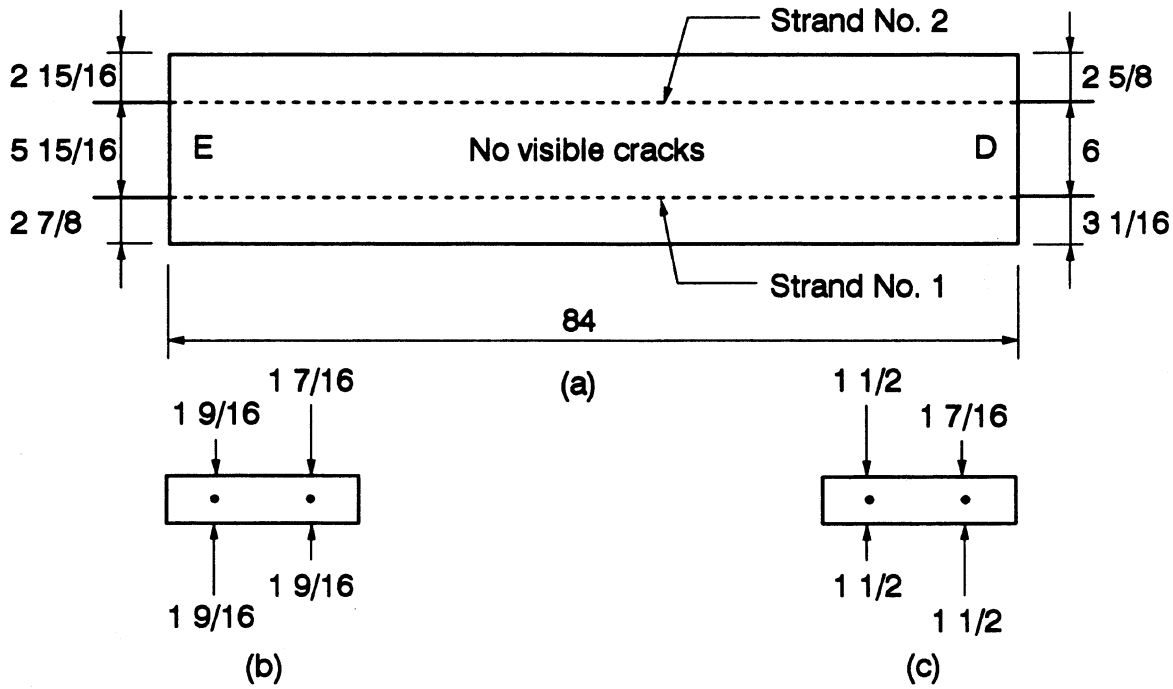


Figure C.38. Specimen No. 4-3.0TC-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

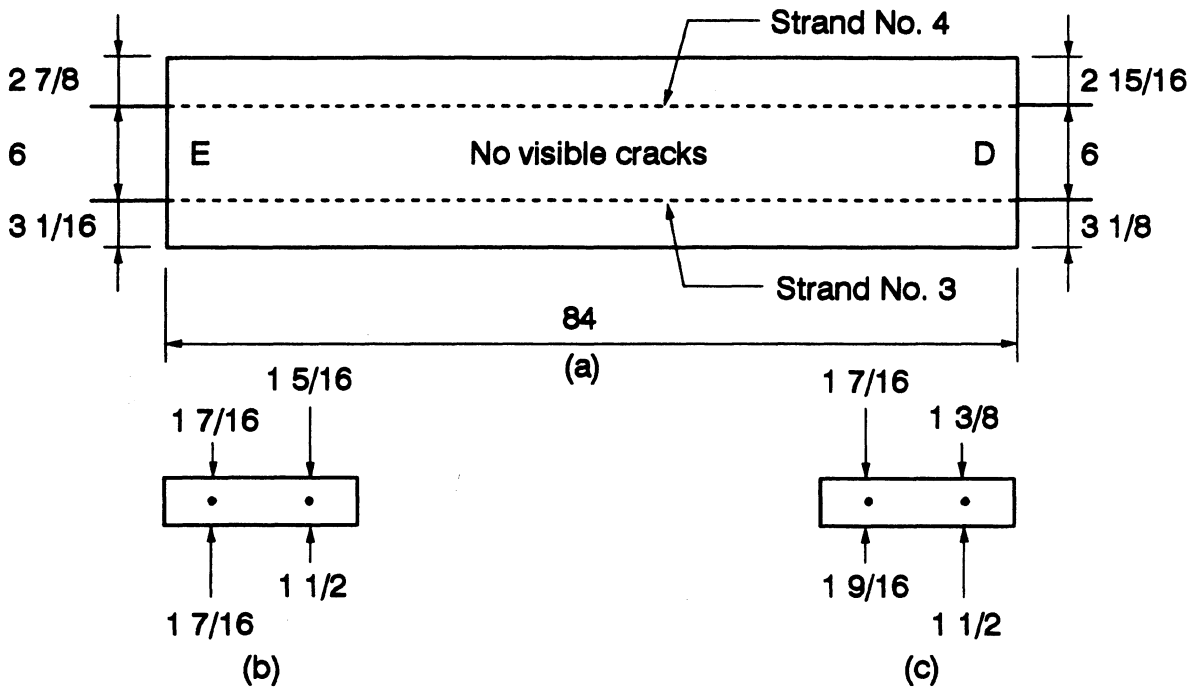


Figure C.39. Specimen No. 4-3.0TC-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

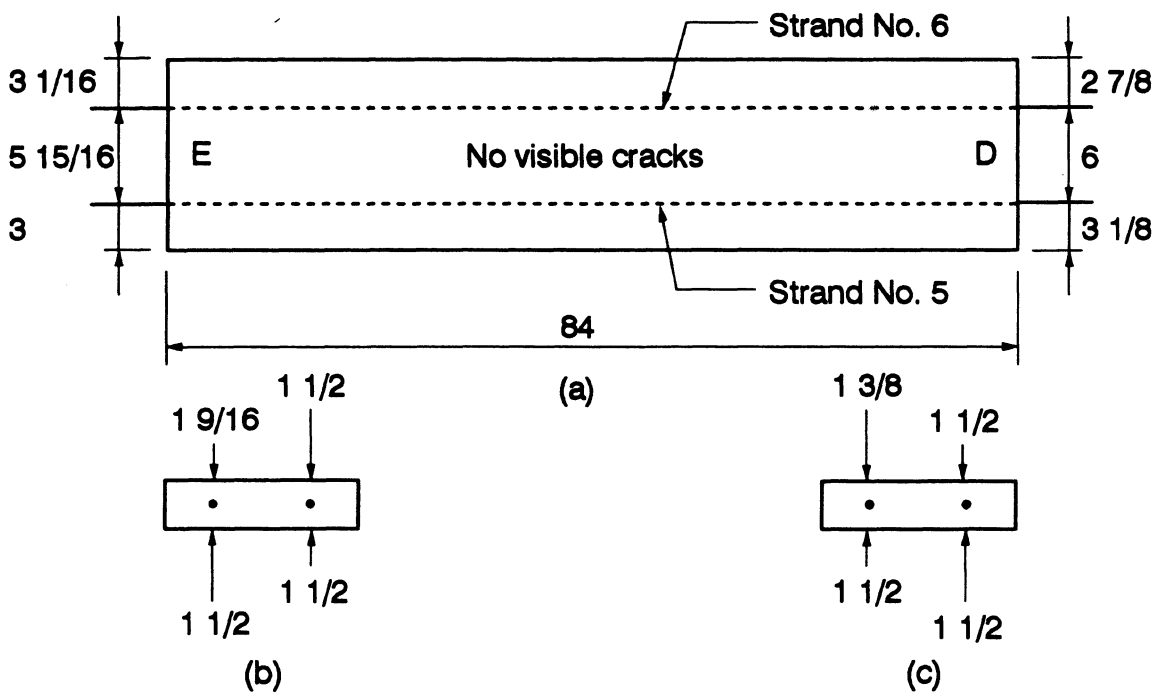


Figure C.40. Specimen No. 4-3.0TC-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

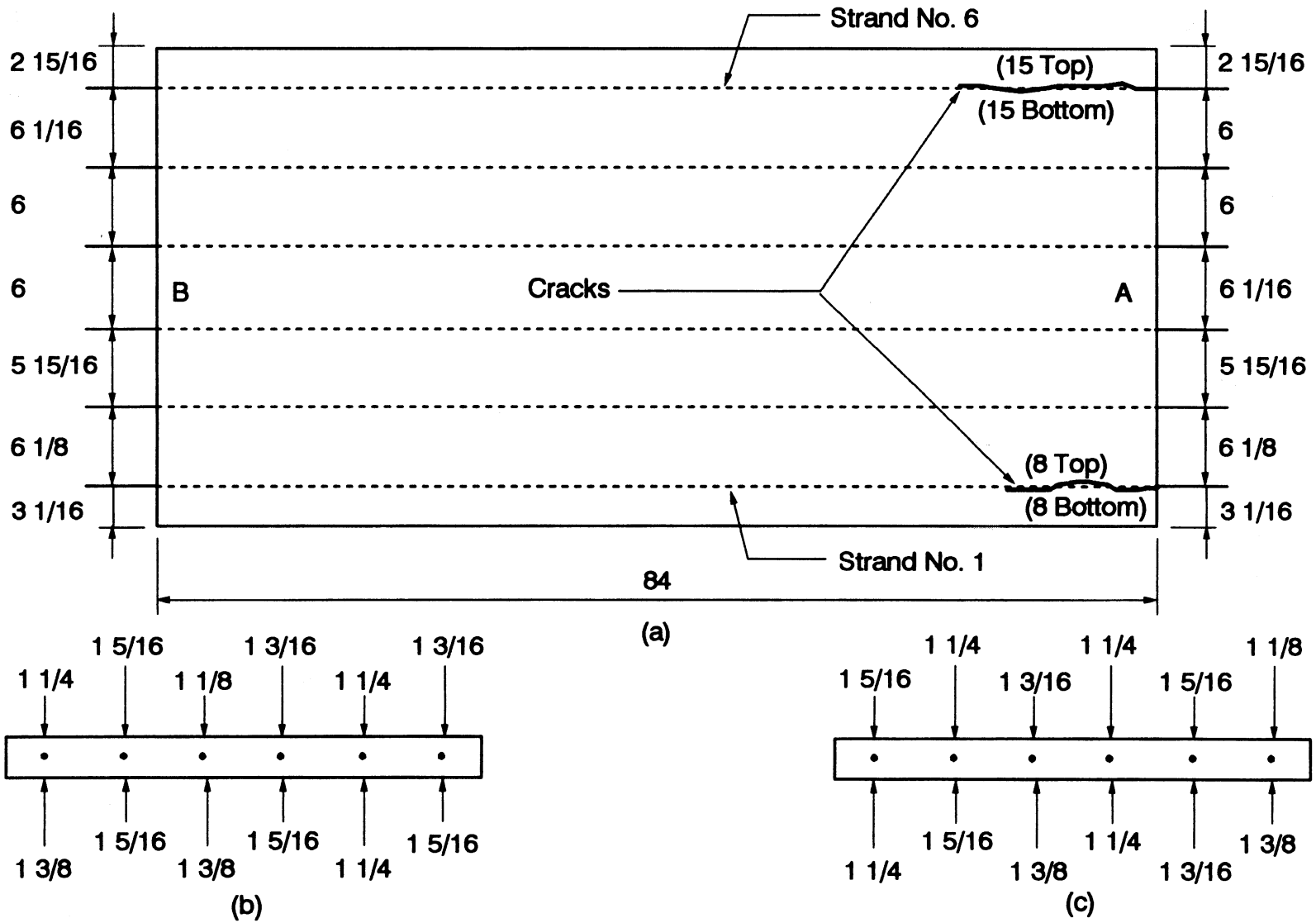


Figure C.41. Specimen No. 5-2.5TC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

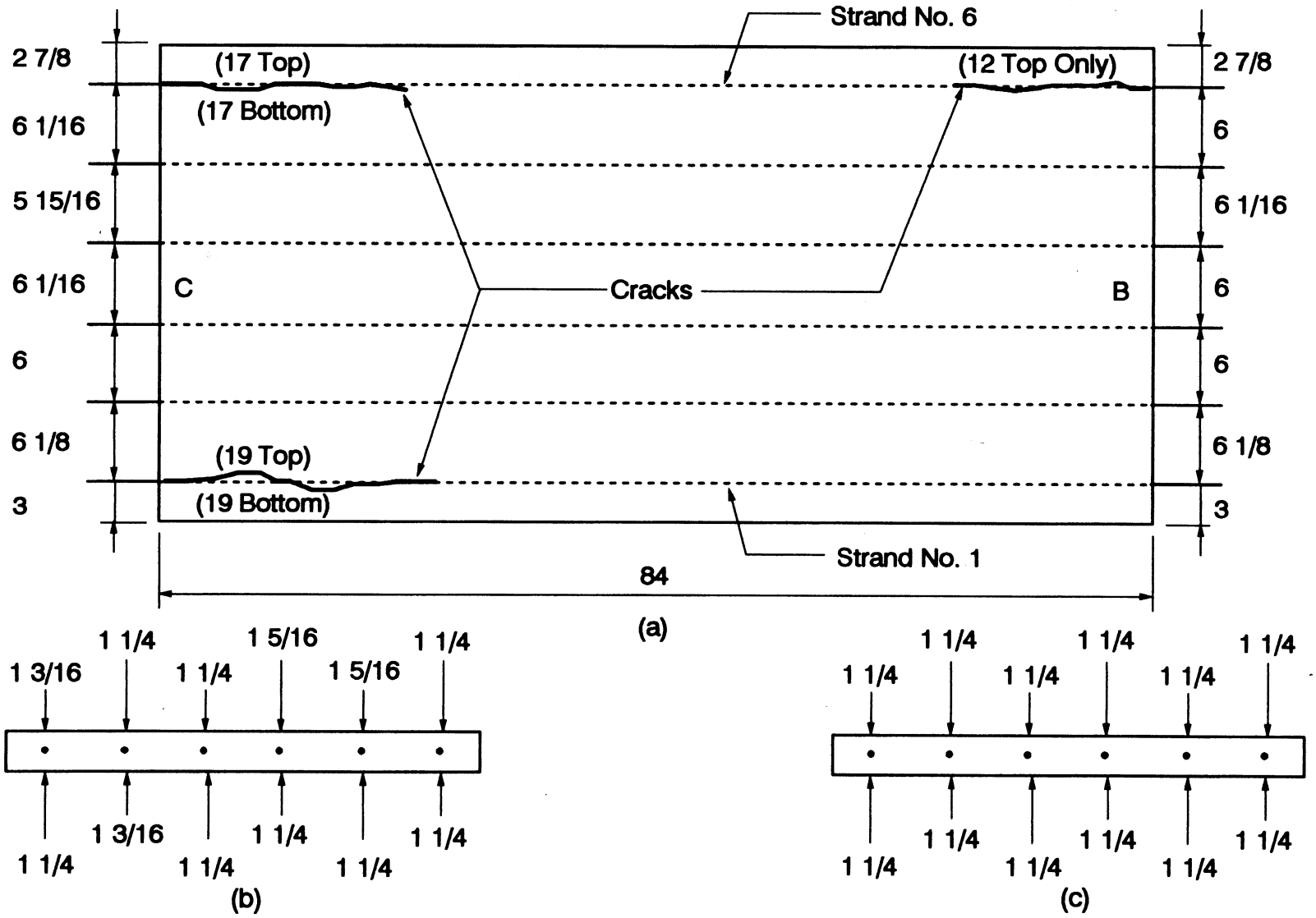


Figure C.42. Specimen No. 5-2.5TC-2 (dimensions shown in inches): (a) plan view; (b) end view at C; (c) end view at B

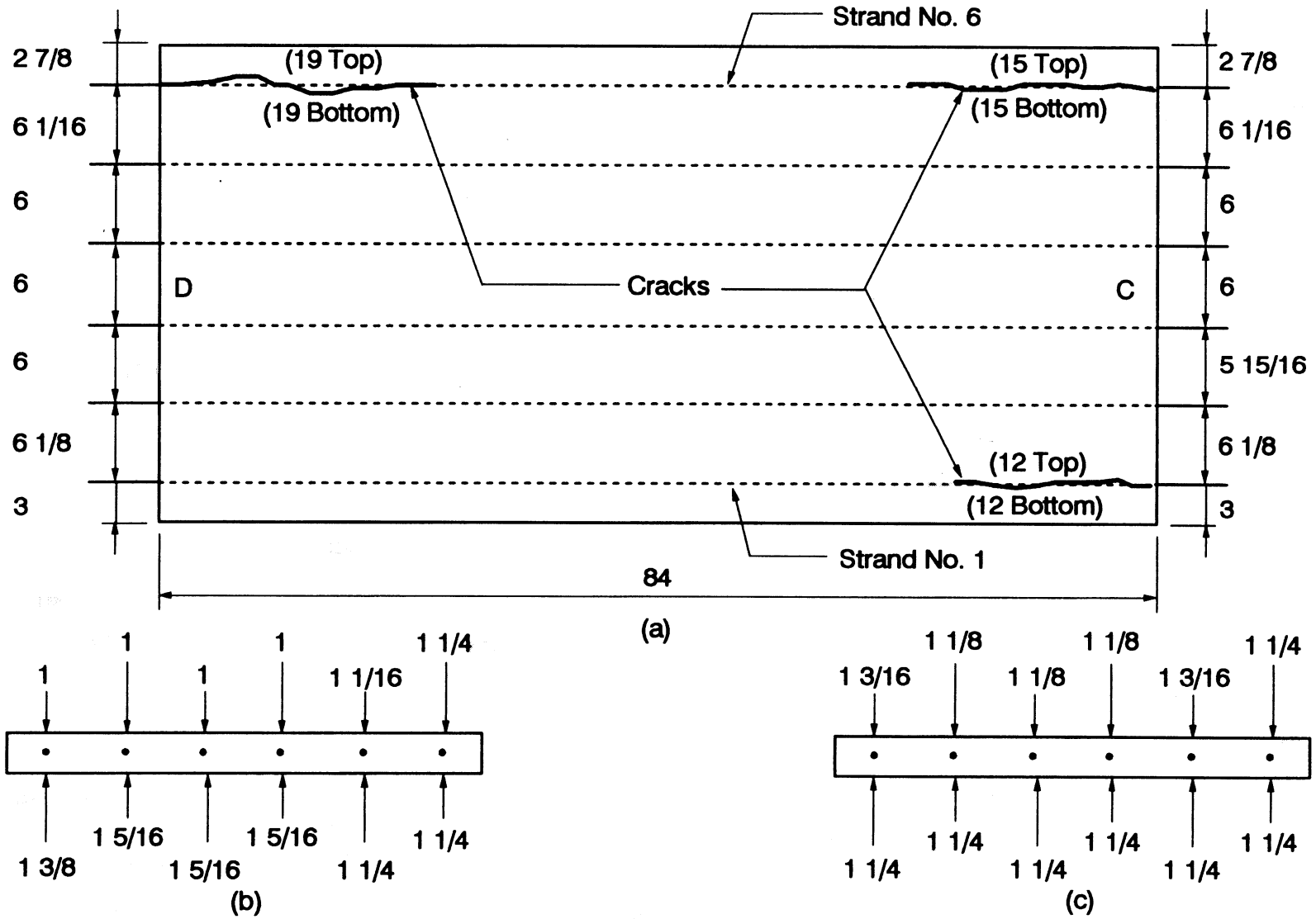


Figure C.43. Specimen No. 5-2.5TC-3 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at C

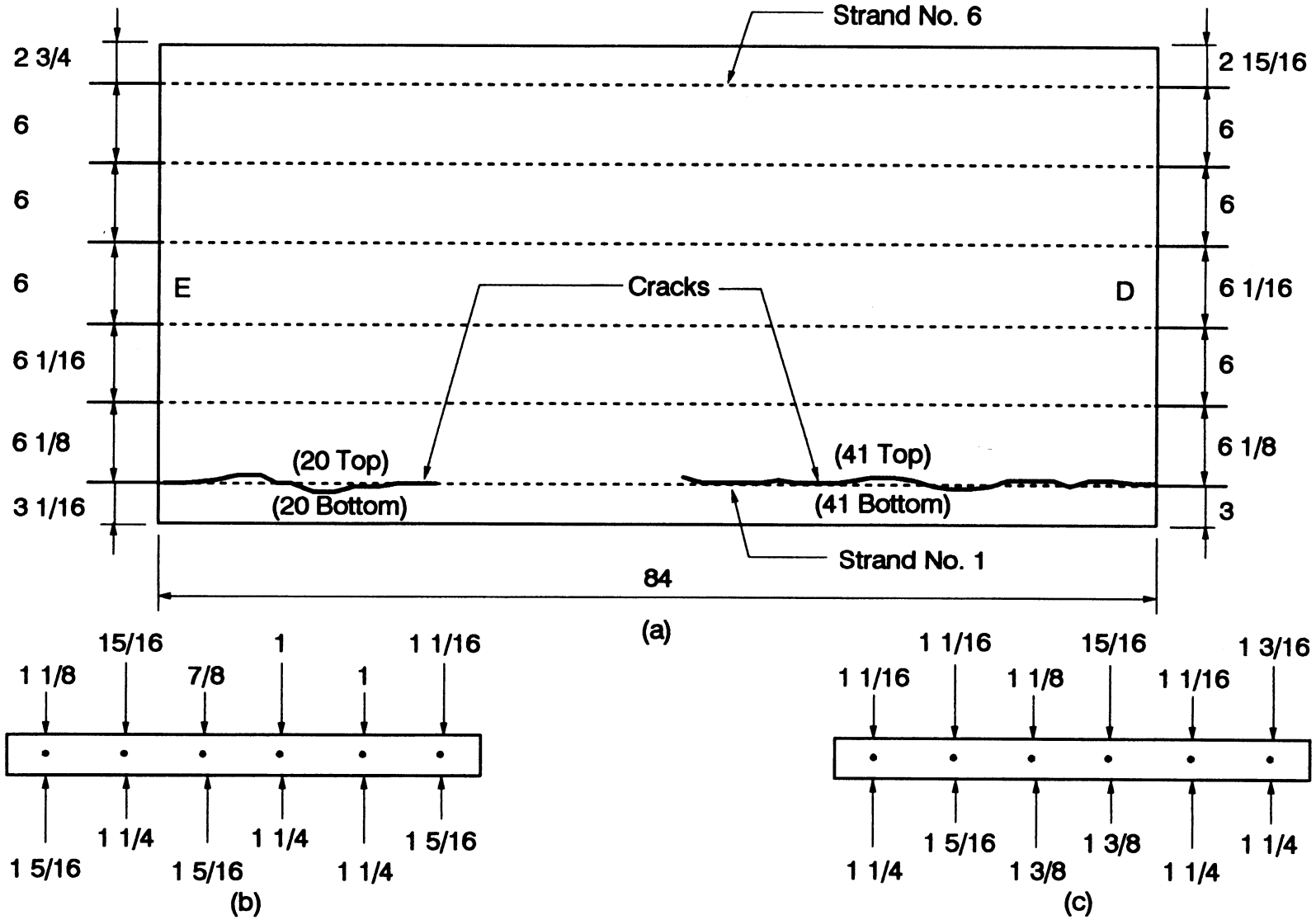


Figure C.44. Specimen No. 5-2.5TC-4 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

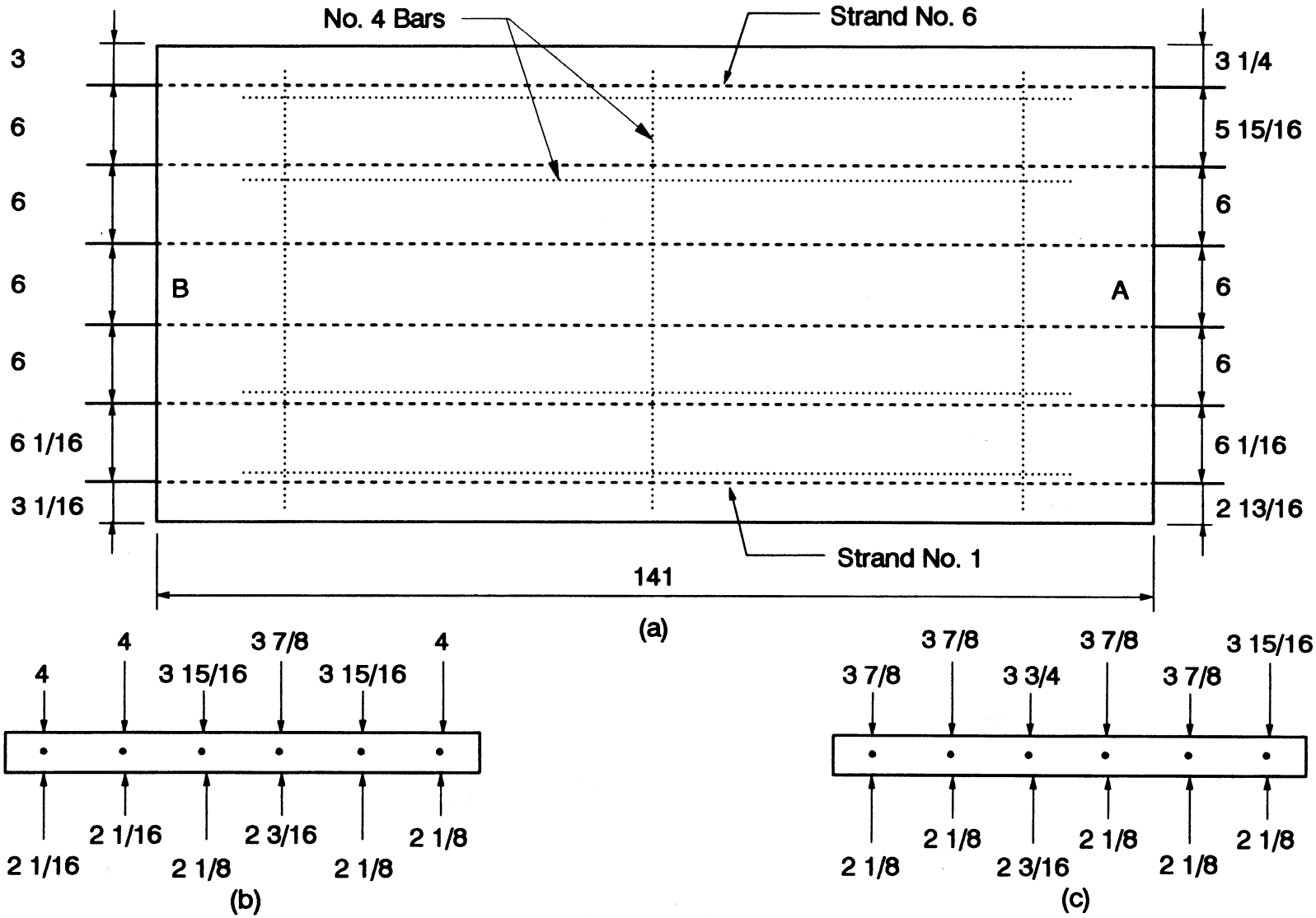


Figure C.45. Specimen No. 6-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

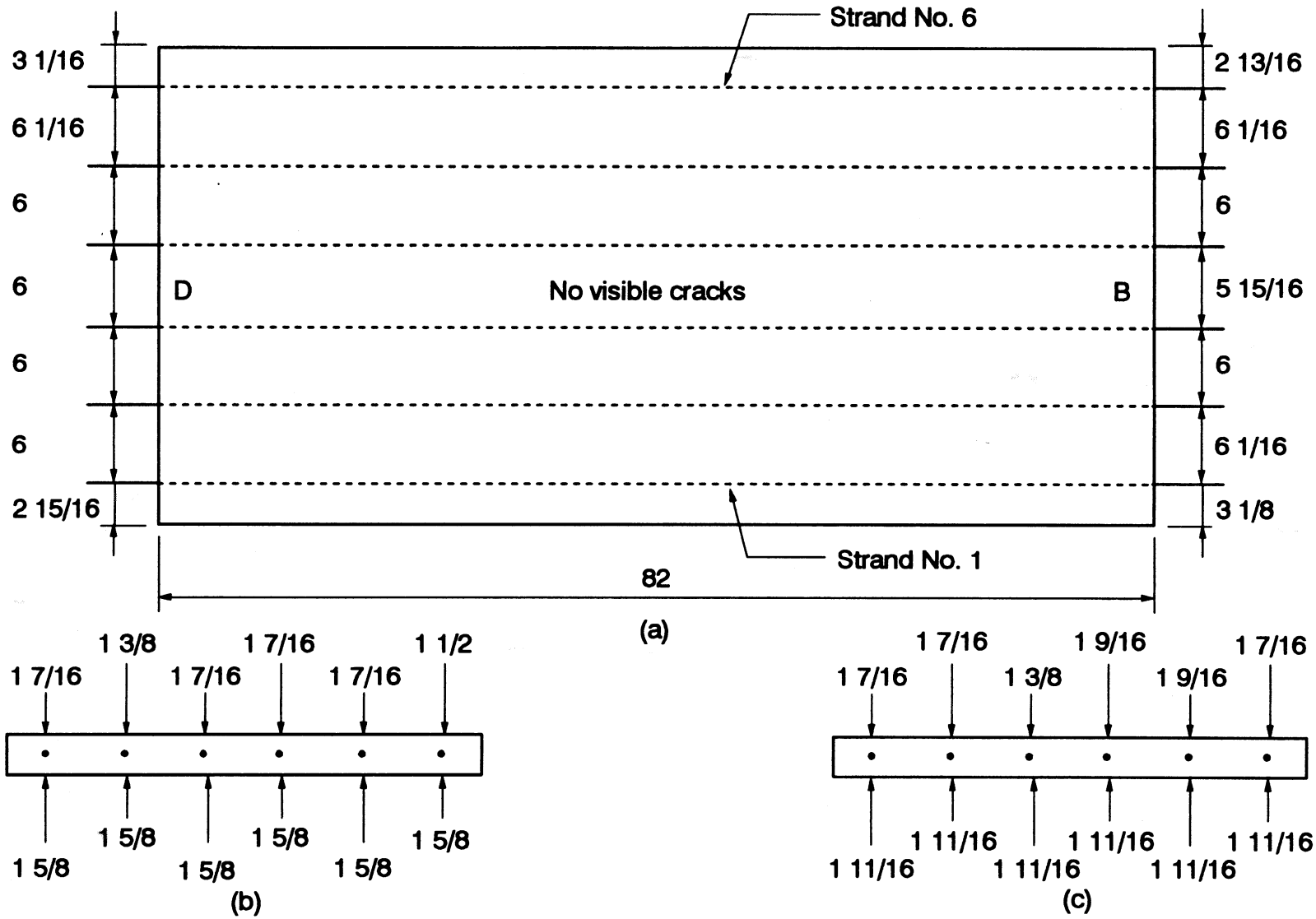


Figure C.46. Specimen No. 6-3.0TU-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

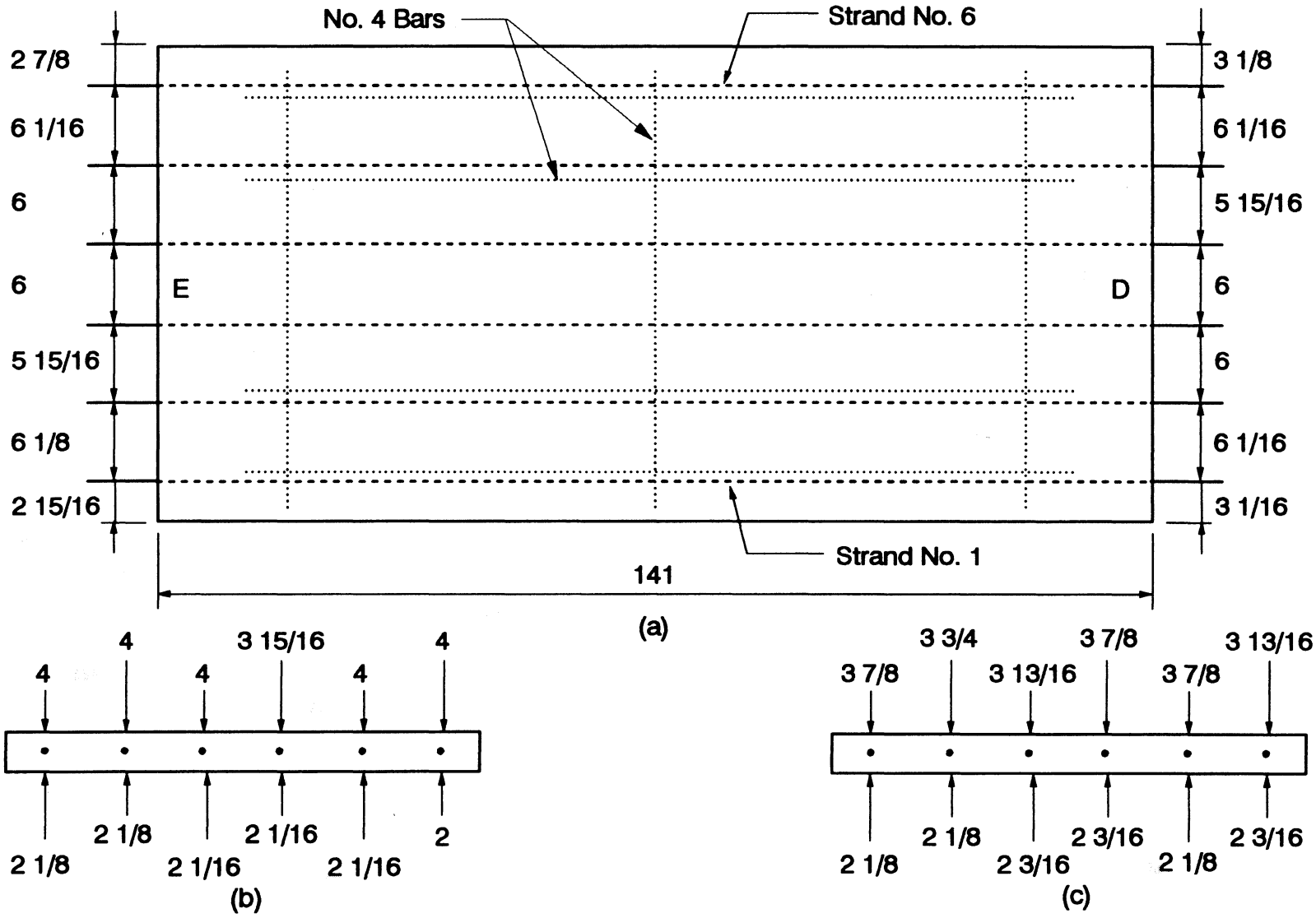


Figure C.47. Specimen No. 6-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

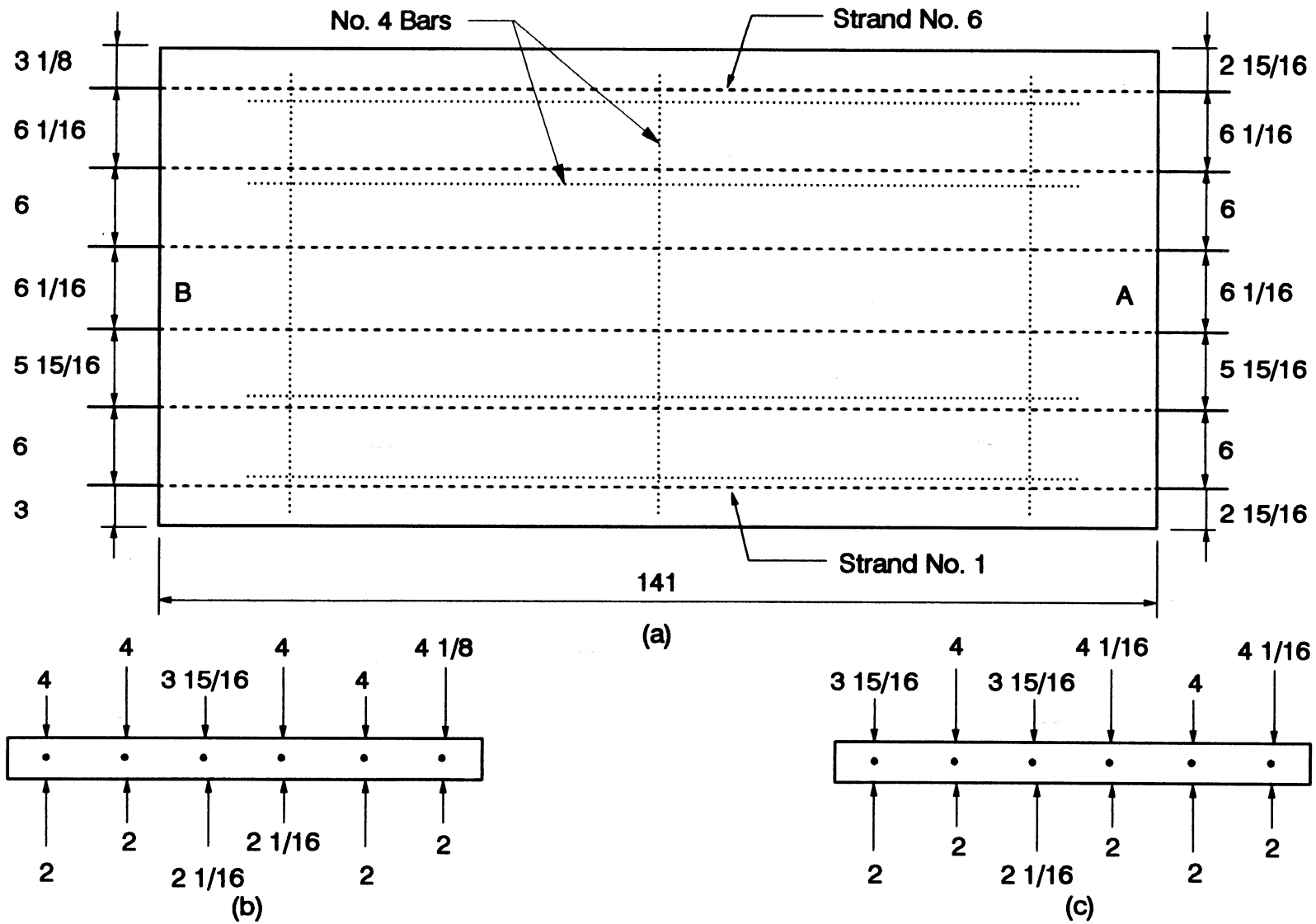


Figure C.48. Specimen No. 7-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

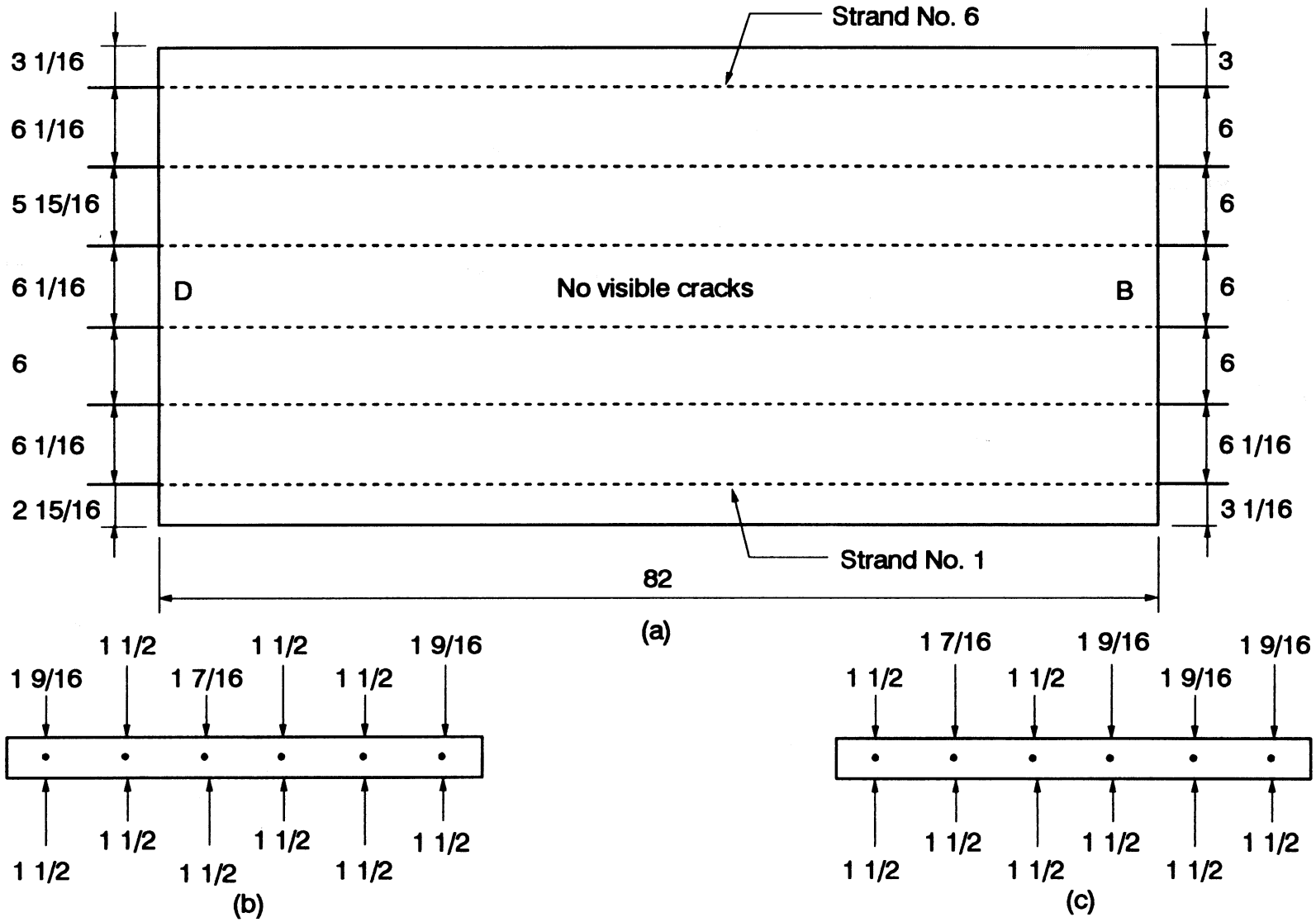


Figure C.49. Specimen No. 7-3.0TU-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

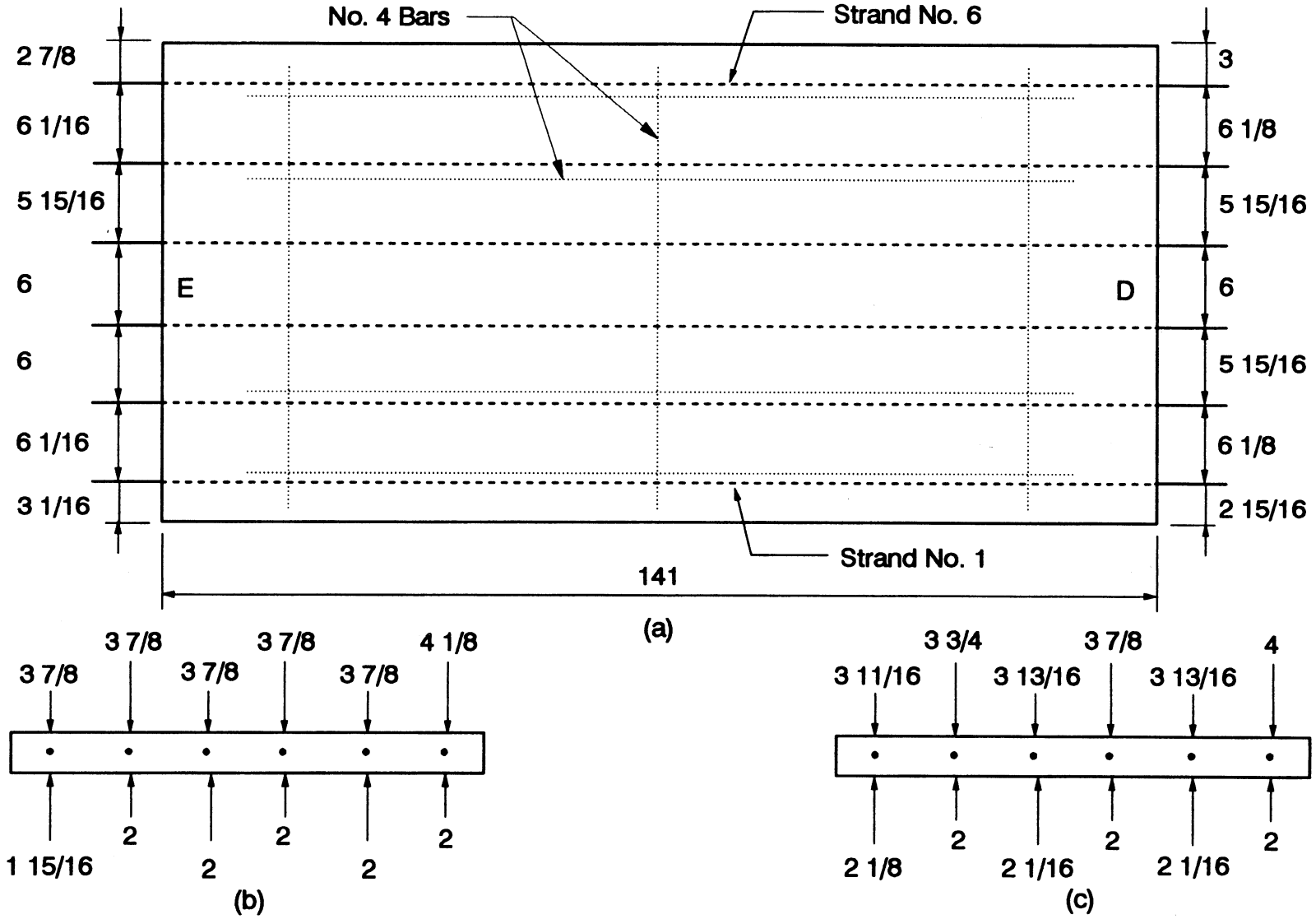


Figure C.50. Specimen No. 7-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

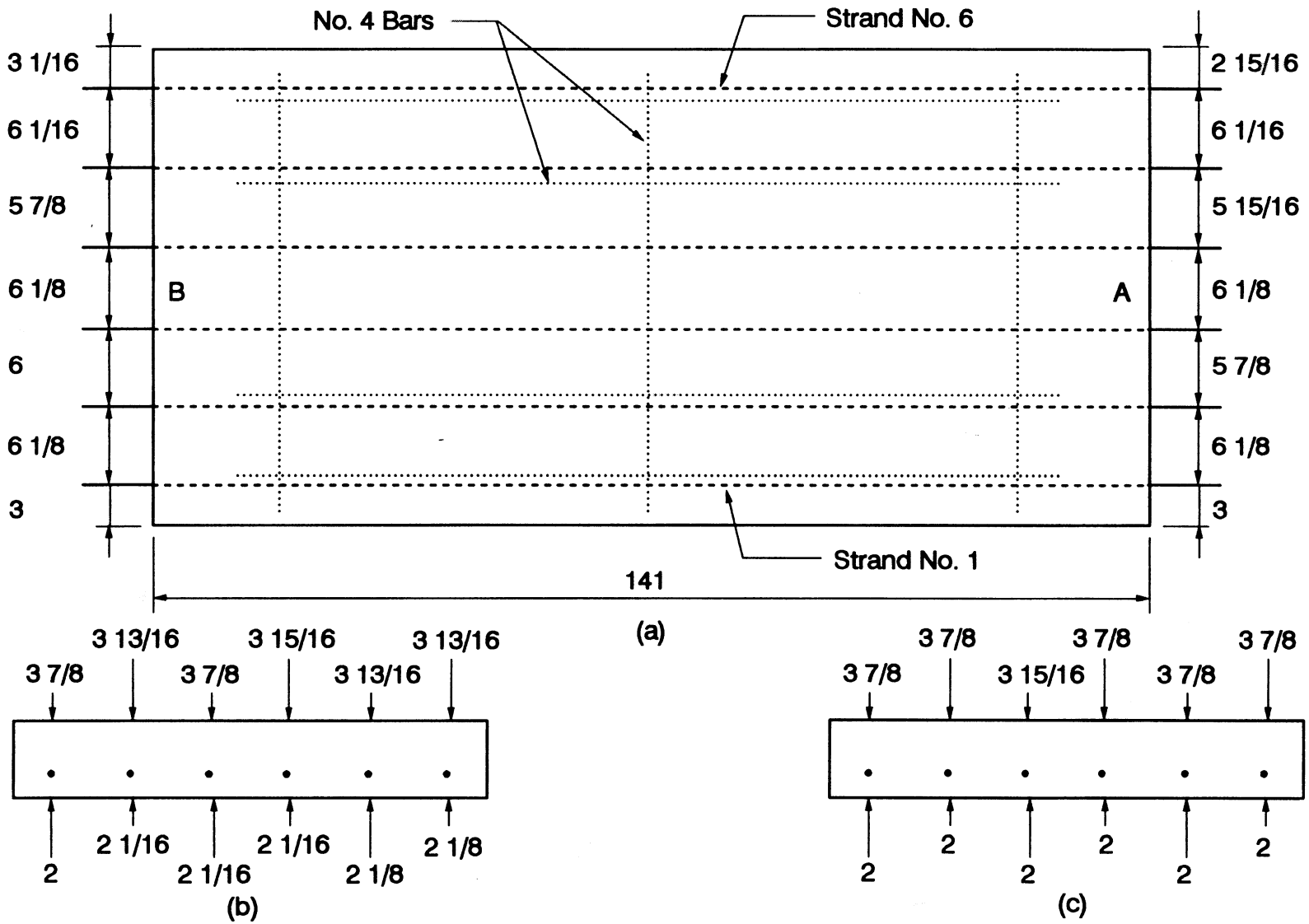


Figure D.51. Specimen No. 8-6.0DC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

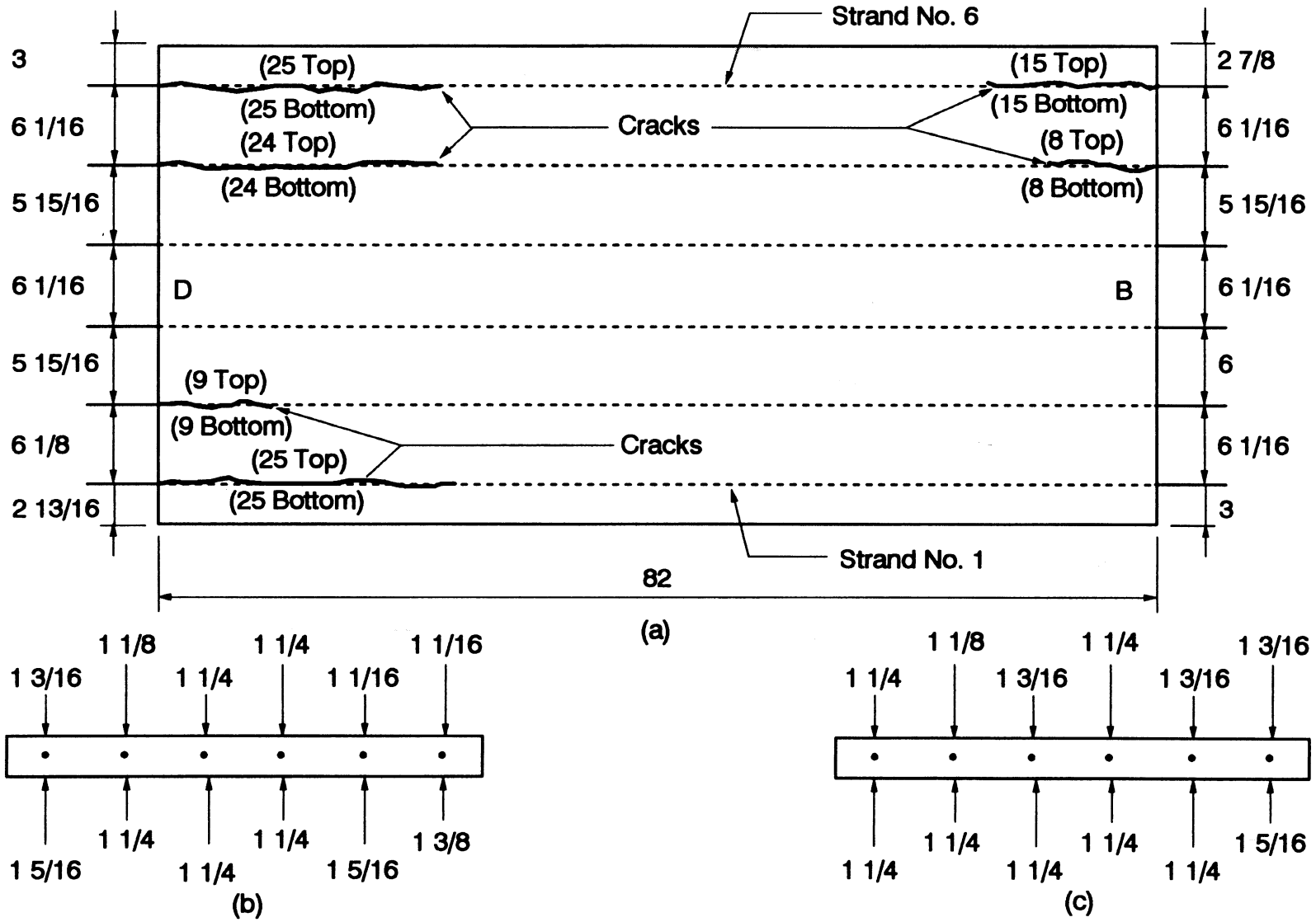


Figure C.52. Specimen No. 8-2.5TC-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

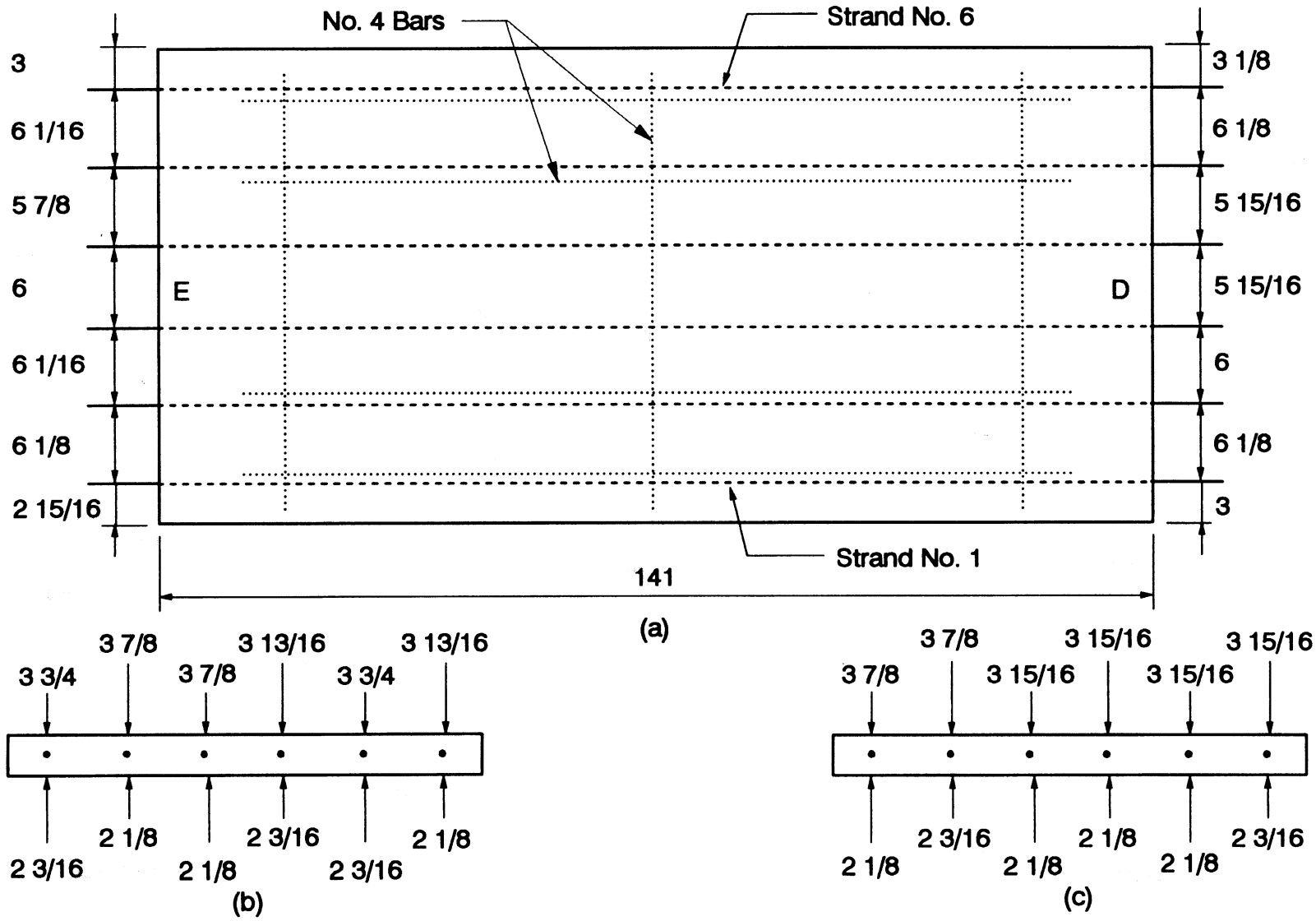


Figure C.53. Specimen No. 8-6.0DC-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

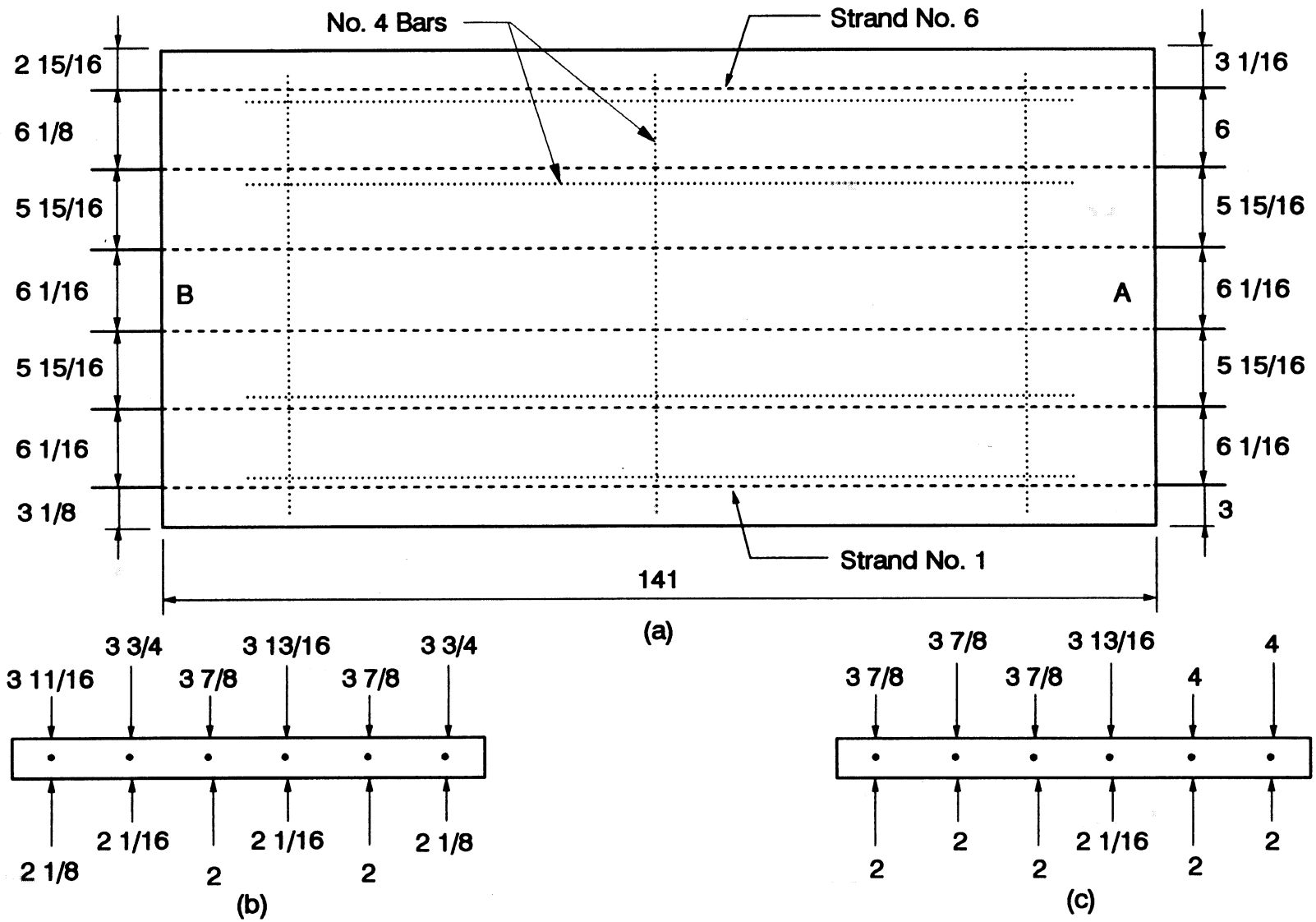


Figure C.54. Specimen No. 9-6.0DC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

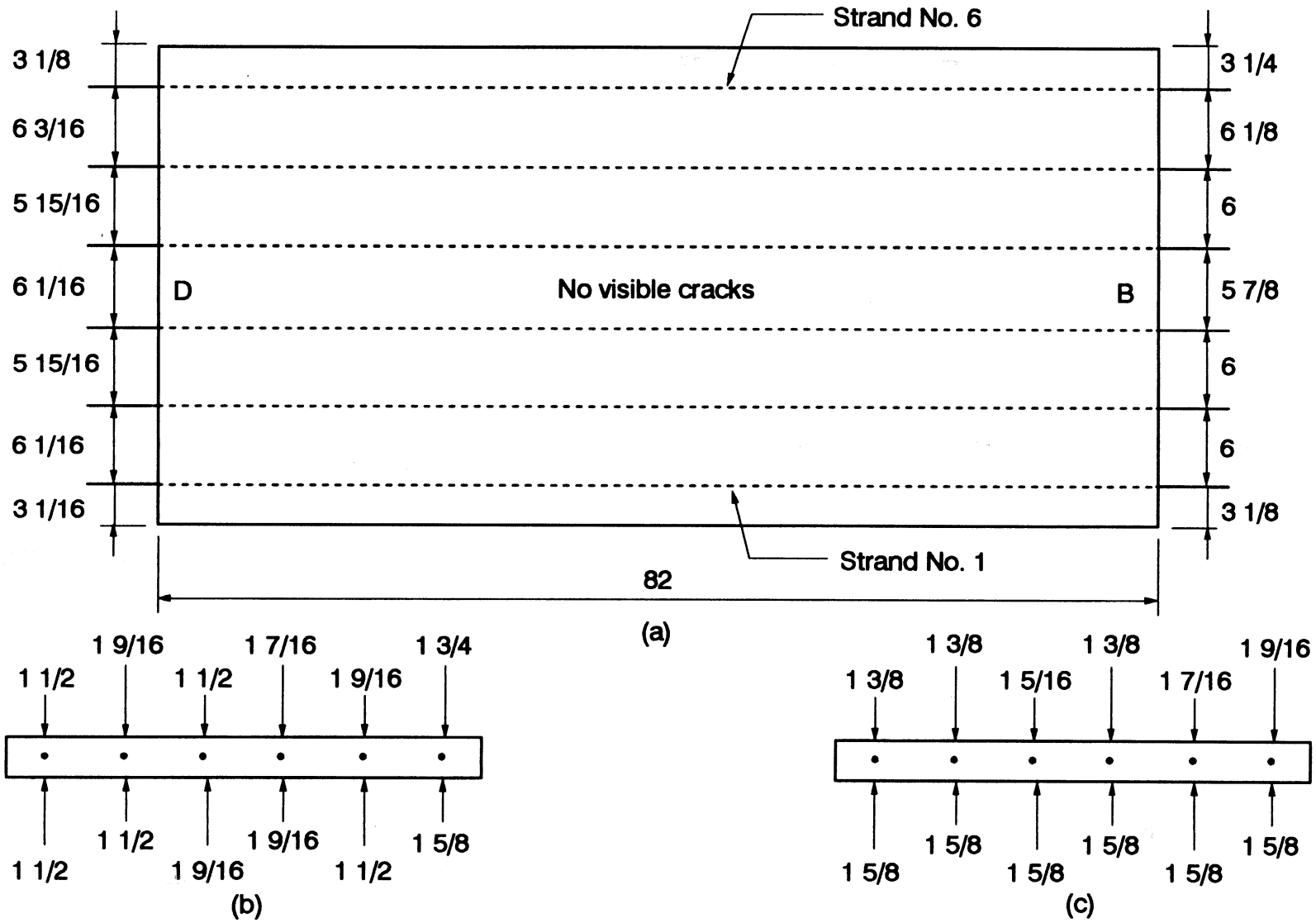


Figure C.55. Specimen No. 9-3.0TC-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

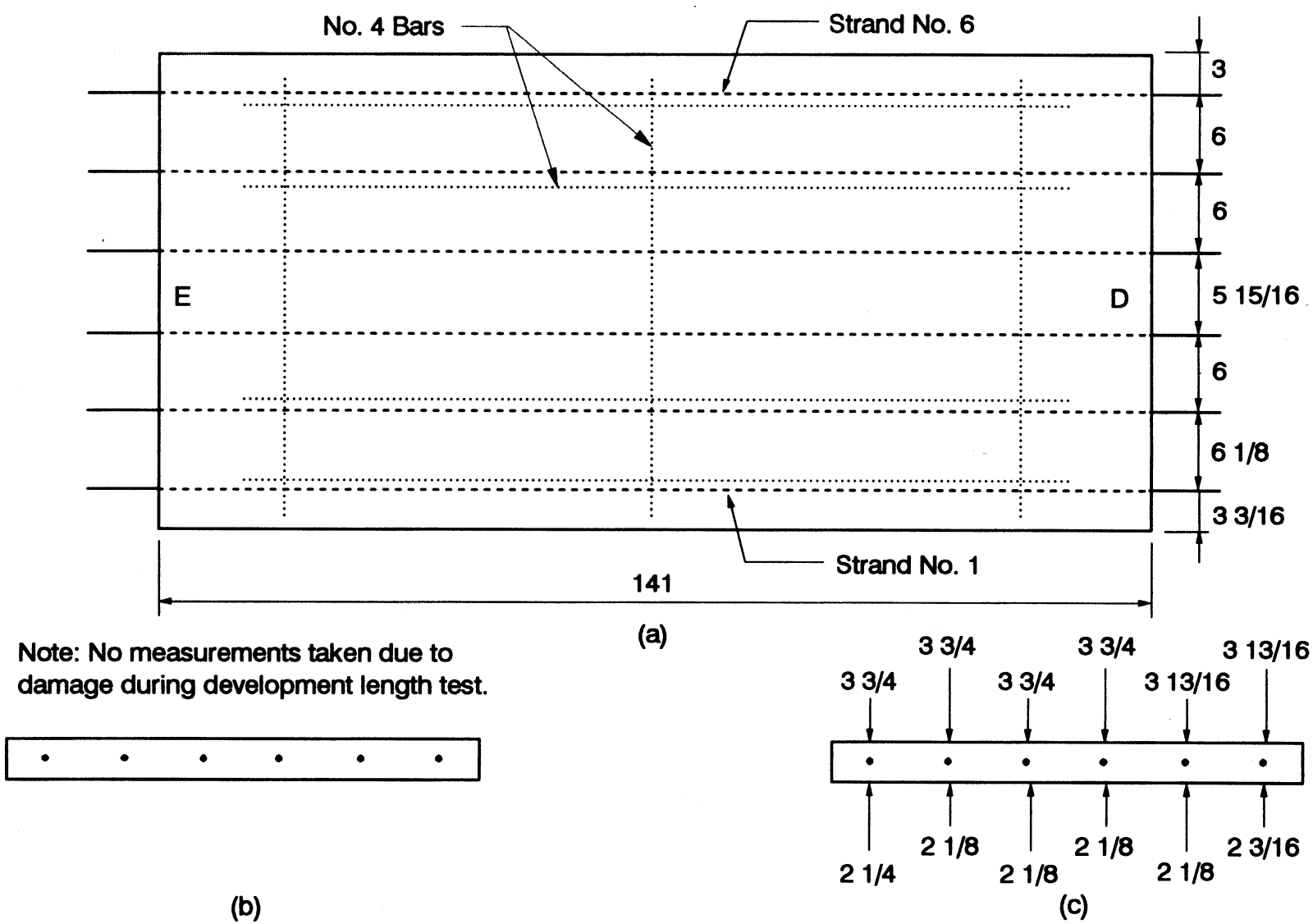


Figure C.56. Specimen No. 9-6.0DC-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

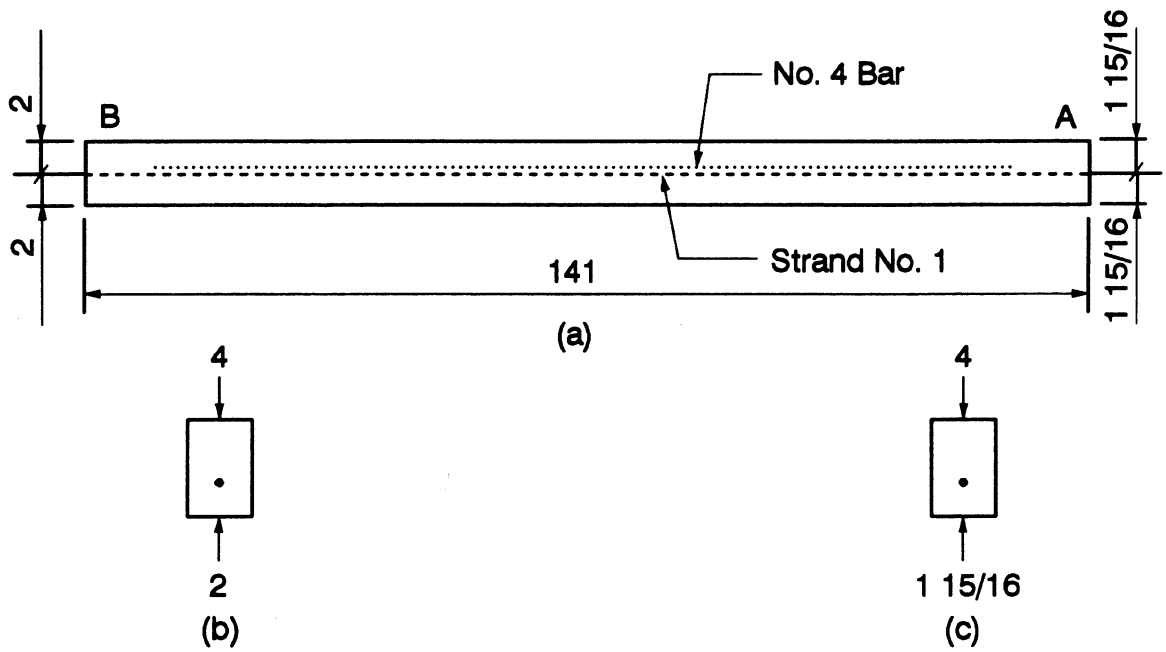


Figure C.57. Specimen No. 10-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

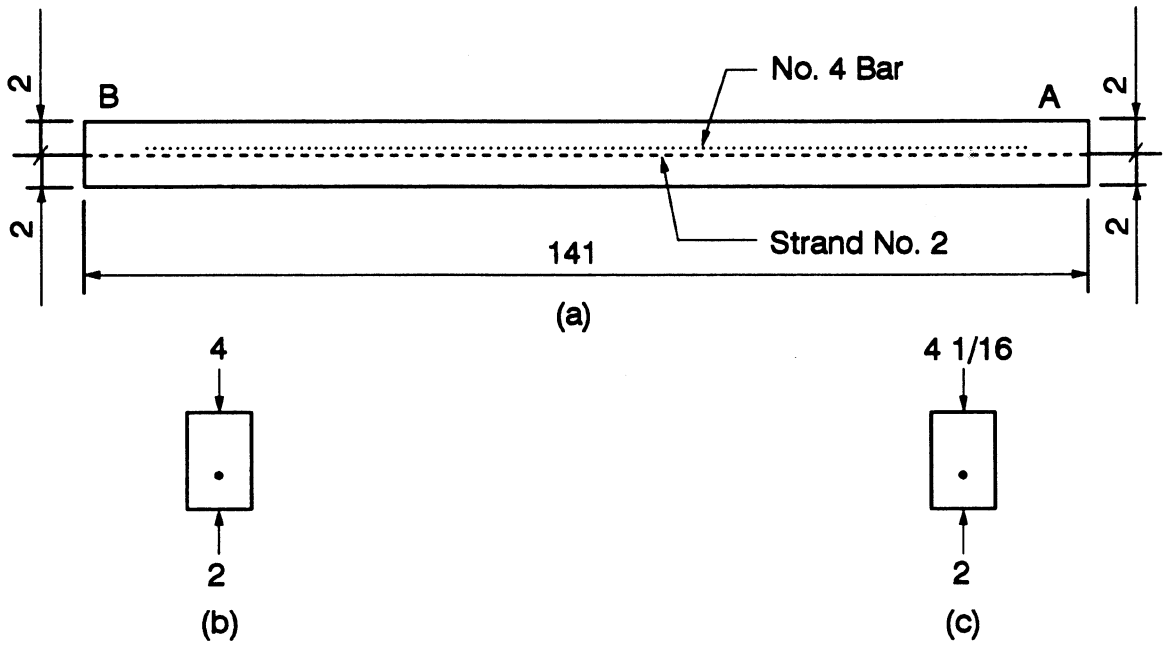


Figure C.58. Specimen No. 10-6.0DU-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

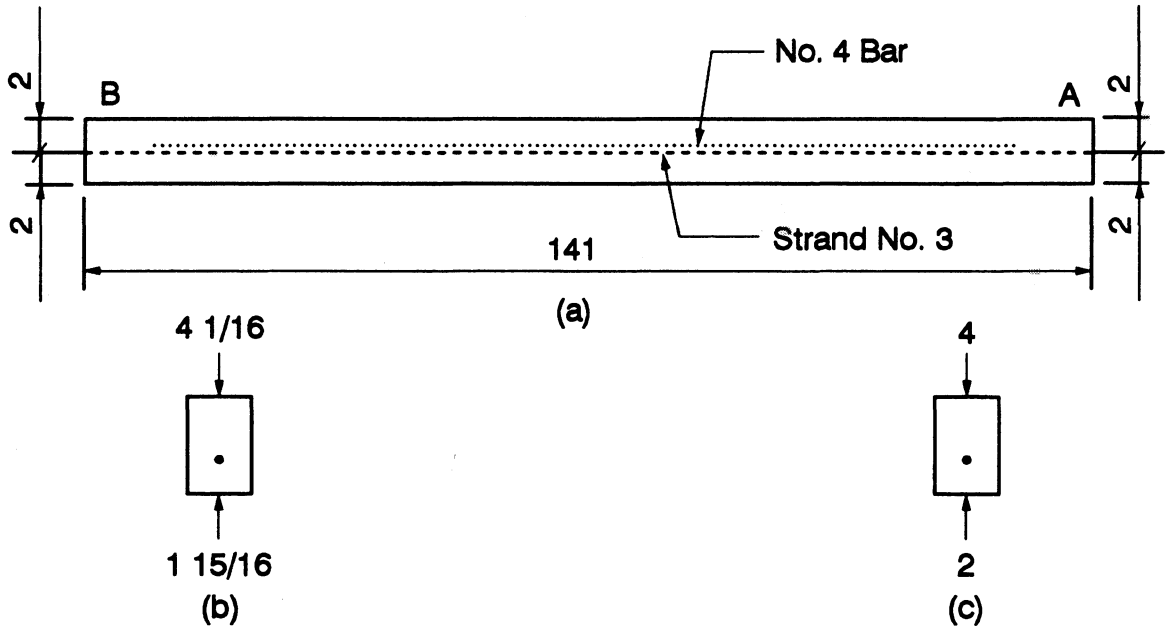


Figure C.59. Specimen No. 10-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

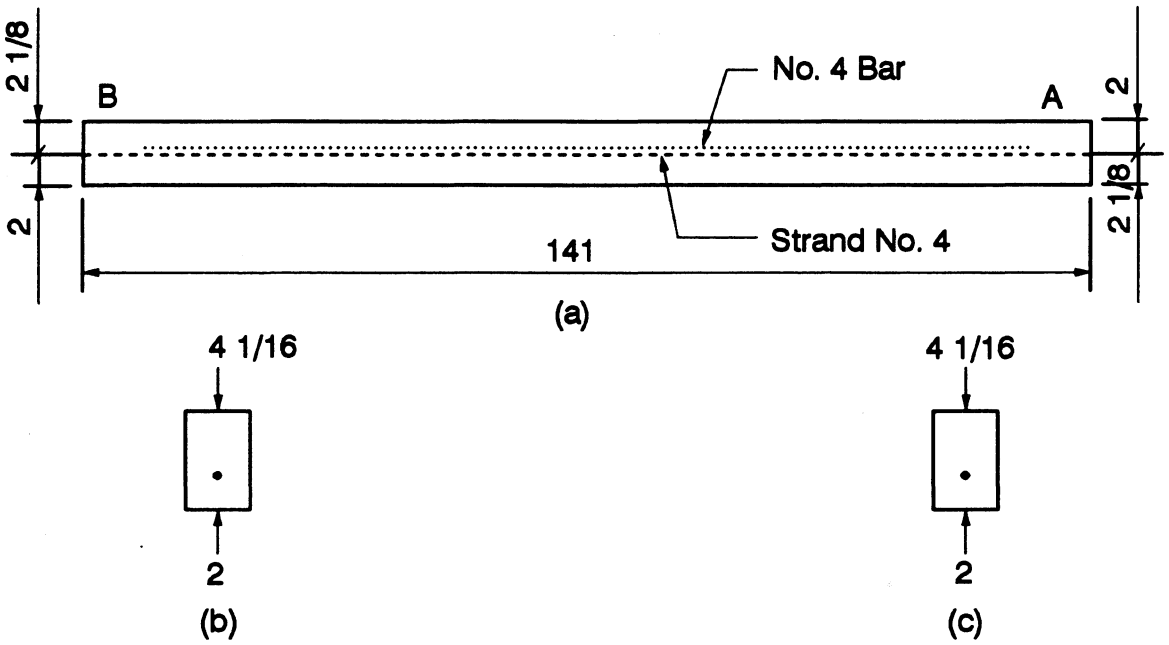


Figure C.60. Specimen No. 10-6.0DU-4 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

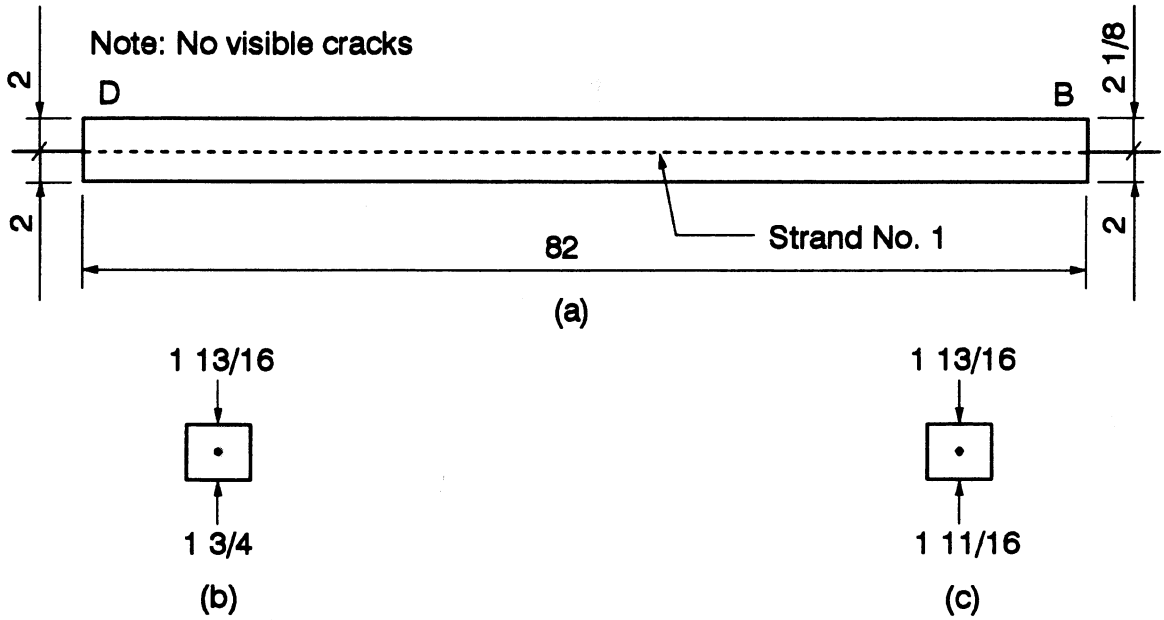


Figure C.61. Specimen No. 10-3.5TU-5 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

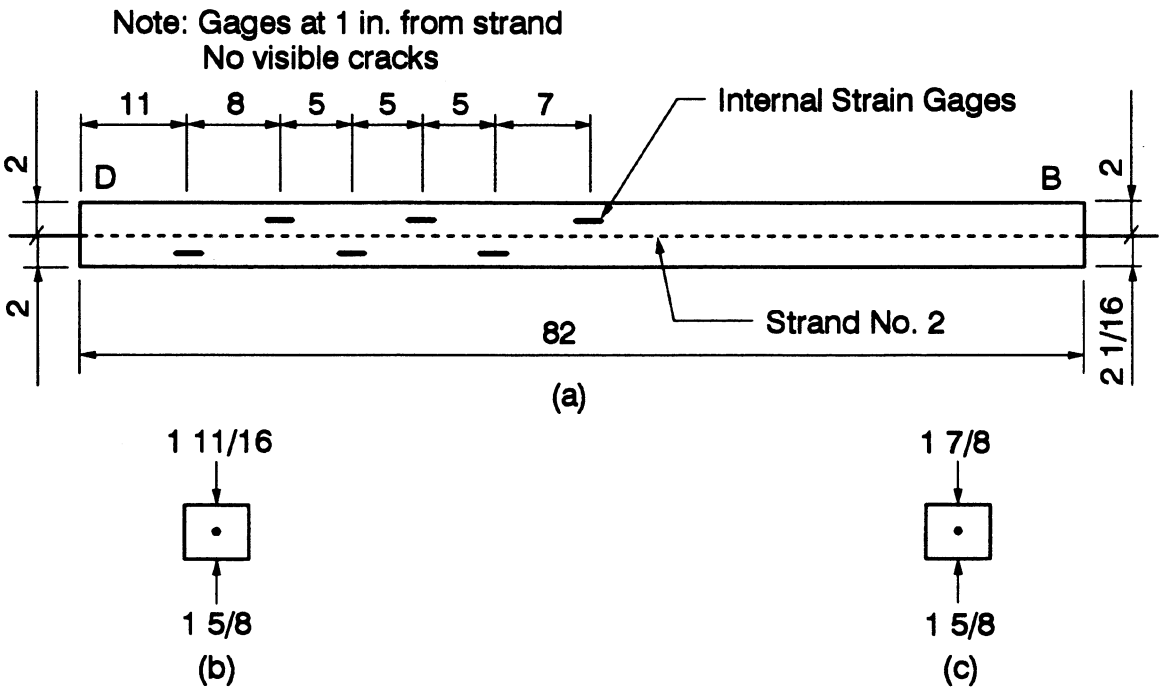


Figure C.62. Specimen No. 10-3.5TU-6 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

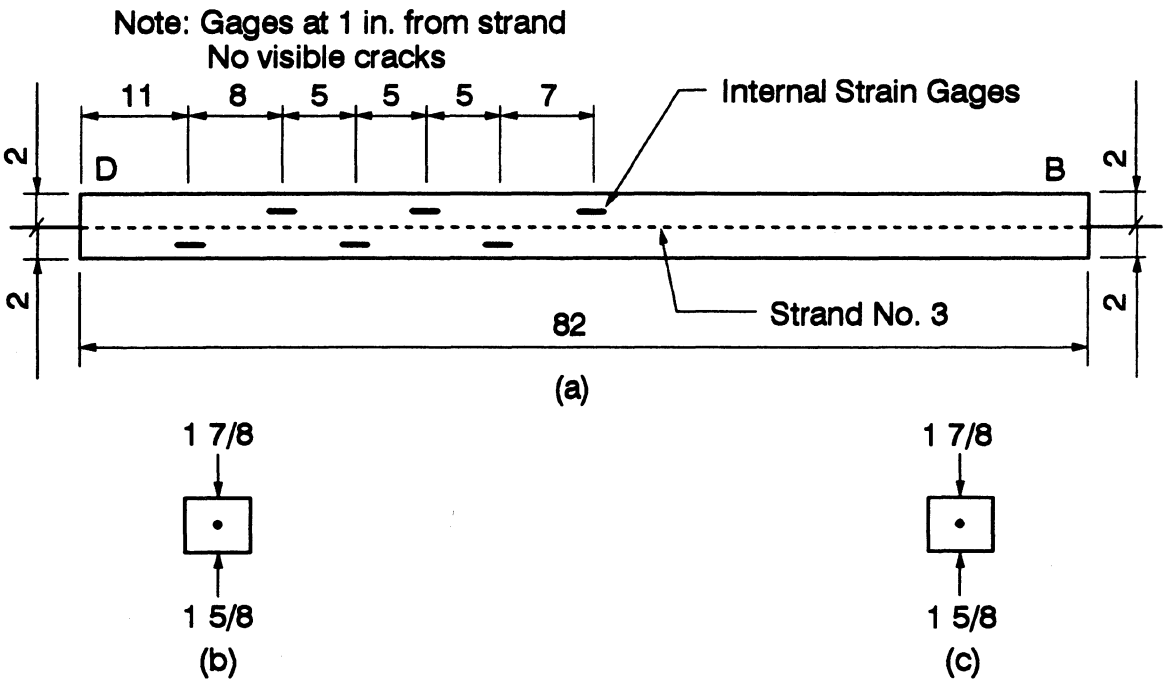


Figure C.63. Specimen No. 10-3.5TU-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

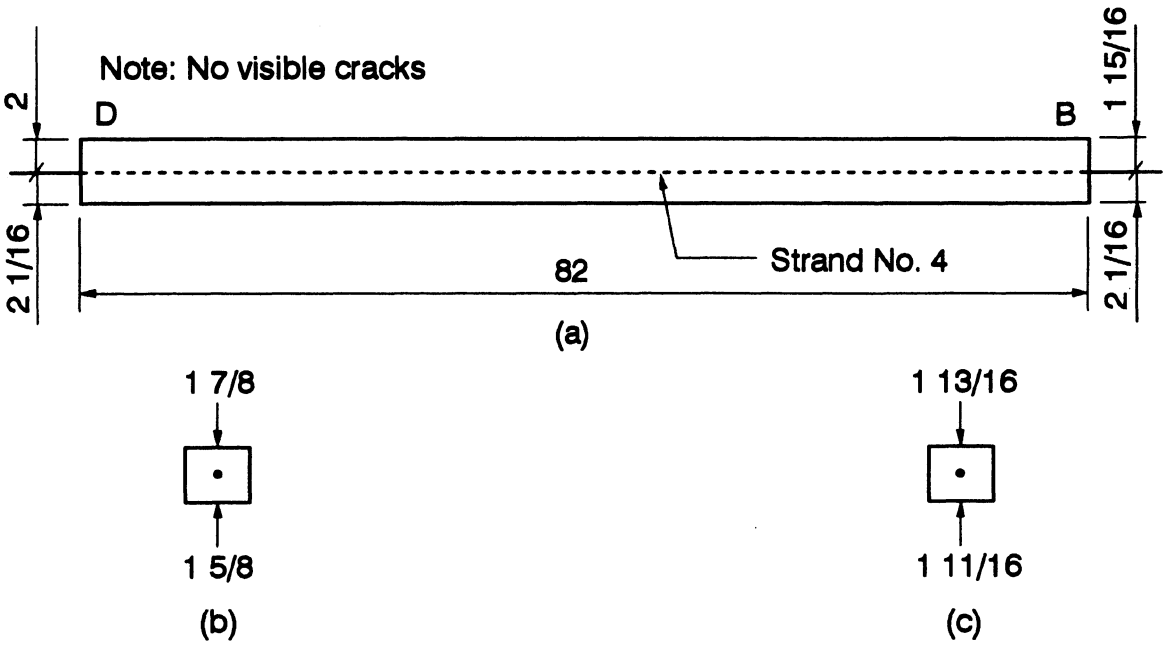


Figure C.64. Specimen No. 10-3.5TU-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

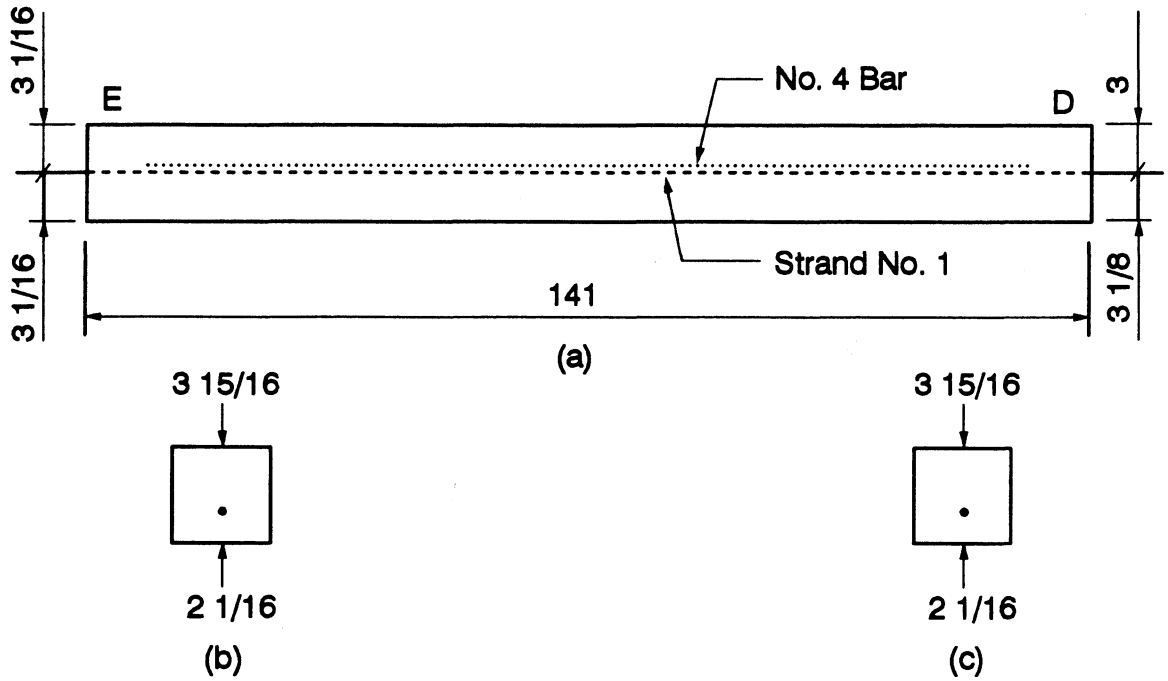


Figure C.65. Specimen No. 10-6.0DU-9 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

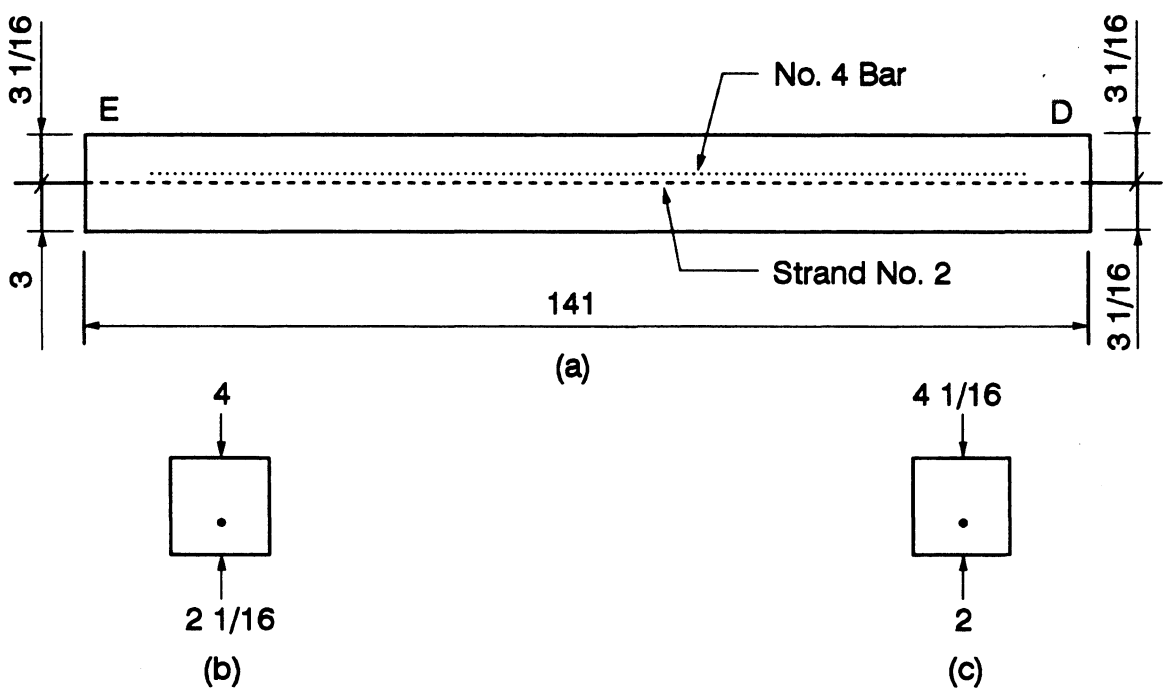


Figure C.66. Specimen No. 10-6.0DU-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

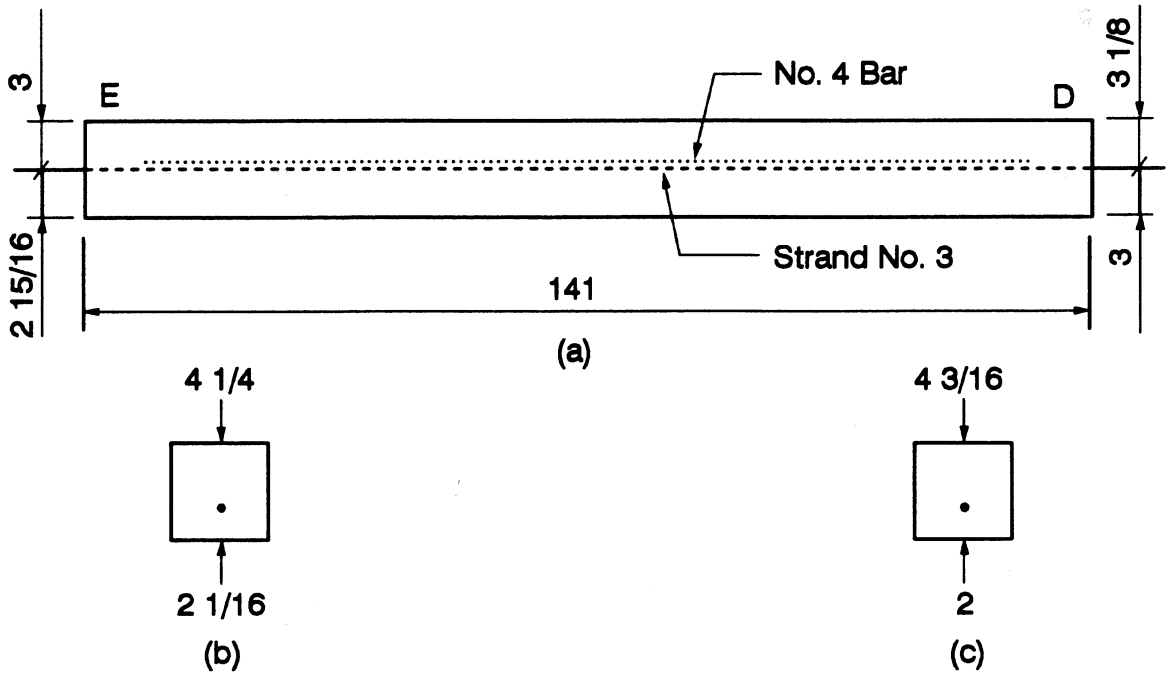


Figure C.67. Specimen No. 10-6.0DU-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

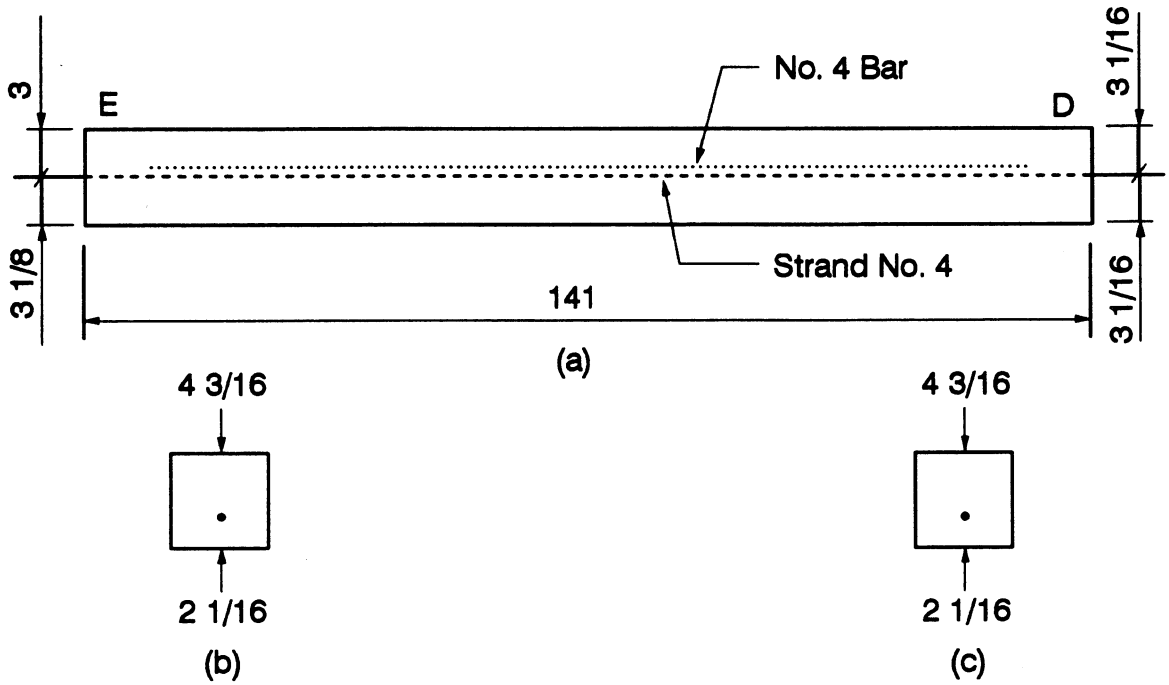


Figure C.68. Specimen No. 10-6.0DU-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

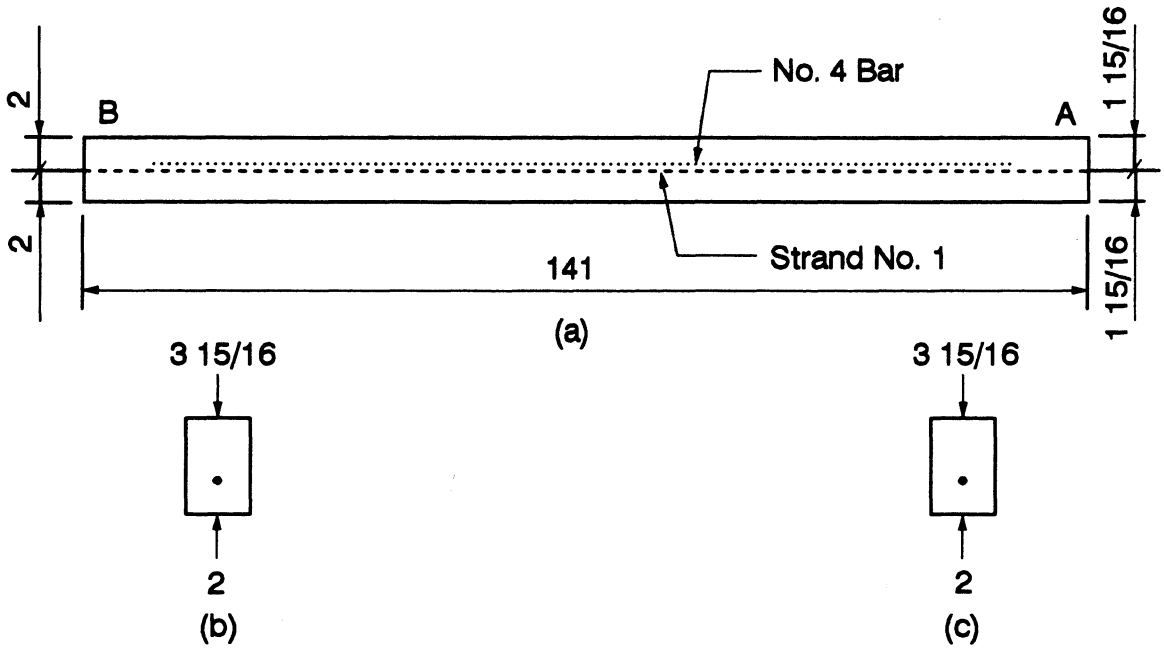


Figure C.69. Specimen No. 11-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

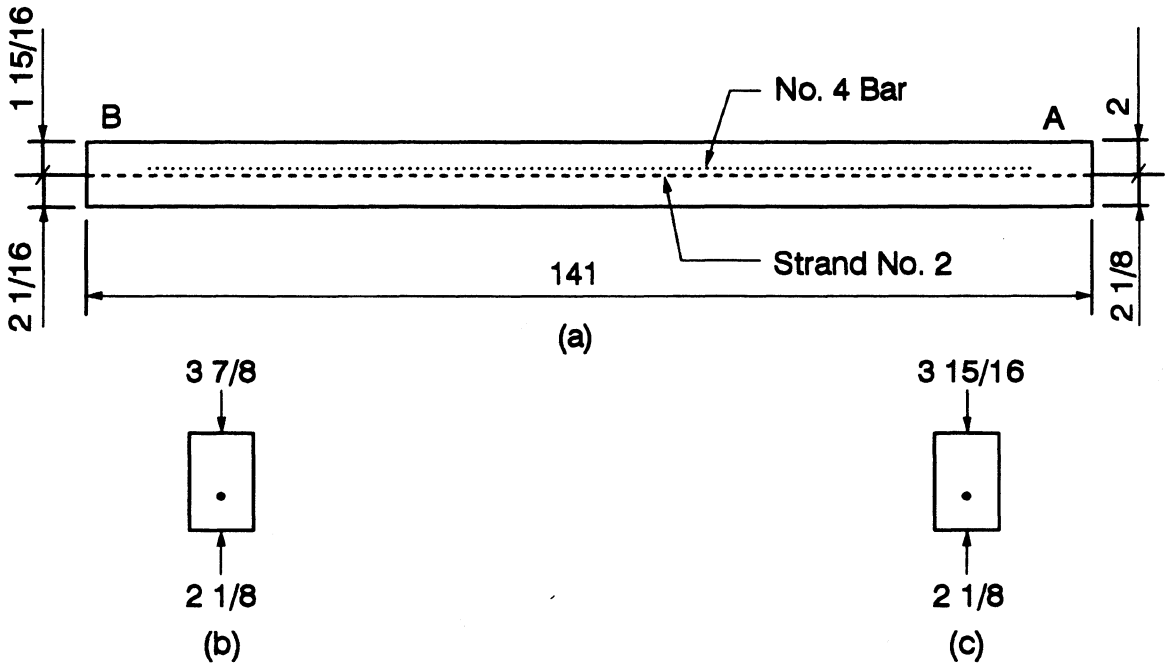


Figure C.70. Specimen No. 11-6.0DU-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

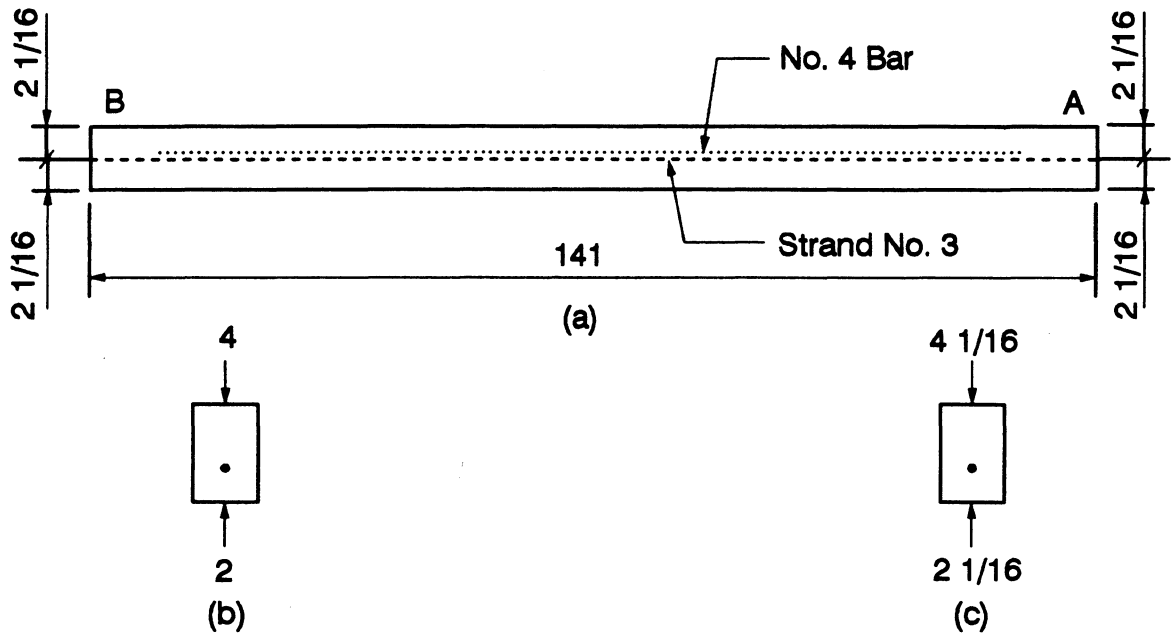


Figure C.71. Specimen No. 11-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

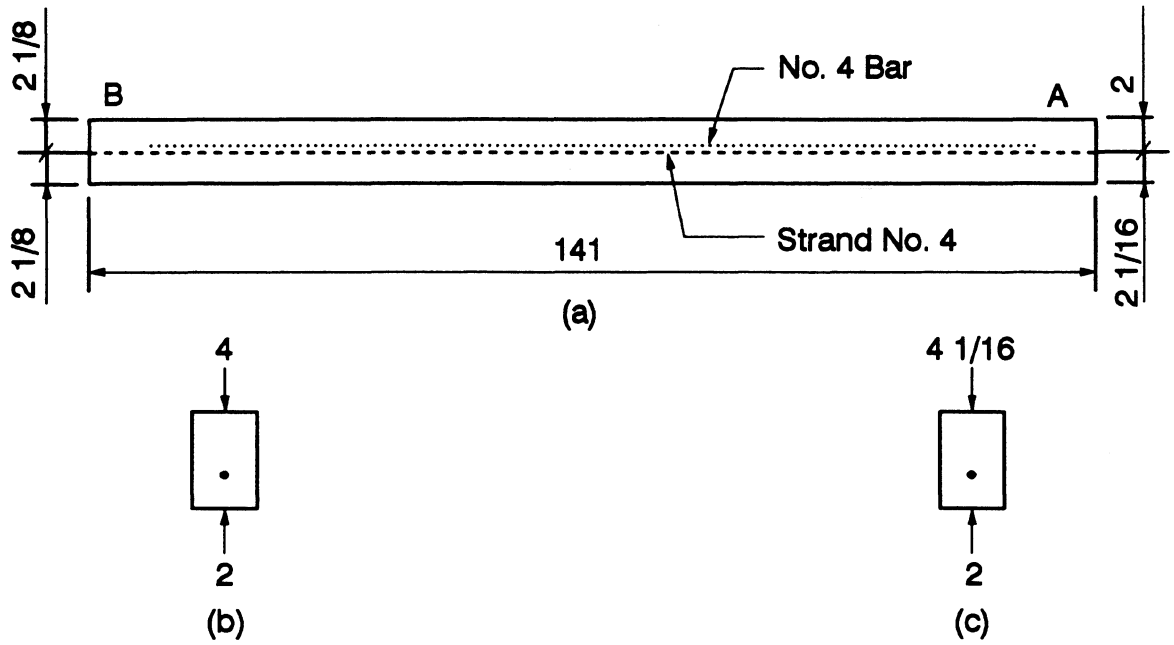


Figure C.72. Specimen No. 11-6.0DU-4 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

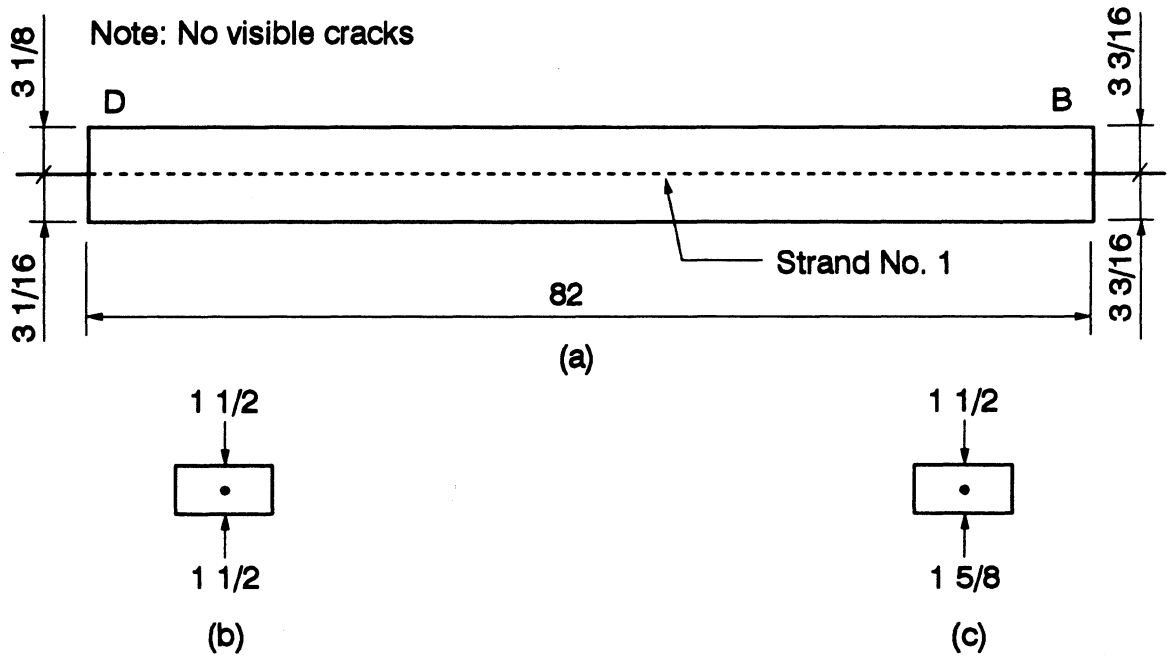


Figure C.73. Specimen No. 11-3.0TU-5 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

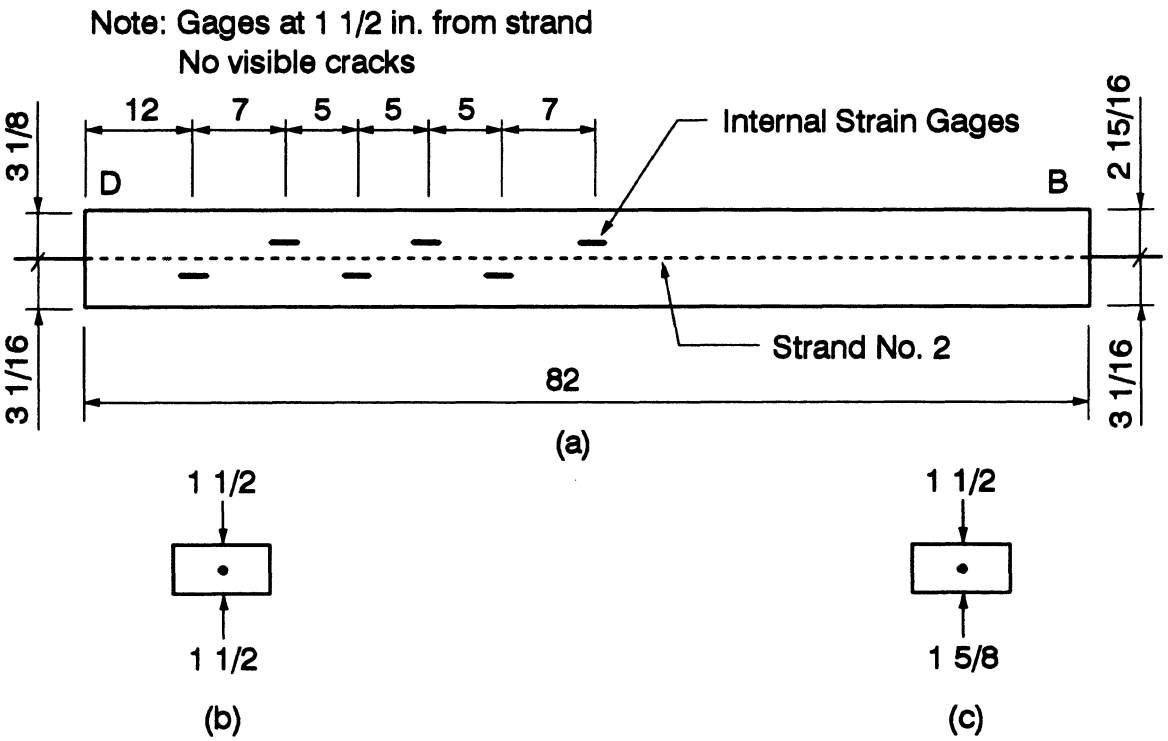


Figure C.74. Specimen No. 11-3.0TU-6 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

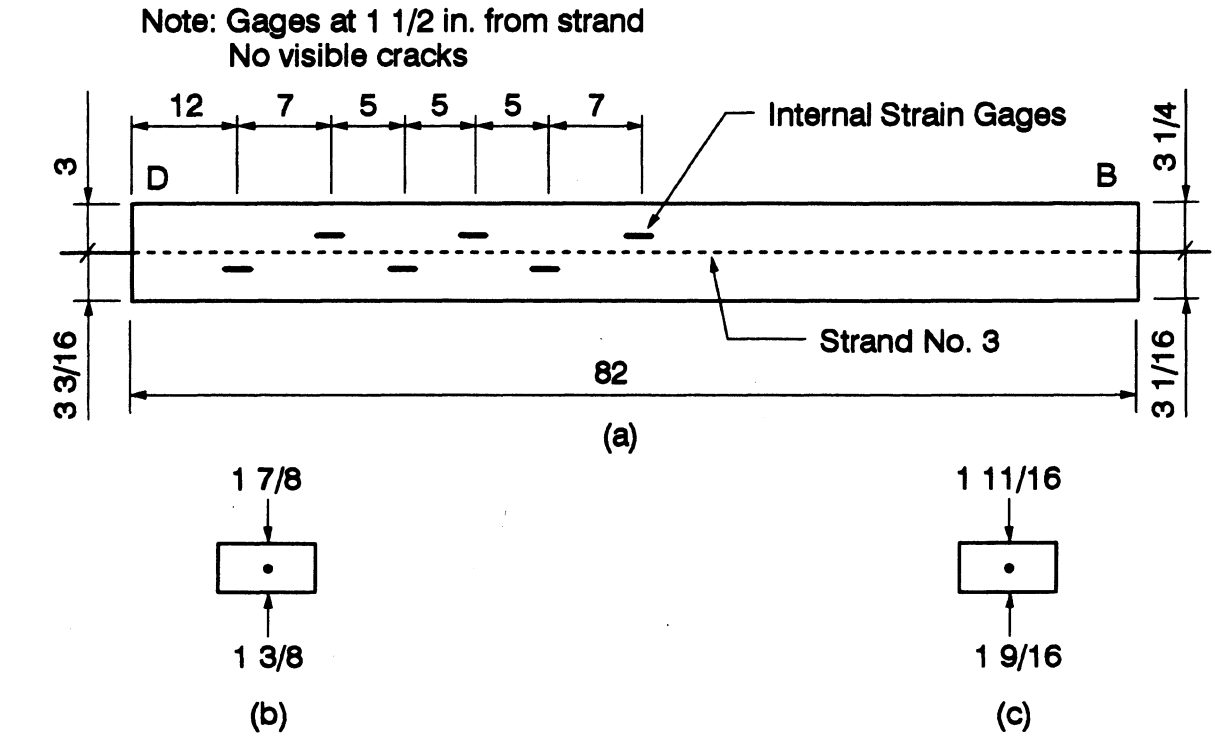


Figure C.75. Specimen No. 11-3.0TU-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

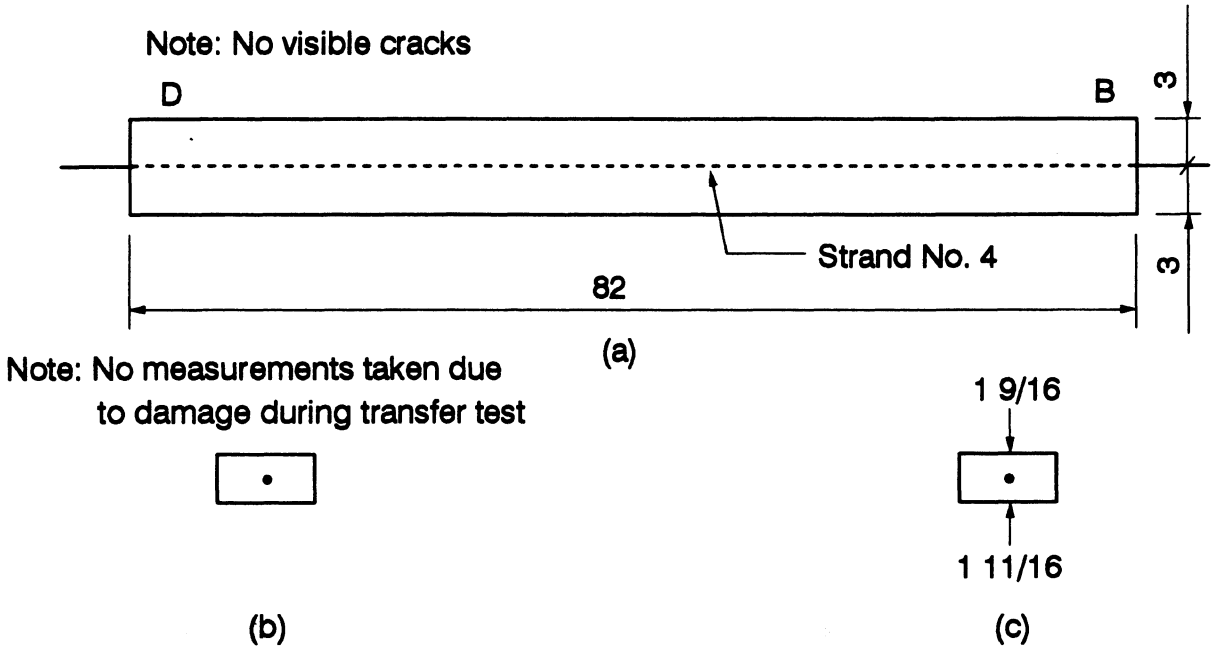


Figure C.76. Specimen No. 11-3.0TU-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

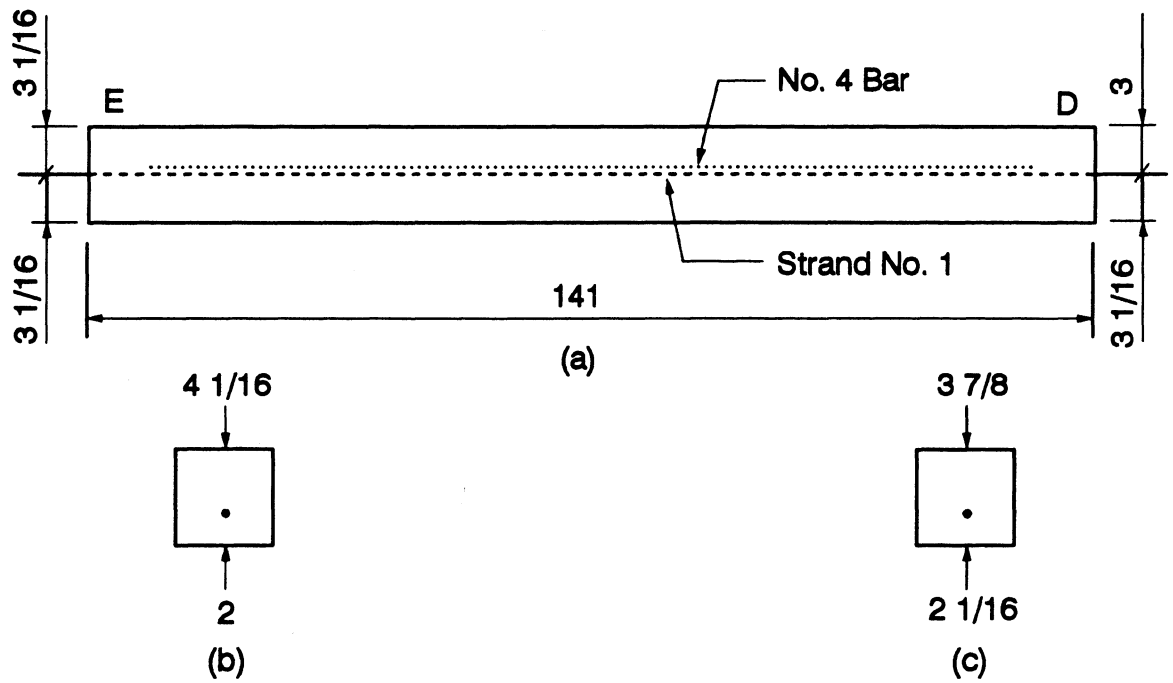


Figure C.77. Specimen No. 11-6.0DU-9 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

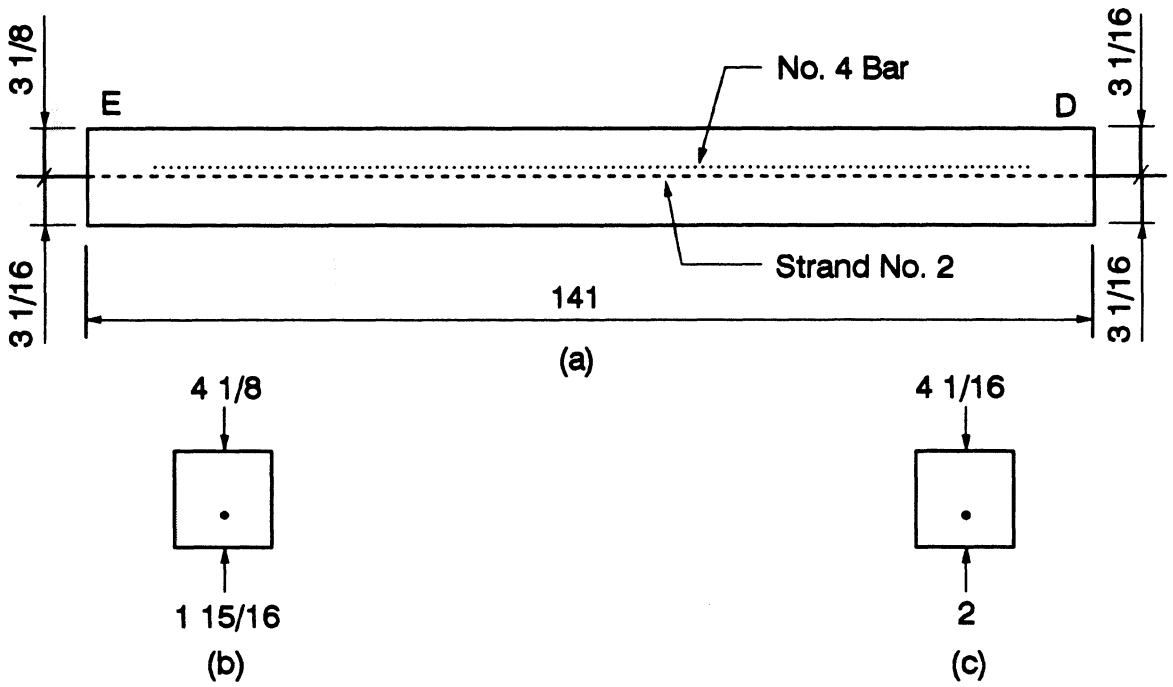


Figure C.78. Specimen No. 11-6.0DU-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

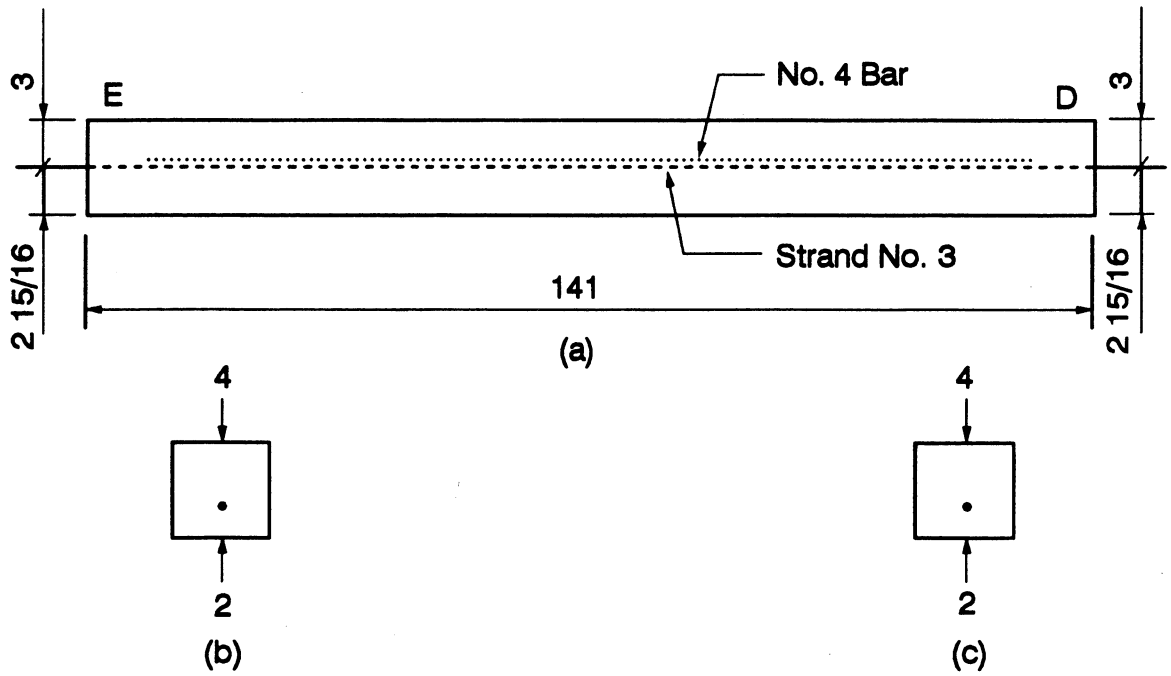


Figure C.79. Specimen No. 11-6.0DU-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

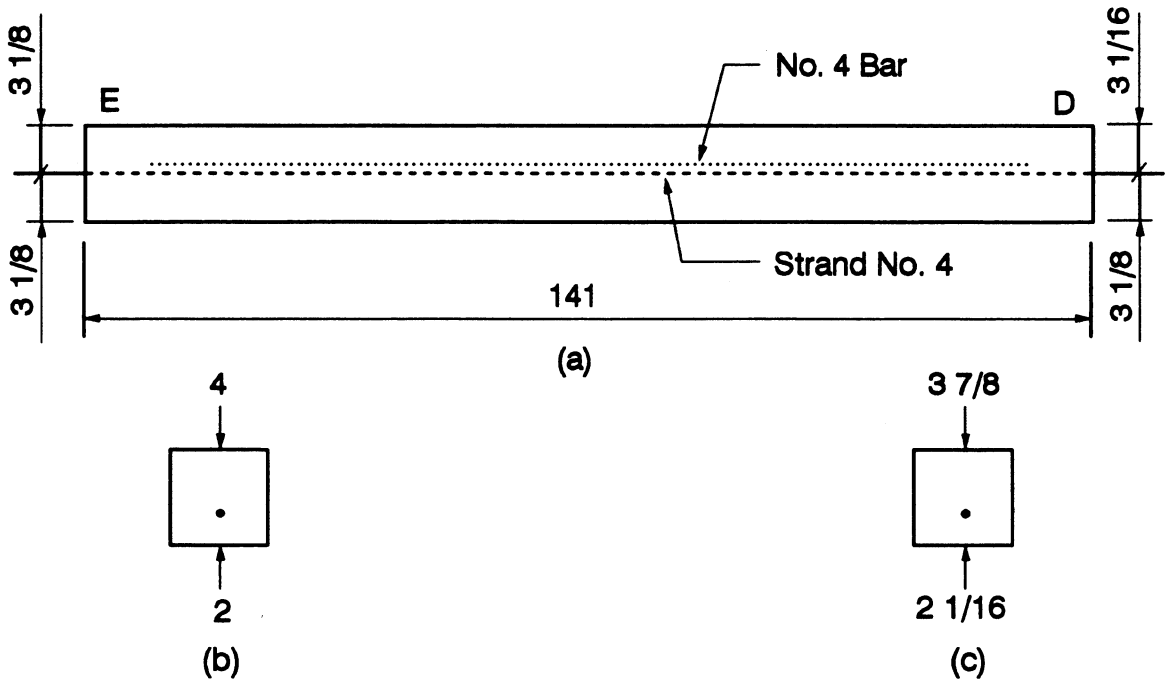


Figure C.80. Specimen No. 11-6.0DU-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

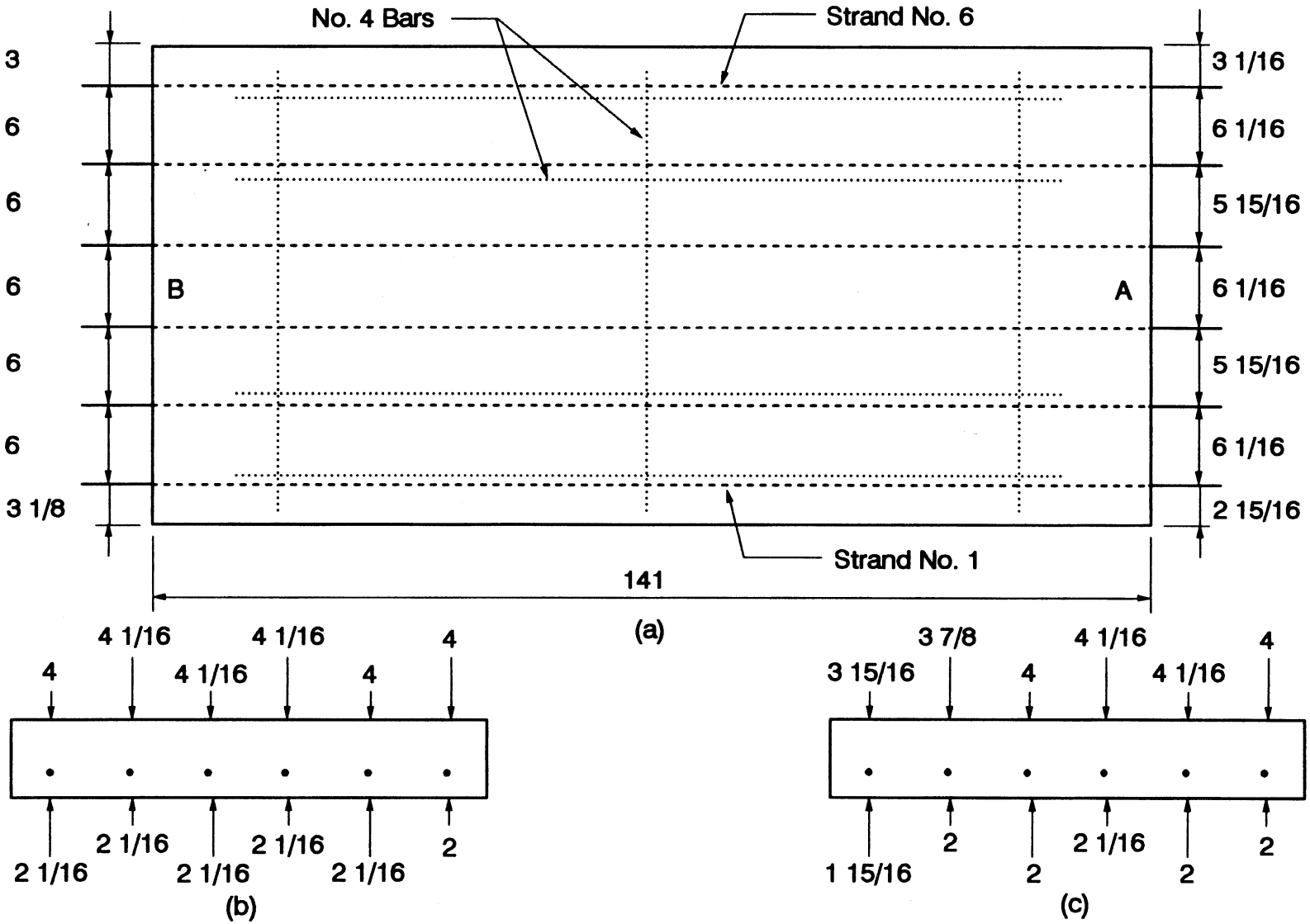


Figure C.81. Specimen No. 12-6.0DC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

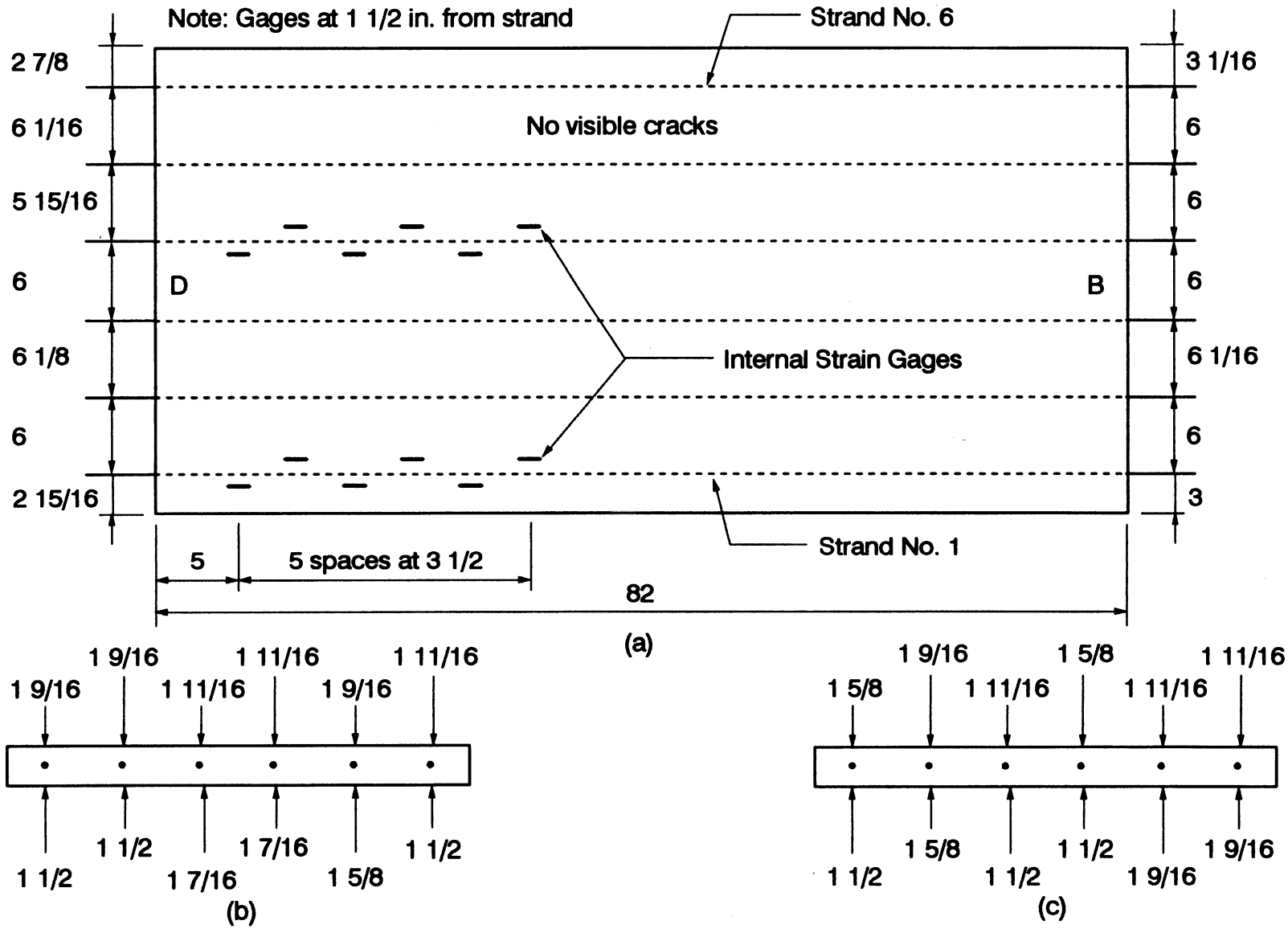


Figure C.82. Specimen No. 12-3.0TC-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

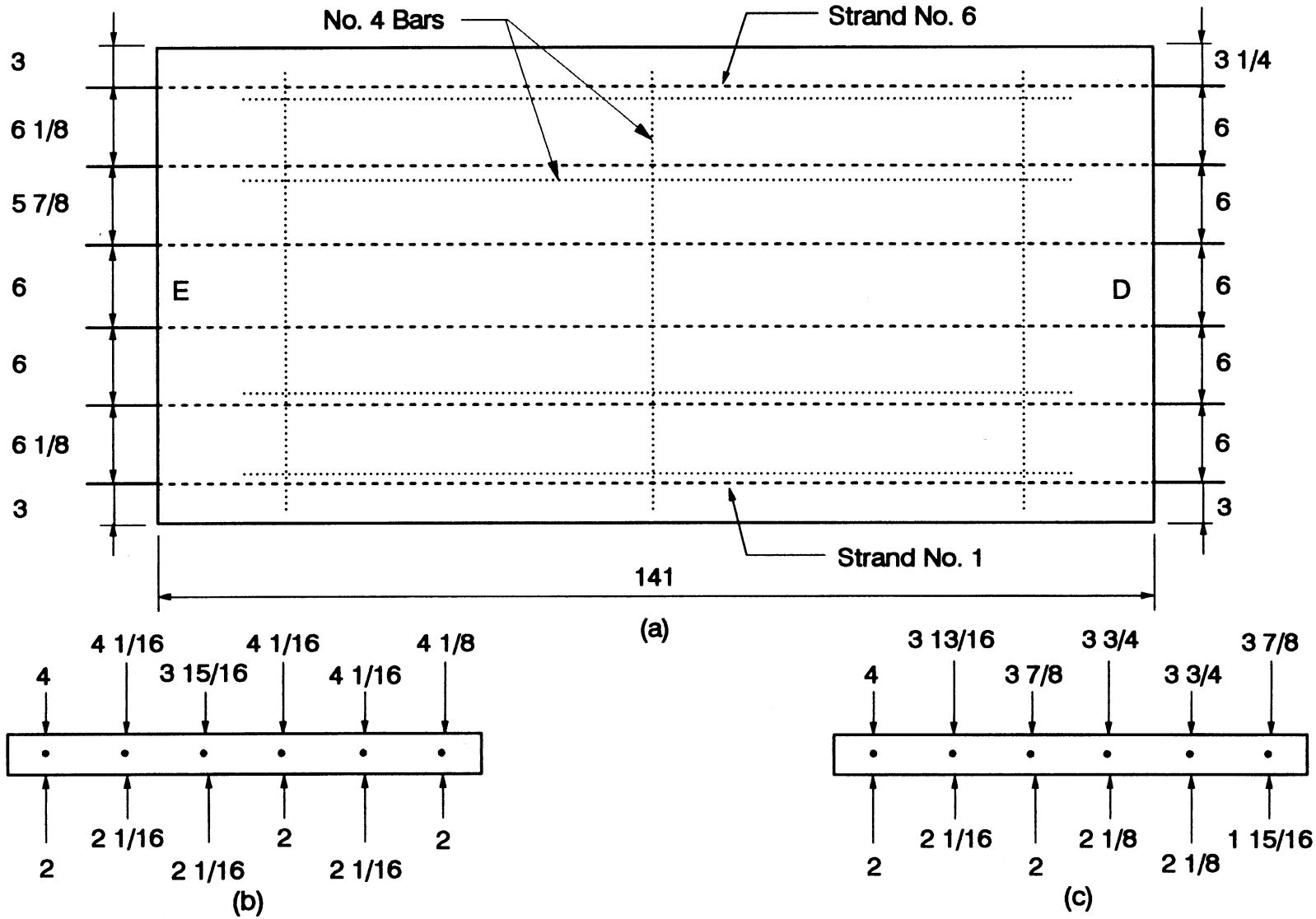


Figure C.83. Specimen No. 12-6.0DC-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

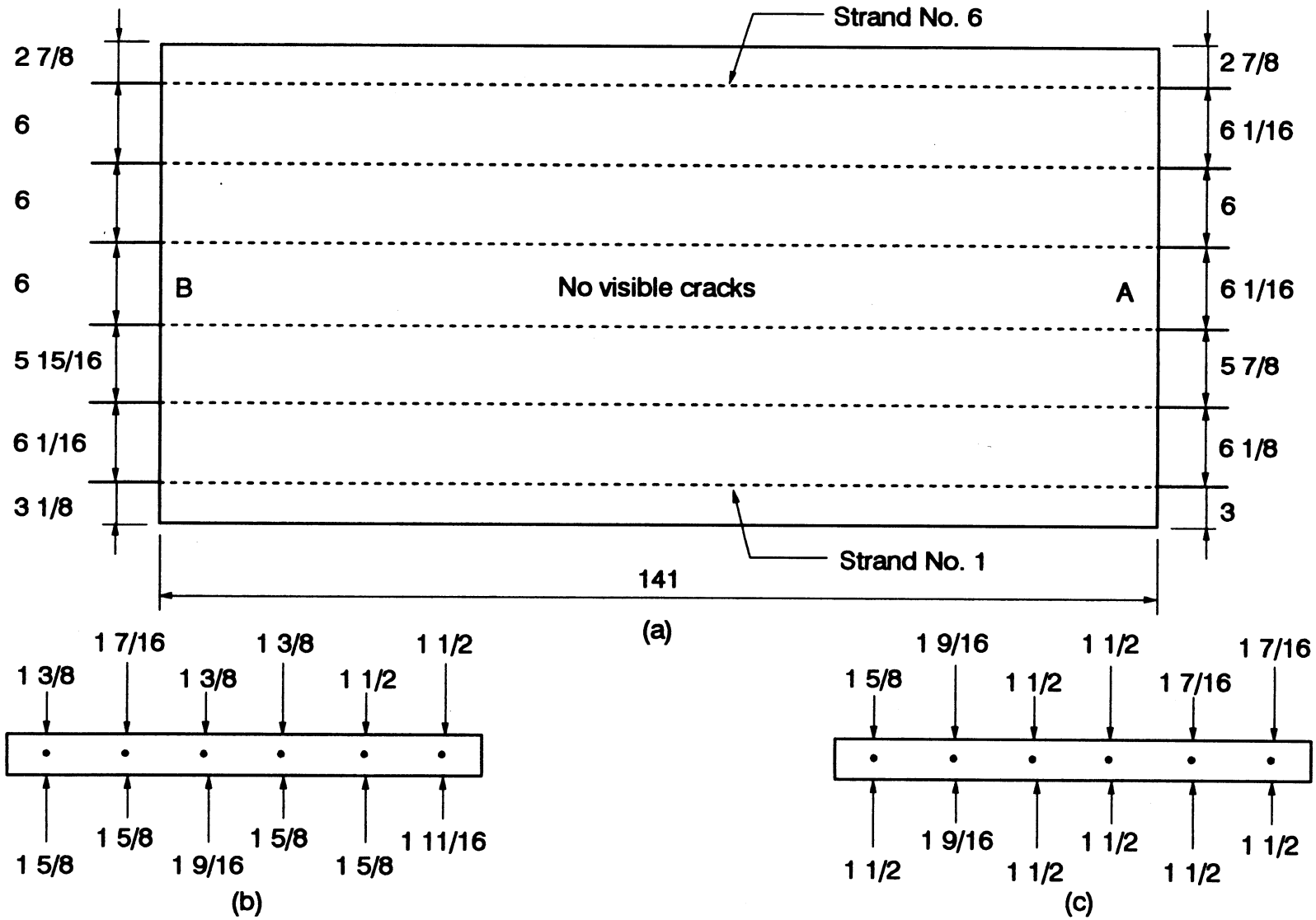


Figure C.84. Specimen No. 13-3.0TC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

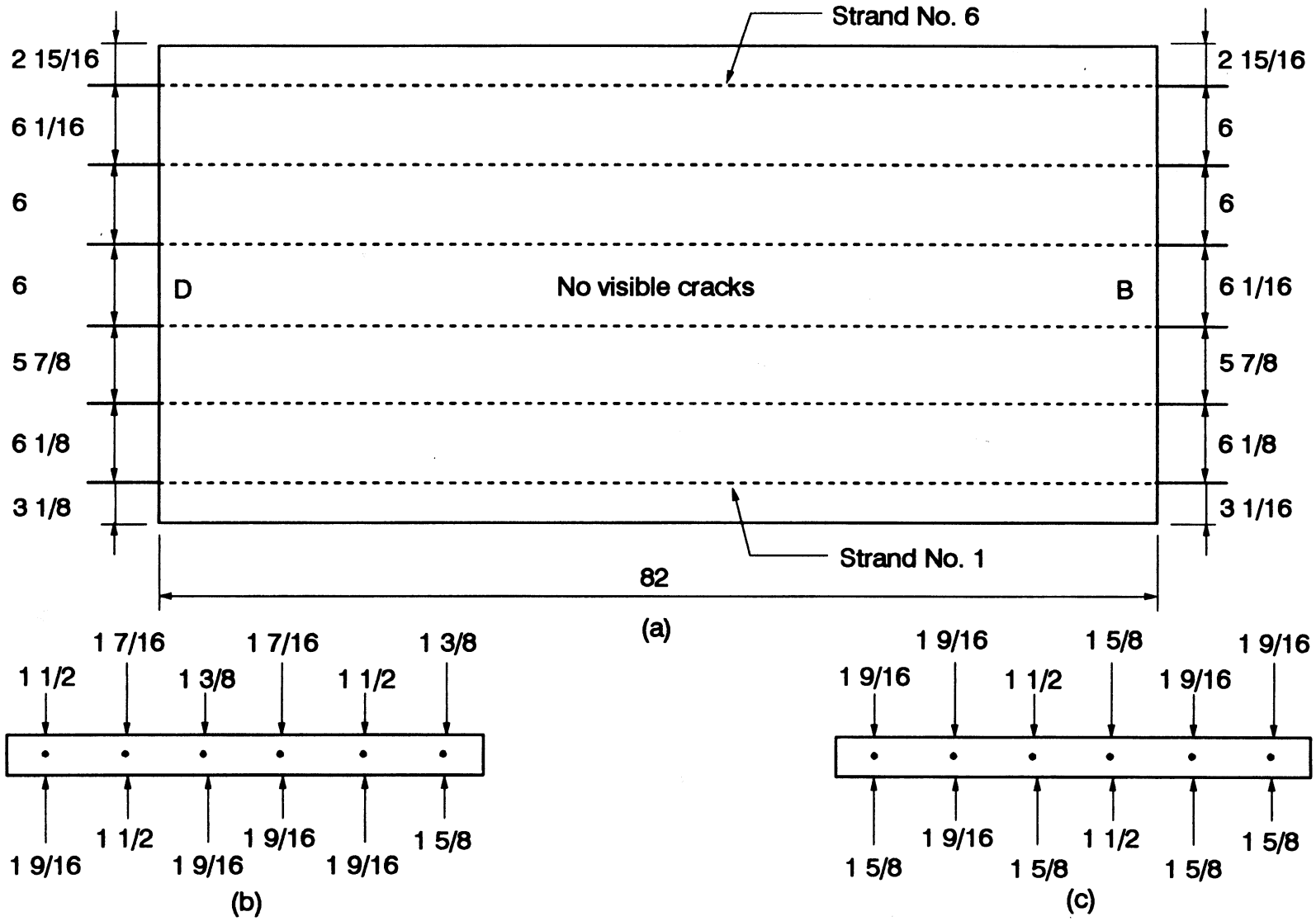


Figure C.85. Specimen No. 13-3.0TC-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

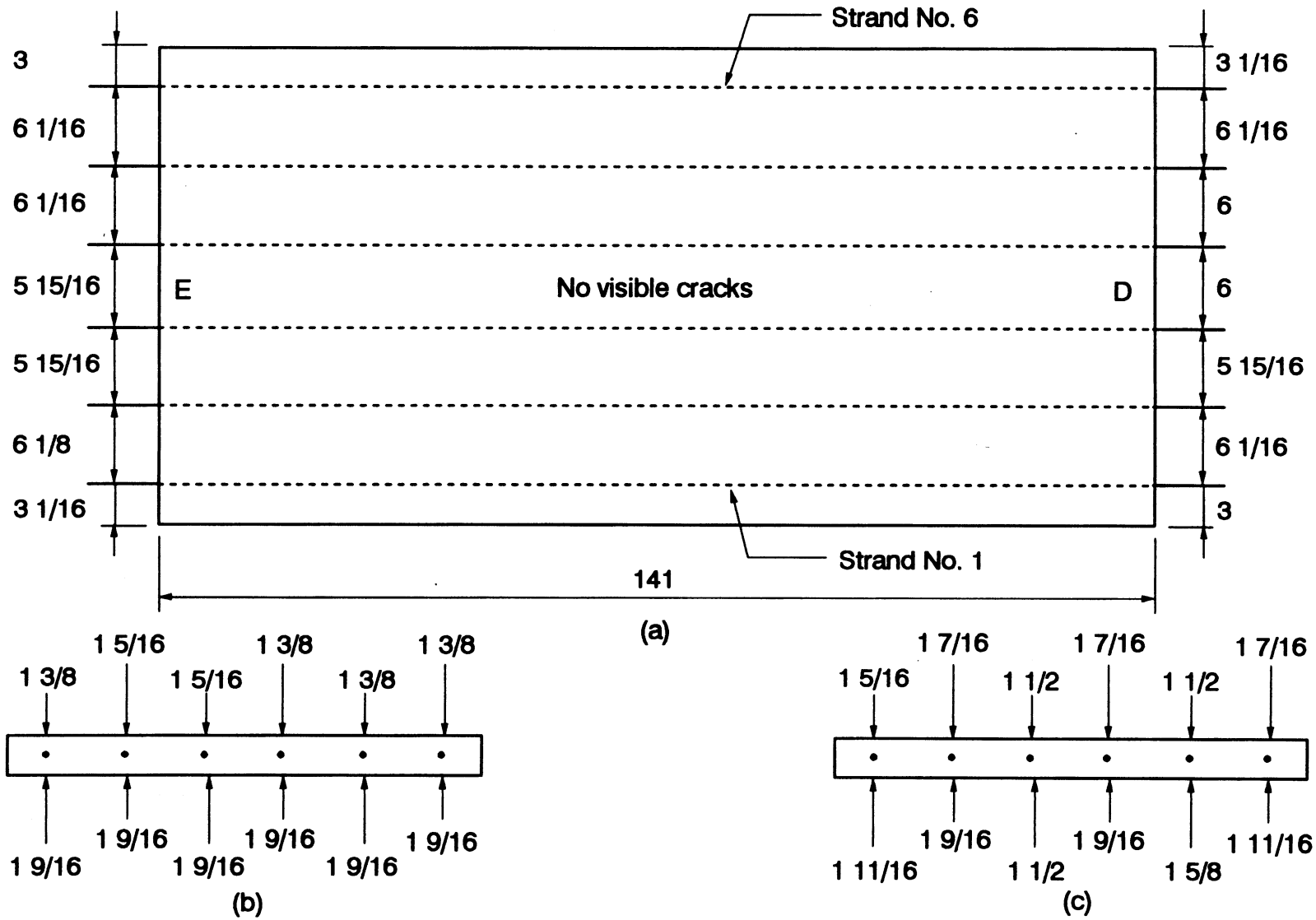


Figure C.86. Specimen No. 13-3.0TC-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

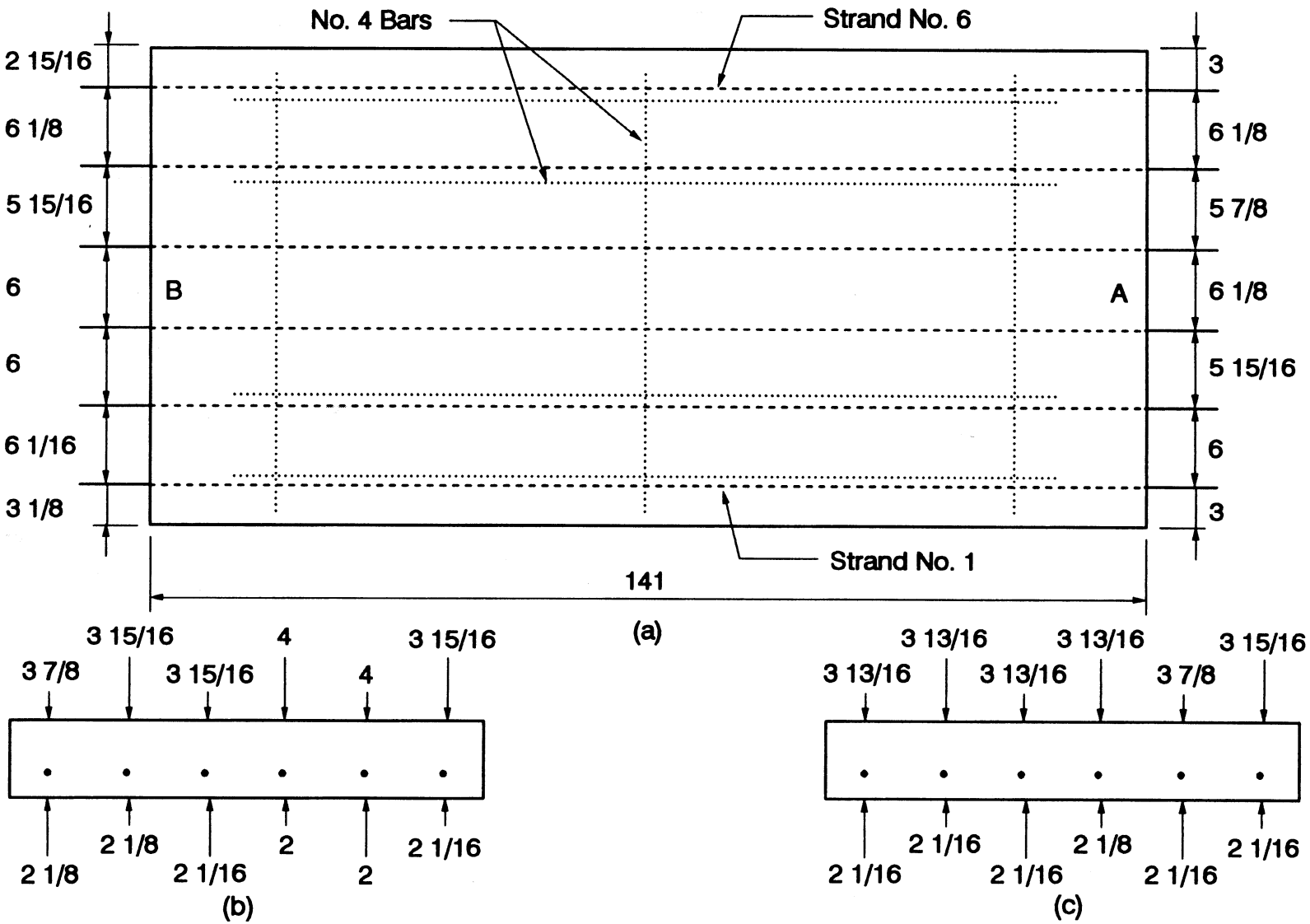


Figure C.87. Specimen No. 14-6.0DC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

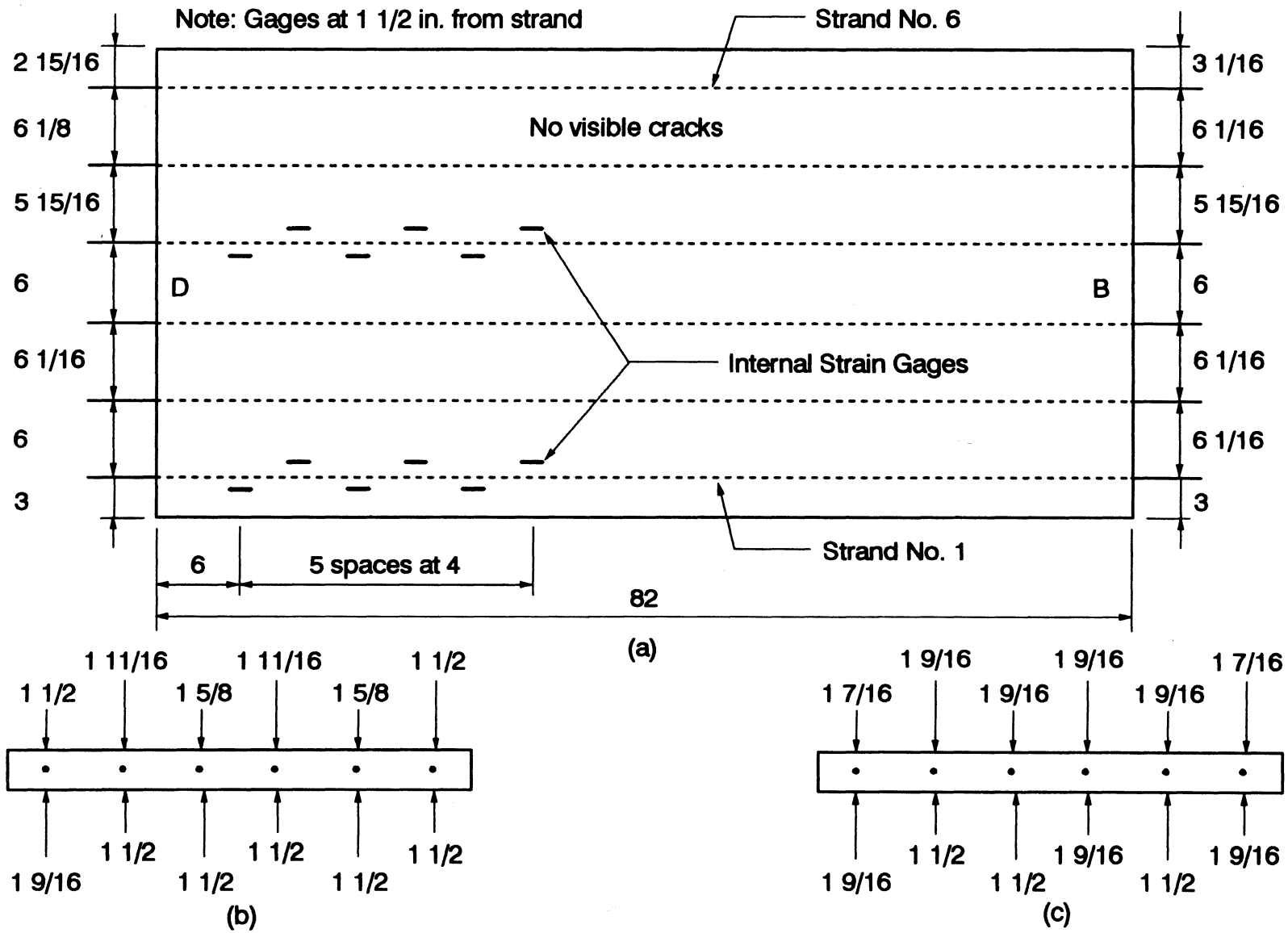


Figure C.88. Specimen No. 14-3.0TC-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

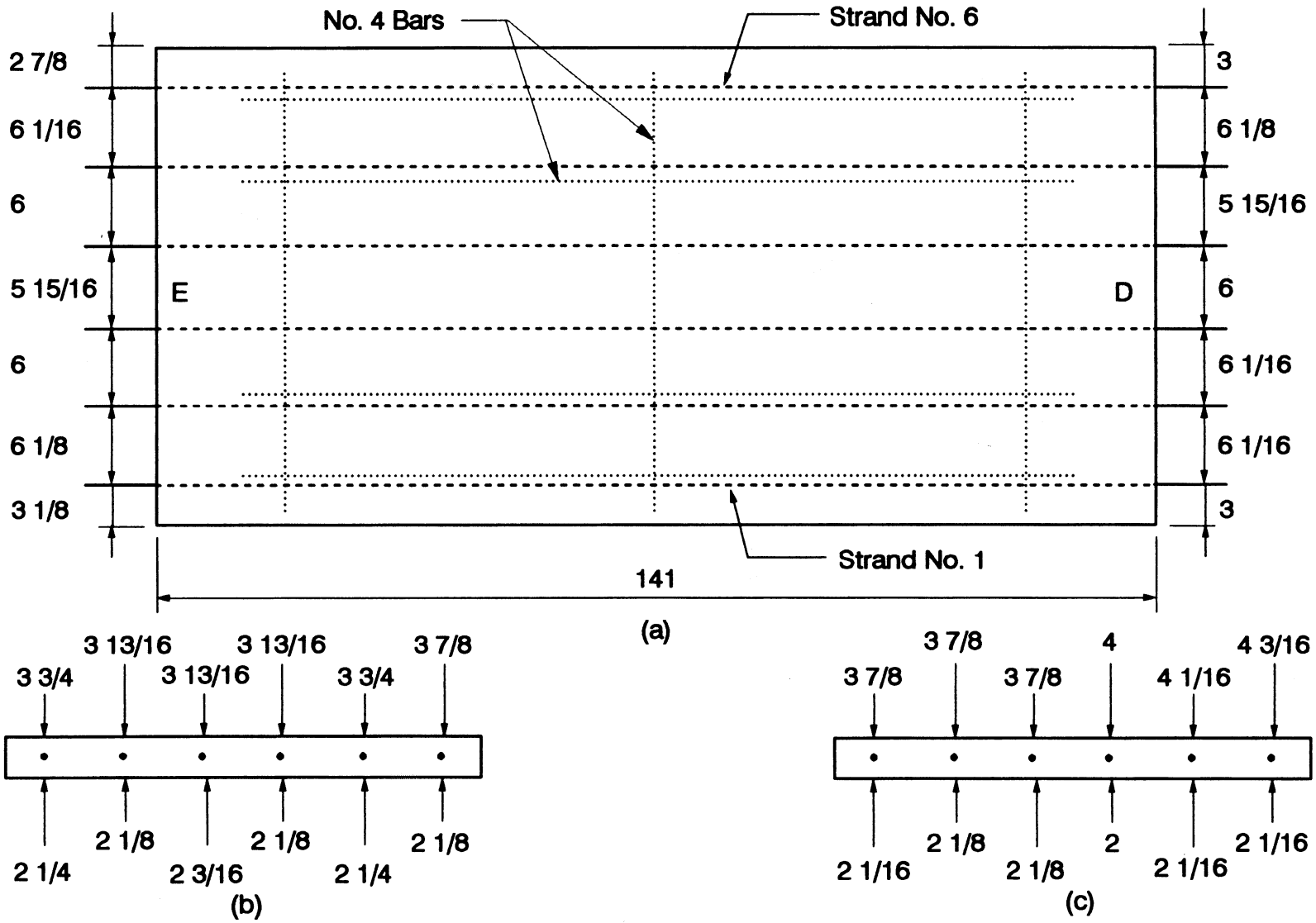


Figure C.89. Specimen No. 14-6.0DC-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

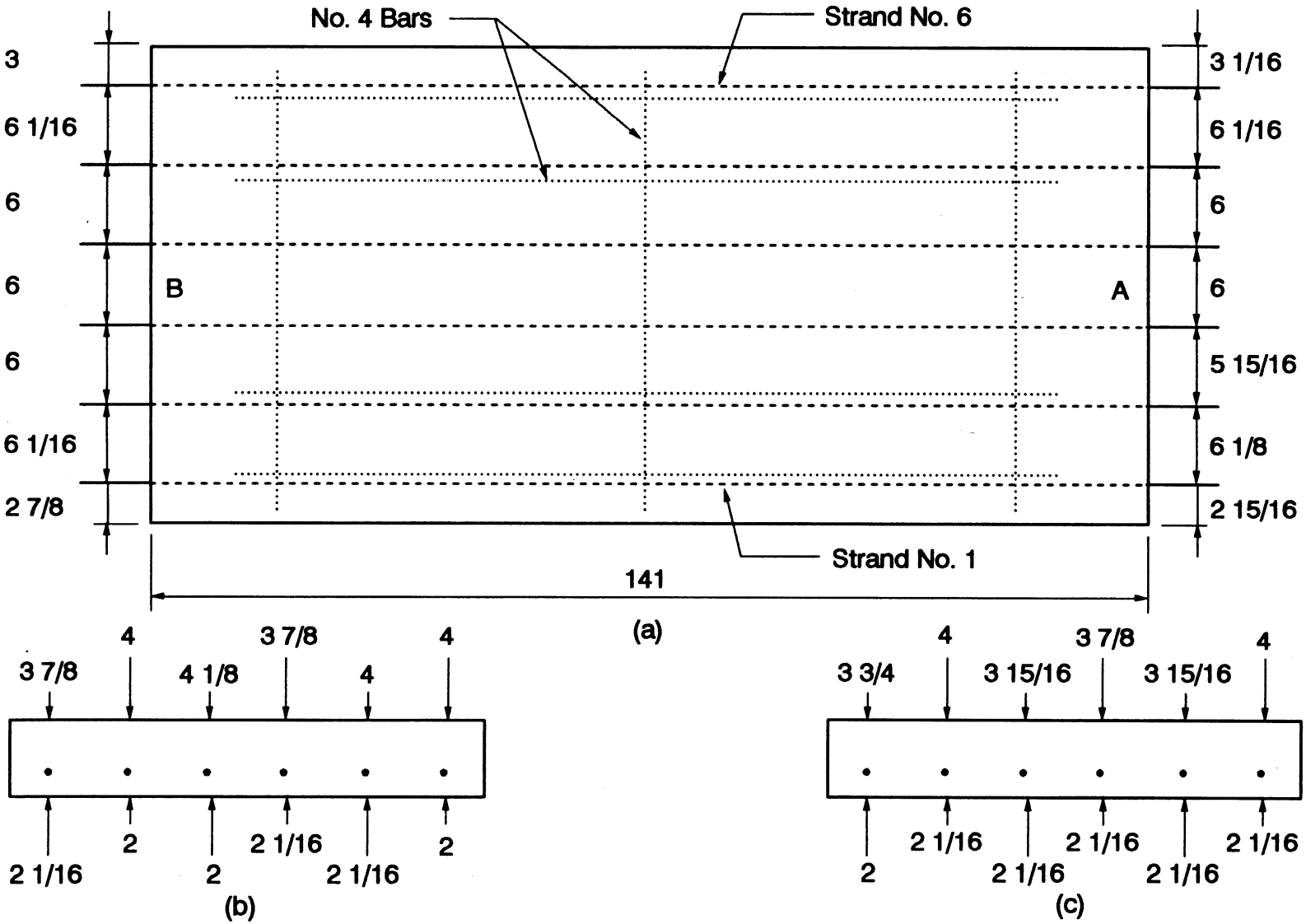


Figure C.90. Specimen No. 15-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

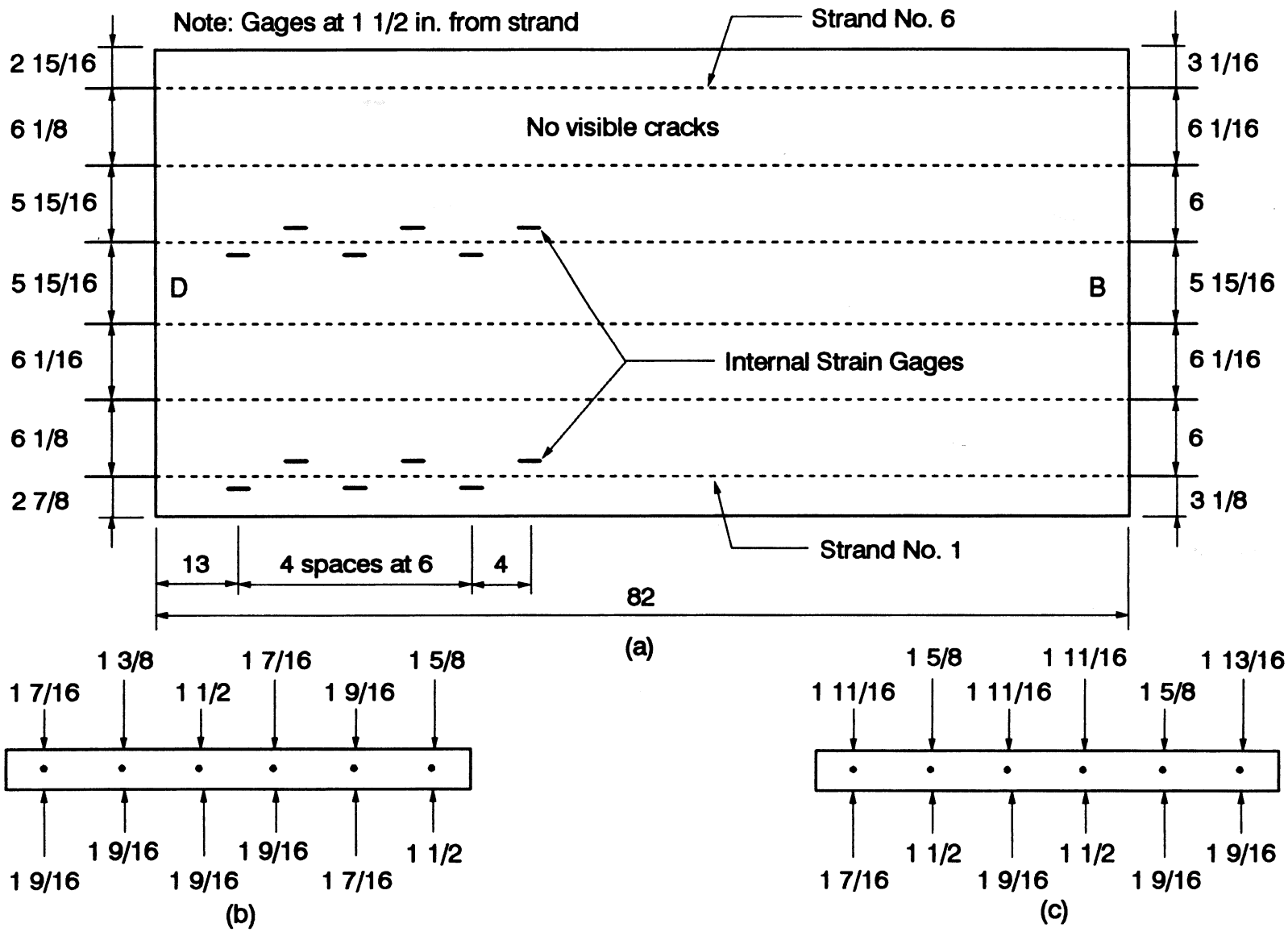


Figure C.91. Specimen No. 15-3.0TU-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

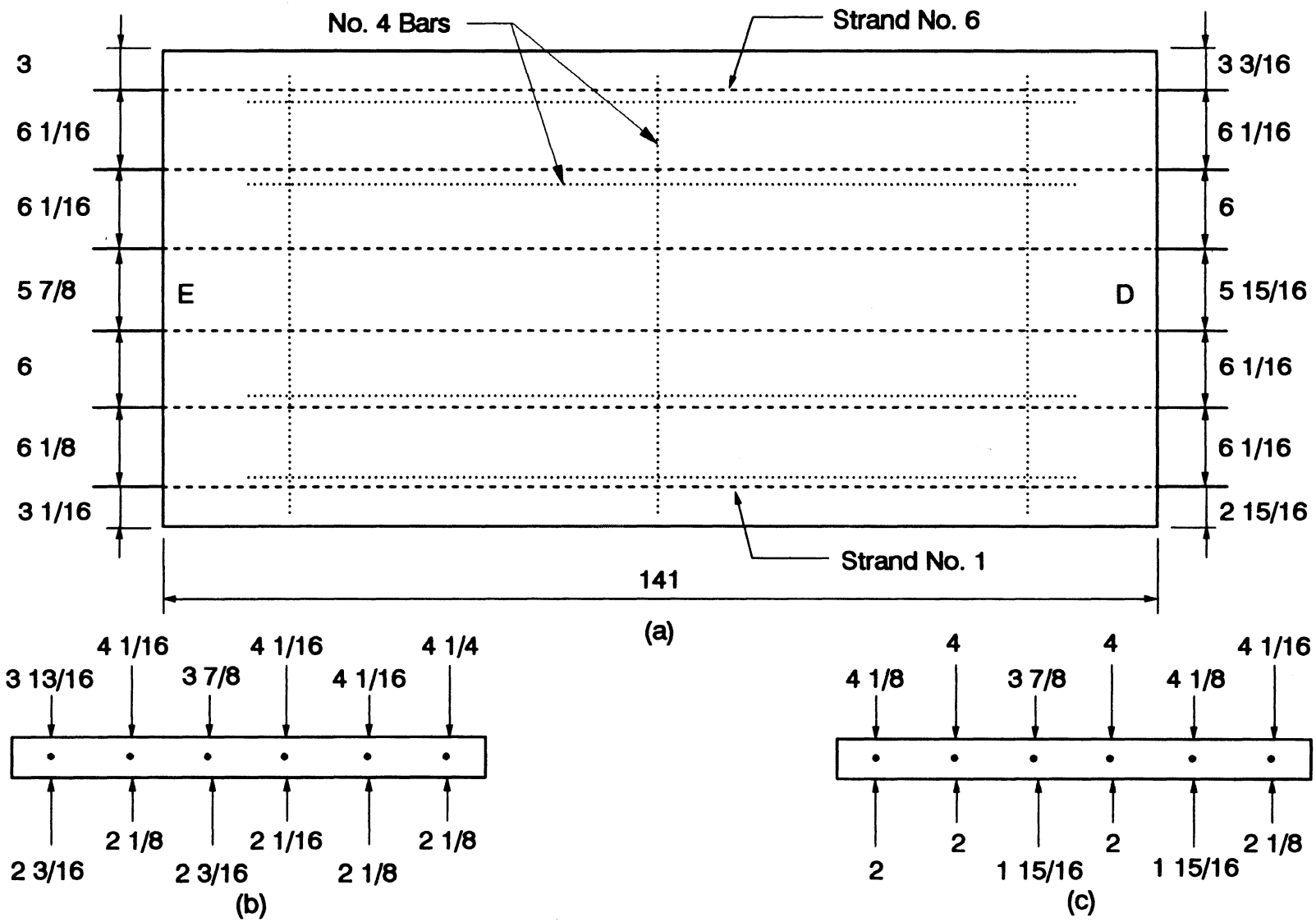


Figure C.92. Specimen No. 15-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

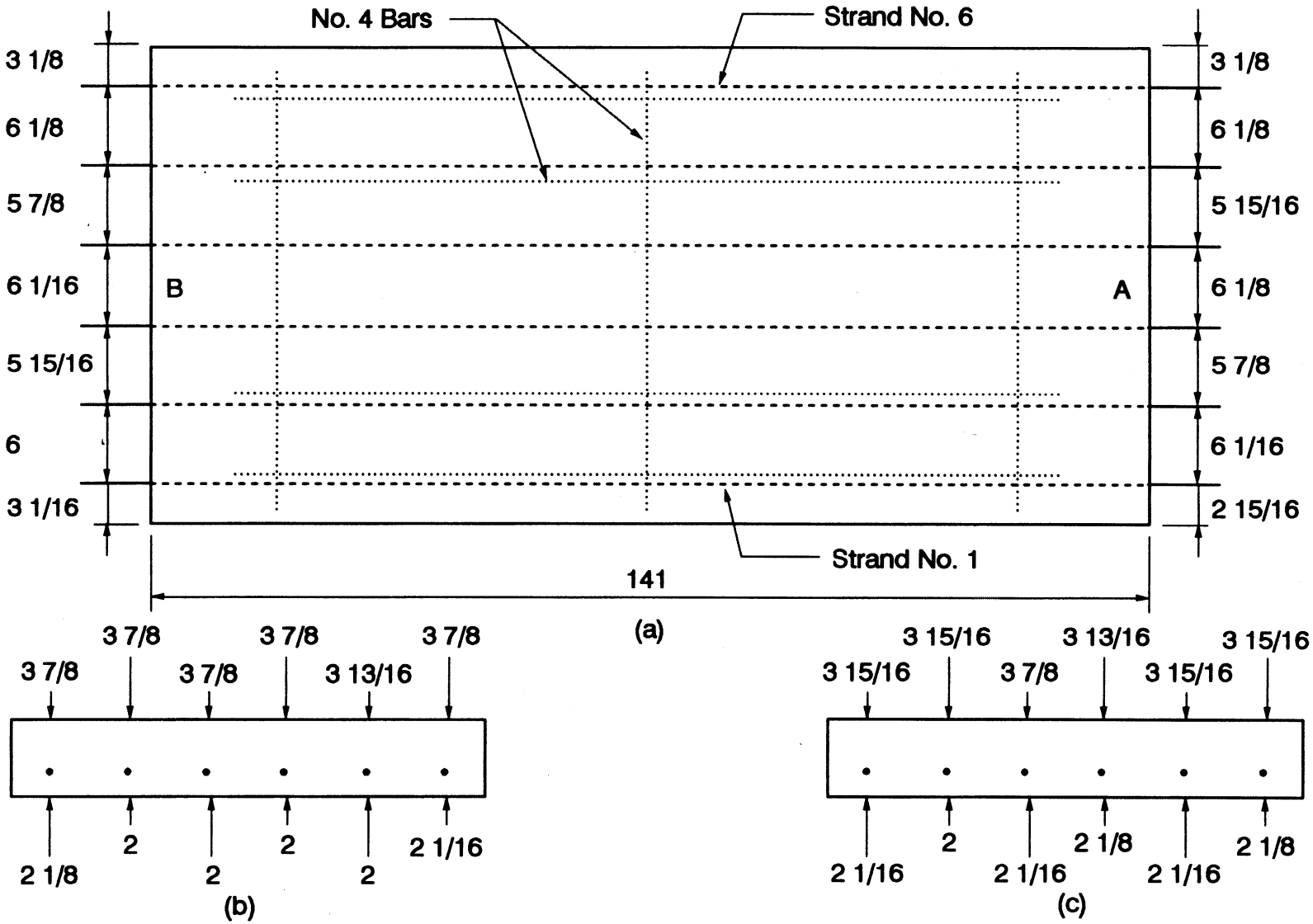


Figure C.93. Specimen No. 16-6.0DU-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

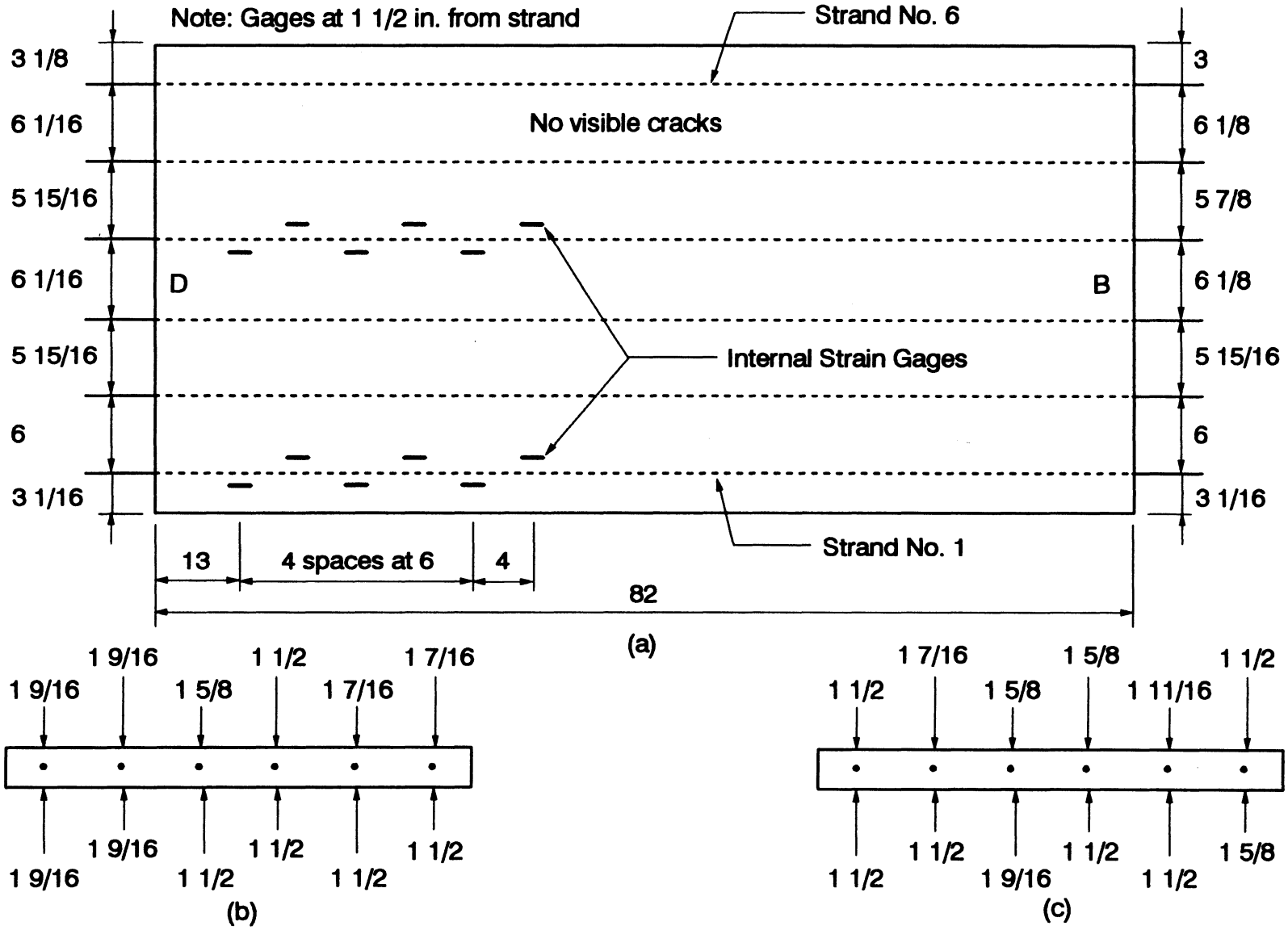


Figure C.94. Specimen No. 16-3.0TU-2 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

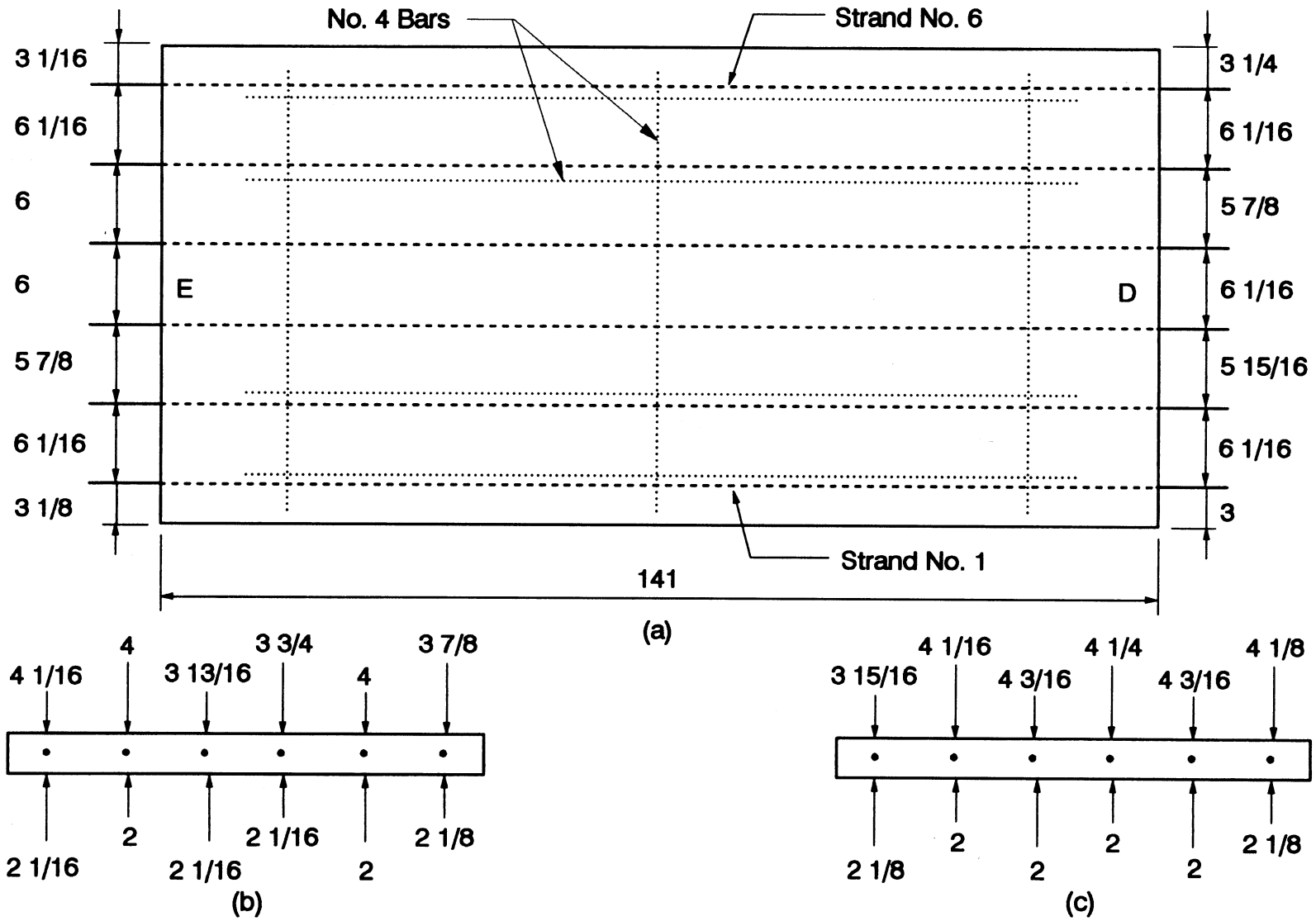


Figure C.95. Specimen No. 16-6.0DU-3 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

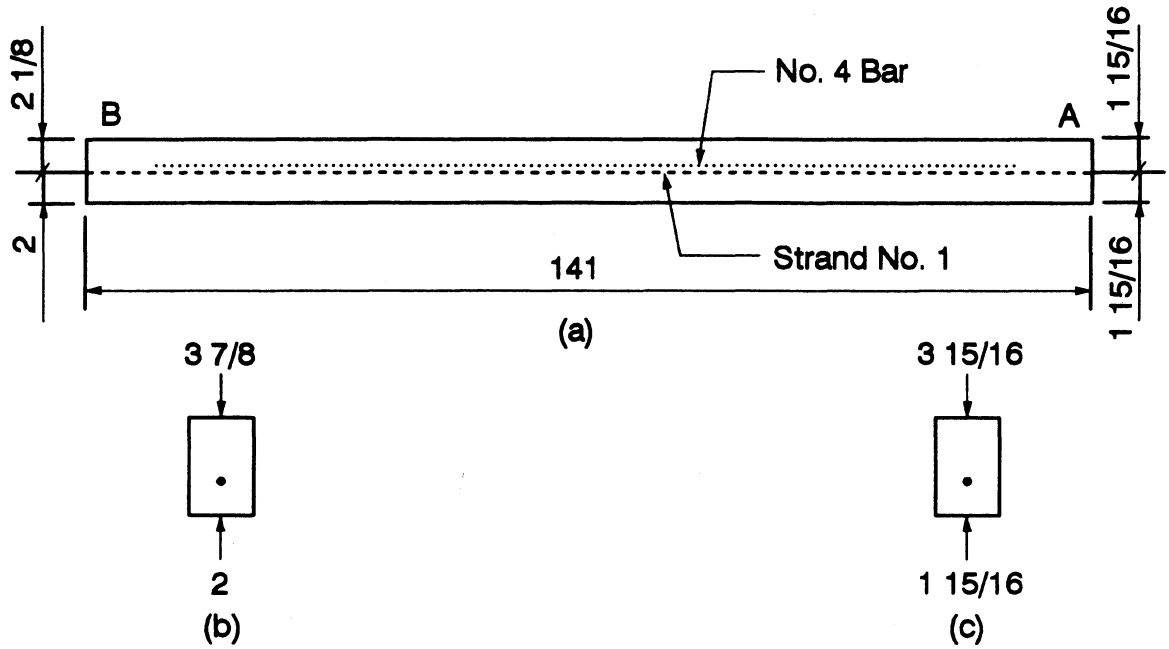


Figure C.96. Specimen No. 17-6.0DC-1 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

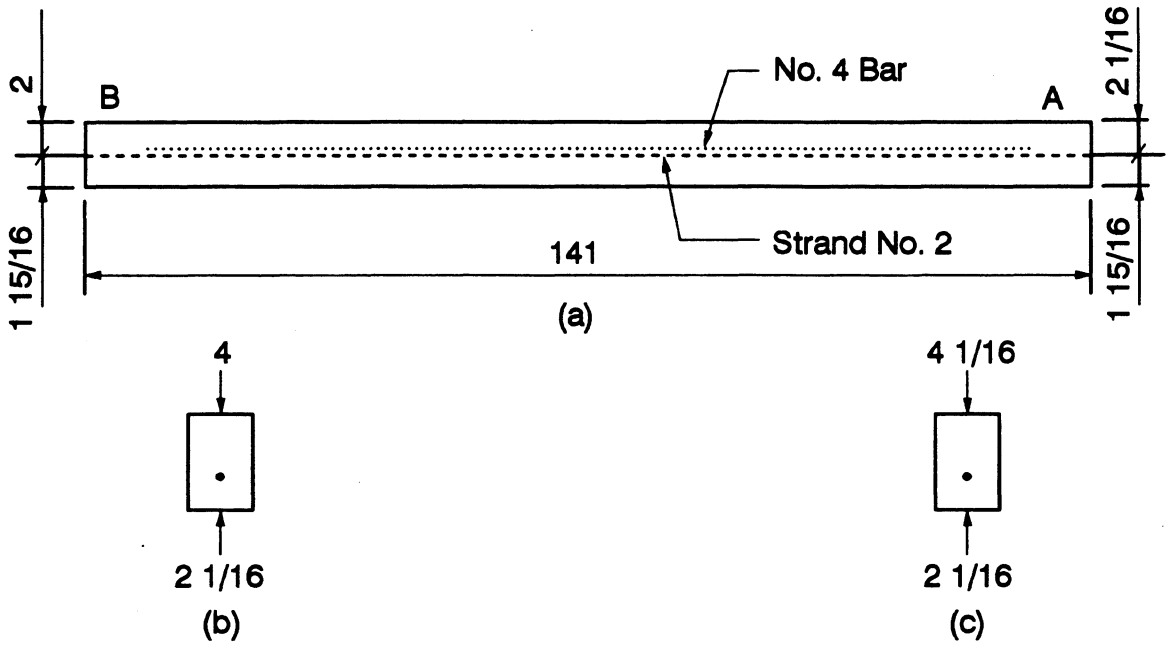


Figure C.97. Specimen No. 17-6.0DC-2 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

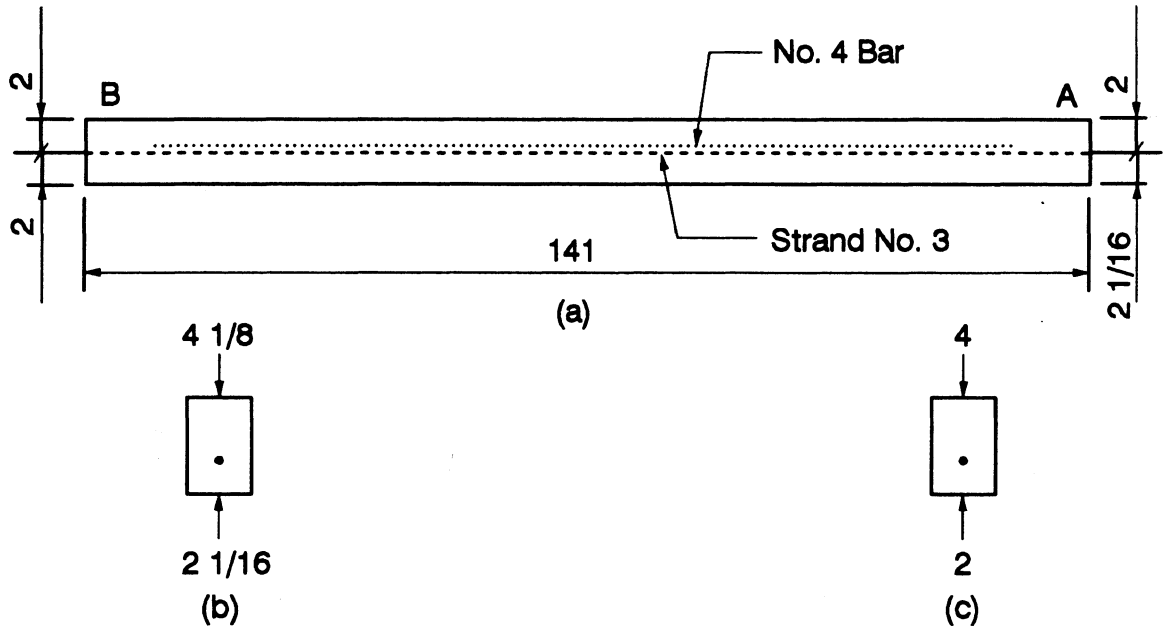


Figure C.98. Specimen No. 17-6.0DC-3 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

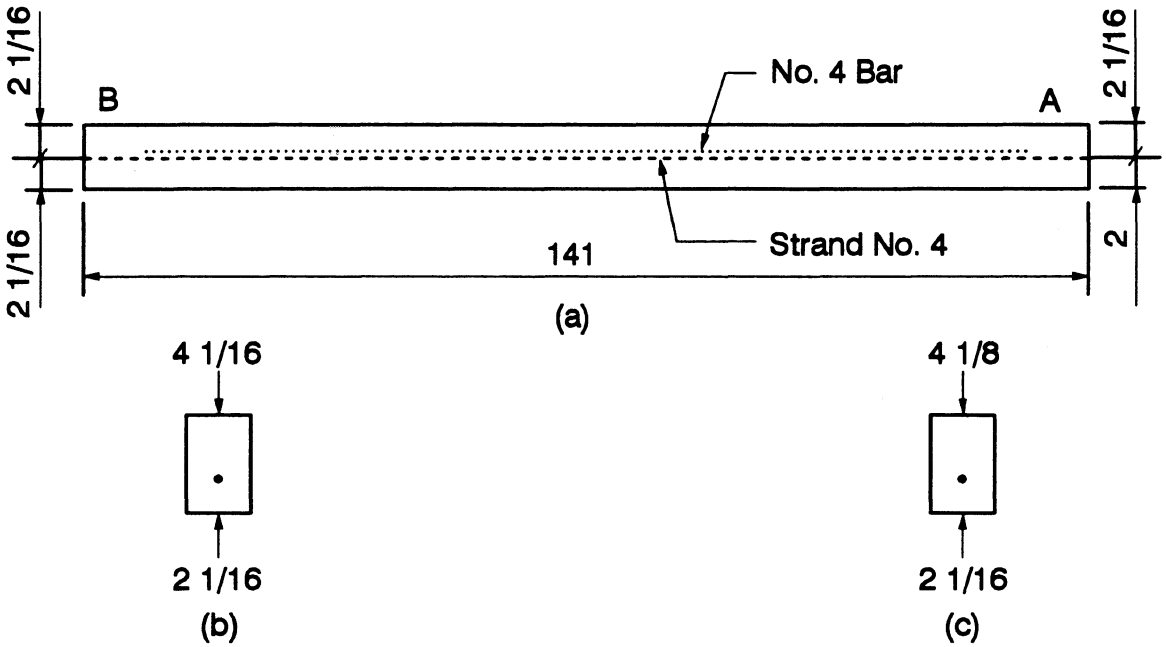


Figure C.99. Specimen No. 17-6.0DC-4 (dimensions shown in inches): (a) plan view; (b) end view at B; (c) end view at A

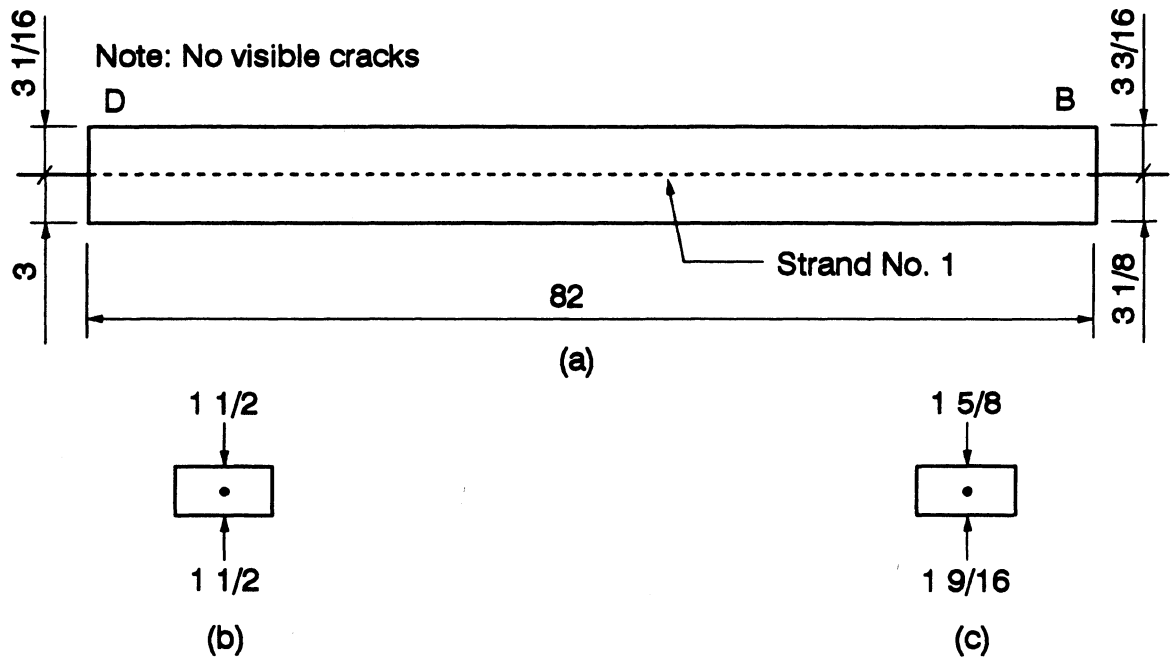


Figure C.100. Specimen No. 17-3.0TC-5 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

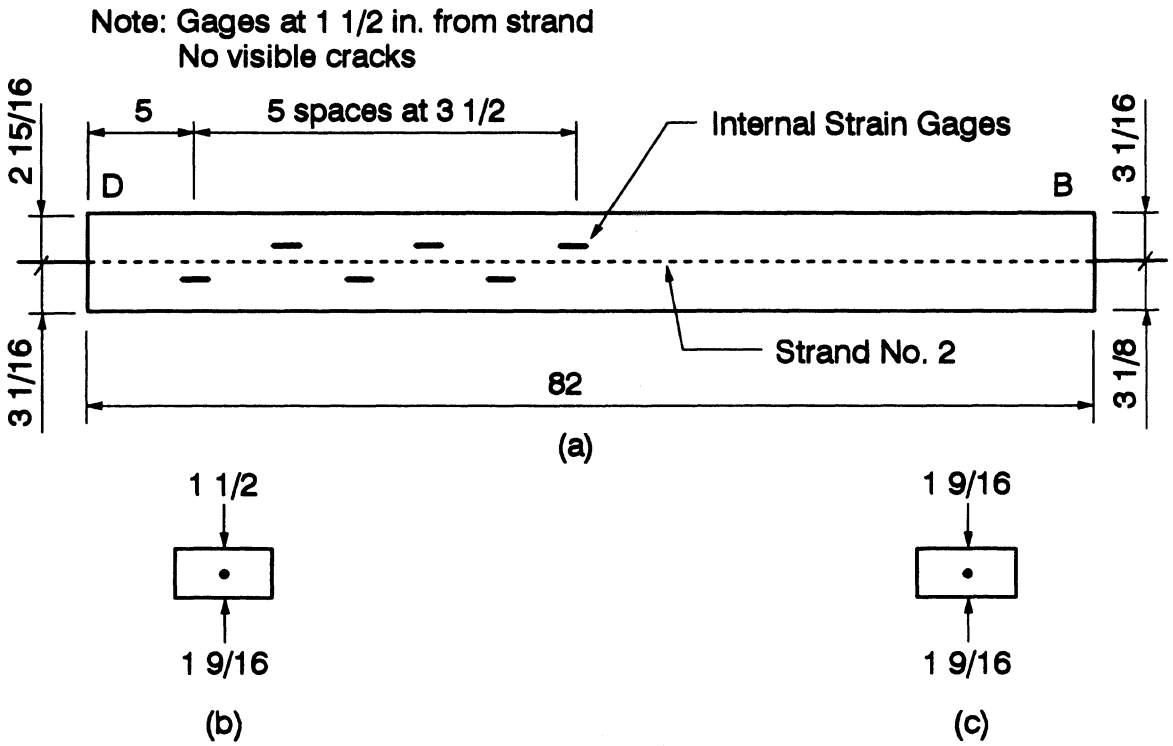


Figure C.101. Specimen No. 17-3.0TC-6 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

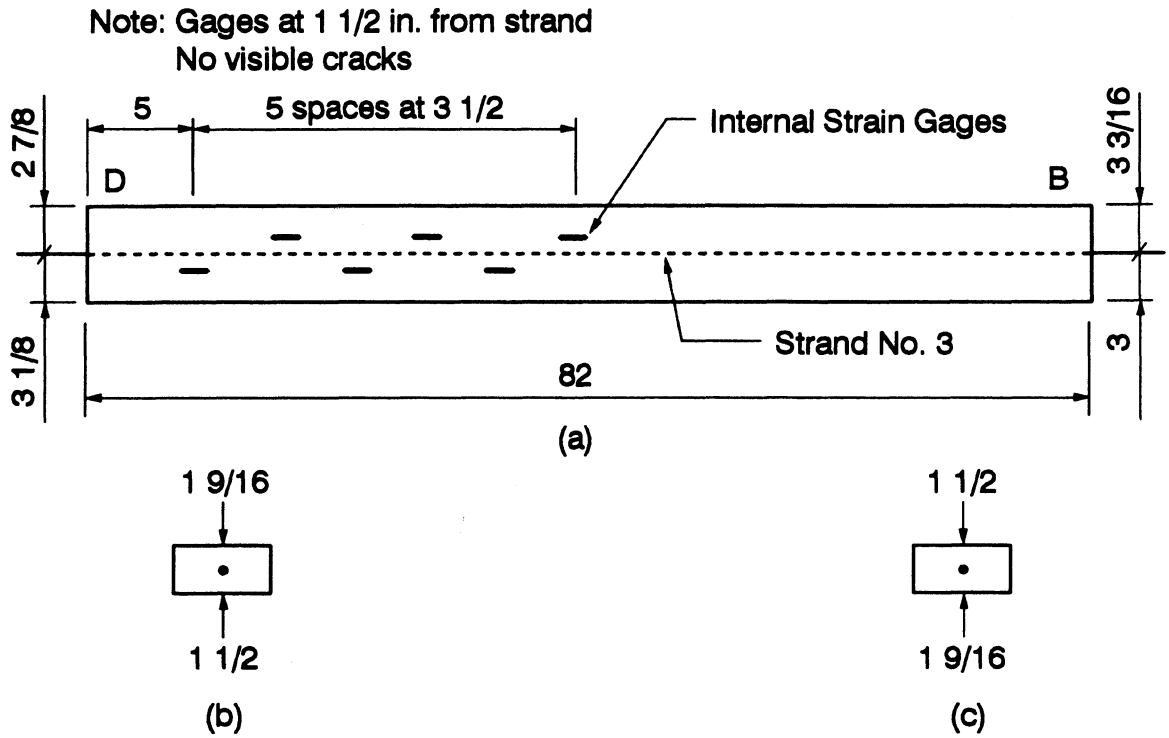


Figure C.102. Specimen No. 17-3.0TC-7 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

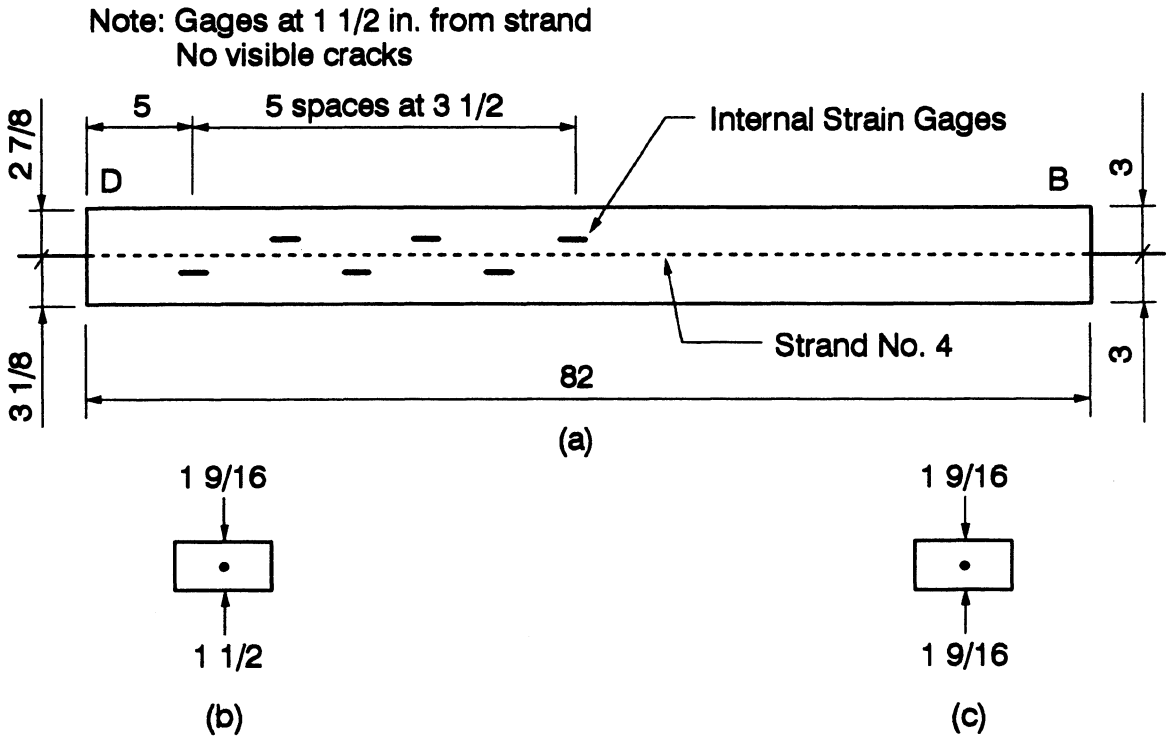


Figure C.103. Specimen No. 17-3.0TC-8 (dimensions shown in inches): (a) plan view; (b) end view at D; (c) end view at B

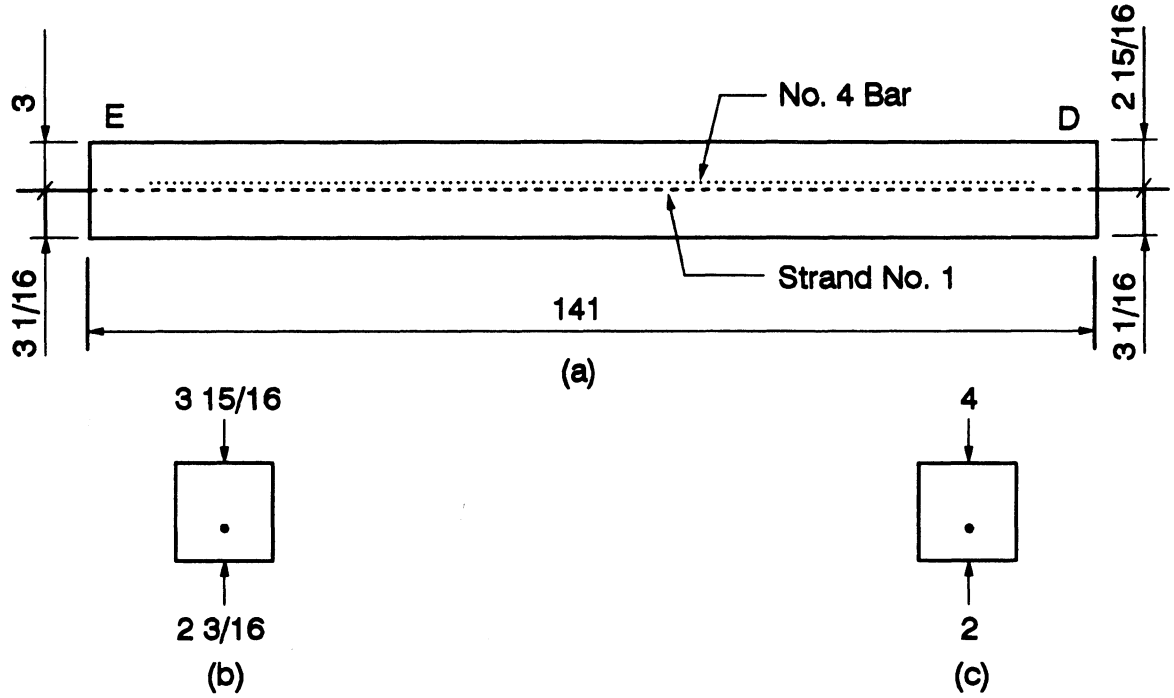


Figure C.104. Specimen No. 17-6.0DC-9 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

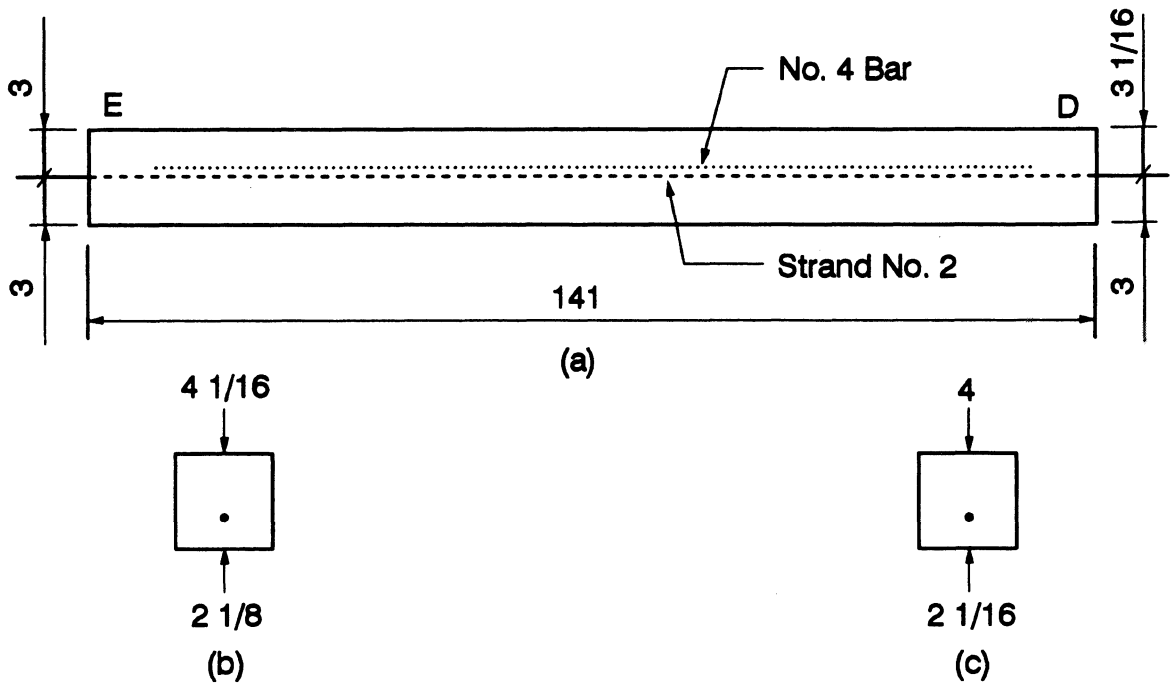


Figure C.105. Specimen No. 17-6.0DC-10 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

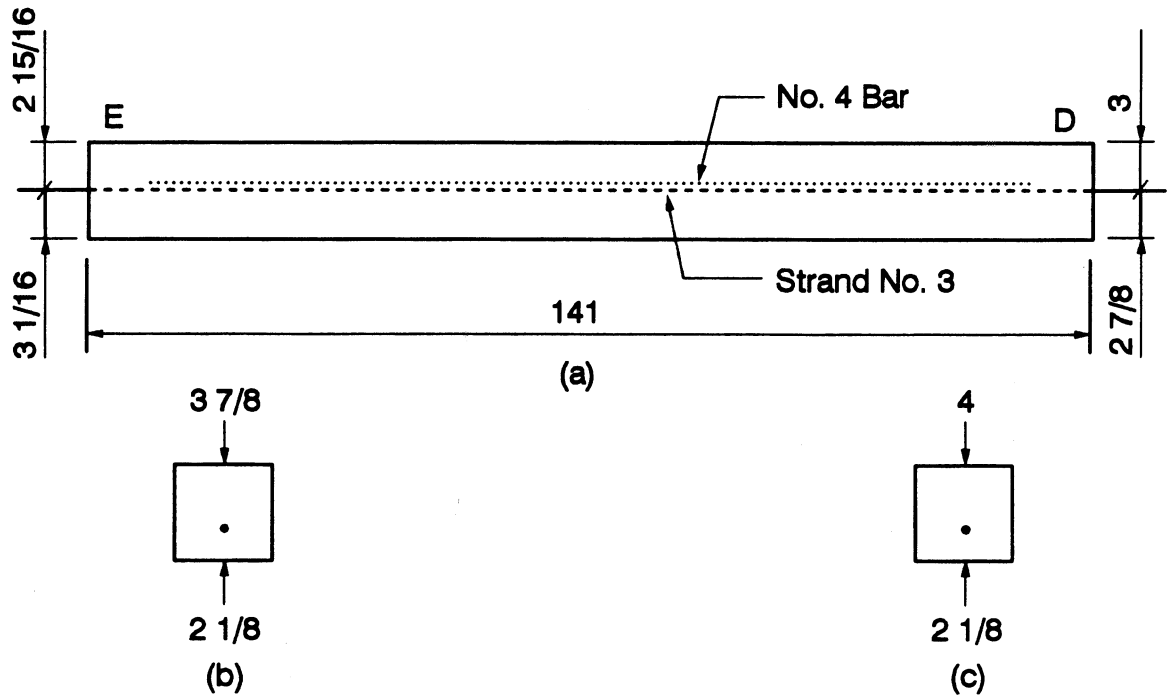


Figure C.106. Specimen No. 17-6.0DC-11 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

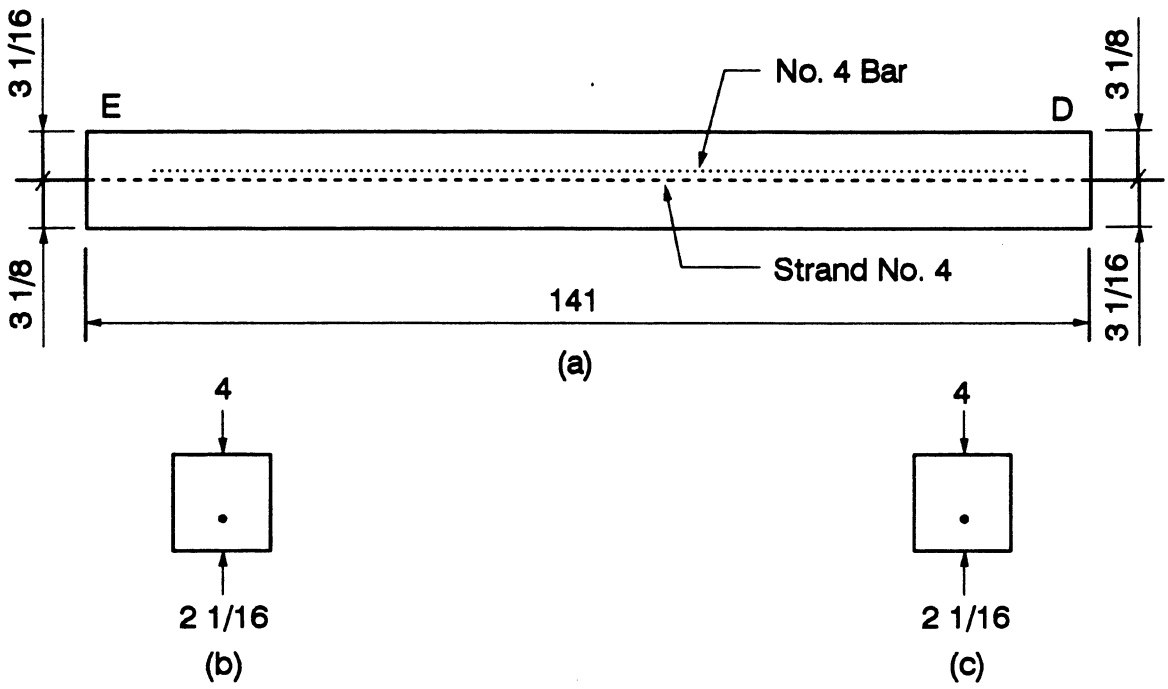


Figure C.107. Specimen No. 17-6.0DC-12 (dimensions shown in inches): (a) plan view; (b) end view at E; (c) end view at D

APPENDIX D: CONCRETE CRACK PATTERNS FOR THE D-TYPE SPECIMENS

The strand development length (Type-D) specimens were cast long enough so that a strand development length test could usually be conducted on each end of a specimen. For the 40, D-type specimens, a plan and two longitudinal side views showing the transverse load position and the concrete cracks that developed during each of the 60 strand development tests are given in Figs. D.1 - D.40. Figures D.1-D.4, D.9-D.24, and D.29-D.32 show the test results for the D-type specimens that were prestressed with uncoated strands; and Figs. D.5-D.8, D.25-D.28, and D.33-D.40 show these results for the coated-strand, D-type specimens. The vertical line that passes through the three views of a particular specimen separates the transverse loading and concrete crack patterns for each test. The concrete cracks are numbered in the order of their formation along the side views for a specimen, and the failure sequence is noted directly below the arrow indicating the test number. The letters F, B, or S shown in a failure sequence represent a flexural, bond (strand-slip at the end of the specimen), or shear failure, respectively. When a particular specimen contained more than one prestressing strand and when a bond failure occurred, the letter listed after the letter B refers to the number for the strand that slipped.

The second test on a specimen was considered to be invalid if a bond failure occurred at the other end of the specimen that was already tested (Fig. D.1, D.8, D.14, and D.16). A second test was not conducted on a D-type specimen if the first test had the transverse load at the midspan of the specimen (Fig. D.9 and D.10), if the failure for the first test caused excessive damage to the specimen (Figs. D.12, D.17, D.18, D.20-D.22, and D.34-D.40), or if one of the strands slipped at the opposite end of the specimen when the first test was conducted (Figs. D.4 and D.10).

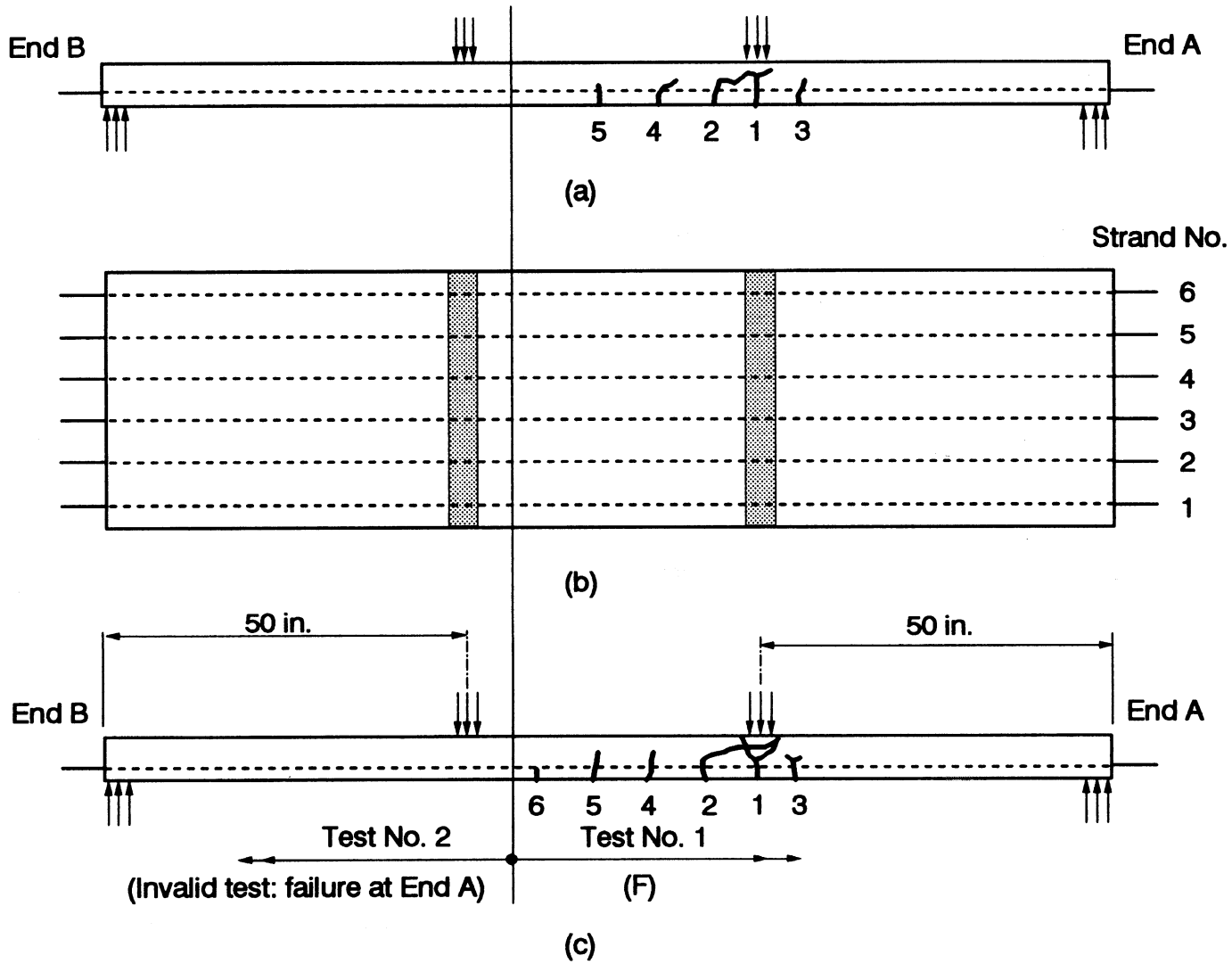


Figure D.1. Crack pattern for D-type Specimen No. 6-6.0DU-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

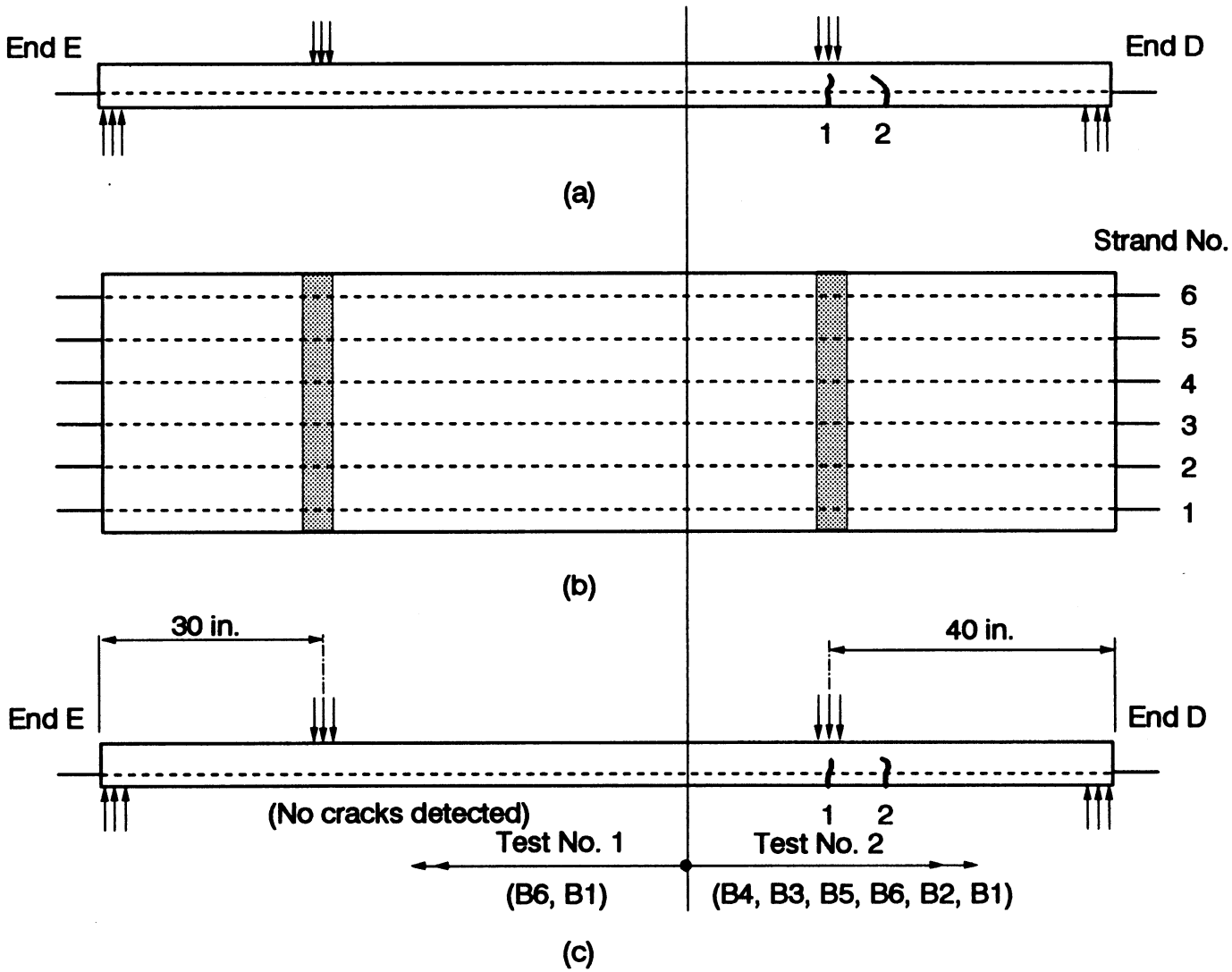


Figure D.2. Crack pattern for D-type Specimen No. 6-6.0DU-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

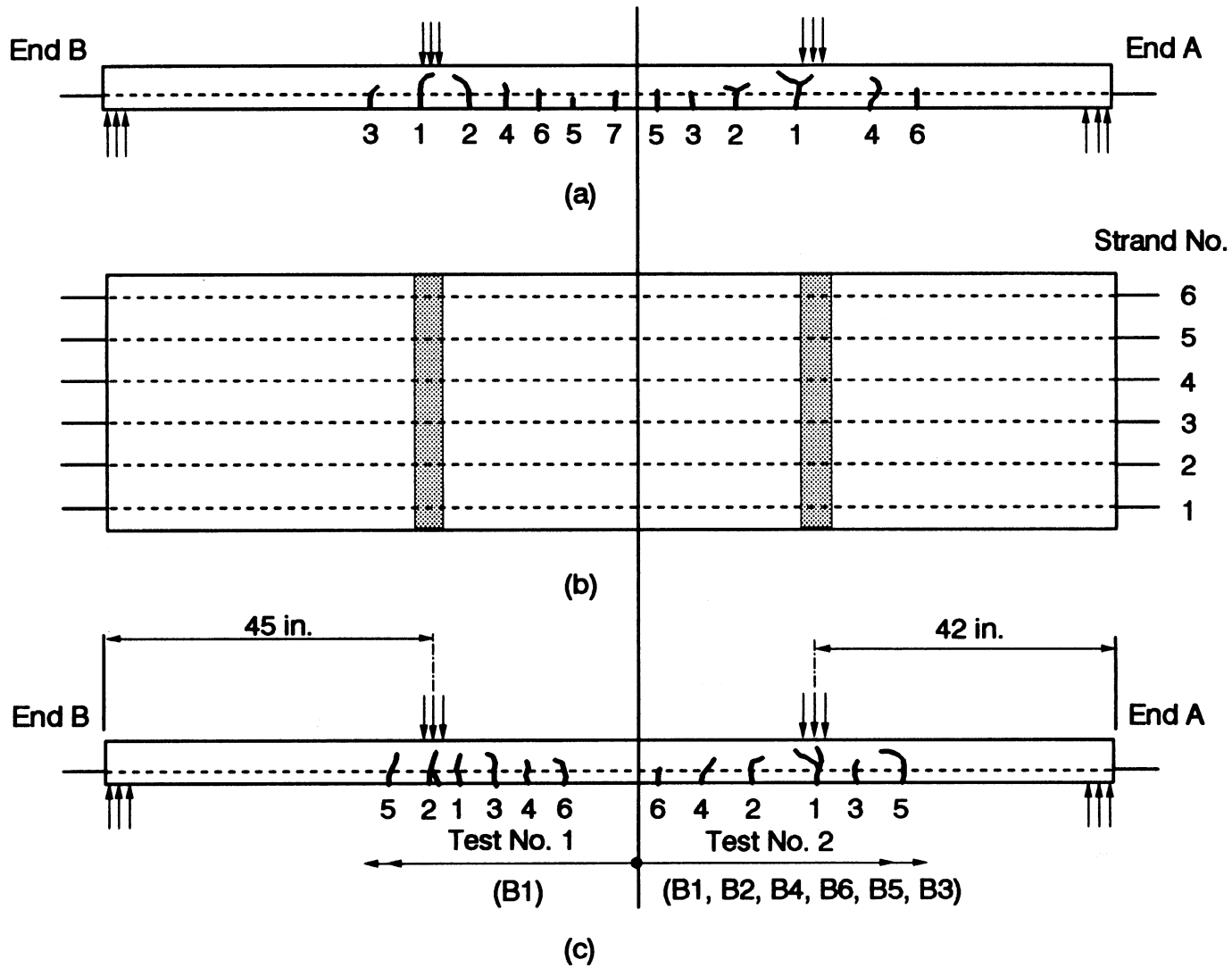


Figure D.3. Crack patterns for D-type Specimen No. 7-6.0DU-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

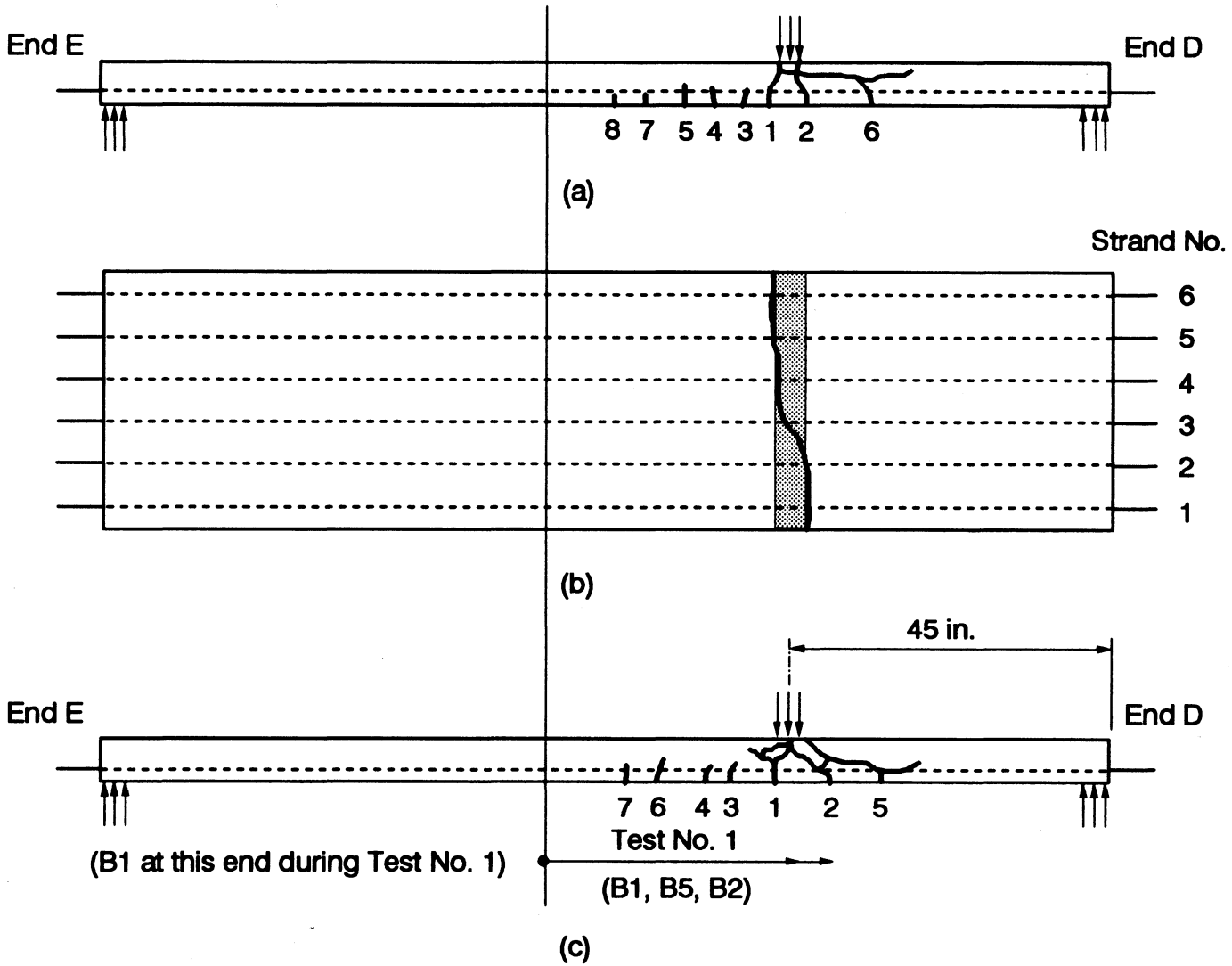


Figure D.4. Crack pattern for D-type Specimen No. 7-6.0DU-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

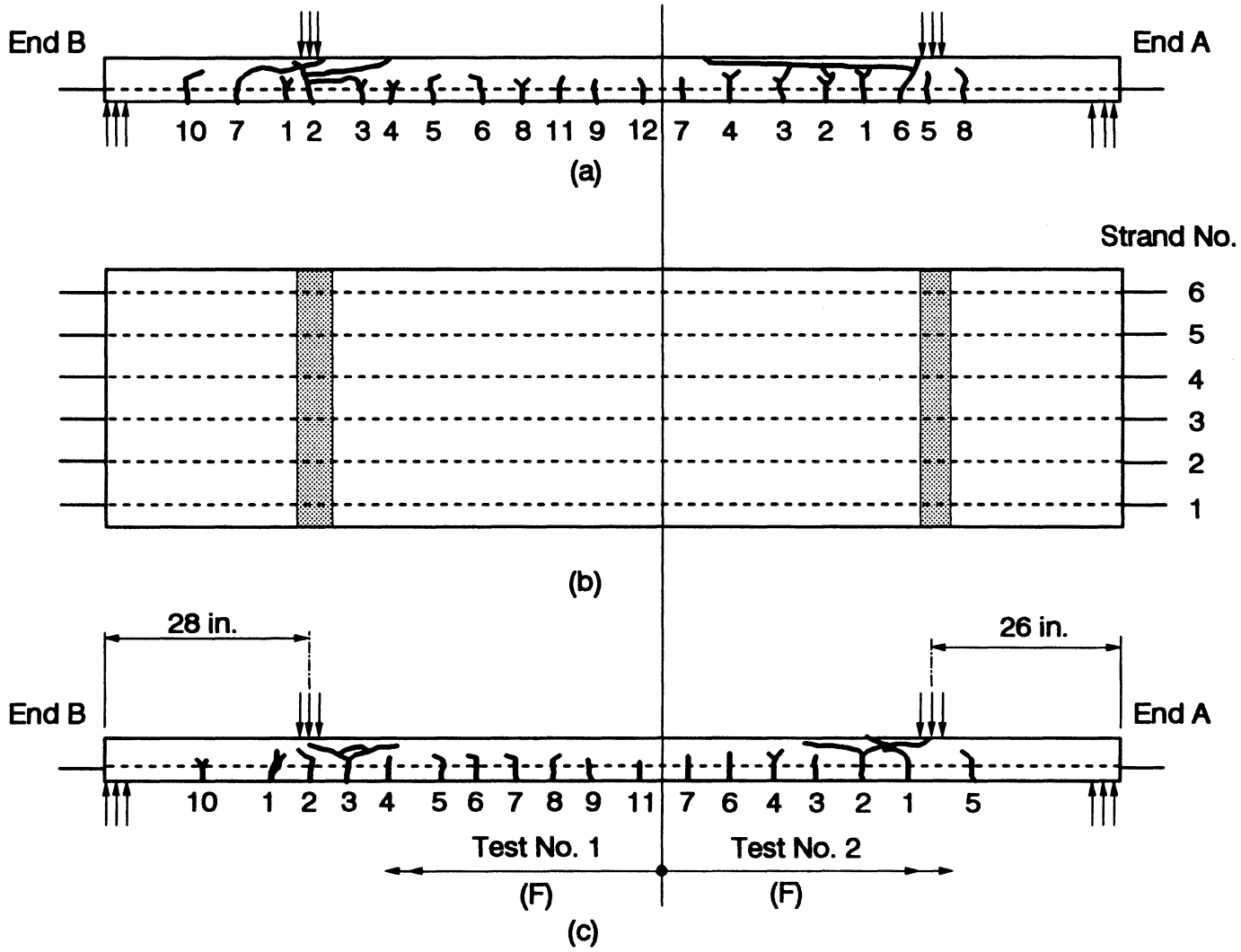


Figure D.5. Crack patterns for D-type Specimen No. 8-6.0DC-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

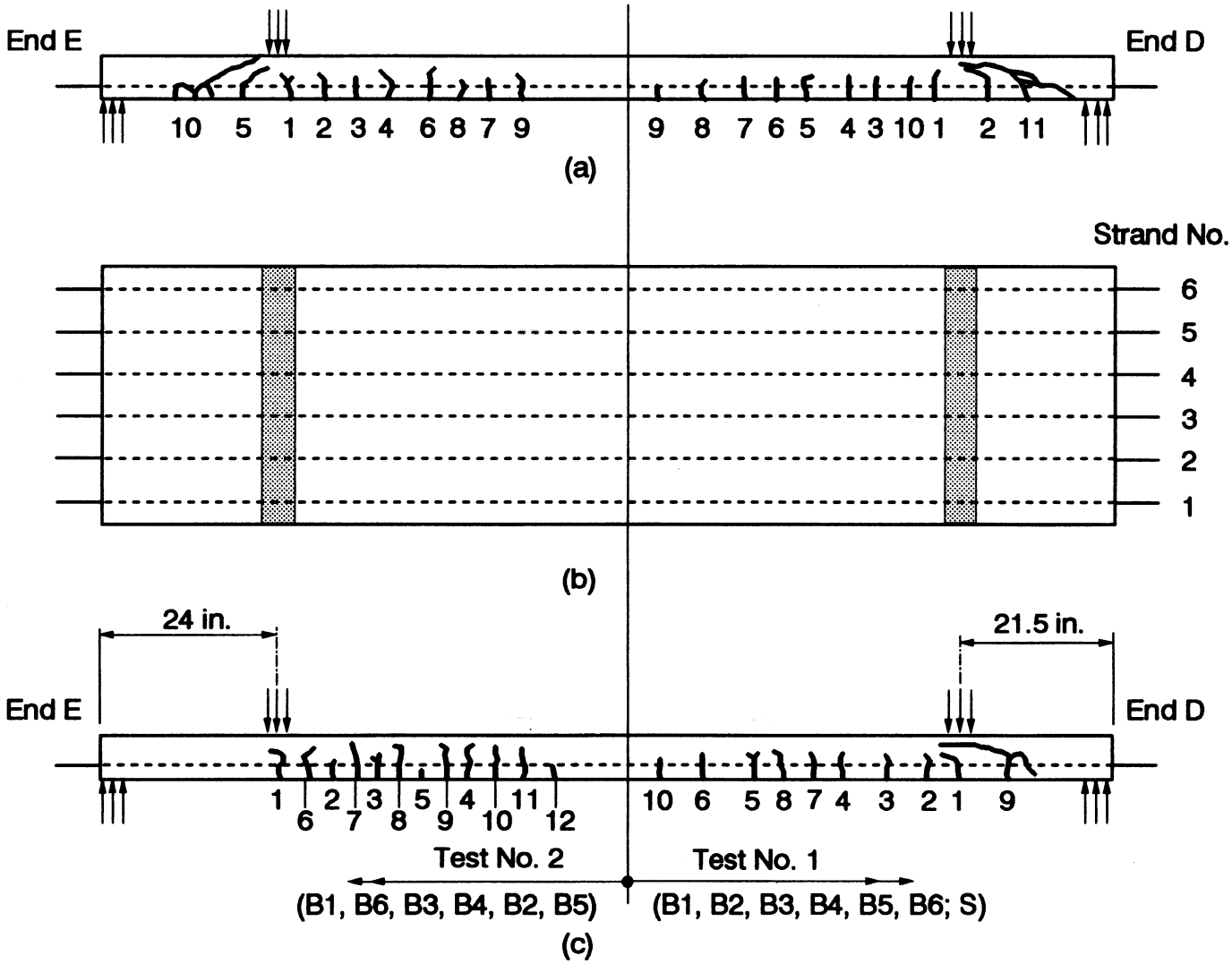


Figure D.6. Crack patterns for D-type Specimen No. 8-6.0DC-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

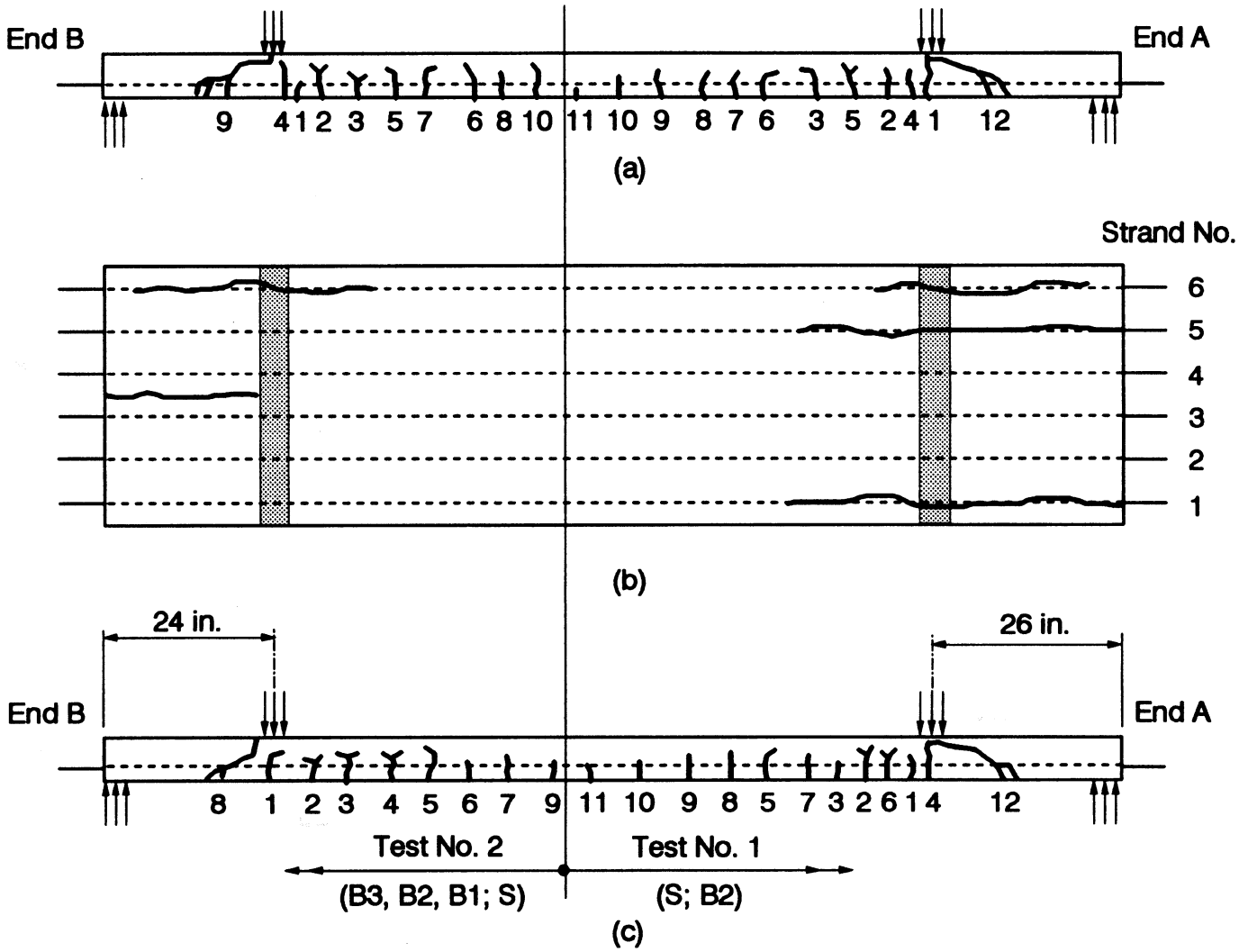


Figure D.7. Crack patterns for D-type Specimen No. 9-6.0DC-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

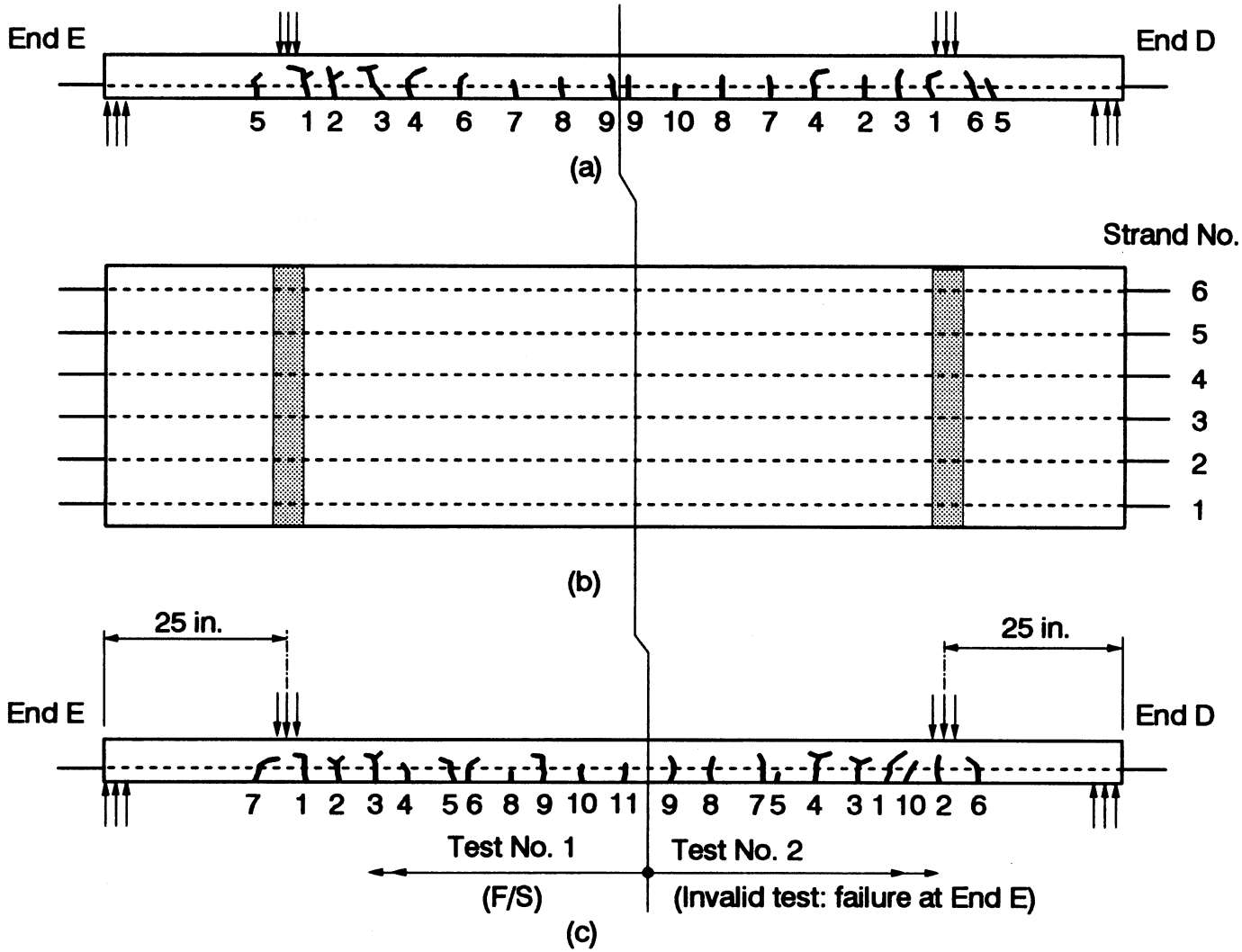


Figure D.8. Crack patterns for D-type Specimen No. 9-6.0DC-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

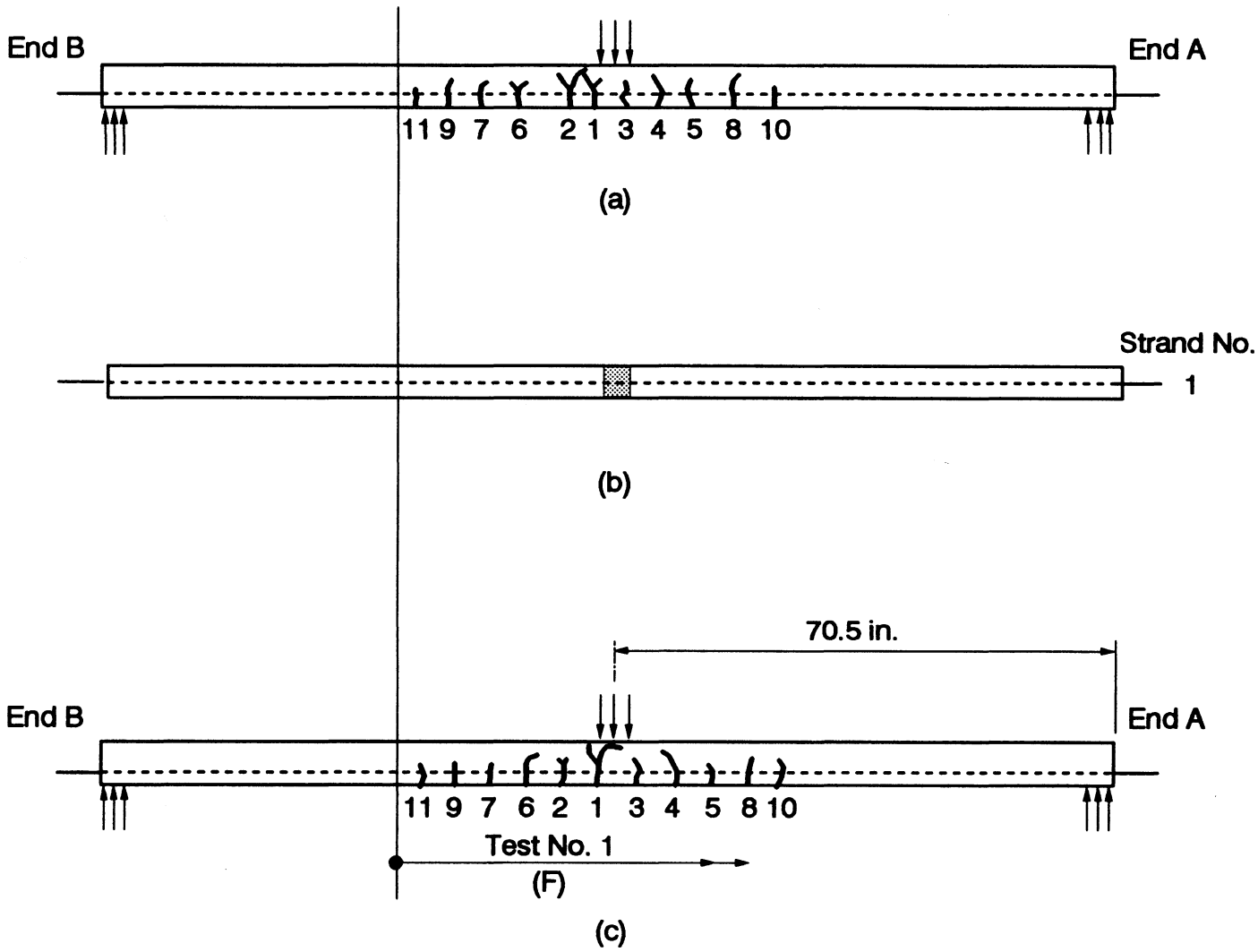


Figure D.9. Crack pattern for D-type Specimen No. 10-6.0DU-1:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

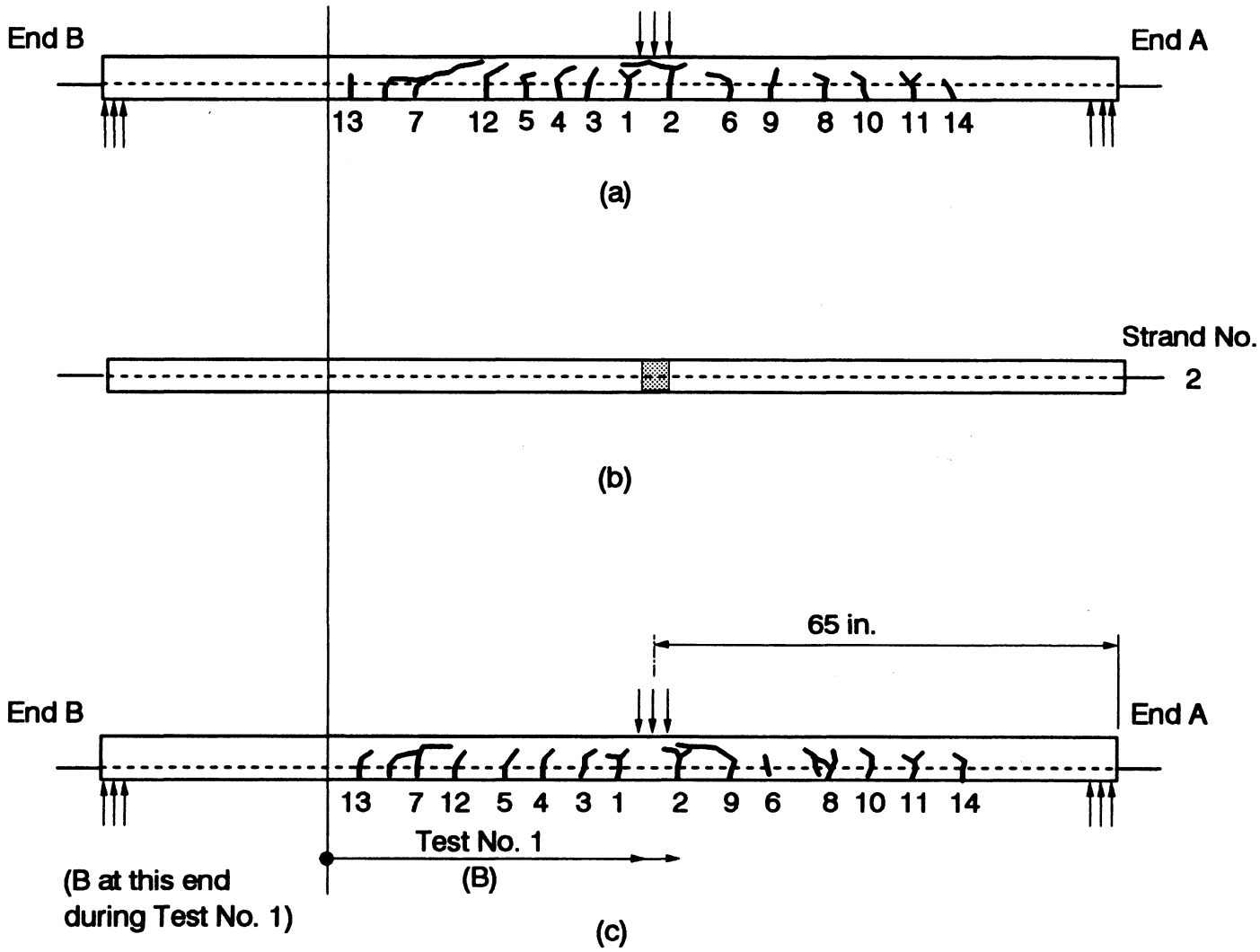


Figure D.10. Crack pattern for D-type Specimen No. 10-6.0DU-2:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

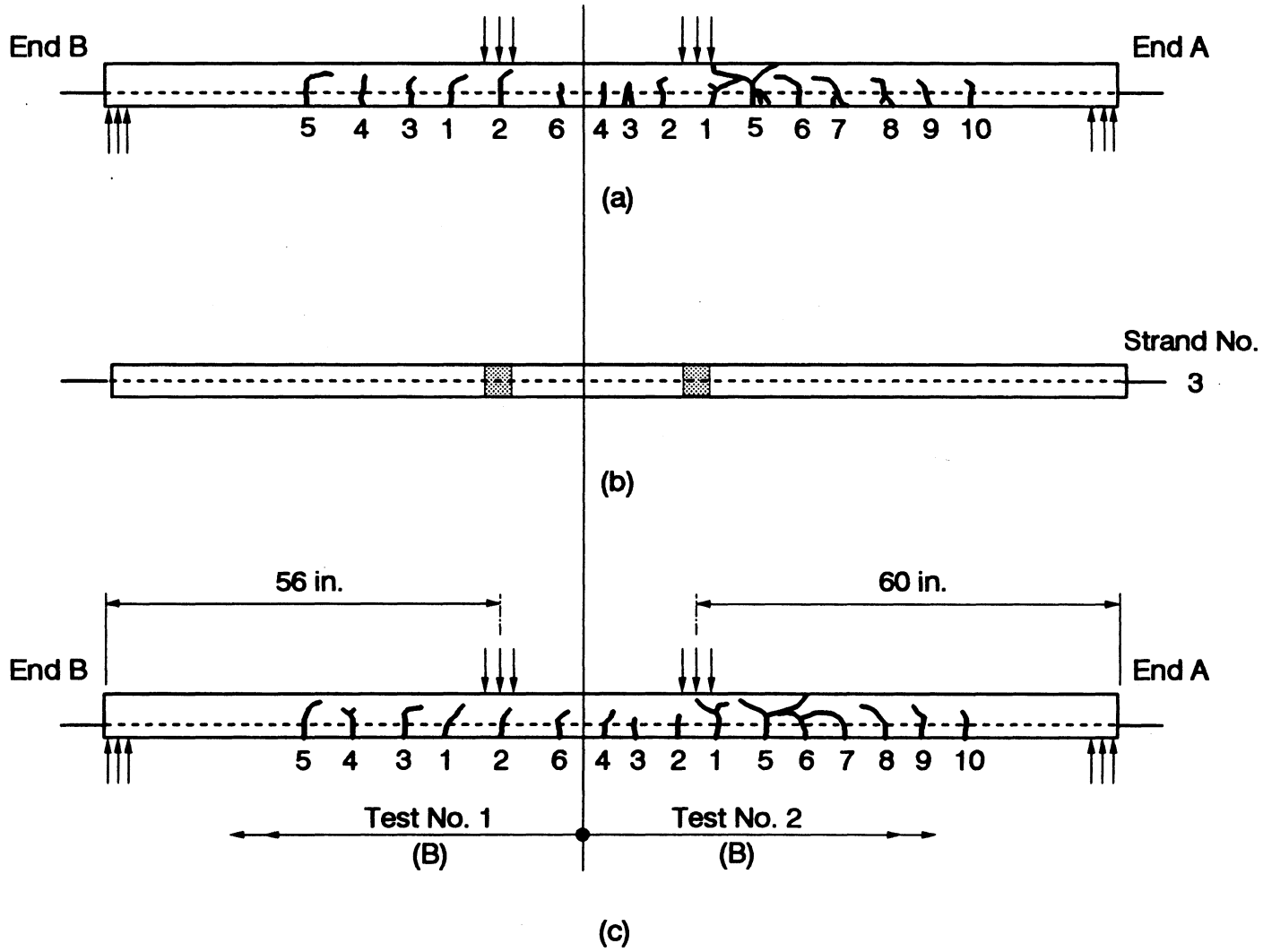


Figure D.11. Crack patterns for D-type Specimen No. 10-6.0DU-3:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

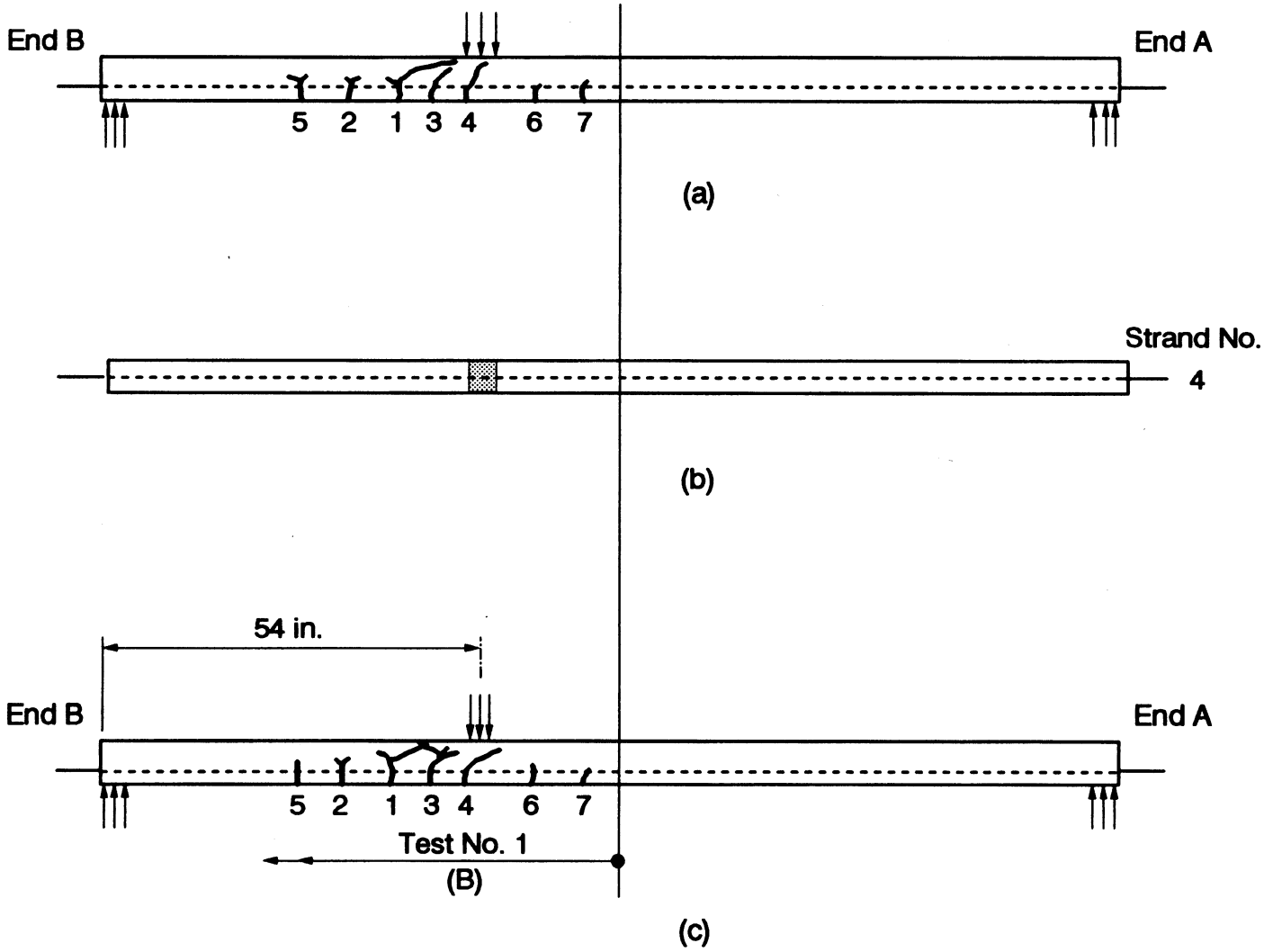


Figure D.12. Crack pattern for D-type Specimen No. 10-6.0DU-4:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

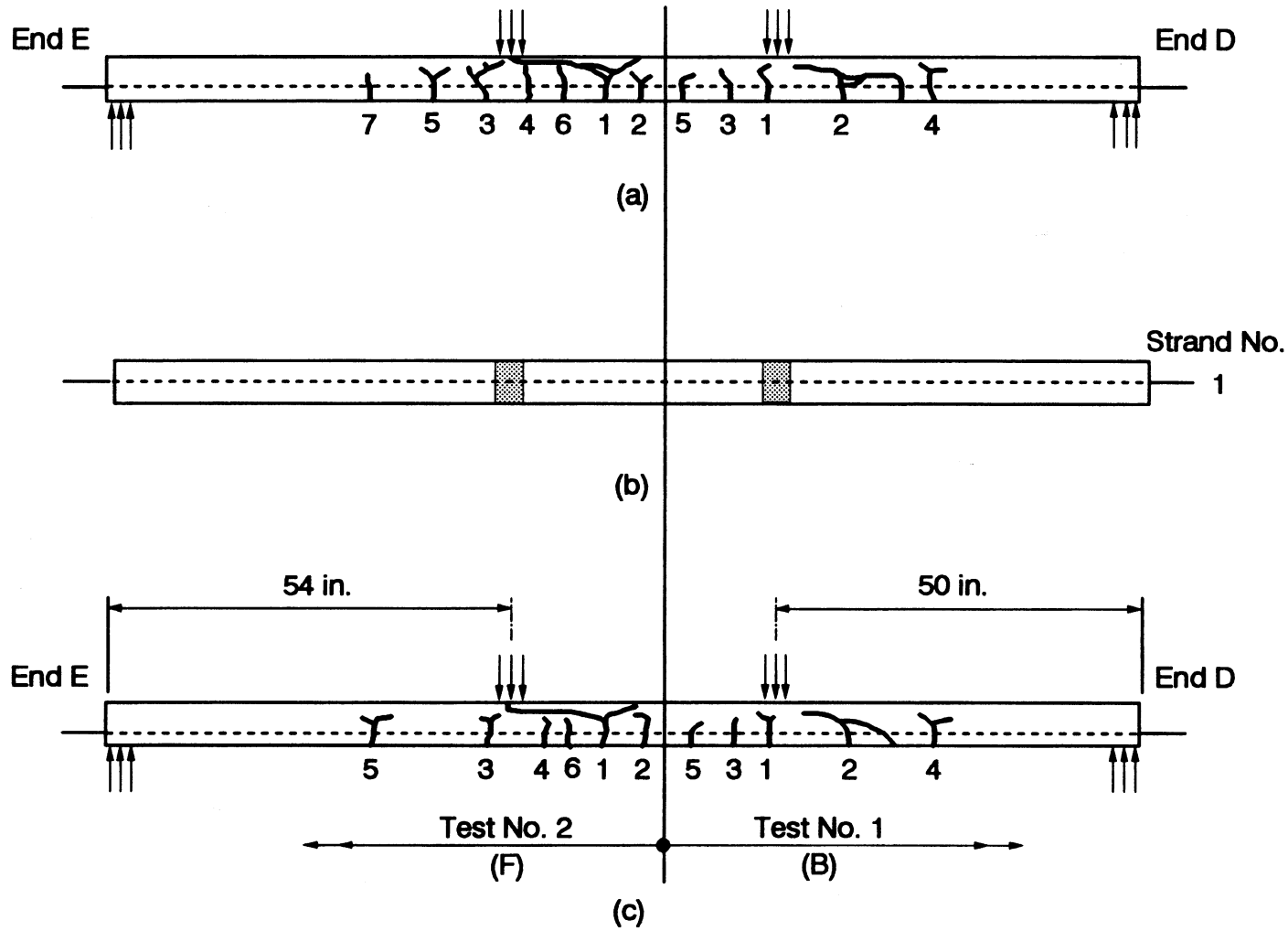


Figure D.13. Crack patterns for D-type Specimen No. 10-6.0DU-9:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

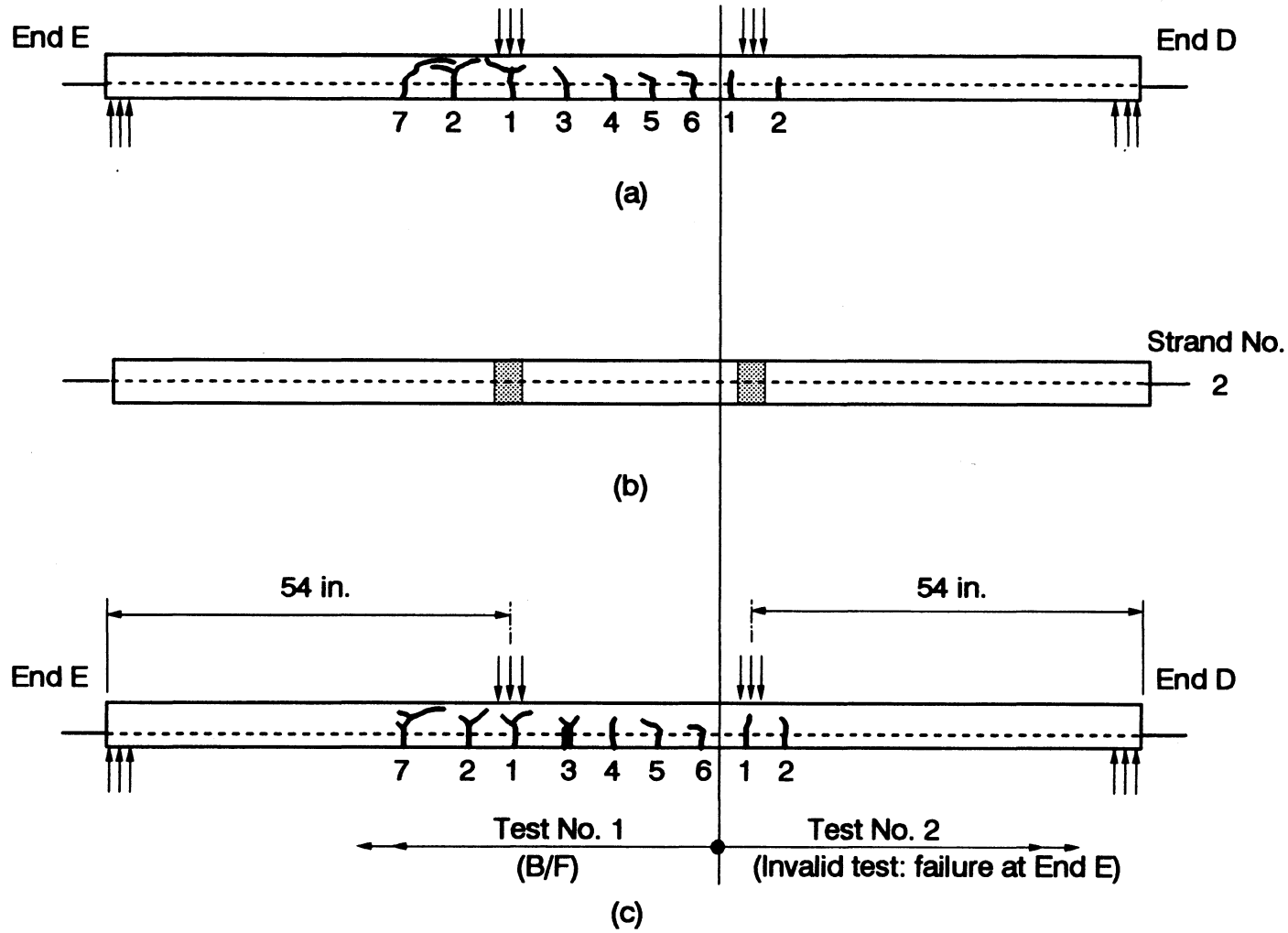


Figure D.14. Crack patterns for D-type Specimen No. 10-6.0DU-10:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

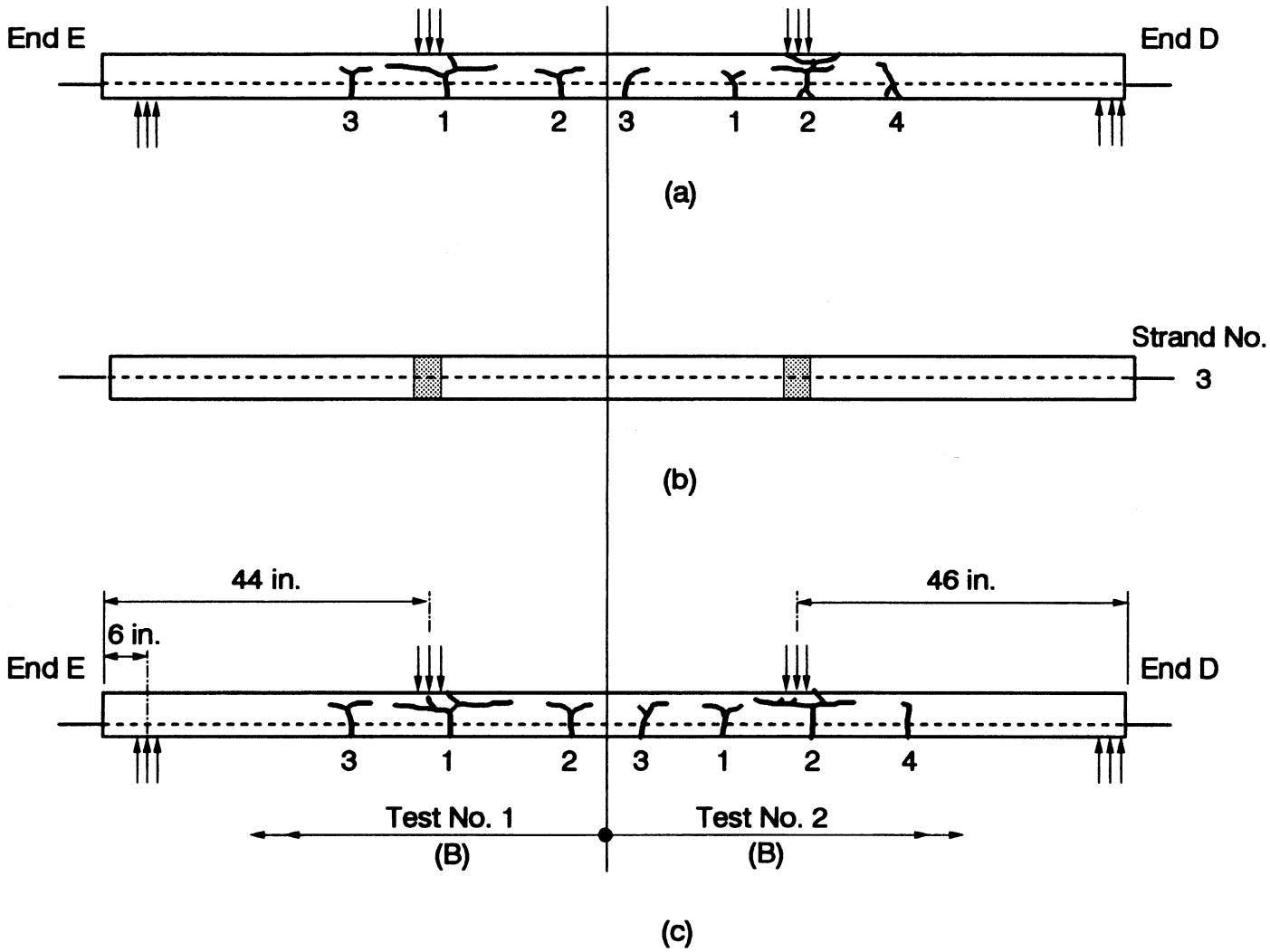


Figure D.15. Crack patterns for D-type Specimen No. 10-6.0DU-11:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

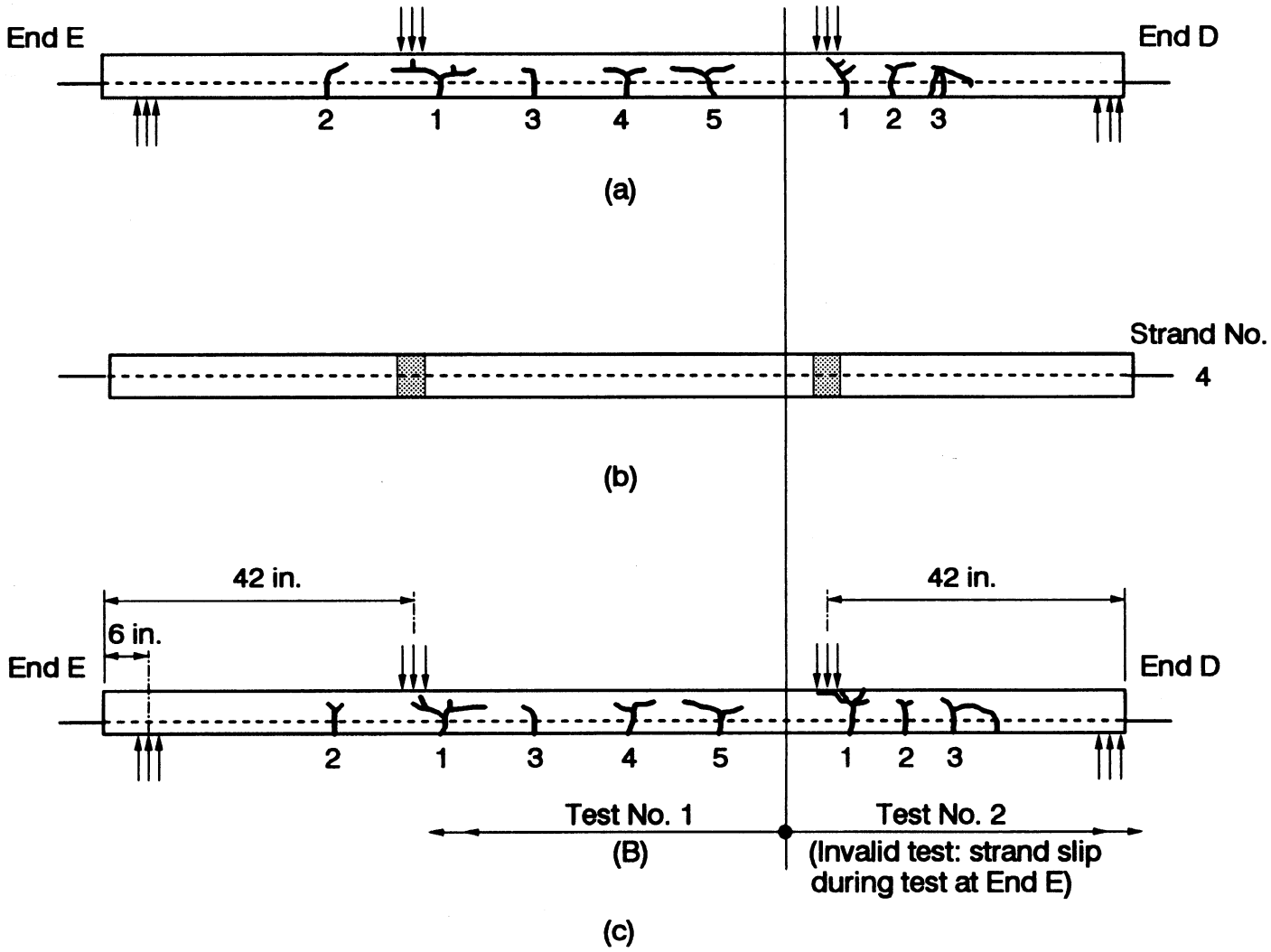


Figure D.16. Crack patterns for D-type Specimen No. 10-6.0DU-12:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

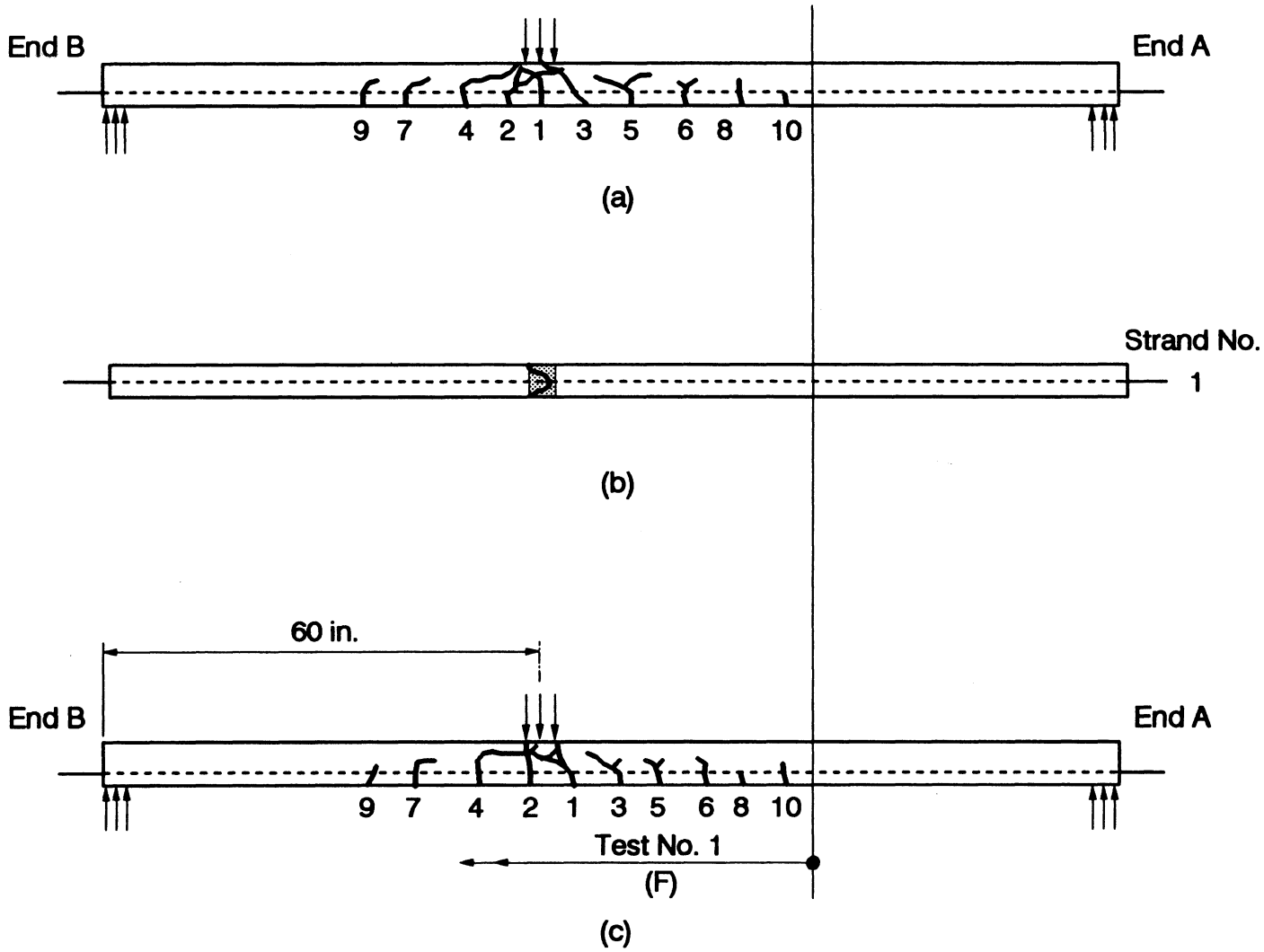


Figure D.17. Crack pattern for D-type Specimen No. 11-6.0DU-1:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

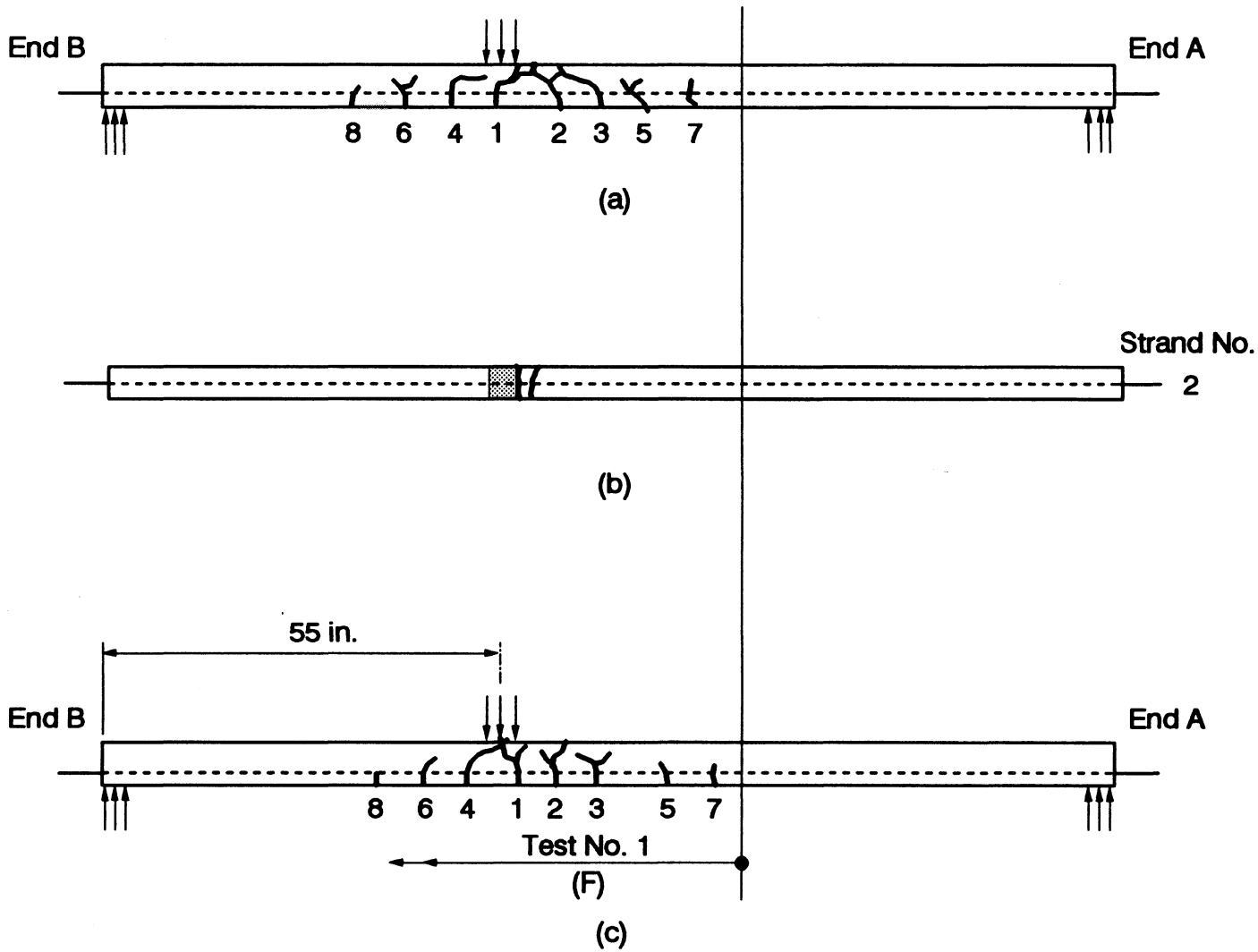


Figure D.18. Crack pattern for D-type Specimen No. 11-6.0DU-2:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

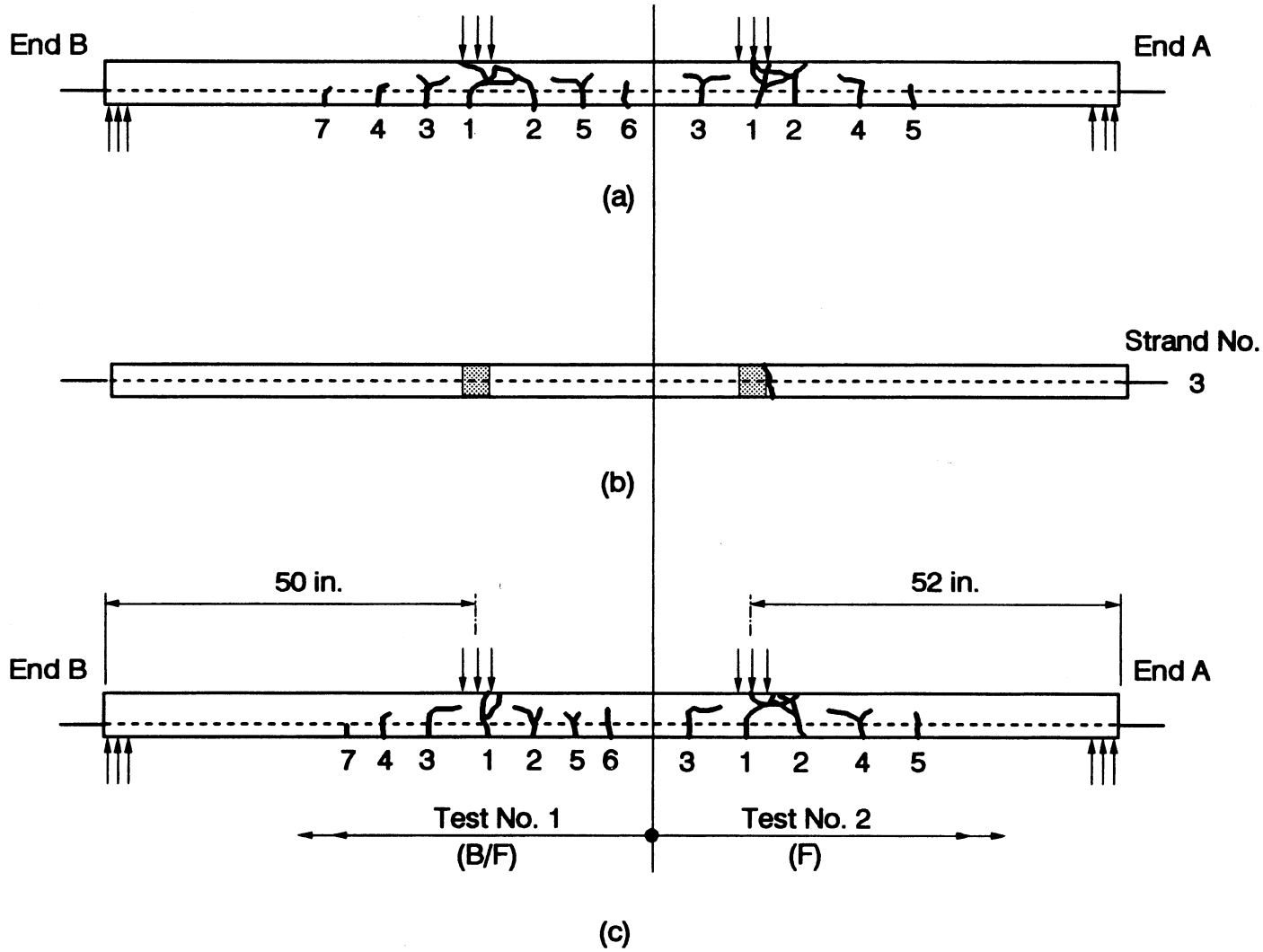


Figure D.19. Crack patterns for D-type Specimen No. 11-6.0DU-3:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

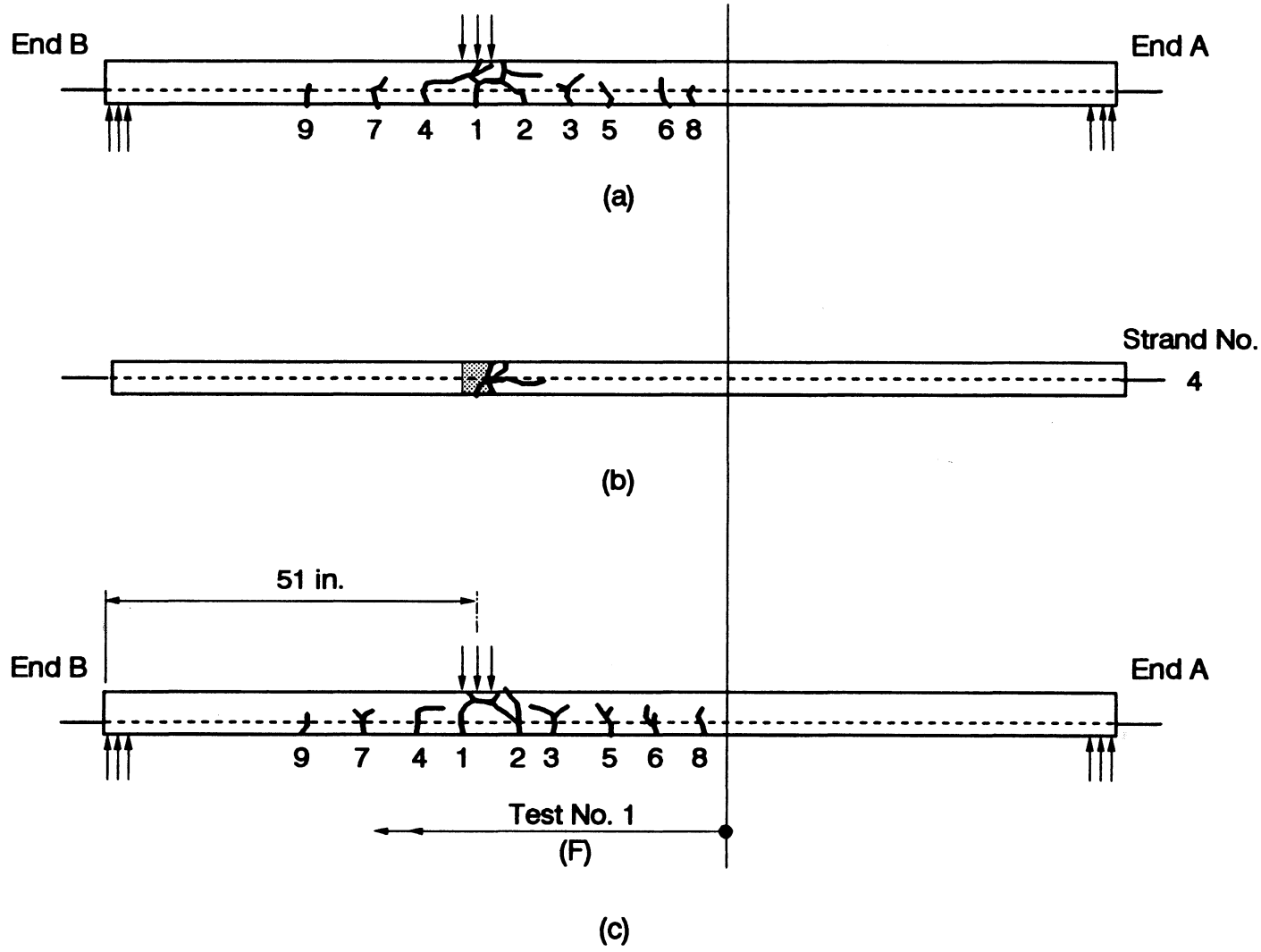


Figure D.20. Crack pattern for D-type Specimen No. 11-6.0DU-4:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

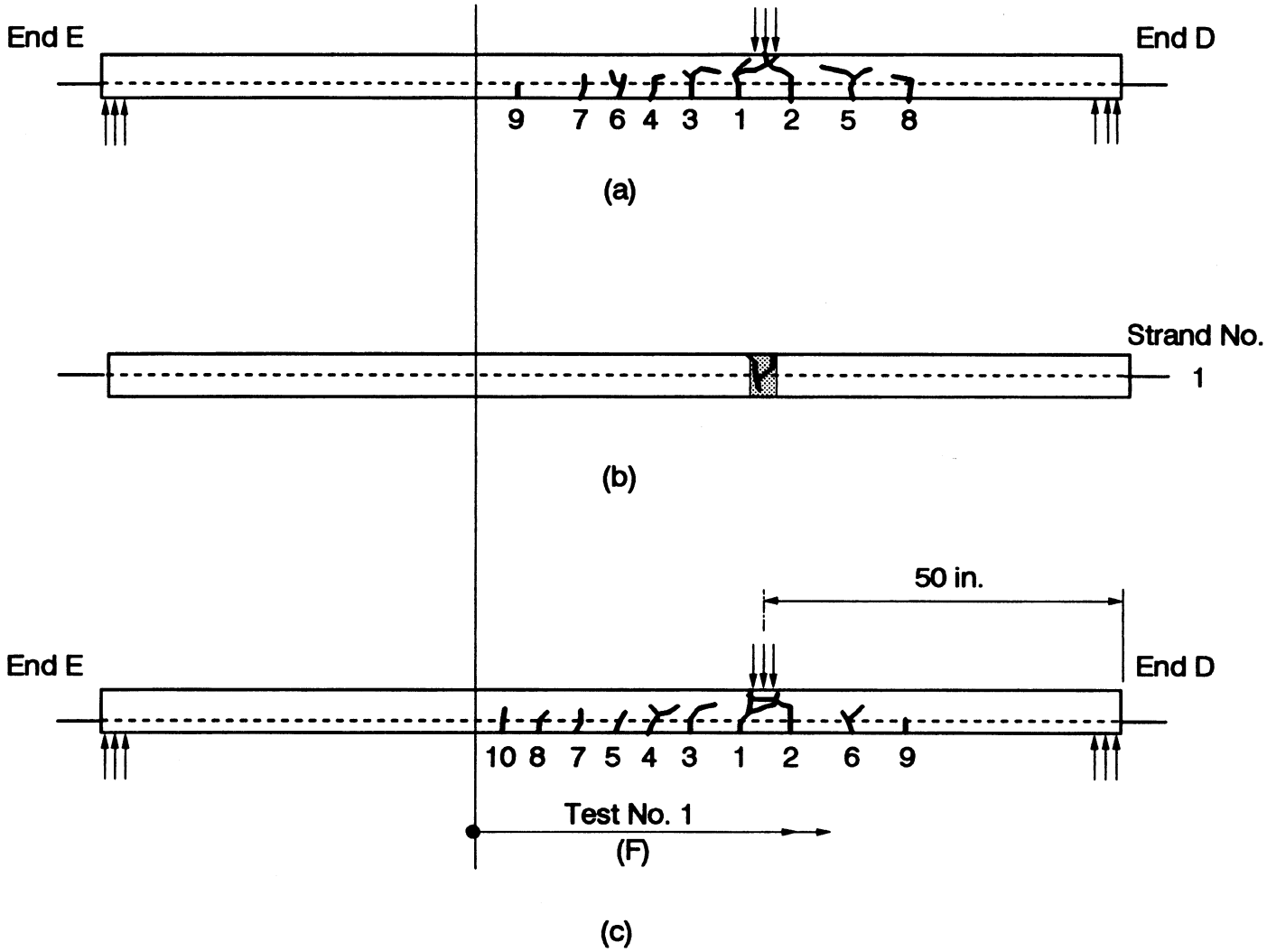


Figure D.21. Crack pattern for D-type Specimen No. 11-6.0DU-9:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

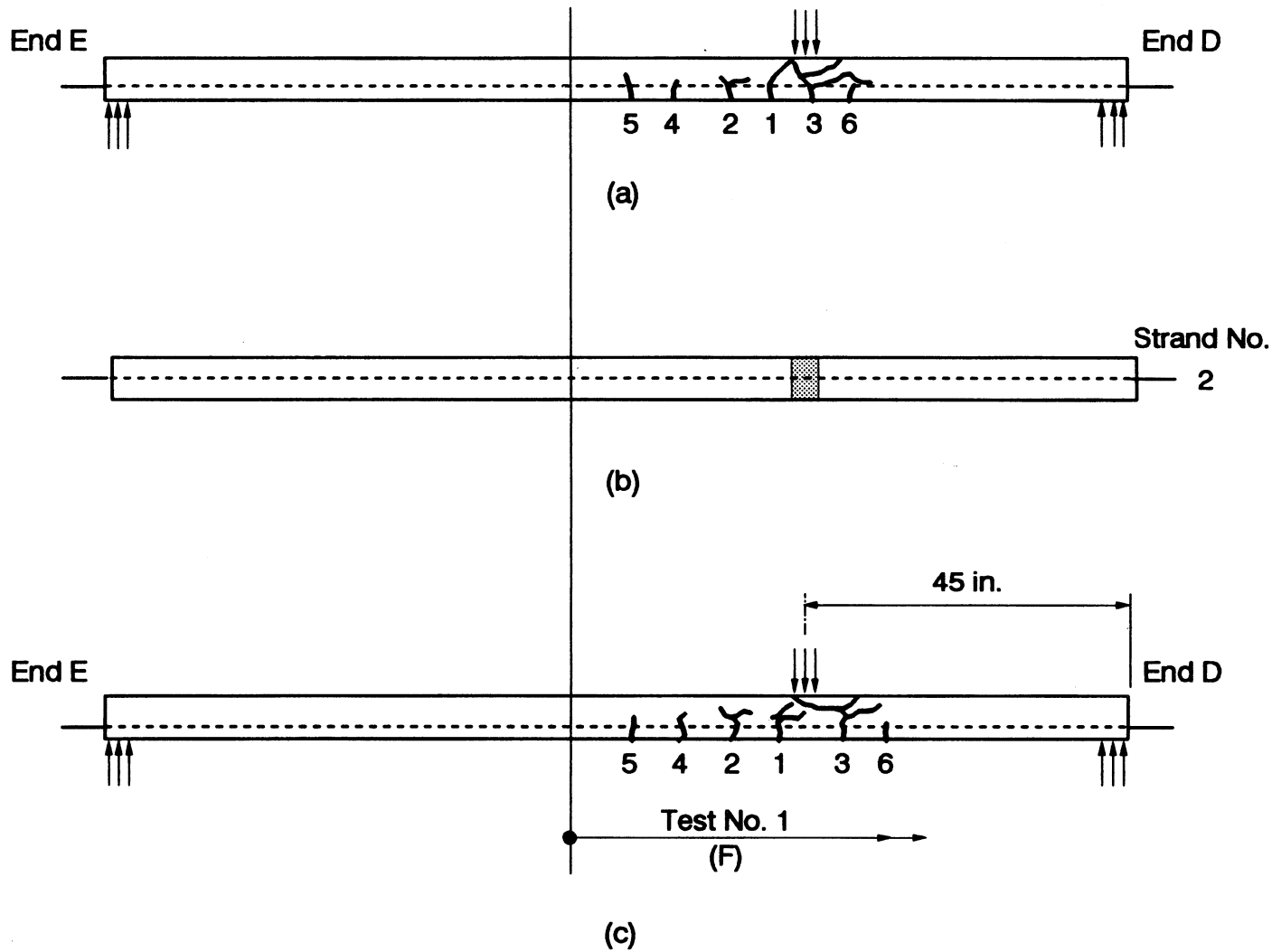


Figure D.22. Crack pattern for D-type Specimen No. 11-6.0DU-10:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

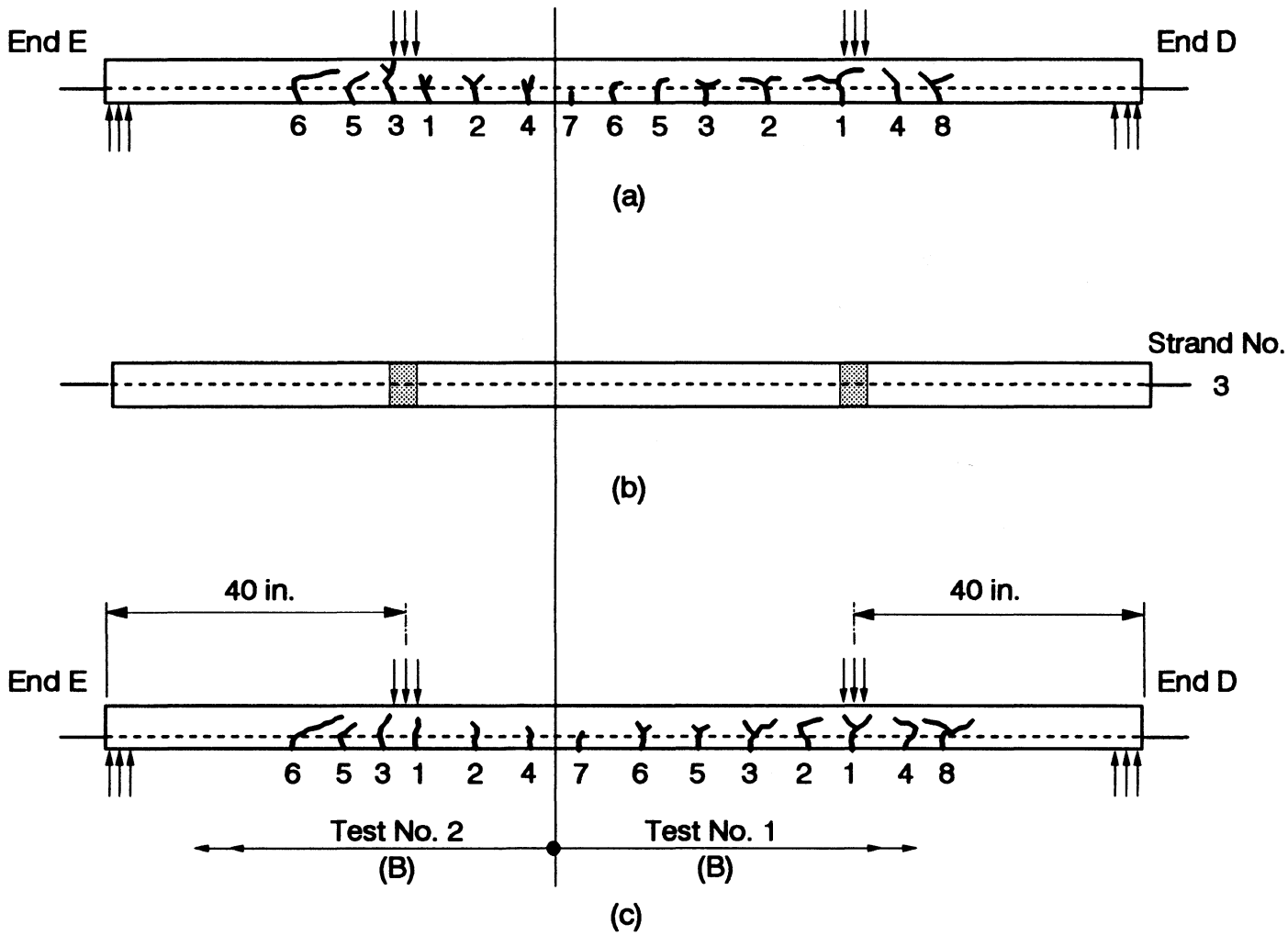


Figure D.23. Crack patterns for D-type Specimen No. 11-6.0DU-11:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

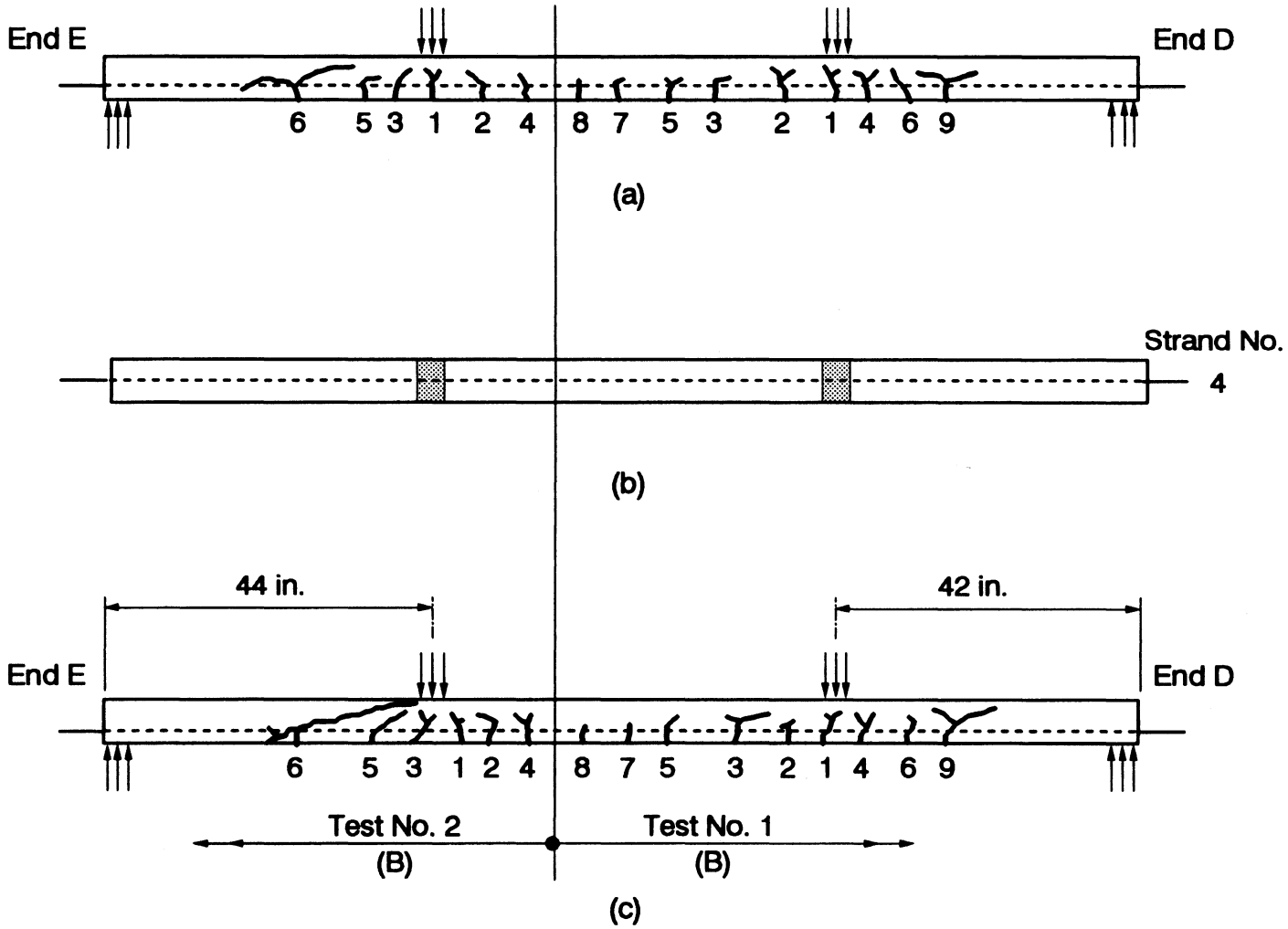


Figure D.24. Crack patterns for D-type Specimen No. 11-6.0DU-12:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

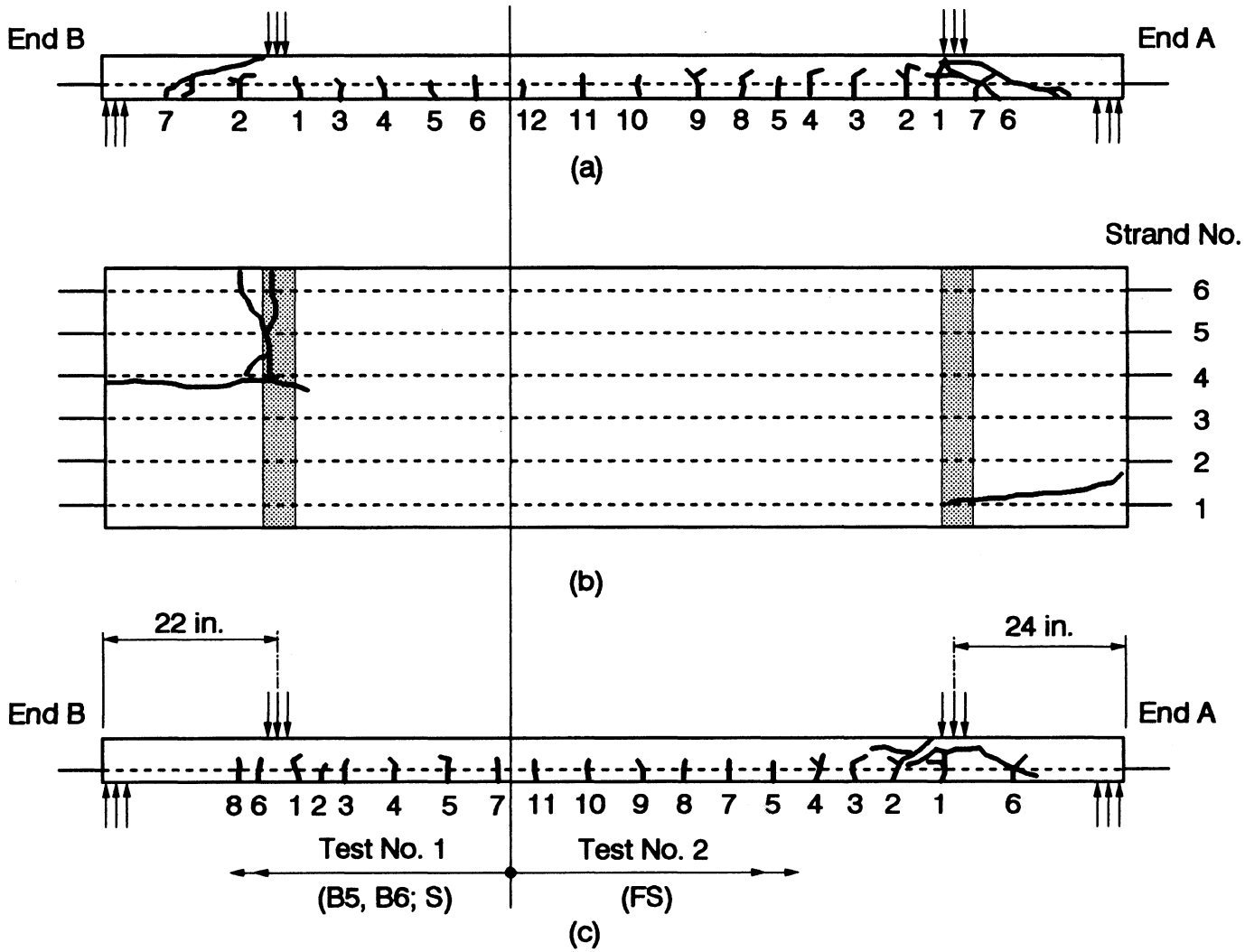


Figure D.25. Crack patterns for D-type Specimen No. 12-6.0DC-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

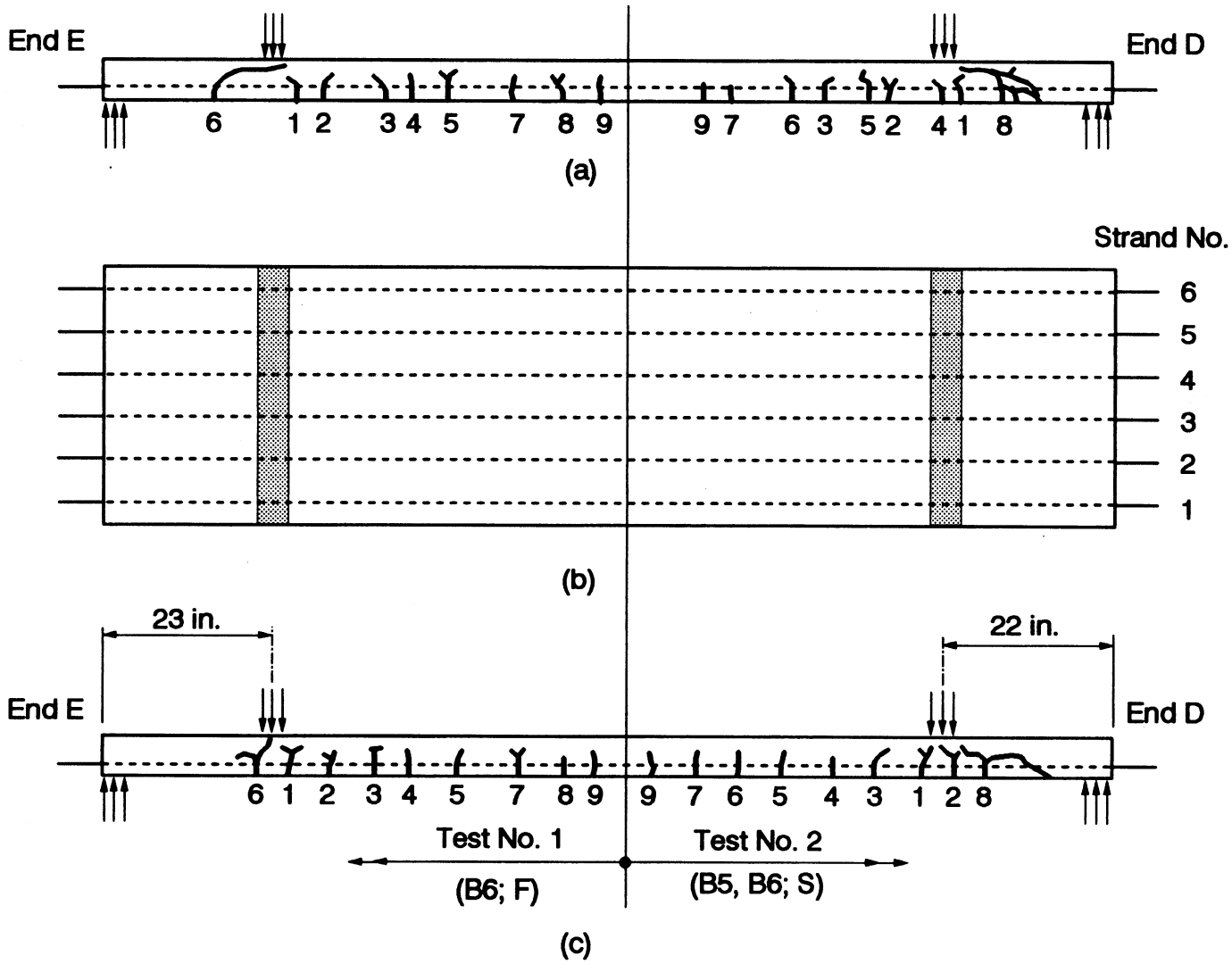


Figure D.26. Crack patterns for D-type Specimen No. 12-6.0DC-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

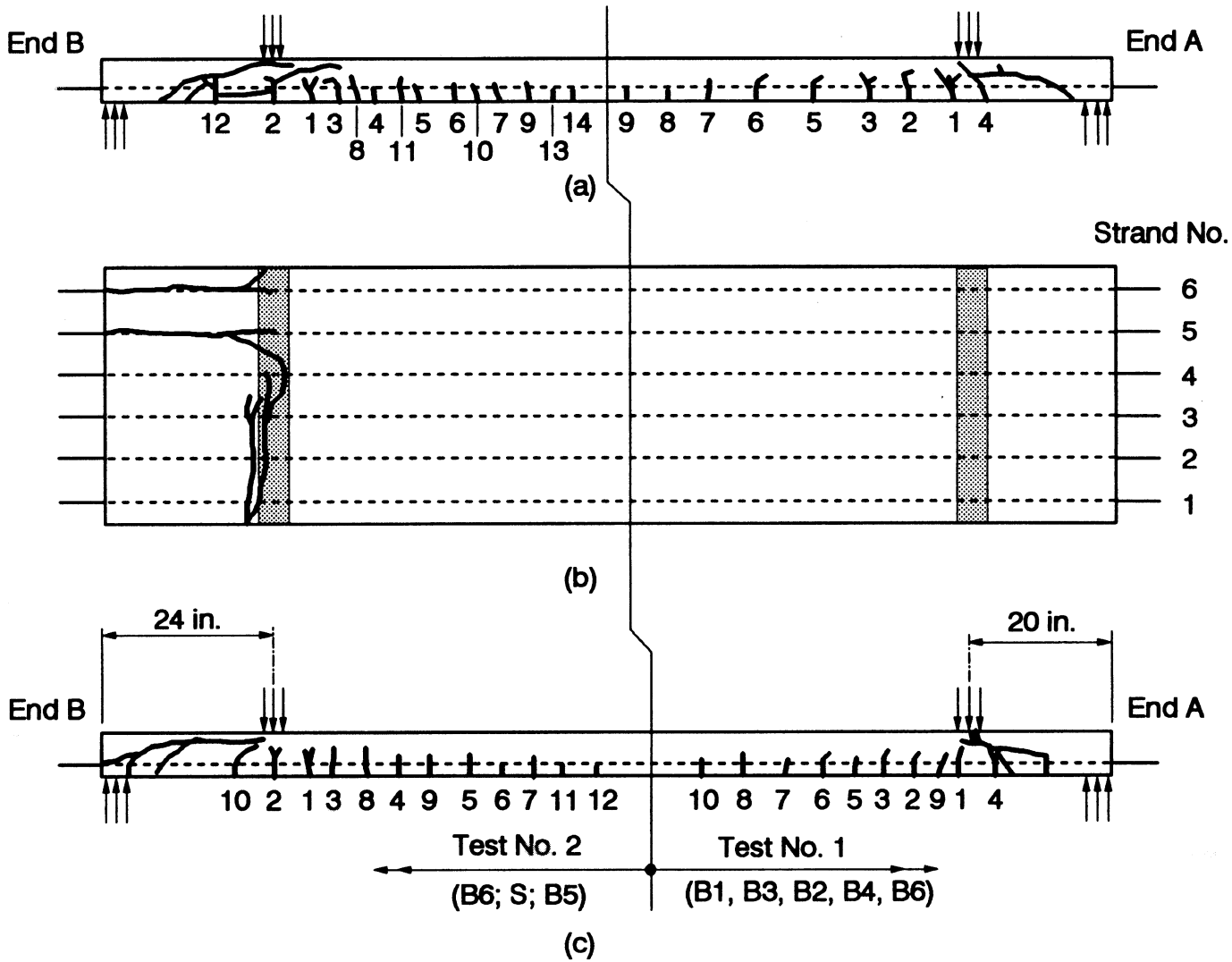


Figure D.27. Crack patterns for D-type Specimen No. 14-6.0DC-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

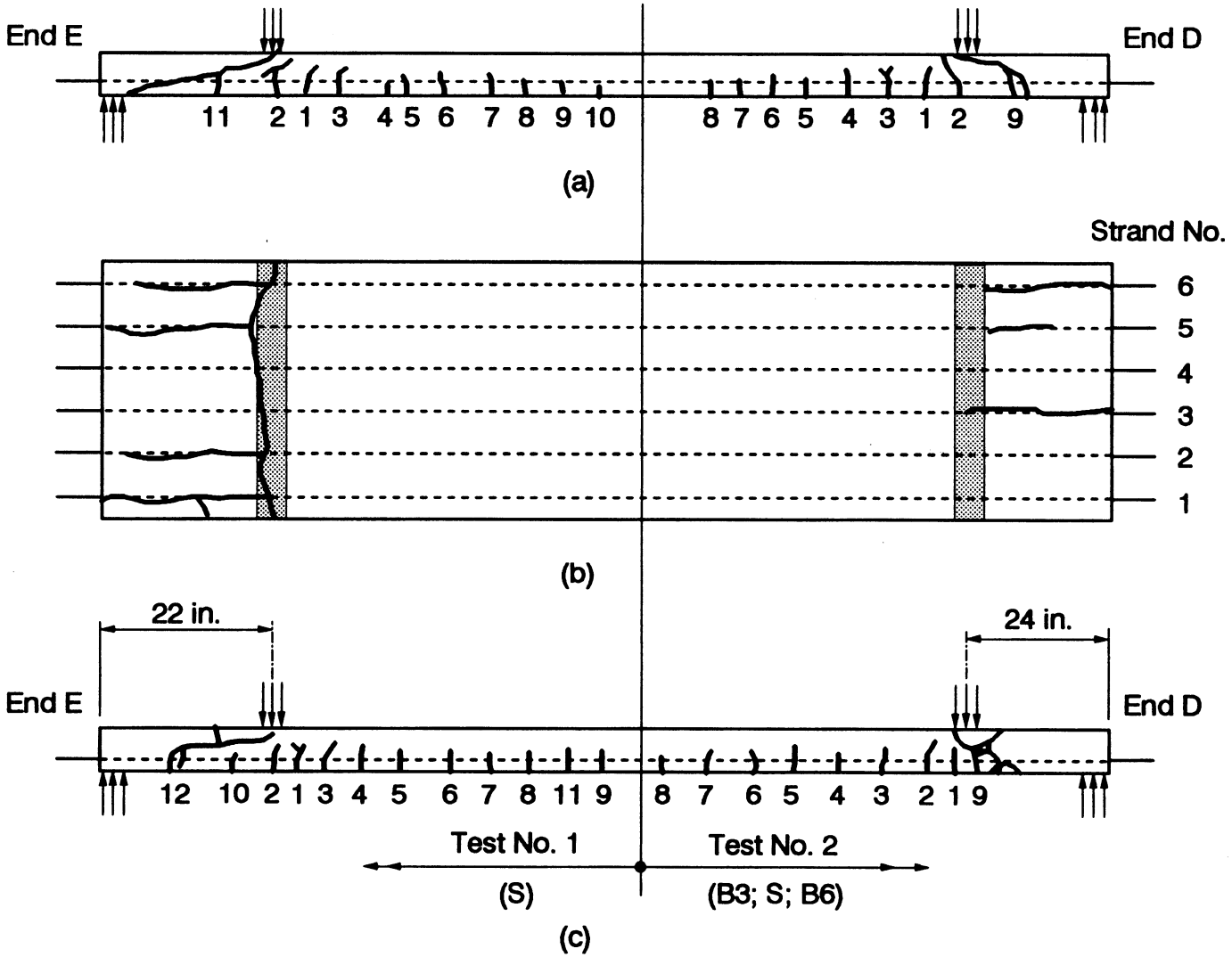


Figure D.28. Crack patterns for D-type Specimen No. 14-6.0DC-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

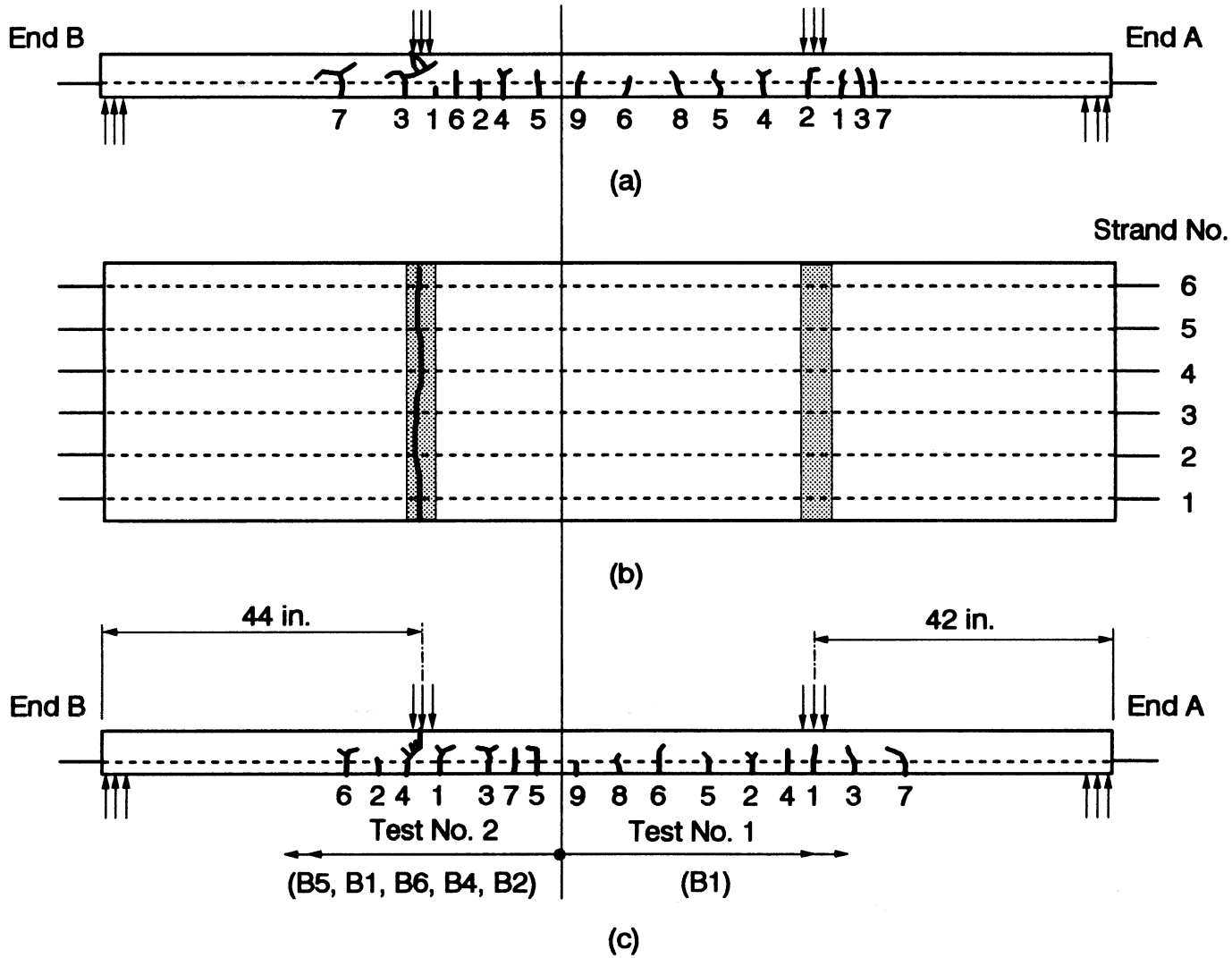


Figure D.29. Crack patterns for D-type Specimen No. 15-6.0DU-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

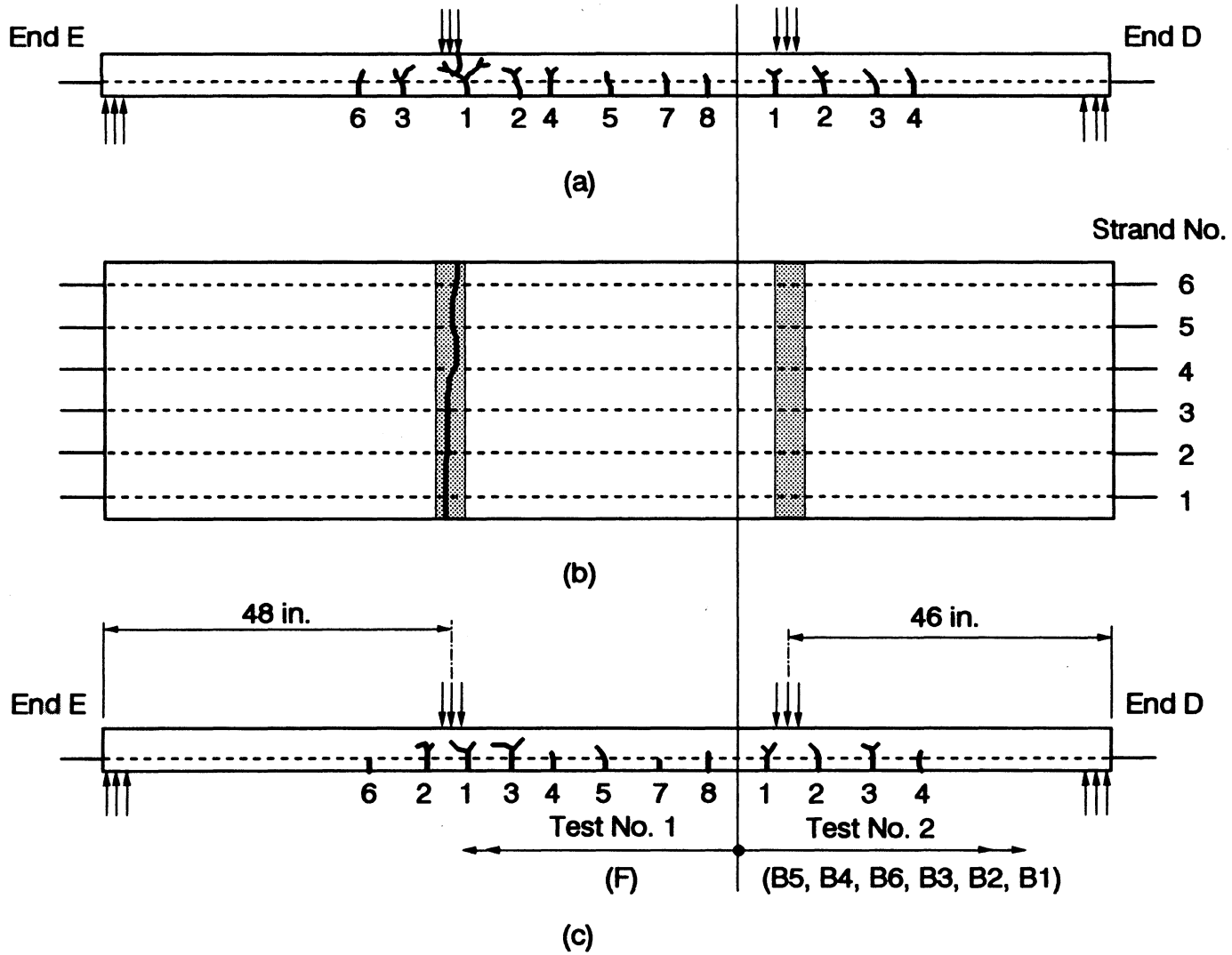


Figure D.30. Crack patterns for D-type Specimen No. 15-6.0DU-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

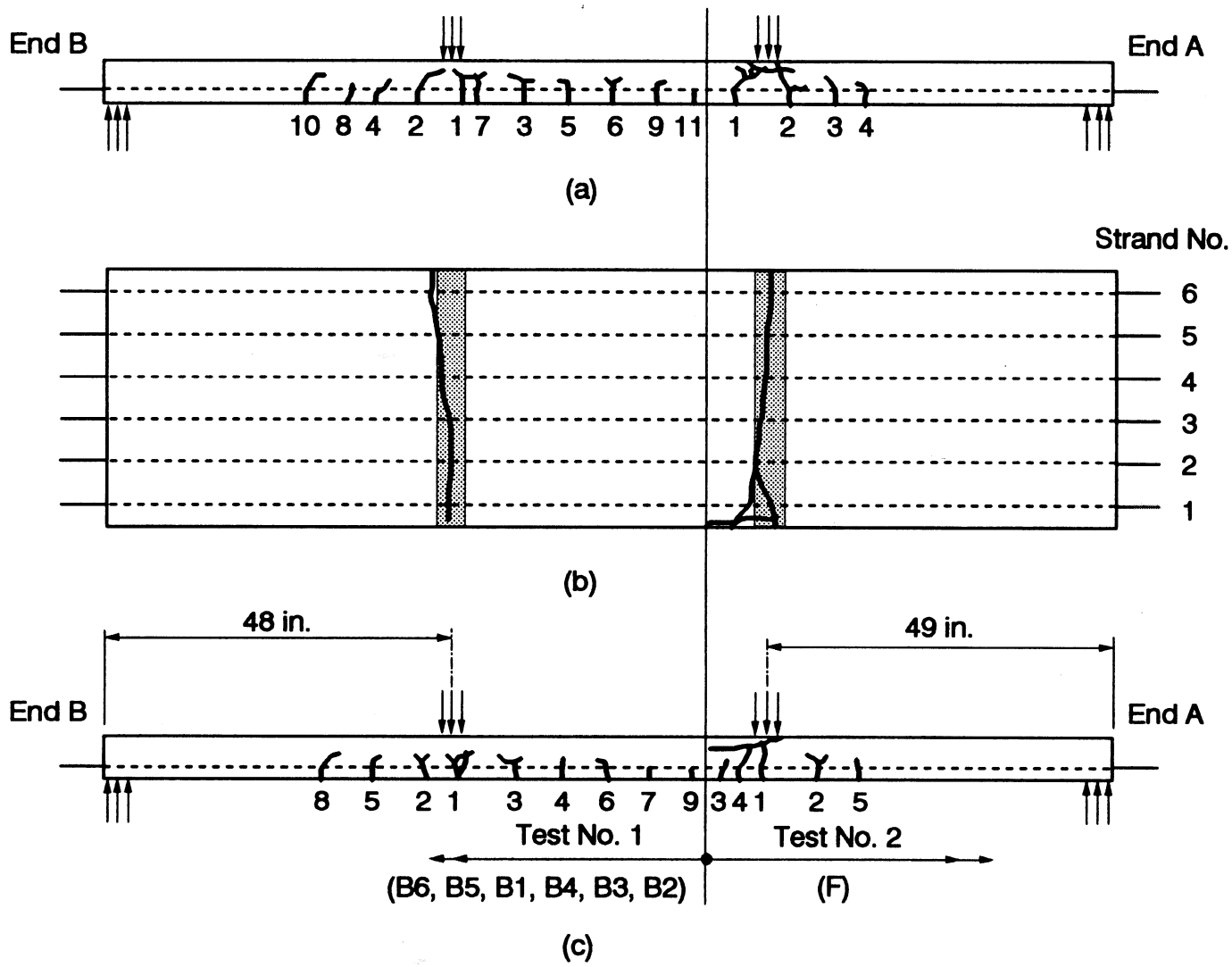


Figure D.31. Crack patterns for D-type Specimen No. 16-6.0DU-1:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

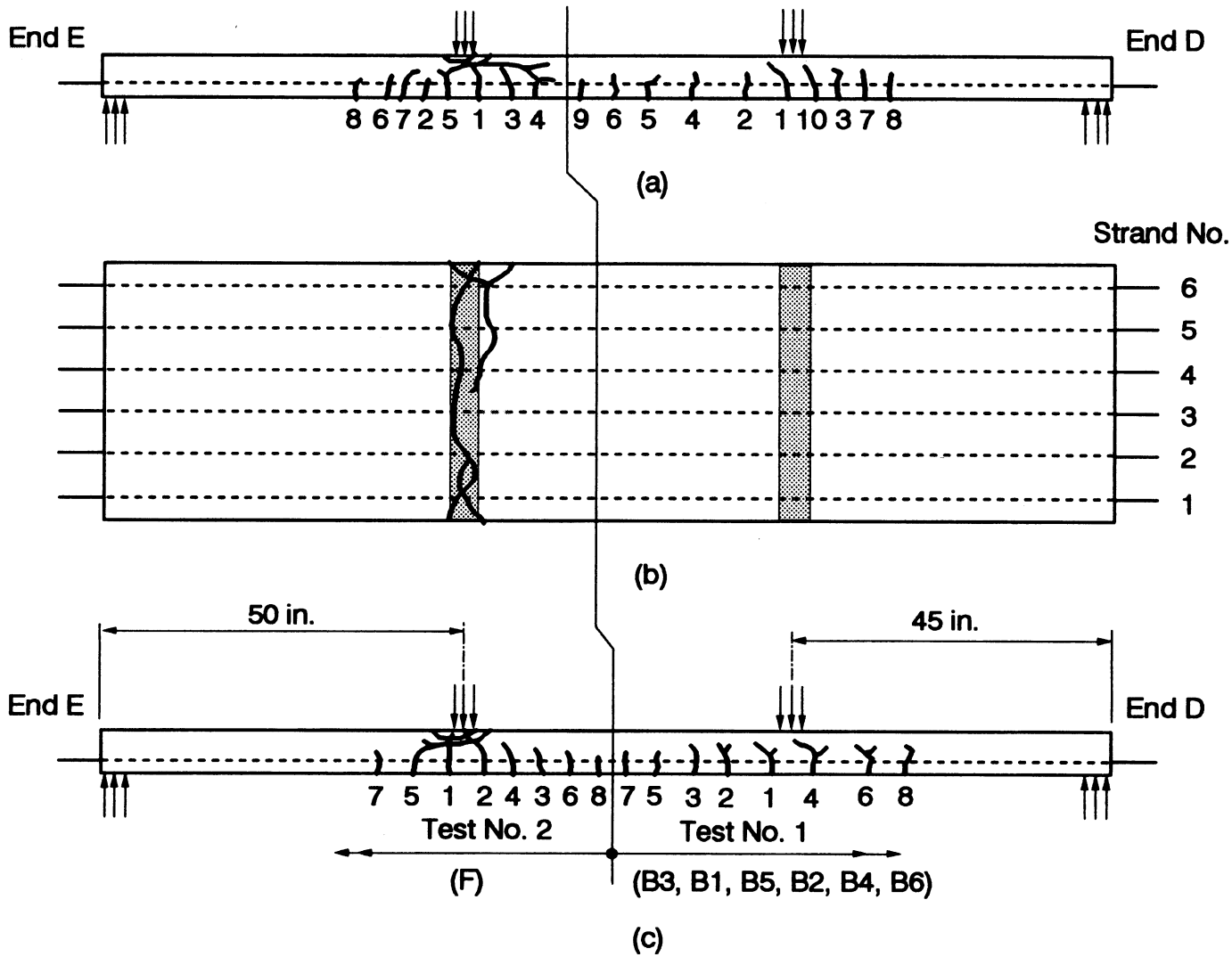


Figure D.32. Crack patterns for D-type Specimen No. 16-6.0DU-3:
(a) mirrored side view along Strand No. 6; (b) top view;
(c) side view along Strand No. 1

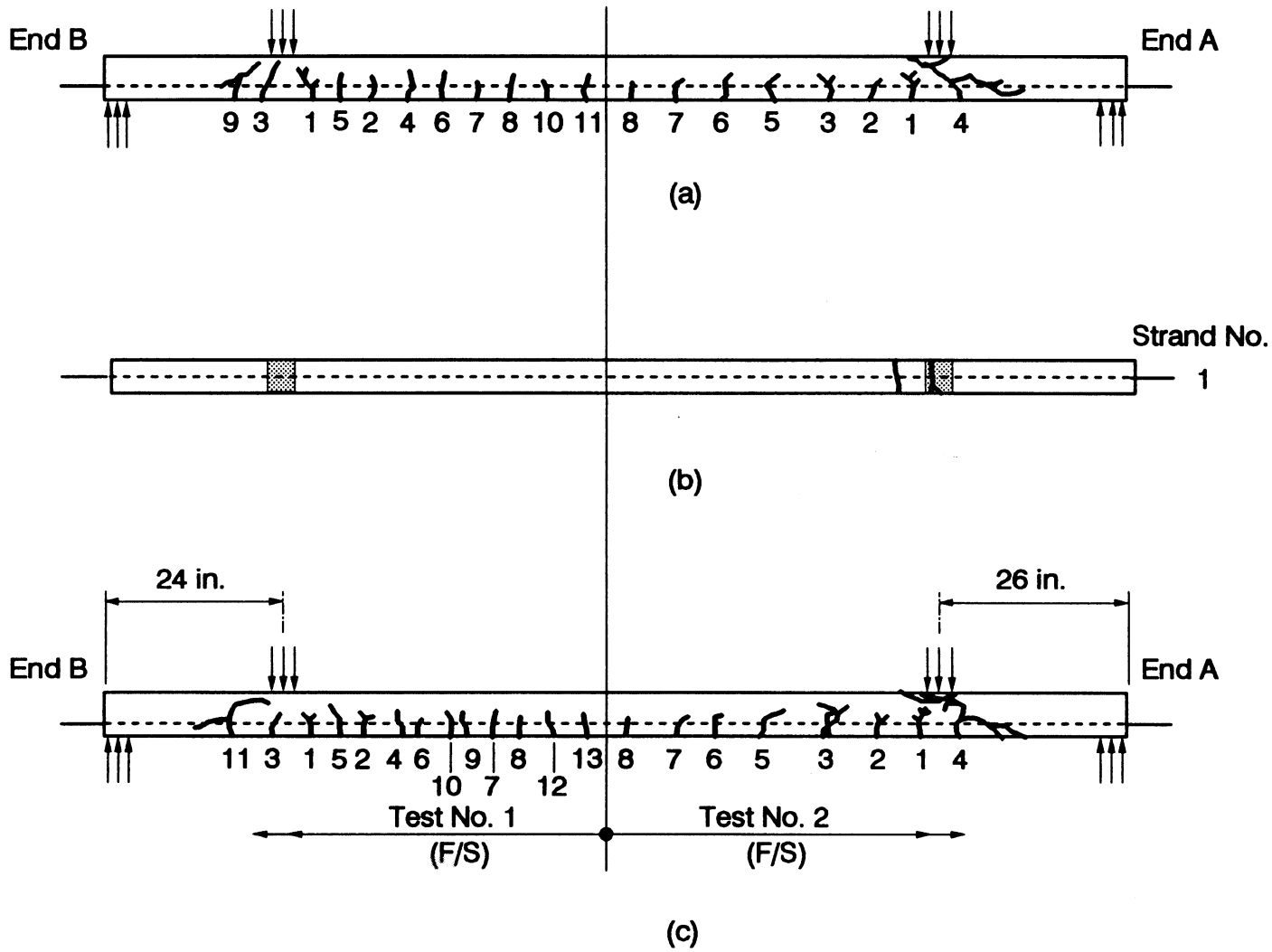


Figure D.33. Crack patterns for D-type Specimen No. 17-6.0DC-1:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

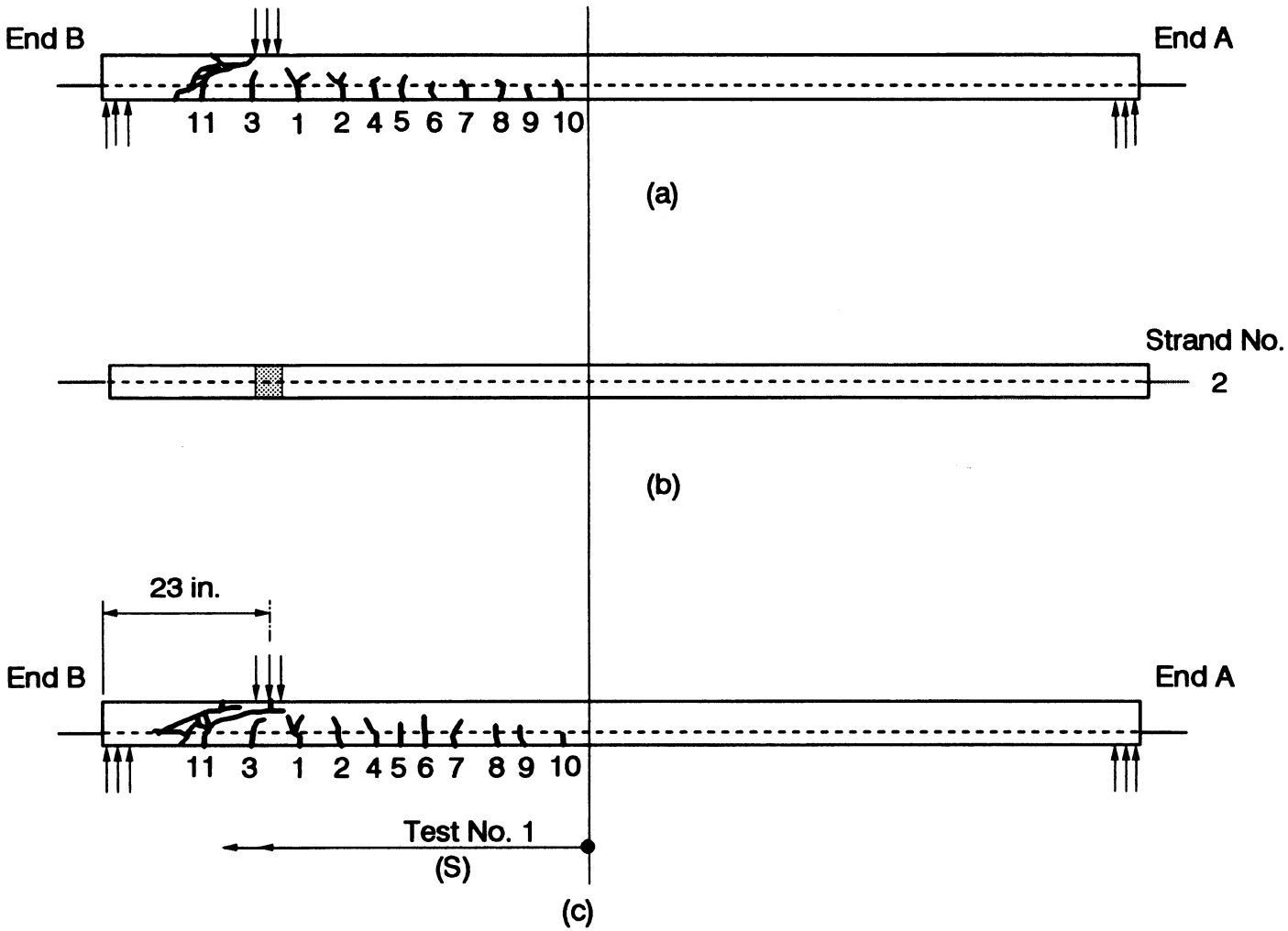


Figure D.34. Crack pattern for D-type Specimen No. 17-6.0DC-2:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

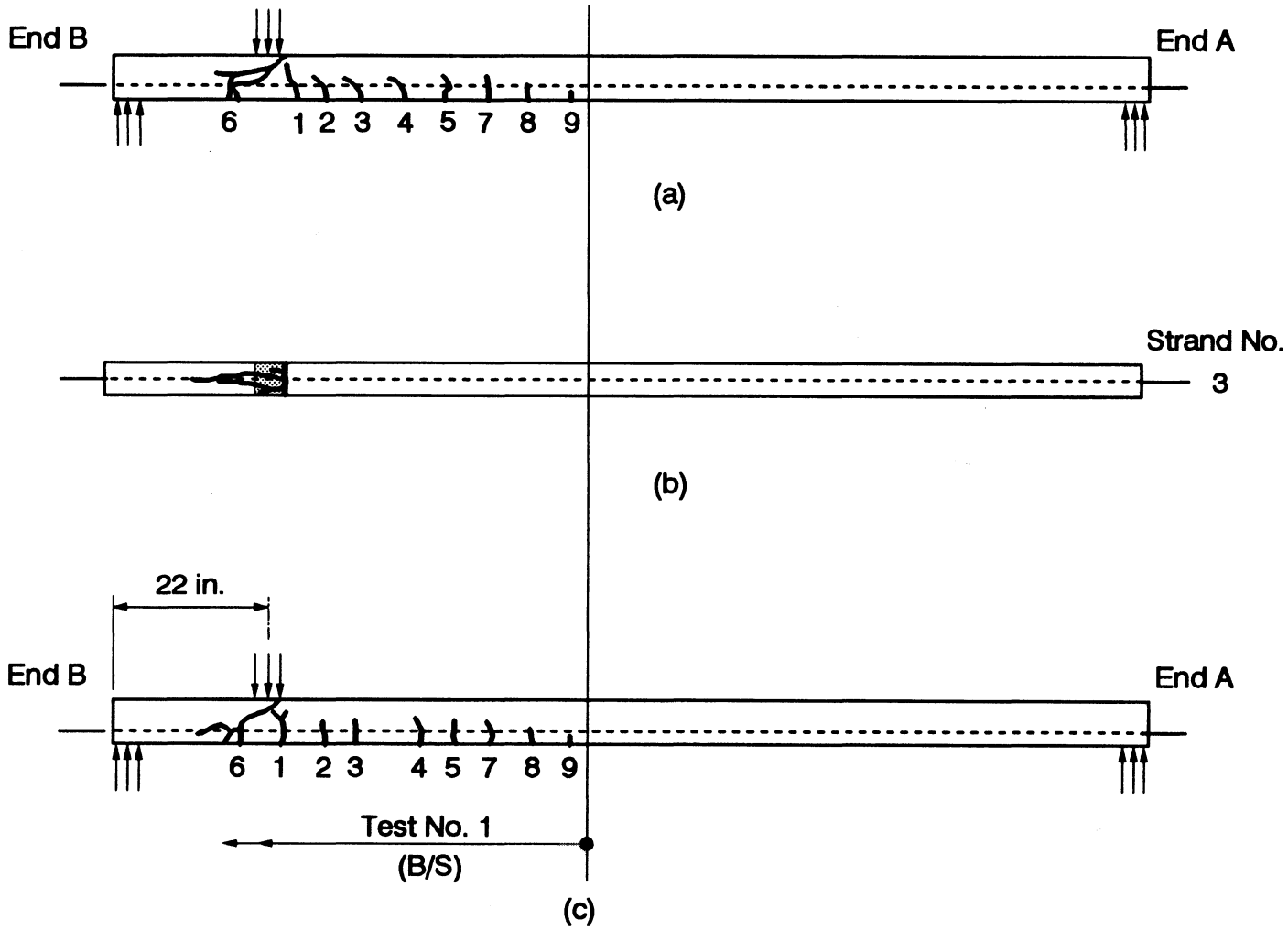


Figure D.35. Crack pattern for D-type Specimen No. 17-6.0DC-3:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

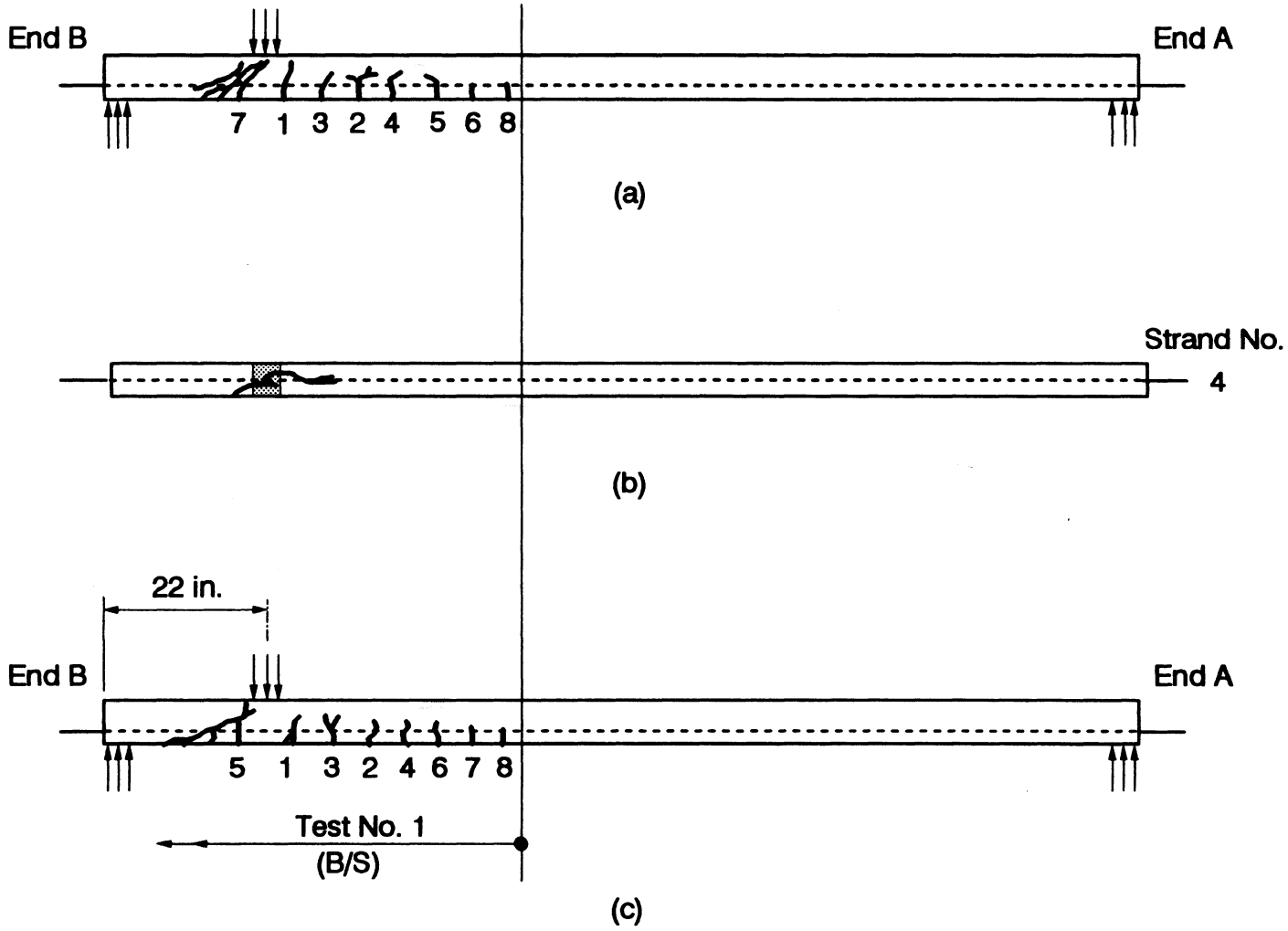


Figure D.36. Crack pattern for D-type Specimen No. 17-6.0DC-4:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

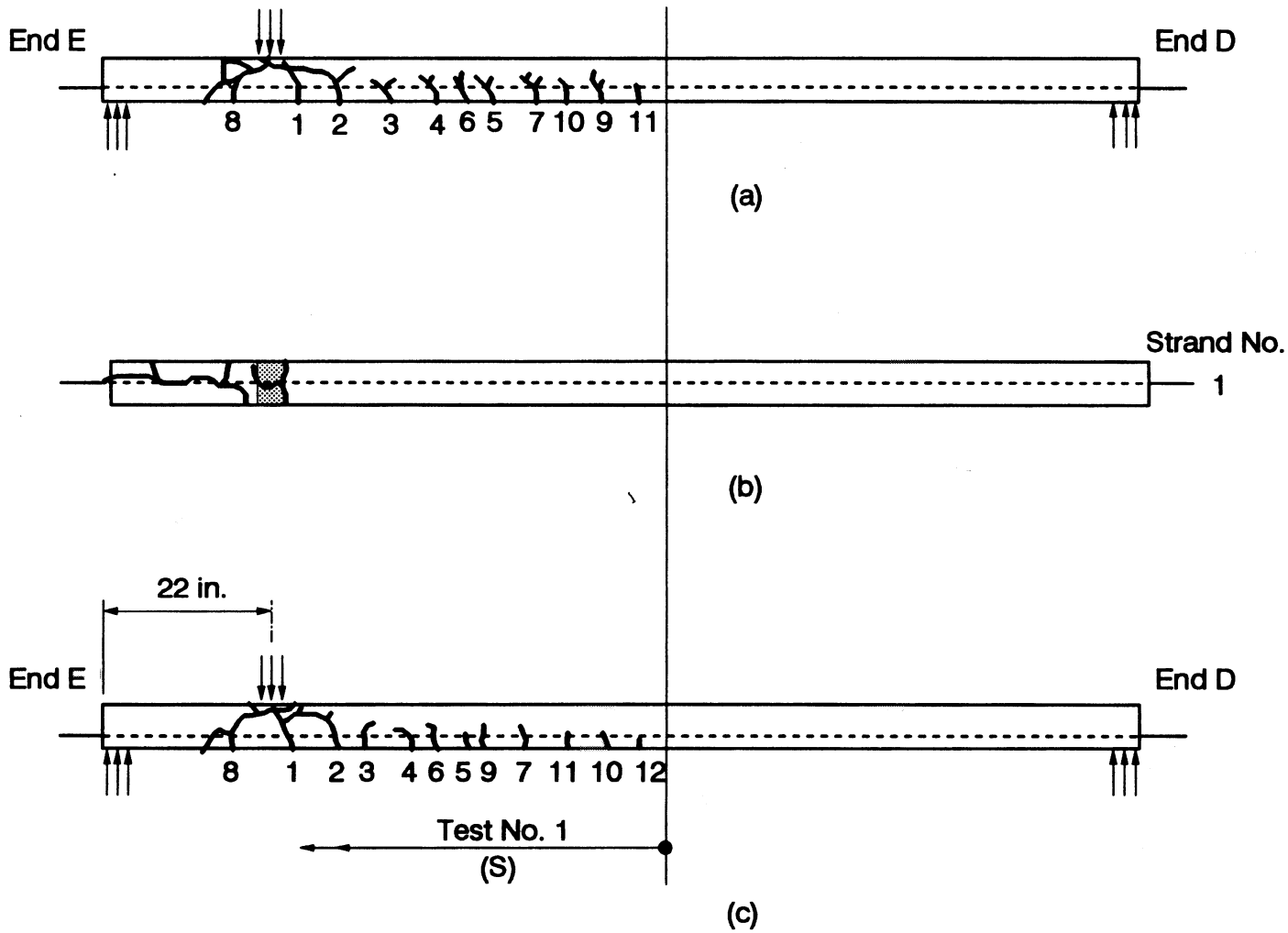


Figure D.37. Crack pattern for D-type Specimen No. 17-6.0DC-9:
(a) mirrored side view along Strand No. 1; (b) top view;
(c) side view along Strand No. 1

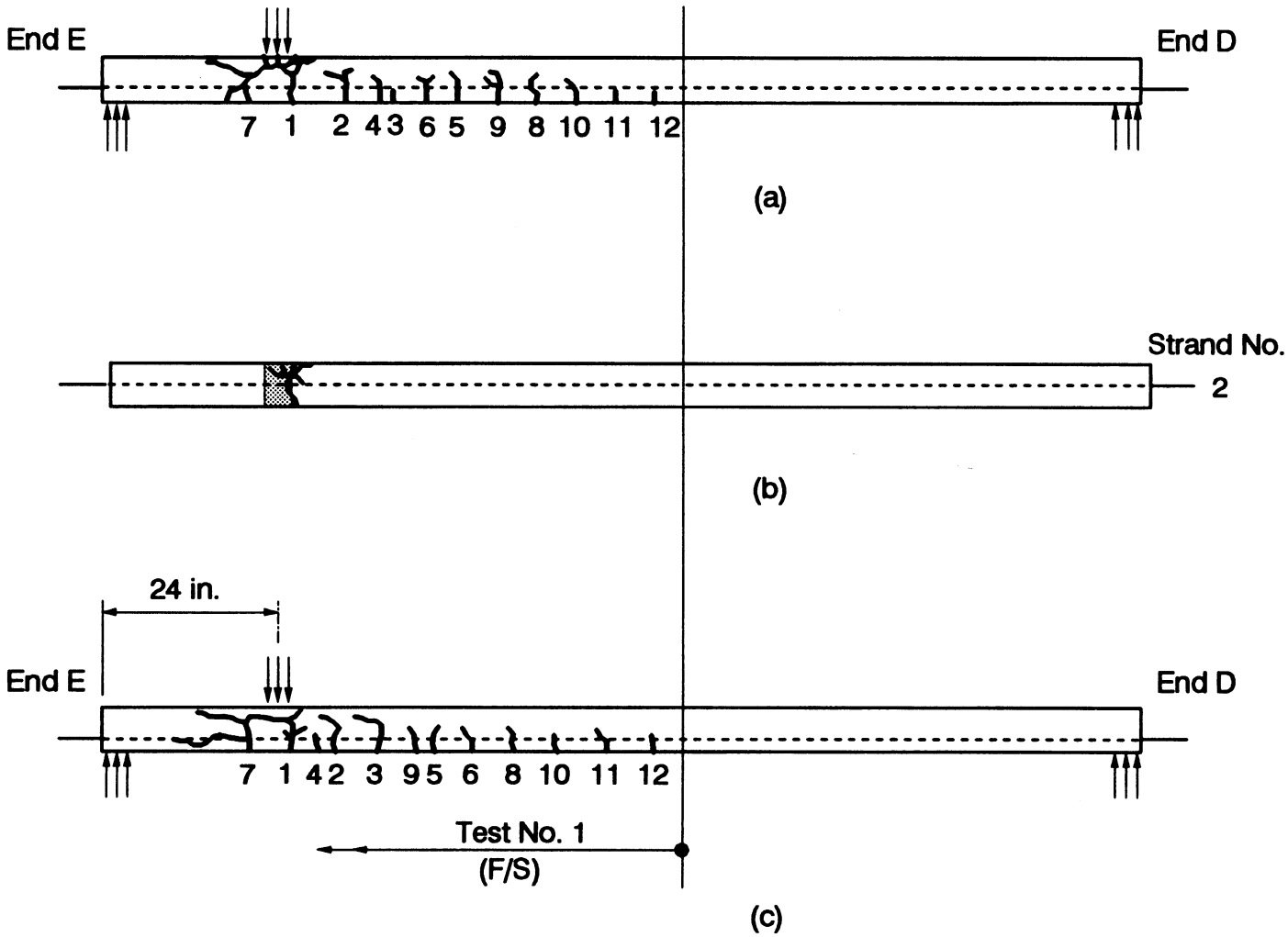


Figure D.38. Crack pattern for D-type Specimen No. 17-6.0DC-10:
(a) mirrored side view along Strand No. 2; (b) top view;
(c) side view along Strand No. 2

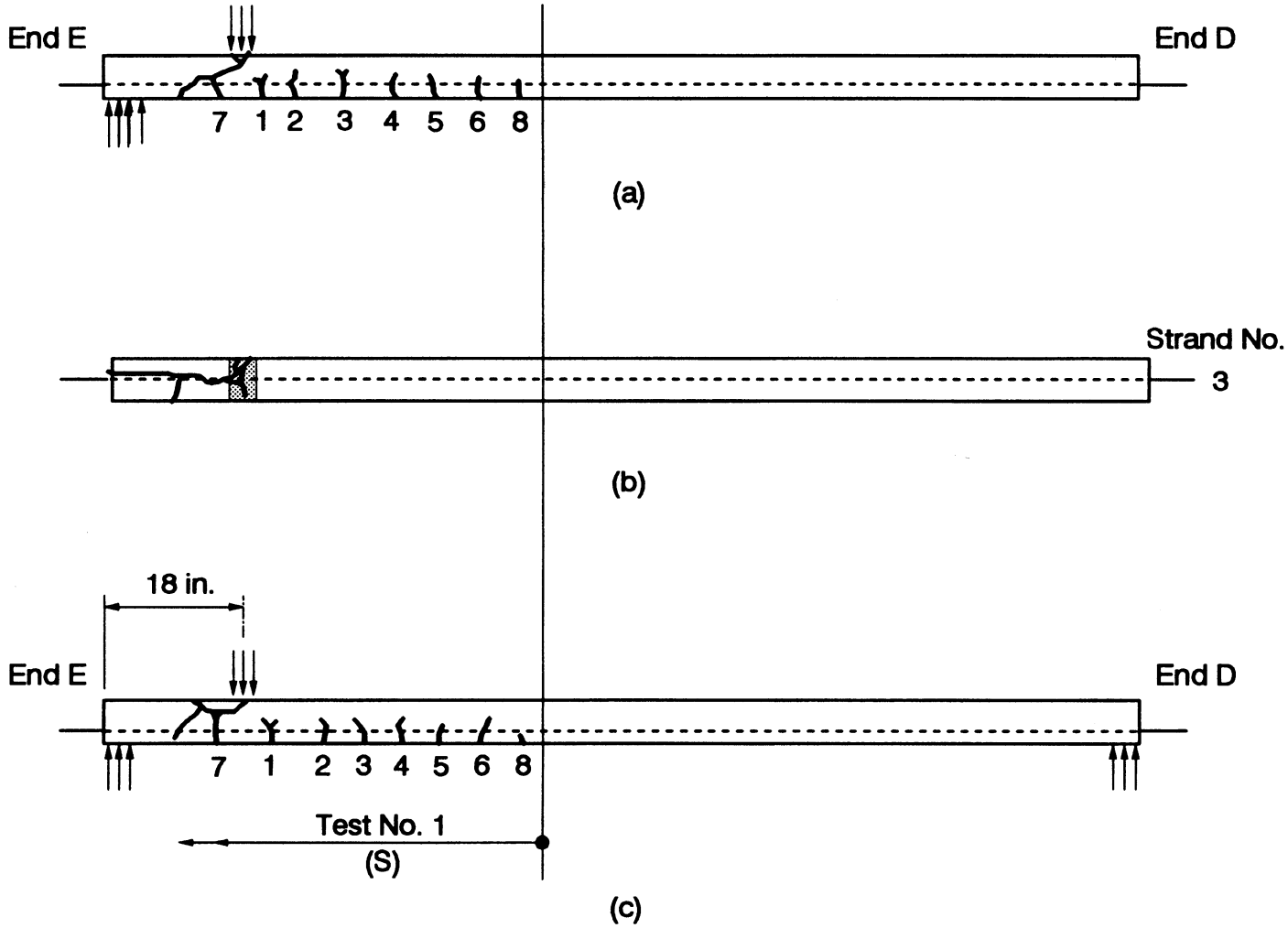


Figure D.39. Crack pattern for D-type Specimen No. 17-6.0DC-11:
(a) mirrored side view along Strand No. 3; (b) top view;
(c) side view along Strand No. 3

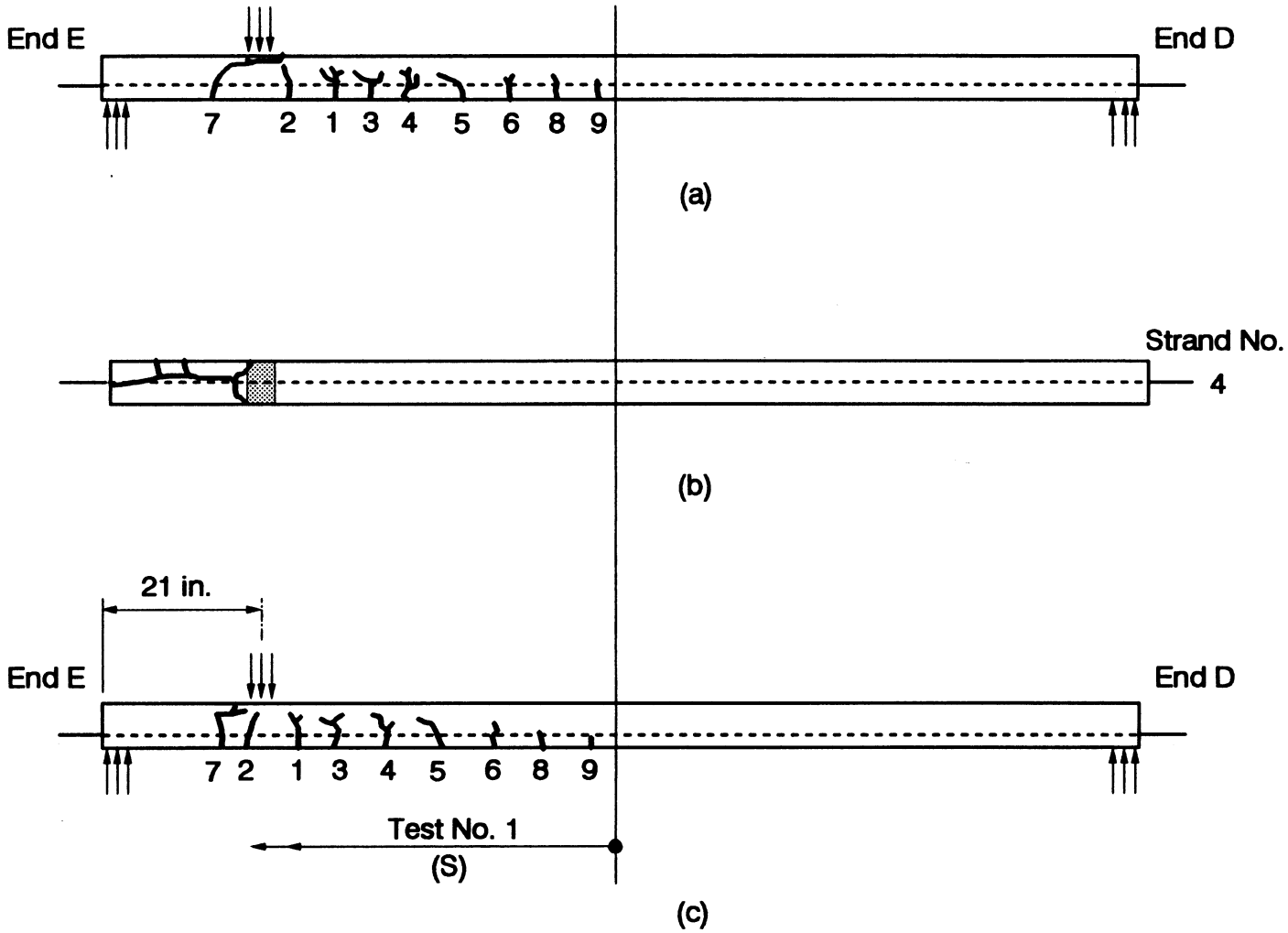


Figure D.40. Crack pattern for D-type Specimen No. 17-6.0DC-12:
(a) mirrored side view along Strand No. 4; (b) top view;
(c) side view along Strand No. 4

APPENDIX E: STRAIN MEASUREMENTS FOR THE T-TYPE SPECIMENS

The transfer lengths for 3/8-in. diameter, seven-wire, 270-ksi, low-relaxation, prestressing strands were experimentally established for grit-impregnated, epoxy-coated strands (coated strands) and for bare strands (uncoated strands). To obtain a graphical representation of the concrete axial strains along a portion of the length of a strand transfer length (T-type) specimen required installation of polyester-mold, embedment strain gages along an end portion and at the middepth of the specimen. These gages that were adjacent to a prestressing strand were used to measure the induced concrete strains immediately after the specimen was prestressed and 18 hours later. By using a slope-intercept approach, the strand transfer length was established as the distance from the end of the specimen to the intersection point of two best-fit straight lines that are drawn through the measured strain data points. Figures E.1-E.4, E.7, and E.8 show the measured strain data and the best-fit straight lines that were established for the monitored uncoated strands; and Figs. E.5, E.6, and E.9-E.11 show these results for the monitored coated strands. The results shown in Fig. E.7a for Strand No. 1 in Specimen No. 15-3.0TU-2 were caused by inadequate consolidation of the concrete around this edge strand.

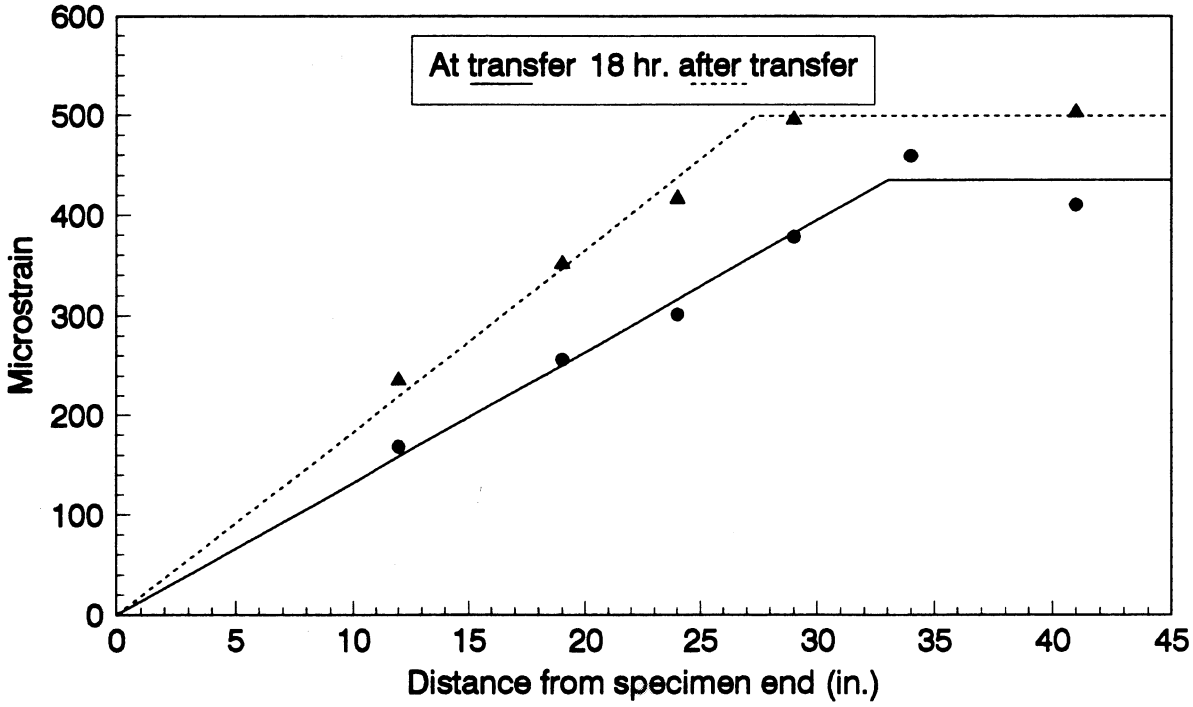


Figure E.1. Strains in Specimen No. 10-3.5TU-6

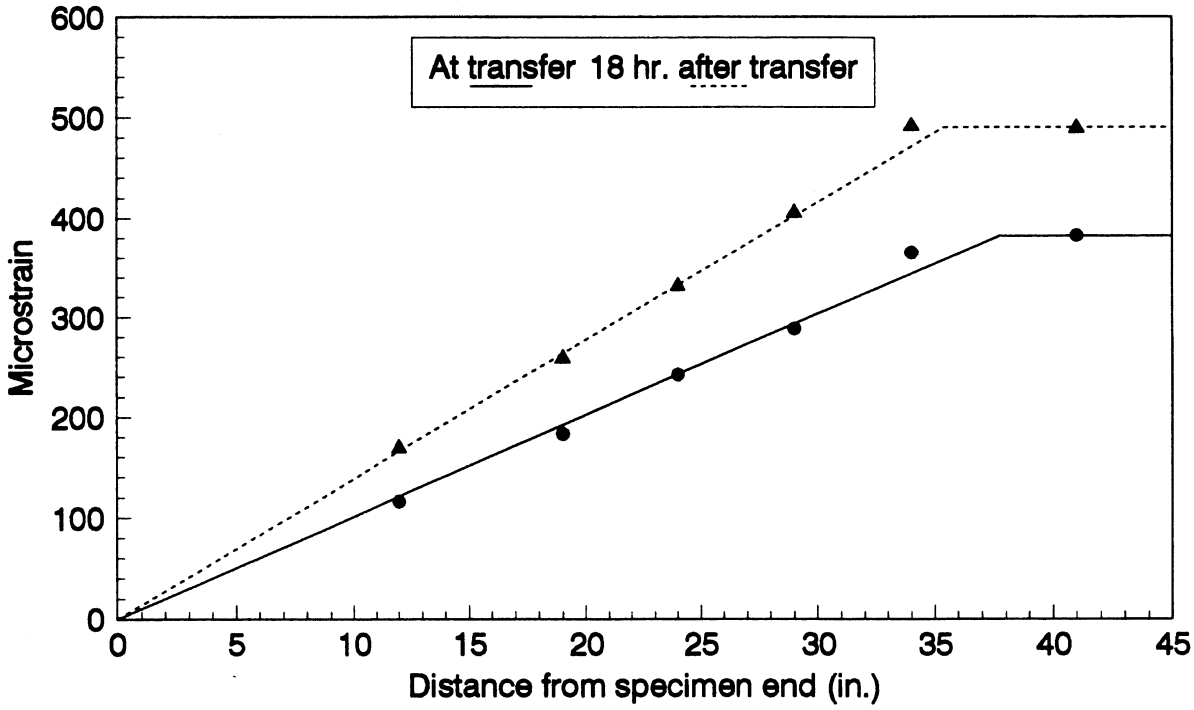


Figure E.2. Strains in Specimen No. 10-3.5TU-7

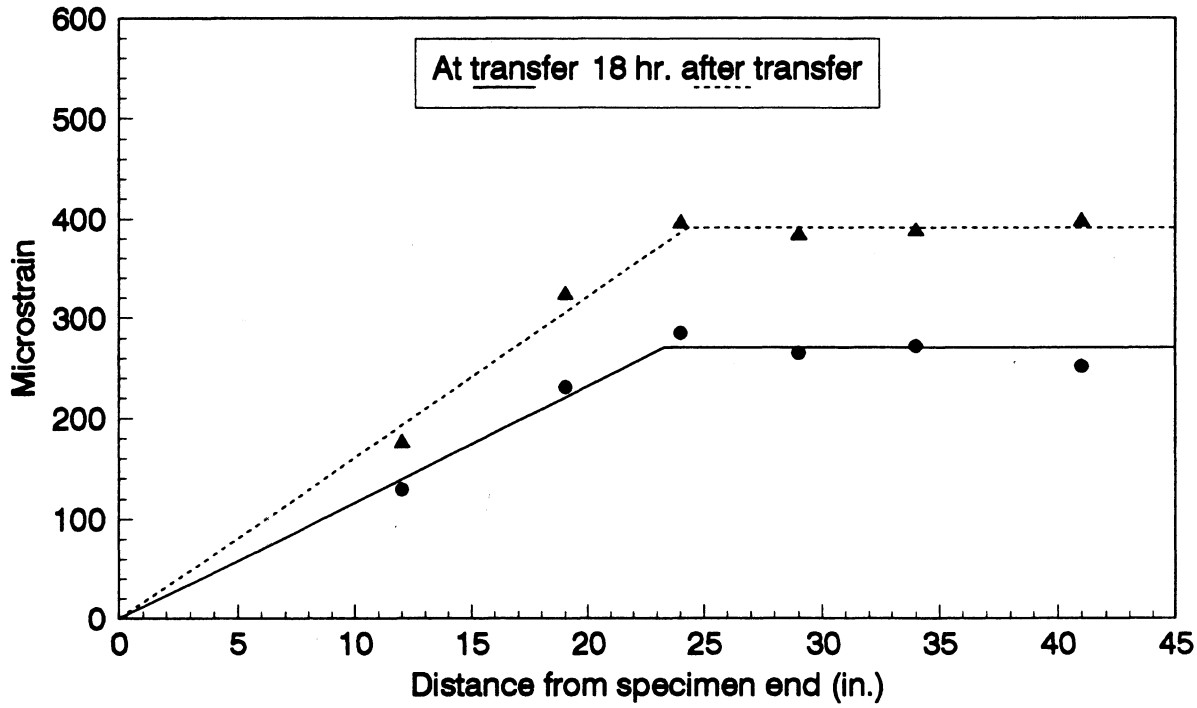


Figure E.3. Strains in Specimen No. 11-3.0TU-6

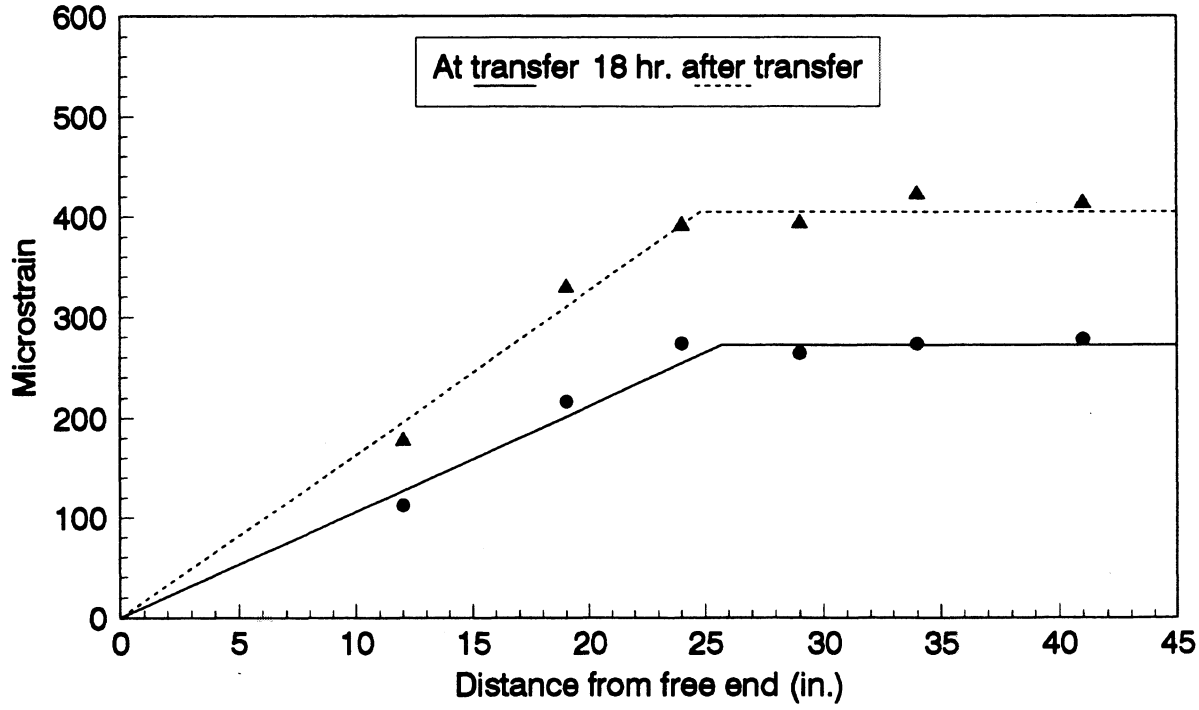
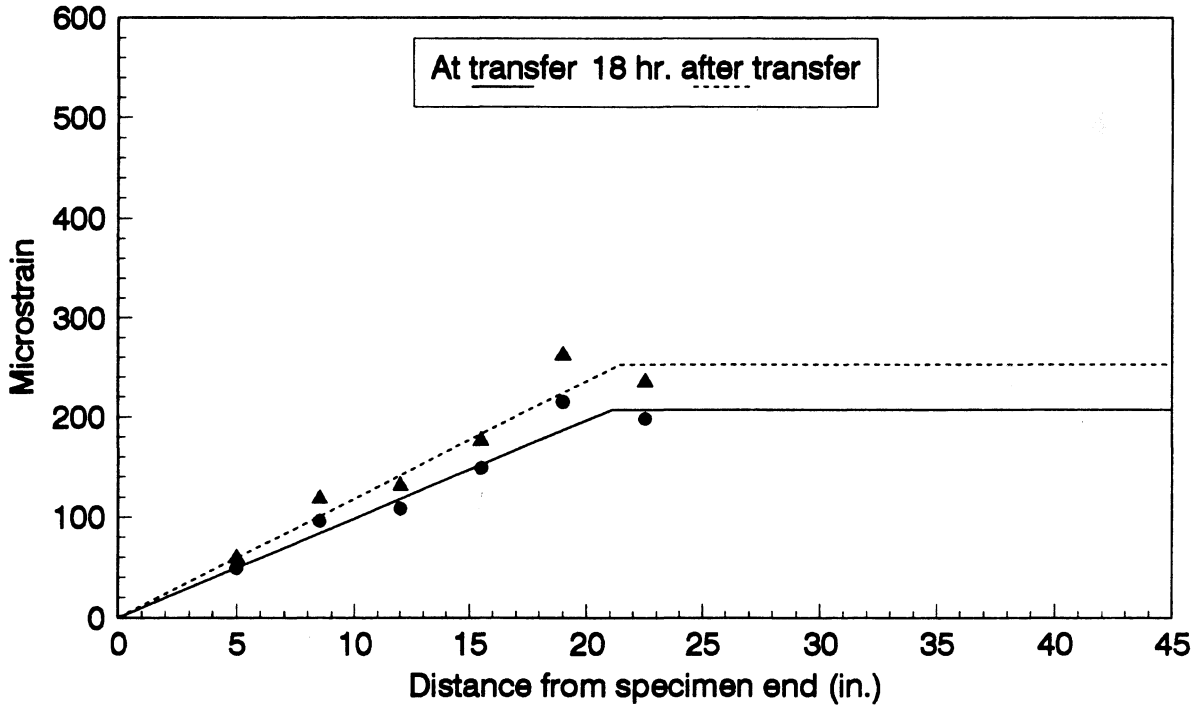
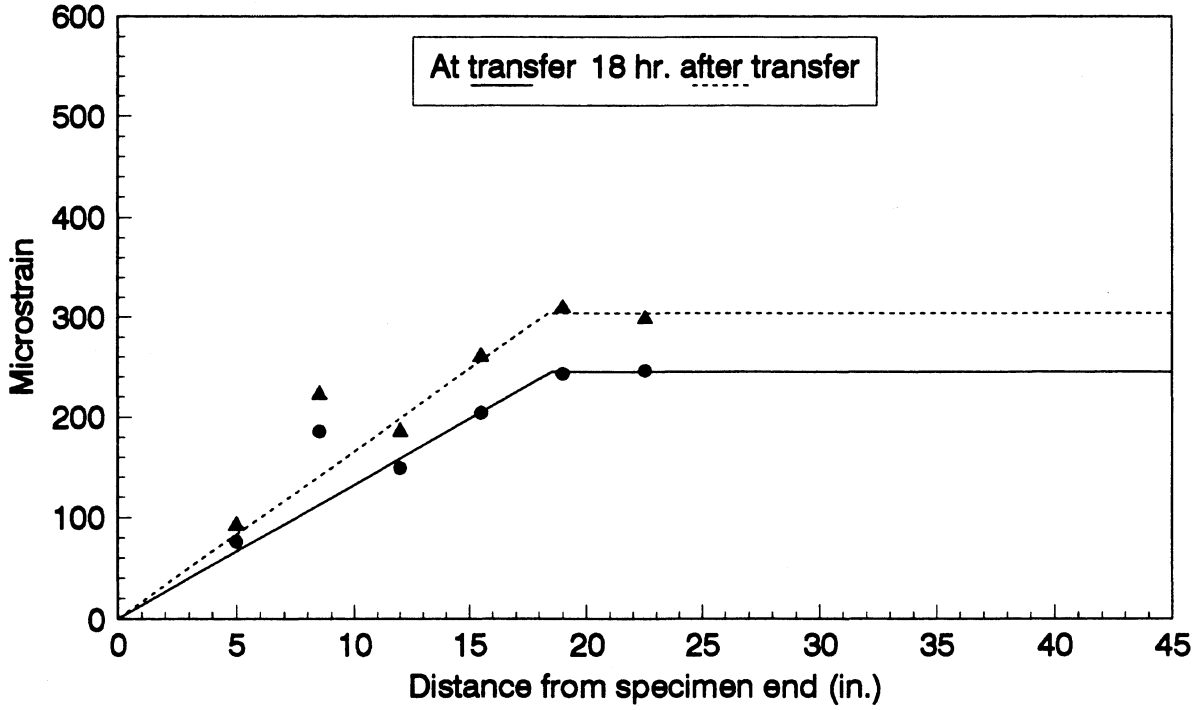


Figure E.4. Strains in Specimen No. 11-3.0TU-7

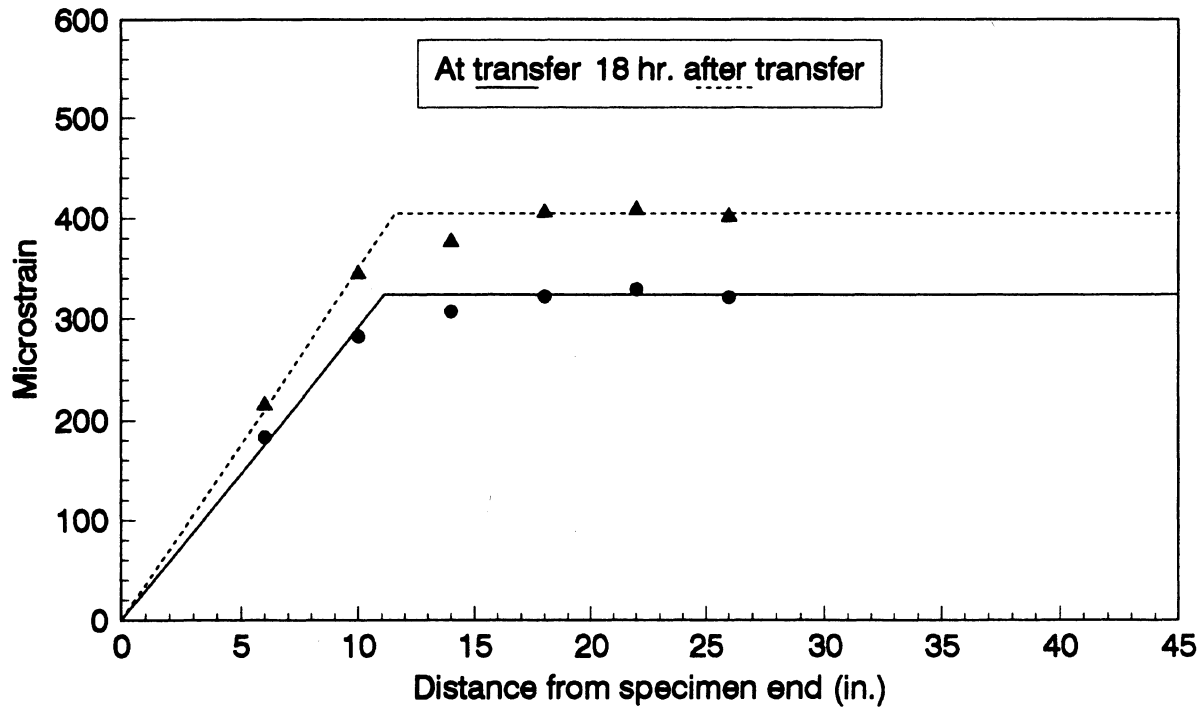


(a)

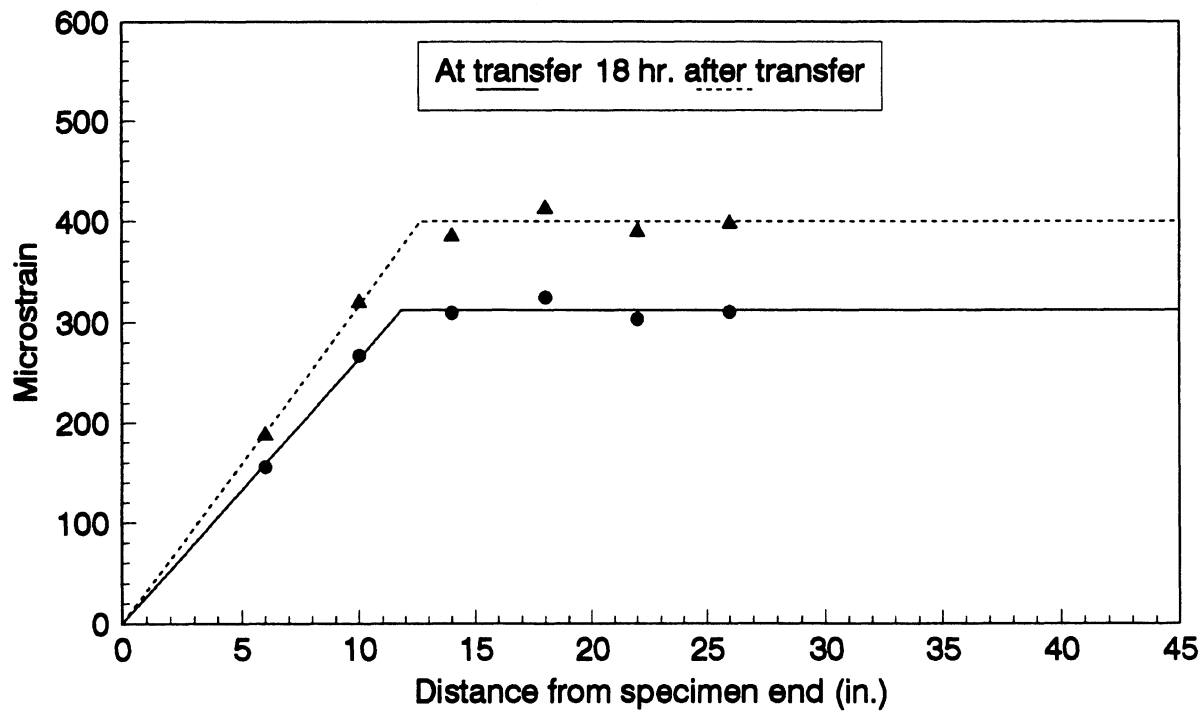


(b)

Figure E.5. Strains in Specimen No. 12-3.0TC-2 at:
(a) Strand No. 1; (b) Strand No. 4

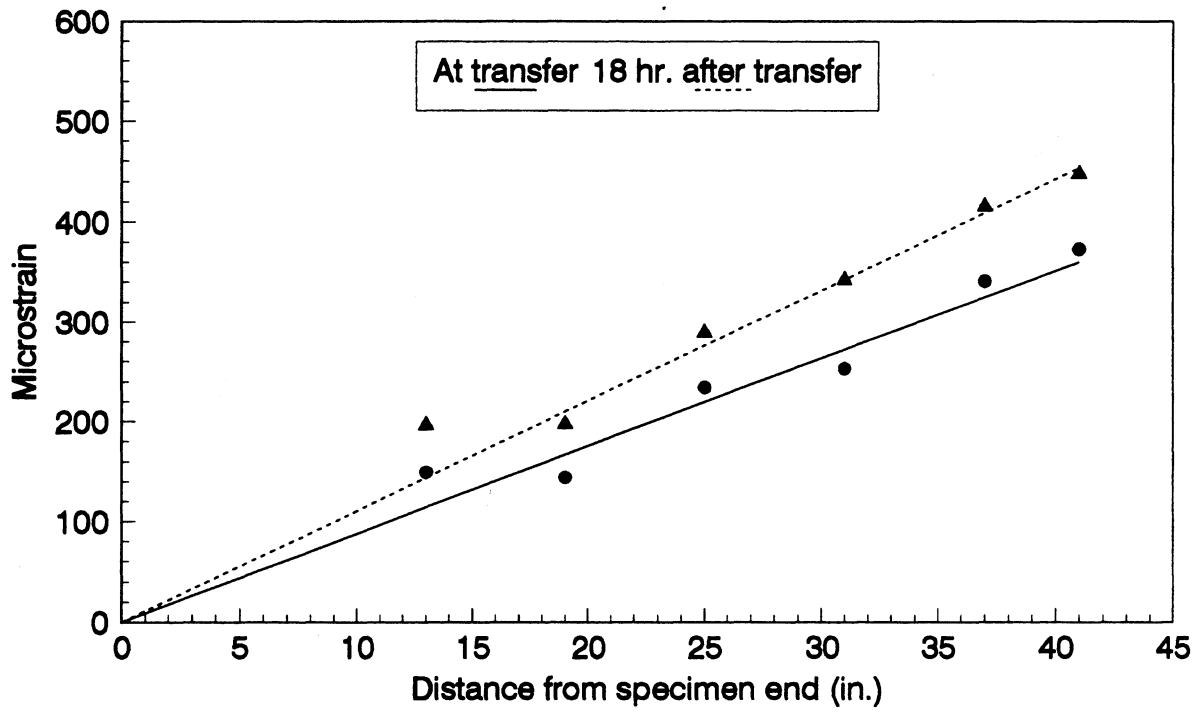


(a)

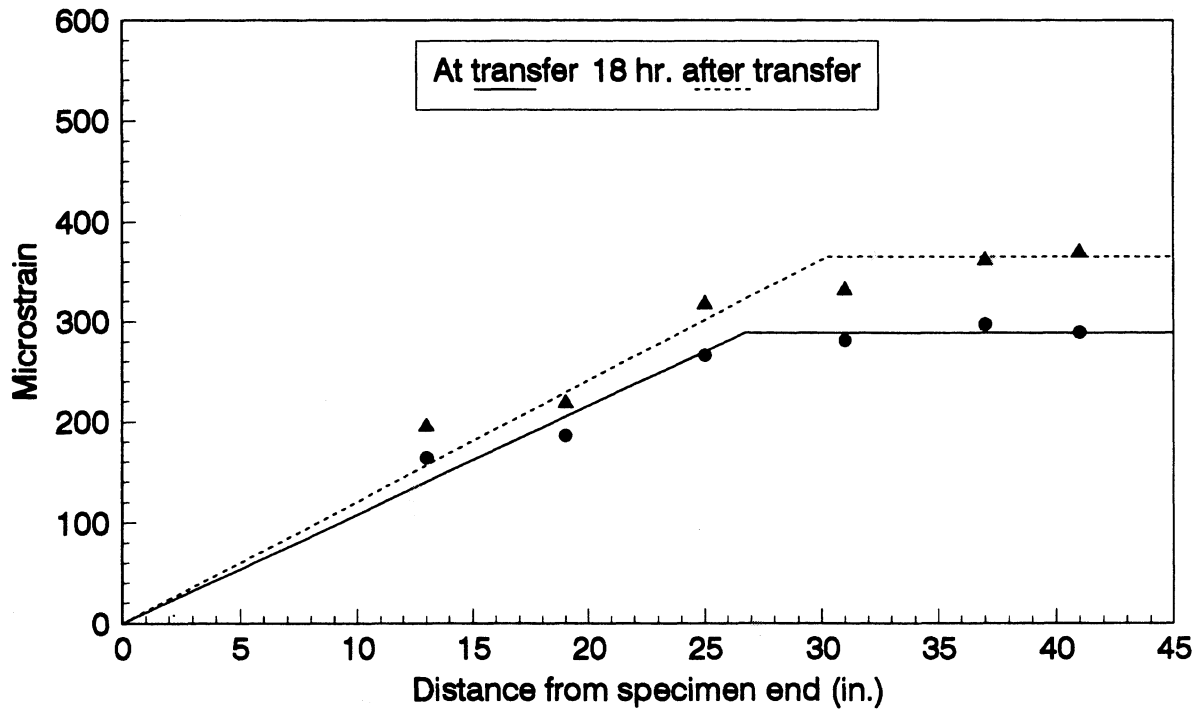


(b)

Figure E.6. Strains in Specimen No. 14-3.0TC-2 at:
(a) Strand No. 1; (b) Strand No. 4

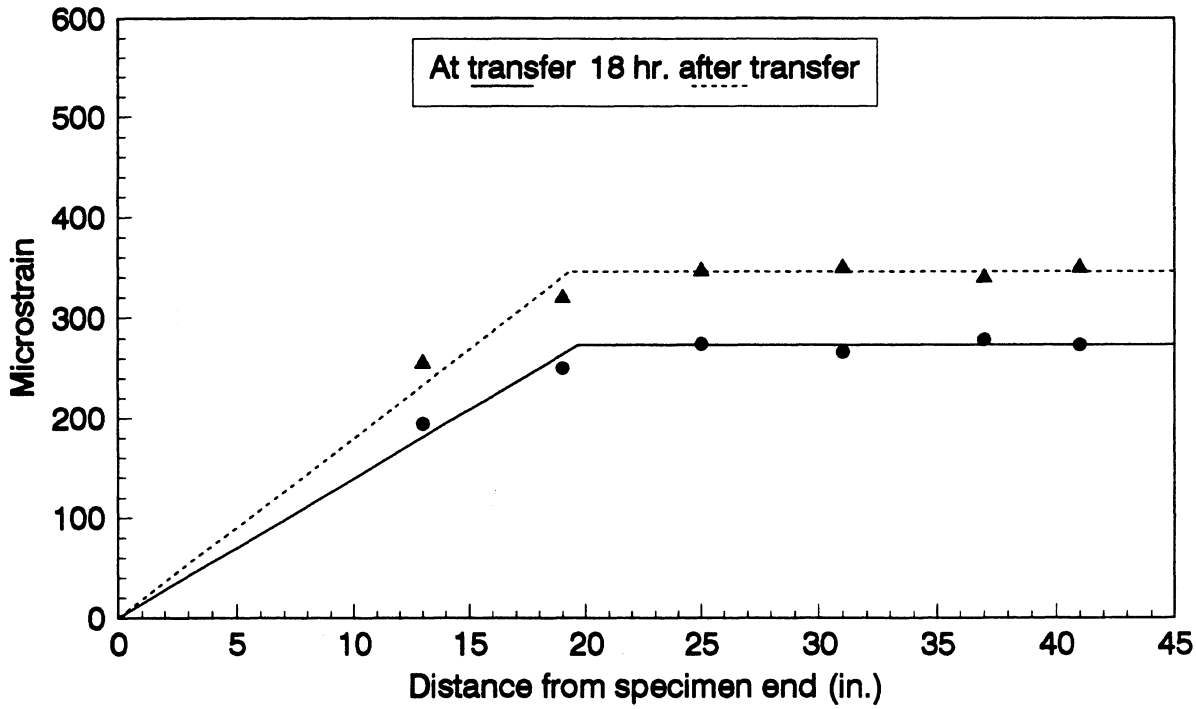


(a)

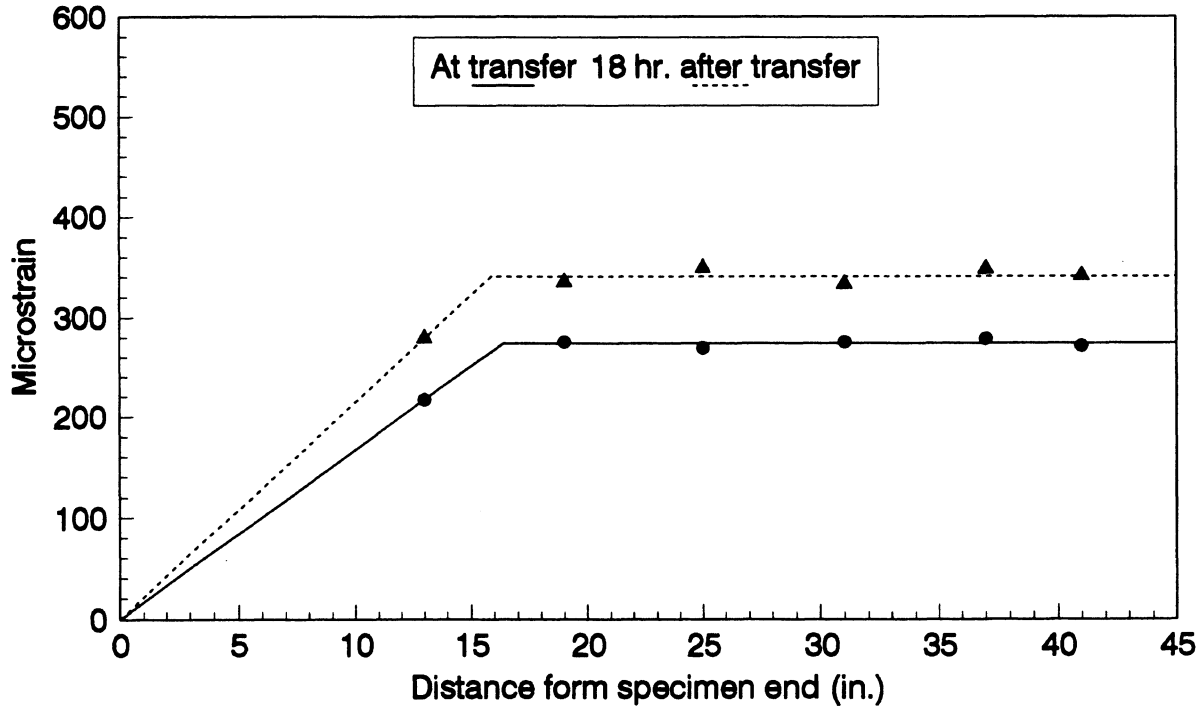


(b)

Figure E.7. Strains in Specimen No. 15-3.0TU-2 at:
(a) Strand No. 1; (b) Strand No. 4



(a)



(b)

Figure E.8. Strains in Specimen No. 16-3.0TU-2 at:
(a) Strand No. 1; (b) Strand No. 4

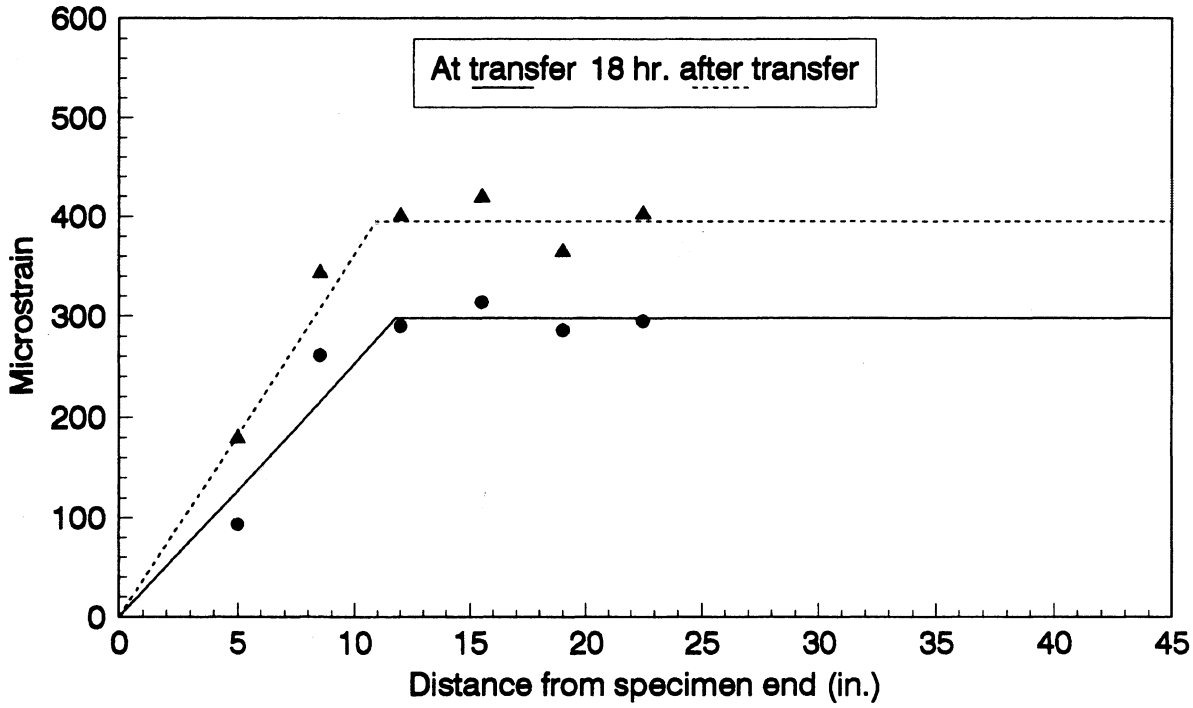


Figure E.9. Strains in Specimen No. 17-3.0TC-6

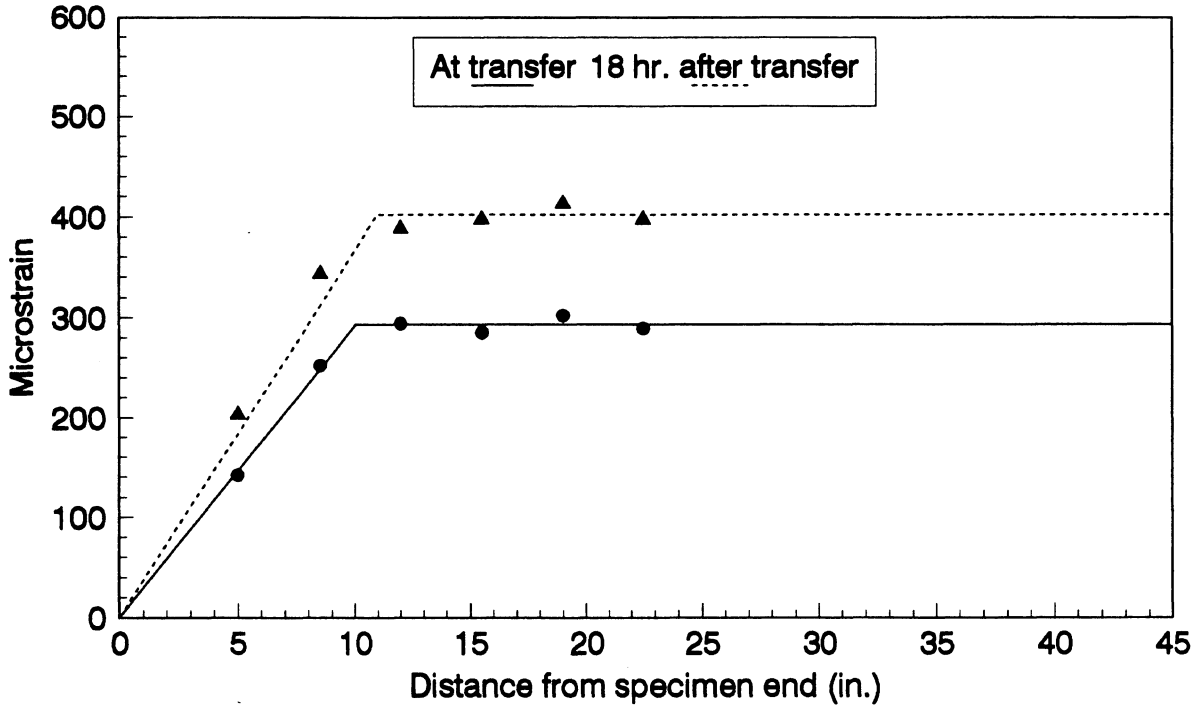


Figure E.10. Strains in Specimen No. 17-3.0TC-7

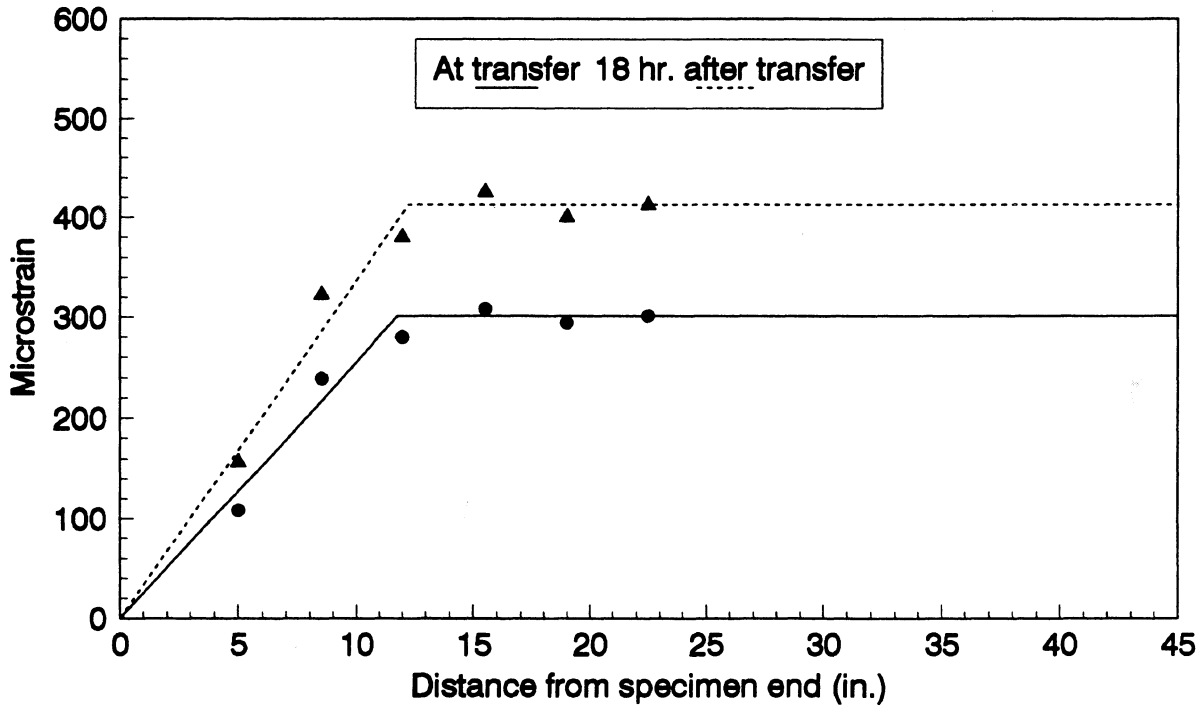
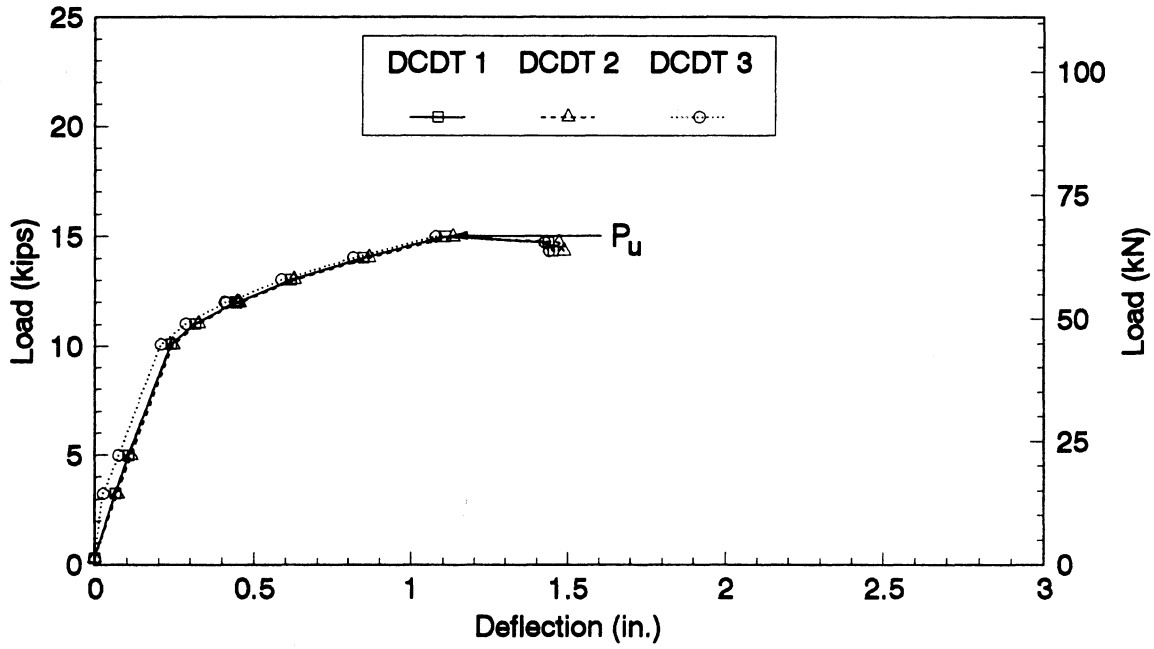


Figure E.11. Strains in Specimen No. 17-3.0TC-8

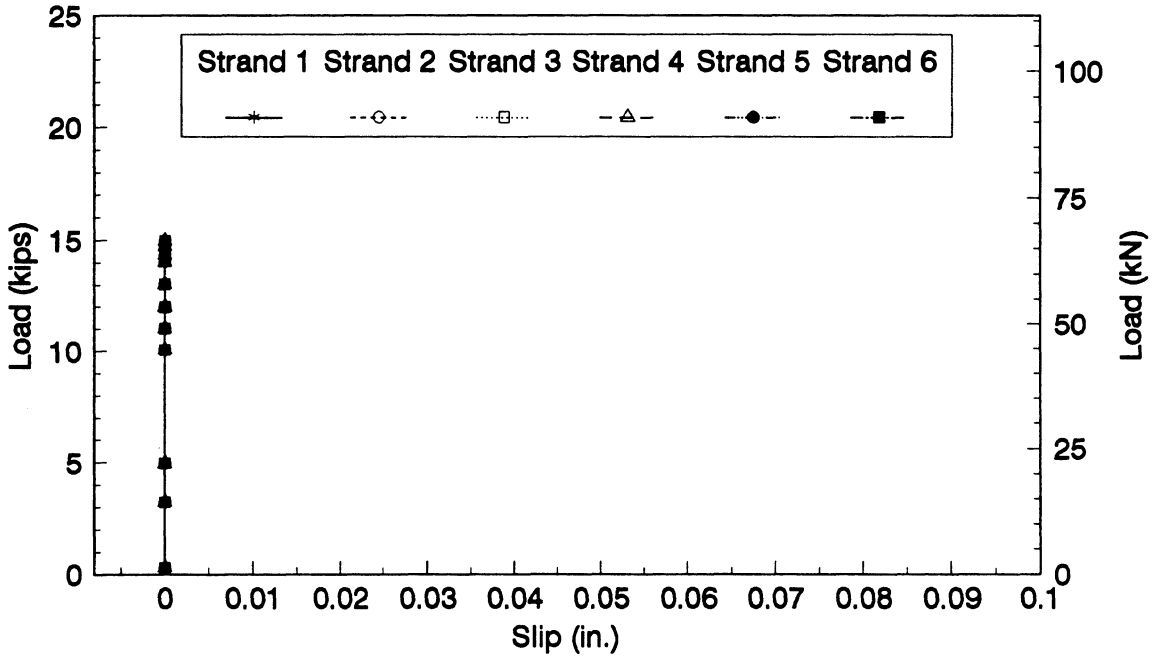
APPENDIX F: DISPLACEMENT MEASUREMENTS FOR THE D-TYPE SPECIMENS

Vertical deflections at the transverse load location and strand-slips at the ends of the strand development length (D-type) specimens that were measured during the strand development length tests are shown in Figs. F.1-F.60. By testing a series of specimens with different locations of the transverse load, the strand development length was established. This length is defined as the shortest distance between the transverse load and the end of the specimen for which a flexural failure of the specimen occurred prior to any of the prestressing strands experiencing slip. The figures in this appendix show the load versus load point deflection and load versus strand-slip relationships for the D-type specimens that were prestressed with 3/8-in. diameter, seven-wire, 270-ksi, low-relaxation, grit-impregnated, epoxy-coated strands (coated strands) and bare strands (uncoated strands). For the load versus deflection graphs, the load notations P_c, P_s, and P_u represent the load for which the first concrete crack was detected, the first strand-slip was obtained, and the ultimate strength of the specimen was reached, respectively. A bond failure of a prestressing strand was considered to have occurred when the strand-slip measurement for a strand reached 0.01 in. The load versus displacement relationships for the uncoated strands are shown in Figs. F.1-F.6, F.14-F.35, and F.44-F.51, and for the coated strands are shown in Figs. F.7-F.13, F.36-F.43, and F.52-F.60.

To produce load versus displacement relationships that can be easily interpreted, the researchers selected different scales in the graphs for the single-strand and multiple-strand specimens and whether coated or uncoated strands were used. The graphs of the load versus displacement were terminated just beyond the displacement corresponding to the load P_u; therefore, for some of the load versus strand-slip relationships, the graphs may not show all of the strand-slips that are listed in Table 5.13-5.18 of Volume 1 and listed in the failure sequences shown in the figures in Appendix D.

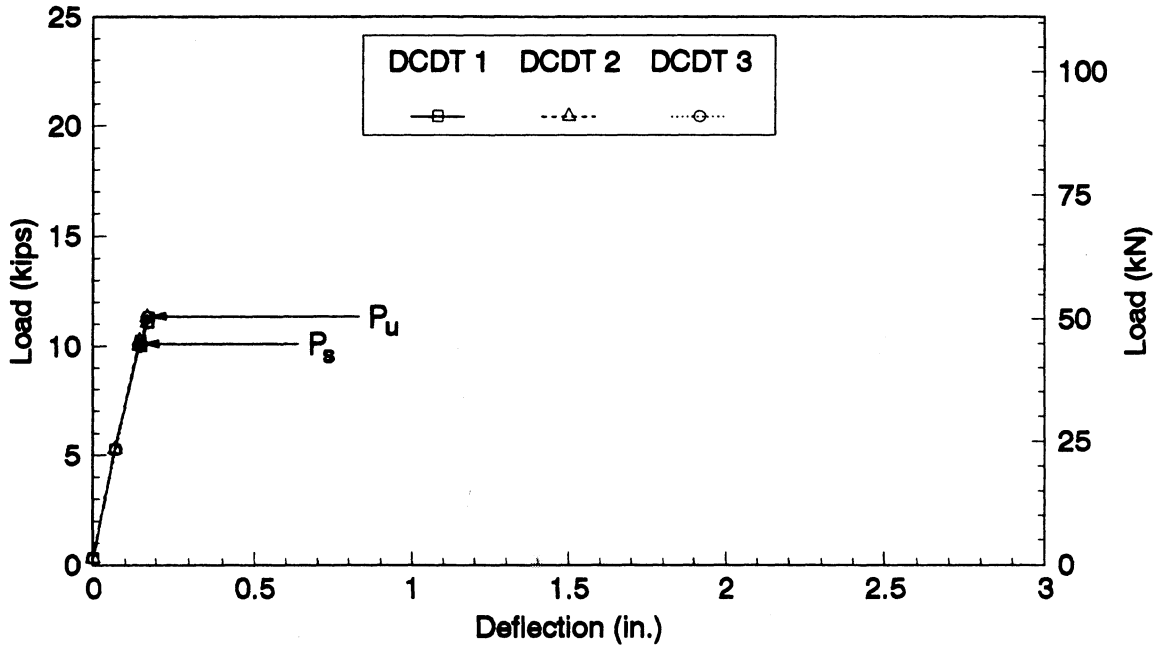


(a)

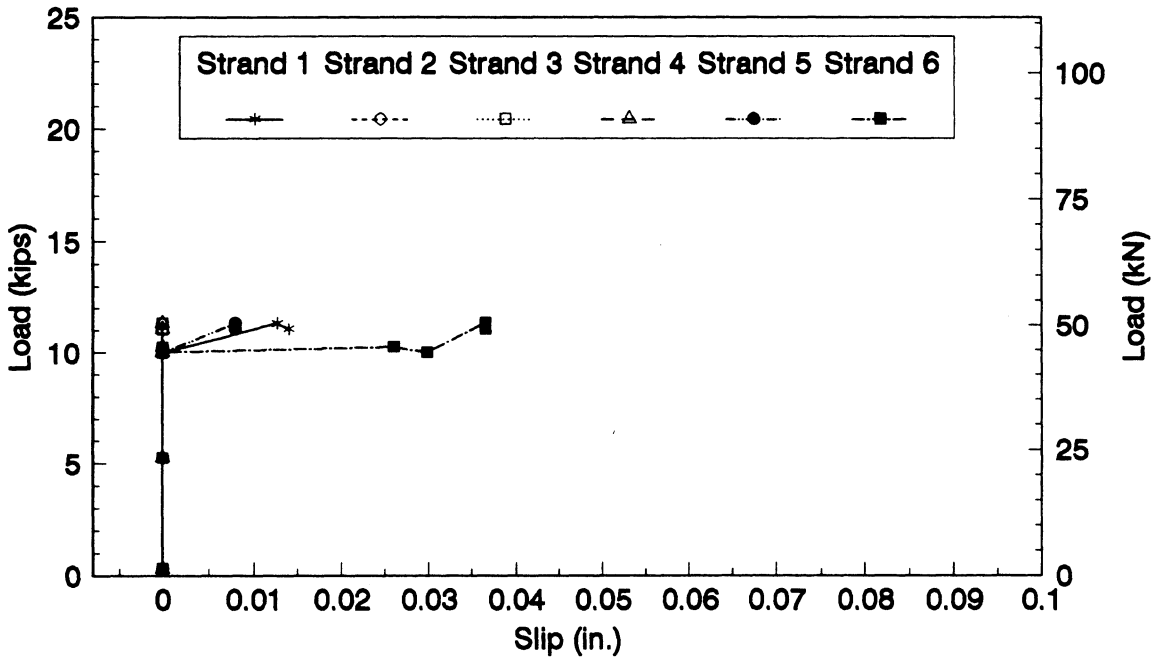


(b)

Figure F.1. Development length test of Specimen No. 6-6.0DU-1 with the load at 50 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

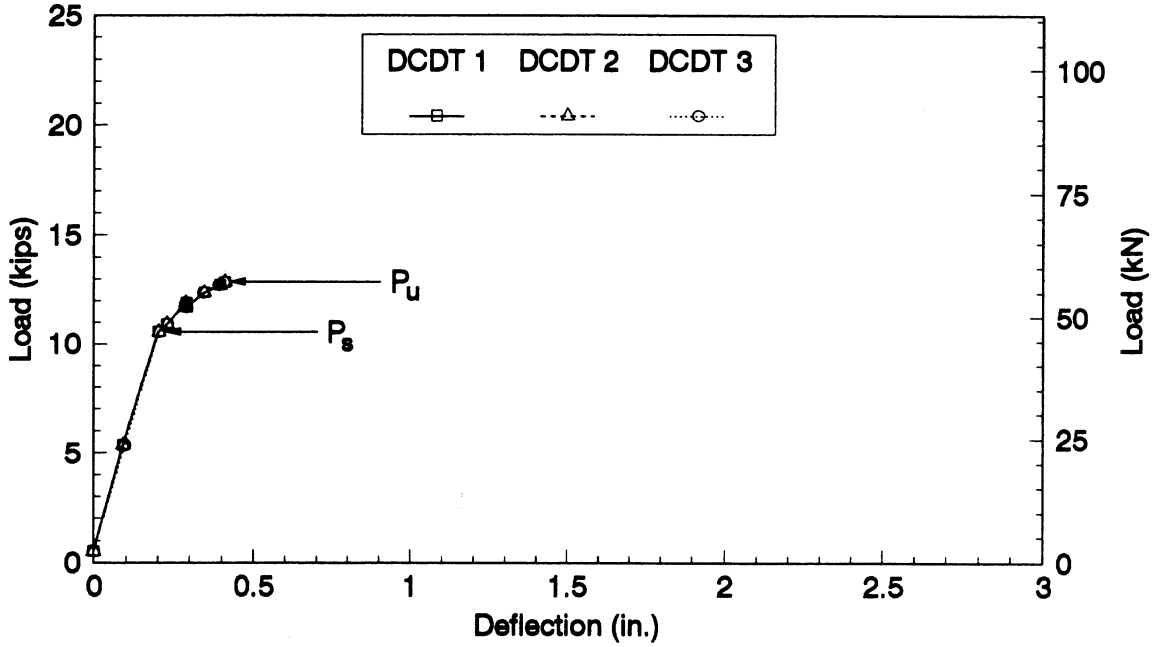


(a)

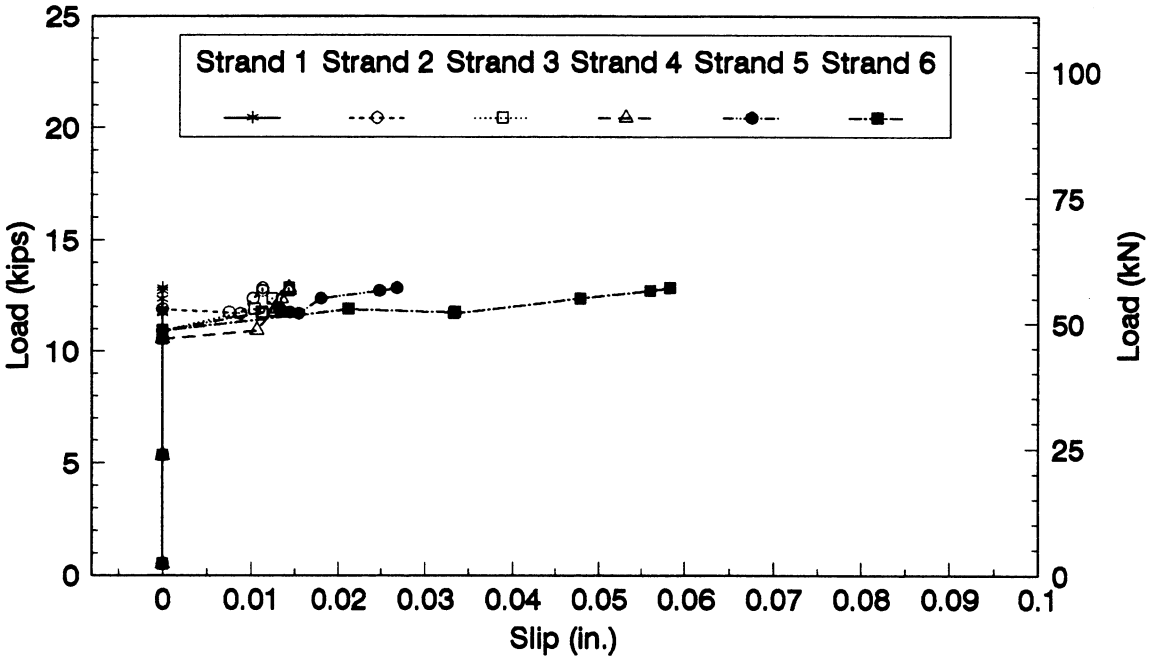


(b)

Figure F.2. Development length test of Specimen No. 6-6.0DU-3 with the load at 30 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

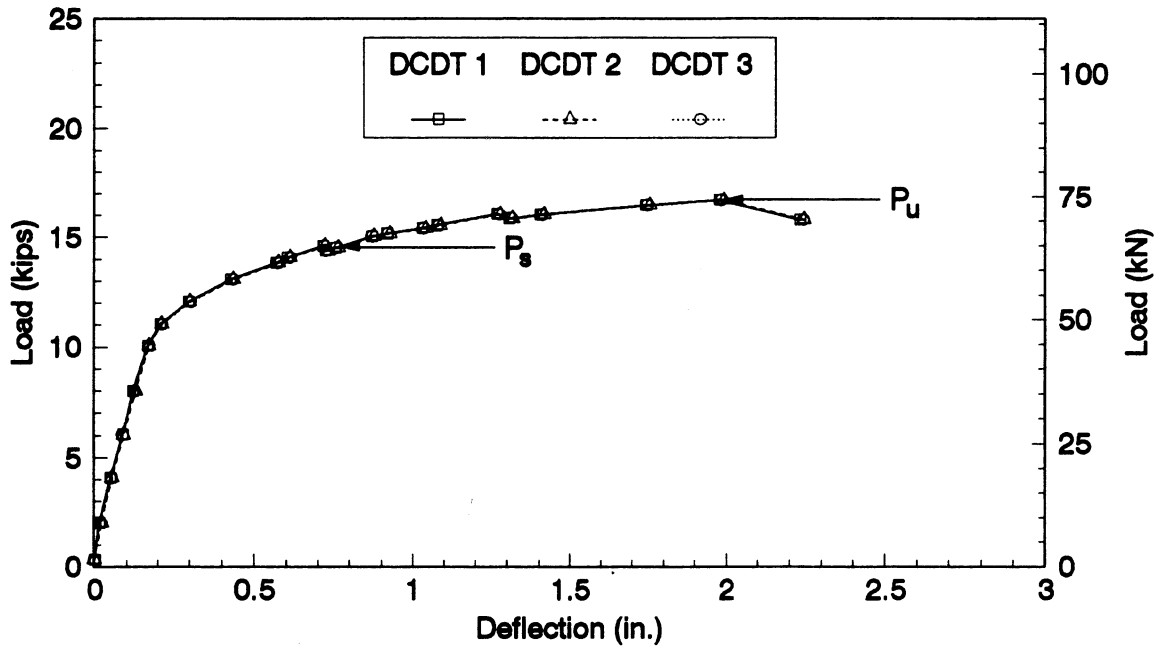


(a)

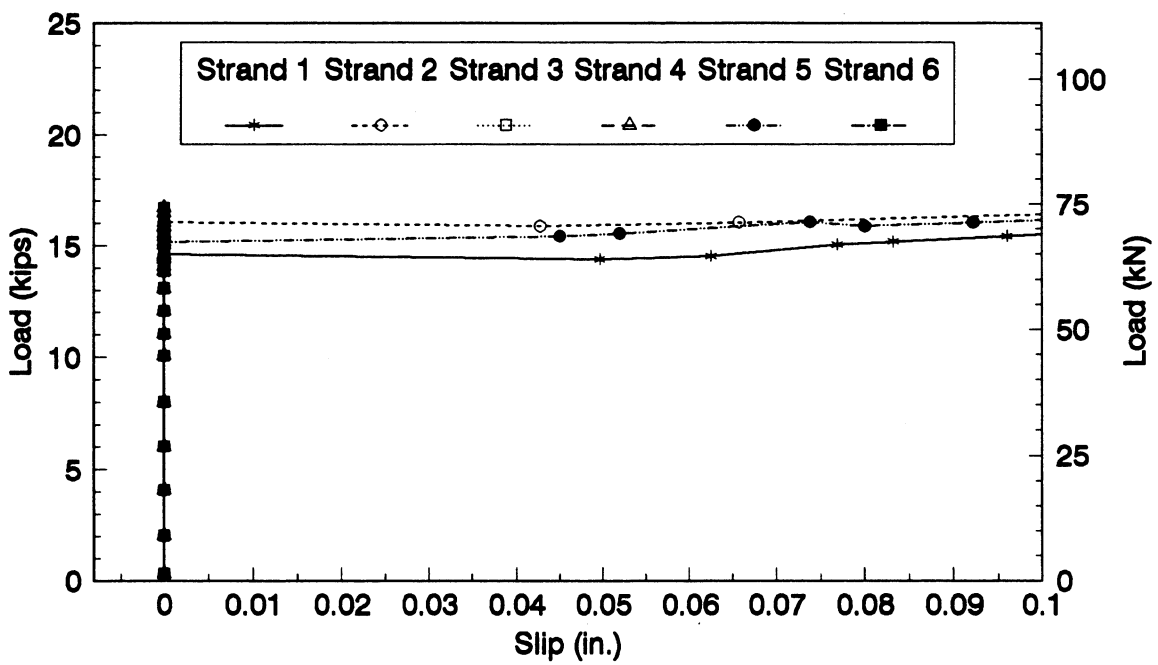


(b)

Figure F.3. Development length test of Specimen No. 6-6.0DU-3 with the load at 40 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

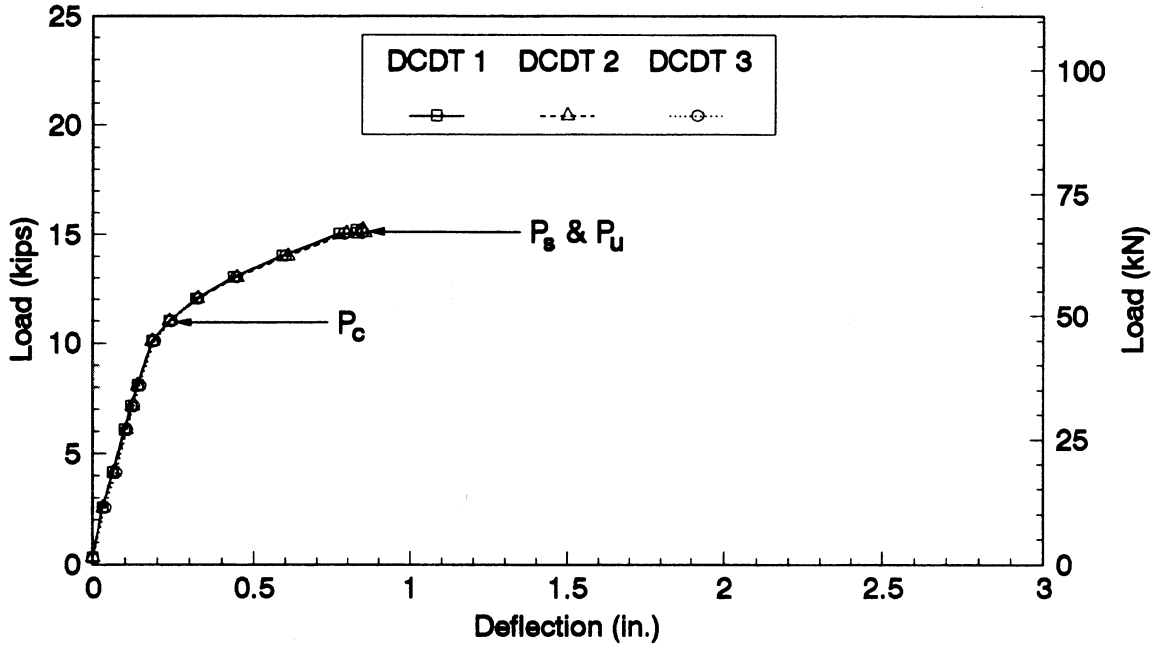


(a)

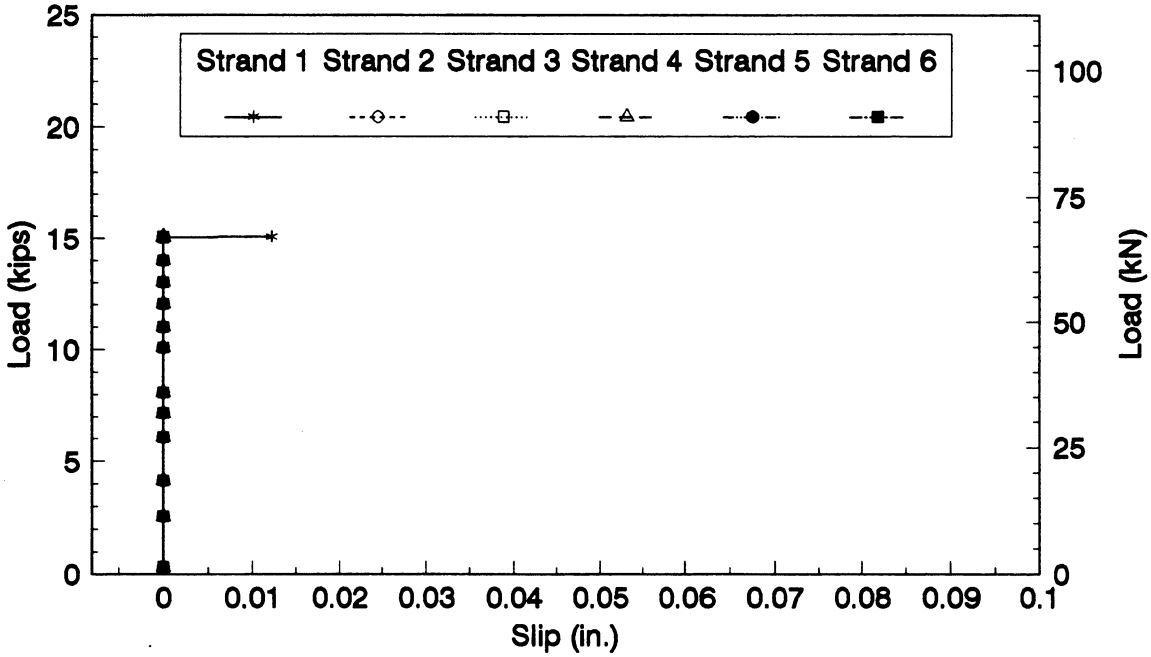


(b)

Figure F.4. Development length test of Specimen No. 7-6.0DU-3 with the load at 45 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

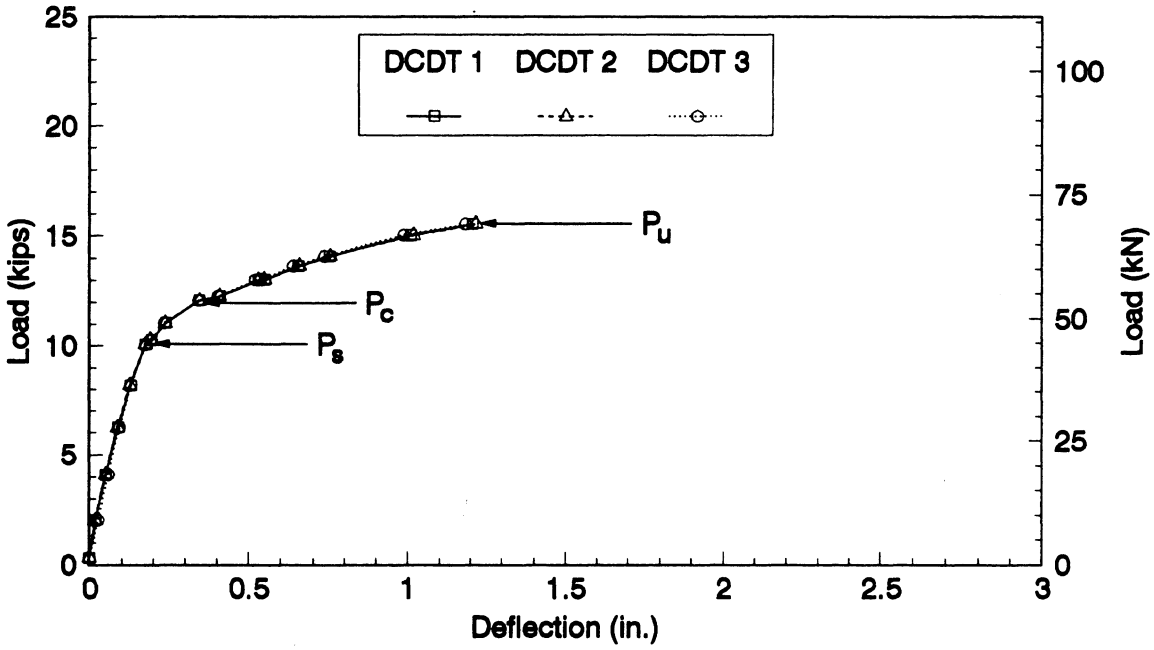


(a)

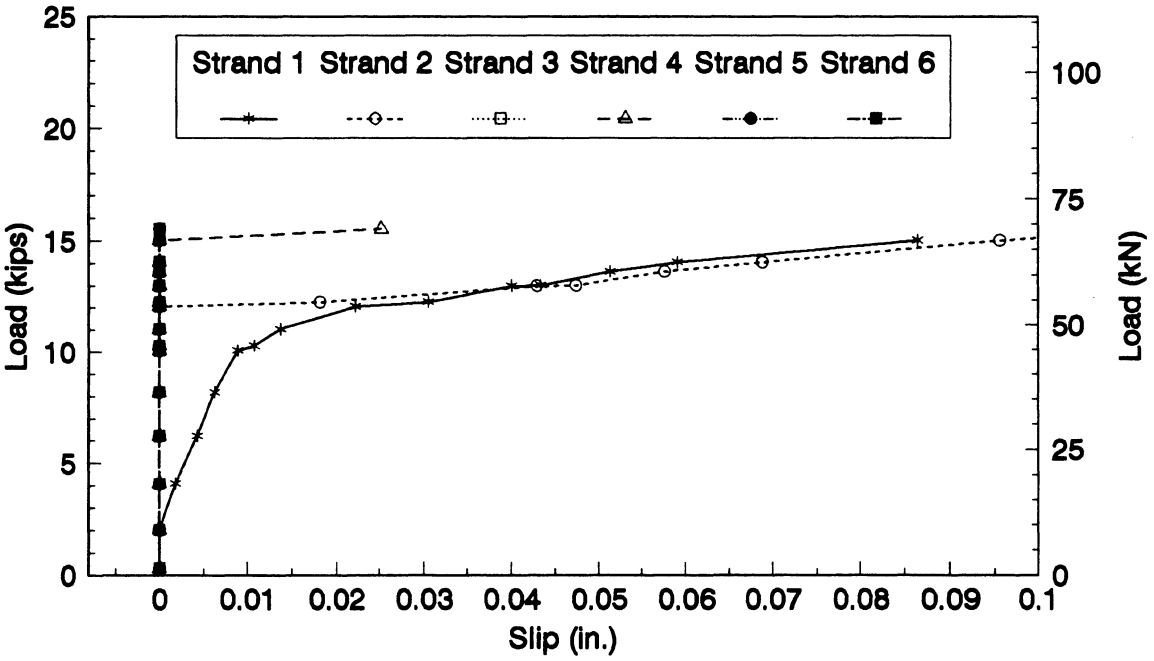


(b)

Figure F.5. Development length test of Specimen No. 7-6.0DU-1 with the load at 45 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

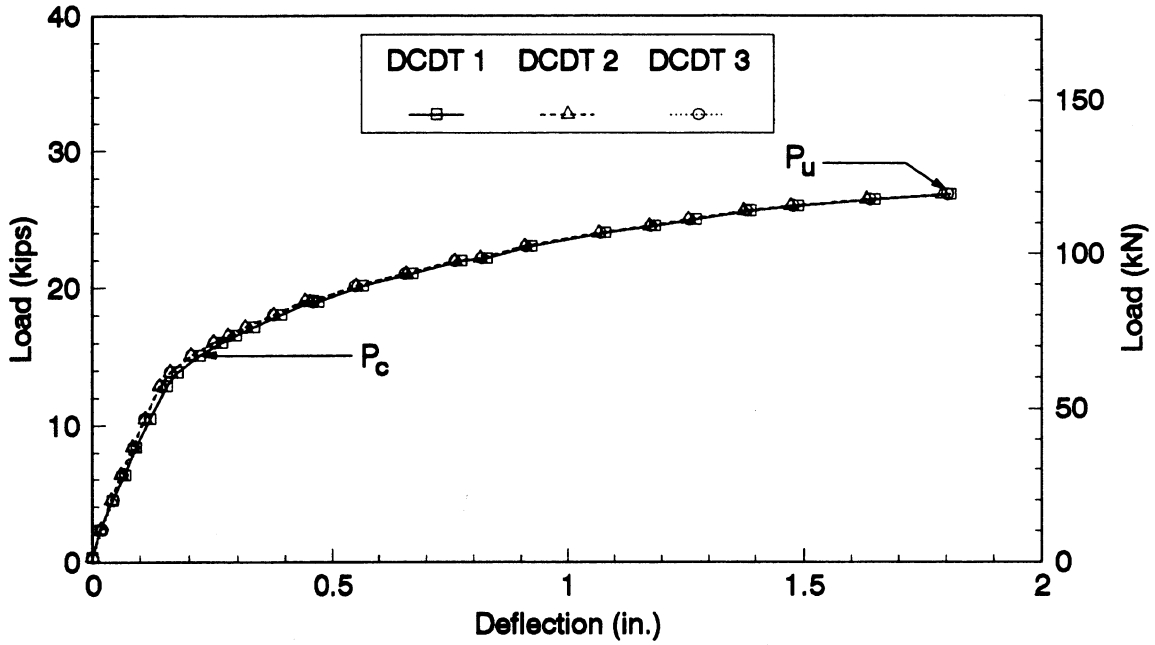


(a)

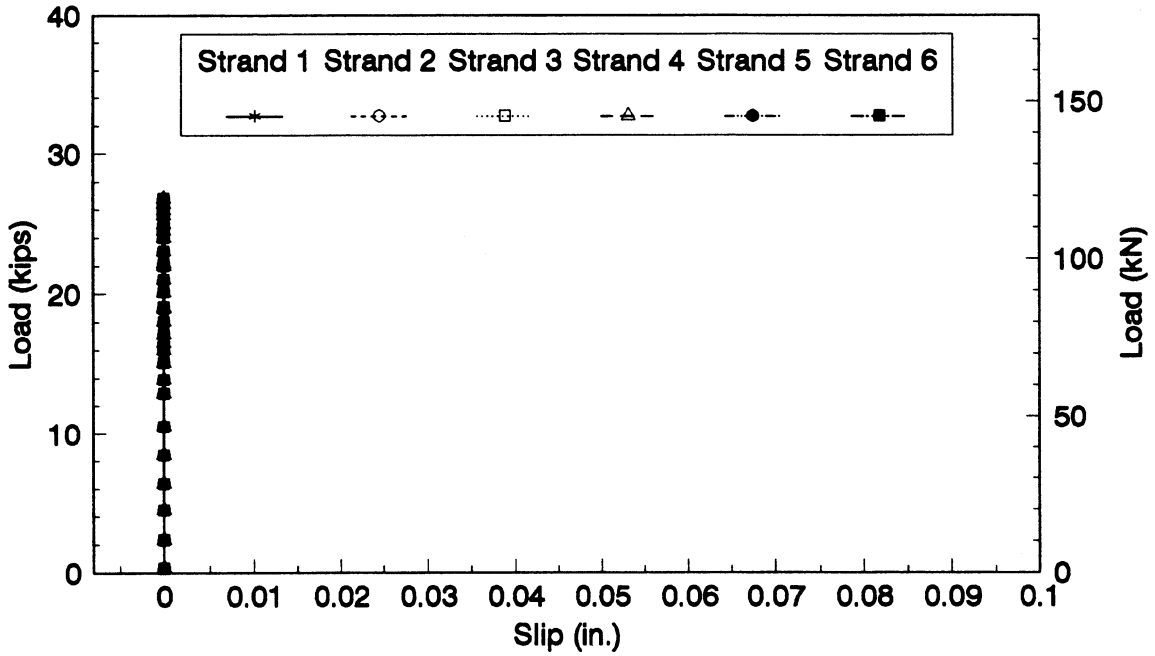


(b)

Figure F.6. Development length test of Specimen No. 7-6.0DU-1 with the load at 42 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

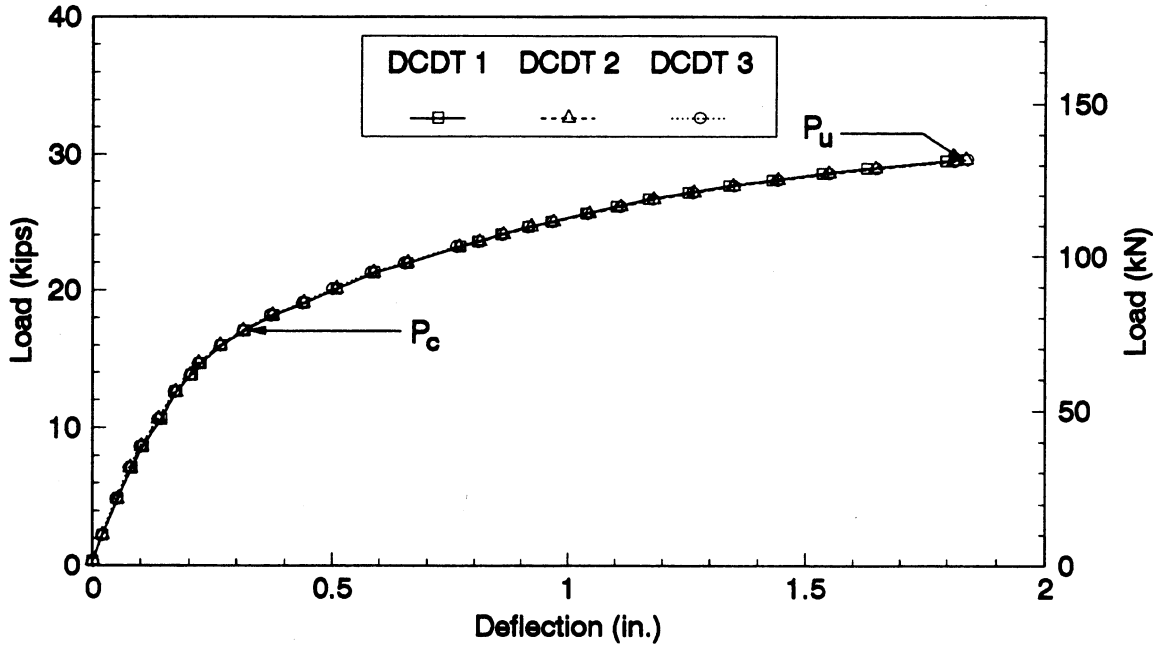


(a)

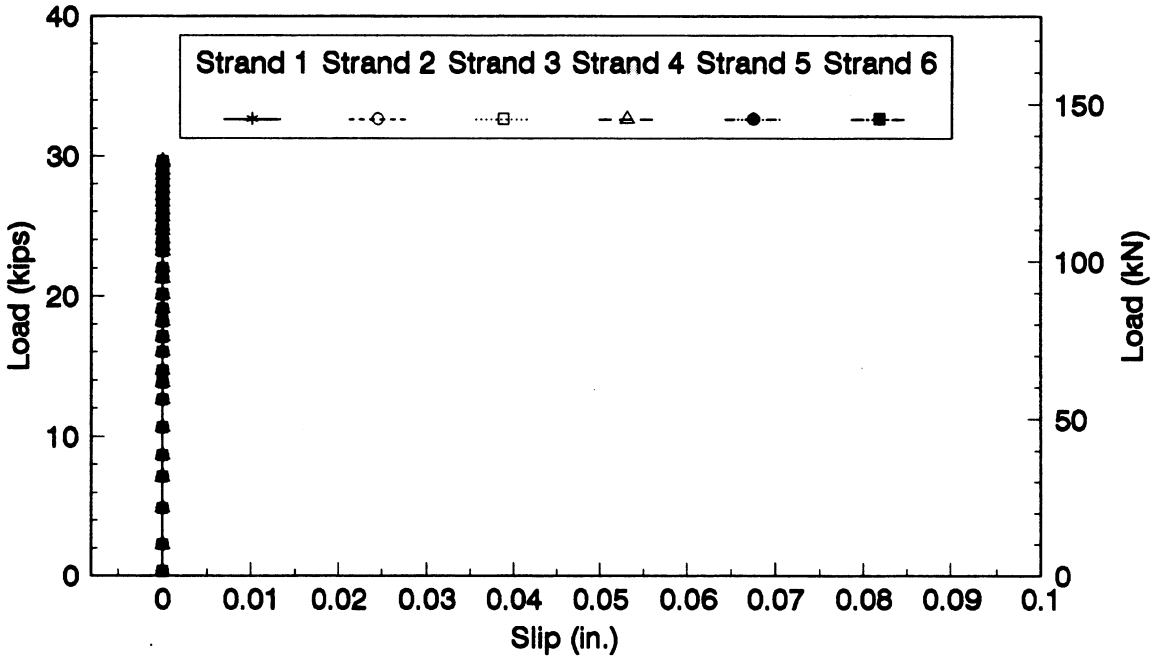


(b)

Figure F.7. Development length test of Specimen No. 8-6.0DC-1 with the load at 28 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

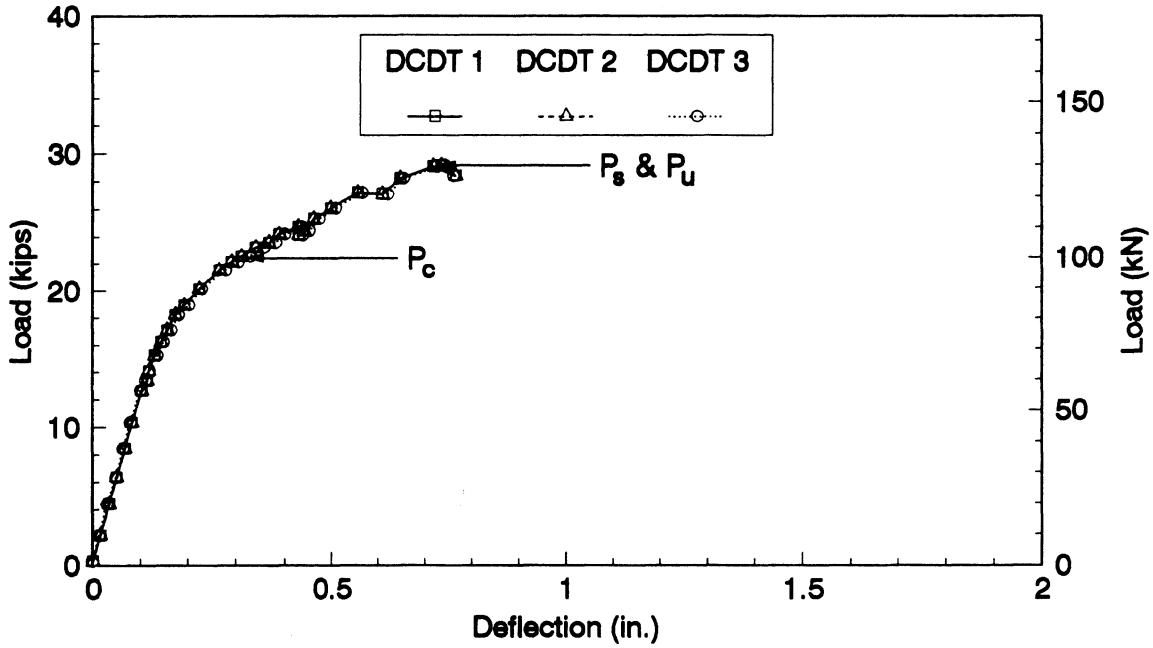


(a)

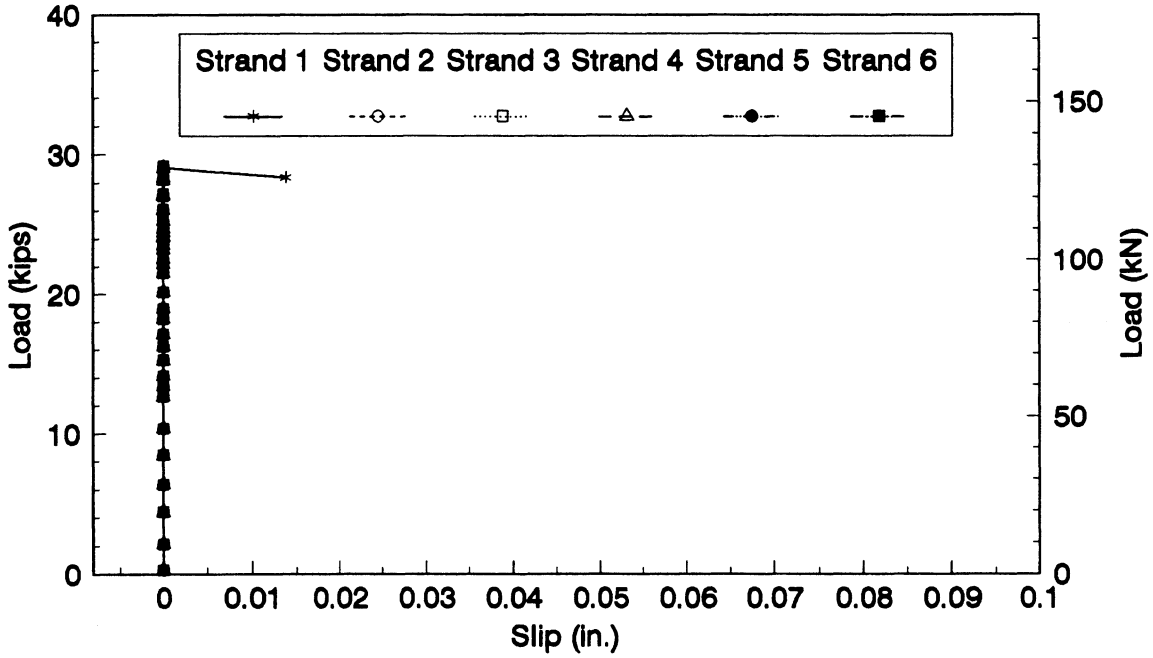


(b)

Figure F.8. Development length test of Specimen No. 8-6.0DC-1 with the load at 26 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

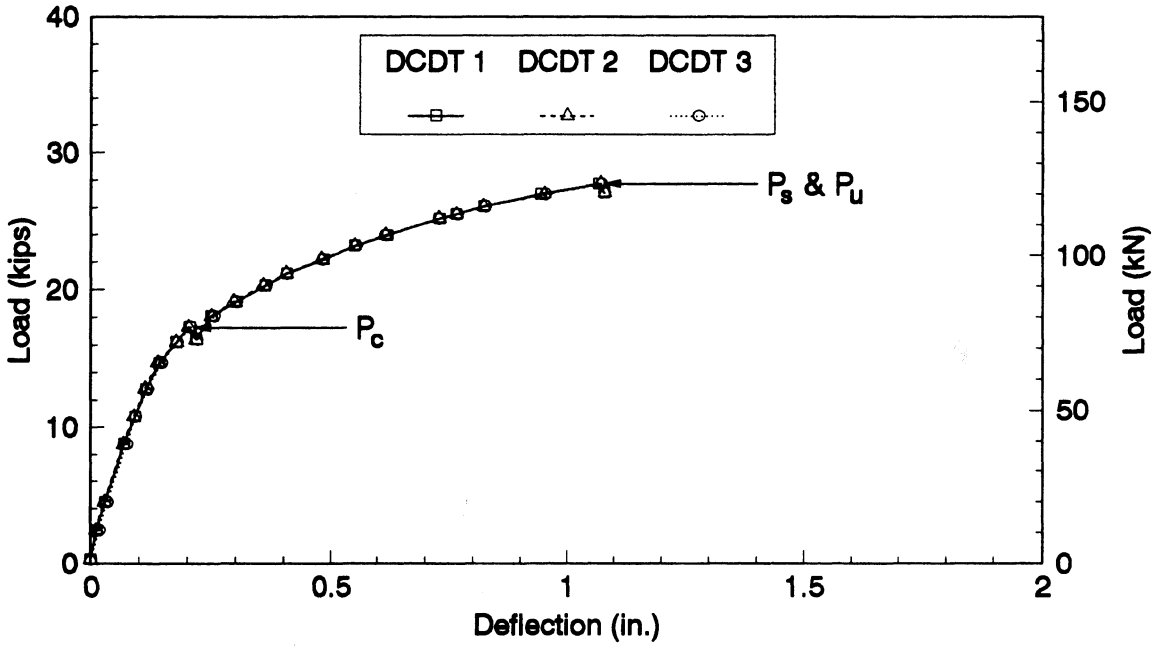


(a)

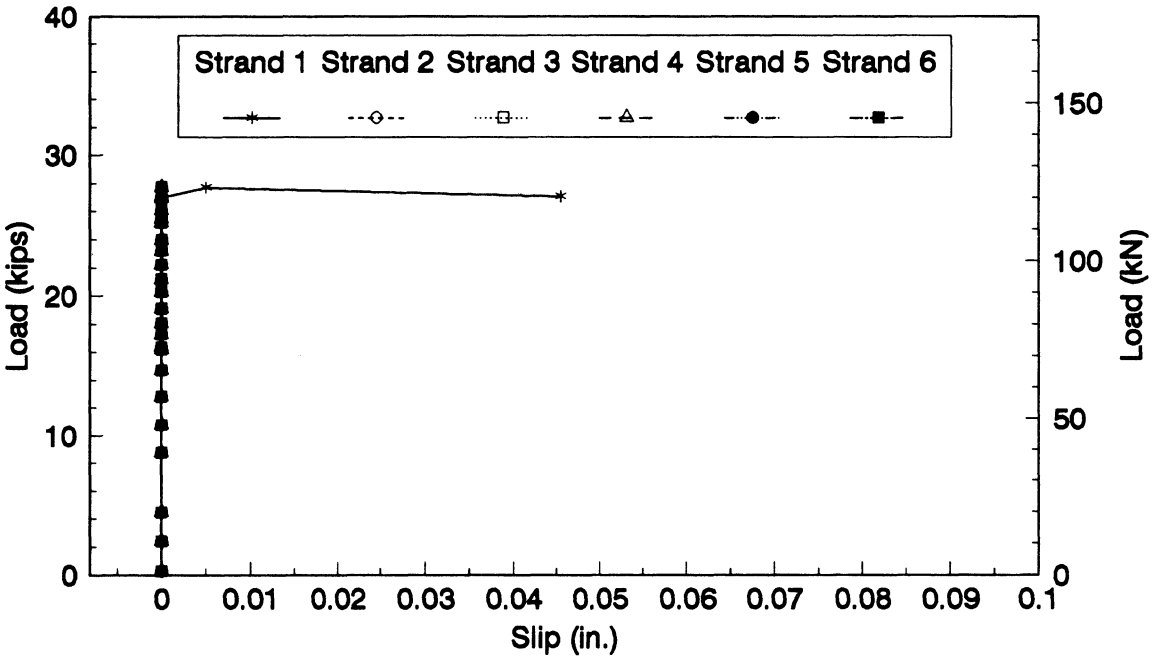


(b)

Figure F.9. Development length test of Specimen No. 8-6.0DC-3 with the load at 21.5 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

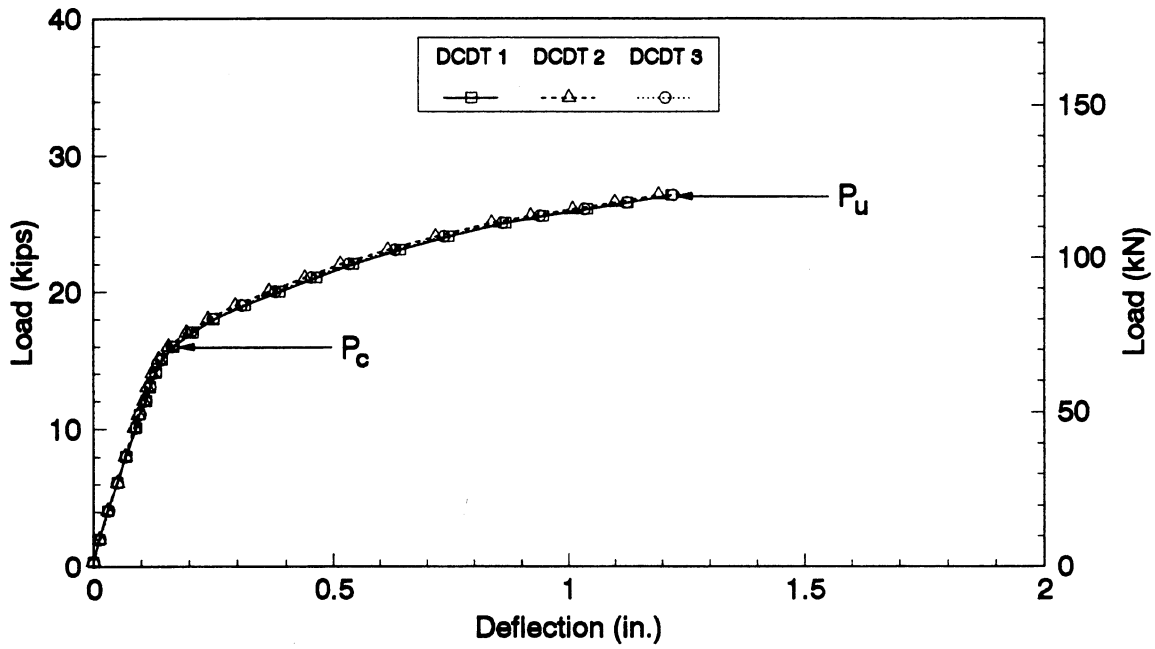


(a)

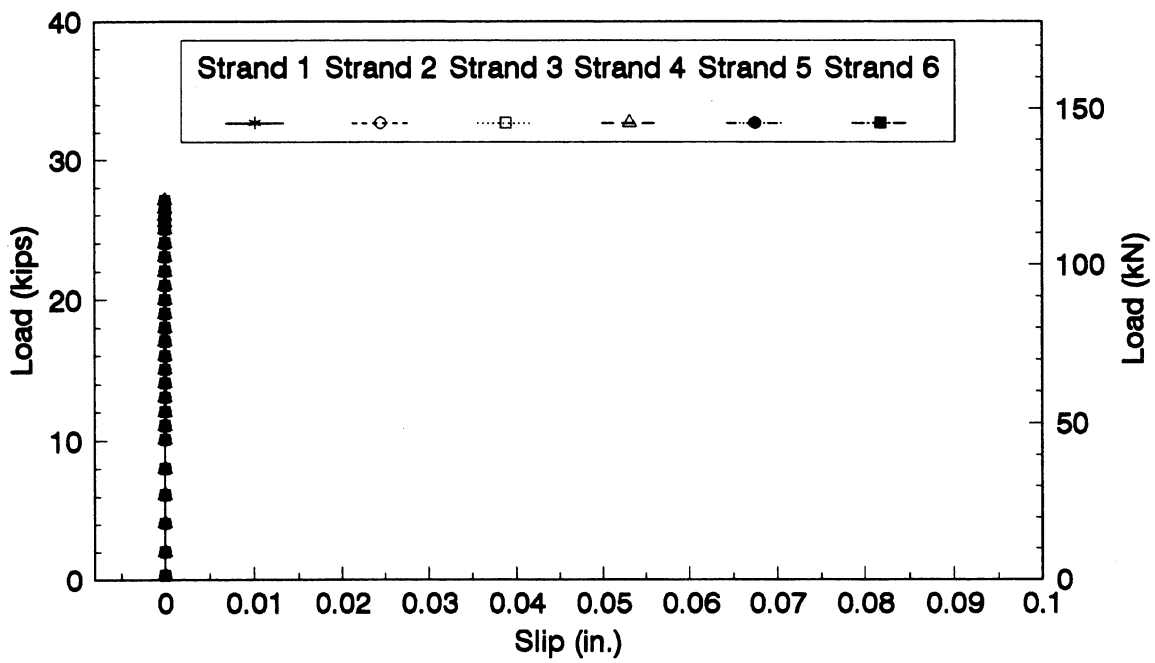


(b)

Figure F.10. Development length test of Specimen No. 8-6.0DC-3 with the load at 24 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

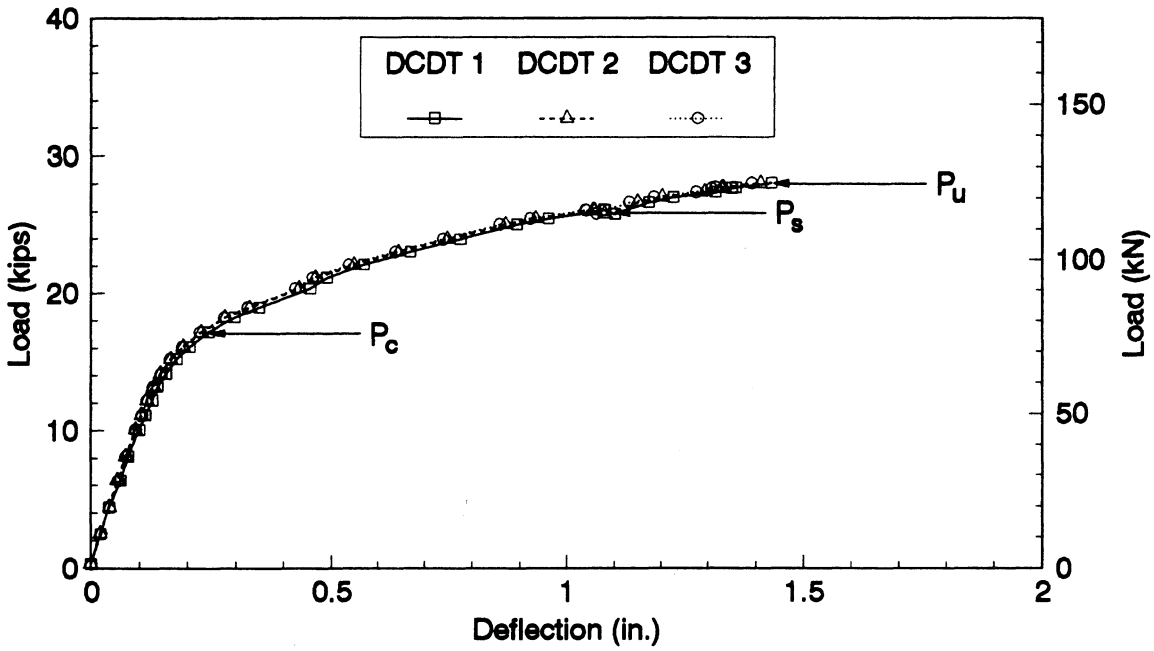


(a)

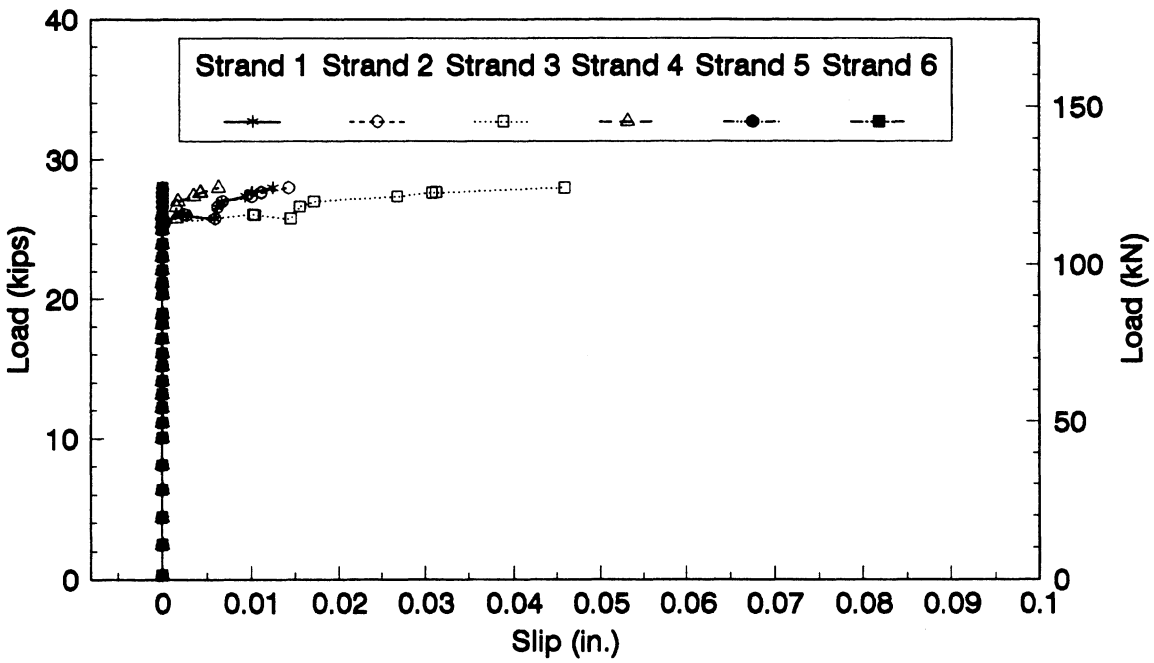


(b)

Figure F.11. Development length test of Specimen No. 9-6.0DC-1 with the load at 26 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

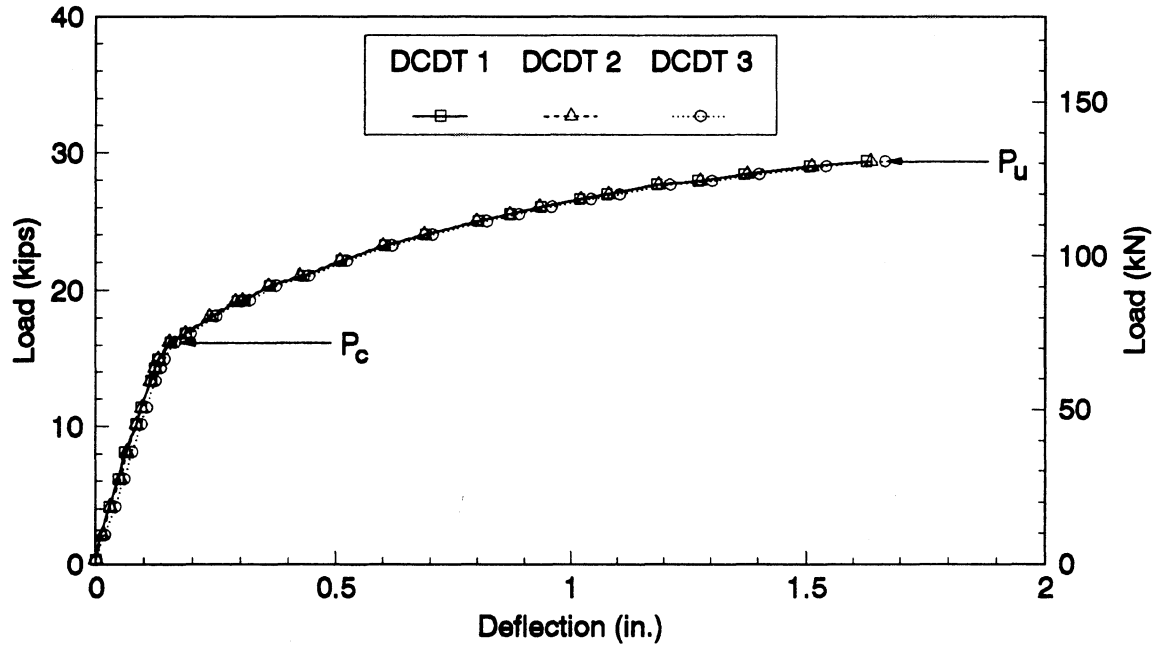


(a)

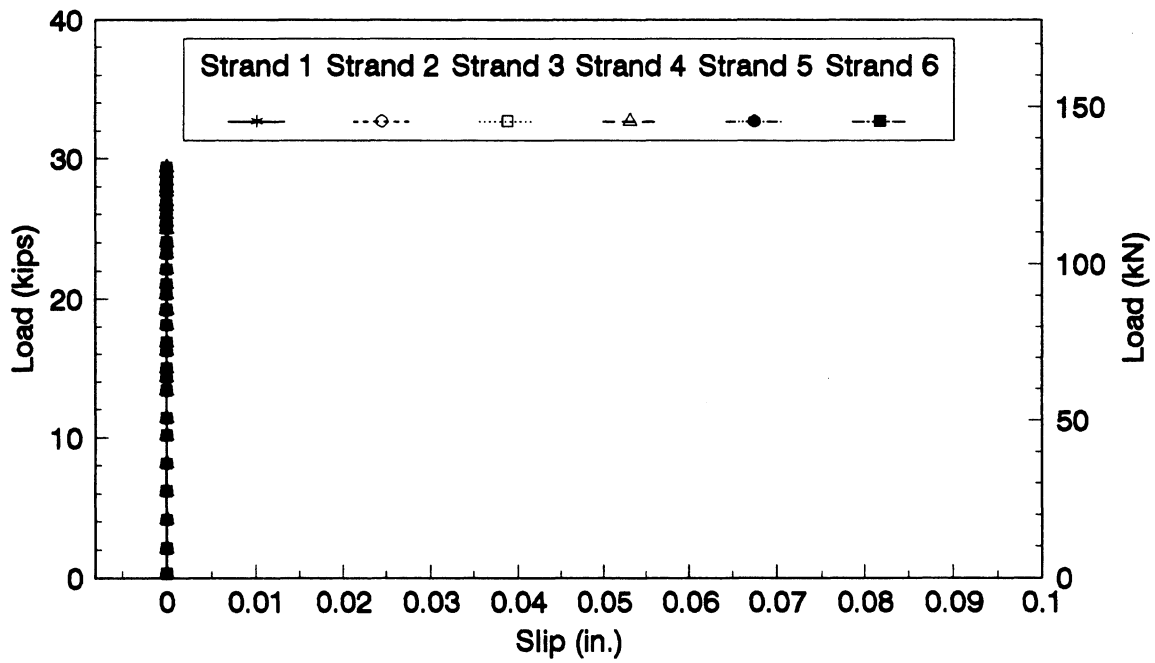


(b)

Figure F.12. Development length test of Specimen No. 9-6.0DC-1 with the load at 24 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

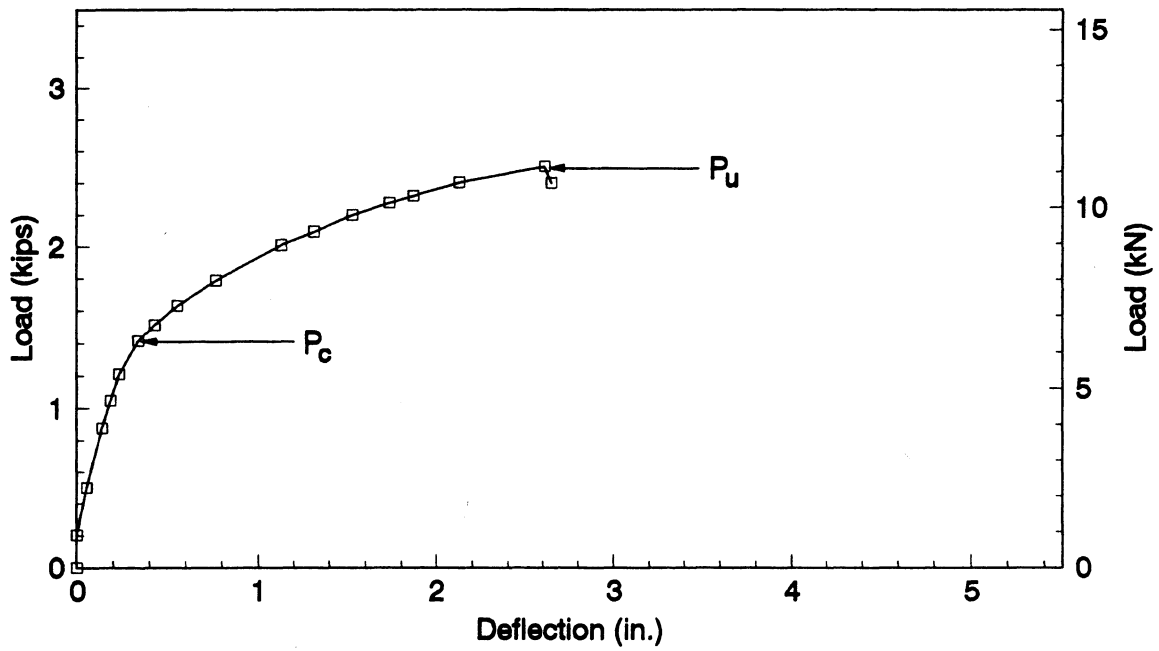


(a)

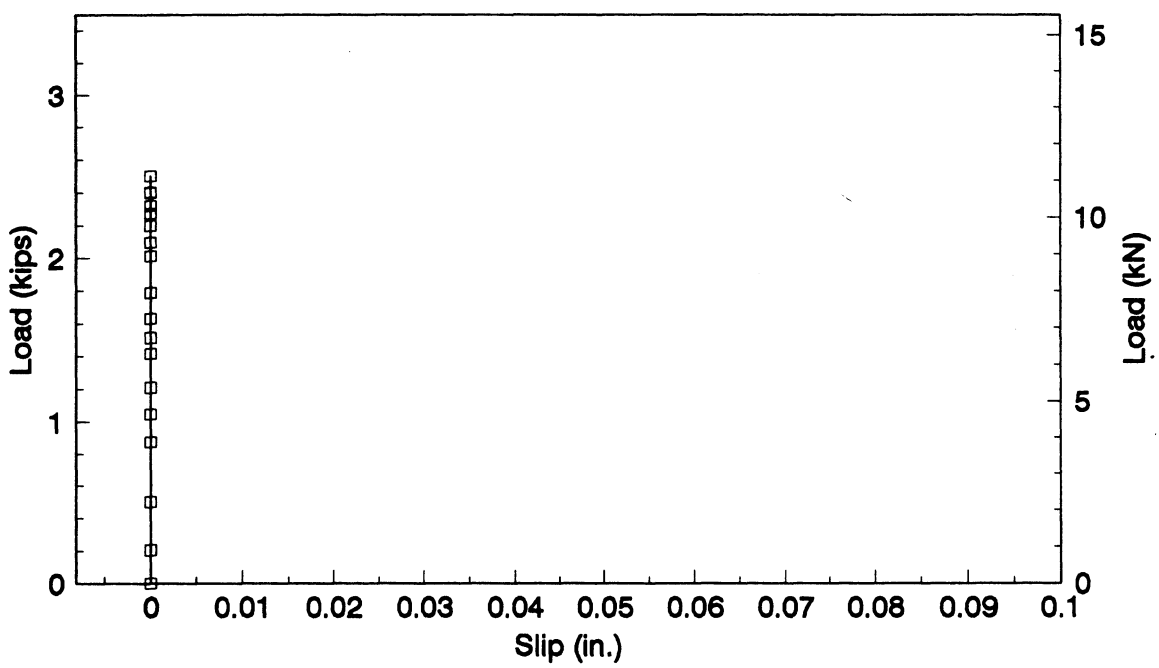


(b)

Figure F.13. Development length test of Specimen No. 9-6.0DC-3 with the load at 25 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

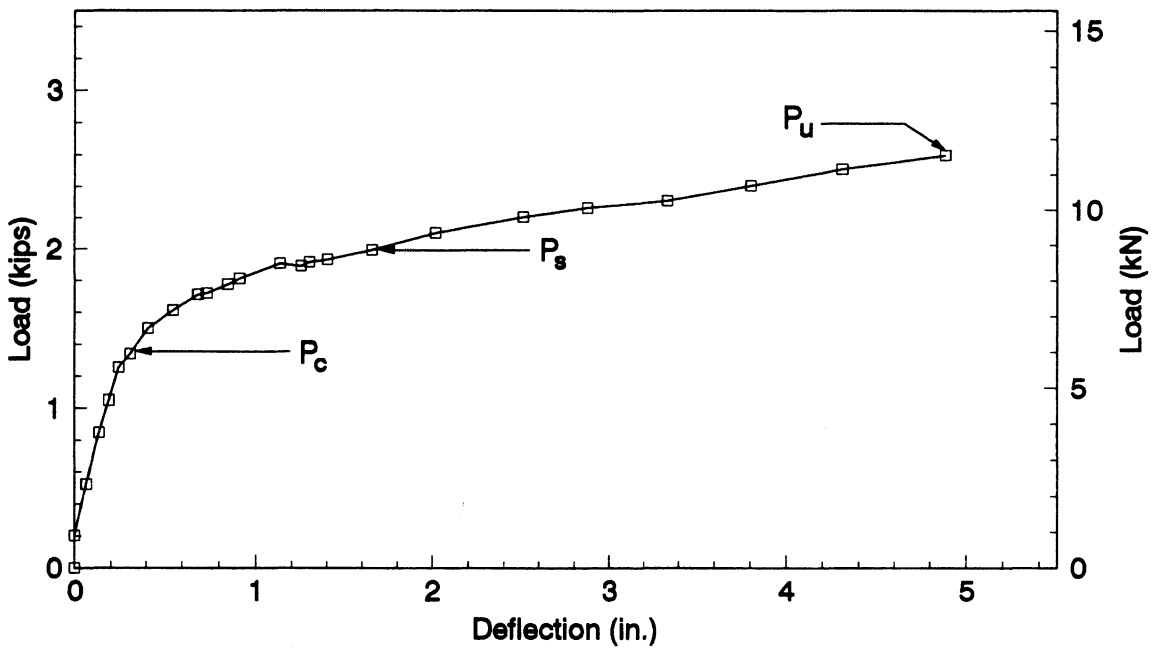


(a)

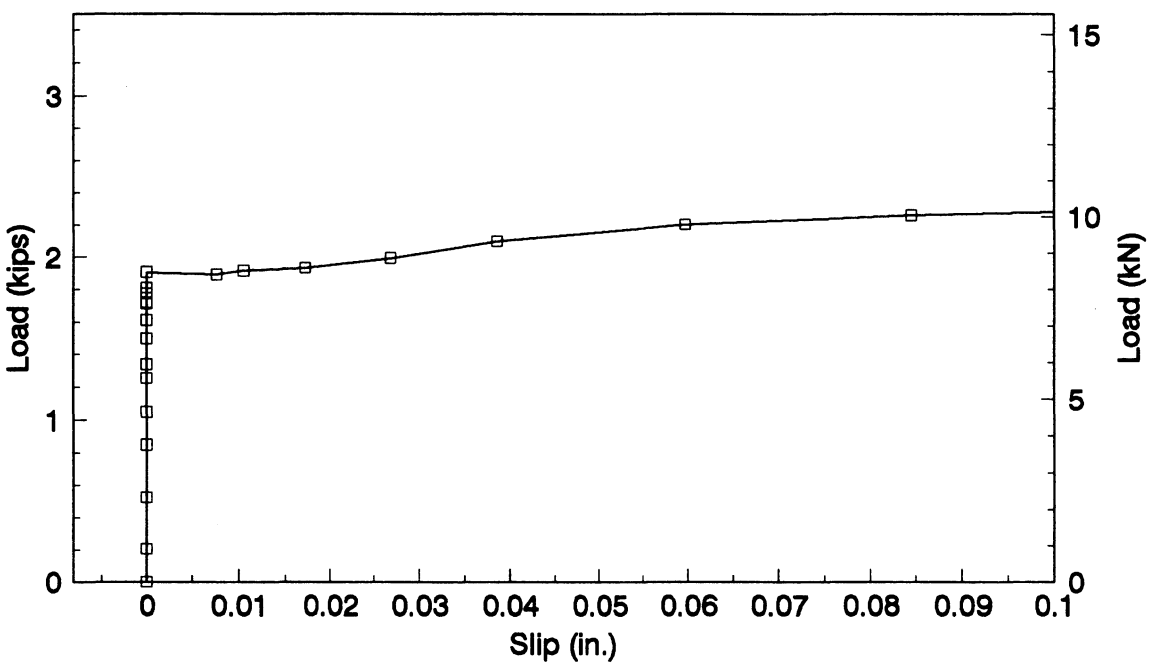


(b)

Figure F.14. Development length test of Specimen No. 10-6.0DU-1 with the load at 70.5 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

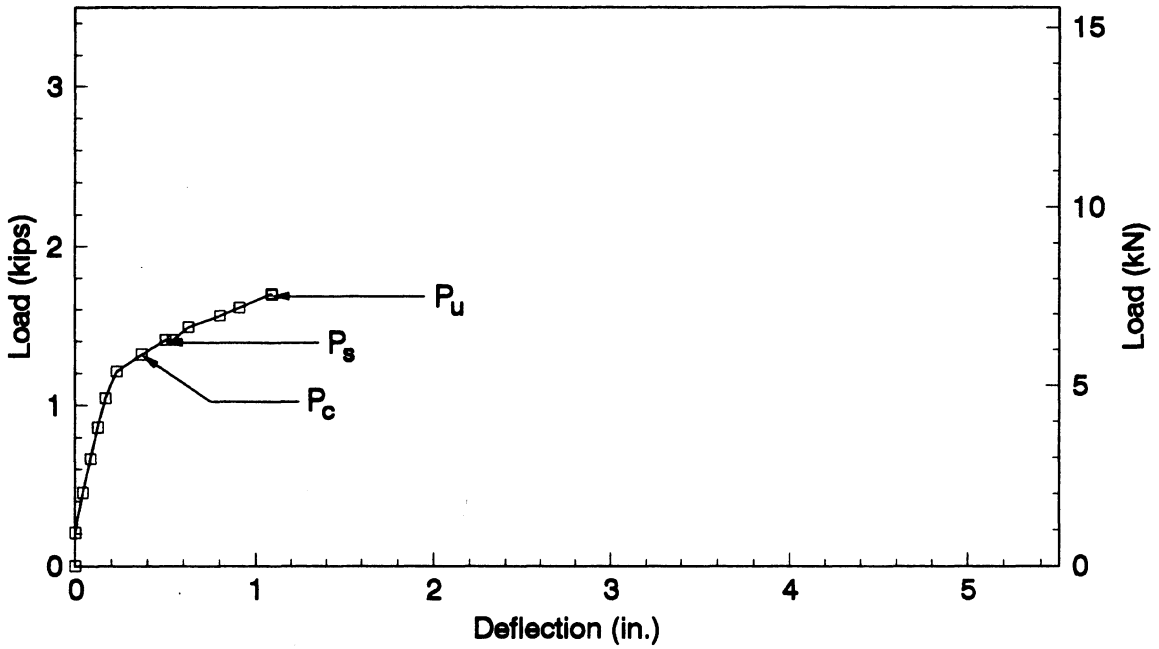


(a)

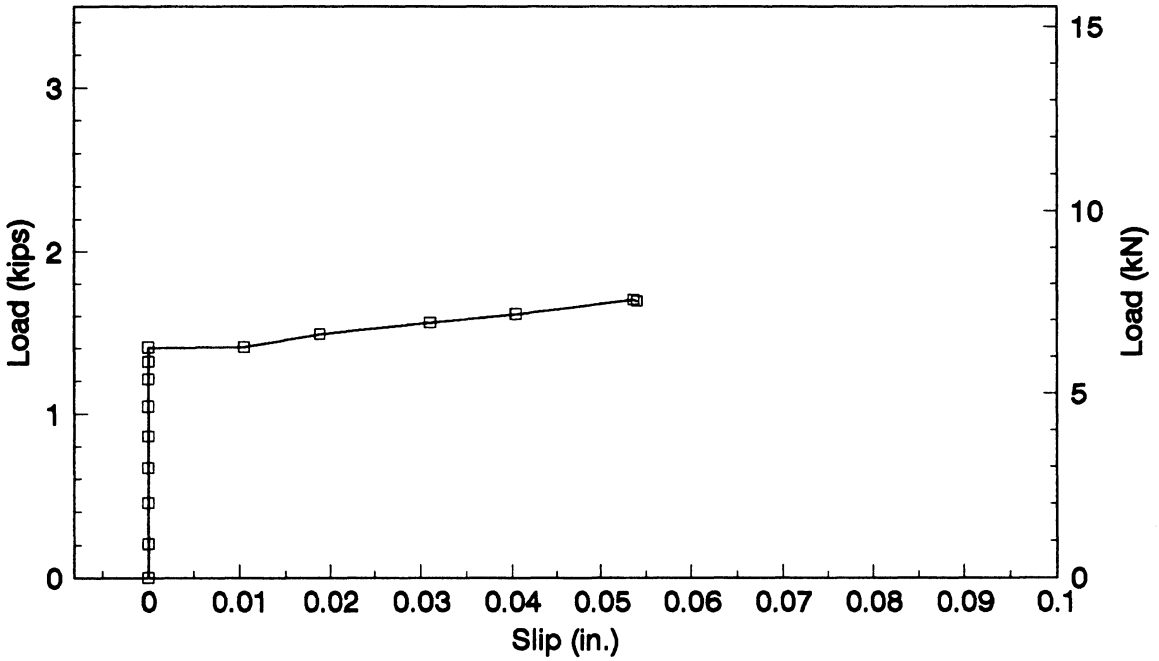


(b)

Figure F.15. Development length test of Specimen No. 10-6.0DU-2 with the load at 65 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

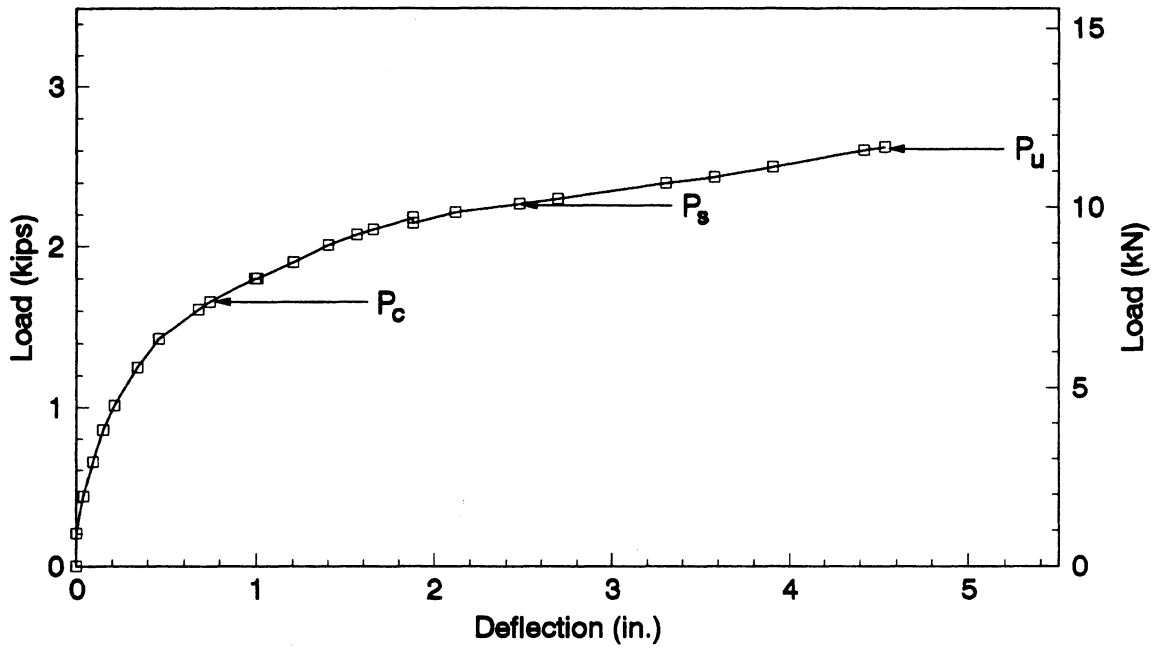


(a)

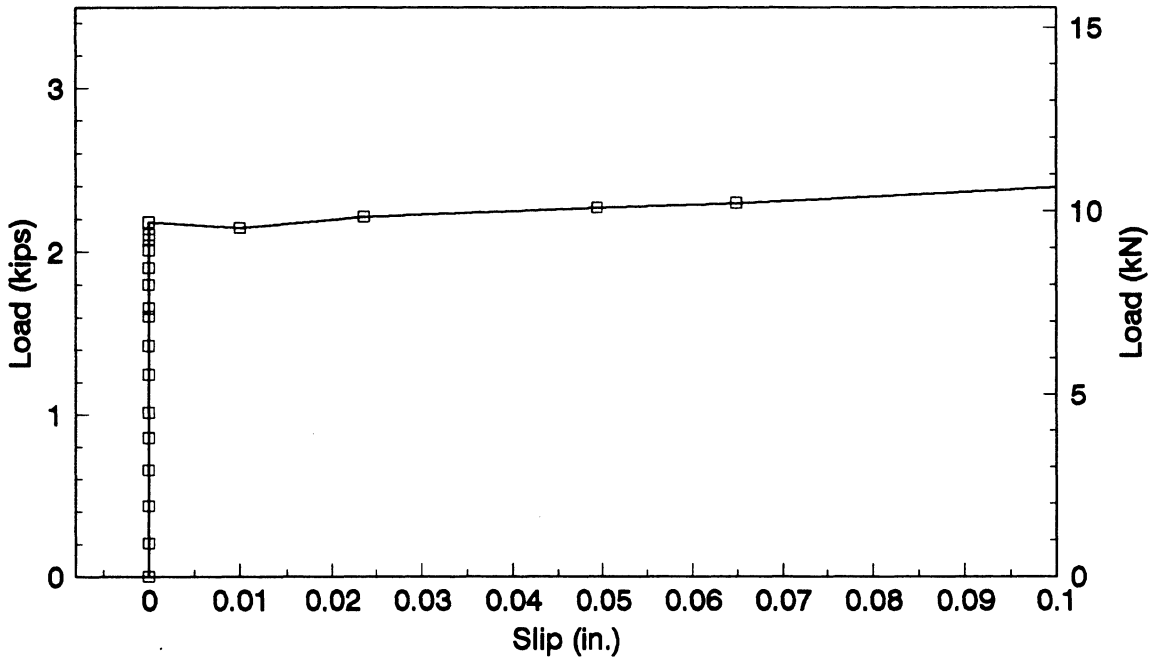


(b)

Figure F.16. Development length test of Specimen No. 10-6.0DU-3 with the load at 56 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

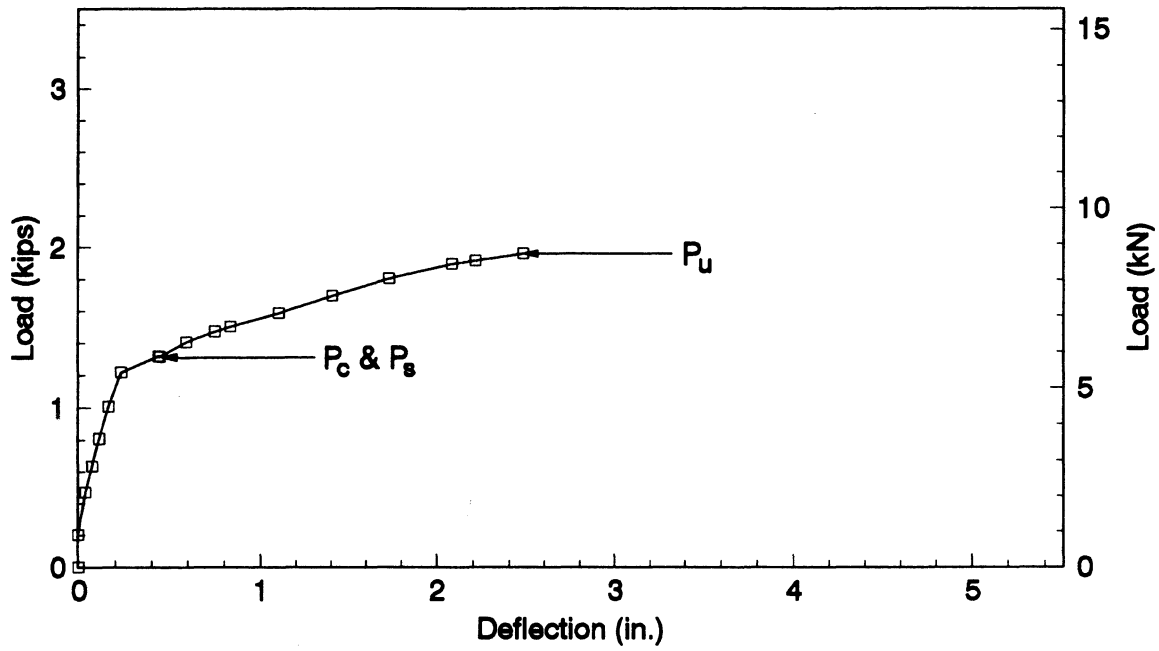


(a)

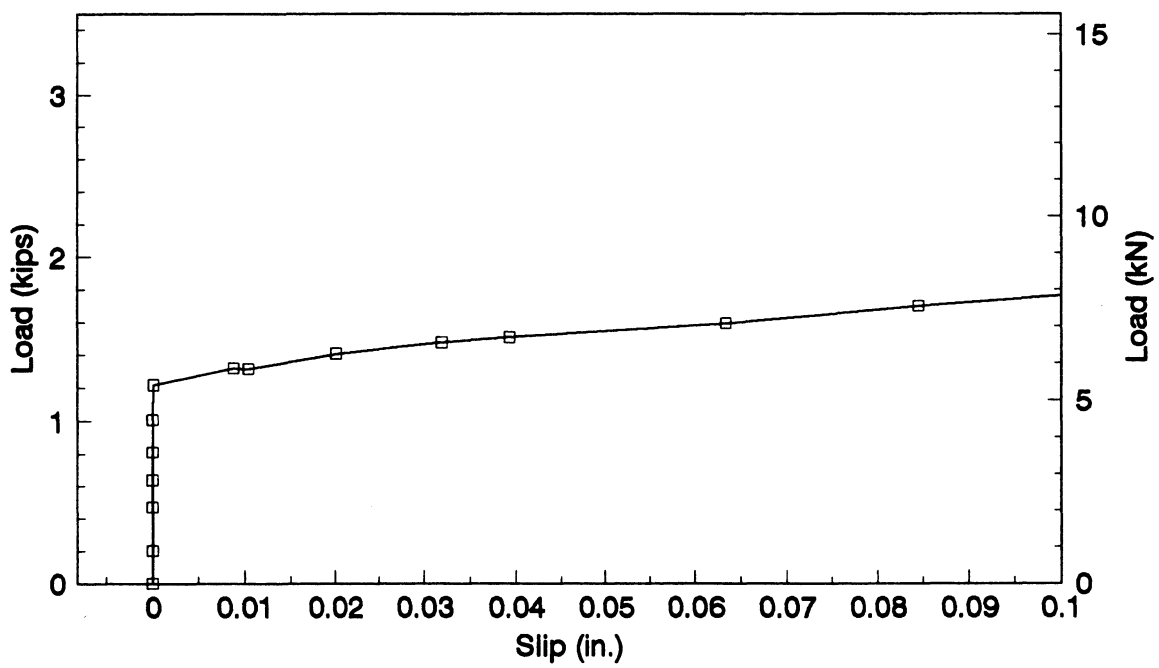


(b)

Figure F.17. Development length test of Specimen No. 10-6.0DU-3 with the load at 60 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

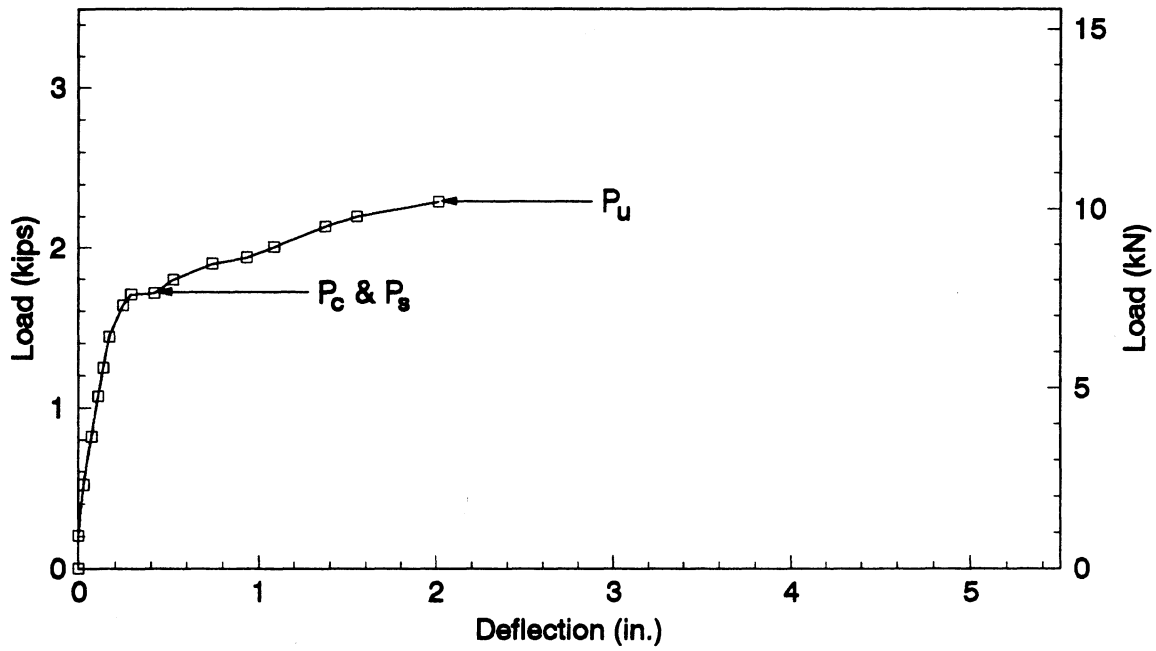


(a)

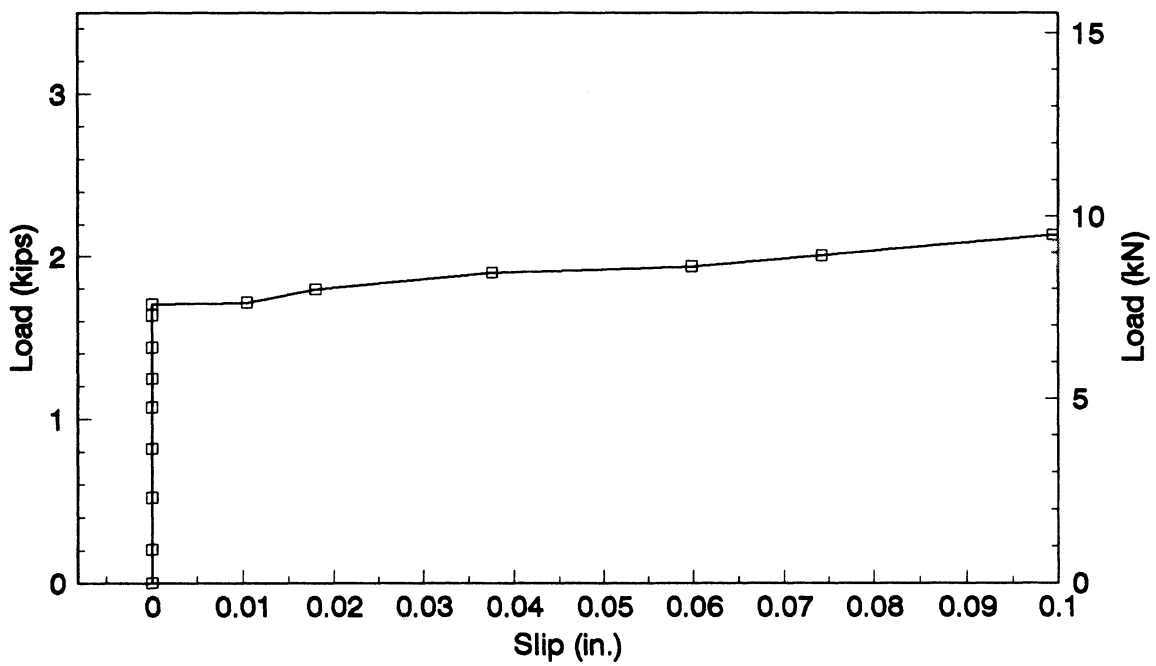


(b)

Figure F.18. Development length test of Specimen No. 10-6.0DU-4 with the load at 54 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

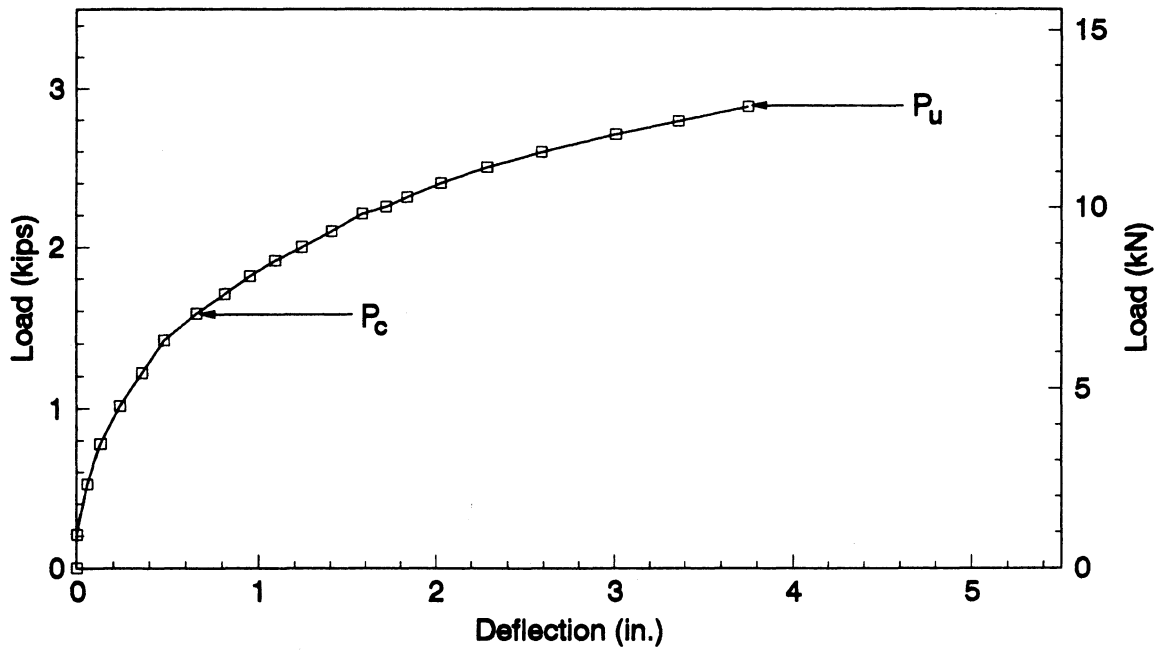


(a)

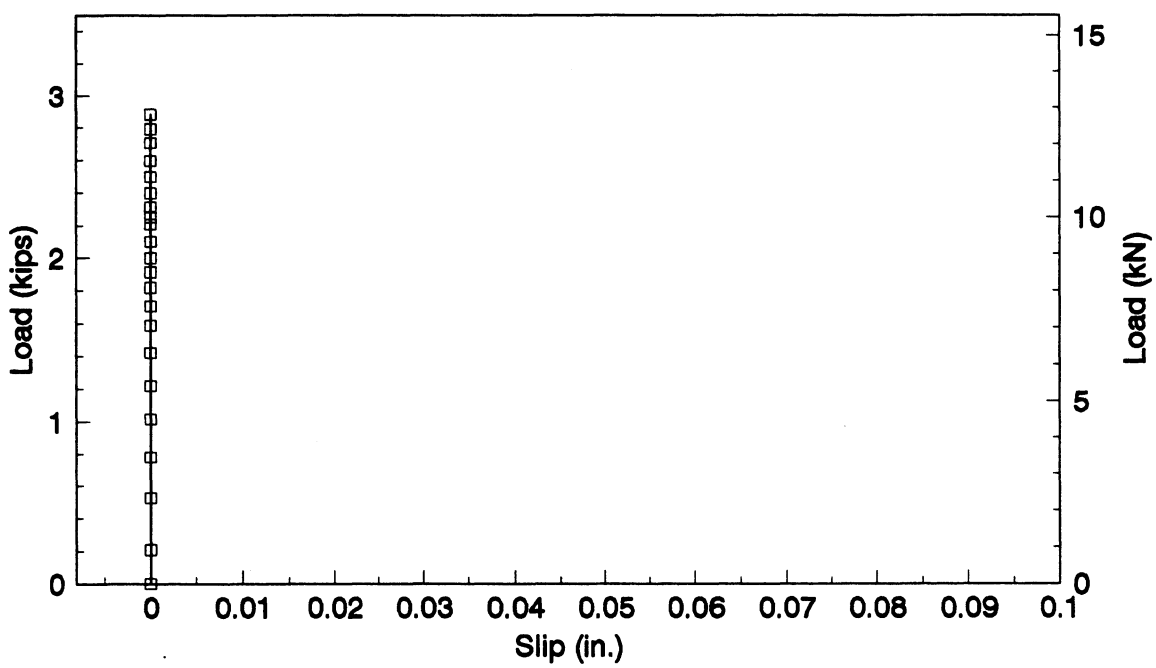


(b)

Figure F.19. Development length test of Specimen No. 10-6.0DU-9 with the load at 50 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

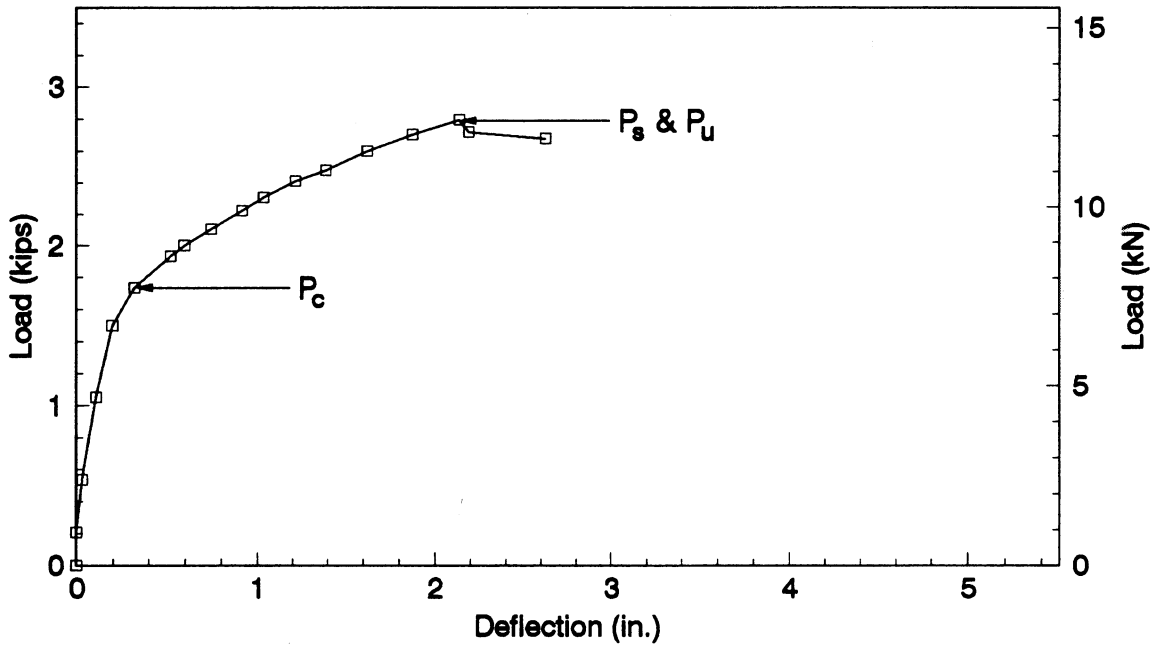


(a)

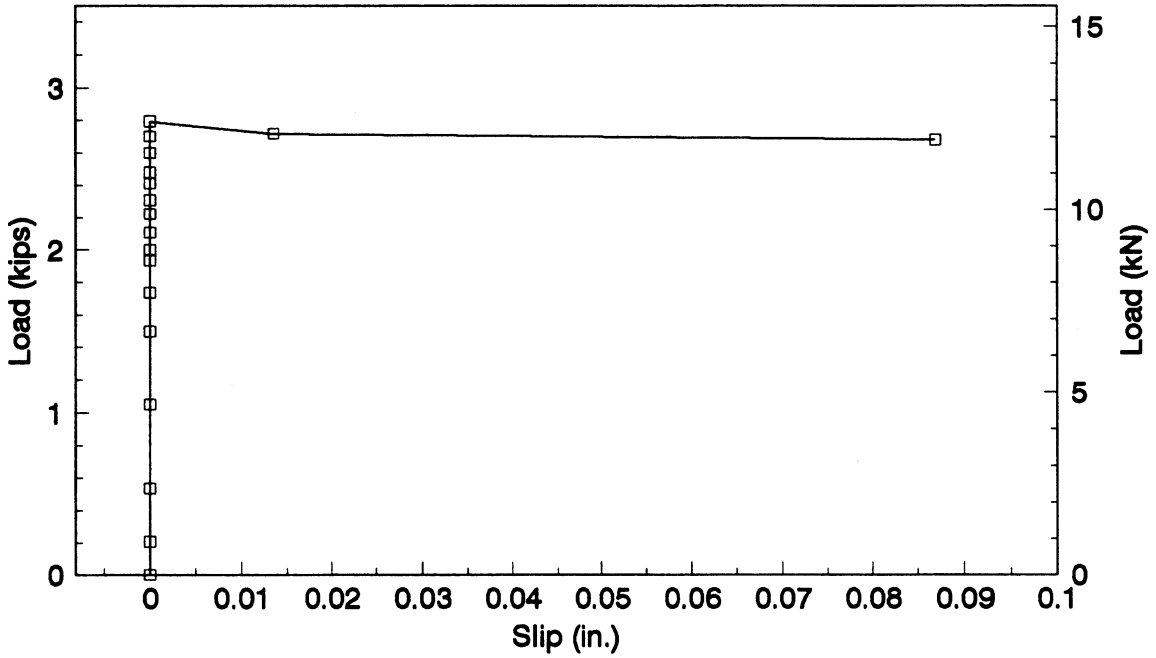


(b)

Figure F.20. Development length test of Specimen No. 10-6.0DU-9 with the load at 54 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

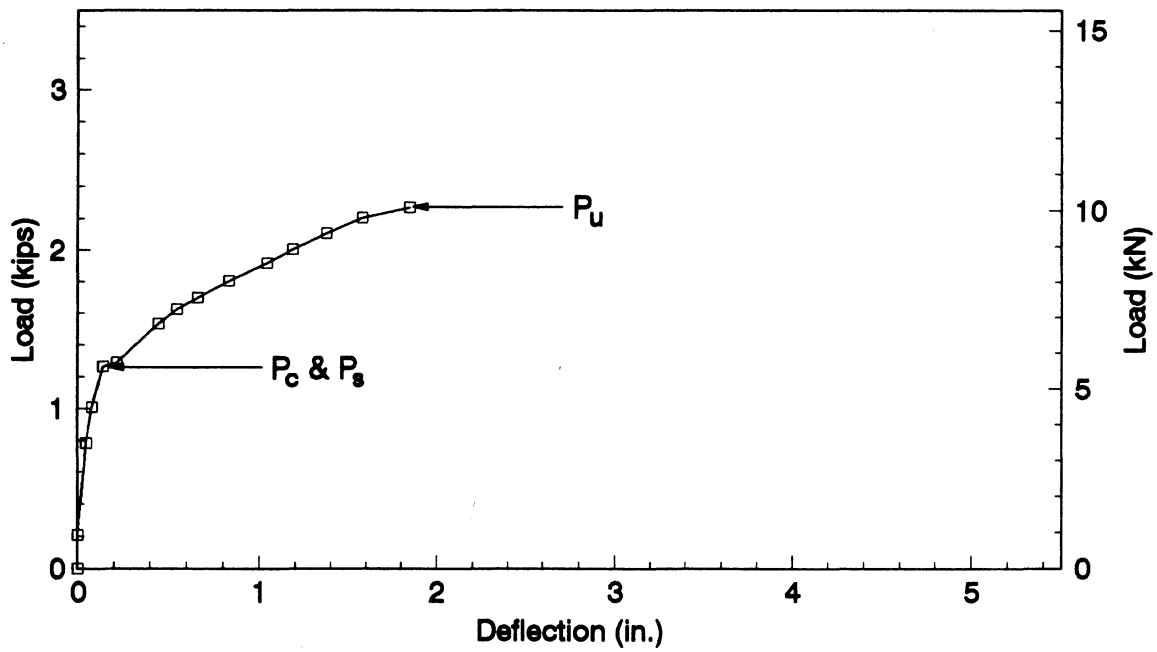


(a)

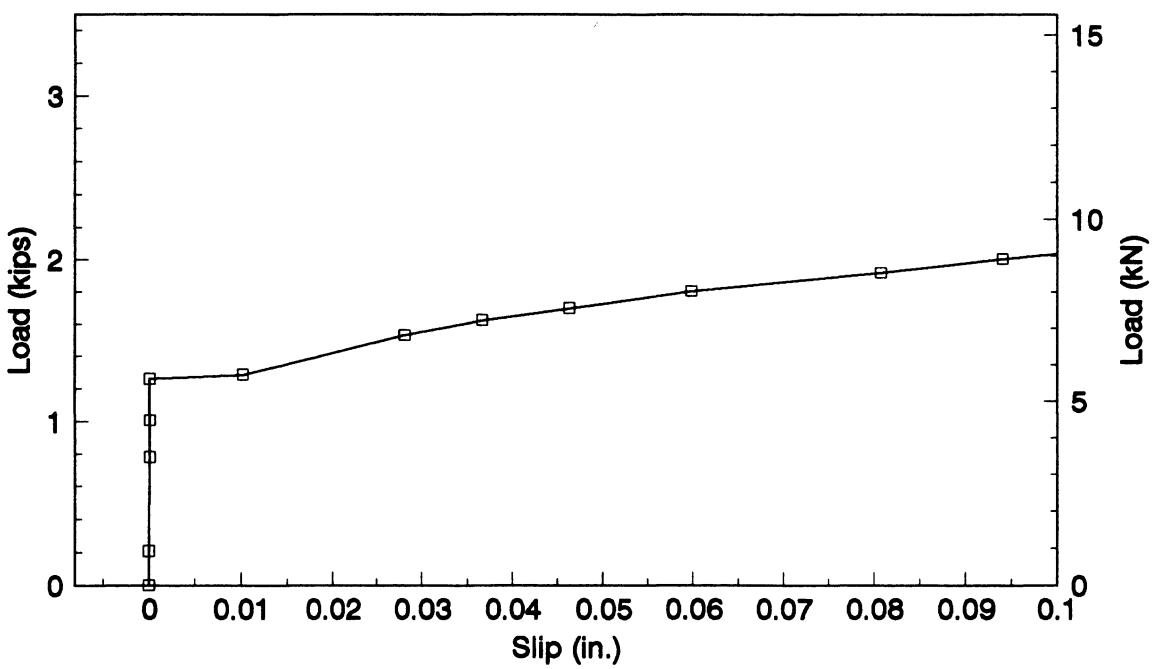


(b)

Figure F.21. Development length test of Specimen No. 10-6.0DU-10 with the load at 54 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

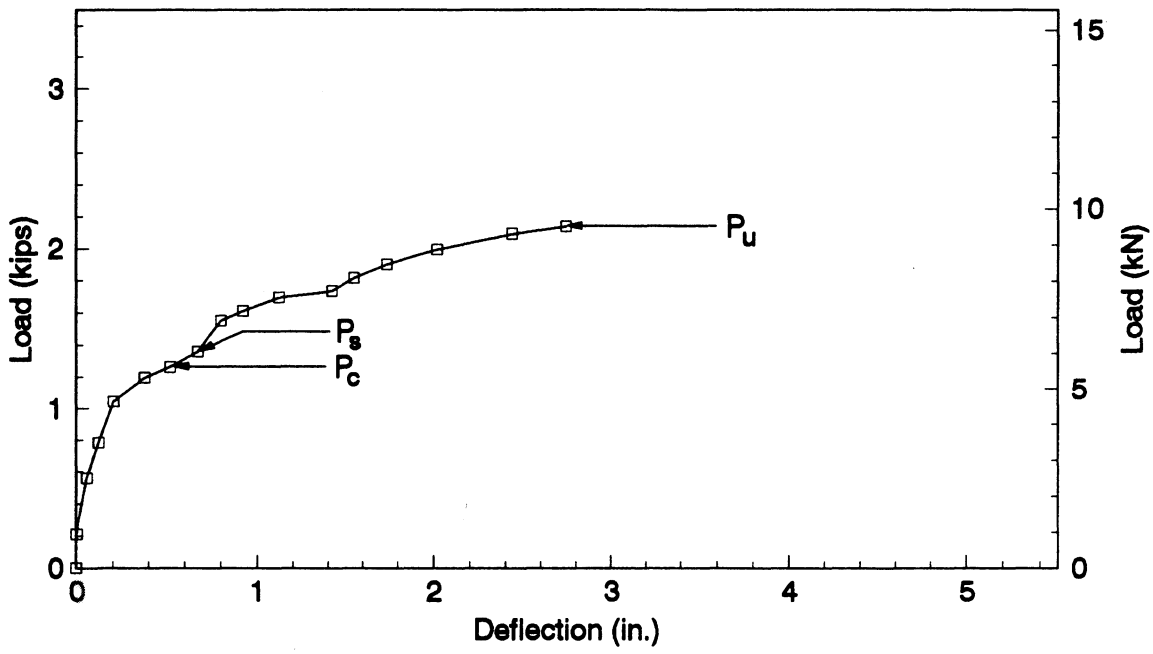


(a)

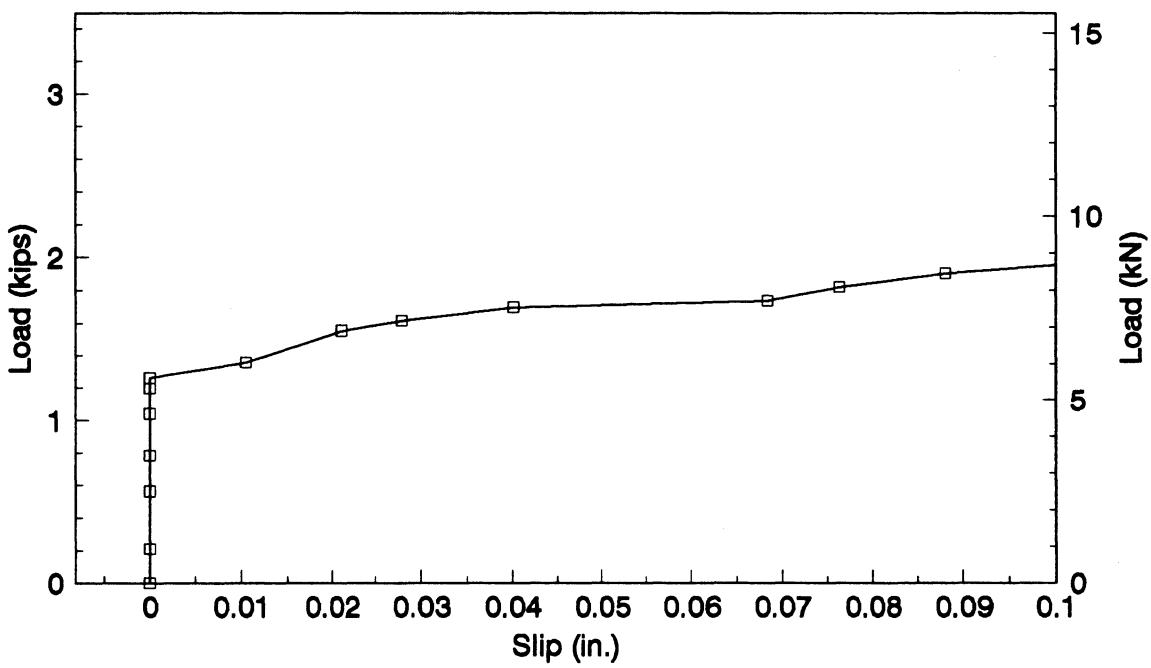


(b)

Figure F.22. Development length test of Specimen No. 10-6.0DU-11 with the load at 44 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

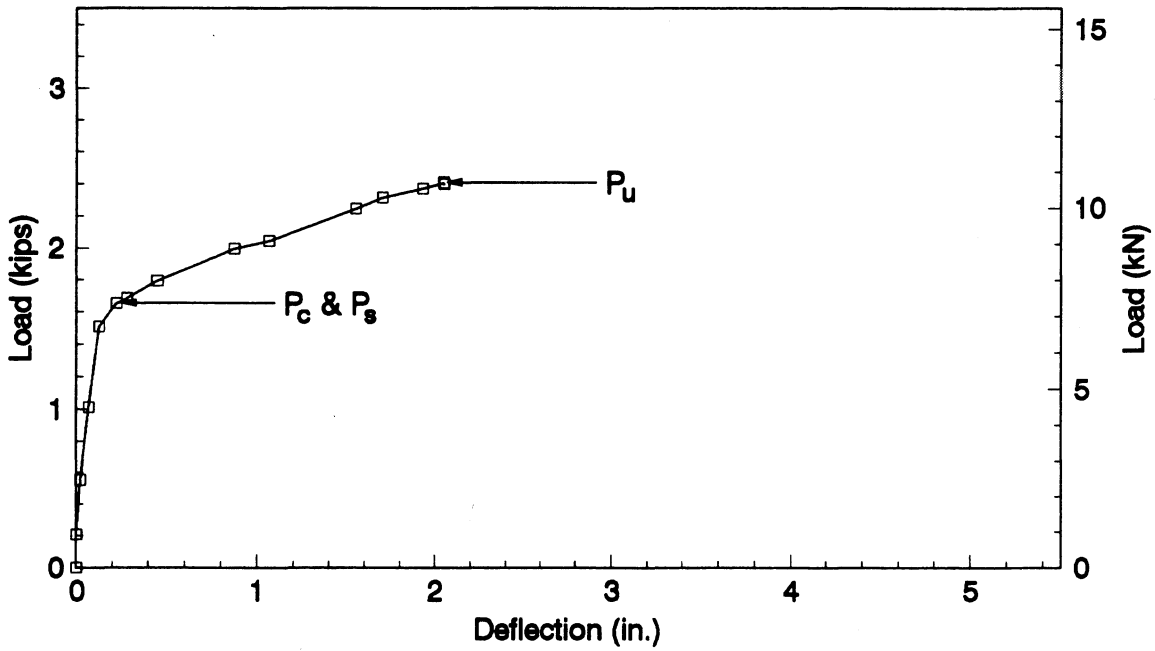


(a)

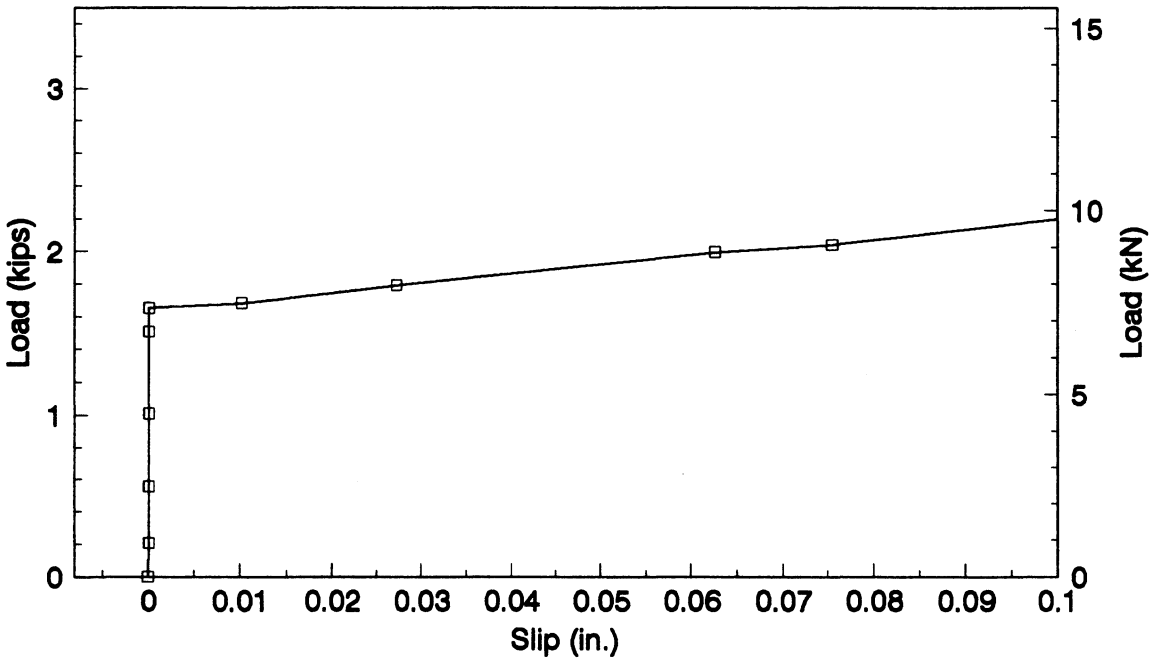


(b)

Figure F.23. Development length test of Specimen No. 10-6.0DU-11 with the load at 46 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

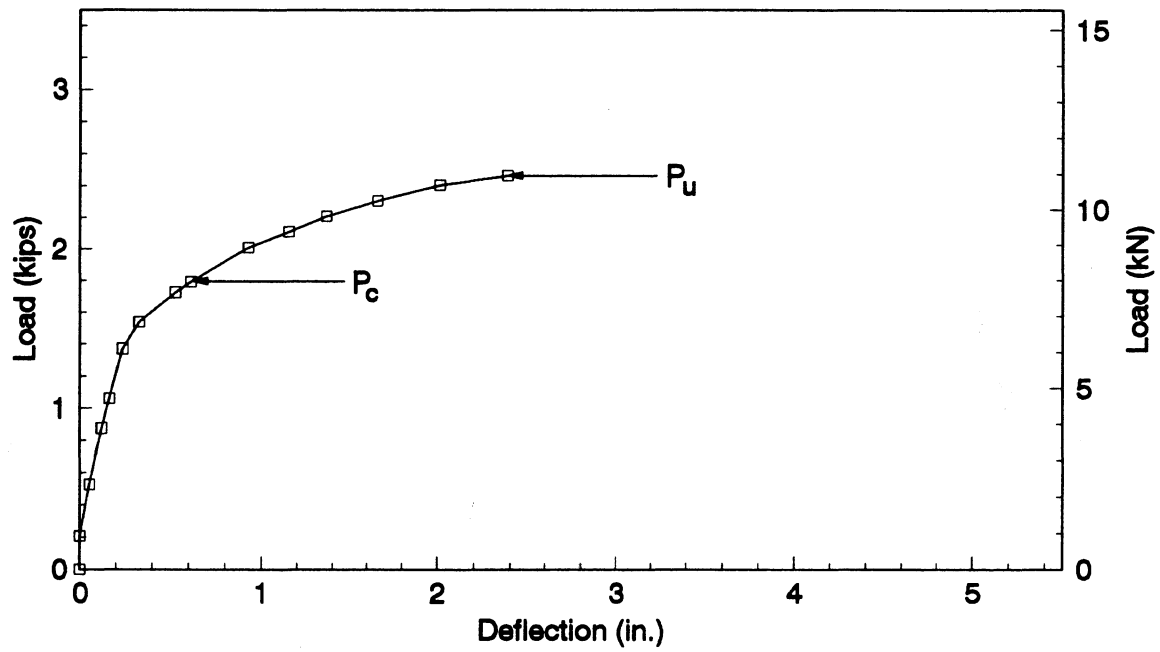


(a)

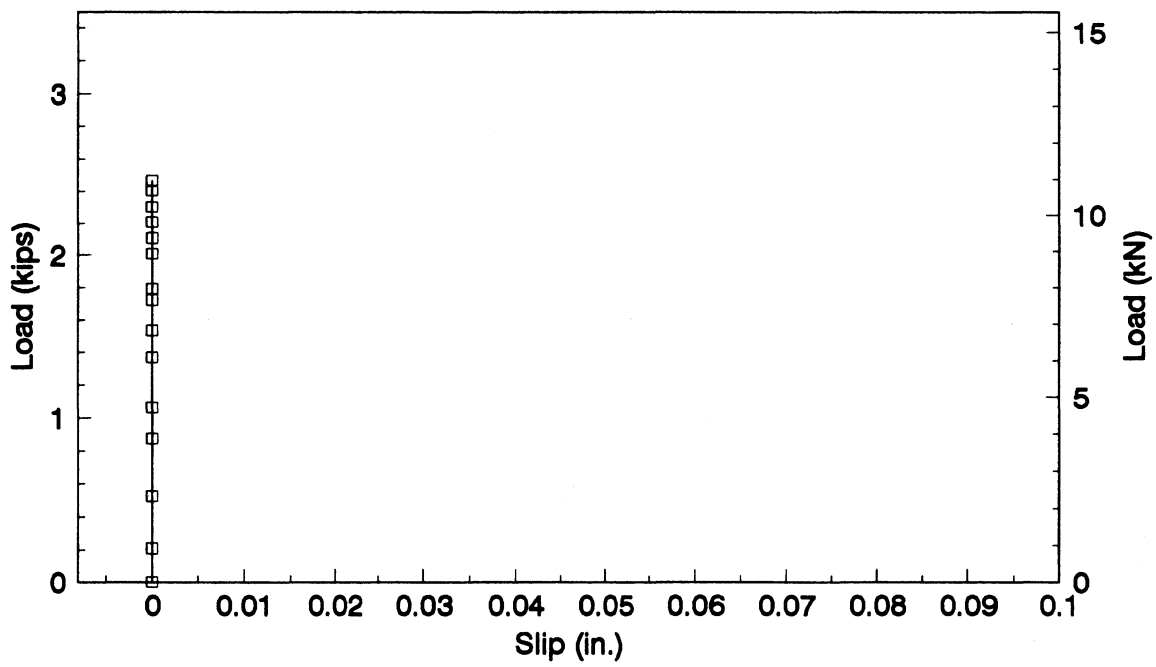


(b)

Figure F.24. Development length test of Specimen No. 10-6.0DU-12 with the load at 42 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

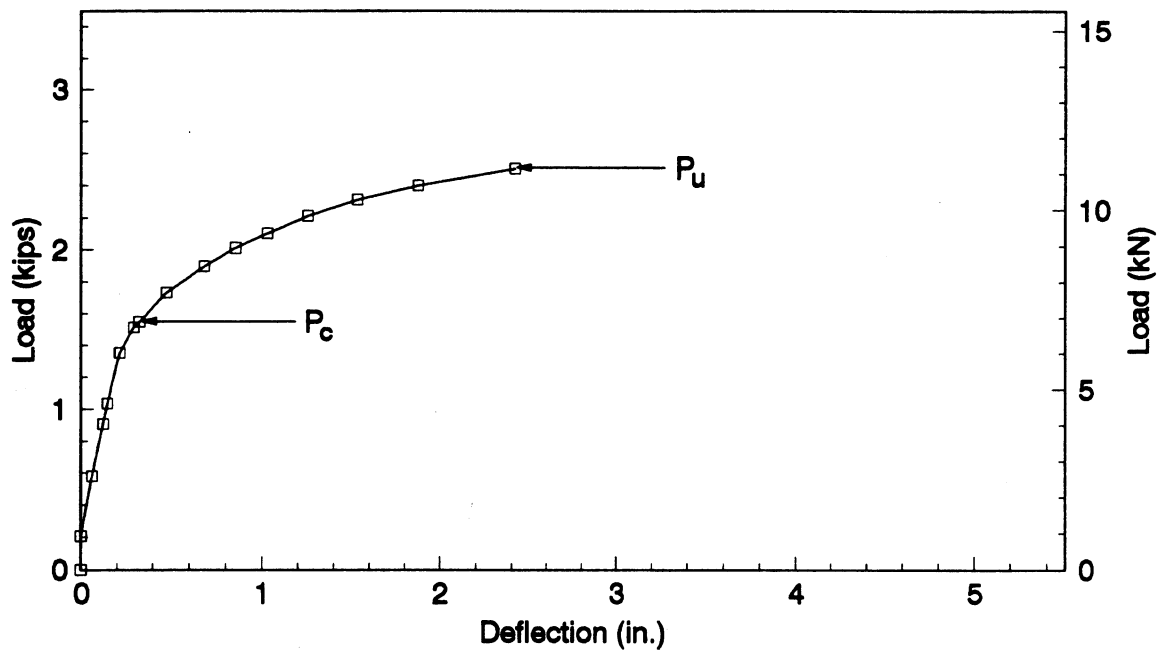


(a)

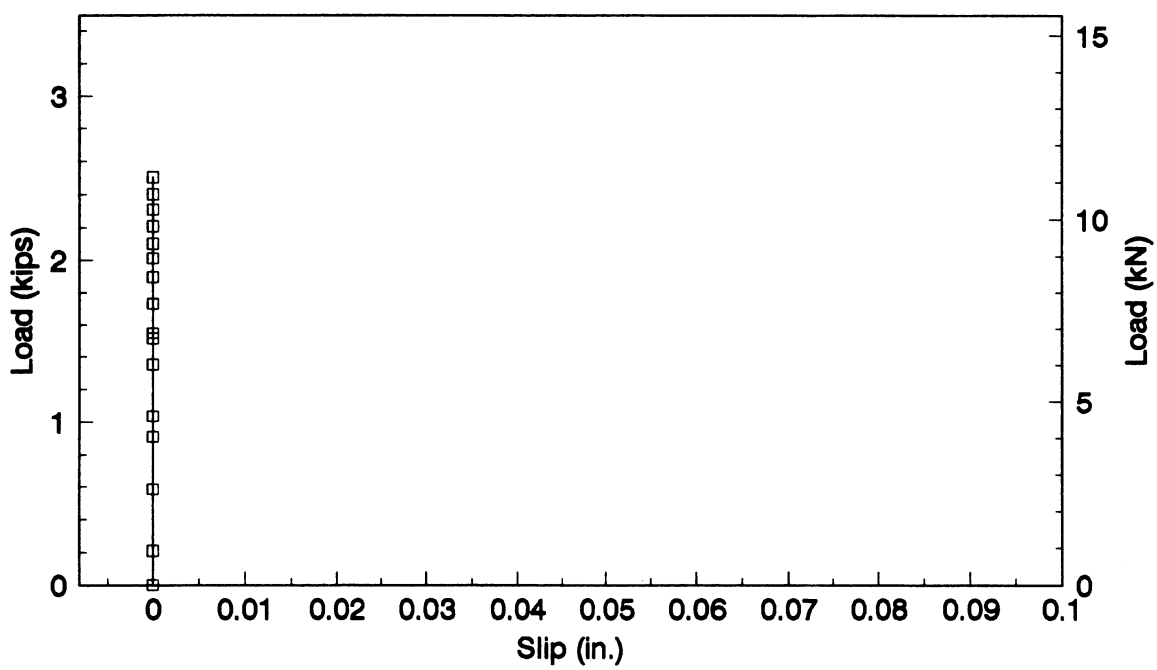


(b)

Figure F.25. Development length test of Specimen No. 11-6.0DU-1 with the load at 60 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

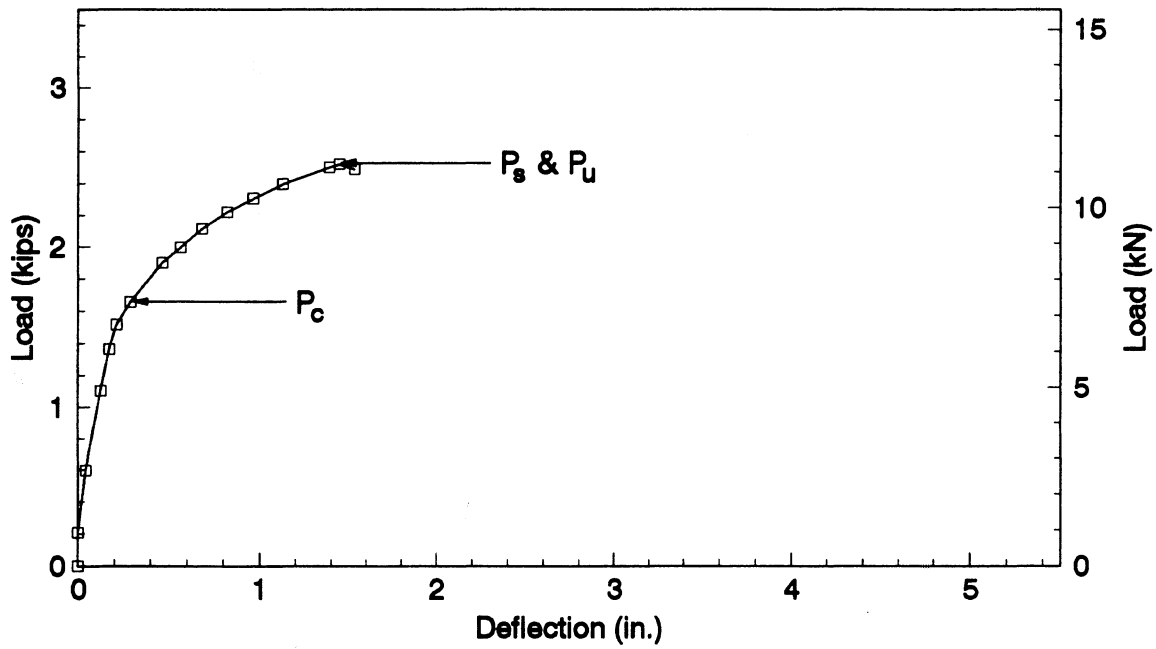


(a)

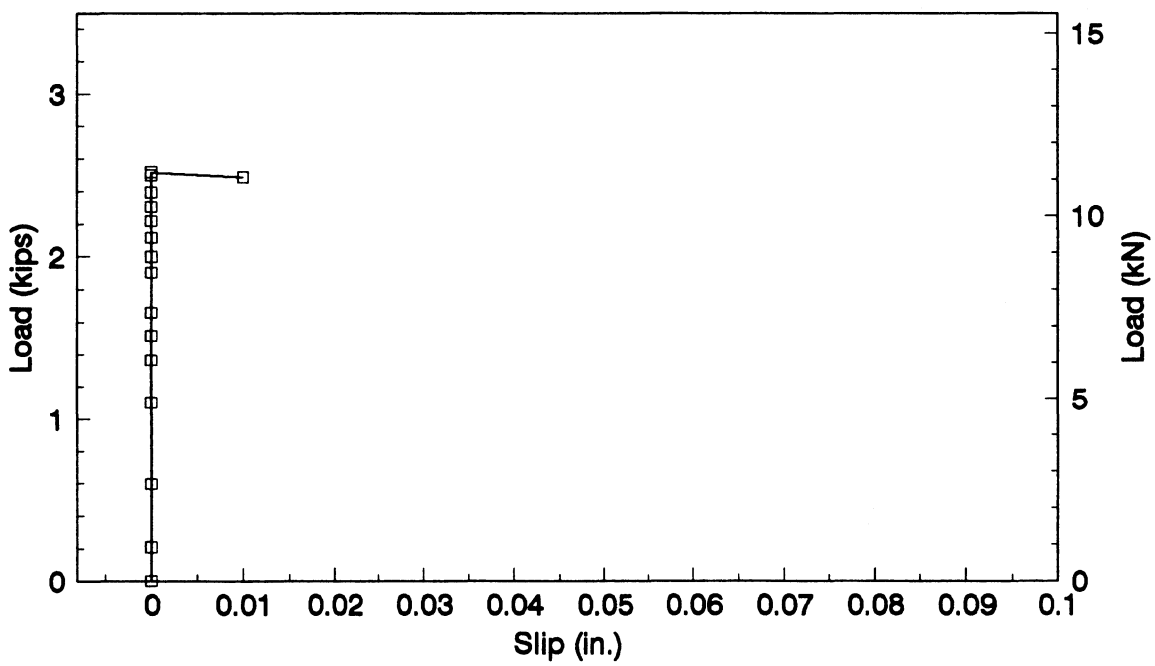


(b)

Figure F.26. Development length test of Specimen No. 11-6.0DU-2 with the load at 55 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

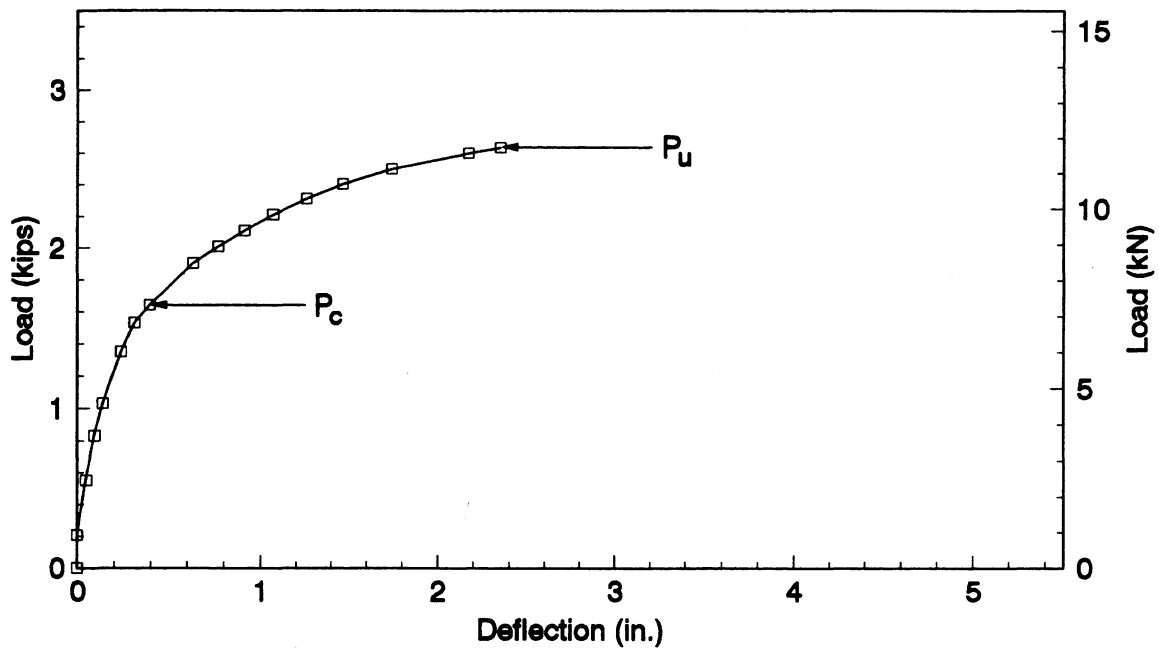


(a)

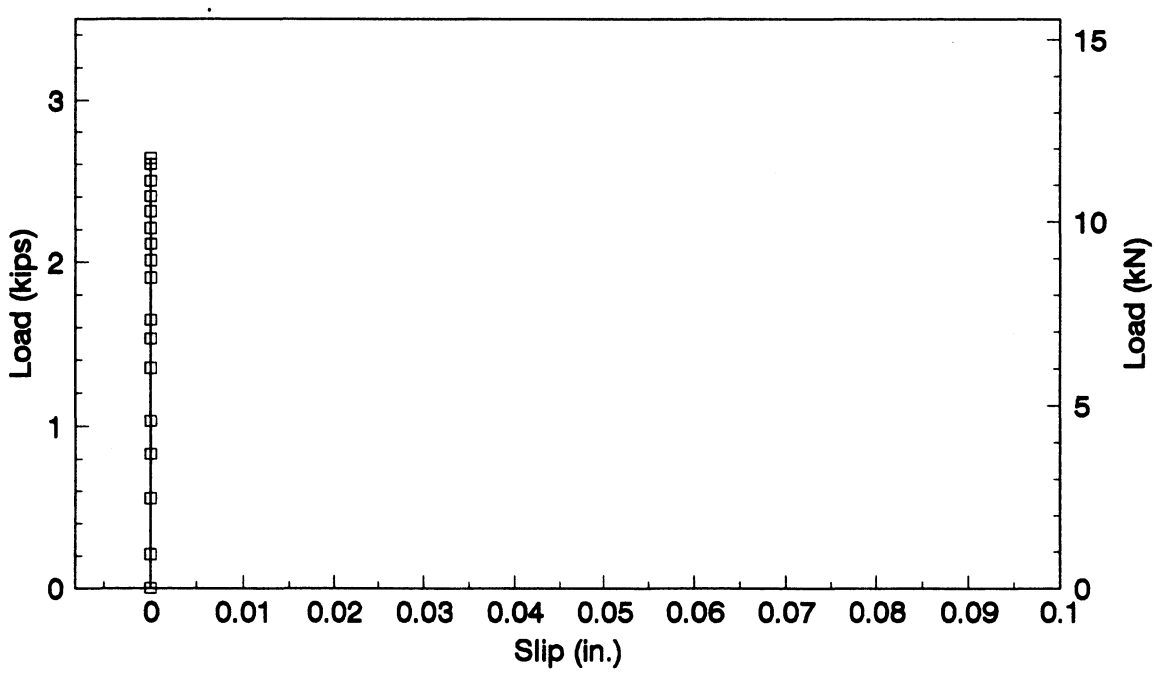


(b)

Figure F.27. Development length test of Specimen No. 11-6.0DU-3 with the load at 50 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

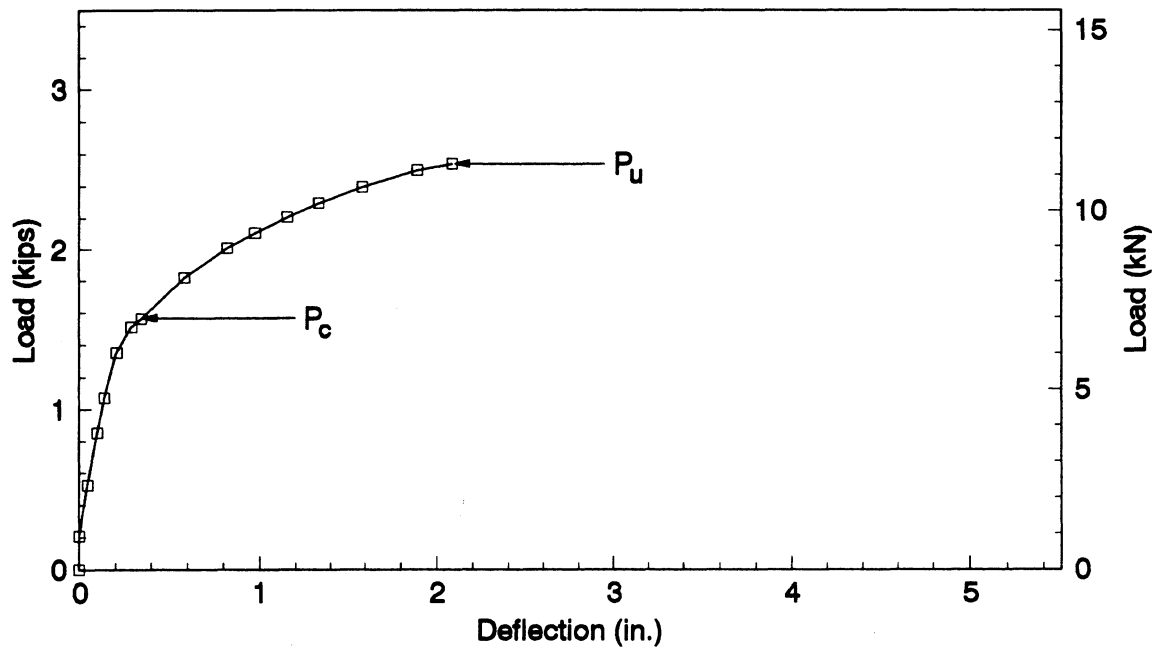


(a)

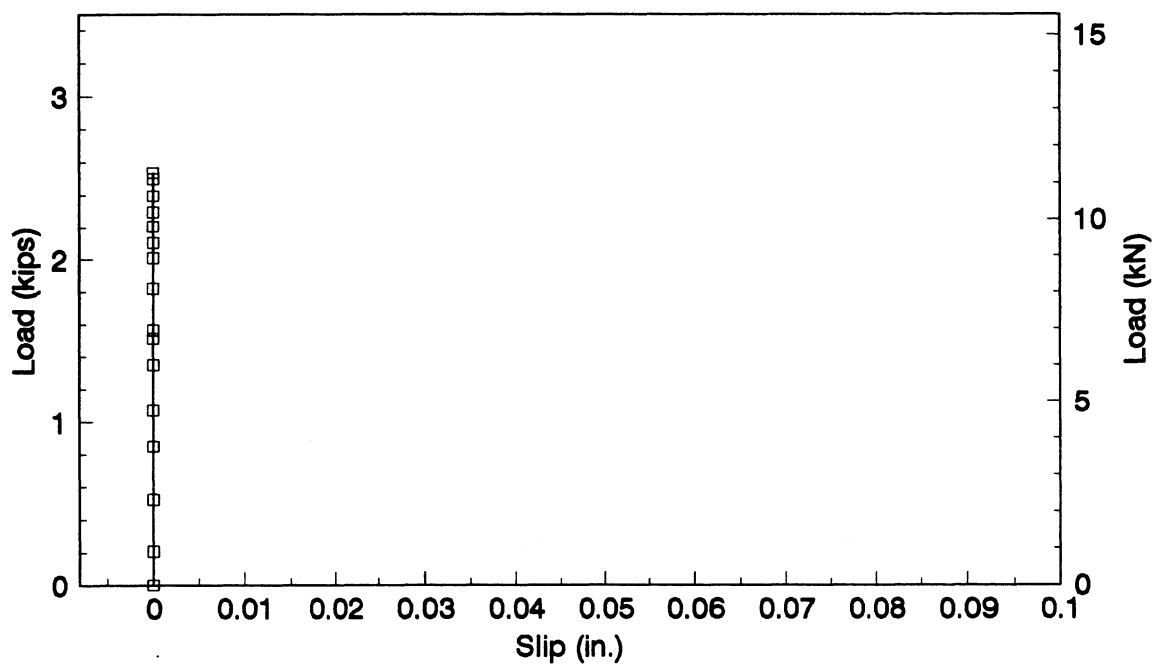


(b)

Figure F.28. Development length test of Specimen No. 11-6.0DU-3 with the load at 52 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

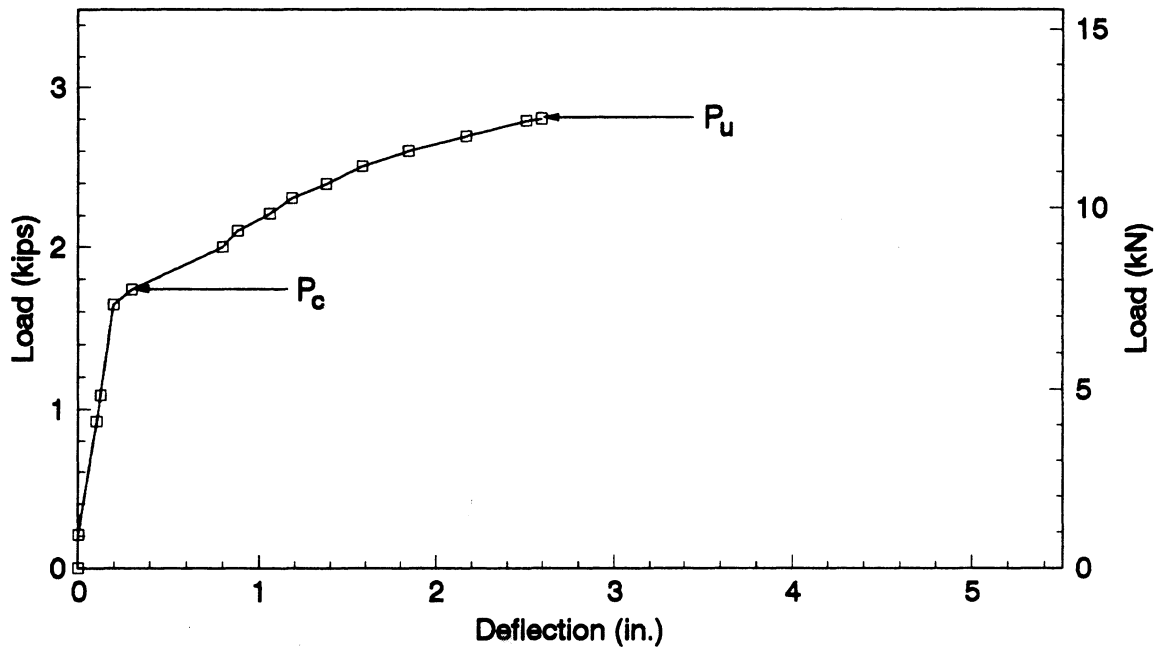


(a)

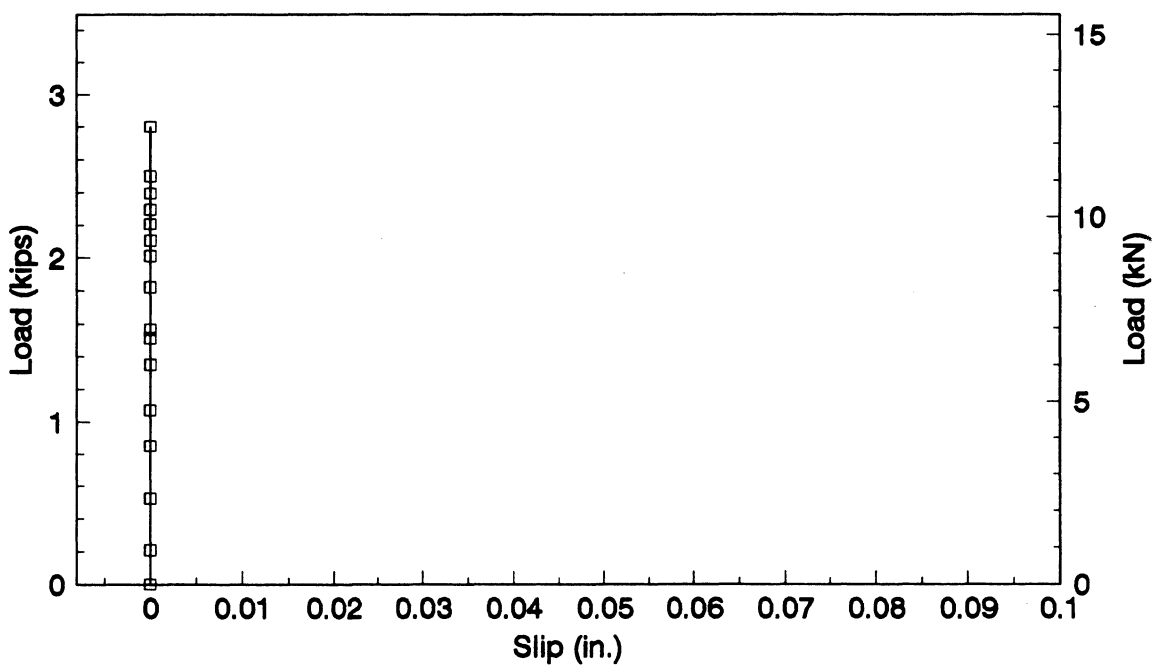


(b)

Figure F.29. Development length test of Specimen No. 11-6.0DU-4 with the load at 51 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

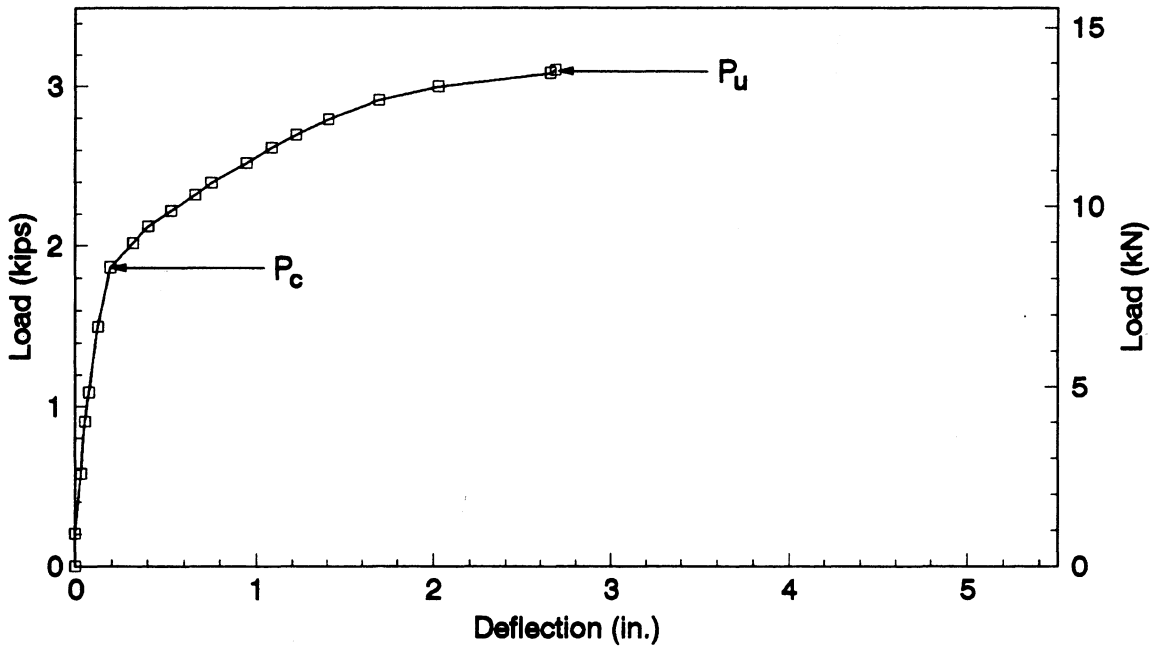


(a)

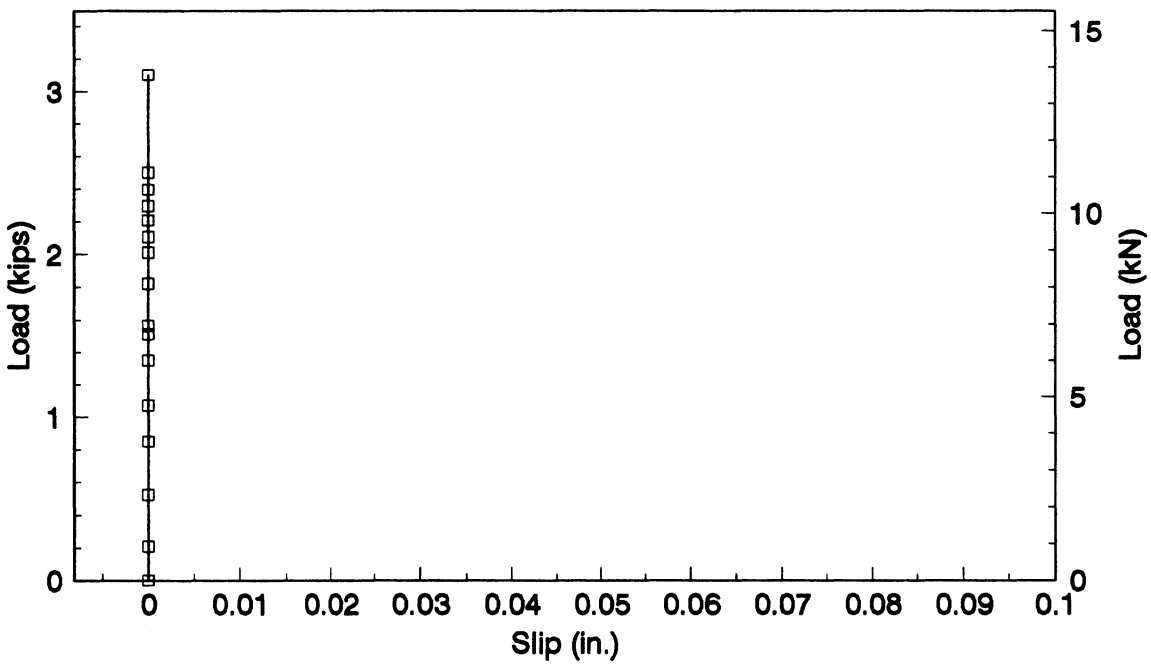


(b)

Figure F.30. Development length test of Specimen No. 11-6.0DU-9 with the load at 50 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

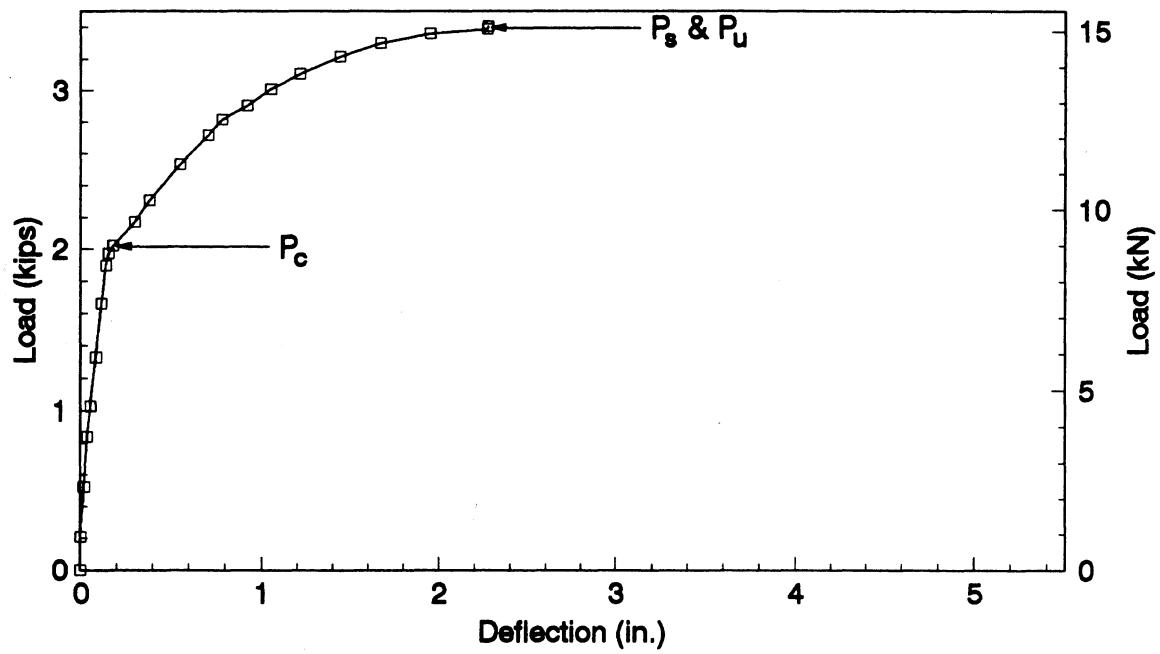


(a)

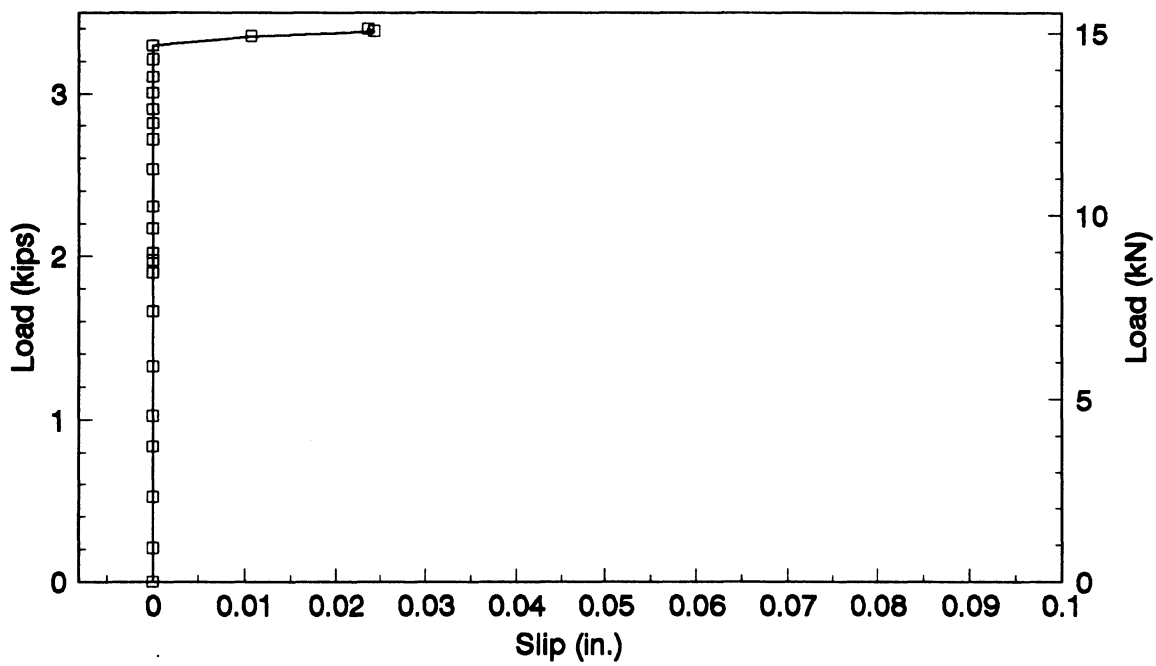


(b)

Figure F.31. Development length test of Specimen No. 11-6.0DU-10 with the load at 45 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

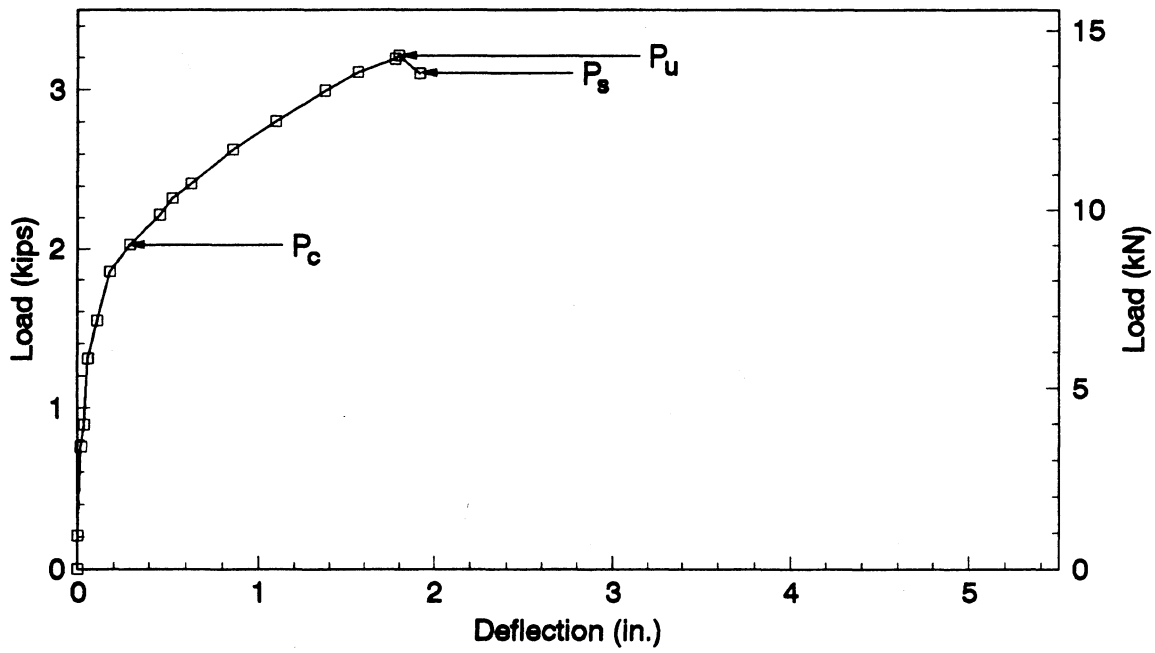


(a)

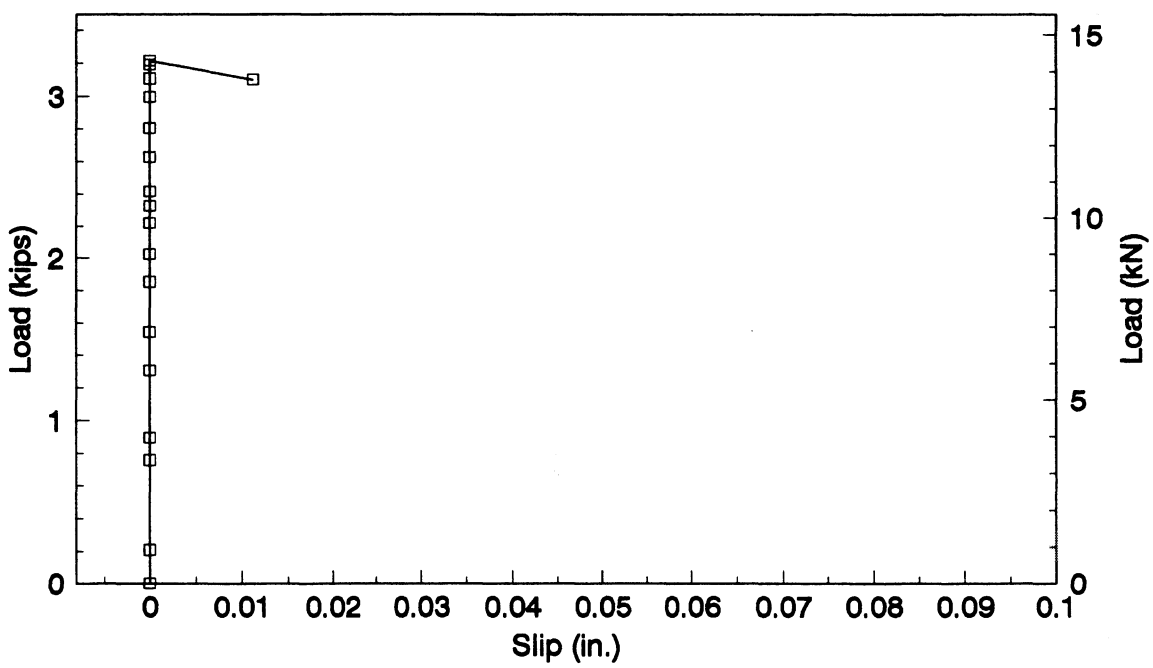


(b)

Figure F.32. Development length test of Specimen No. 11-6.0DU-11 with the load at 40 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

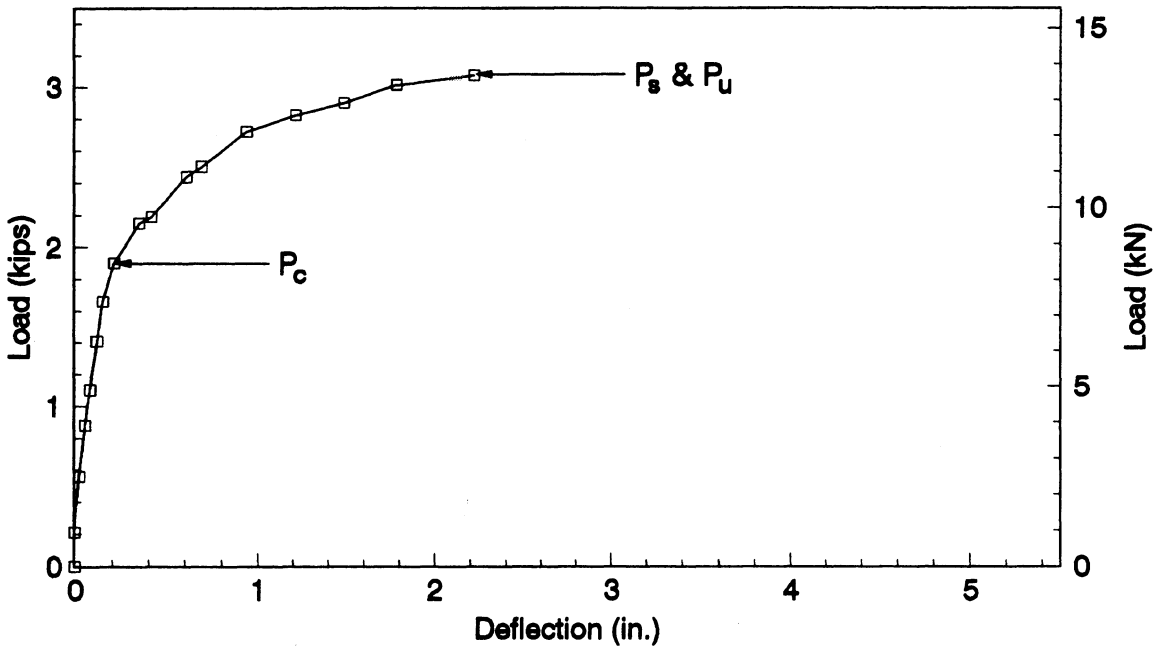


(a)

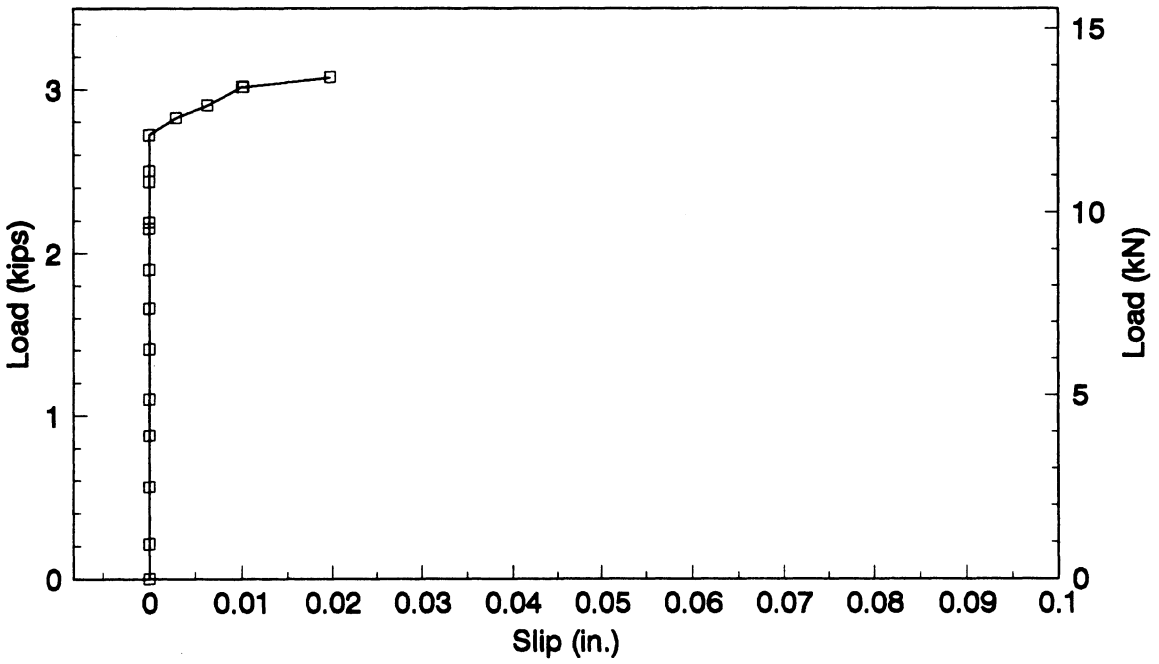


(b)

Figure F.33. Development length test of Specimen No. 11-6.0DU-11 with the load at 40 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

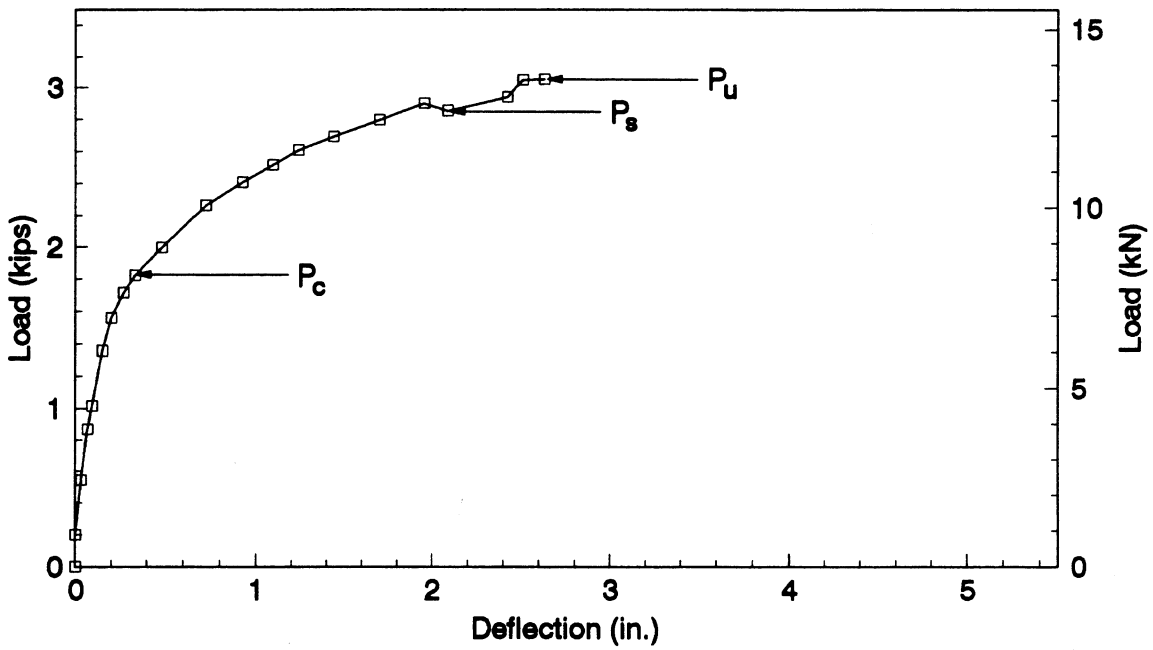


(a)

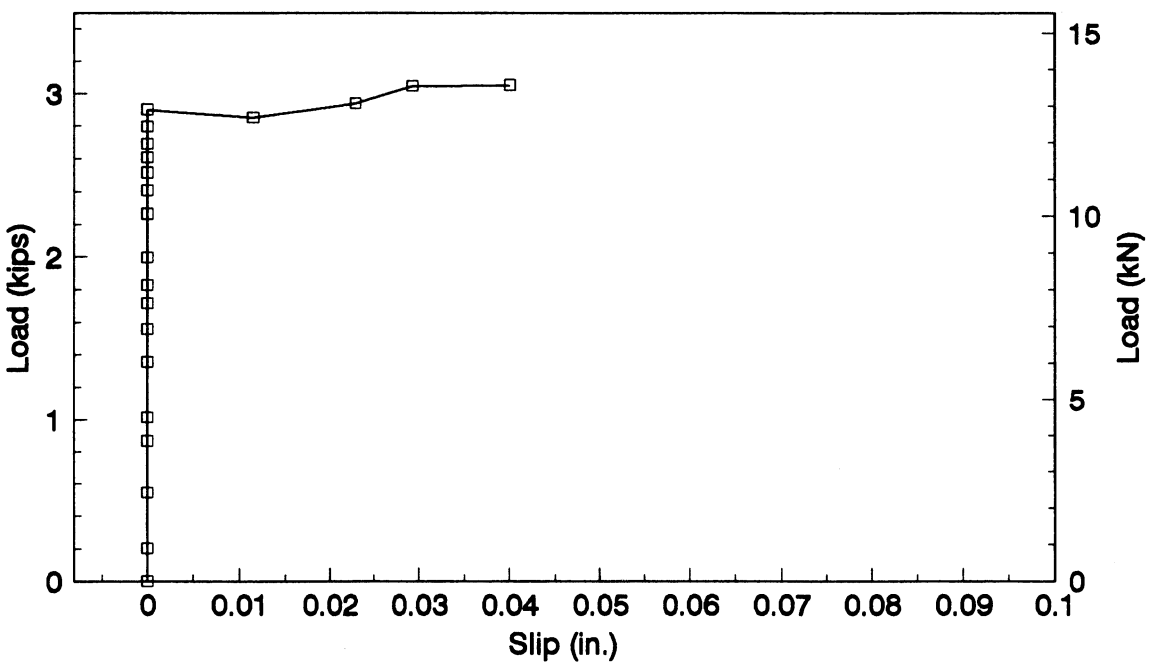


(b)

Figure F.34. Development length test of Specimen No. 11-6.0DU-12 with the load at 42 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

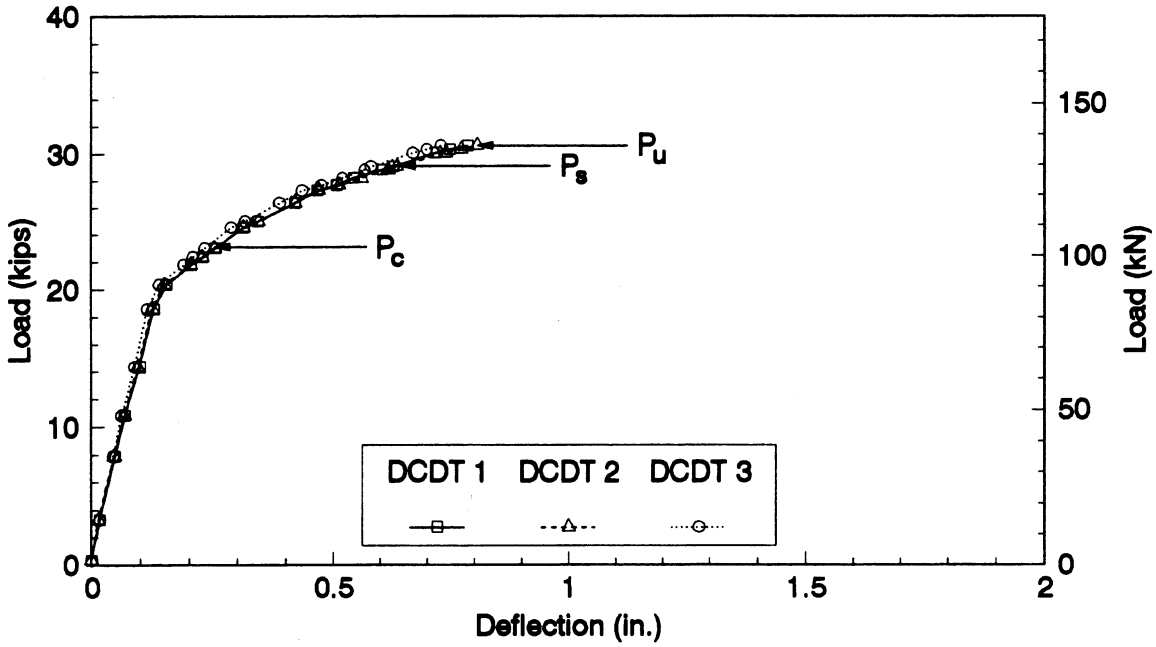


(a)

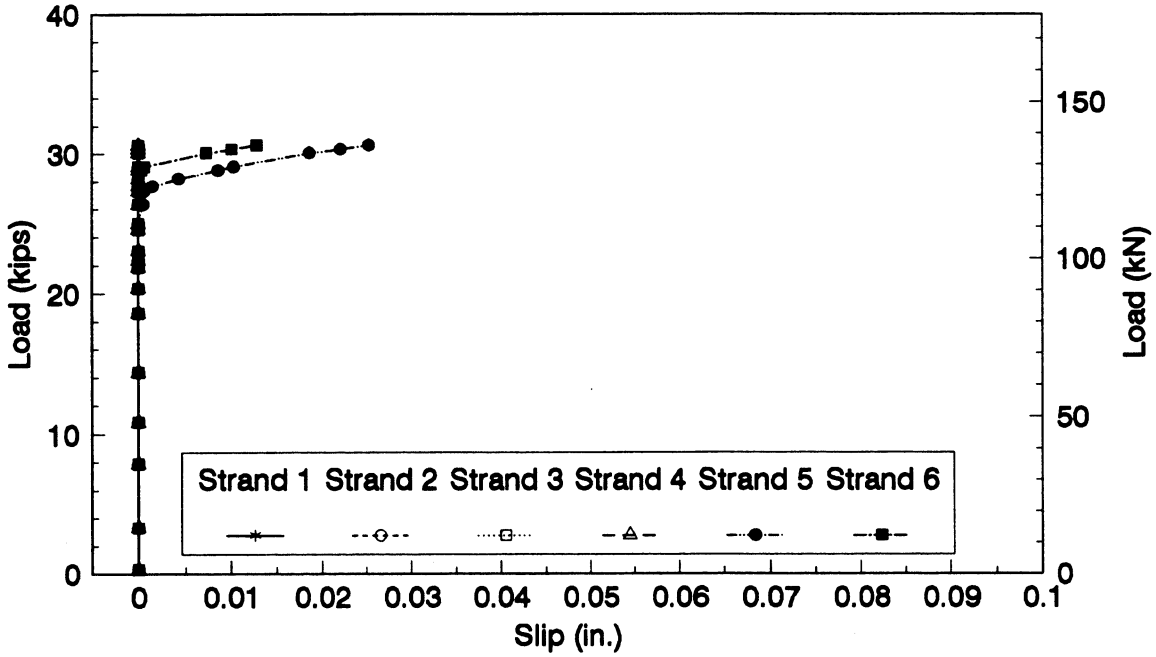


(b)

Figure F.35. Development length test of Specimen No. 11-6.0DU-12 with the load at 44 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

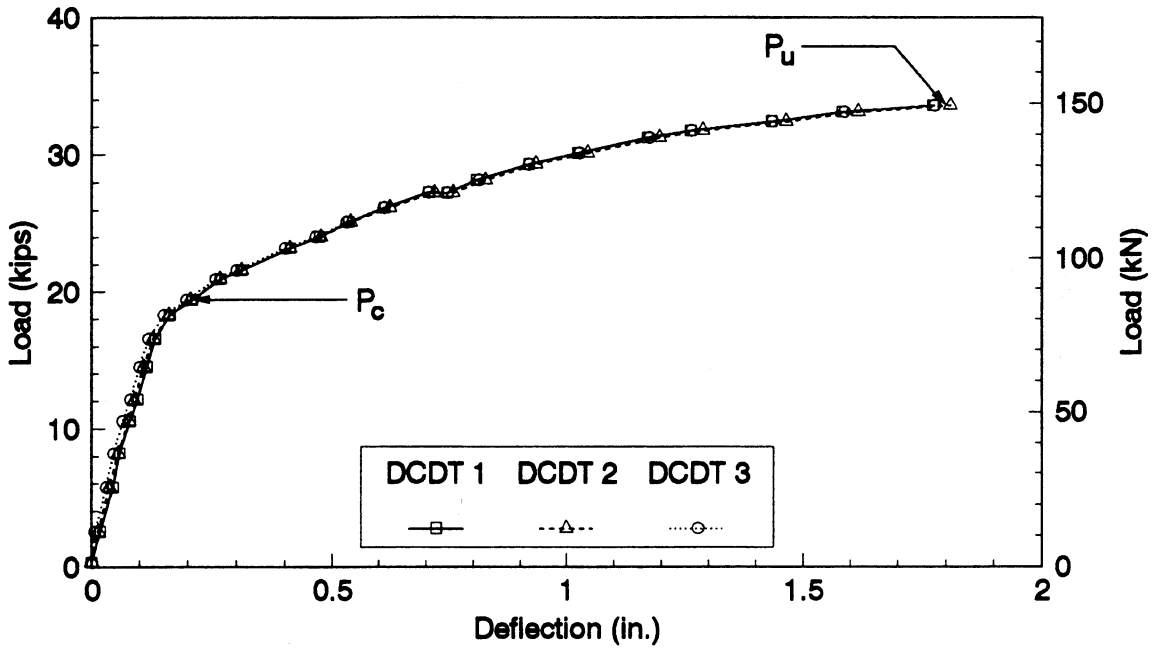


(a)

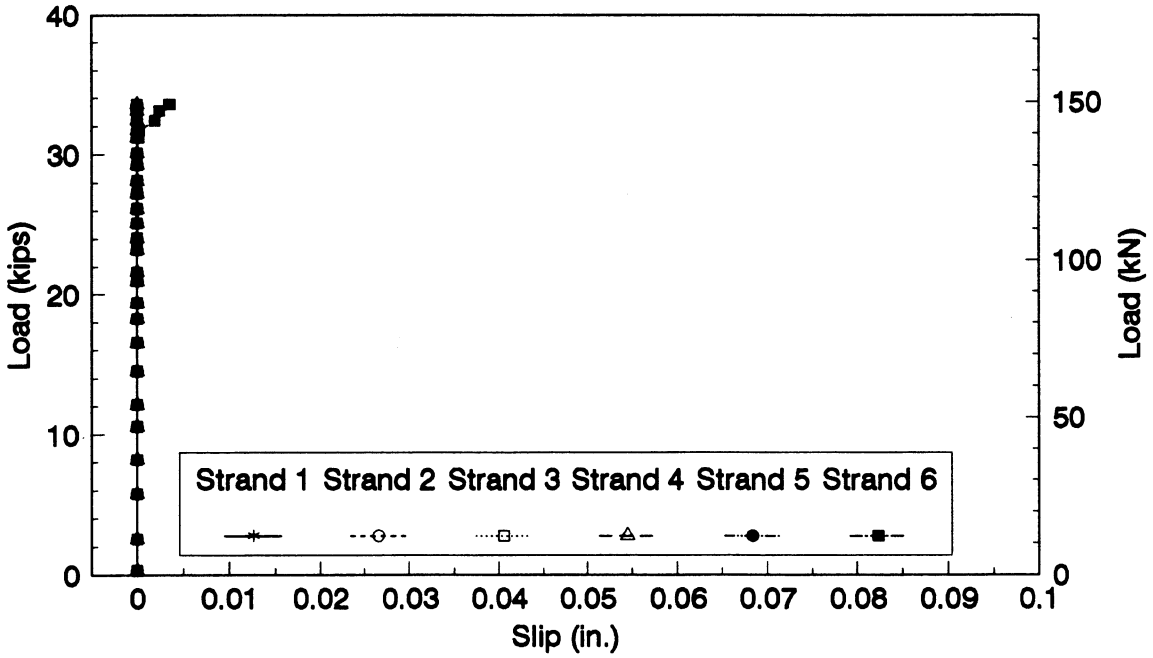


(b)

Figure F.36. Development length test of Specimen No. 12-6.0DC-1 with the load at 22 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

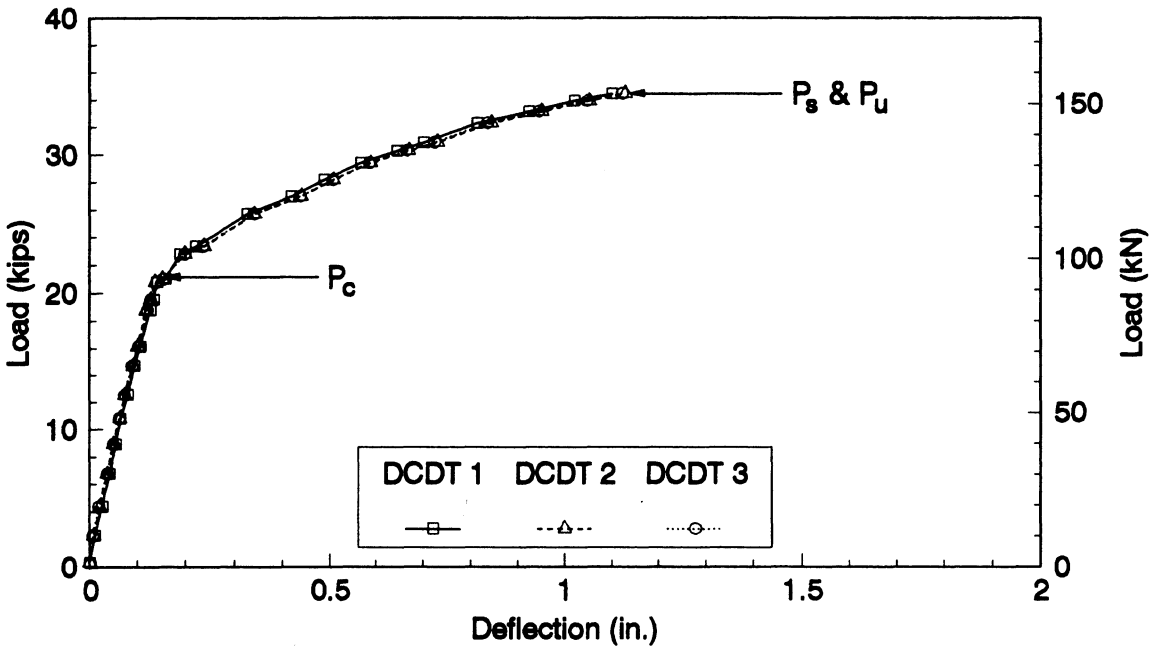


(a)

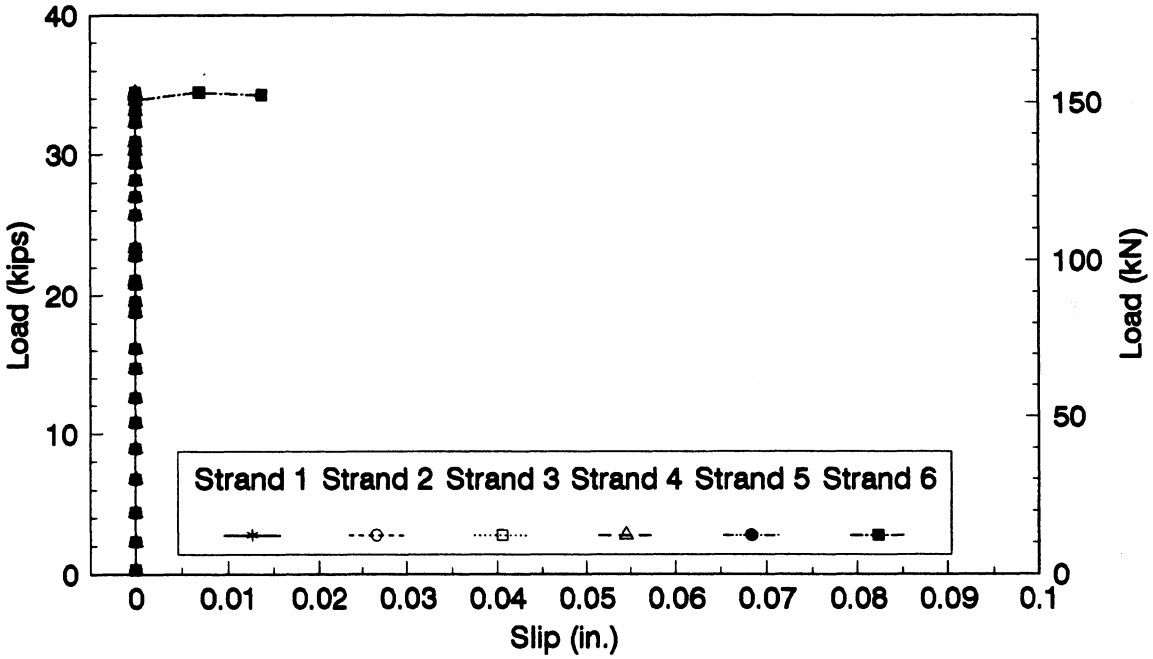


(b)

Figure F.37. Development length test of Specimen No. 12-6.0DC-1 with the load at 24 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

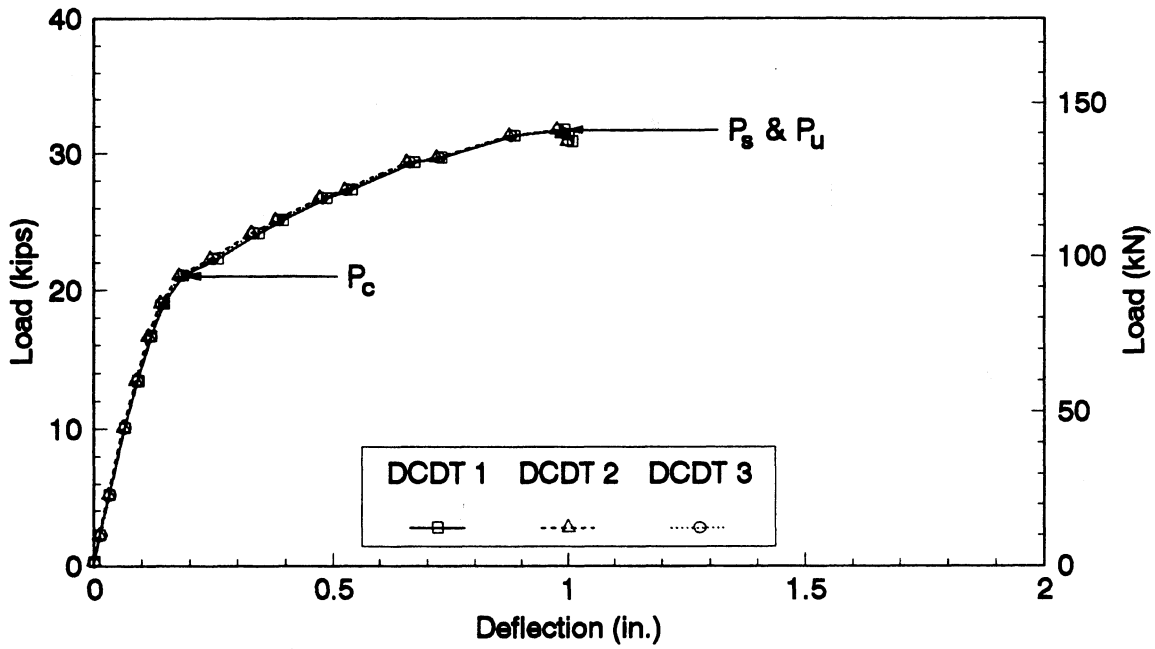


(a)

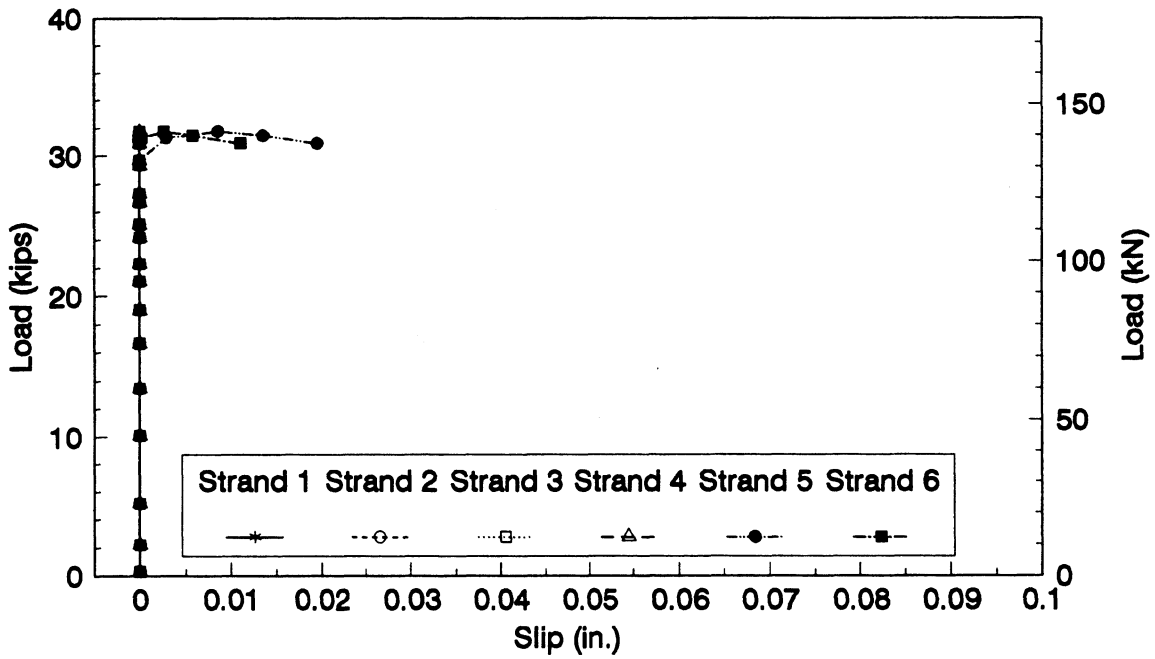


(b)

Figure F.38. Development length test of Specimen No. 12-6.0DC-3 with the load at 23 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

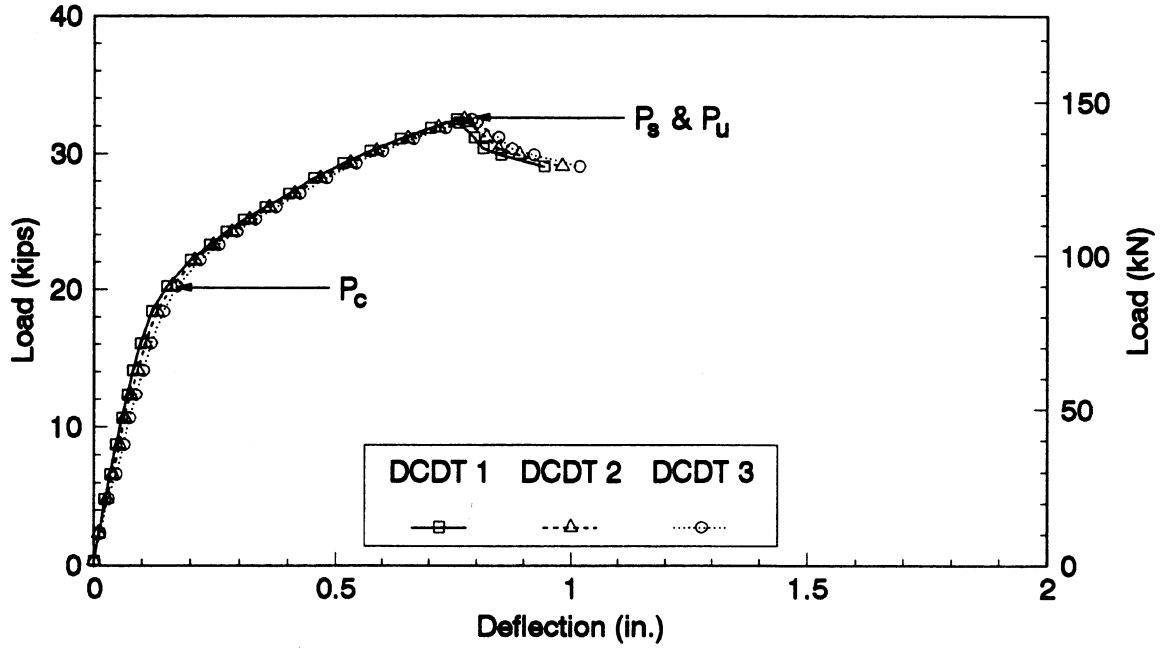


(a)

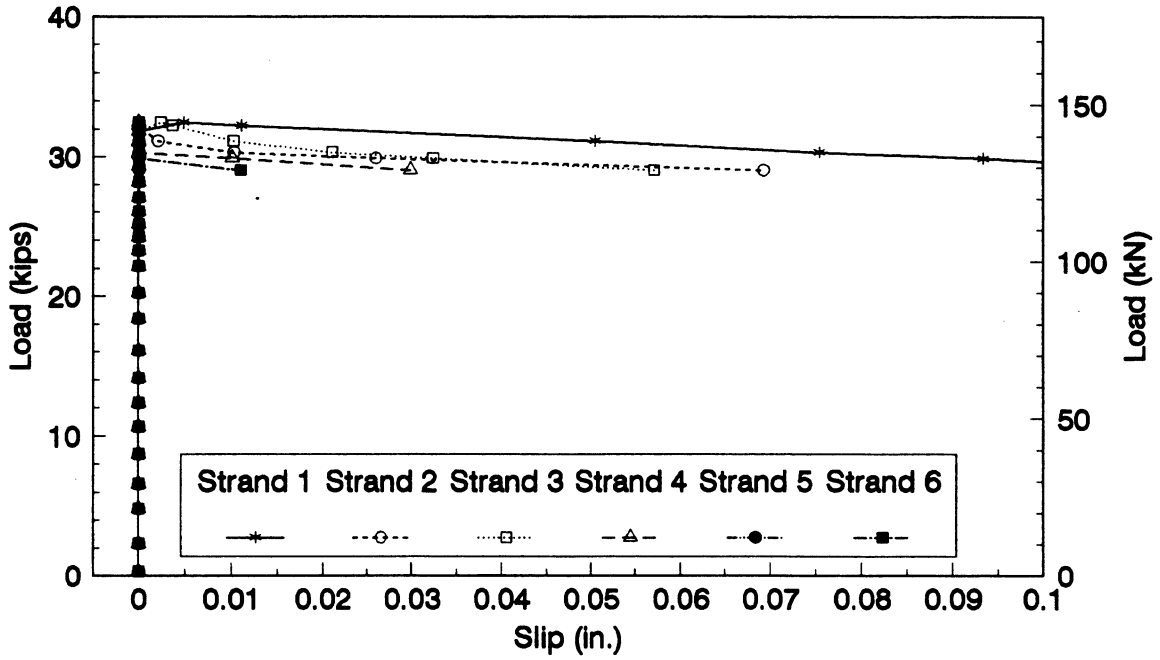


(b)

Figure F.39. Development length test of Specimen No. 12-6.0DC-3 with the load at 22 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

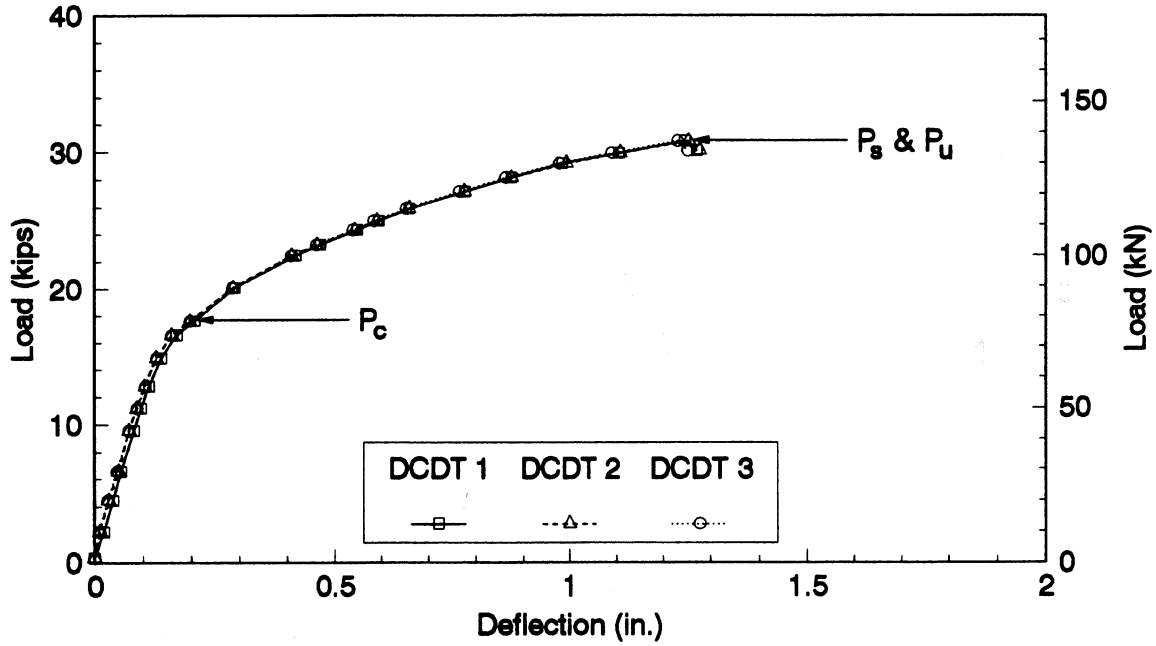


(a)

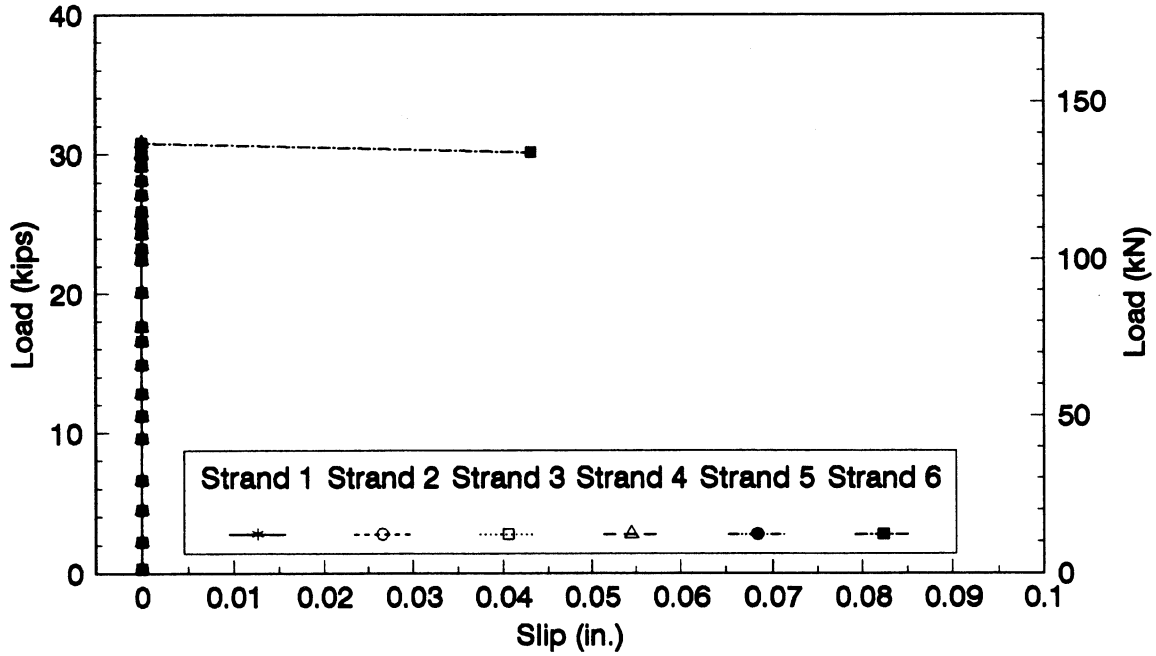


(b)

Figure F.40. Development length test of Specimen No. 14-6.0DC-1 with the load at 20 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

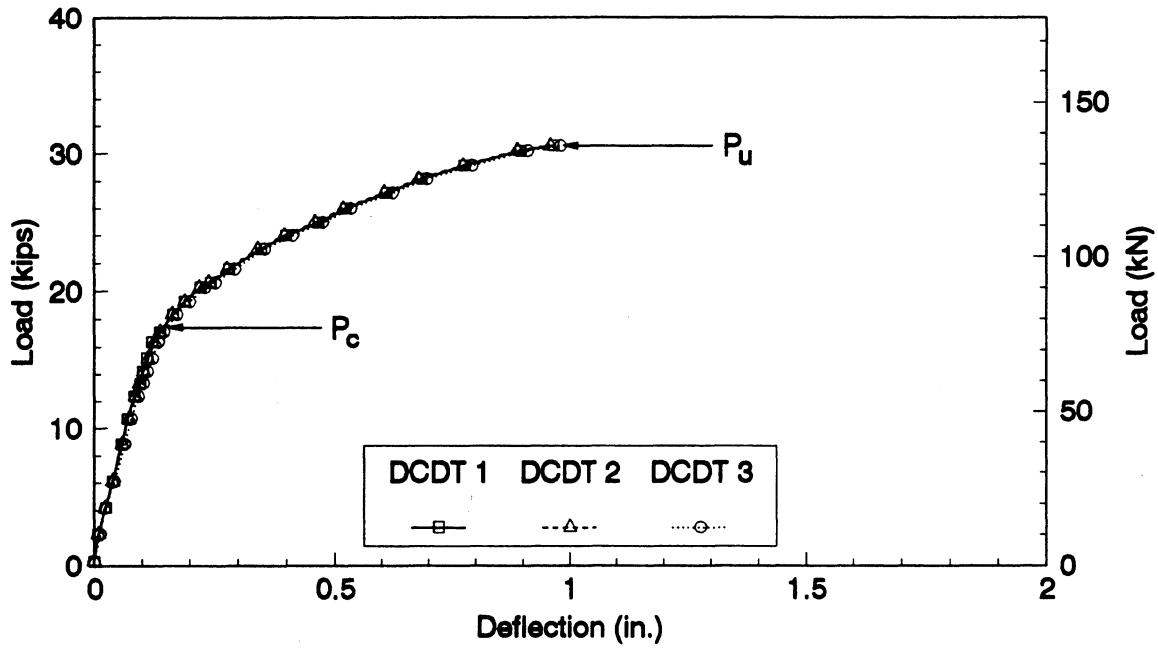


(a)

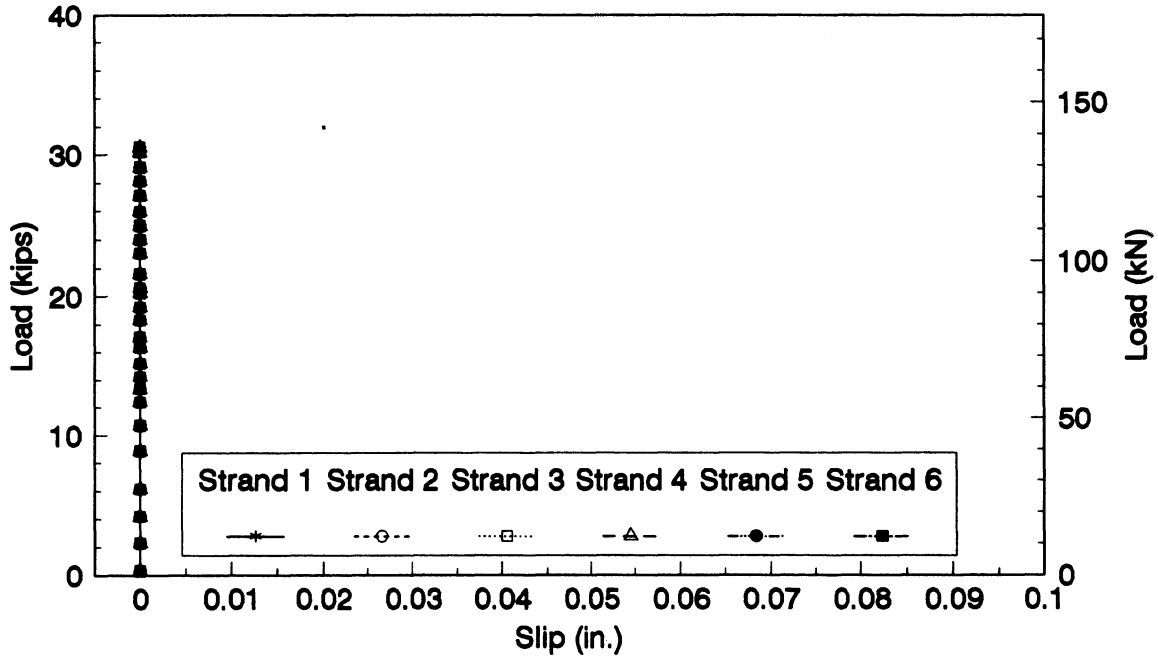


(b)

Figure F.41. Development length test of Specimen No. 14-6.0DC-1 with the load at 24 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

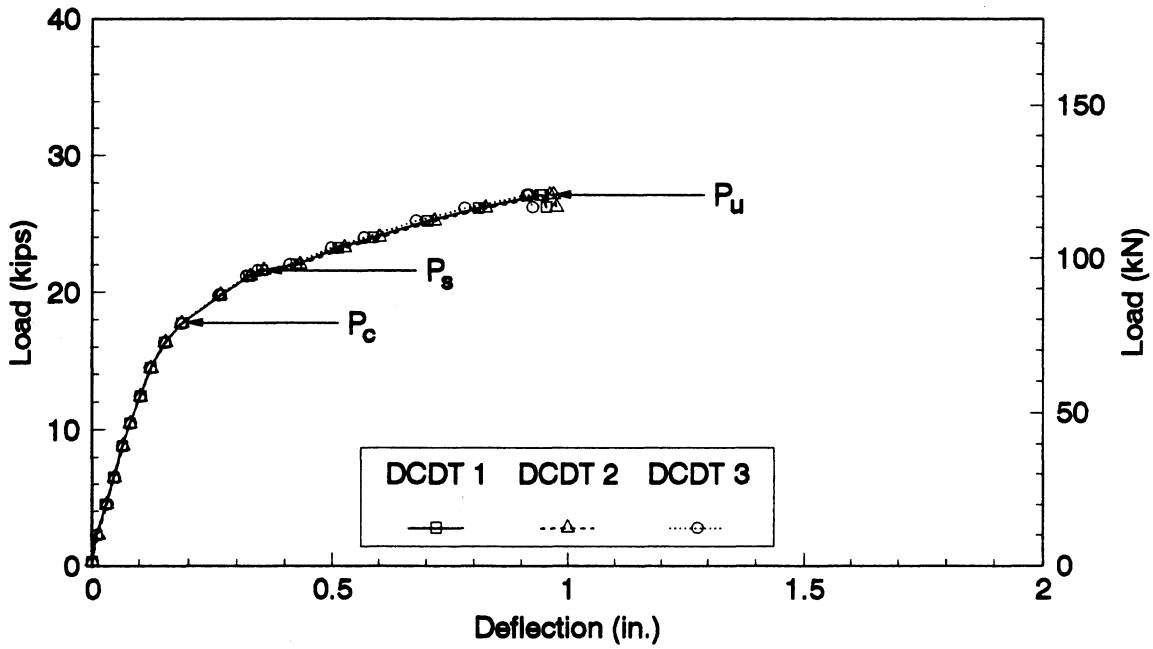


(a)

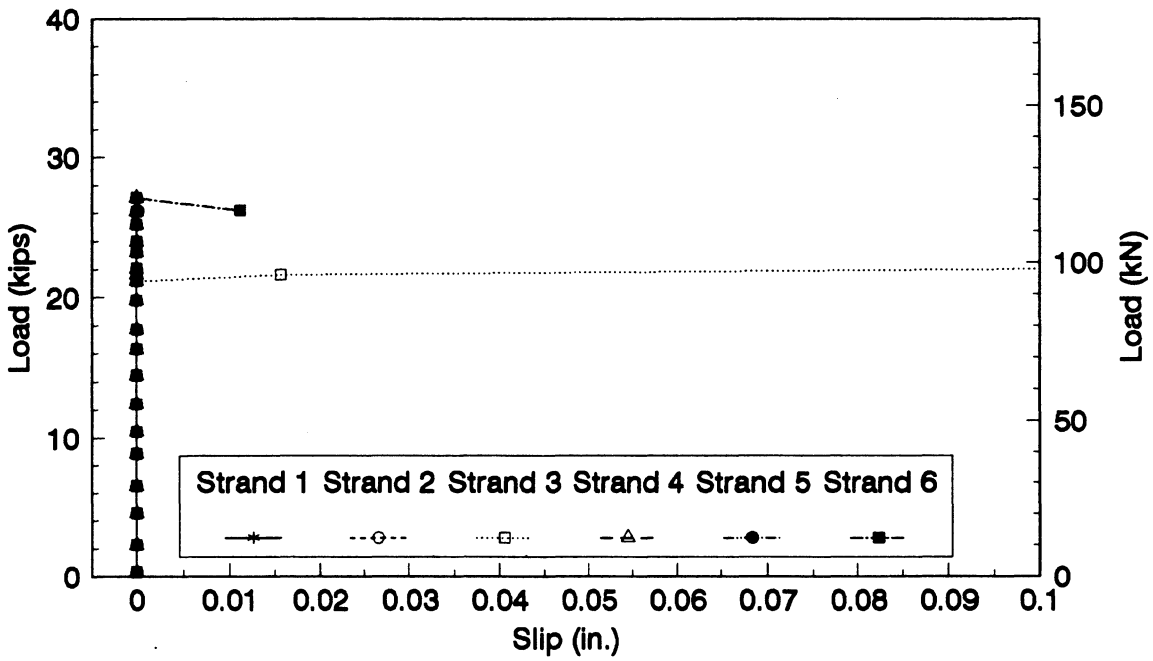


(b)

Figure F.42. Development length test of Specimen No. 14-6.0DC-3 with the load at 22 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

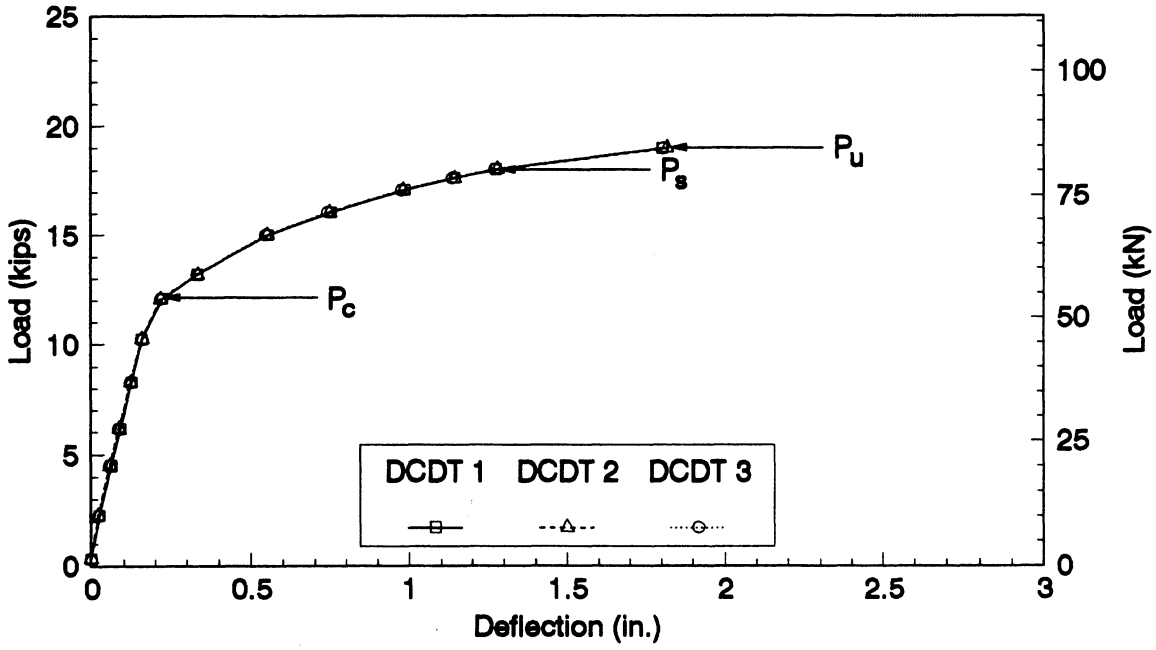


(a)

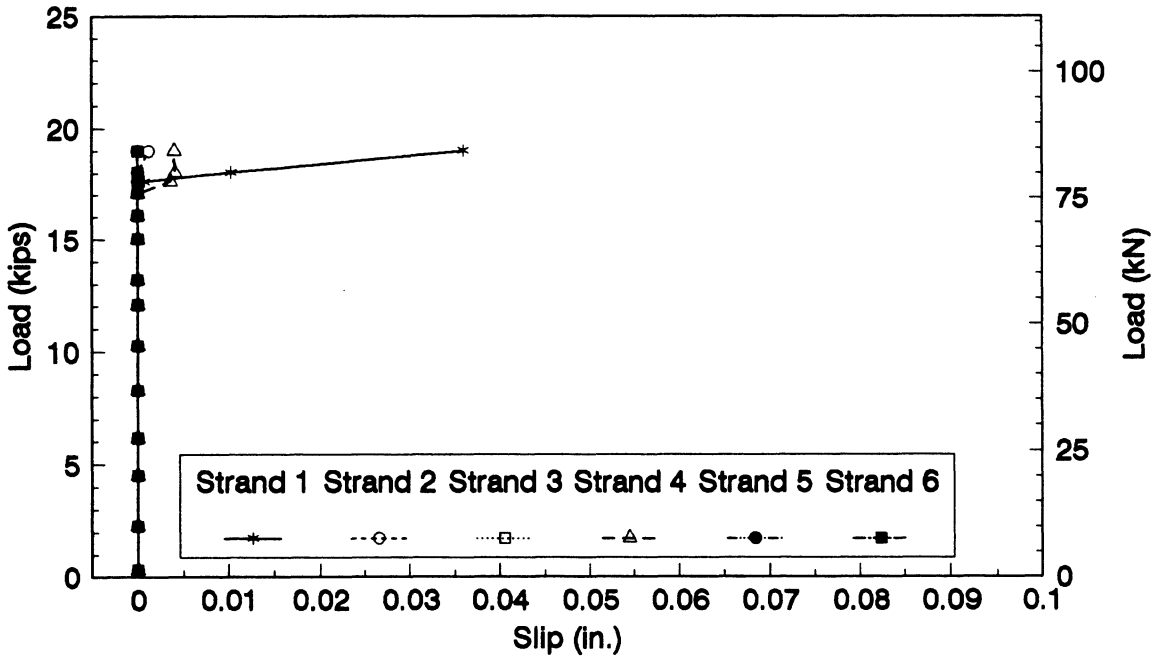


(b)

Figure F.43. Development length test of Specimen No. 14-6.0DC-3 with the load at 24 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

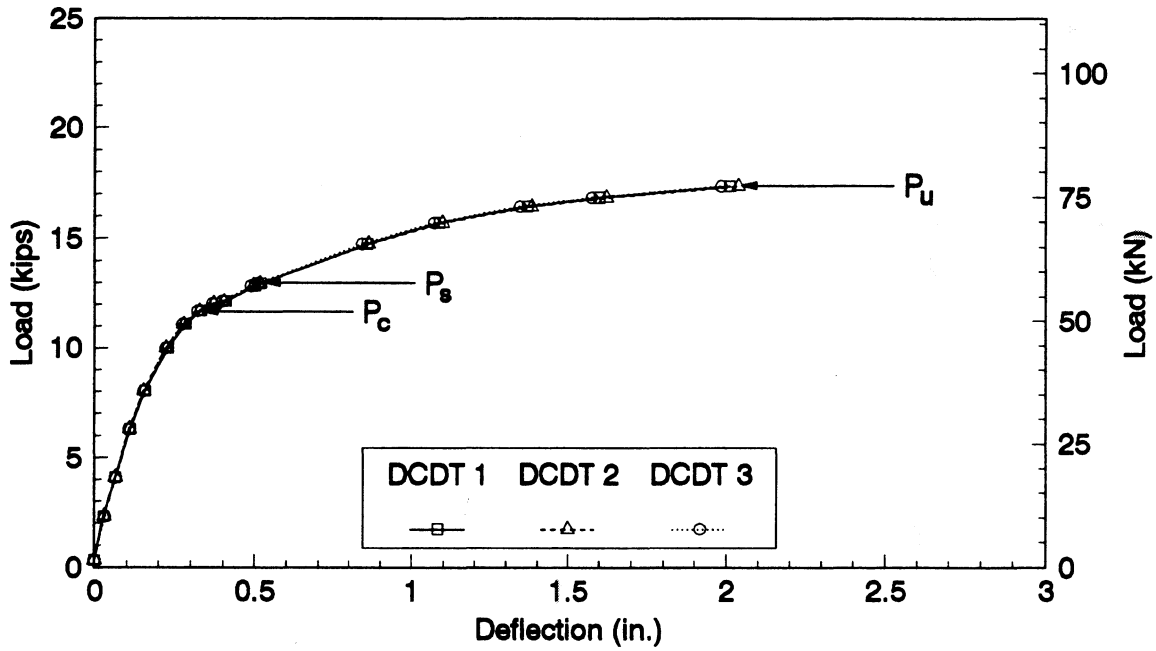


(a)

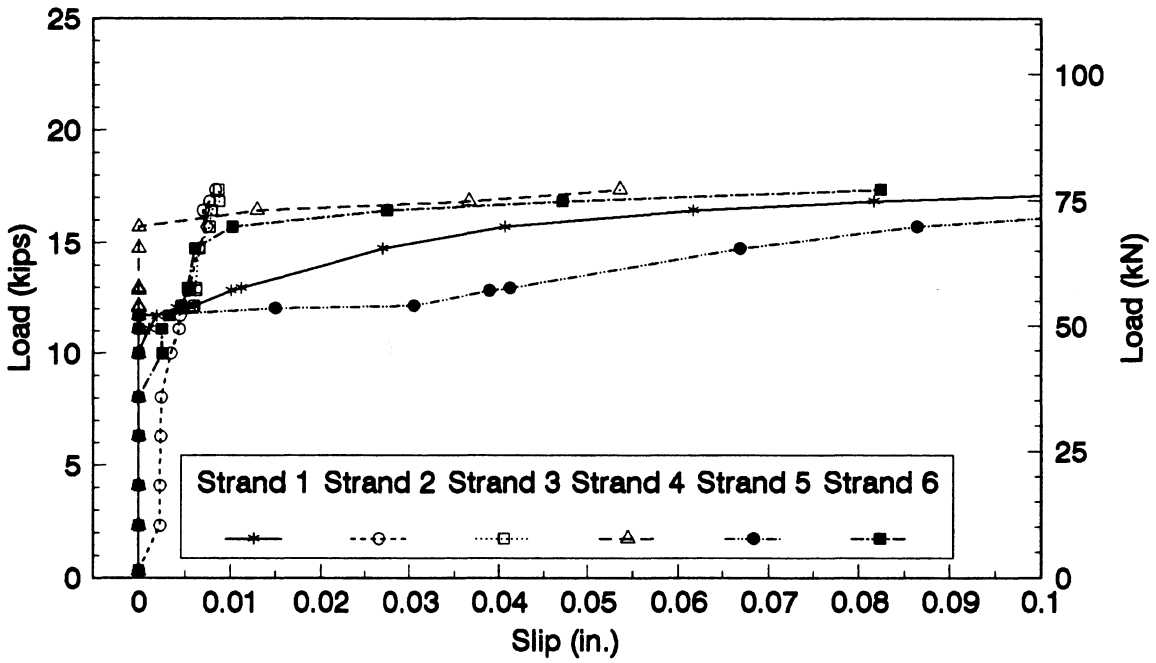


(b)

Figure F.44. Development length test of Specimen No. 15-6.0DU-1 with the load at 42 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

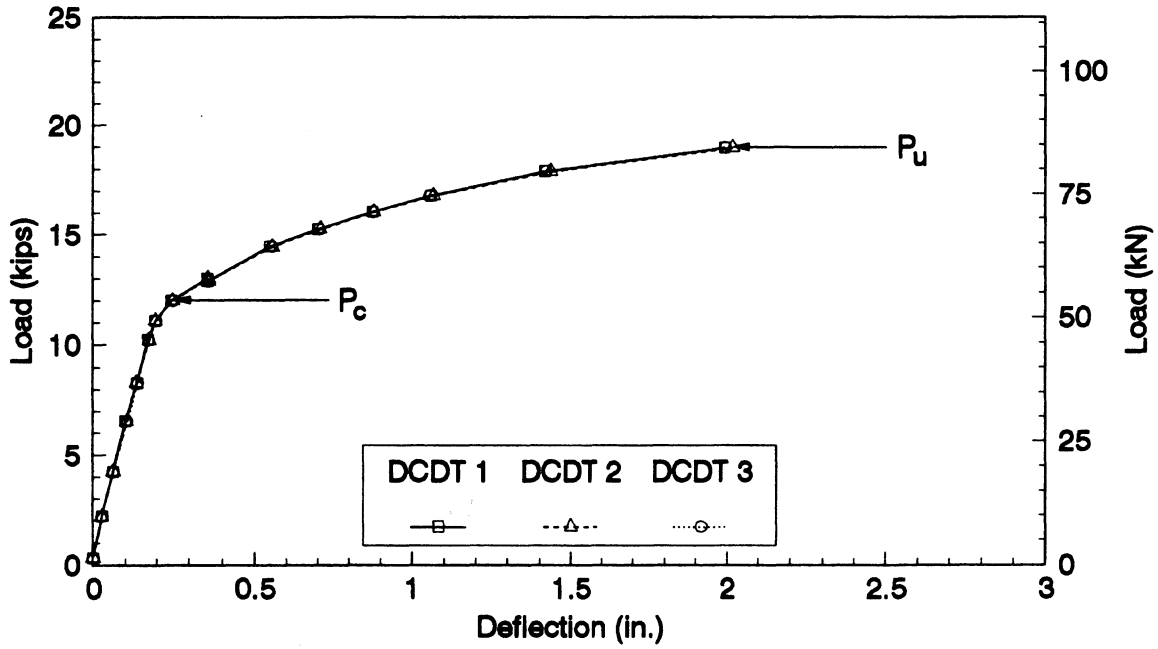


(a)

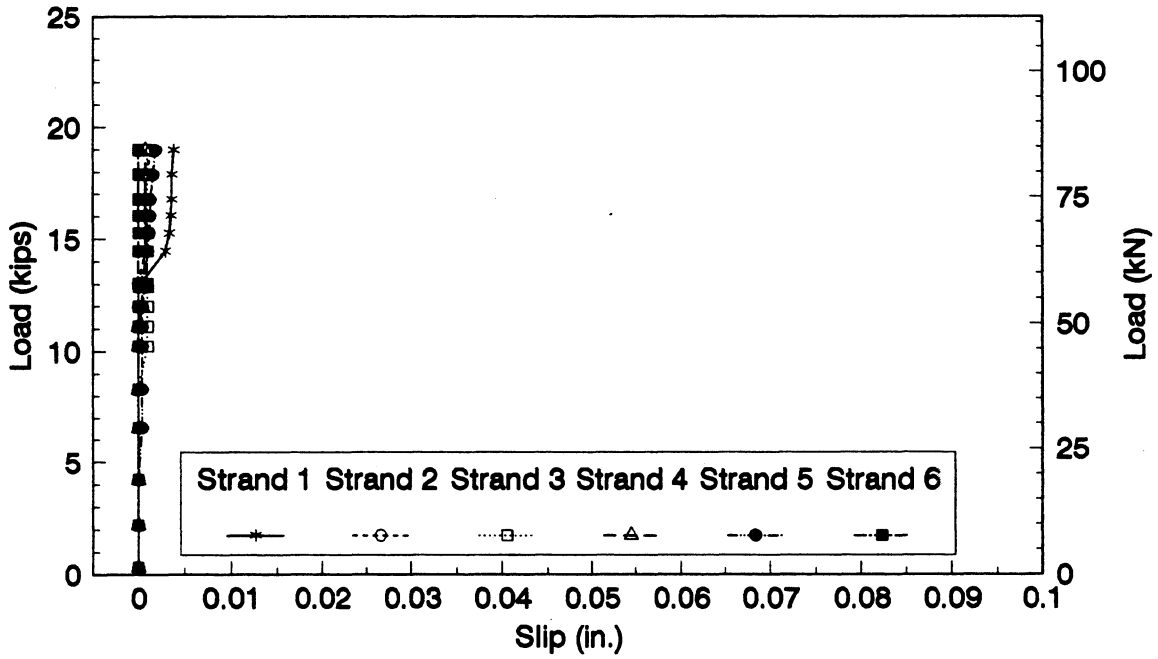


(b)

Figure F.45. Development length test of Specimen No. 15-6.0DU-1 with the load at 44 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B



(a)



(b)

Figure F.46. Development length test of Specimen No. 15-6.0DU-3 with the load at 48 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

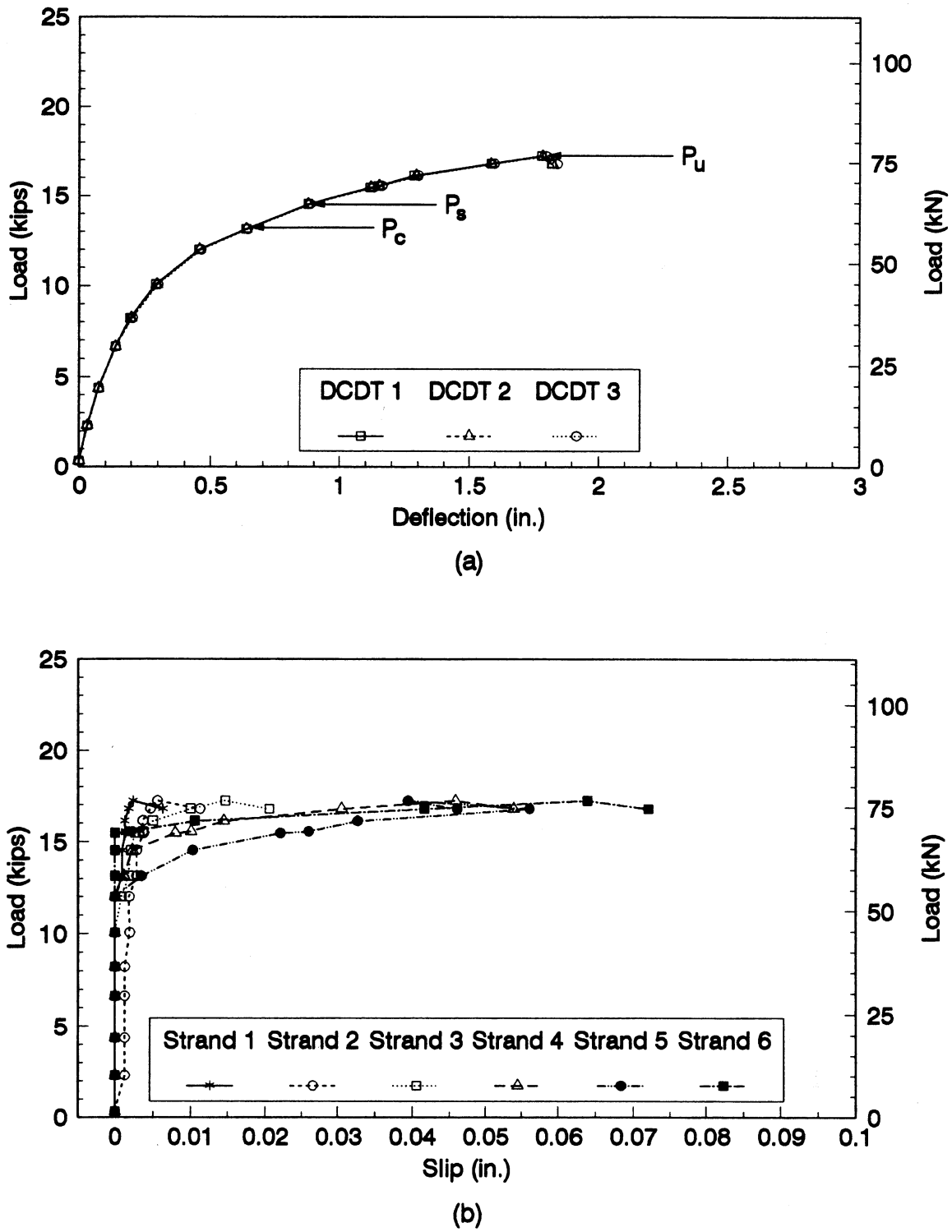
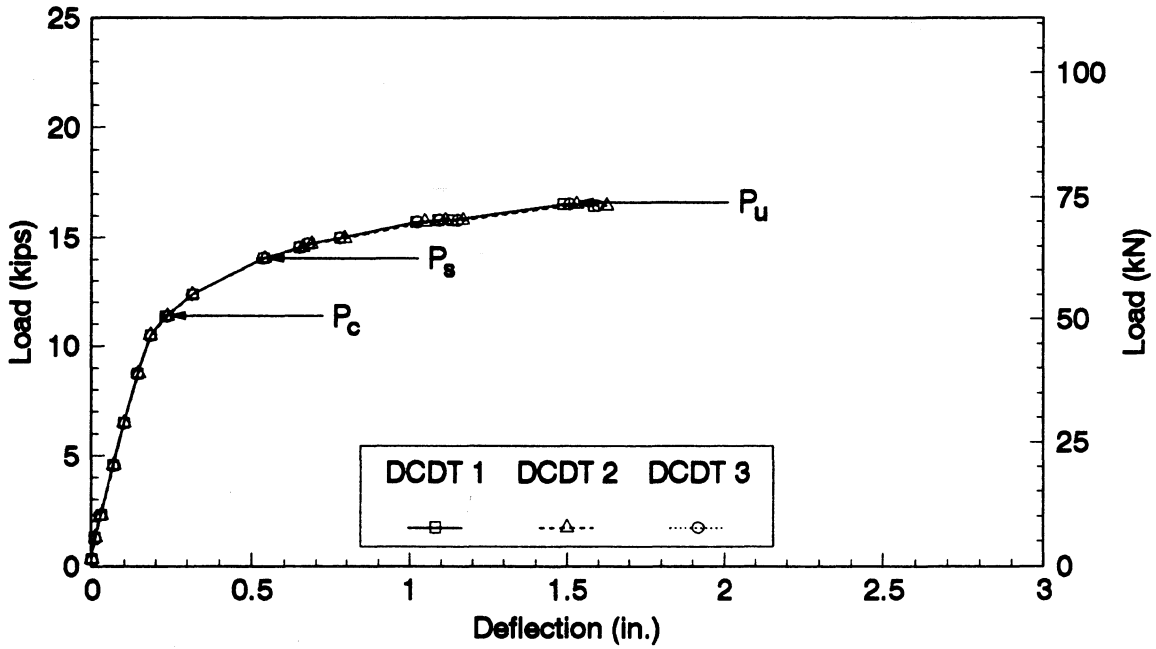
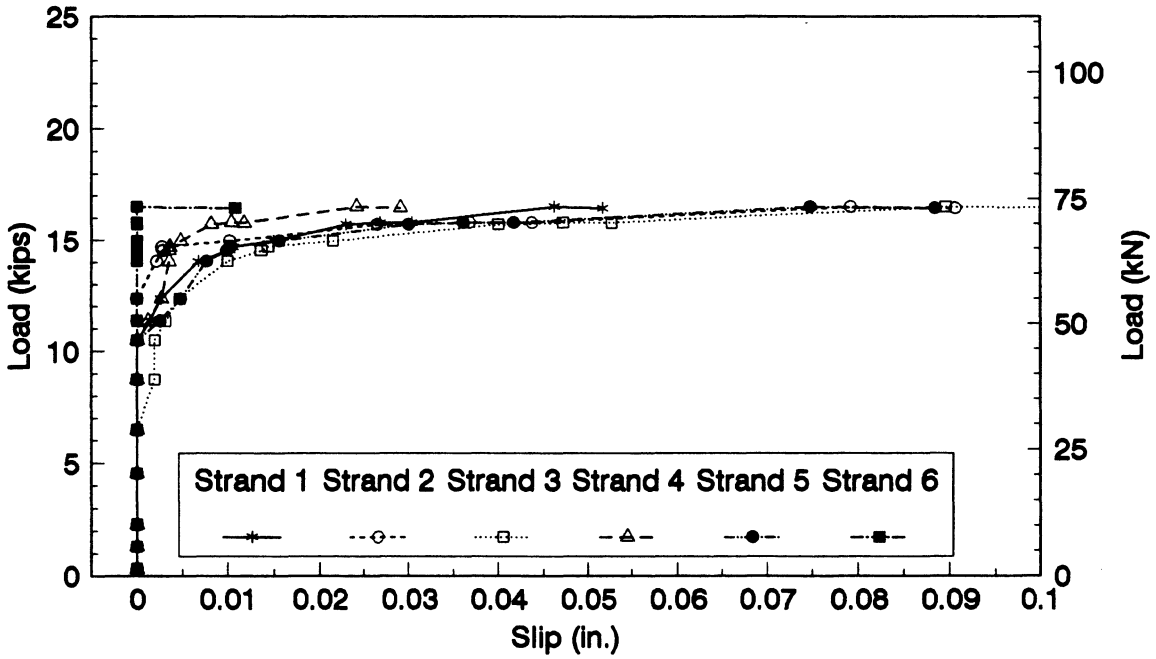


Figure F.47. Development length test of Specimen No. 15-6.0DU-3 with the load at 46 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

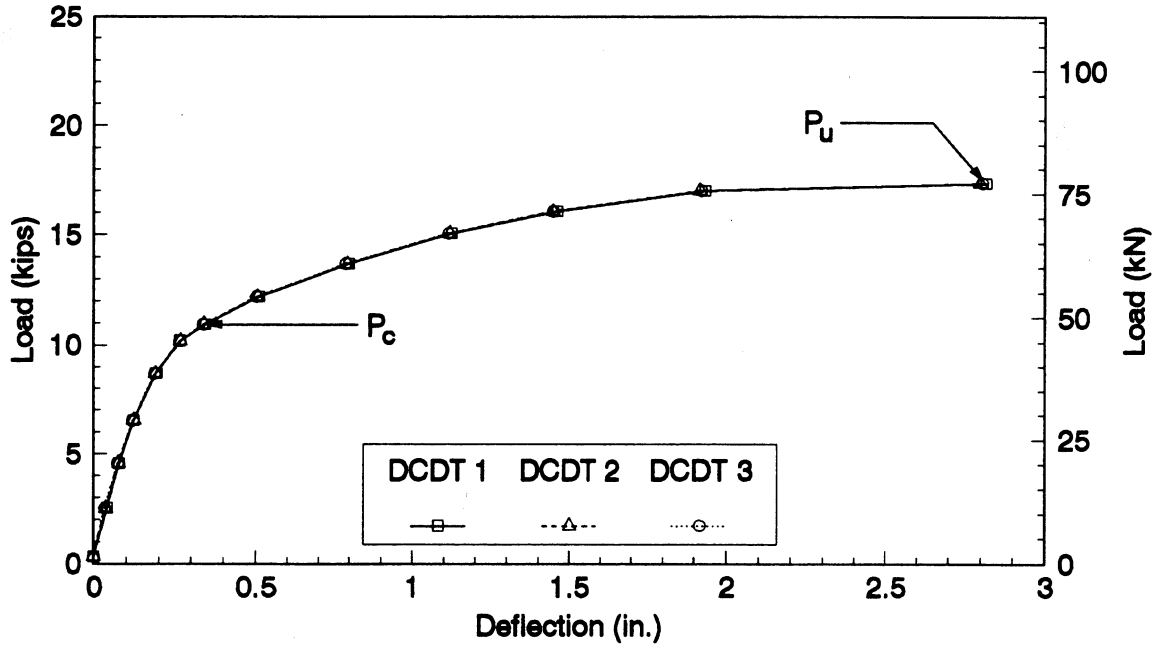


(a)

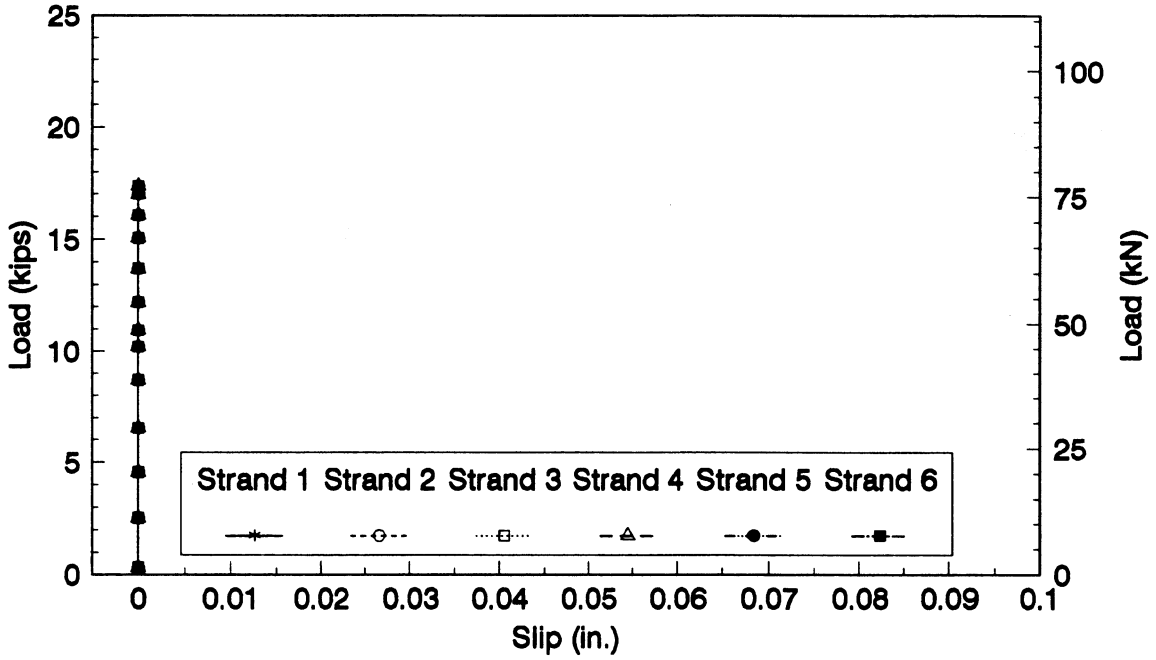


(b)

Figure F.48. Development length test of Specimen No. 16-6.0DU-3 with the load at 45 in. from End D: (a) load versus deflection; (b) load versus strand-slip at End D

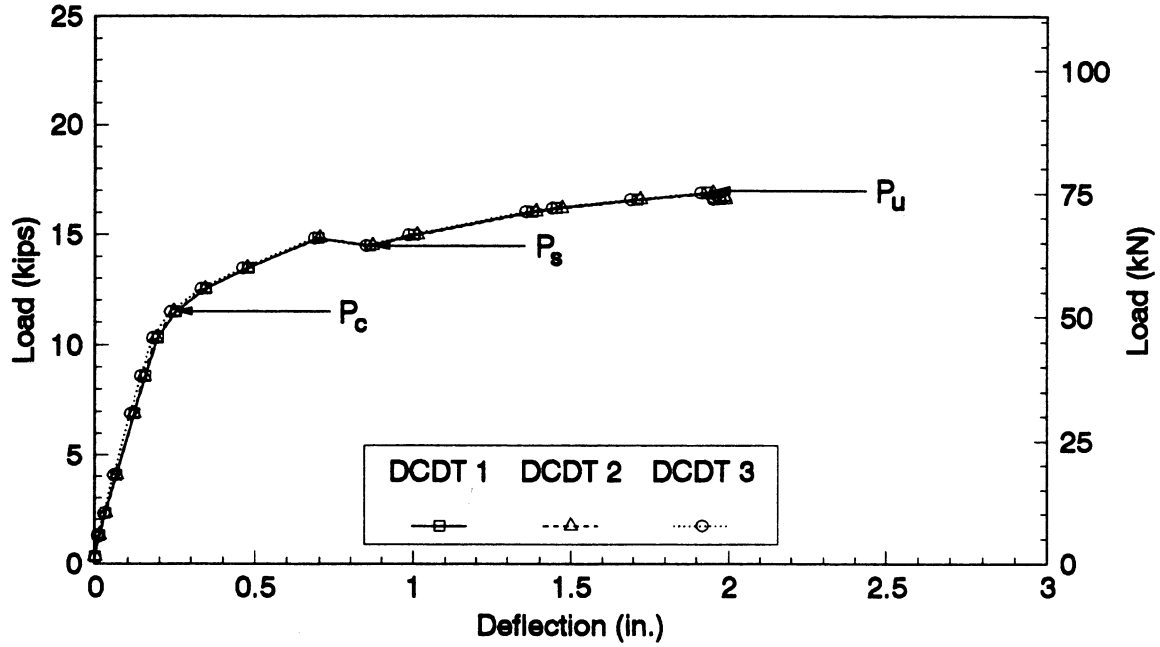


(a)

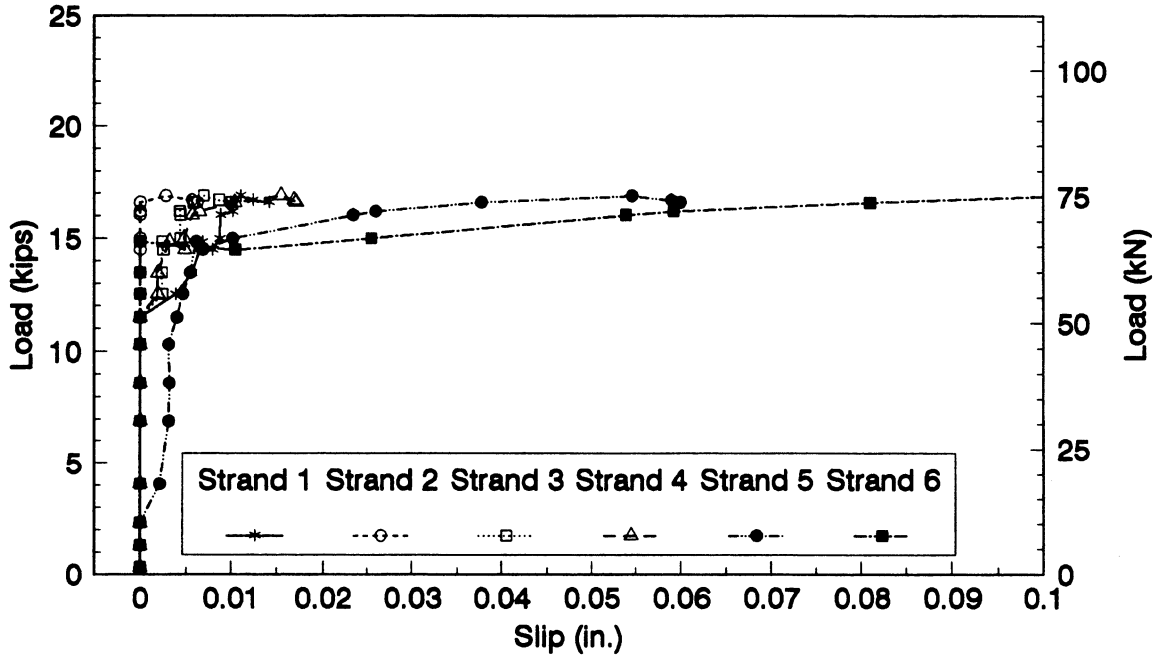


(b)

Figure F.49. Development length test of Specimen No. 16-6.0DU-3 with the load at 50 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

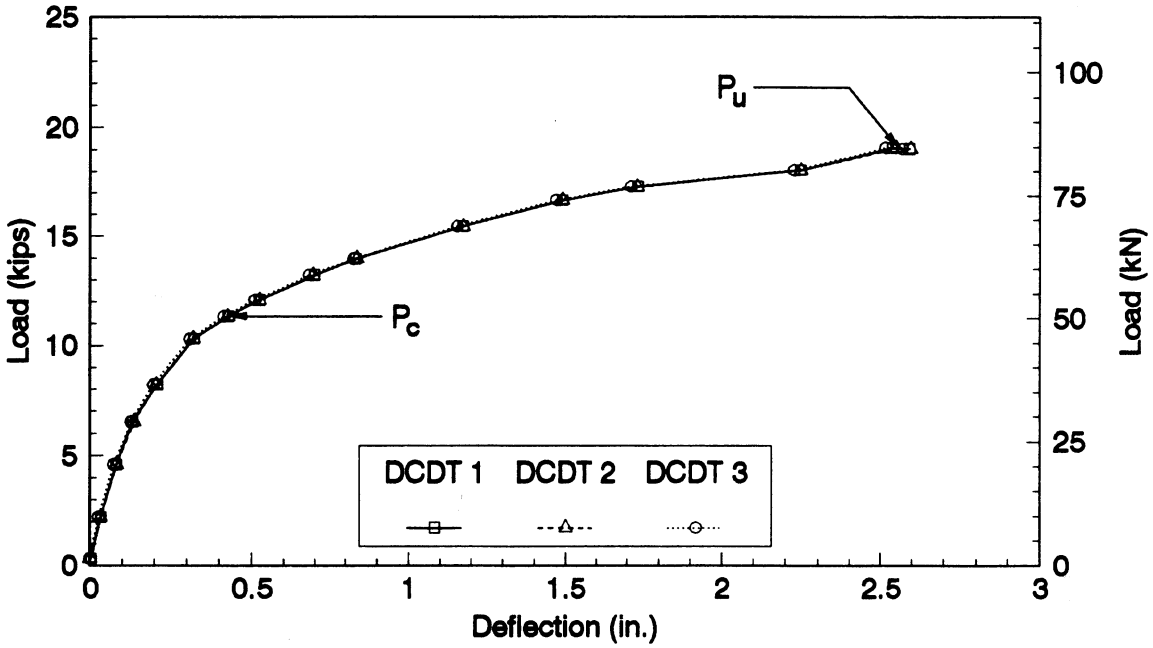


(a)

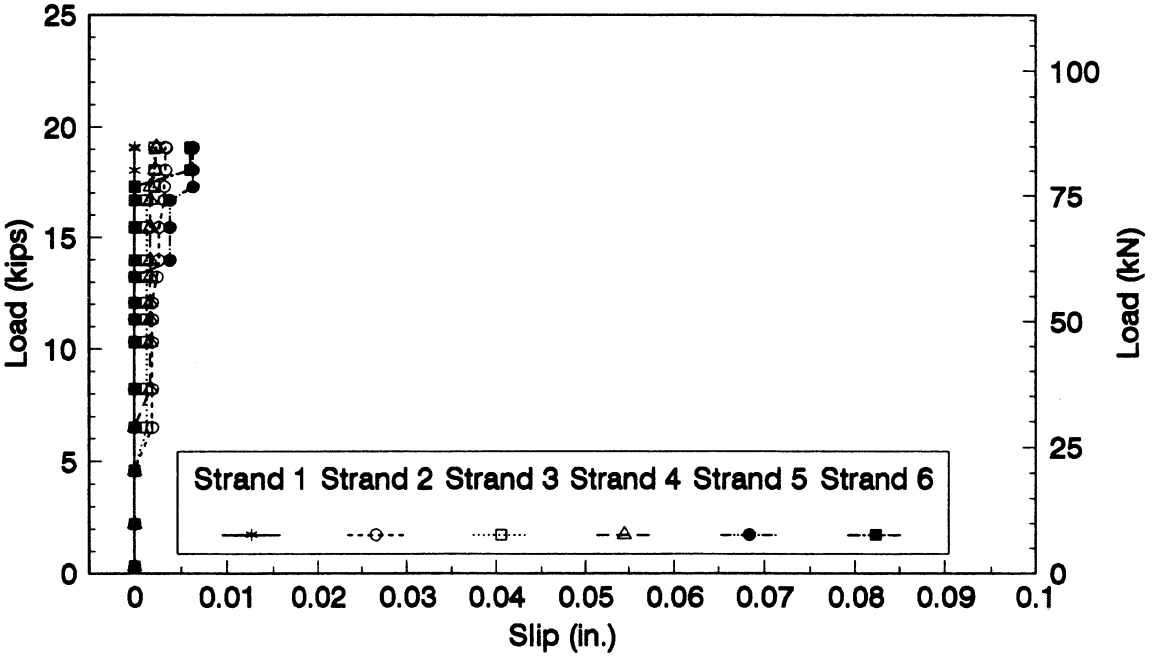


(b)

Figure F.50. Development length test of Specimen No. 16-6.0DU-1 with the load at 48 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

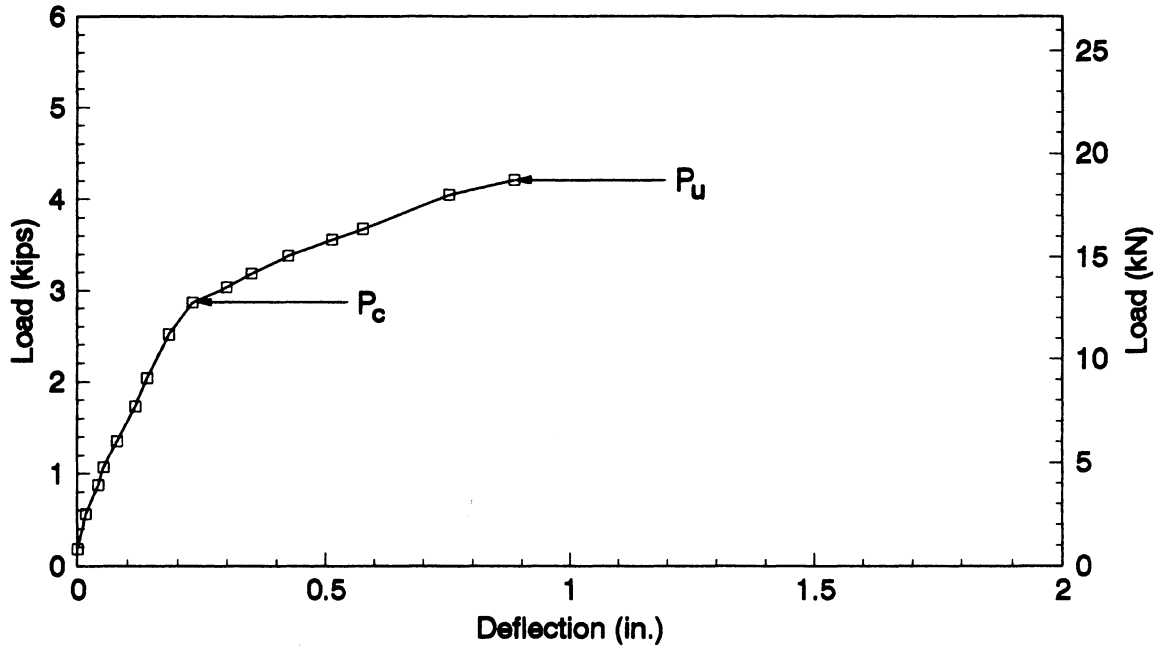


(a)

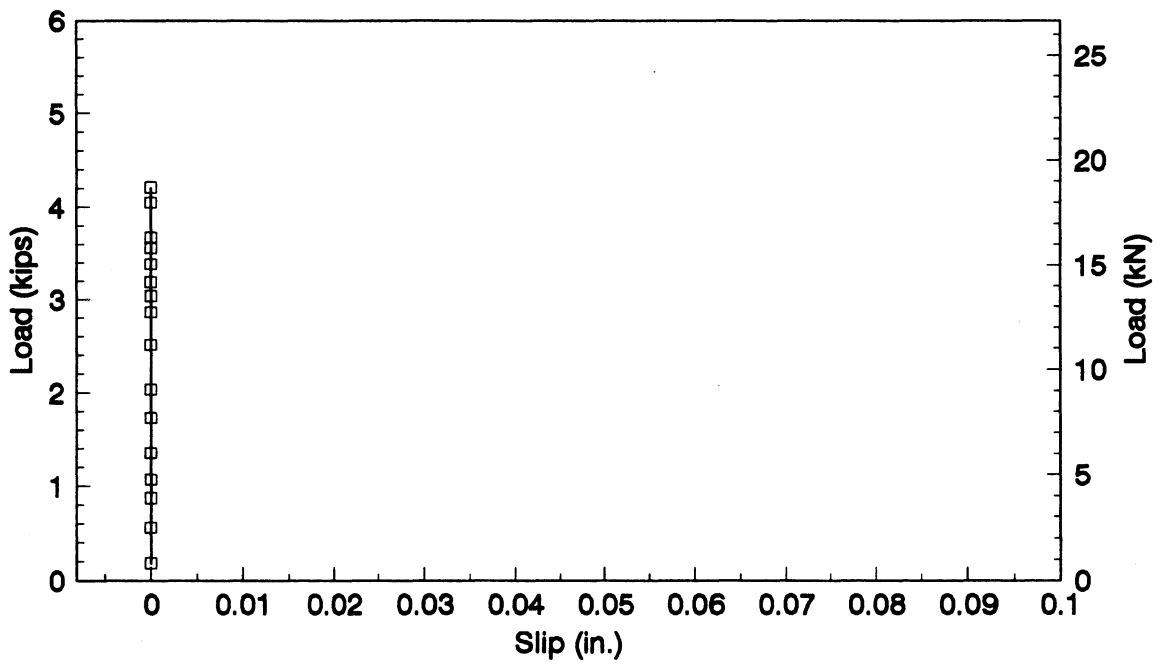


(b)

Figure F.51. Development length test of Specimen No. 16-6.0DU-1 with the load at 49 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

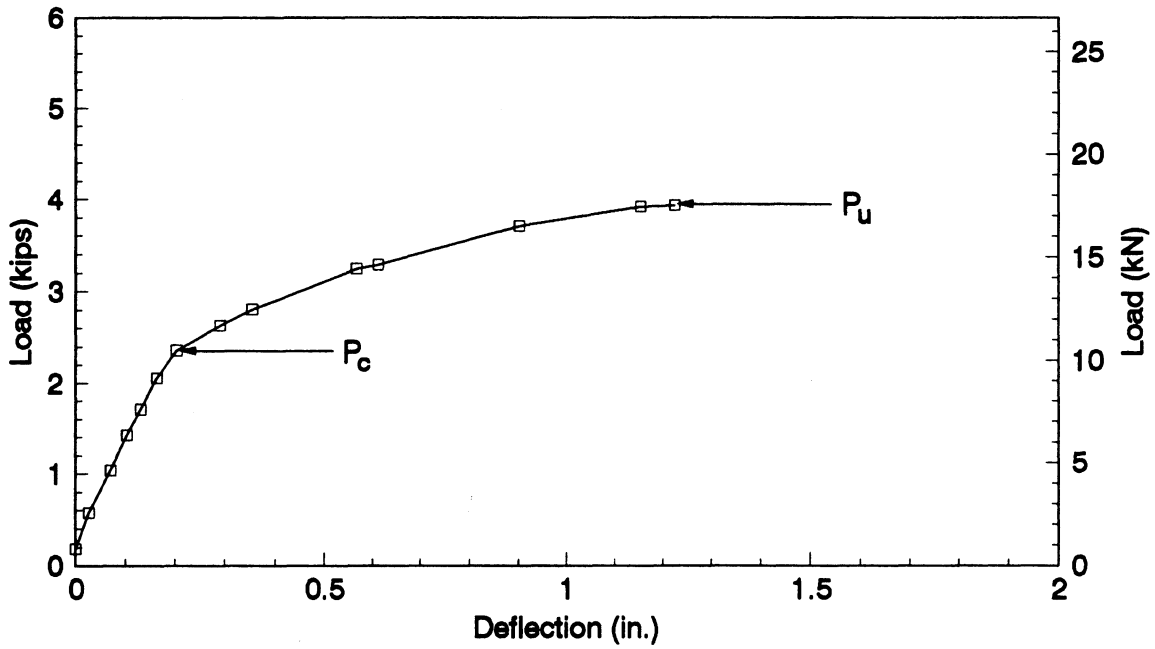


(a)

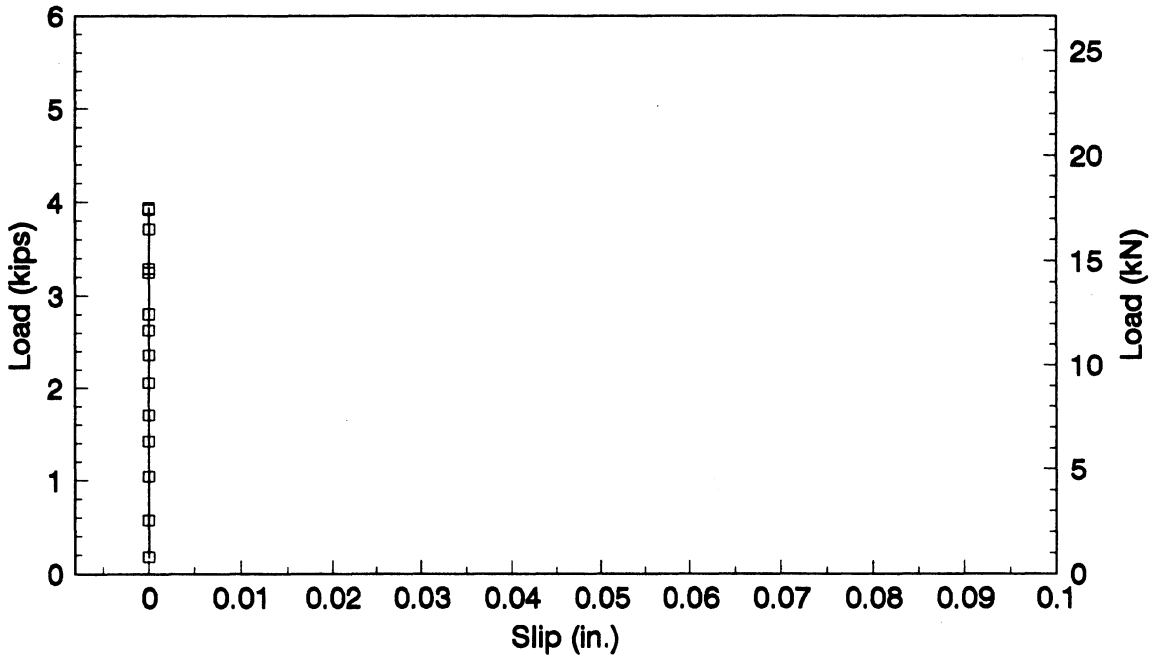


(b)

Figure F.52. Development length test of Specimen No. 17-6.0DC-1 with the load at 24 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

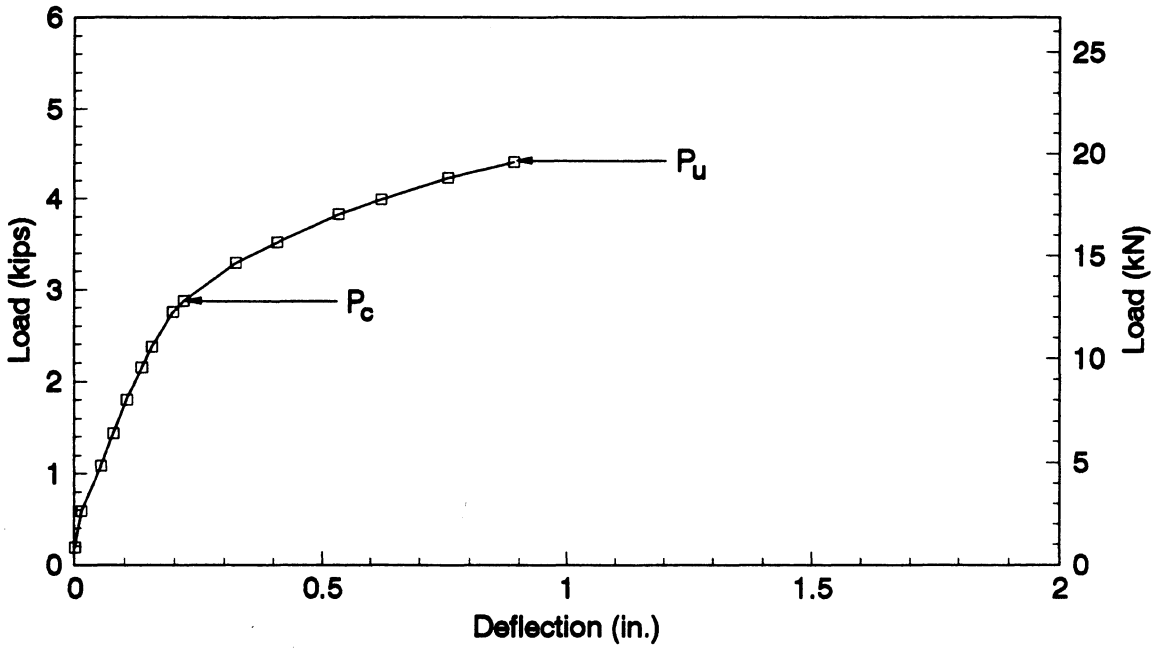


(a)

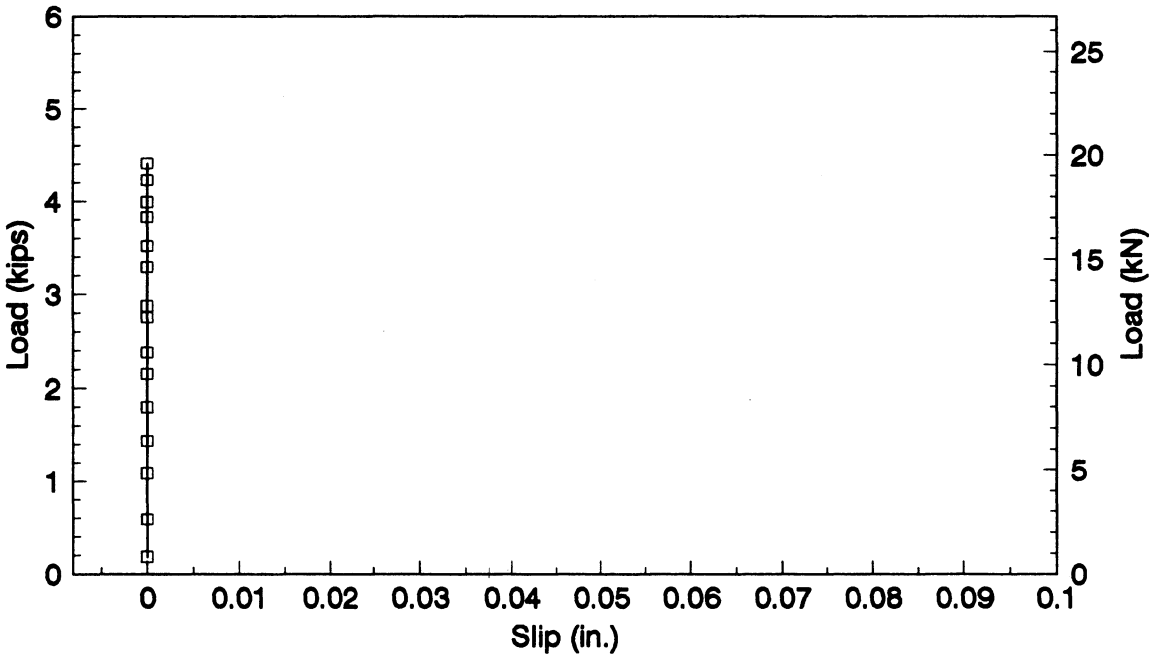


(b)

Figure F.53. Development length test of Specimen No. 17-6.0DC-1 with the load at 26 in. from End A: (a) load versus deflection; (b) load versus strand-slip at End A

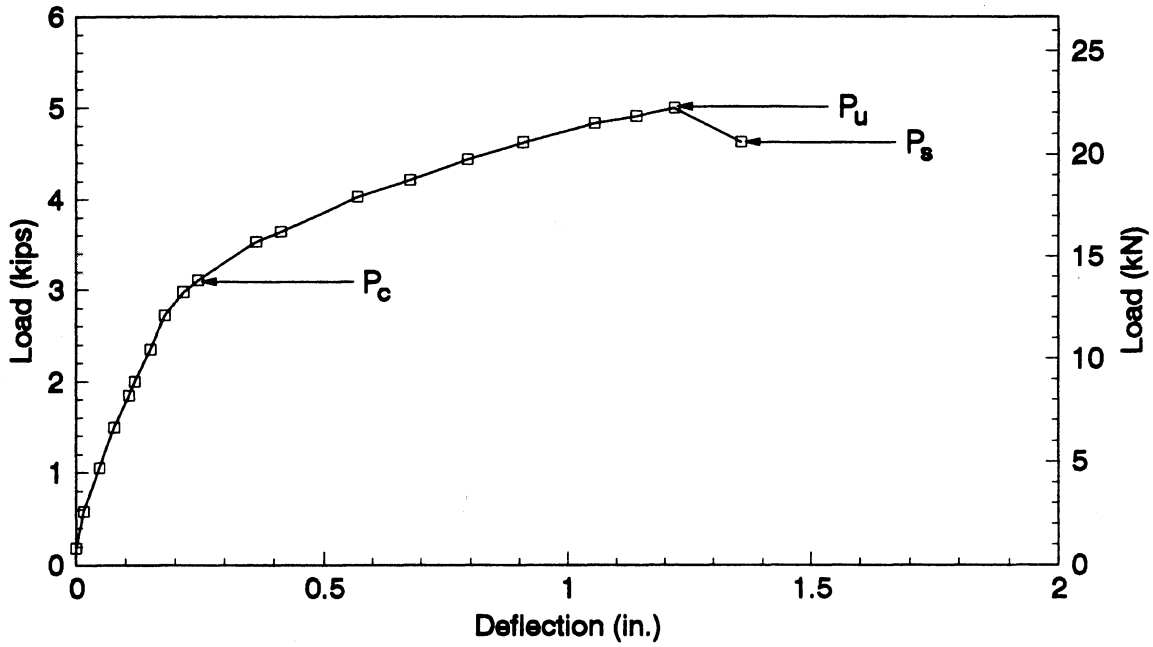


(a)

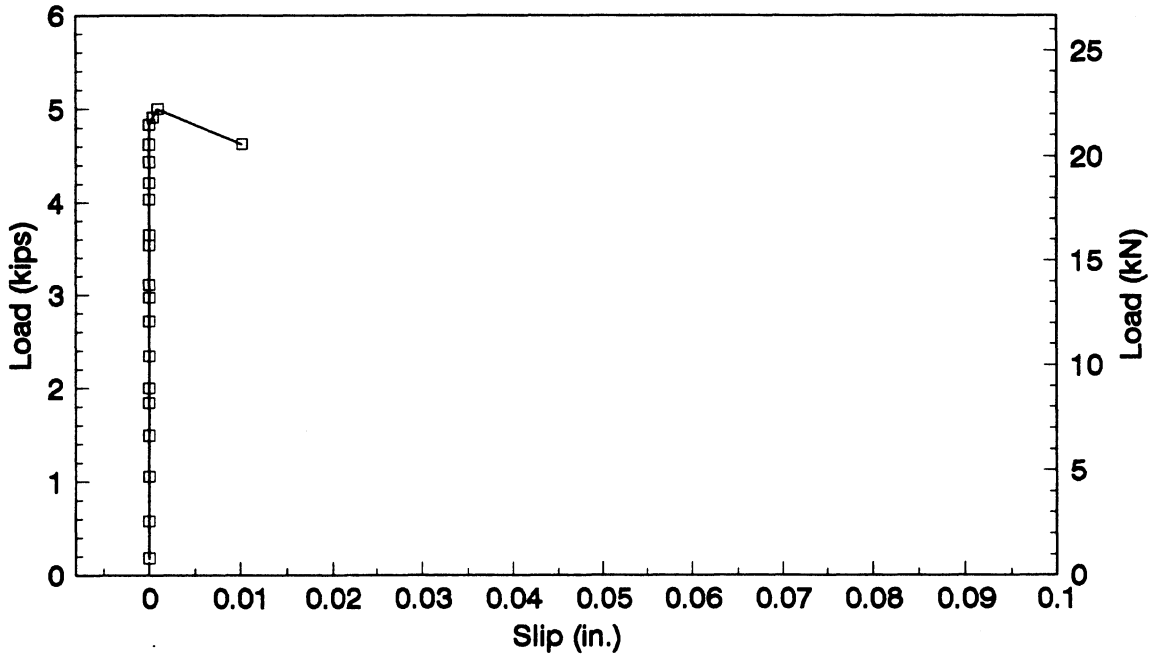


(b)

Figure F.54. Development length test of Specimen No. 17-6.0DC-2 with the load at 23 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

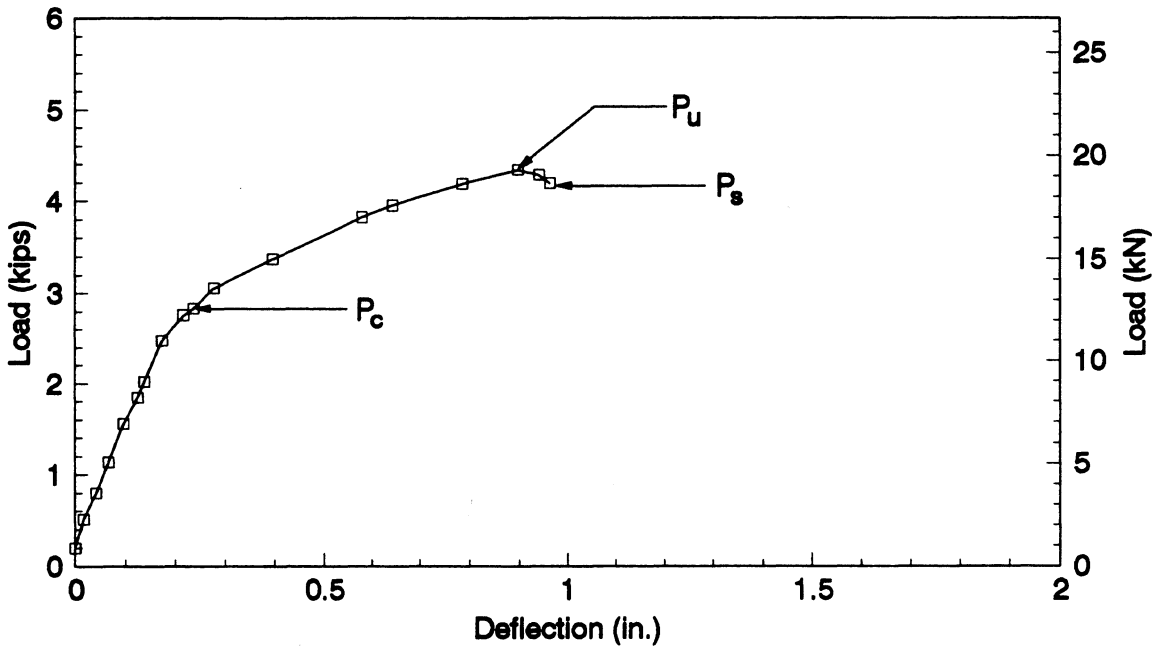


(a)

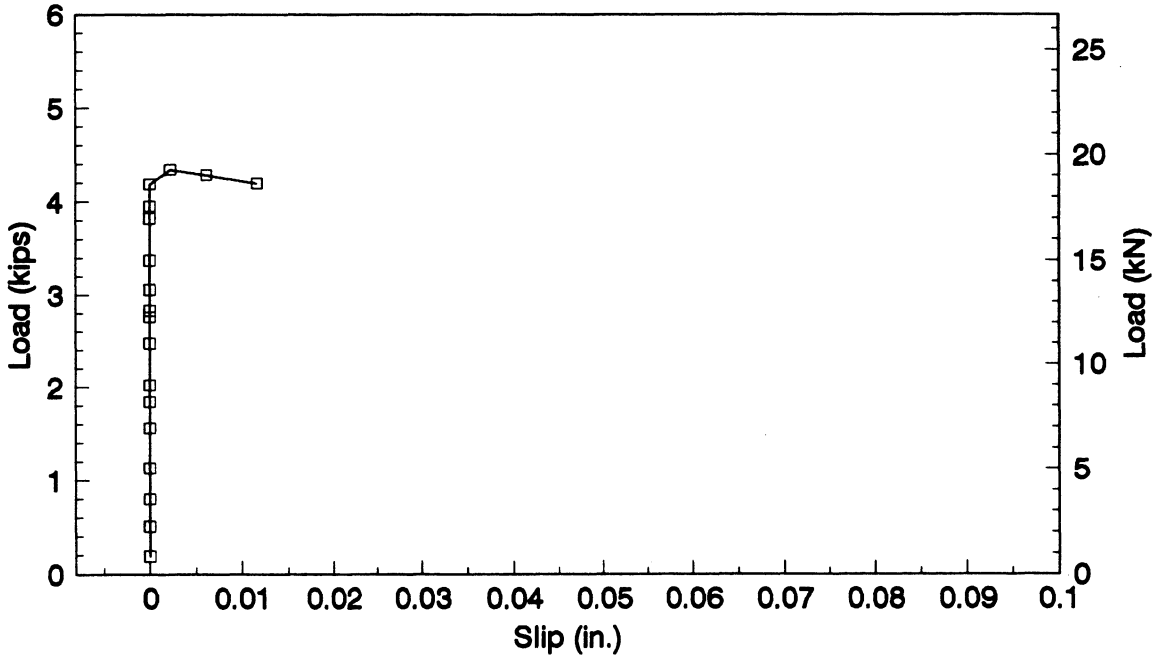


(b)

Figure F.55. Development length test of Specimen No. 17-6.0DC-3 with the load at 22 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

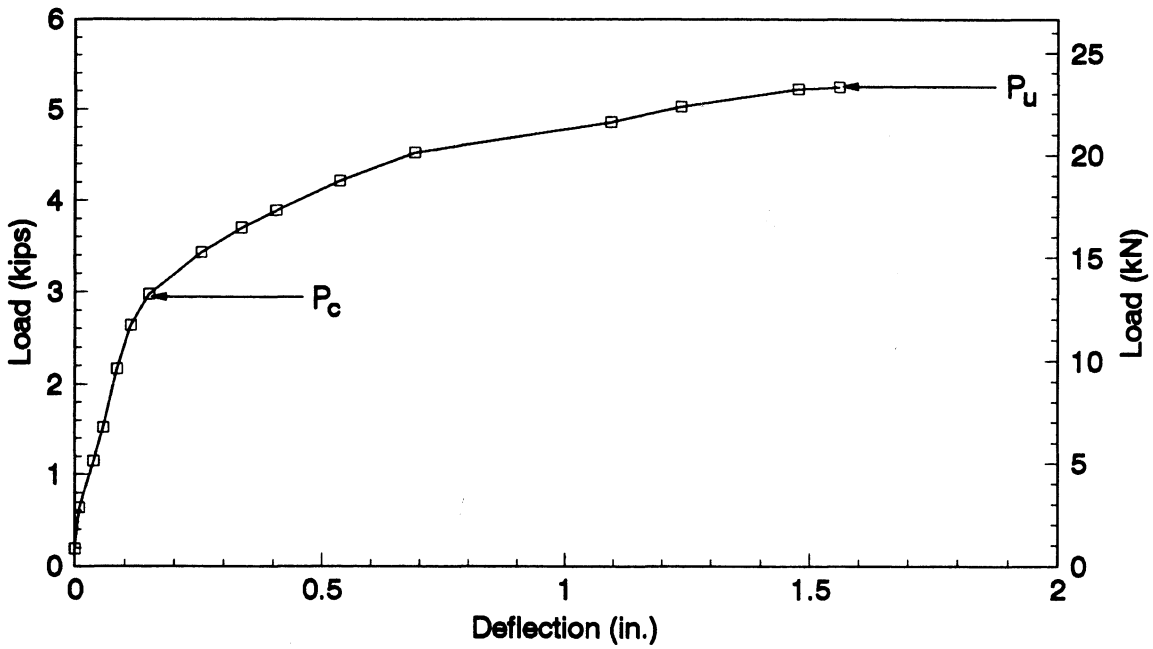


(a)

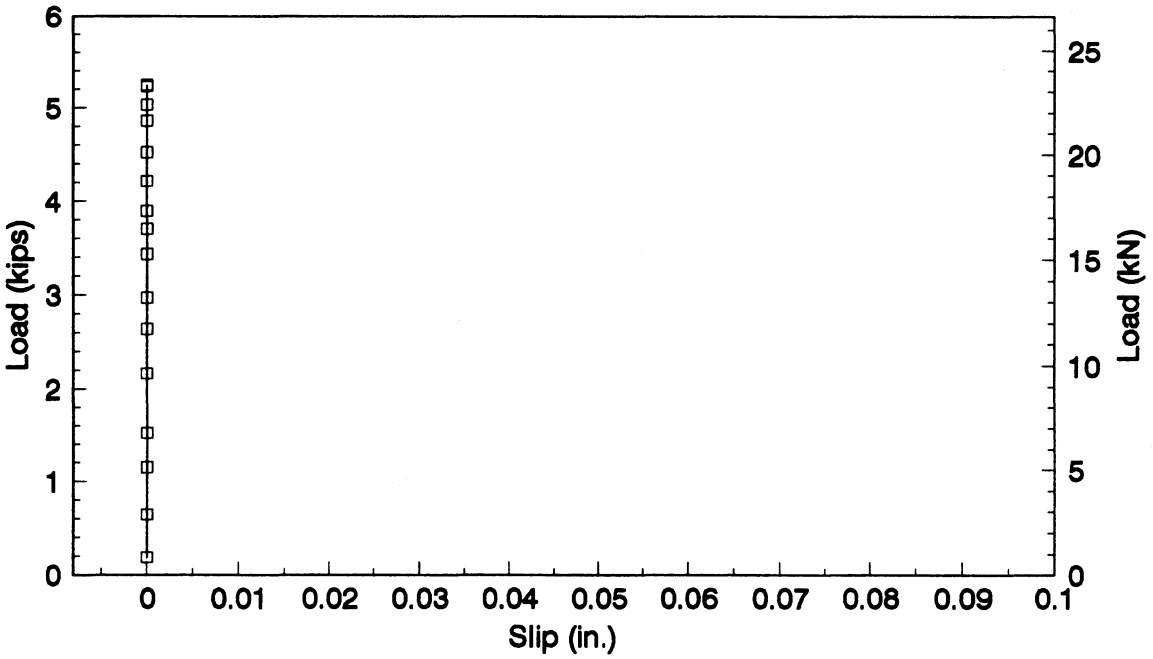


(b)

Figure F.56. Development length test of Specimen No. 17-6.0DC-4 with the load at 22 in. from End B: (a) load versus deflection; (b) load versus strand-slip at End B

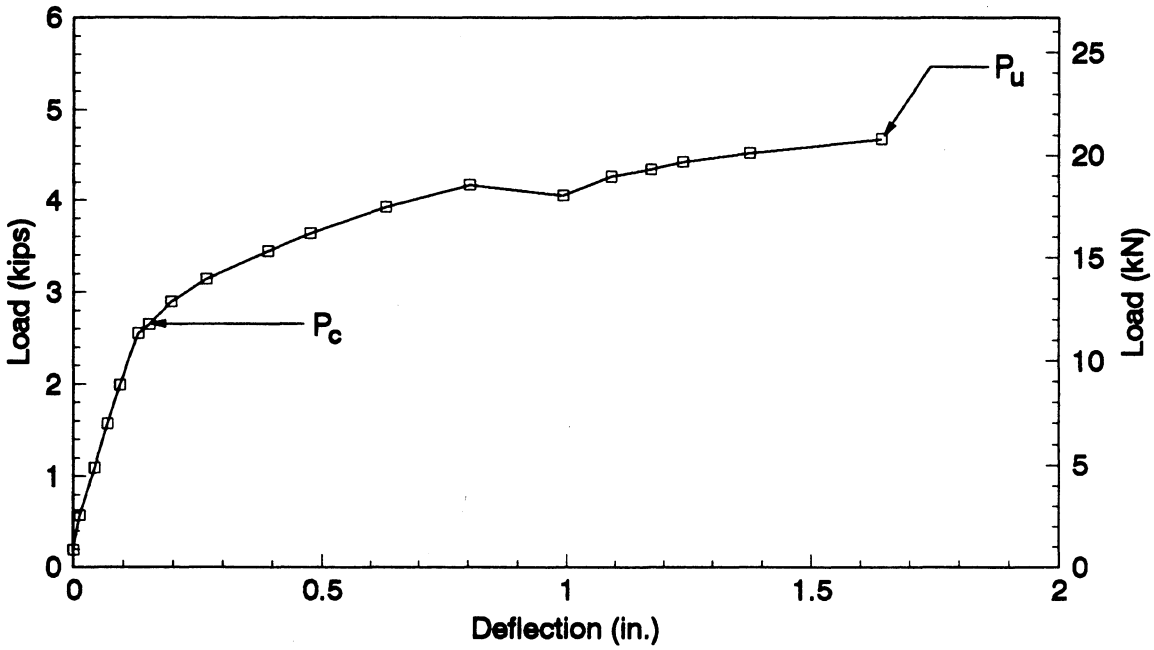


(a)

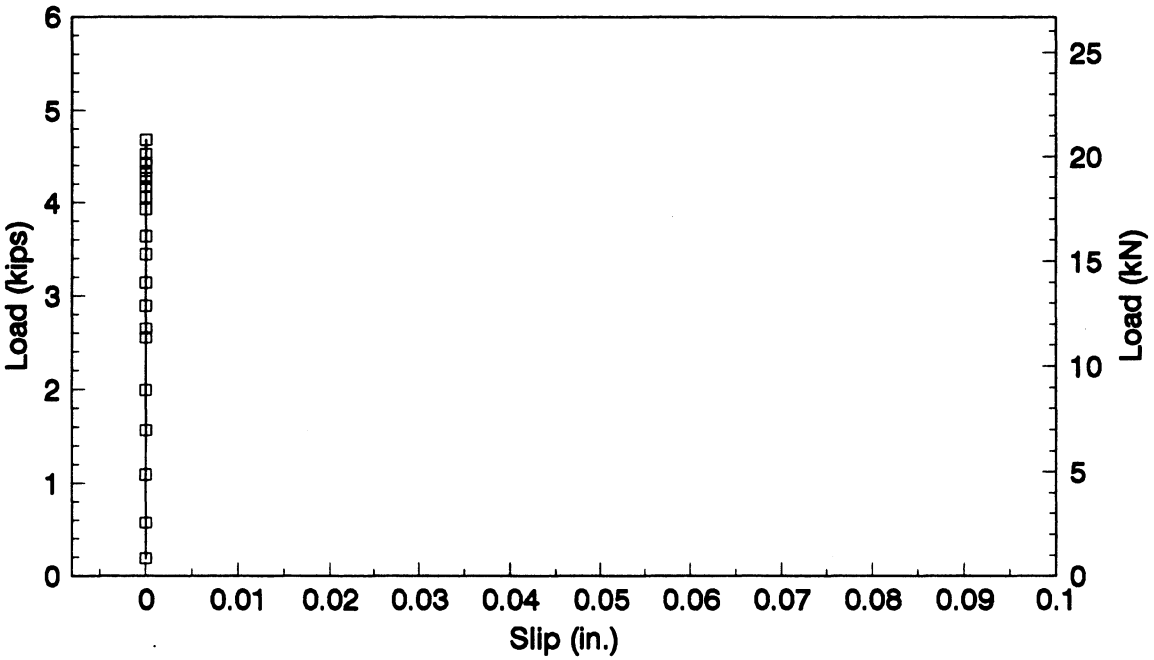


(b)

Figure F.57. Development length test of Specimen No. 17-6.0DC-9 with the load at 22 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

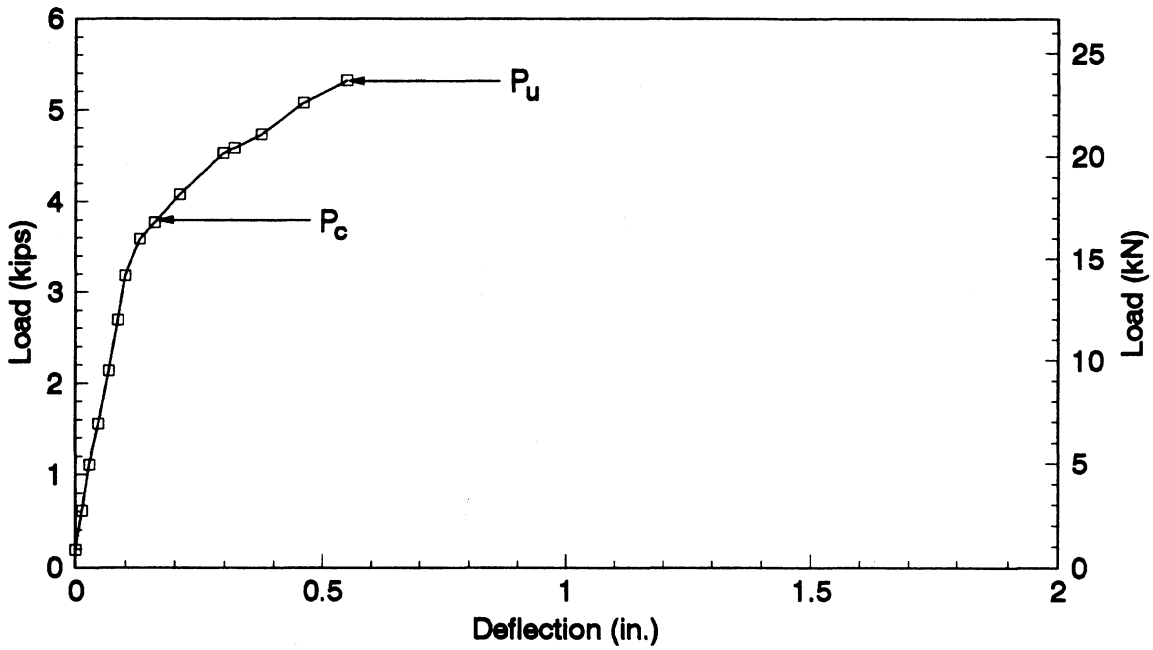


(a)

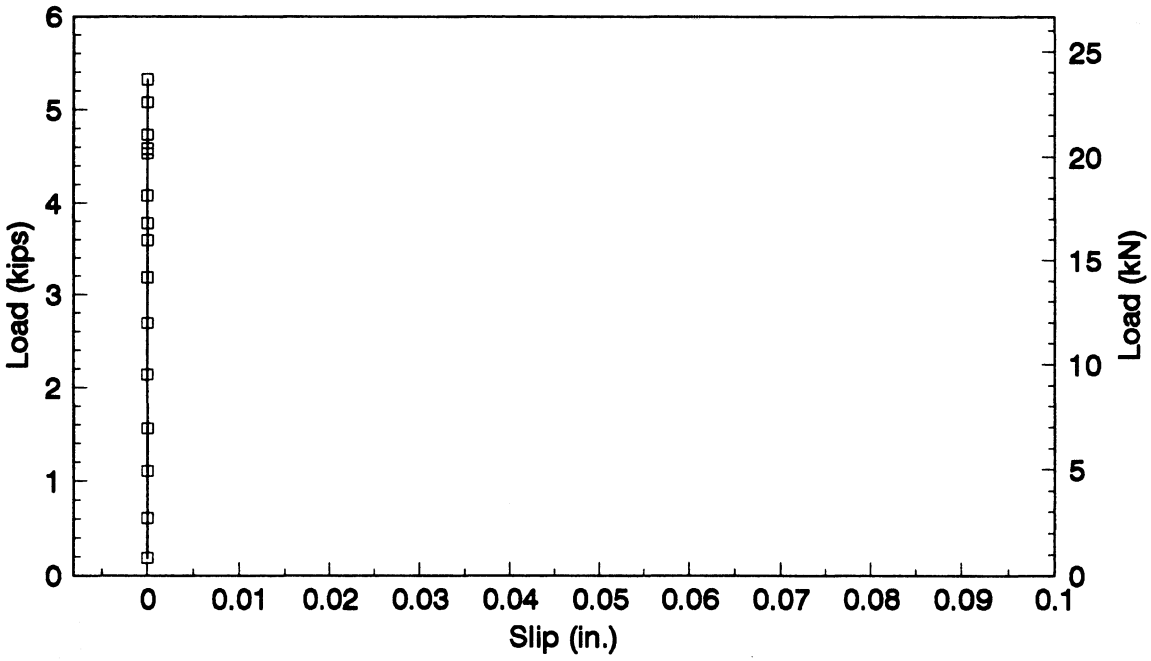


(b)

Figure F.58. Development length test of Specimen No. 17-6.0DC-10 with the load at 24 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E

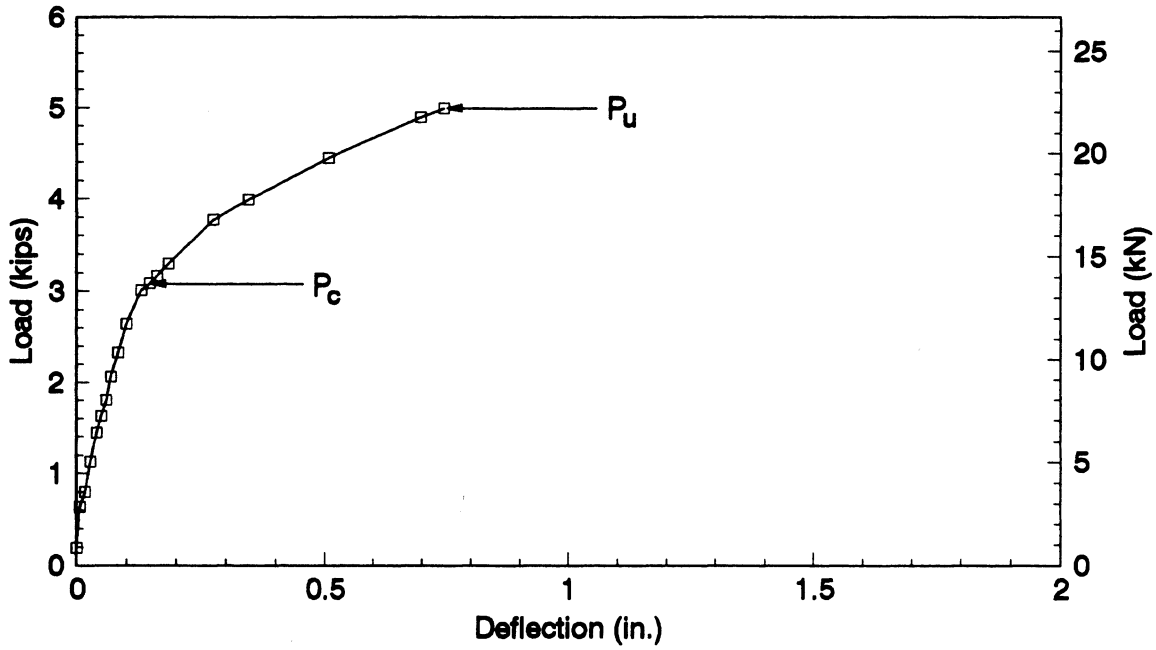


(a)

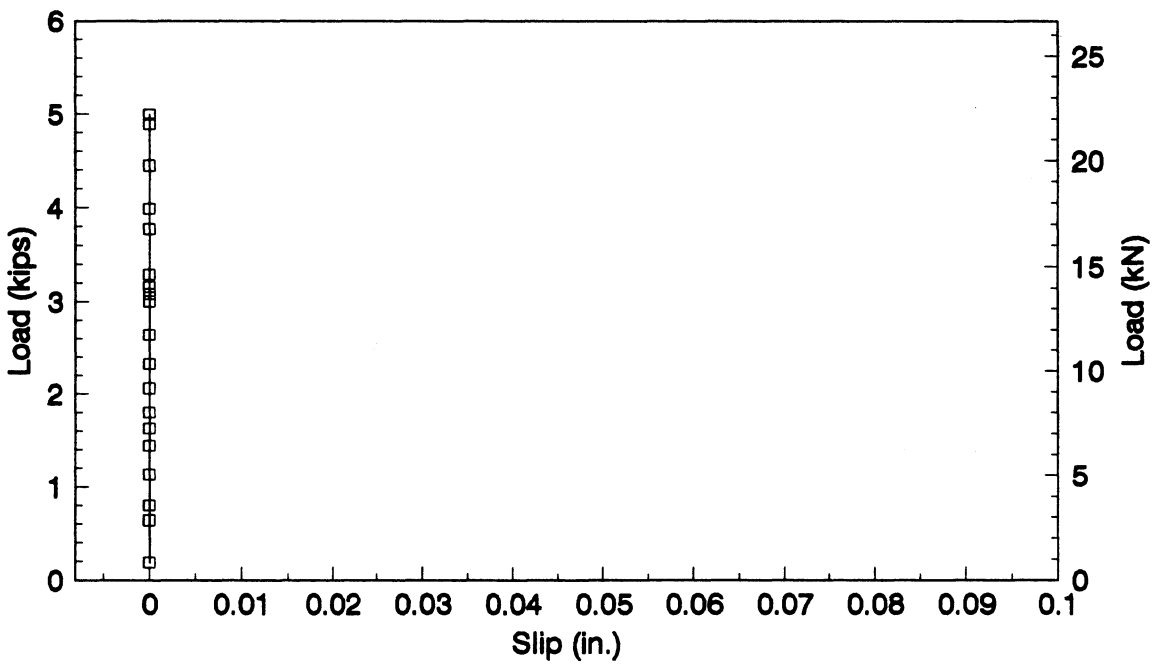


(b)

Figure F.59. Development length test of Specimen No. 17-6.0DC-11 with the load at 18 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E



(a)



(b)

Figure F.60. Development length test of Specimen No. 17-6.0DC-12 with the load at 21 in. from End E: (a) load versus deflection; (b) load versus strand-slip at End E