E90 Project Proposal:

The Use of Glass Fiber Reinforced Polymer Reinforcement in Concrete Beams

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Introduction

Plastics and fibers are relatively new materials for use in concrete reinforcement. While not widely used in industry, these materials are particularly useful in constructions where corrosion resistance is important. Much research has been done recently on the ability of GFRP to increase flexural and shear capacity of concrete. Carbon fiber grid is important for its high tensile strength to weight. The use of both materials can allow the construction of structures that would impractical with conventional steel reinforcement.

For this project I will be exploring FRP composite reinforced concrete design. By optimizing a design created within the rules of the 2007 ACI FRP Composites Competition, I will be looking into ways to best increase the flexural and shear capacities of FRP reinforced concrete beams. The competition will provide constraints within which such an optimization can be performed, as well as providing results with which to compare my beams.

By designing these beams, I will be integrating all I have learned about design from my structures and materials classes. In the design, I will be considering how these materials could be best used in the field. As a part of this consideration, and toward the competition goal of reducing beam weight, I will reduce the amount of material used in the beam, hence limiting the costs, financial and economic, to the consumer.

Technical Discussion

Fiber reinforced polymer bars can be produced with glass fibers (GFRP), carbon fibers (CFRP) or aramid (AFRP). GFRP is the most widely used due to price, hence they were the bars chosen for use in the competition. The manufacturer that supplied bars to the competition was Hughes Brothers, who provided documentation about the properties of their bars. These properties include a guaranteed tensile strength, tensile modulus of elasticity and maximum bond stress. All of these properties are necessary for use in reinforced concrete design. The manufacturer also specifies situations for the use of these bars. These instructions discourage prestressing or bending of the bars as it can lead to creep rupture over time.

Also available for use in the competition is C-3000 carbon grid provided by Tech-Fab. This manufacturer also provided a specifications sheet with a nominal tensile strength for use in design. It is clear from the notes on this sheet, though, that there has not yet been enough testing for widespread use of this material.

Competition Rules

The complete competition rules are attached as Appendix A. Of particular importance are the size limitations and reinforcement requirements. These requirements limit reinforcement to two 1000 mm long GFRP bars or two 1000 mm strips of carbon grid, or some combination of these materials not to exceed a combined length of 2000 mm. The reinforcement may be cut to any length as long as the combined length requirement is met.

Also important is the competition’s focus on load-weight ratio. To this end it is best to reduce weight of all materials used in the beams. Hydro-cure sand left over from Jessica Mandrick’s E90 will be used to reduce the weight of the beams. This sand was provided at no cost by Swarthmore alumnus John Roberts, owner of Northeast Solite Corporation. The amount of cementious material is not directly limited by the rules, but should be limited in design in order to reduce weight.

For the competition, it was also necessary to estimate the load at a specified deflection, as well as at failure. This requirement tests the ability of each team to perform analysis in addition to design. In the past, prediction has been the most difficult aspect of the regional beam competition for our team. I hope that with extra tests, I will be able to improve my predictions, as well. Toward this end, I will also be creating an ANSYS model of my beams. The above rules provide some restrictions but also allow enough freedom to experiment as well as providing a goal for the design.

Project Plan

This project can be divided into four parts; reinforcement materials testing, concrete mix design, beam design and construction, and beam strength predictions and testing. The first part is occurring in conjunction with my E82 project. I am testing GFRP bars in three-point bending, in order to make my own estimate of the modulus of elasticity. I also hope to do my own tension tests on the carbon grid, once I have acquired some from the manufacturer. Having done the tests myself, I hope to have a better idea of how best to use the various materials.

For the second part, I will create a limited number of concrete mix designs to be tested as compressive cylinders. The basic mix will be the design used by the Swarthmore team in the regional beam competition, but it will need to be updated in order to accommodate the Hydro-Cure. The Hydro-Cure absorbs moisture during mixing, releasing it later in the curing process, which requires changing the water added to the mix. For my mixes, I will vary the water and cement added in order to choose the most efficient mix based on load-weight ratio.

The various designs tried in the third phase of the project will depend to a large extent on the properties determined in the testing phase. A total of at least eight beams will be produced, with the final two being “competition” beams, on which prediction will be made. At least one beam will be produced with a simple layout of GFRP bars in the lower portion of the beam. Another beam will use only carbon grid. Other options involve combinations. Designs will be chosen to focus on the following factors: preventing sudden failure, increasing shear strength, reducing the required concrete, reducing weight, and reducing the likelihood of creep over time.

Since neither GFRP bars nor carbon grid undergo yielding, the least sudden failure for concrete reinforced with these materials is crushing of concrete. This requires designs which, in steel reinforced design, would be considered over-reinforced. To have results of this sort, it is necessary to maintain a high level on tensile reinforcement, particularly at mid-span.

To increase shear strength, there needs to be reinforcement in the vertical direction. This could be provided through angling the bars or mesh, upward from the center of the span. Towards the ends is the location of highest shear and lowest tensile forces, so it is the location where having some reinforcement in the vertical plane is most necessary. Designs focusing on this aspect will most likely use mainly carbon grid.

Reducing the amount of concrete is the best method for reducing the weight of the beams, though changing the concrete mix design to reduce weight may also be tried. The most important aspect to consider when reducing the amount of concrete is whether the reinforcement will have an adequate bond.   Bond failure is a very sudden failure and is best avoided.

The final factor to be addressed is the reduction of creep over time. According to the specifications for the bars, creep is only an issue at loads above 60% of ultimate load. This is the reason given for avoiding prestressing, as that decreases the amount of load that can be regularly applied. Bending of the bars would have a similar affect, though I may attempt a beam with bent bars in order to determine whether the increase in shear strength would be worth the necessary increase in reinforcement to prevent creep.

The construction of these beams will require the new formwork made for the larger dimensions. I will attempt to create formwork for at least two beams that is easy to assemble and disassemble so that pouring can be done easily. The materials for the forms will probably be lumber, though I will attempt to avoid the need to screw the formwork together for each casting, which increases the time for each batch. Also required for the forms will be plastic sheeting and caulk to prevent sticking and leaking of the concrete.

Each beam will be poured from it’s own batch of concrete, along with at least three cylinders to determine the compressive strength of the concrete. Two of the cylinders will be tested at seven days, and all remaining cylinders will be tested at 28 days, along with the beams. I intend to create a schedule such that all beams will be tested at 28 days, so that the resulting strengths are comparable. Both pouring and testing of concrete may require the help of other students.

The final phase of the project is the prediction of results for the two “competition” beams. The prediction will depend upon the reinforcement design chosen and the strength of the concrete as determined by cylinders. The analysis may be rather complex if shear reinforcement is provided in an unconventional manner. In order to help with these predictions I will build an ANSYS model of the beams using solid elements.

In addition to the beams created by the process above, I will also help with the regional ACI beam competition beams, which will be produced during the spring semester using steel reinforcement. Hopefully, the expertise I gain through my project will aid us in winning this competition, once again winning the monetary prize.

Project Costs

Costs for this project should be rather limited. The lumber for the formwork will be a one-time cost, though it may be possible to build with used boards present in the shop. The forms will remain with the department and may be used in the future for actually entering the competition. Materials, other than cement, for the concrete mix are already present in the concrete lab, and cement can be purchased for approximately $15 per bag. The reinforcing bars are already present in the lab, and I am hoping to get a donation of the carbon grid by the manufacturer that donates it to the competition.

Critical Path and Gantt Chart

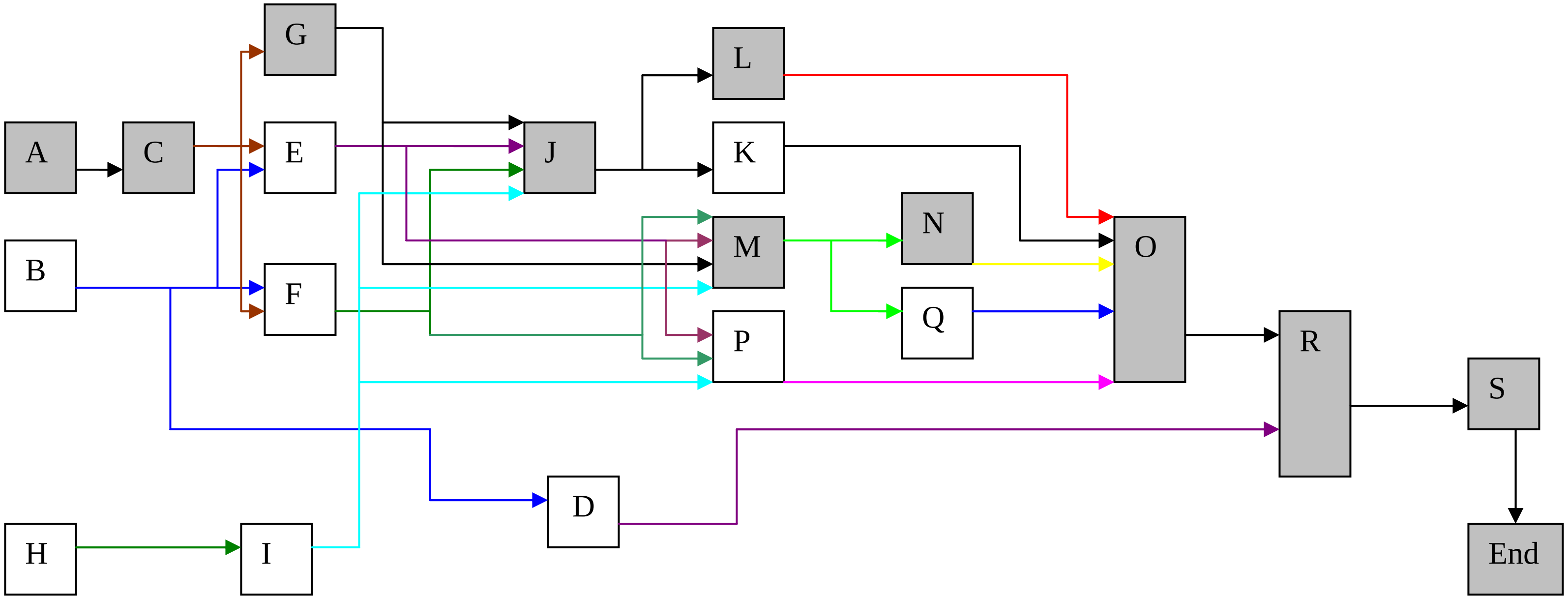
Activities List

Phase	Activity	Description
	A	Contact Organizer of ACI Competition for Rules
	B	Research GFRP and Carbon Grid Reinforcement
3	C	Acquisition of Materials for Formwork and Concrete
	D	Writing E90 Proposal
1	E	Testing of GFRP Bars (E82 Project) for Modulus of Elasticity
1	F	Testing of Carbon Grid for Tensile Strength
3	G	Construction of Formwork for 2 Beams
2	H	Concrete Mix Design and Pouring of Cylinders
2	I	Testing Mix Design Cylinders
3	J	Pouring of Test Design Beams
4	K	Testing of Cylinders Test Design Beams
4	L	Testing of Test Design Beams
3	M	Design and Pouring of "Competition" Beams
4	N	Testing of Cylinders from "Competition" Beams
4	O	Predicting Results
4	P	ANSYS Model
4	Q	Testing "Competition Beams"
	R	Writing E90 Report and Comparing Results to Competition
	S	Presentations

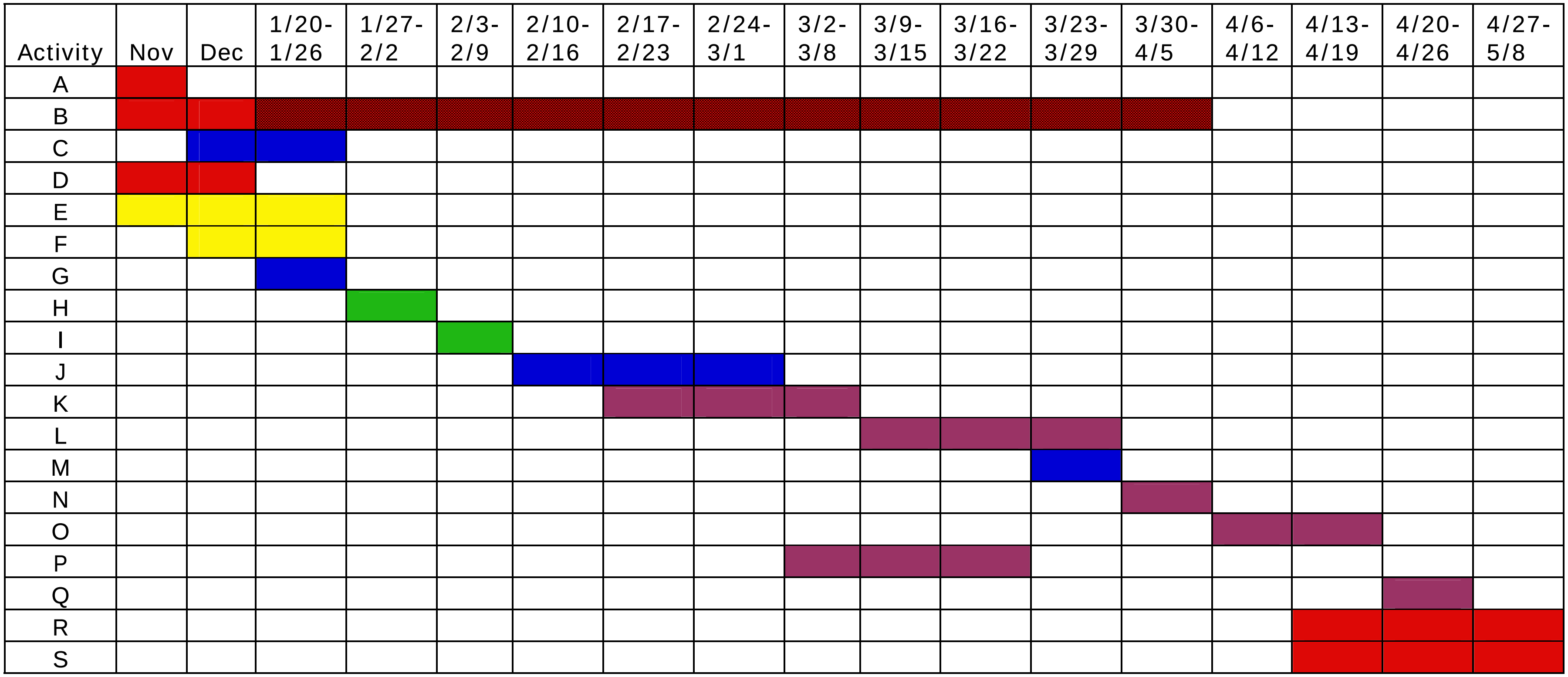
Activities with Needs/Feeds, Duration and Effort

Phase	Activity	Needs	Feeds	Duration (Weeks)	Effort (Hours)
	A		C	1	1
	B		D,E,F	12	36
3	C	A	E,F,G	2	4
	D	B	R	2	10
1	E	B,C	J,M,P	3	10
1	F	B,C	J,M,P	2	10
3	G	C	J,M	1	10
2	H		I	1	12
2	I	H	J,M,P	1	8
3	J	E,F,G,I	K,L	3	30
4	K	J	O	3	15
4	L	J	O	3	15
3	M	E,F,G,I	N,Q	1	12
4	N	M	O	1	5
4	O	K,L,N,P	R	2	15
4	P	E,F,I	O,R	3	30
4	Q	O	R	1	4
	R	D,O,P,Q	S	3	15
	S	R		3	15

Critical Path Method



Gantt Chart



Activity	Nov	Dec	1/20-1/26	1/27-2/2	2/3-2/9	2/10-2/16	2/17-2/23	2/24-3/1	3/2-3/8	3/9-3/15	3/16-3/22	3/23-3/29	3/30-4/5	4/6-4/12	4/13-4/19	4/20-4/26	4/27-5/8
A	🟥																
B	🟥	🟥	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫				
C		🟦	🟦														
D	🟥	🟥															
E	🟨	🟨	🟨														
F		🟨	🟨														
G			🟦														
H				🟩													
I					🟩												
J						🟦	🟦	🟦									
K							🟪	🟪	🟪								
L										🟪	🟪	🟪					
M												🟦					
N													🟪				
O														🟪	🟪		
P									🟪	🟪	🟪						
Q																🟪	
R															🟥	🟥	🟥
S															🟥	🟥	🟥

References

ACI FRP Composites Competition Rules 2007, http://www.concrete.org/students/st_FRPcomposites.htm, Accessed 11/14/07

Hughes Brothers Specifications Sheet for Aslan 100 GFRP Rebar, from ACI FRP Composites Competition Website

Kentucky Transportation Center, “GFRP Reinfrced Concrete Bridges”, July 2000, www.ktc.uky.edu/Reports/KTC_00_09_SPR96_169.pdf, Accessed 11/15/07

Tech-Fab Specifications Sheet for C-3000 Carbon Grid for Concrete Reinforcement, from ACI FRP Composites Competition Website

Appendix A

ACI FRP Composites Competition

Objective

These are the challenges in this competition:

Design, construct, and test a concrete structure reinforced with fiber-reinforced polymer (FRP) bars and/or grids to achieve the optimal load-to-weight ratio.

Predict the ultimate load.

Predict the load that will result in a piston deflection of 2.5 mm (0.1 in).

Rules

THE MATERIALS AND THE SPECIMEN GEOMETRY (See Structure Geometry Requirements Diagram)

1. The structure's cross section must fit into a 200 mm (7.87 in) wide by 350 mm (13.75 in) high envelope. The cross section may vary over the length, provided the structure can be mounted on supports and loaded as shown in the attached sketch. The structure's overall length may not be less than 950 mm (37.4 in) nor more than 1000 mm (39.4 in) on a 900 mm (35.4 in) center-to-center span. Dimensional tolerances are ± 6 mm (1/4 in) on the length and ± 3 mm (1/8 in) on all other dimensions. If time permits, structures not meeting this requirement may be tested, but the teams submitting such specimens will not be eligible for prizes.

2. The specimen must be constructed using a minimum of one and a maximum of two of the following reinforcement forms: 1000 mm (39.4 in) long #4 FRP reinforcing bars and/or 300 mm (11.8 in) wide by 1000 mm (39.4 in) long sheet of C3000 carbon/epoxy thin grids. Note that the width of the carbon/epoxy thin grids may be slightly less than 300 mm to insure that a continuous strand of carbon/epoxy borders the width. Other reinforcing materials are not allowed. Reinforcing bars and grids may not be prestressed. Mechanical anchorages of bars and grids are not permitted. Bars and grids may be cut to provide a larger number of shorter pieces, as long as a minimum of 1000 mm (39.4 in) and a maximum of 2000 mm (78.8 in) of FRP reinforcing bars and /or grids are used in the structure. The grid may be cut to any width as long as the limitation on total length (minimum of 1000 mm and maximum of 2000 mm) is satisfied. Reinforcement may be used in any combination of bars and/or grids as long as the limitation on total length (minimum of 1000 mm and maximum of 2000 mm) is satisfied.

3. A student team may use any combination of these bars and/or grids in their structure, but the competition specimen must be fabricated with a least one (1) and not more than two (2) of these bars and/or grids. Additional bars and grids are supplied for student experimentation. Reinforcing bars and grids from other sources are not permitted.

Participating manufacturers have agreed to provide FRP reinforcement free of charge to the schools, in reasonable quantities consistent with the contest rules. Students and advisors, in return for receiving the FRP bars and grids free of charge, must agree to only use the FRP reinforcement supplied to them for purposes directly related to the competition. Failure to comply with the requirement prohibiting the use of FRP bars and grids supplied for the competition in other projects will disqualify the student team from the competition and may also disqualify the faculty advisor from participation in future competitions. Faculty advisors are required to sign a statement on the Preregistration Form stipulating they will not use the bars and grids for purposes (research or others) not directly related to the competition. Should faculty advisors desire to use these types of reinforcements in other projects, they are encouraged to directly contact the manufacturers.

4. Total structure weight must be between 5 kg (11.0 lbs) and 15 kg (33.1 lbs).
5. The cementitious materials shall consist of any combination of portland cement meeting ASTM C 150, blended cement meeting ASTM C 595 or ASTM C 1157, ground-granulated blast furnace slag meeting ASTM C 989, fly ash meeting ASTM C 618, and/or silica fume meeting ASTM C 1240. Any type of nonmetallic aggregate may be used. Chemical admixtures meeting ASTM C 494 are allowed. Epoxies and other polymers, glue, and binders may NOT be used.
6. Teams must provide the actual measured batch weights of all materials (including admixtures) used in their concrete mix, as specified on the Official Registration Form. Teams must also provide a diagram showing placement and dimensions of reinforcements used. The diagram must accompany the specimen to the competition and be identified with the specimen beam mark.
7. Curing shall be at atmospheric pressure, and the curing temperature must not exceed the boiling point of water at atmospheric temperature.
8. No structure shall be more than 56 days old at the time of the test.
9. Reinforcing support wires and/or chairs are not permitted in the clear span area. Any manner of nonmetallic bar support may be used outside the clear span, as long as the bar support does not act to enhance the behavior of the structure, such as by anchoring the bar in the concrete.

THE TESTING PROCESS:

1. Entries will be weighed and measured, and those judged acceptable by the FRP Competition Committee will be positioned in the testing apparatus, which will apply a midspan concentrated load by means of a pivoting load plate. The center-to-center span is 900 mm (35.4 in) and reaction forces are through bearing surfaces measuring not less than 50 mm (2 sq in) by 50 mm (2 sq in) and providing no restraint against rotation at the ends of the specimen.

2. Once seated in the testing apparatus, a seating load of approximately 0.25 kN (56 lbs) will be applied and recorded. Additional load will be applied until the structure fails or is loaded to the test fixture's capacity of 67 kN (15,000 lbs). The maximum load achieved will be recorded as the maximum load prior to failure or 67 kN (15,000 lbs), whichever is smaller. In lieu of obvious physical signs of failure, failure will be assumed to have occurred when total load on the structure has decreased to 50% of the maximum load achieved by that specimen. The loading rate will be determined by adjusting the cylinder's manual speed setting so that the manual speed valve is closed hand tight. This setting will correspond to a piston movement of approximately 1 mm/minute, but may be affected by the stiffness of the specimen. Deflection will be measured as the movement of the loading piston, which is assumed to correspond to deflection of the specimen at the loading plate.

3. If a structure fails to reach a deflection of 2.5 mm (0.1 in) prior to either failing or reaching the test fixture's capacity of 67 kN (15,000 lbs), that entry shall be disqualified for the Most Accurate Prediction prizes but will be permitted to compete for the Highest Ultimate Load-to-Weight Ratio prizes.

4. To arrive at the actual load corresponding to a 2.5 mm (0.1 in) deflection, the total load at 2.5 mm (0.1 in) deflection will be reduced by the 0.25 kN (56 lbs) seating load (for which no deflection was measured).

5. The maximum load achieved (as specified in paragraph 3b), without deduction of the seating load, will be recorded as the measured ultimate load.

THE EVALUATION PROCESS:

1. Load-to-weight ratios will be calculated as the ultimate load, as defined in paragraph 3e, divided by the weight of the structure. Any structure that does not fail prior to reaching the 67 kN (15,000 lb) test fixture capacity will have its load-to-weight ratio calculated as 67 kN divided by the weight of the structure.

2. Prediction accuracy will be measured by the relative difference between predicted and actual results. The Most Accurate Predictions of load will be the teams that achieve the smallest absolute value for "Delta", the estimated percentage difference, computed as follows: $D = 50\{DP_{2.5}/P_{2.5} + DP_{ult}/P_{ult}\}$ Where $DP_{2.5}$ = ½$P_{\text{est @ 2.5 mm midspan deflection}}$ - $P_{2.5}$½ = the absolute value of the difference between the predicted load at 2.5 mm (0.1 in) deflection and the measured load corresponding to 2.5 mm (0.1 in) deflection, where the measured load is defined in paragraph 3d. $P_{2.5}$ = measured load corresponding to 2.5 mm (0.1 in) deflection, defined in paragraph 3d. DP_{ult} = ½$P_{\text{est @ ult}}$ - P_{ult}½ = the absolute value of the difference between the predicted ultimate load and the measured ultimate load as defined in paragraph 3e. P_{ult} = the measured ultimate load as defined in paragraph 3e. Any structure that does not fail prior to reaching the 67 kN (15,000 lb) test fixture capacity will have D calculated with P_{ult} taken equal to 67

kN.