
***NIST Workshop on Standards Development
for the Use of Fiber Reinforced Polymers for the
Rehabilitation of Concrete and Masonry Structures,
January 7-8, 1998, Tucson, Arizona.
Proceedings***

Editor:

Dat Duthinh¹

Session secretaries:

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John L. Gross¹

Oscar Barton Jr.

Session chairs:

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Yan Xiao

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¹Structures Division

Building and Fire Research Laboratory

National Institute of Standards and Technology

Gaithersburg, MD 20899-001

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NIST

United States Department of Commerce

Technology Administration

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U.S. Department of Commerce
William M. Daley, *Secretary*
Technology Administration
Cheryl L. Shavers, *Under Secretary for Technology*
National Institute of Standards and Technology
Raymond G. Kammer, *Director*

APPENDIX 3.1B

CALTRANS SPECIFICATIONS

Composite column casings: memo to designers 20-4B	3-40
Alternative column casing specifications for seismic retrofit:	
pre-qualification requirements	3-42
AENC. DOC 8.11.97	3-52

In conformance with NIST policy, SI units are used as primary units in this document. U.S. customary units, used exclusively in the original specifications, are included in parentheses.

Caltrans Memo to Designers 20-4B, August 1996:

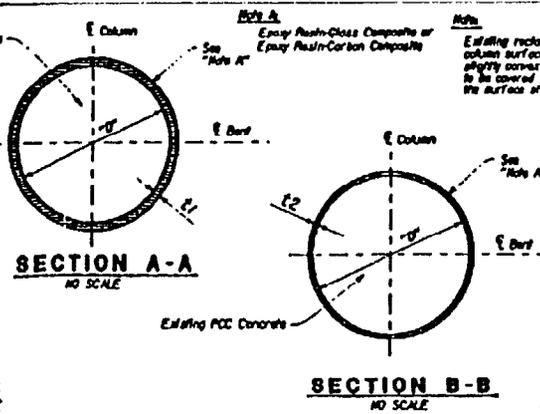
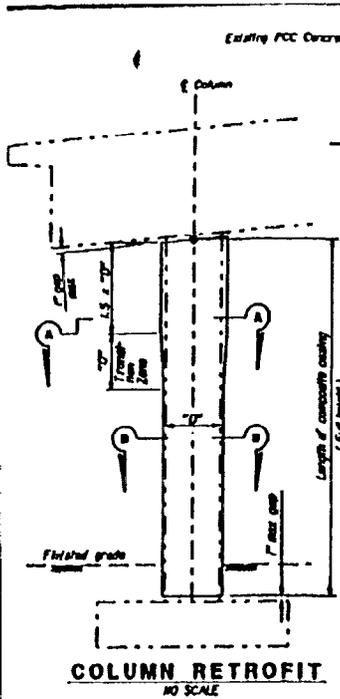
Composite Column Casings

Several composites columns casing systems have undergone laboratory testing and are approved for use in limited situations. Composite column casing thicknesses as shown on the Standard Drawing are designed to prevent plastic shearing. Material testing standards and provisional specifications have been developed to allow limited field installations for both E-glass and carbon fiber composites, under strict conditions.

Composites systems shall be specified as an alternative if conditions below are satisfied:

1. In all cases, all projects shall be detailed for steel casings as a standard with composites retrofit as an alternative.
2. Displacement ductility demand shall be not more than 6 for circular columns and not more than 3 for rectangular columns. It may be permissible to use composites on circular columns with ductility demands approaching 8, with the written approval of the Office of Earthquake Engineering and the Design Supervisor.
3. For rectangular columns, the longest dimension is limited to a maximum of 0.91 m (36 in). Rectangular column sides aspect ratio shall not be greater than 1.5.
4. For circular columns, the diameter must be 1.83 m (72 in) or less.
5. A steel jacket is the only approved retrofit method for columns that require a fully contained (fixed) lap splice. Composites may be used if a pin or slipping is assumed in the analysis at a lap splice.
6. Composites shall not be used for single column bent structures.
7. Composites shall not be used if the axial dead load is greater than $0.15 f_c' A_g$.
8. Composites shall not be used if the columns longitudinal reinforcement ratio is greater than 2.5 %.
9. Composites shall not be used for bridges which require flame-sprayed plastic.
10. Composites shall be used with prismatic columns only.

For situations not falling within the above limits, the Office of Earthquake Engineering shall be consulted for necessary design guidelines and approval. A list of current allowable systems may be obtained from the Office of Earthquake Engineering, New Technology Management Branch at (916) 227-8247. Requirements above are subject to change as more information becomes available. Questions on the above should be directed to the New Technology Management Branch at (916) 227-8247 or Seismic Technology at (916) 227-8806.

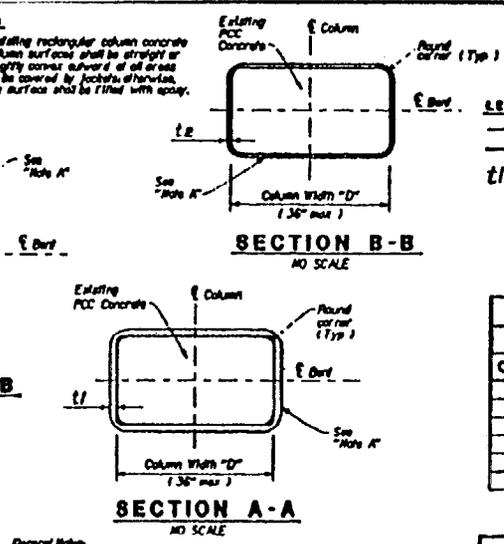


E-Glass Notes

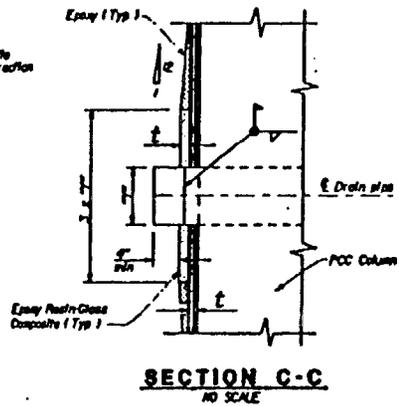
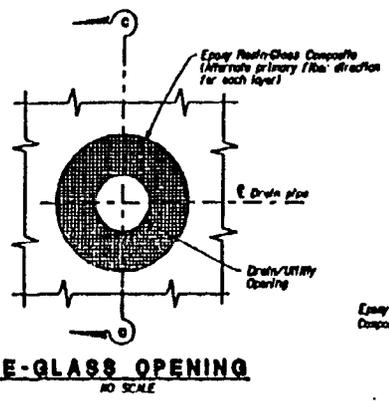
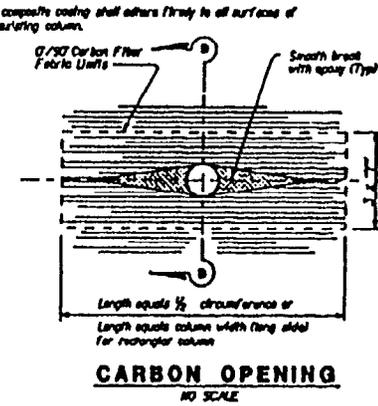
- Each composite section shall be wrapped using continuous E-glass fabric not less than 2 feet in height. All wraps of continuous E-glass wraps shall be horizontal a minimum of 18" past the starting side of the initial wrap. Subsequent wraps shall be started 1 burr 1 of the ending point of the last wrap.
- All cut edges shall be sealed with epoxy.

Carbon Notes

- Pre-wrap carbon fabric shall be completely cured by elevated temperature.
- Pre-wrap carbon fiber strips shall contain continuous strands not less than 100 feet in length.



- General Notes**
- For column heights less than 5:1, use constant thickness full height of t1.
 - For horizontal or vertical columns use composite thickness specified in "Rectangular Column" table.
 - Remove any sharp corners to 1/8" radius minimum.
 - All materials shall be protected from moisture.
 - Drainage opening reinforcement shall be of the same material used for the column casing.
 - The coating thickness shall taper evenly the full length of the transition zone.
 - The composite coating shall adhere firmly to all surfaces of the existing column.



DESIGNER	CHECKED	DATE	POST DATE	SHEET NO.

REGISTERED ENGINEER - CIVIL

APPROVED BY:

The State of California or its officers or agents shall not be responsible for the accuracy or completeness of electronic copies of this plan sheet.

LEGEND

--- Indicates Existing Structure
 - - - - - Indicates New Construction

t1, t2
 Denotes Minimum Thickness of Accumulated Dry E-Glass Wraps or completed Carbon Jacket Thickness (including coating)

SYSTEM 1
FIBER VOLUME = 38% min

E-GLASS

ROUND COLUMN

COLUMN DIA	t1 (min)	t2 (min)
12"	.80"	.80"
14"	.85"	.85"
16"	.90"	.90"
18"	.95"	.95"
20"	.95"	.95"
22"	1.00"	1.00"

SYSTEM 2
FIBER VOLUME = 60% min

CARBON

ROUND COLUMN

COLUMN DIA	t1 (min)	t2 (min)
12"	.05"	.05"
14"	.08"	.08"
16"	.10"	.09"
18"	.13"	.08"
20"	.17"	.08"
22"	.20"	.10"

E-GLASS

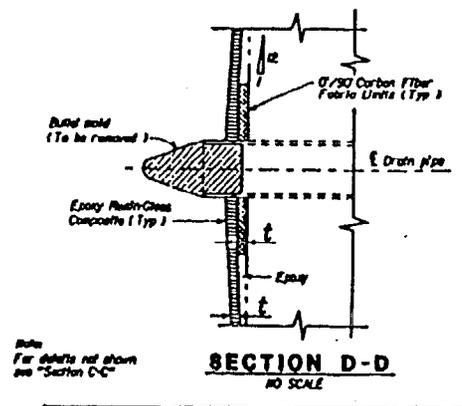
RECTANGULAR COLUMN

COLUMN WIDTH	t1 (min)	t2 (min)
12"	.85"	.85"
14"	.90"	.90"
16" max	.95"	.95"

CARBON

RECTANGULAR COLUMN

COLUMN WIDTH	t1 (min)	t2 (min)
12"	.05"	.05"
14"	.07"	.05"
16" max	.10"	.08"



STANDARD DRAWING				DESIGNED BY: <i>[Signature]</i>		STATE OF CALIFORNIA		DIVISION OF STRUCTURES		PROJECT NO.	
DATE: 8/00	SCALE: AS SHOWN	BY: P. J. HOPLEY	CHECKED: P. J. HOPLEY	COMPOSITE COLUMN CASING		DEPARTMENT OF TRANSPORTATION		STRUCTURE DESIGN		SHEET NO.	
REVISIONS				APPROVED BY: <i>[Signature]</i>		DATE: 8/00		DRAWING PRINTED BY: []		CHECKED BY: []	

CALTRANS 7/1/97
Pre-qualification Requirements for
Alternative Column Casings for
Seismic Retrofit (Composites)

SECTION I - GENERAL

Part 1.

Caltrans will specify only those composite column casing systems which have been prequalified for use on its projects.

For purposes of prequalification, a composite column casing system consists of the unique physical form of the system; the materials system, including the fiber material, physical form of the fiber material, resin, primer, and adhesive as applicable; the installation process; the system supplier; the materials supplier; and the installer. If any part of the system is changed, it will be considered to be a new system.

The technical requirements for system prequalification are outlined in Section II of this document. All the test requirements may not apply to a particular system, and additional tests may be appropriate for some proposed systems. Caltrans will determine the specific test requirements for prequalification of each proposed system. Testing shall be performed by an independent laboratory located in California and approved by Caltrans. Satisfactory performance of a system subjected to the tests will be determined by Caltrans.

All new systems proposed will be subject to all the prequalification requirements. If limited testing is proposed because a new system is similar to a currently prequalified system, Caltrans will determine the extent of testing required.

Except as otherwise noted, all test data submitted for prequalification of composite column casing systems or generated during the prequalification process will become public information.

A proposed design procedure shall be submitted which is based on the results of test data and generally accepted structural theory. Design formulas should be simplified in a rational manner so as to be useful for practical design purposes. Caltrans will implement the design of column casings on its projects where appropriate, and may use either the proposed design equations or other formulas which have been shown to be more practical.

A specification shall be submitted to fully describe the proposed system. This information will be incorporated into the project special provisions as appropriate.

Part 2. Prequalified systems

Composite column casing systems which have been prequalified will be incorporated into the Caltrans standard special provision for alternative column casing.

At the present time, no system has been subjected to the full list of requirements for durability testing in accordance with Section II, Part 4 of this document. Therefore, the prequalification of any composite system is conditional upon the following criteria:

1. Composite column casing system suppliers who have satisfactorily completed structural testing and who possess their own 1 000 hour durability test data will be allowed to provide composite column casing, when it is specified in the contract documents, for Caltrans projects advertised no later than June 30, 1996.
2. After June 30, 1996, all composite column casing system suppliers must provide Caltrans with independent 1 000 hour durability test data as a minimum to prequalify or remain prequalified.
3. After November, 1996, all composite column casing system suppliers must provide Caltrans with independent 3 000 hour durability test data as a minimum to prequalify or remain prequalified.
4. After November, 1997, all composite column casing system suppliers must provide Caltrans with independent 10 000 hour durability test data as a minimum to prequalify or remain prequalified.

An adjustment factor for durability will be applied to the thickness design for column casing, due to the fact that there is only limited durability test data available. After evaluation of 3 000 hour and 10 000 hour durability test data, the adjustment factor may be reduced.

Part 3. Coordination With Caltrans

All inquiries regarding prequalification of composite column casing systems should be addressed to Mohsen Sultan, Caltrans, Office of Earthquake Engineering, P.O. Box 942874, MS 9, Sacramento, CA 94274-0001; phone 916-227-8247.

SECTION II - TECHNICAL REQUIREMENTS

Scope

This section provides a detailed listing of the requirements for prequalification of materials and processes intended to be used as composite alternative column casings for seismic retrofit applications. The document is divided into six Parts: General System Description, Basic Materials Testing and Information, Composite Testing, Durability Testing, Column Testing, and Process Specification.

Because of the possible wide variety of materials and systems that may seek qualification under this requirement, it is understood that some tests listed under the various Parts may not be applicable to a particular system. If there is a question as to applicability, Caltrans should be consulted.

Part 1. General System Description

Applicant shall furnish to the Department a brief, general description of the proposed system to be qualified. Information to be supplied in this document, in the order listed, should include but is not limited to the following:

- Section 1. Primary material(s)**
Glass, carbon/graphite, polymer, etc.
- Section 2. Form(s)**
Woven fabric, sheet, hybrid, tow or yarn, pre-preg, preform, laminate, etc.
(Preforms and laminates should indicate construction)
- Section 3. Application Method(s)**
Hand lay-up, machine winding, any consolidation/compaction processes, etc.
- Section 4. Composite Matrix Binder/Resin and Adhesive***
Epoxy, polyester, polyurethane, vinylester, etc.
- Section 5. Composite Curing Process(s)**
Ambient temperature cure, elevated temperature cure (Include details of proposed methods)
- Section 6. Composite Properties**
Tensile strength, strain at failure, modulus, lap shear strength, apparent interlaminar shear strength
- Section 7. Quality Control/Quality Assurance Protocols**
- Section 8. Protective Finish Coating(s)**
- Section 9. Listing of Basic Materials Suppliers**

*Throughout this document a distinction is made between a 'resin', such as used in prepreg materials, on-site fiber saturation, and the construction of preforms and laminates, and an 'adhesive', such as would be applied between layers of preformed laminates during assembly to the column.

Part 2. Basic Materials Testing And Information

Applicant shall furnish to the Department quality control/quality assurance procedures, test methods, test data, and typical values for all materials to be used in composite alternative column casing systems to be qualified. This requirement shall apply specifically to Sections 1, 2, and 4 listed in the preceding section. Upon qualification of the composite casing system, a certificate of compliance for the respective materials shall be available to the Engineer when requested, such certificate traceable to supporting test data.

For **Section 1, Primary Materials**, information to be furnished shall include as a minimum test methods used and test data for:

Ultimate Tensile Strength

(Primary material)

Modulus

Mass per Unit Length

Mfg. Description / Designation

Strain to Failure

Density / Specific Gravity

Sizing Content

(When applicable)

For **Section 2, Form**, information to be furnished shall include as a minimum test methods used and test data for:

Fabric Construction

(Including fiber or yarn orientations, weight ratio of primary fiber/others)

Mass per Unit Area

Tensile Strength

(Primary and 90° to primary)

Strain at Failure

(Primary and 90° to primary)

Thickness

Tows, Fibers or Yarns per Inch of Width

(Both directions, if applicable)

Resin Content, mass %

Fiber Content, volume % and mass %

Gel Time @ Curing Temperature

Cure Time @ Curing Temperature

Interlaminar Shear Strength

(Laminates)

Modulus

Fibers per Tow or Yarn

(Twisted or Non twisted)

Volatiles, Mass %

Glass Transition Temperature

(Preforms and laminates)

Drape

Density and / or Specific Gravity

(ASTM D 792, D 1505)

Tack

Mfg. Description / Designation

For **Section 4, Matrix Binder/Resin and Adhesive**. Test results to be furnished shall be derived from flat panels of the neat, cured materials. The panels shall be cured in the manner identical to that which will be used in the composite column casing at installation. Ambient cure materials shall be cured at least seven days at 24 °C ± 2 °C (75 °F ± 3 °F) prior to testing, and no elevated temperature post-curing of ambient systems shall be done unless such post-curing is also done as a matter of course during field installations. Test methods used and test data shall be furnished on the following parameters:

Tensile Strength

Modulus

Glass Transition Temperature, Tg

Temperature / Time / Gel Time Curve

Temperature / Time / % Cure Curve

Lap Shear Strength

(Composite adherents)

Strain at Failure

Mixing Ratio, volume and mass

Infrared or HPLC Curves

(Component A, Component B)

DTA, DCS, or DMA Curves

Mfg. Description / Designation

Part 3. Composite Testing - Flat Laminate Samples

The following Section describes the required properties and test data to be furnished to Caltrans for the proposed alternative composite column casing system, as determined from prepared flat laminate panels of the composite.

Composite sample testing shall be performed by an independent testing facility, which shall be located in California. The applicant will be responsible for all composite sample preparation. Caltrans shall be notified prior to any sample preparation or testing. Such notification shall include the name and location of the testing facility or facilities. Caltrans or a designated representative shall retain the right to be present at any time during sample preparation or any testing related to a proposed composite column casing system. Caltrans reserves the right to request additional tests or testing and to perform or have performed any correlation testing or other tests as may be deemed necessary.

Flat laminate samples of the composite shall be prepared consistent with techniques of field application of the composite system. These shall be cured in a manner identical to that which will be used in column casing installation in the field. Ambient-cure composite laminates shall be cured at least 7 days at $24\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ ($75\text{ }^{\circ}\text{F} \pm 3\text{ }^{\circ}\text{F}$) prior to any testing. No elevated temperature post-curing of ambient cure materials will be permitted unless such curing is also performed as a matter of course during system field application. ASTM test methods indicated shall be used except where published alternative equivalent methods by an industry-recognized organization (SACMA, etc.), may be available. The use of such alternative methods shall be documented.

All parameters listed below shall be determined on all systems submitted for qualification. Results should be expressed in U.S. Customary (inch-pound) units. International System (metric, SI) conversions may be reported if enclosed in parentheses following the inch-pound units, i.e., 175 ksi (1.21 GPa).

Results from the following tests will be used to establish 'baseline' or reference values for comparison to results from the Durability Testing, Part 4. In those instances where indicated (*) the testing of a minimum of twenty (20) specimens will be required in order to establish statistical information. At least five (5) control specimens shall be tested from each individually processed test panel. Other tests shall consist of a minimum of five (5) control specimens with at least one (1) specimen tested for each individually processed panel.

***ASTM D 3039, Primary Fiber Direction**

(Tabbed-end specimens)

Tensile Strength

Strain at Failure

Modulus

Thickness

ASTM D 792 or D 1505

Density and/or Specific Gravity

***ASTM D 3165**

Lap Shear Strength

***ASTM D 3418 or D 4605**

Glass Transition Temperature, T_g

***ASTM D 2344**

Interlaminar Shear Strength

ASTM D 3171 or D 2584, as appropriate

Fiber Content, Volume % and Mass %

ASTM D 2734

Void Content, Volume %

ASTM D 2240

Shore Hardness

Test results shall be averaged, and normalized based on composite dry fiber thickness or alternatively, composite fiber volume. The normalization process, normalizing value, and normalizing calculations shall be indicated in the report, and shall be consistent for all tests.

Part 4. Durability Testing

Durability testing shall be performed on specimens derived from flat laminate samples of the composite system prepared in 3, above. To avoid any wicking influences or other problems all cut, machined, or otherwise exposed edges of the panels shall be sealed with a suitable sealant prior to exposure. Except for Glass Transition Temperature tests, where a minimum of two (2) specimens shall be tested per interval, a minimum of five (5) specimens shall be tested in each of the conditions listed at the intervals stated and the results normalized and averaged prior to comparison to baseline values.

Caltrans will determine those systems for which adhesive environmental testing is required. In general, any casing system in which a separately cured adhesive is used to bond previously cured composite components together or onto the column is susceptible to adhesive degradation. Thus, environmental durability must be demonstrated for these systems. The environmental durability matrix for adhesives is equivalent to that for composite laminates. Lap shear strength will be used to measure adhesive degradation on samples having composite adherends. A minimum of twenty (20) specimens will be required to establish a statistical baseline. A minimum of five (5) lap shear specimens shall be tested in each of the conditions listed at the intervals stated.

The determination of material properties used for specifying minimum overwrap thicknesses for column casings will take into account any reductions in properties resulting from durability testing. Appearance of delamination or decomposition of the panels during exposure, or of the panels or specimens following exposure, shall constitute unsatisfactory or non-qualifying performance. In addition, all qualifying samples subjected to durability testing must retain a minimum of 85 % of the baseline values for the tests listed. Except where noted, all samples subjected to durability testing conditions shall be tested after exposure according to the following methods and tests. All tests shall be conducted at $24\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ ($75\text{ }^{\circ}\text{F} \pm 3\text{ }^{\circ}\text{F}$).

ASTM D 3039, Primary Fiber Direction

(Tabbed-end specimens)

Tensile Strength

Strain at Failure

Modulus

ASTM D 3165

Lap Shear Strength

ASTM D 3418 or D 4065

Glass Transition Temperature, T_g

ASTM D 2344

Interlaminar Shear Strength

ASTM D 2240

Shore Hardness

A. Water Resistance

Panels shall be exposed to a condition maintained at 100 % relative humidity and $38\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ ($100\text{ }^{\circ}\text{F} \pm 2\text{ }^{\circ}\text{F}$). (Apparatus as described in ASTM D 2247 or ASTM E 104 is satisfactory.) Specimens shall be tested at intervals of 1 000 hours, 3 000 hours, and 10 000 hours exposure. Specimens should be tested as soon as possible after removal from the water.

B. Ultraviolet Resistance

Panels shall be subjected to exposure in equipment meeting the requirements of ASTM G 53, using FS 40 UV-B bulbs. One cycle shall be four (4) hours at $60\text{ }^{\circ}\text{C}$ ($140\text{ }^{\circ}\text{F}$) and four (4) hours of condensate exposure at $40\text{ }^{\circ}\text{C}$ ($104\text{ }^{\circ}\text{F}$). After 100 cycles the specimens shall be removed and tested as above.

C. Temperature Resistance

Panels shall be subjected to a continuous temperature of $60\text{ }^{\circ}\text{C}$ ($140\text{ }^{\circ}\text{F}$) for 1 000 hours and 3 000 hours before testing. Specimens shall be allowed to return to ambient temperatures prior to testing.

D. Salt Water Resistance

Panels shall be totally immersed at $24\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ ($75\text{ }^{\circ}\text{F} \pm 3\text{ }^{\circ}\text{F}$) in an artificial sea water solution prepared according to ASTM D 1141, omitting heavy metal reagents, for intervals of 1 000 hours, 3 000 hours, and 10 000 hours prior to testing. The artificial sea water shall be regularly monitored and changed or refreshed as needed. Specimens should be tested as soon as possible after removal from the salt water.

E. Fuel Resistance

Panels shall be immersed for four (4) hours in diesel motor fuel prior to testing. Specimens should be tested as soon as possible following removal from the diesel fuel.

F. Alkali Resistance

Panels shall be immersed in a saturated solution of calcium hydroxide (pH 12.4) at $24\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ ($75\text{ }^{\circ}\text{F} \pm 3\text{ }^{\circ}\text{F}$) for intervals of 1 000 hours, 3 000 hours, and 10 000 hours prior to testing. The pH of the solution shall be monitored at regular intervals and the solution changed as needed.

G. Freeze-Thaw Resistance

Panels shall be subjected to freeze-thaw cycling by exposure for 24 hours under A, above, followed by 24 hours at $-18\text{ }^{\circ}\text{C}$ ($0\text{ }^{\circ}\text{F}$). Panels shall be subjected to twenty (20) freeze-thaw cycles, and shall be allowed to return to ambient temperature prior to specimen preparation and testing.

Part 5. Column Testing

A. Reduced Scale Structure Test

All composite column casing systems shall satisfy reduced scale cyclic column testing to verify casing's constructability and effectiveness as a seismic retrofit measure. To qualify a system as an alternative column casing for seismic retrofit, a minimum of two types of retrofit enhancements shall be demonstrated and tested in accordance with the requirements specified herein. Test results must satisfy Caltrans requirements relative to ductility performance, shear strength, and flexural enhancement. For each shape, cyclic tests shall be conducted to demonstrate the performance of both retrofit enhancements and corresponding unretrofitted "As-Built". Manufacturers may elect to qualify only one shape (circular or rectangular) by satisfying all tests requirements for either the circular tests or rectangular tests, thus limiting their qualifications to these systems.

For each geometrical shape, and for each corresponding enhancement, a minimum of one retrofitted "As-Built" column and one unretrofitted column shall be built and tested. For example, to qualify a system for circular column retrofit applications, the following four test specimens must be constructed and tested:

1. Circular Shear As-Built Column (Unretrofitted)
2. Circular Lap Splice As-Built Column (Unretrofitted)

3. Circular Shear Retrofitted Column subjected to double bending load
4. Circular Lap Splice Retrofitted Column subjected to single bending load.

All column details shall conform to the requirements provided herein. Retrofit jacket thickness (or fiber ratio) shall comply with the current Caltrans design criteria, with proper scaling factors when applicable, and shall satisfy the following:

1. Minimum confinement stress of 2.0 MPa (300 psi) in the lap splice and/or plastic hinge zone;
2. Maximum material strain of 0.001 in the lap splice zone and 0.004 in the plastic hinge zone;
3. Minimum confinement stress of 1.0 MPa (150 psi) and material strain of 0.004 must be maintained elsewhere in the column with appropriate transition;
4. Minimum displacement ductility for the retrofitted column of 8 to 12 is to be expected.

An expected concrete strength of 34 MPa (5 000 psi) at the time of testing and Grade 60 reinforcing steel shall be used, although Grade 40 is preferable when available.

The concrete design shall have aggregate no larger than 13 mm (0.5 in). The footing block as well as the loading block of the test columns shall be properly reinforced such that no degradation in these locations is allowed.

The test specimens shall conform to the following :

1. Cross Sections

The cross section of the rectangular test column shall be 610 mm x 610 mm (24 in x 24 in) with a total of 28 #6 longitudinal bars evenly spaced with #2 ties at 125 mm (5 in) spacing. The cross section of the circular test column shall be 610 mm (24 in) in diameter with a total of 20 #6 longitudinal bars evenly spaced with #2 ties at 125 mm (5 in) spacing.

2. Shear Enhancement Specimen

The shear enhancement test columns shall have a clear span of 2.4 m (96 in) shear arm between anchorage blocks.

Note: The shear test specimen shall maintain a maximum aspect ratio of 4 in the direction of the test if dimensions are modified.

3. Lap Splice Enhancement Specimen

The lap splice enhancement columns shall have the moment arm of 3.66 m (144 in).

4. Loading

Test columns shall be subjected to a vertical load (axial) of $0.1 f'_c A_g$ where concrete strength based on the original design strength of 22.4 MPa (3 250 psi). For example, the column with rectangular section should have a vertical load of 845 kN (190 kips).

The attached figures illustrate column configuration requirements.

5. Instrumentation

The structure test specimens shall be instrumented to record strains at various locations during the testing. The minimum instrumentation requirements are listed below:

- 4 strain gages shall be installed on each of the 2 ties (hoops) at the location closest to the column mid-height.
- 4 strain gages shall be installed on each of the lower 3 ties (hoops) at the bottom of the column.
- 6 strain gages shall be installed on the 2 vertical bars in the directions of push and 6 strain gages shall be installed on the 2 vertical bars in the directions of pull at locations of -150 mm, -50 mm, 50 mm, 150 mm, 250 mm and 350 mm (-6 in, -2 in, 2 in, 6 in, 10 in, and 14 in) from the bottom of the column.
- 20 horizontal strain gages shall be installed on the surface of the composite casing system at the locations where strain gages were installed on the ties.
- A minimum of 12 vertical strain gages shall be uniformly installed on the surface of the composite casing system as approved by Caltrans.
- A minimum of 12 strain gages in 45° slope shall be uniformly installed on the surface of the composite casing system as approved by Caltrans.
- Lateral displacement and rotation of the top and bottom block shall be monitored throughout the test.
- Column flexure deformation measurements are preferred but not required.

6. Loading History

All test columns shall be subjected to a number of full reversed cycles of loads and displacements. Initial cycles up to 75 % of the lateral yielding force shall be carried out under load control. Two fully reversed cycles at 25 %, 50 % and 75 % of the yielding force to verify that both the load and data acquisition system. Subsequent tests beyond 75 % yielding force shall be carried out under displacement control. Three fully reversed cycles shall be imposed at each ductility level of 1, 2, 3, 4, 6 and 8. If at the end of the test the column maintain more than 80 % of the peak lateral strength, a final push with the maximum of full stroke in a single direction shall be performed.

B. Confinement Effectiveness Test

To verify the confinement effectiveness, 36 standard concrete cylinders 150 mm x 300 mm (6 in x 12 in) shall be cased. Three different concrete strengths shall be used. In addition to three unconfined concrete cylinders, nine concrete cylinders shall be wrapped in a manner identical to column casing application in the field. A gap of 6 mm (0.25 in) shall be left at top and bottom of the cylinders. Any deviation from field practices shall be approved by Caltrans prior to proceeding. The composite jacket used on the cylinders shall have the same fiber volume ratio as the test columns. Three

different composite fiber area ratios¹ shall be used with the composite fiber area ratio used on the test column as the basis. The composite fiber area ratio used on the cylinders shall be 0.5, 1.0 and 1.5 times the composite fiber area ratio of the confinement enhancement test column. The composition of the aggregate shall be the same as the structure tested. A preferred concrete strength of 25 MPa, 35 MPa, and 45 MPa (3 500 psi, 5 000 psi, and 6 500 psi) shall be used.

All cylinders shall be closely monitored to obtain stress-strain relationship of the concrete in both axial and transverse directions.

General Requirements and Data Submittals

Caltrans' engineers shall be involved in all phases of the testing program. All shop drawings to construct test specimens and instrumentation plan shall be approved by Caltrans prior to construction. A testing schedule shall be submitted to Caltrans two weeks in advance. Testing shall be performed at a California university or by a qualified independent laboratory located in California and approved by Caltrans. All tests shall be performed in the presence of a Caltrans' engineer. Failure to do so will risk the possibility of the testing results not being accepted by Caltrans. Twenty copies of final test reports along with one copy of test data shall be delivered to the Caltrans' Office of Earthquake Engineering.

Part 6. Process Specification Manual

Applicants for system qualification shall furnish to Caltrans a Process Specification Manual that shall consist of a detailed description of the composite retrofit system as well as a quality assurance plan, and shall include a Standard Operating Procedure (SOP) delineating and documenting all construction procedures to be used during column retrofit with the system, including the methods and processes for preparation of progress samples.

¹The ratio of volume of composite fiber jacket to total volume of core of a reinforced compression member.

CALTRANS AENC. DOC 8.11.97

Composite Column Casing – Composite column casing consists of either System 1, an epoxy E-glass fiber, composite casing with painted exterior surface, System 2, an epoxy resin-prepreg carbon fiber composite casing with painted exterior surface or Systems 3 and 4, an E-glass prefabricated, segmented composite shell assembled around the column with epoxy adhesive and with painted exterior surface.

The working drawings for composite column casing alternatives shall contain details of the dry sheet, fabric or winding thickness; the number of wraps or layers to construct the minimum composite thickness shown on the plans; fiber volume; details of joints and ends of fiber construction; details of the transition in composite thickness; plan for curing, if required; methods for coring and for fabrication of test samples; name of independent testing facility located within 500 km (300 air line miles) from both Sacramento and Los Angeles to be used to test samples and cores; 3 copies of the Process Specification Manual furnished with prequalification; and all information required for the proper construction of the system at each location including any required revisions or additions to drainage systems or other facilities. Composite casing shall be constructed by wrapping the column with layers of continuous fiber embedded in resin, or prefabricated, segmented, continuous fiber composite shells. The composite column casing for Systems 1 or 2 shall conform to the following requirements:

Properties at 22 °C ± 1 °C (72 °F ± 2 °F)	System 1	System 2	ASTM TEST METHOD***
Ultimate Tensile Strength, in primary fiber direction*, MPa, (ksi), min.	450** (65**)	1 210 (175)	D 3 039
Ultimate Strain, min.	1.8 %	0.9 %	
Tensile modulus of primary fibers, GPa, (ksi), min.	21 (3 000)	103 (15 000)	
Ultimate Tensile Strength at 90° to primary fibers, MPa, (ksi), max.	48 (7.0)	Not applicable	
Fiber volume, min.	35 %	50 %	System 1: D 2 584 System 2: D 3 171
Glass transition temperature, min.	66 °C (150 °F)	104 °C (220 °F)	D 3 418 or D 4 065
Flammability, max.	5 s	5 s	D 3 801, test per paragraph 10.5
<p>* Horizontal fibers circumscribing the column. ** Prior to testing, samples for System 1 shall be cured at least 7 days at 24 °C ± 2 °C (75 °F ± 3 °F). *** Subject to approval of the Engineer, other test methods, such as those published by Suppliers of Advanced Composite Materials Association (SACMA), or manufacturer's published Quality Control Procedures may be used when equivalency and suitability have been documented.</p>			

The composite column casing for Systems 3 and 4 shall conform to the following requirements:

Properties at 22 °C ± 1 °C (72 °F ± 2 °F)	System 3	System 4	ASTM TEST METHOD
Ultimate Tensile Strength, MPa, (ksi), min.	655 (95)	550 (80)	D 3 039
Ultimate Strain, min.	1.8 %	1.6 %	
Tensile modulus, GPa, (ksi), min.	31 (4 500)	34 (5 000)	
Ultimate Tensile Strength at 90° to primary fibers, MPa, (ksi), max.	75.8 (11.0)	Not applicable	
Fiber volume of composite shells, min.	45 %	45 %	System 1: D 2 584 System 2: D 3 171
Glass transition composite shells, temperature, min.	104°C (220°F)	104°C (220°F)	D 4 065

The adhesive for Systems 3 and 4 shall confirm to the following requirements:

Properties	System 3	System 4	ASTM TEST METHOD
Glass transition temperature (min. after 1 week)	66°C (150°F)	20°C (68°F)	D 4 065-93
Hardness (min. Barcol, after 1 week)	55	45	D 2 583

Fabric for System 1 shall be woven continuous E-Glass fiber filament. Carbon fibers of System 2 shall consist of polyacrylonitrile (PAN) based continuous fibers, bundled into tows and resin impregnated (towpreg). The prefabricated composite shells for Systems 3 and 4 shall be stitched fabric construction made with continuous E-glass fiber filament.

Epoxy resins for all systems shall conform to the requirements in Section 95-1, "Epoxy," of the Standard Specifications and these special provisions, except that (1) no State Specification Number will be required and (2) the epoxies shall be the same as that used in prequalification testing.

The storage and handling of materials and the construction of the composite casing for Systems 1, 2, and 3 shall be in accordance with the requirements of the approved Process Specification Manual, except as modified in these special provisions. Materials shall be protected from dirt, moisture, chemicals, extreme temperatures, and physical damage.

Surfaces to receive composite for Systems 1, 2 and 3 shall be free from fins, sharp edges and protrusions that will cause voids or depressions behind the installed casing or that in the opinion of the Engineer, will damage the fibers. Voids or depressions are defined as volumes greater than 13 mm (½ in) in diameter by 3 mm (1/8 in) deep when measured from a 30 cm (1 ft) long straight edge placed on the column surface. Existing uneven surfaces to receive composite, including voids or depressions shall be

The contact surfaces of the columns shall be completely dry at time of application of the composite. The ambient temperature and temperature of epoxy resin components shall be between 7 °C (45 °F). and 35 °C (95° F). at time of mixing and application. The composite shall be applied when the relative humidity is less than 90 % at the site and the surface temperature is more than 3 °C (5° F) above the dew point.

If, in the opinion of the Engineer, the composite is damaged by the elements it shall be replaced or repaired by the Contractor at the Contractors expense.

Subject to approval by the Engineer in writing, the Contractor may provide suitable enclosures to permit application and curing of the composites during inclement weather. Provisions shall be made to control atmospheric conditions artificially inside the enclosures within limits specified for application and curing of the composite.

Prior to application of the composites, the area of the column to be encased using Systems 1, 3, or 4 shall be completely coated with a 1/8 mm (5 mil), minimum, thick coat of system-compatible resin.

Following the application and curing of all systems, the exterior surfaces shall be completely coated with a 3/8 mm (15 mil), minimum, thick coat of resin that produces a uniform finished surface. The resin used for this cover shall be a system-compatible resin formulated to resist crazing and chipping.

Components which have exceeded their shelf life shall not be used.

Composite column casing systems shall not support combustion.

Daily Installation Data Log.—During construction of Systems 1, 2 or 3, the Contractor shall maintain a Daily Installation Data Log. The Daily Wrapping Data Log shall be available for review by the Engineer, and a copy furnished to the Engineer at completion of installation and construction for each day's production. The data log shall provide materials traceability and process records for each casing installation, and shall include all of the following information:

Casing identification with bridge number, construction and installation requirements, including plans and drawings, or references thereto.

Materials information including product description, date of manufacture, and lot or batch numbers.

Fabrication, inspection and verification data for the manufacturing and construction operations including, wrap counts, number of shells, composite thickness measurements, installation time per casing, towpreg band pitch measurements, ambient temperature and humidity readings at beginning, middle and end of each casing installation shift, curing processes including full documentation of time and temperature of curing ramping and at final curing temperature and thickness measurements of any protective coating applied to the completed composite casing following installation.

System 1: Application.—The components of epoxy resin for System 1 may be proportioned and mixed by automatic equipment. Provisions shall be made for checking the accuracy of proportions and mixing.

The composite shall be applied within one hour after a batch has been mixed.

Both epoxy resin and fabric for System 1 shall be measured accurately, combined, and applied uniformly at the rates shown on the approved working drawings.

Fabric for System 1, which is comprised of the woven fibers, shall be applied to the surface of the column by wrapping using methods that produce a uniform constant tensile force that is distributed across the entire width of the fabric.

Successive layers of composite materials for System I shall be placed before the onset of gelation of the previous layer of epoxy is too complete to achieve complete bond between layers. No more than three layers can be added to any column in one day unless approved by the Engineer

The primary fibers of the fabric for System 1 shall not deviate from a horizontal line more than 42 mm/m (½ in/ft), and the transverse fibers shall be approximately perpendicular to the primary fibers.

The epoxy application rate for each layer of composite for System I shall be such as to ensure complete saturation of the fabric. Gaps between adjoining fabric layers shall be filled with epoxy.

Undulations in the surfaces of composite column casings for System 1 shall not exceed 21 mm/m (¼ in/ft) in any direction.

Except as otherwise specified, entrapped air beneath each layer shall be released or rolled out before the epoxy sets for System 1, and each individual layer and ending of composite shall be firmly bedded and adhered to the preceding layer or substrate.

The cured composite for System shall have uniform thickness and density, bond between layers, and lack of porosity.

This system shall be protected from exposure to rainfall or water for a period of at least 5 days.

System 2: Application—Bands of towpreg for System 2 shall be applied to the surface of the column by wrapping, using methods that produce a uniform constant tensile force that is distributed across each towpreg of the band.

The primary fibers of the fabric for System 2 shall not deviate from a horizontal line more than 21 mm/m (½ in/ft).

Towpreg for System 2 shall be continuous throughout the wrap, except as required for splicing. Towpreg splice ends shall overlap by at least 380 mm (15 in). Splices shall be staggered so that the minimum distance between towpreg splices is 150 mm (6 in).

Undulations in the surfaces of composite column casings for System 2 shall not exceed 10 mm/m (⅓ in/ft) in any direction.

System 2 casing shall be completely cured at an elevated temperature. For composite casings 4 mm (0.15 in) or less in thickness, the temperature shall be monitored and controlled by devices installed at or near the

surface of the casing. For composite casings greater than 4 mm (0.15 in) in thickness, the temperature shall be monitored at both the surface and at the column to casing interface and controlled by devices installed on the surface of the composite casing.

System 3: Application.—The components for the adhesive shall be machine mixed and used without delay to thoroughly coat the bonding surfaces of the composite shells. The mixing of the 2 part adhesive shall be kept to within 5 % of the specified mixing ratio.

The entire composite shell section for System 3 shall be assembled and clamped within one hour of the initial mixing of the adhesive.

The clamping system for System 3 shall ensure close contact of the composite casing components and shall be maintained for 24 hours to complete the initial cure of the adhesive. The final adhesive thickness in the composite system shall not exceed 3 mm (0.125 in). The adhesive between composite sections shall have a minimum shear capacity of 5.5 MPa (800 psi) for a 3 mm (0.125 in) bond layer in accordance with ASTM Designation: D 3165.

System 4: Application—The pre-manufactured shells shall be bonded to the column using an airless adhesive spray gun to apply a continuous film of adhesive between each layer of composite. The shells are applied in 4-foot high sets which are banded in place until the adhesive cures. Beginning at the column footing the sets are stacked vertically until the last set is cut to fit closely at the soffit of the bridge. The entire composite shell section for Systems 4 shall be assembled and clamped within 2 hours of the initial mixing of the adhesive.

The clamping system for System 4 shall ensure close contact of the composite casing components and shall be maintained for 24 hours to complete the initial cure of the adhesive. The final adhesive thickness in the composite system shall not exceed 3 mm (0.125 in). The adhesive between composite sections shall have a minimum shear capacity of 5.5 MPa (800 psi) for a 3 mm (0.125 in) bond layer in accordance with ASTM D 3 165.

Job Control Tests, Inspection and Repair.—During progress of the work, in addition to inspection performed by the Engineer, job control tests shall be made on samples and cores of composite casing for Systems 1, 2 and 3, and check test cores shall be furnished to the Engineer at the Contractor's expense. Samples and cores for job control tests of composite casing (and adhesive for Systems 3 and 4) shall be fabricated or cored by the Contractor and tested at the Contractor's expense in the presence of the Engineer, unless otherwise directed. The job control testing shall be done at an independent testing facility approved by the Engineer. A copy of the job control test results shall be furnished to the Engineer within 30 days following sample fabrication and within sufficient time to allow for review by the Engineer and correction by the Contractor of any deficiencies without delaying completion of the work.

The composite samples for job control tests shall be used to verify compliance with the requirements for ultimate tensile strength, ultimate elongation, and tensile modulus of the composite column casings. The composite samples shall consist of 2-ply laminates for System 1 3-ply laminates at 12 tows per inch of width per lamination for System 2 and flat plates made at the factory by the same resin infusion as the column shells with manufacturing documentation for Systems 3 and 4. At least four test specimens will be made by applying adhesive to the flat plates in the field to test the bond strength of the adhesive in accordance with ASTM Designation: D 3165. The test specimens shall be provided throughout the duration job at intervals

determined by the Engineer. The test specimens shall have a minimum of 5.5 MPa (800 psi) in lap shear. Each sample of composite shall be at least 0.37 m² (4 ft²) in total area for each type of composite to be used, and may consist of one piece or individual pieces not less than 305 mm x 305 mm (12 in x 12 in) in area. One sample of each day's production of column casing shall be tested. Each composite sample shall be manufactured and cured in the same manner as composite used in the field installation.

The composite casings for all Systems shall at least the number of wraps and thickness as shown on the plans, and shall conform to the requirements for fiber volume and glass transition temperature for composite column casings. These dimensions and properties shall be verified, after application and cure, by taking 13 mm (0.5 in) diameter cores from the composite for job control testing. One job control core shall be taken by the Contractor on every tenth composite casing or as determined by the Engineer. One check test core shall be taken by the Contractor and furnished to the Engineer for testing for each column at a location determined by the Engineer. Care shall be taken during coring operations to ensure that undamaged cores are obtained, and that minimal damage occurs to the adjacent composite and column. All cores shall be placed in labeled and sealed polyethylene bags prior to shipment to the testing facility or furnishing to the Engineer. Core holes shall be filled with a system-compatible resin and smoothed flush prior to painting the composite casing.

When Systems 3 and 4 are used, a sample of the adhesive delivered by the mixing machine each day shall be used to verify compliance of the adhesive system with requirements for hardness and T_g after at least 7 days ambient cure at the job site. The sample shall consist of adhesive cast into one sheet of minimum dimensions 3 mm x 152 mm x 152 mm (1/8 in x 6 in x 6 in). Each adhesive sample shall be manufactured and cured in the same manner as adhesive used in the field installation. One sheet of the daily adhesive samples shall be cast by the Contractor and furnished to the Engineer for testing at a location determined by the Engineer. All sheets shall be placed in labeled and sealed polyethylene bags prior to shipment to the testing facility or furnishing to the Engineer.

Should the results of tests for Systems 1, 2 and 3 on the samples or cores in any job control test fail to comply with these specifications, the composite casing represented by that test will be rejected in accordance with the provisions in Section 6-1.04, "Defective Materials," of the Standard Specifications.

Composite column casings shall be constructed in a manner consistent with the best commercial practices. The cured composite material encasing columns will be inspected for defects consisting of external abrasions or blemishes, delaminations, voids, external cracks, chips, cuts, loose fibers, foreign inclusions, depressible raised areas, or fabric wrinkles. The following criteria shall apply:

All defects with a dimension greater than 38 mm (1.5 in), defect areas greater than 645 mm² (1.0 in²), or defect areas with any dimension greater than 25 mm (1 in) within 300 mm (1.0 ft) from another defect area of similar size, shall be repaired or replaced as determined by the Engineer.

Any voids larger than 6 mm (1/4 in) shall be filled by injection with a system-compatible resin.

Preparing Surfaces and Painting Composite Casing.--Exposed surfaces of composite casing for Systems 1, 2 and 3 including surfaces below ground, shall be cleaned and painted in accordance with the provisions in Sections 59-1, "General," and 9 1, "Paint," of the Standard Specifications and these special provisions.

The surfaces to be cleaned and painted shall be lightly roughened by uniform abrasive blasting using an abrasive no larger than 80 mesh. The air pressure at the nozzle used for abrasive blasting shall not exceed 550 kPa (80 psi). The abrasive shall be of appropriate hardness to roughen the surface without damage to the fiber portion of the composite. The fiber portion of the composite shall not be exposed by the abrasive blasting operation. Abrasive blasting will not be required for System 1 if the first coat of paint is applied no sooner than 24 hours and within 72 hours after mixing the components for the final 0.38 mm (15 mil) resin coating.

Dust and residue shall be removed from all surfaces by flushing with clean water before painting.

All cleaned and roughened surfaces of the composite casing shall be completely dry before receiving a minimum of 2 finish coats of an exterior grade paint that is formulated to be system-compatible with the composite in accordance with ASTM D 3 359, Method A, with a minimum rating of 4A. The first finish coat shall be applied in 2 applications. The total dry film thickness of all applications of the first finish coat shall be not less than 0.05 mm (2 mils).

Successive applications of paint shall be of such a shade as to contrast with the paint being covered.

Except as approved by the Engineer, a minimum drying time of 12 hours shall be allowed between finish coats.

The second finish coat color shall match Federal Standard 595B No. 26 408. The total dry film thickness of all applications of the second finish coat shall be not less than 0.05 mm (2 mils).

The 2 finish coats shall be applied in 3 or more applications to a total dry film thickness of not less than 0.10 mm (4 mils) or more than 0.20 mm (8 mils).

MEASUREMENT AND PAYMENT.--Alternative column casing will be measured by the square foot. The quantity to be paid for will be the area of the existing concrete column surface to be encased by the casing alternative shown on the plans.

The contract price paid per unit area for the various types of alternative column casing shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all the work involved in furnishing and constructing alternative column casings complete in place, including removing and disposing of plants and other materials. removal of fins, sharp edges and protrusions and filling of voids in casings or depressions in surfaces to receive composite, job control testing, and cleaning and painting column casings as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

Full compensation for any additional testing, materials, enclosures, or work required because of the use of a particular kind of column casing shall be considered as included in the contract price paid per unit area for the alternative column casing, and no additional compensation will be allowed therefor.

Excavation and backfill at locations where the column casing is below the ground limits shown on the contract plans or original contract plans shall be required as directed by the Engineer and such work will be paid for as extra work as provided in Section 4-1.03D of the Standard Specifications.