ACI FRP Composites Competition

REGISTRATION OPENS NOVEMBER 28, 2016

Objectives

These are the challenges in this competition:

- Design, construct, and test a concrete structure reinforced with fiber-reinforced polymer (FRP) reinforcement to achieve the lowest cost-load ratio. Cost is defined as the calculated batch cost for concrete materials and chemical admixtures plus the cost of the FRP used to reinforce the structure; adjusted for forming costs for more complicated geometries and reduced by credits given for implementation of sustainable design concepts.
- Predict the ultimate load.
- Predict the load that will result in a piston deflection of 3.5 mm (0.14 in.).
- **Registration opens on November 28, 2016.** Comply with the contest rules. The completed **Advance Registration Form is due February 1, 2017.** The Official Mix and Cost Form, and a diagram showing placement and dimensions of all FRP reinforcing materials must be received **by March 1, 2017 11:59 p.m. EST.**
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Prizes

Prizes will be awarded in the following manner:

- First, Second, and Third Prizes will be awarded to the teams in each of two structure type categories (TYPE 1 and TYPE 2), using the evaluation process defined in Paragraph 5. First Prize will be awarded $750, with $500 for Second Prize and $250 for Third Prize.
- Each school may only enter one team in each structure type category.
- First-, second-, and third-place entries will also be awarded a certificate of recognition, recognition on ACI's website, and will be recognized in *Concrete International* magazine if space allows.

Rules

1. THE STUDENT TEAM

1.1. Each team must have a supervising faculty advisor who will see that the student team complies with the rules of the competition. The faculty member is permitted to advise more than one team.

1.2. Each team must consist of not more than five students currently enrolled in an undergraduate program at any college or university worldwide. Undergraduate students on cooperative or internship work assignment are eligible to compete. All members of a given team must be from the same school. A student may not be a member of more than one team.

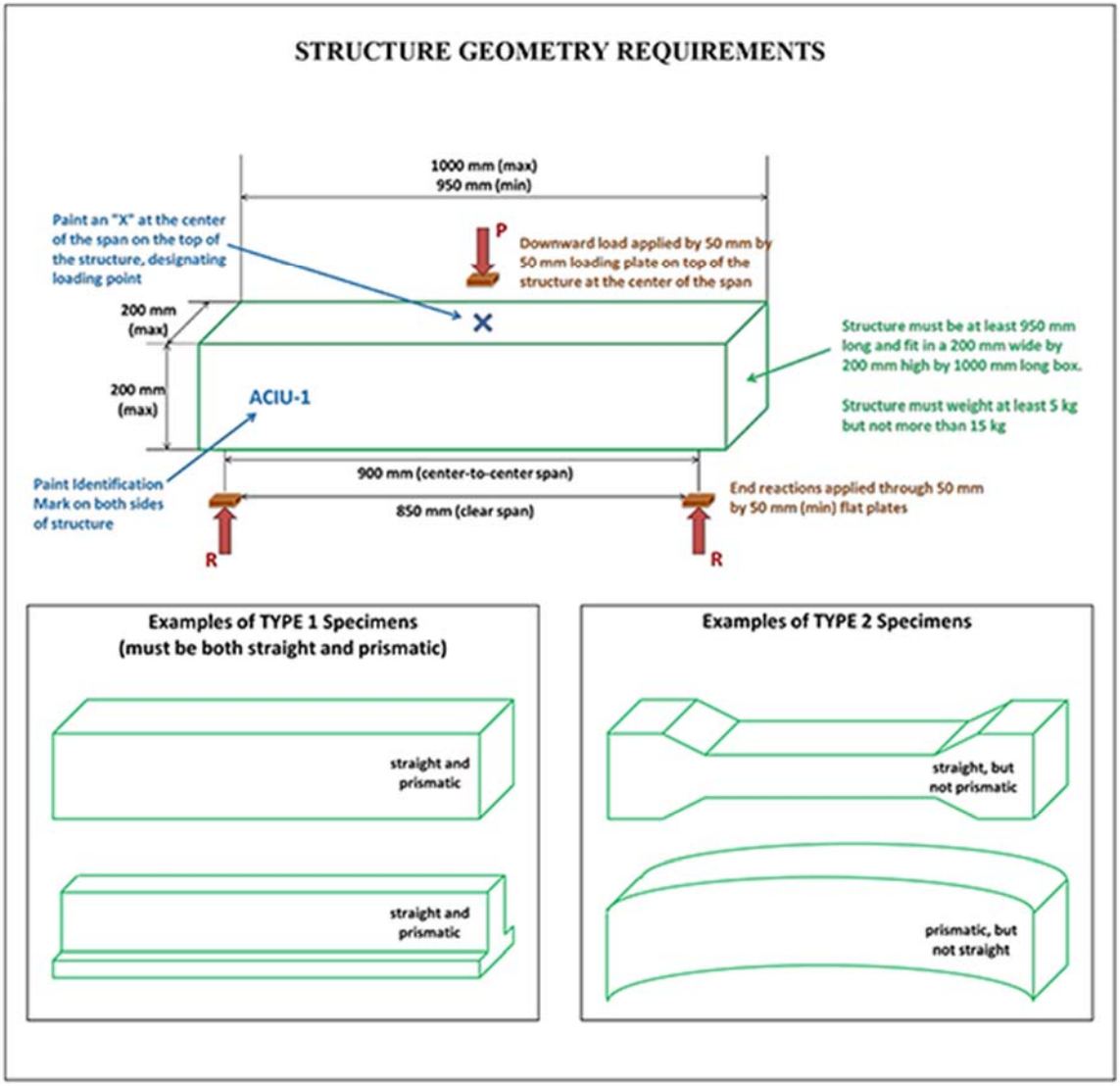
1.3. It is strongly recommended that at least one individual (faculty advisor or student team member) be designated to represent each team and be present during testing of the structure at the time and location specified for this competition. Participation by additional team members is both permitted and encouraged.

1.4. Each team must complete and submit the **Advance Registration Form—due February 1, 2017 11:59**

p.m. EST., the Official Mix and Cost Form, and a diagram showing placement and dimensions of all FRP reinforcing materials by **March 1, 2017 11:59 p.m. EST.**

1.5. Each school will be permitted to send no more than two teams to the competition (one in each structure type category). The first two properly completed applications (Advance Registration Form, and Official Mix and Cost Form with reinforcement diagram) will be accepted as that school's entries. Additional teams will only be accepted if an earlier entry from the same school withdraws from the competition.

2. THE MATERIALS AND THE STRUCTURE GEOMETRY



2.1. **Structure Type:** A structure will be classified as a TYPE 1 structure if it is a straight prismatic beam; that is, its cross section is prismatic and the centroid of the cross section (based on the gross concrete cross section) does not vary along the span. A TYPE 1 structure may have a rectangular or non-rectangular, cross section; however, if the cross section is non-rectangular then a Complex Formwork cost adjustment will be applied as specified in Paragraph 4.3. Any structure that does not meet the requirements for TYPE 1 will be designated as

a TYPE 2 structure. Any TYPE 2 structure that is non-rectangular in cross section and or nonprismatic along the span will have a Complex Formwork cost adjustment applied as specified in Paragraph 4.3. Examples of TYPE 1 and TYPE 2 structures are shown in the Structure Geometry Requirements Diagram.

2.2. **Structure Size:** Regardless of whether the structure is classified as TYPE 1 or TYPE 2, the structure must fit into a 200 mm (7.87 in.) wide by 200 mm (7.87 in.) high by 1000 mm (39.4 in.) long box. The structure's overall length may not be less than 950 mm (37.4 in.) nor more than 1000 mm (39.4 in.), including any protruding reinforcement. The structure must be able to be placed on supports and loaded as shown in the Structure Geometry Requirements Diagram. All dimensional measurements will made by the competition committee with common measurement devices. Measurements made by the committee are final.

2.3. **Structure Markings:** At the center of the structure, a large "X" shall be painted on the upper surface where the concentrated load will be applied. In addition, student teams must select an identification mark (for example, the school initials followed by the numeral 1 for team #1 or 2 for team #2), which must be marked so as to be clearly visible on both sides of the structure. Teams may also apply decals of their school logo and/or decorate their entry with felt-tip markers to improve its appearance, if desired. No other markings or surface treatment shall be permitted.

2.4. **Structure Weight:** Total structure weight must be between 5 kg (11.0 lb) and 15 kg (33.1 lb). All weight measurements will be made by the competition committee using common measurement devices. Measurements made by the committee are final

2.5. **Structure Materials**

2.5.1. Use only materials listed in the Official Mix and Cost worksheet.

2.5.2. The cementitious materials shall consist of any combination of portland cement meeting ASTM C150, or blended cement meeting ASTM C595 or ASTM C1157. Supplementary cementitious materials that may also be used include slag cement ("slag") meeting ASTM C989, fly ash meeting ASTM C618, and/or silica fume meeting ASTM C1240. These cementitious and supplementary cementitious materials shall only be used in producing a concrete mixture and may not be used for other purposes such as to coat reinforcement as a bond-enhancing agent.

2.5.3. Any type of nonmetallic aggregate may be used.

2.5.4. Chemical admixtures meeting ASTM C260, C494, or C1017 are allowed. Epoxies and other polymers, glue, and binders may NOT be used.

2.5.5. Teams must provide the measured weights of all materials used in the concrete batch prepared to cast their competition structure, as specified on the Official Mix and Cost Form.

2.5.6. Every eligible student team submitting the Advance Registration Form will receive an FRP reinforcing materials kit from the manufacturers supplying FRP for the competition. FRP reinforcing materials supplied for the competition are listed in the Official Mix and Cost Worksheet. The FRP reinforcing materials supplied for the competition, along with the manufacturers' data sheets on engineering properties, will be shipped to the U.S. or Canadian address specified on the Advance Registration Form. Due to difficulties in shipping to countries outside the United States and Canada, all teams must provide a shipping address in the United States or Canada. Schools/student teams are responsible for arranging for trans-shipment from the U.S. or Canadian address they provide.

2.5.7. A student team may use any combination of the FRP reinforcing materials supplied for the competition in their structure, but the competition structure must be fabricated with at least one (1) full piece of the FRP reinforcing materials supplied for the competition. The FRP reinforcing material may be cut in any manner. Other reinforcing materials not supplied in the FRP reinforcing materials kit are not allowed. The FRP reinforcing materials may not be prestressed. Mechanical anchorages, if used, must be made from the FRP reinforcing materials supplied for the competition. Students may experiment with the supplied FRP materials.

2.5.8. Students and advisors, in return for receiving the FRP reinforcing materials free of charge, must agree to only use the FRP reinforcing materials supplied to them for purposes directly related to the competition. Failure to comply with the requirement prohibiting the use of FRP reinforcing materials 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. Should faculty advisors desire to use these types of reinforcements in other projects, they are encouraged to directly contact the manufacturers.

2.6. **Structure Construction:**
2.6.1. Curing shall be at atmospheric pressure, and the curing temperature must not exceed the boiling point of water at atmospheric temperature.

2.6.2. No structure shall be more than 56 days old at the time of the test.

2.6.3. Reinforcing supports are not permitted in the 850 mm clear span. Any manner of bar support including chairs, wires, and precast concrete blocks 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; these bar supports are NOT included in the total cost. All reinforcement supports must be made from nonmetallic materials or must be galvanized (zinc-coated) or coated with nonmetallic materials. Mechanical anchorages, if used, must be made from the materials provided, as specified in paragraph 2.5.7 and ARE included in the total cost.

2.7. **Submissions:**
2.7.1. Teams must submit a 75 x 150 mm (3 x 6 in.) cylinder placed from the same concrete batch as that used to place the competition structure. The cylinder MUST be identified with the same structure identification mark and MUST be submitted with the structure on the day of the competition. The cylinder will be used by ACI as required by the judges to confirm materials used. Teams failing to submit the required cylinder will be disqualified from the competition.

2.7.2. Teams must also provide a diagram showing placement and dimensions of all FRP reinforcing materials used. The diagram must include the structure identification mark and must be submitted along with the Official Mix and Cost Form by the date specified on the competition website. Teams are encouraged to prepare an 11 x 17 in. poster with their school name and logo, their structure identification mark, and the names of student team members and faculty advisor to be displayed with their structure at the competition..

2.7.3. Entries not meeting the specified requirements may be tested if time permits but will not be eligible for prizes. MODIFICATION OF ENTRIES SHALL NOT BE PERMITTED AT THE COMPETITION SITE.

3. THE TESTING PROCESS:

3.1. 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 in.^{2}) x 50 mm (2 in.^{2}) and providing no restraint against rotation at the ends of the structure.
3.2. The student team or their faculty representative, if present, will place their structure in the testing apparatus. A seating load of approximately 0.25 kN (56 lb) will then 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 lb). In lieu of obvious physical signs of failure, after initial cracking, failure will be assumed to have occurred when total load on the structure has decreased to 75% of the maximum load achieved by that structure. 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 2.5 mm/minute, but may be affected by the stiffness of the structure. Deflection will be measured as the movement of the loading piston, which is assumed to correspond to deflection of the structure at the loading plate.

3.3. The maximum load achieved (P_{ult}) will be recorded as the maximum load prior to failure or 67 kN (15,000 lb), whichever is smaller, without deduction of the seating load.
3.4. The load corresponding to a deflection of 3.5 mm (0.14 in.) will also be recorded. To arrive at the load corresponding to this deflection ($P_{3.5}$), the measured load will be reduced by the 0.25 kN (56 lb) seating load (for which no deflection was measured). If a structure fails to reach a deflection of 3.5 mm (0.14 in.) prior to failing or reaching the test fixture’s capacity of 67 kN (15,000 lb), ($P_{3.5}$) will be taken as the maximum load achieved (as specified in Paragraph 3.3) less the seating load of 0.25 kN (56 lb).

4. STRUCTURE COST:

4.1. The Final Cost (**COST**) will be calculated as the sum of the material cost for the materials used times the Complex Formwork and Sustainability Credit Multipliers, as specified in the Official Mix and Cost Worksheet.
4.2. The cost for FRP reinforcing materials will be calculated on a per-piece basis and will NOT be prorated when less than the full piece of an FRP reinforcement is used. (For example, an entry that uses one complete piece of FRP reinforcement as required by Paragraph 2.5.7 and a part of another piece of FRP reinforcement as permitted by Paragraph 2.5.7 would be assigned the material cost associated with two full pieces of FRP reinforcing materials.)

4.3. Complex Formwork Multipliers will be assigned to account for the additional costs of more involved cross sections. Complex Formwork Multipliers will be applied to only the concrete material costs. Multipliers will be assigned for the following geometries:

4.3.1. If the cross section is nonrectangular, a multiplier of 1.1 will be applied to the concrete material costs;

4.3.2. If the cross section is nonprismatic (that is, varies in the clear span), a multiplier of 1.1 will be applied to the concrete material costs;

4.4. Sustainability credits will be granted for reduction in cement content and for use of recycled supplementary cementitious materials (SCMs). The Sustainability Credit Multiplier will be applied to both the concrete and the FRP material costs. The Sustainability Credit Multiplier will be calculated by subtracting the sum of the sustainability credits awarded from 100%. Sustainability Credits will be awarded for implementation of the following sustainable design concepts:

4.4.1. If the measured batch weight of cement (in lb or kg) is less than 15% of the total batch weight (in lb or kg) of all concrete materials, as reported on the Mix and Cost Form worksheet, a 1% sustainability credit will be awarded;

4.4.2. If the measured batch weight of cement (in lb or kg) is less than 10% of the total batch weight (in lb or kg) of all concrete materials, as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.3. If the measured batch weight of cement (in lb or kg) is less than 5% of the total batch weight (in lb or kg) of all concrete materials, as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.4. If the measured batch weight (in lb or kg) of fly ash is more than 20% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag cement [slag], and silica fume), as reported on the Mix and Cost Form worksheet, a 1% sustainability credit will be awarded;

4.4.5. If the measured batch weight (in lb or kg) of fly ash is more than 30% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.6. If the measured batch weight (in lb or kg) of fly ash is more than 40% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.7. If the measured batch weight (in lb or kg) of slag cement (slag) is more than 20% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, a 1% sustainability credit will be awarded;

4.4.8. If the measured batch weight (in lb or kg) of slag is more than 35% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.9. If the measured batch weight (in lb or kg) of slag is more than 50% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded;

4.4.10. If the measured batch weight (in lb or kg) of silica fume is more than 5% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, a 1% sustainability credit will be awarded; and

4.4.11. If the measured batch weight (in lb or kg) of silica fume is more than 10% of the sum of the measured batch weights (in lb or kg) of all cementitious materials (including cement, fly ash, slag, and silica fume), as reported on the Mix and Cost Form worksheet, an additional 1% sustainability credit will be awarded.

5. THE EVALUATION PROCESS:

5.1. The Cost-Load Ratio (R_1) will be calculated as the Final Cost of the structure, as defined in Paragraph 4, divided by the maximum load achieved (P_{ult}), as defined in Paragraph 3.3.

$$R_1 = \text{COST} / P_{ult,measured}$$

5.2. The Maximum Load Prediction Ratio (R_2) will be calculated as the absolute value of the percent difference between predicted and measured values for P_{ult} as follows:

$$R_2 = 100\% * \text{ABS}[(Pult_{,predicted} - Pult_{,measured}) / Pult_{,measured}]$$

5.3. The 3.5 mm Deflection Load Prediction Ratio (R_3) will be calculated as the absolute value of the percent difference between predicted and measured values for $P_{3.5}$ as follows:

$$R_3 = 100\% * \text{ABS}[(P_{3.5,predicted} - P_{3.5,measured}) / P_{3.5,measured}]$$

5.4. Teams will be ranked in ascending order in each of three categories based on the Ratios defined in paragraphs 5.1 to 5.3. For example, the team with the lowest Cost-Load Ratio will be ranked 1, the team with the second-lowest ratio will be ranked 2, etc. Teams will be ranked separately in each structure type category (TYPE 1 and TYPE 2) for each of the three ratios.

5.5. A team's final ranking points will be determined by multiplying its ranking in the Cost-Load Ratio by 0.50 and the ranking in each of the other two categories by 0.25. For example, a team finishing third in the Cost-Load Ratio, second in the Maximum Load Prediction Ratio, and seventh in the 3.5 mm Deflection Load Prediction Ratio would receive 3.75 ranking points, computed as follows: [(0.50 * 3) + (0.25 * 2) + (0.2 5* 7) = 3.75]. Ties will be broken by the ranking in the Cost-Load Ratio category.

5.6. Within each structure type category (TYPE 1 and TYPE 2), the team with the lowest final ranking points will be declared the winner, and all other groups will be ranked based on final ranking points in ascending order.

6. TIME AND LOCATION FOR TESTING AND COMPLIANCE WITH RULES:

6.1. The competition will be held in conjunction with The Concrete Convention and Exposition in Detroit, MI, on Sunday March 26, 2017, beginning at 9:00 A.M. All entries must be delivered to the check-in of the competition area in person, expected to begin at or before 9:00 A.M. the morning of the competition. The entry does not have to be delivered by a team member. The check-in time and requirements may change depending on the total quantity of teams registered for the competition.

6.2. A panel of judges will be appointed by the FRP Competition Committee. Interpretations and decisions made by the judges will be final, and appeals will not be considered. ACI reserves the right to perform a detailed examination and check all entries for compliance with the competition rules. Due to the complexity of this task, the examination may be done after the competition, if needed. If the examination shows that a team did not follow the rules, the team, their advisor, and all of his/her teams will be disqualified. ACI Committee S801 will further document recommendations to disallow the team, their advisor, and/or school/university from participation in future ACI competitions and submit this to the Student and Young Professional Activities

Committee.

CONTACT INFORMATION

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