LEGACY REPORT

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Legacy report on the 1997 *Uniform Building Code*™, the 2000 *International Building Code*®, the BOCA® *National Building Code*/1999 and the 1999 *Standard Building Code*©

DIVISION: 06—WOOD AND PLASTICS
Section: 06170—Prefabricated Structural Wood

FIBER-REINFORCED PLASTIC (FiRP®) REINFORCED GLUED-LAMINATED WOOD BEAMS

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1.0 SUBJECT

Fiber-reinforced Plastic (FiRP®) Reinforced Glued-laminated Wood Beams.

2.0 DESCRIPTION

2.1 General:

The construction and design approach for the FiRP® reinforced glued-laminated wood beams described in this evaluation report, is an acceptable alternative construction and design to that specified in Section 2303, Item 2, of the 1997 *Uniform Building Code*™ (UBC), in Section 2303.1.3 of the 2000 *International Building Code*® (IBC), in Section 2304.1 of the BOCA® *National Building Code*/1999 (NBC) and in Sections 2301.2.5 and 2301.4.2 of the 1999 *Standard Building Code*© (SBC).

FiRP® reinforced glued-laminated wood beams covered by this evaluation report, consist of laminations of lumber, having a nominal thickness of two inches or less, and fiber-reinforced plastic (FiRP®) acting as tension or compression, or both, reinforcement. The wood laminations and FiRP® reinforcement are glued into rectangular cross sections of uniform or tapered depth and meet grading and performance standards established in the approved quality control manual.

2.2 Materials:

2.2.1 Lumber: Lumber is E-rated or visually graded and complies with standard specifications for structural glued-laminated timber of softwood species, except for specific requirements noted in the quality control manual. Quality control for E-rating and beam fabrication is conducted under the supervision of an approved independent quality control agency.

2.2.2 Adhesives: Adhesives used in face and end joint bonding comply with ASTM D 2559 for exterior or wet use. End joints must comply with ANSI/AITC A190.1-1992 and ASTM D 3737, except for provisions for a safety factor of 2.1, using 5 percent LEL for a normalized population, in specific design situations specified in the approved quality control manual.

2.2.3 FiRP® Reinforcement: Fiber-reinforced plastic (FiRP®) reinforcement panel material meets proprietary performance and manufacture requirements specified in the quality control manual. FiRP® reinforcement panels are reinforced with either aramid, glass or carbon fibers. Pure aramid FiRP® panels (ARP plastic panels) are restricted to use in the tension zone of the reinforced glued-laminated wood beam. The glass and carbon FiRP® panels (GARP and CARP plastic panels, respectively) have compression and tension capacity and can be used in either the compression or tension zones of the reinforced glued-laminated wood beam. Only manufacturers approved for production of FiRP® reinforcement panel, as indicated in the quality control manual, shall supply FiRP® reinforcement for use in reinforced glued-laminated wood beams designed in accordance with this evaluation report. Only FiRP® reinforcement panel types specified in the approved quality control manual shall be used.

2.3 Fabrication:

Fabrication complies with AITC requirements and the quality control manual. Beams are fabricated in accordance with ANSI/AITC A190.1-1992 using the following grade combinations noted in the approved quality control manual with the prescribed variance:

Visually Graded	
AITC Combination #1	Douglas Fir-Larch, L3
AITC Combination #2	Douglas Fir-Larch, L2
AITC Combination #5	Douglas Fir-larch L1
AITC Combination #15	Hem-fir, L2
AITC Combination #16	Hem-fir, L1
AITC Combination #17	Hem-fir, L1D
AITC Combination #23	Western Woods, N3
AITC Combination #24	Western Woods, N2
AITC Combination #25	Western Woods, N1
AITC Combination #47	Southern Pine, N2M
AITC Combination #48	Southern Pine, N2D
AITC Combination #50	Southern Pine, N1D
E-rated	
AITC Combination #32	Douglas Fir-Larch, 2.3 E-1/6
AITC Combination #44	Western Woods, 2.1 E-1/6
AITC Combination #58	Southern Pine, 2.3 E-1/6

2.4 Beam Design:

The design of FiRP® Reinforced Glued-laminated Wood Beams shall comply with the design formulae noted in this section. (Refer to the following URL for design examples: http://www.americanlaminators.com/firp/example.pdf.)

2.4.1 Nomenclature:

a = Distance of neutral axis (NA) from top of beam, inches.

a' = Distance of neutral axis from top of beam before correction for reinforcement, inches.

b = Width of beam, inches. Also, depth for bending about the y-y axis, inches.

BT_c = Bumper layer thickness in compression zone, inches.

BT_t = Bumper layer thickness in tension zone, inches.

c = Distance from neutral axis (NA) to bottom extreme fiber in tension of beam in bending, inches.

C = Compressive force portion of bending moment couple.

C_c = Curvature factor, NDS®-97.

C_D = Load duration factor, NDS®-97.

C_L = Beam stability factor, NDS®-97.

C_M *(bending)* = Wet service factor for bending, extreme fiber stress in tension or compression, NDS®-97.

C_M *(compression)* = Wet service factor for compression parallel to grain stress, NDS®-97.

C_M *(MOE)* = Wet service factor for Modulus of Elasticity, NDS®-97.

C_M *(shear)* = Wet service factor for shear parallel to grain stress. NDS®-97.

C_P = Column Stability factor, NDS®-97.

C_t = Temperature factor, NDS®-97.

C_V = Volume factor, NDS®-97.

d = Depth of beam, inches.

d_o = Depth of unreinforced beam, inches. When the thickness of reinforcement termination (T_{rc} or T_{rt}) is less than 0.18 inch, fillers are not used and $d_o = d_{core} + BT_c + BT_t$

d_1 = Depth for bending about x-x axis, inches.

d_{core} = Core depth, inches. For a tension-only reinforced beam, this is the depth above the reinforcing, and for a double-reinforced beam, this is the depth between tension and compression reinforcement.

D_v = Shear value constant.

f_c = Applied compression parallel to grain stress from axial loads, psi.

f_t = Applied tension parallel to grain stress from axial loads, psi.

f_{b1} = Applied bending stress (extreme fiber in bending in the tension zone) about the x-x axis, psi.

f_{b2} = Applied bending stress (extreme fiber in bending in the tension zone) about the y-y axis, psi.

F_{bx} = Allowable design value for extreme fiber in bending (in tension) for unreinforced glulam, AITC 117-93 – Design, Table 2, psi.

$F_{bx'}$ = Allowable design bending stress extreme fiber in bending (in tension—F_{bx}) adjusted by applicable factors for unreinforced glulam, psi.

$F_{bx}{}^*$ = Transformed equivalent allowable bending stress (in tension) for bending about the x-x axis for FiRP® Reinforced glulam, psi.

F_{by}' = Allowable design bending stress for bending about the y-y axis adjusted by applicable factors, psi.

F_{bEx} = Critical buckling design value for bending in the x-x axis for FiRP® Reinforced glulam, psi.

F_{bEy} = Critical buckling design value for bending in the y-y axis for FiRP® Reinforced glulam, psi.

F_c = Tabular design value for compression parallel to grain for glulam, AITC 117-93–Design, psi.

F_c' = Allowable design stress for compression parallel to grain for FiRP® Reinforced glulam, as adjusted by applicable factors, psi.

$F_c{}^*$ = Allowable design compression parallel to grain stress adjusted by applicable factors excluding C_L and C_v FiRP® Reinforced glulam, psi.

$F_c{}^{**}$ = Allowable design compression parallel to grain stress adjusted by applicable factors excluding C_L and C_v but including C_p for FiRP® Reinforced glulam, psi.

F_{cE} = F_{cE1} or F_{cE2}, depending on the orientation of the critical buckling plane.

F_{cE1} = Critical buckling design value for compression parallel to grain for FiRP® Reinforced glulam (buckling about the x-x axis), psi.

F_{cE2} = Critical buckling design value for compression parallel to grain for FiRP® Reinforced glulam (buckling about the y-y axis), psi.

F_{rv} = Allowable design horizontal shear stress resistance of FiRP® Reinforced glulam, psi.

F_{rv}' = Allowable design horizontal shear stress for FiRP® Reinforced glulam adjusted for service conditions, psi.

F_t = Tabular design value for tension parallel to grain stress for glulam, AITC 117-93 – Design, Table 2, psi.

Ft' = Allowable design tension parallel to grain stress value adjusted by applicable factors, psi.

FJD = End joint design stress level, psi.

FJQ = End joint qualification stress level provided by manufacturer based on testing and determined according to ICBO approved quality control manual(s), psi. Sample end joint values are noted in Table 1.

FRR_r = Fire resistance rating of FiRP® Reinforced glulam, minutes.

FS_c = Adjustment factor for compression parallel to grain for FiRP® Reinforced glulam. See Section 2.4.6.1 for values.

g = Distance from neutral axis (NA) to centerline of reinforcement in tension zone, inches.

h_c = Depth of the wood between the neutral axis and the compression reinforcement, inches.

h_t = Depth of the wood between the neutral axis and the tension reinforcement, inches.

I_o = Moment of inertia for the unreinforced portion of the beam.

I_r = Moment of inertia for the cross section of beam about the neutral axis of Reinforced glulam, inches^4.

K_{bE} = 0.609.

K_{cE} = 0.418.

K_L = Loading condition coefficient.

l_{e1} = Unsupported length of bending member span in x-x axis direction, inches.

l_{e2} = Unsupported length of bending member span in y-y axis direction, inches.

M_a = Applied moment from axial effects, ft-lbs.

M_c = Adjustment value for reinforcement in compression zone, inches.

M_r = Allowable design resisting moment for FiRP® Reinforced glulam adjusted for service conditions, ft-lbs.

M_r' = Allowable design resisting moment for FiRP® Reinforced glulam adjusted for reinforcement insufficiency in tension and adjusted for service conditions, ft-lbs.

M_r'' = Allowable design resisting moment for FiRP® Reinforced glulam adjusted for reinforcement insufficiency in compression and adjusted for service conditions, ft-lbs.

M_r^* = Allowable design resisting moment for FiRP® Reinforced glulam including effects of axial tensile stress adjusted for service conditions, ft-lbs.

M_r^{**} = Allowable design resisting moment for FiRP® Reinforced glulam including effects of axial compression stress adjusted for service conditions, ft-lbs.

M_t = Adjustment value for reinforcement in tension zone, inches.

M_{ao} = Applied moment at the end of reinforcement in partial length reinforcement for FiRP® Reinforced glulam, in-lbs.

M_{ro} = Allowable design resisting cut-off moment for FiRP® Reinforced glulam adjusted for service conditions, ft-lbs.

MOE_{roxx} = FiRP® Reinforced glulam modulus of elasticity for bending about the x-x axis, psi. Allowable M_{roxx} values are noted in Table 2.

MOE_{roxx}' = FiRP® Reinforced glulam modulus of elasticity for bending about the x-x axis adjusted by applicable factors, psi.

MOE_{royy} = FiRP® Reinforced glulam modulus of elasticity for bending about the y-y axis, psi.

MOE_{royy}' = FiRP® Reinforced glulam modulus of elasticity value for bending about the y-y axis adjusted by applicable factors, psi.

MOE_{wc} = Modulus of elasticity of wood in axial compression, psi.

MOE_{wt} = Modulus of elasticity of wood in axial tension, psi.

n = Modular ratio of wood in axial tension (MOE_{wt}) to wood in axial compression (MOE_{wc}). Modular ratio values are noted in Table 3.

n' = Modular ratio of reinforcement in tension (MOE_{rt}) to wood in axial compression (MOE_{wc}).

n'' = Modular ratio of reinforcement in compression (MOE_{rc}) to wood in axial compression (MOE_{wc}).

N_c = Adjustment value for bumper layer in compression zone, inches.

N_t = Adjustment value for bumper layer in tension zone, inches.

R_B = Slenderness ratio of bending member (bending about the x-x axis).

R_c = Distance from centerline of compression reinforcement group to outer edge of beam on compression side, inches.

R_t = Distance from centerline of tension reinforcement group to outer edge of beam on tension side, inches.

S_o = Section modulus at end of reinforcement in unreinforced portion of FiRP® Reinforced glulam beam, $inches^3$.

S_r = Stress raiser factor at the ends of reinforcement in partial length reinforcement glulams.

ST_{rc} = Axial compressive stress in FiRP® Reinforcement panel in compression zone, psi.

$ST_{rc\ allowable}$ = Allowable design axial compressive stress in FiRP® Reinforcement panel in compression zone, psi.

ST_{rt} = Axial tensile stress in FiRP® Reinforcement panel in tension zone, psi.

$ST_{rt\ allowable}$ = Allowable design axial tensile stress in FiRP® Reinforcement panel in tension zone, psi.

T = Tensile force portion of bending moment couple, lbs.

T_{rc} = Total thickness of reinforcement in compression zone (ignore thickness of any gluelines), inches.

T_{rt} = Total thickness of reinforcement in tension zone (ignore thickness of any gluelines), inches.

V_r = Allowable design resisting horizontal shear for FiRP) Reinforced glued-laminated beam (adjusted for service conditions), lbs.

V_{ao} = Applied shear at the end of reinforcement in partial length reinforced FiRP® Reinforced glued-laminated beam, lbs.

V_{ro} = Allowable design resisting shear strength at end of reinforcement in partial length reinforced FiRP® Reinforced glulam based on F_{rv}, lbs.

x = Percentage of reinforcement by cross section (total of tension and compression reinforcement), %.

X = Distance from end of beam to reinforcement for partial length reinforcement, ft.

Z = Load factor for calculating fire resistance rating.

z' = Moment arm, inches.

σ_{tr} = Tensile stress in reinforcement in tension zone, psi.

2.4.2 Beam Geometry Calculation: Calculation of distance from top of member to neutral axis (NA), distance *a*. Figure 1 illustrates the various cross-section components in a compression and tension reinforced glulam beam.

Tension reinforced FiRP® reinforced glulams:

$$a = a' + M_t - N_t$$

Compression and tension reinforced FiRP® reinforced glulams:

$$a = a' + M_t - N_t - M_c + N_c$$

where:

$$a' = d\frac{\sqrt{n}}{1 + \sqrt{n}}$$

$$M_t = n(n' - 1)^{0.63}\ T_{rt}$$

$$N_t = nR_t\ (n' - 1)\frac{T_{rt}}{a'}$$

$$M_c = n(n'' - 1)^{0.7}T_{rc}$$

$$N_c = nR_c(n'' - 1)\frac{T_{rc}}{a'}$$

2.4.3 Composite Stiffness Calculation: Composite stiffness ($MOE_{wc}\ I_r$) of the FiRP® reinforced glued-laminated wood beam is determined in accordance with the following formulas.

$$MOE_{wc} = 2\frac{MOE_{roxx}'}{n + 1}$$

$$MOE_{wt} = n\ MOE_{wc}$$

$$MOE_{roxx}' = MOE_{roxx}C_M\ C_t$$

MOE_{royy} = Is obtained by multiplying MOE_{roxx} by 0.95; reference AITC 500-91.

$MOE_{royy}' = MOE_{royy}\ C_M\ C_t$.

$$I_r = b\frac{BT_c^3}{12} + b\,BT_c\left(a - \frac{BT_c}{2}\right)^2 + b\,n''\frac{T_{rc}^3}{12} + b\,n''T_{rc}(a - R_c)^2$$
$$+ b\frac{h_c^3}{12} + b\,h_c\left(\frac{h_c}{2}\right)^2 + b\,n\,\frac{h_t^3}{12} + b\,n\,h_t\left(\frac{h_t}{2}\right)^2 + b\,n'\frac{T_{rt}^3}{12}$$
$$+ \; b\;n'T_{rt}(c \; - \; R_t)^2 \; + \; b\;n\frac{BT_t^3}{12} \; + \; b\;n\;BT_t\left(c \; - \; \frac{BT_t}{2}\right)^2$$

where:

h_c = a - BT_c - T_{rc}.

h_t = d - a - BT_t - T_{rt}.

The I_r equation can be simplified by combining terms. If compression reinforcement is not used, the first four terms of the equation can be eliminated and the following equation can be used:

$$I_r = \frac{b \cdot h_c^3}{3} + \frac{b \cdot n \cdot h_t^3}{3} + b \cdot n' \cdot T_{rt}\left[\frac{T_{rt}^2}{12} + (c - R_t)^2\right] +$$
$$b \cdot n \cdot BT_t\left[\frac{BT_t^2}{12} + \left(c - \frac{BT_t}{2}\right)^2\right]$$

MOE_{roxx} values for various AITC combinations are listed in Table 2. These values must not be used for unreinforced glulams or portions of unreinforced glulams. They represent average values for use with various concentrations and types of reinforcement as well as various beam lengths and sizes. All service factors relevant to modulus of elasticity are applicable to MOE_{roxx}.

Shear modulus values used in calculating MOE_{roxx} values range from 100,000 psi for L-3 hem-fir to 150,000 psi for 2.3E-1/6 Douglas fir-larch.

2.4.4 Resisting Moment Calculation: Allowable design resisting moment adjusted for service conditions, M_r, is determined in accordance with the following formula:

$$M_r \;=\; \frac{C\;z'}{12}\left(\frac{FJQ'}{FJD}\right)$$

where:

$$FJQ' = FJQ\;C_L\;C_M\;C_D\;C_t$$

The minimum percentage of reinforcement for moment resistance is 0.25%.

Figure 2 illustrates the forces in a FiRP® Reinforced Glued-laminated Wood Beam and the resisting moment, M_r.

where:

C = $F_c'\,a\,b$ (sum of forces in compression, lbs.).

F_c' = $F_c\,C_D\,C_M$ (compression) C_t (C_L or C_V whichever is less).

The lateral stability factor, C_L, for beams in bending is defined by the following formula:

$$C_L \;=\; \frac{1 + \frac{F_{bEy}}{F_{bx}^*}}{1.9} \;-\; \sqrt{\left[\frac{1 + \frac{F_{bEy}}{F_{bx}^*}}{1.9}\right]^2 \;-\; \frac{\frac{F_{bEy}}{F_{bx}^*}}{0.95}}$$

where:

$$F_{bx}^* \;=\; 12\left(\frac{cM_r}{I_r}\right)$$

$$F_{bEx} \;=\; \frac{K_{bE}\;\;MOE_{roxx}'}{R_B^2}$$

$$R_B \;=\; \sqrt{\frac{l_{e1}\;d_1}{b^2}}$$

The beam stability factor, C_L, applies when the depth is greater than the width.

In the compression zone of reinforced beams, tension reinforcement is ignored in the calculation of resisting moment.

$$z' \;=\; \frac{a}{2} \;+\; g$$

$$FJD \;=\; \frac{F_c'\;a\;(FS_c)}{(n'\;T_{rt}) \;+\; \frac{c}{2}}$$

Balanced beams require all provisions specified in this evaluation report for both top and bottom of beam.

2.4.5 Finger Joint Qualification: Finger joint qualification (*FJQ*) strength values are controlled by the percentage of reinforcement. Minimum percentages of reinforcement in the tension zone and the corresponding *FJQ* value shall comply with this section.

2.4.5.1 End Joint Qualification Strength Value Determination: For design purposes, the method used to calculate the End Joint Qualification (*FJQ*) strength value is determined by the reinforcement concentration or F_c values as following:

For designs where reinforcement is less than 1.2% by cross section in the tension zone and less than or equal to:

1. 0.21 inch thickness of Aramid Reinforced Plastic FiRP® Reinforcement panel or
2. 0.14 inch of thickness Carbon - Aramid Reinforced Plastic FiRP® Reinforcement panel or
3. 0.28 inch thickness of Glass - Aramid Reinforced Plastic FiRP® Reinforcement panel, the 5 percent lower exclusion limit (LEL), with 75 percent confidence level, of a normalized end joint population shall be used as the *FJQ* value.

For all other designs where a greater percentage of reinforcement by cross section or greater thickness of reinforcement is used, the average end joint strength value shall be used as the *FJQ* value.

For AITC Combinations 2 and 5, the maximum *FJQ* value is 5,200 psi when the reinforcement is less than:

1. 2.0% tension reinforcement by cross section for ARP FiRP® Reinforcement panel, or
2. 1.5% CARP FiRP® Reinforcement panel by cross section, or
3. 2.5% GARP FiRP® Reinforcement panel by cross section,regardless of how high the *LEL* end joint values are. All other combinations have no maximum.

For all combinations where the value for F_c is less than 1,200 psi, the *FJQ* value to use is the average end joint strength value regardless of reinforcement type and concentration.

If $FJQ \div FJD > 2.0$, then $FJQ \div FJD = 2.0$.

2.4.6 Compression Safety Factors: The following safety factors shall apply to the compression strength values (service adjusted) for resisting moment calculations:

2.4.6.1 Compression Zone Reinforcement: A safety factor (*FSc*) of 2.5 is applicable between points of zero moment in the compression zone of reinforced beams with partial length reinforcement less than 60 percent, lengthwise of the beam. All other beams have a safety factor of (*FSc*) 1.9 in the compression zone.

2.4.6.2 Tension Zone Reinforcement: A safety factor of 1.9 is applicable for tension only reinforced beams in compression.

At no time is the beam permitted to be reinforced in the compression zone only.

2.4.7 Resisting Moment Calculations for Partially Reinforced Beams: The following formulae apply to any combination of loading on a FiRP® reinforced glued-laminated beam. Figure 2 shows the forces in a FiRP® beam.

Allowable design resisting cutoff moment for FiRP® Reinforced Glued-laminated Wood Beams, M_{ro}, is determined as follows:

$$M_{ro} = \frac{F_{bx}'\ S_o}{12\ (S_r)}$$

where:

$$S_o = \frac{b\ d_o^2}{6}$$

S_r = 1.538 T_{rt} + 1.6

S_r = 1.0 when the thickness of terminated reinforcement is < 0.18 inches.

Applied moment at the end of reinforcement in partial length reinforcement, M_{ao}, must be less than allowable design resisting cutoff moment, M_{ro}. That is, $M_{ao} < M_{ro}$.

For F_b value selection from AITC 117-93, Table 2, the tension laminations strength/grade for FiRP® Reinforced glulams in extreme stress tension zone are equal to or greater than special tension lamination strength/grades specified by AITC 117-93 for unreinforced beam with the same combination number.

One foot of length is added to FiRP® reinforcement panel on each end upon completion of partial length requirements. Additionally, minimum length reinforcement in tension or compression zone is 40 percent of span between points of zero moment in any one zone.

2.4.8 Axial Stress in FiRP® Reinforcement Panel Calculation:

2.4.8.1 Tension Zone: The axial tensile stress in the FiRP® reinforcement panel, ST_{rt}, must be less than the allowable design axial tensile stress, $ST_{rt\ allowable}$. That is, $ST_{rt} < ST_{rt\ allowable}$

where:

$$ST_{rt} = \frac{M_r\left(g + \frac{T_{rt}}{2}\right)n'}{I_r} + f_t\ \frac{MOE_{rt}}{MOE_{roxx}}$$

Values for various FiRP® reinforcement panels comply with the performance requirements specified in the approved quality control manual and are obtained from the FiRP® reinforced glued-laminated beam manufacturer. Table 4 provides an example of FiRP® reinforcement panel design values.

When $ST_{rt} > ST_{rt\ allowable}$, the allowable design resisting moment must be adjusted for reinforcement insufficiency as follows:

$$M_r' = \left(\frac{ST_{rt\ allowable}}{ST_{rt}}\right) M_r$$

$M_r' \le M_r$

2.4.8.2 Compression Zone: The axial compressive stress in the FiRP® reinforcement panel, ST_{rc}, must be less than the allowable design axial compressive stress, $ST_{rc} < ST_{rc\ allowable}$.

where:

$$ST_{rc} = \frac{M_r\left(a - BT_c - \frac{T_{rc}}{2}\right)n''}{I_r} + f_c\frac{MOE_{rc}}{MOE_{roxx}}$$

Values for various FiRP® reinforcement panels comply with the performance requirements specified in the approved quality control manual and are obtained from the FiRP® reinforced glued-laminated beam manufacturer. Table 4 provides an example of FiRP® reinforcement panel design values.

When $ST_{rc} > ST_{rc\ allowable}$, the allowable design resisting moment is adjusted for reinforcement insufficiency as follows:

$$M_r'' = \left(\frac{ST_{rc\ allowable}}{ST_{rc}}\right) M_r$$

$M_r'' \le M_r$

2.4.9 Allowable Shear Calculation: Allowable design resisting horizontal shear, V_r, is determined in accordance with the following formula:

$$V_r = \frac{2}{3}\ F_{rv}'\ b\ d$$

where:

F_{rv}' = $F_{rv}\ C_D\ C_M$ (shear) C_t.

F_{rv} = D_v + 20 Ln (x)

D_v = Shear value constant: 278 for Douglas fir-Larch, 270 for southern pine and 268 for hem fir glued-lam combinations and 223 for western woods glued-laminated combinations.

Applied shear at the end of reinforcement in partial length reinforced FiRP® reinforced beam, V_{ao}, must be less than the allowable shear strength at cutoff point of the plastic reinforcement panels, V_{ro}. That is, $V_{ao} < V_{ro}$. Allowable design resisting shear strength at cutoff is based on F_{rvb}. Refer to Table 5 for F_{rvb} base values. Applied shear is neglected a distance equal to the depth of the beam away from the support.

The total amount of reinforcement is limited by cross section from minimum 0.25 percent to maximum 4.0 percent of the total cross-sectional area of the beam for the calculation of shear strength. For amounts above 4 percent, the maximum values (F_{rv}) shown in Table 5 are used. For amounts equal to 0.25 percent, the base F_{rvb} values from Table 5 are used in lieu of F_{rv} to calculate V_{ro}. Maximum amount of tension reinforcement is 2.0 percent of the total cross-sectional area of the beam, and the maximum amount of compression reinforcement is 2.0 percent of the total cross-sectional area of the beam in calculations of x. In all situations, F_{rv} maximum allowable shear shall not exceed those shown in Table 5.

For unreinforced portions of the glued-laminated wood beam, the maximum allowable shear, F_{rvb}, shall not exceed the base value shown in Table 5.

2.4.10 Combined Bending and Axial Loading:

2.4.10.1 Bending and Axial Tension: Members subjected to a combination of bending moments and tensile loads shall comply with the following formula:

$$\frac{f_t}{F_t'} + \frac{M_a}{M_r*} \le 1.0$$

where:

F_t' = $F_t\ C_D\ C_M$ (compression) C_t.

$$M_r^* = \frac{C\ z'\ FJQ'}{12\ (FJD + f_t)}$$

Equations concerning ST_{rt} and ST_{rc} must be checked for further adjustments to M_r^* for reinforcement insufficiencies. If $M_r^* > M_r'$ or M_r'', then M_r^* is equal to the lessor of M_r' or M_r''.

2.4.10.2 Bending and Axial Compression: members subjected to a combination of bending moments and compressive loads shall comply with the following formula:

$$\left(\frac{f_c}{F_c**}\right)^2 + \frac{M_a}{M_r**\left(1 - \frac{f_c}{F_{cE1}}\right)} + \frac{f_{b2}}{F_{by}'\left\{1 - \frac{f_c}{F_{cE2}} - \left(\frac{f_{b1}}{F_{bE}}\right)^2\right\}} \le 1$$

The applied parallel-to-grain compressive stress for either uniaxial or biaxial bending shall comply with the following formula:

$$f_c \;<\; F_{cE1} \;=\; \frac{K_{cE}\; MOE_{roxx}'}{\left(\frac{l_{e1}}{d_1}\right)^2}$$

and

$$f_c \;<\; F_{CE2} \;=\; \frac{K_{cE}\; MOE_{royy}'}{\left(\frac{l_{e2}}{b}\right)^2}$$

$$f_{b1} \;=\; 12\left(\frac{M_a\; c}{I_r}\right)$$

and

$$f_{b1} \;<\; F_{bEx}$$

Allowable axial compressive stress adjusted for service conditions including column stability factor, C_P, and excluding beam stability factor, C_L, is derived by the following formula:

$$F_c^{**} = F_c\; C_D\; C_M\; (compression)\; C_t\; C_P$$

where:

$$C_P \;=\; \frac{1 \;+\; \left(\frac{F_{cE}}{F_c^*}\right)}{1.8} \;-\; \sqrt{\left[\frac{1 \;+\; \left(\frac{F_{cE}}{F_c^*}\right)}{1.8}\right]^2 \;-\; \frac{\left(\frac{F_{cE}}{F_c^*}\right)}{0.9}}$$

$$F_c^* = \; F_c\; C_D\; C_M\; (compression)\; C_t$$

F_{cE} = The lesser of F_{cEx} or F_{cEy}

Allowable resisting moment including effects of axial compression stress adjusted for service conditions is defined by the following formula:

$$M_r{**} \;=\; \frac{C \cdot z' \cdot FJQ'}{12\;(FJD \;-\; f_c)}$$

Equations concerning ST_{rt} and ST_{rc} must be checked for further adjustments to M_r^{**} for reinforcement insufficiencies. If $M_r^{**} > M_r'$ or M_r'', then M_r^{**} is equal to the lesser of M_r' or M_r''.

2.4.10.3 Eccentric Compression Loading: Section 3.9 of the "National Design Specification for Wood Construction" (NDS), 1997 edition, is applicable for FiRP® reinforced glulam members subjected to combined bending and axial compression caused by eccentric loading or eccentric loading in combination with other loads, with the formula modifications noted in Section 2.4.10 for reinforcement considerations.

2.5 Connector Design:

Connector design for FiRP® reinforced glulams shall comply with code provisions for connectors used in conventional unreinforced glued-laminated wood beams, except for the following:

- Bolt shank allowable stress values parallel and perpendicular to longitudinal axis shall be calculated and added to those calculated for wood in the applicable direction. These values apply to the area of reinforcement in contact with the bolt shank and not the glue line thickness. See Table 6 for bolt bearing design values and specifications.
- Standard bolt holes shall have a tolerance of 0.1 inch. When bolt holes have tolerances between 0.1 and 0.15 inch, the bolt bearing design values must be reduced 50 percent. Tolerances greater than 0.15 inch are not permitted.

2.6 Fire-resistance Rating:

The following formulae apply to the design of one-hour fire-resistive exposed FiRP® reinforced glued-laminated wood beams. The beams are reinforced with either carbon /aramid reinforced plastic (CARP) or fiberglass/aramid reinforced plastic (FARP) or aramid reinforced plastic (ARP), and shall have a minimum nominal thickness of 6 inches. When beams are reinforced with ARP, the formulae in this section must be multiplied by a factor of 0.7. The reinforcement plastic panels must be covered with an additional lamination of minimum 1.25-inch actual thickness placed on both the compression and tension face of the beam and must be equivalent in quality to that required by design for outer compression and tension laminations.

The following procedure establishes the fire rating of a FiRP® Reinforced glued-laminated wood beam (FRR_r). The fire-resistance rating, in minutes for beams with a nominal dimension of 6 inches, is defined by one of the following formulas:

For beams that may be exposed to fire on four sides:

$$FRR_r \;=\; 2.54\; Z\; b\left[4 \;-\; 2\left(\frac{b}{d}\right)\right]$$

For beams that may be exposed to fire on three sides:

$$FRR_r \;=\; 2.54\; Z\; b\left[4 \;-\; \left(\frac{b}{d}\right)\right]$$

Connectors and fasteners that support the member shall be protected for an equivalent fire resistance. When the minimum one-hour fire resistance is required, connectors and fasteners shall be protected from fire exposure by not less than $1^1/_2$ inches of wood, appropriate thickness or layers of Type X gypsum board, or any coating approved for one-hour rating.

2.7 Installation:

The installation and handling procedures as well as in-service requirements are outlined in ANSI/AITC A190.1-1992, AITC 117-93, and AITC 200-92, except for the following:

- Installation of FiRP® reinforced glulam beams that utilize FARP type of reinforcing panels is limited to interior dry locations. FARP is not allowed where cyclic loading is greater than 100,000 cycles.
- FiRP® reinforced glulam beams that utilize FARP type of reinforcing panels are not permitted to support applied dead loads that are greater than 50 percent of the total design load.
- FiRP® reinforced glulam beams that utilize FARP type of reinforcing panels shall not be used where long-term loading is greater than 70 percent of the total design load.

2.8 Identification:

Each FiRP® Reinforced Glued-laminated Wood Beam is identified with a label bearing the manufacturing layup combination; name of the beam fabricator; type of FiRP® reinforcing panel; evaluation report number; and the name of the quality control agency, APA—The Engineered Wood Association (AA-649).

Figure 3 shows a typical identification label that shall be affixed to FiRP® reinforced glued-laminated wood beams.

FiRP® reinforced glued-laminated wood beams that are designed for one-hour fire rating in accordance with Section 2.6 of the report, shall be marked "Fire-rated One-hour" by the manufacturer to indicate compliance with this report.

3.0 EVIDENCE SUBMITTED

Data in accordance with ICBO ES Acceptance Criteria for the Development of Proprietary Design Formulae for Plastic-reinforced Glued-laminated Beams (AC102), dated July 1994; test data in accordance with UBC Standard 7-1; and quality control manuals.

4.0 FINDINGS

That the FiRP® Reinforced Glued-laminated Wood Beams described in this report comply with the 1997 *Uniform Building Code*™, the 2000 *International Building Code*®, the BOCA *National Building Code*/1999 and the 1999 *Standard Building Code,* subject to the following conditions:

4.1 Design of the reinforced glued-laminated wood beams complies with this report. Calculations showing compliance are submitted to the building official for review and approval.

4.2 Installation of the FiRP® Reinforced Glued-laminated Wood Beams complies with this report.

4.3 Design procedures apply to beams loaded predominantly in bending.

4.4 For applications requiring a fire-resistive rating, the FiRP® reinforcement panel is laminated on the exterior surface with a minimum 1.25-inch-thick layer of graded lumber complying with the approved quality control manual.

4.5 FiRP® reinforced glued-laminated beams that are reinforced with either carbon/aramid reinforced plastic (CARP) or glass/aramid reinforced plastic (GARP) have a fire-resistive rating in accordance with Section 2.6. FiRP® reinforced glued-laminated beams that are reinforced with aramid reinforced plastic (ARP) have a fire-resistive rating in accordance with Section 2.6, provided the FRR_r rating is multiplied by a 0.7 modification factor.

4.6 Aramid reinforced plastic panels (ARP) are not permitted to be used as compression reinforcement since ARP has no design compressive strength.

4.7 FiRP® reinforcement is not permitted to be notched or cut.

4.8 The beams are fabricated by American Laminators, Inc., at their manufacturing facilities located in Drain, Oregon, with independent quality control audits performed by APA—The Engineered Wood Association.

This report is subject to re-examination in two years.

TABLE 1—SAMPLE END JOINT QUALIFICATION (*FJQ*) VALUES[1,2]

Species	Size	Mean *FJQ* (psi)	5% LEL *FJQ* (psi)
DF-L	2 x 4	5900	4850
DF-L	2 x 6	5600	4650
DF-L	2 x 8	5550	4600
DF-L	2 x 10	5450	4550
HF	2 x 6	5200	4750
HF	2 x 8	5000	4550

For **SI:** 1 psi = 6.9 kPa.
[1]Data contained in the table are shown as representative of actual end joint test values. FJQ values to use for design shall be obtained from the manufacturer.
[2]$FJQ \div FJD \leq 2.0$.

TABLE 2—ALLOWABLE MOE_{roxx} VALUES (x 10^6 psi)[1]

AITC COMBINATION	GRADE	SPECIES	FiRP® MOE_{roxx}
32	2.3E-1/6	DF-L	2.50
5	L-1	DF-L	2.10
2	L-2	DF-L	1.80
1	L-3	DF-L	1.80
16	L-1	HF	1.90
17	L-1D	HF	1.90
15	L-2	HF	1.80
58	2.3E-1/6	SP	2.50
50	N-1D	SP	2.00
48	N-2D	SP	1.90
47	N-2M	SP	1.90
44	2.1E-1/6	WW	2.10
25	N-1	WW	1.60
24	N-2	WW	1.50
23	N-3	WW	1.50

For **SI:** 1 psi = 6.9 kPa.
[1]Tabulated values are averages that consider reinforcement sizes, lengths, types and concentrations. Shear modulus values used to calculate tabulated MOE_{roxx} values range from 100,000 psi for L-3 hem-fir to 150,000 psi for 2.3E - 1/6 Douglas fir. These values are not applicable to unreinforced glued-laminated wood beams. All service factors relevant to modulus of elasticity specified in the code are applicable to MOE_{roxx}

TABLE 3—MODULAR RATIOS (*n*-VALUES)

WOOD SPECIES	GRADE	*n*-VALUE
Douglas fir-larch	All grades	1.06
Hem-fir	L-1D	1.06
	L-1	1.08
	L-2	1.10
	L-3	1.10
Western woods	N-1	1.06
	N-2	1.08
	N-3	1.10
Southern pine	All grades	1.06
All species	E-rated grades	1.06

TABLE 4—FiRP® REINFORCEMENT PANEL DESIGN VALUES[1]

FiRP® REINFORCEMENT PANEL	MOE_{rt} x 10^6 (psi)	MOE_{rc} x 10^6 (psi)	ST_{rt} (ksi)	ST_{rc} (ksi)	SHEAR STRENGTH (psi)
Glass/Aramid Reinforced Plastic (GARP)	8.0	8.0	35	10	1080
Aramid Reinforced Plastic (ARP)	11.6	--	143	--	490
Carbon/Aramid Reinforced Plastic (CARP)	16.6	16.6	121	34	980

For **SI:** 1 psi = 6.9 kPa.
[1] These values are presented as an example only. Current values developed under the supervision of the approved quality control agency are obtained from the beam manufacturer.

TABLE 5—FiRP® REINFORCED GLULAM ALLOWABLE HORIZONTAL SHEAR VALUES

SPECIES	BASE F_{rvb} (psi)	MAXIMUM ALLOWABLE F_{rv} (psi)	D_v
DF-L	240	270	278
HF	230	270	268
SP	270	270	270
WW	185	225	223

For **SI:** 1 psi = 6.9 kPa.

TABLE 6—BOLT BEARING VALUES FOR FiRP® REINFORCEMENT PANELS[1,2]

TYPE OF FiRP® REINFORCEMENT PANEL	DESIGN STRESS (psi)	
	Parallel to Longitudinal Axis	Perpendicular to Longitudinal Axis
GARP	1800	1125
ARP	4480	1525
CARP	3000	2450

For **SI:** 1 psi = 6.9 kPa.

[1]Tabulated stress values are limited to bolts with a maximum diameter of 1 inch. Design values are reduced 50 percent for bolts having a diameter between 1 and 2 inches. Values are not applicable to bolts having diameters over 2 inches.

[2]Standard bolt holes shall have a tolerance of 0.1 inch. For tolerances between 0.10 and 0.15 inch, the tabulated design values must be reduced by 50 percent. Tolerances greater than 0.15 inch are not permitted.

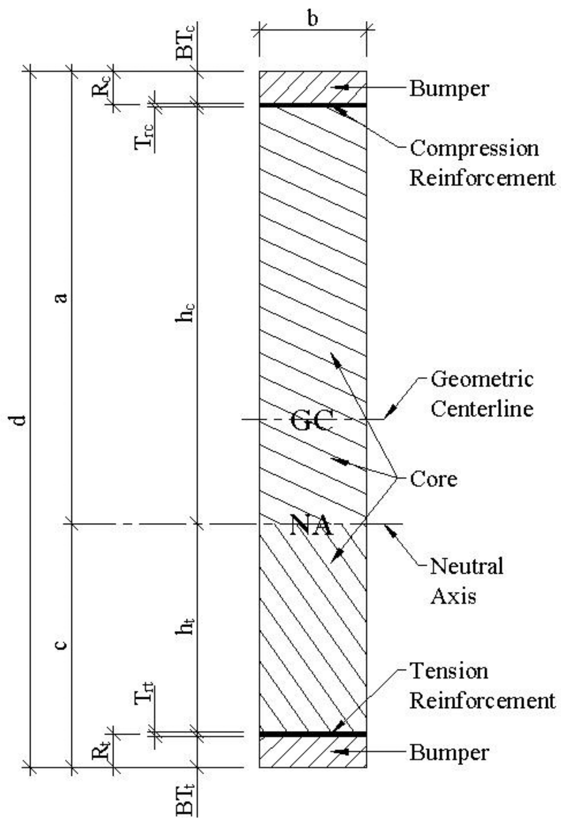

FIGURE 1—CROSS SECTION OF REINFORCED GLULAM BEAM

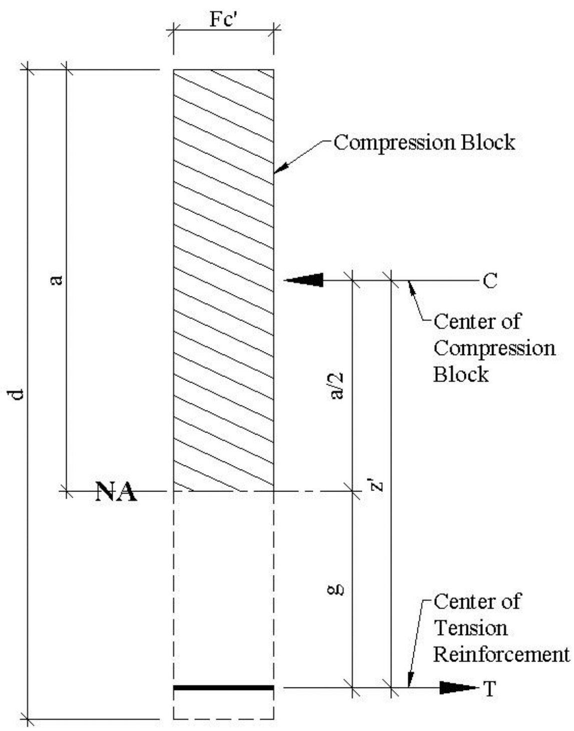

FIGURE 2—FORCES IN FiRP® BEAM

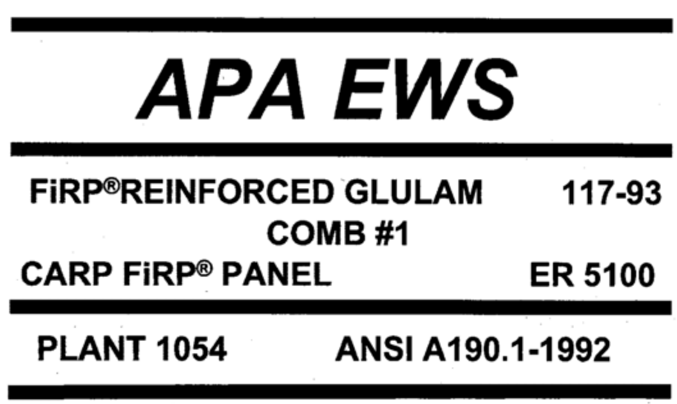

FIGURE 3