ECOCONCRETE STUDENT COMPETITION

Presented to
SUBCOMMITTEE ACI S-801 - Student Activities

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November, 2018
Sherbrooke, QC, Canada

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1 OBJECTIVES AND PRIZES

1.1 Objectives

In order to follow the current orientation of the concrete industry, this student competition aims to promote the idea of environmental performance in concrete mix design as an important aspect of sustainability. Teams thus have the mission to develop an innovative concrete mixture, which will have the lowest possible environmental impacts while maintaining optimal mechanical and durability performances. To achieve this goal, teams are encouraged to seek out and use local resources of concrete materials such as supplementary cementitious materials (SCMs), alternative SCMs, fillers, recycled and alternative aggregates, and other environmentally friendly materials.

After designing their concrete mixture, teams are asked to perform a simplified life-cycle assessment (LCA) and present their results in a written report and a poster. The format of this report is inspired by an environmental product declaration document, which is favored by the industry to communicate the environmental footprint of products.

In addition to the report, teams shall prepare two concrete cylinders of their alternative-case and base-case scenarios and carry them to the competition place. The four total cylinders will be submitted early on Sunday morning of the competition and will be tested for compressive strength and resistivity at an offsite lab, and their results factored into the overall score. At the competition, teams will also have to present a poster of their innovative concrete to the audience and judges, with an emphasis on the environmental aspect considered in their mix design.

1.2 Prizes

The use of recycled aggregates and/or alternative supplementary cementitious materials combined with the quality of the written report, environmental score from the simplified life-cycle assessment, and the results of the hardened tests will be the parameters in determining the winners. First, second and third-place entries will each be awarded a certificate of recognition, will be recognized on the ACI website as well as *Concrete International* magazine if space allows. In addition, the first-place team will receive a $750 award, the second-place team will receive $500, and the third-place team will receive $250. Winners will not be announced, and prizes will not be awarded until the student lunch on Monday following the competition.

2 RULES

2.1 Eligibility

a. Each team must consist of students in high school, technical school, trade school, or undergraduate students of a college or university at the time of the competition. Undergraduate students on cooperative or internship work assignment are also eligible to compete. All members of a team must be from the same school.

b. Each team can ask the help of one graduate student to participate in the mix design and the simplified life-cycle assessment (LCA), though the student shall be mentioned in the report.

c. A team is limited to eight individuals and a school may register only one team.

d. Each team must have a supervising faculty advisor who will see that the student team complies with the rules of the competition.

e. Since this competition involves a poster presentation, it is required that at least one team member be present at the convention at the time of tests and poster presentation. Participation by additional team members is both permitted and encouraged.

f. Registration dates are listed at the end of these rules. Teams will receive confirmation of registration from ACI and must be sure to submit all required paperwork and information by the deadlines noted.

g. Please review and adhere to additional **General Competition Information** found at https://www.concrete.org/students/studentcompetitions.aspx.

2.2 Materials

All materials and mix design(s) used for the competition have to be clearly described in the written report and poster (see Section 2.3). Material requirements indicated below should be closely followed, as teams failing to do so will be penalized, possibly with disqualification from the competition.

a. Portland cement Type I or II satisfying ASTM C150 or hydraulic cement GU type complying with ASTM C1157 must be used. Commercial blended cement is not allowed.

b. Supplementary cementitious materials (SCM), such as fly ash and natural pozzolans meeting ASTM C618, silica fume meeting ASTM C1240, or slag cement meeting ASTM C989, can be incorporated to the concrete mixtures but as separate products from the portland cement (see 2.2a).

c. Alternative supplementary cementitious materials (ASCMs) can be used in the concrete mixtures. If ASCMs do not meet any ASTM standard, the team shall provide a Material Technical Data Sheet (MTDS) (see Appendix) for the corresponding material.

d. Mineral fillers, complying with ASTM standard, C1797, are also allowed.

e. Chemical admixtures meeting ASTM C494 or C1017 may be used.

f. The blend of aggregates used to produce the Alternative-Case Scenario (ACS) concrete mixture may contain natural, crushed, by-product, co-product or recycled fine and coarse aggregates, as defined in Table 1. The mass percentage of the replacement by recycled aggregates shall be calculated from a comparison of the total mass of all recycled aggregates in the oven-dry condition to the total mass of the concrete (based on yielded proportions).

To qualify the type of cementitious materials or aggregate as natural, co-product, by-product, main-product, recycled or crushed material shall correspond to the brief definition shown in Table 1.

Table 1: Type of cementitious materials and aggregates

Type	Comments
Natural	Natural product – No treatment is required for its use | Free of production inputs | Transport must be included | If any type of transformation is required, please select Main-product
Co-Product	Jointly manufactured product from a multiple products-production (e.g. electricity and coal fly ash in a coal power plant)| Production inputs of commercial co-produced SCM are given in the database | Transport must be included
By-Product	Manufactured product without economic value destined for disposal (e.g. landfill) | Free of production inputs | Transport must be included | If any type of transformation is required for its use, select Co-Product to consider transformation energy
Main-Product	Main and only manufactured product from production | All production inputs must be included | Transport must be included
Recycled	Reuse of end-of-life product | Production inputs must include any type of transformation energy required for the use of the recycled materials (e.g. grinding) | Transport must be included
Crushed	Natural products needed to be crushed before its use as aggregates | Production inputs given in the database | Transport must be included

g. For alternative aggregates that do not meet any ASTM standard, the team shall provide a Material Technical Data Sheet (MTDS) for the material. A sample MTDS is included in the Appendix.

2.3 Concrete mix design

Mix design requirements indicated below shall be closely followed, as teams failing to do so will be penalized, possibly with disqualification from the competition.

a. Water-to-binder ratio
    i. The water-to-binder ratio (by mass) is fixed to **0.43**. The binder shall include all type portland or hydraulic cement spedified in section 2.2.a, SCMs,

ASCMs, natural pozzolans and mineral fillers as identified in section 2.2, that are used in the mix.

b. Binder content
    i. A **maximum of 40%** of the mass of the binder materials can be replaced by non-Portland cement material (e.g. SCMs, ASCMs, mineral fillers, etc.).

c. Aggregate proportioning
    i. The aggregate(s) shall constitute **a minimum of 50%** of the total mass of concrete mixtures meeting aggregate requirements described in ASTM C33. This percentage shall be calculated based on a comparison of the total mass of all aggregates in surface saturated dry (SSD) condition, to the total mass of the concrete (based on yielded proportions). The contribution of coarse aggregates (aggregates with a minimum size of 5 mm) mass must be more than 30% of the total aggregates mass.

2.4 Curing

The concrete specimens shall be cured according to ASTM C192 prior to submitting. The specimens must also meet all the requirements for testing (as specified in Section 2.6.b), which includes providing two specimens for each mix design in a fully saturated state for resistivity and compressive strength testing.

2.5 Simplified Life Cycle Assessment

Each team must prepare a simplified LCA using the EcoConcrete Calculation Tool V2.01, following the specifications listed below. This simplified LCA calculates environmental impacts of the mixtures. For each process, five environmental impact categories, namely global warming, carcinogenic, ozone depletion, ecotoxicity, and fossil fuel depletion, are computed. The average reduction in the value of these five categories is considered to form the Single Score Ratio. More information of this approach is provided in the "EcoConcrete calculation tool instruction" document provided on the competition website.

a. Goal and Scope

The objective of this competition is to design a concrete mix using an alternative material with low environmental impacts while preserving good mechanical properties AND good durability.

b. Functional unit

The functional unit is the production of one cubic meter of concrete mixture complying with rules mentioned in sections 2.2 and 2.3.

c. System boundaries

The system boundaries analyzed, in compliance with ready-mix concrete supply chain, including the extraction of the raw materials to production of one cubic meter of ready-mix concrete (See Figure 1). Each team shall comply their Simplified LCA with the following system boundaries for a **cradle to gate**;

i. Extraction of raw materials and transportation to plant;
ii. Transportation of processed or raw materials from plant or site to the batching plant (your school location);

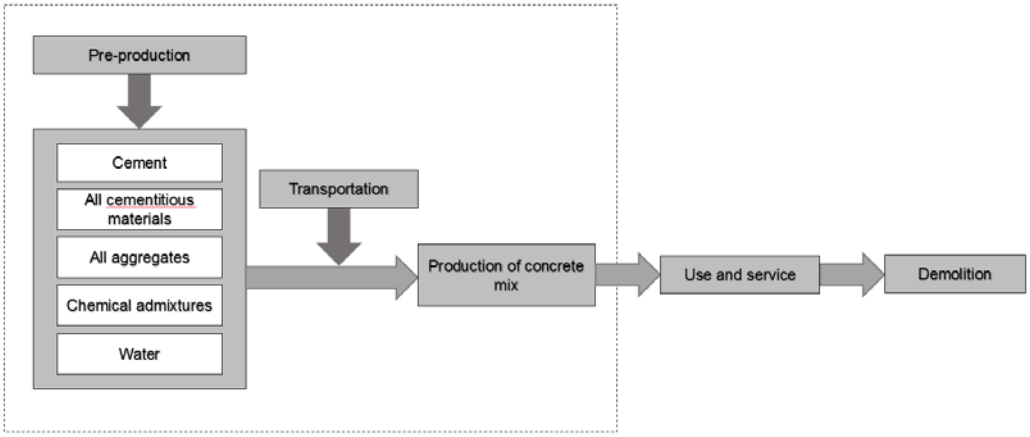

Figure 1: Schematic representation of system boundaries

The following shall not be included in the simplified LCA;

iii. Production of concrete at batching plant (your school location);
iv. Manufacturing and maintenance;
v. Demolition and end-of-life.

d. Inventory (To be completed in the EcoConcrete Calculation Tool V2.01)
   i. Each team shall consider electrical and/or thermal energy used to produce (transform) each material into concrete mixture ingredients. The appropriate energy mix of the region must be selected in the EcoConcrete Calculation Tool V2.01 to represent their local production.
   ii. Transport of each material should be considered. The batching plant shall be the location of your university lab.

Each team shall provide a travel map demonstrating the transportation path of each input material. Each transportation impact should be listed in the calculation table provided in the EcoConcrete Calculation Tool V2.01.

Each team must design two concrete mixtures using the corresponding worksheets in the EcoConcrete Calculation Tool V2.01: (1) Base-Case Scenario (BCS) and (2) an Alternative-Case Scenario (ACS). Both scenarios must respect criteria presented in sections 2.2 and 2.3.

2.5.1 Designing Base-Case Scenario and Alternative-Case Scenario

a. Designing Base-Case Scenario (BCS) concrete mixtures
   i. BCS cementitious binder must be designed with 100% Portland or hydraulic cement specified in section 2.2.a.

b. Designing Alternative-Case Scenario (ACS) concrete mixtures
   i. ACS must be designed with the same amount of total cementitious materials (binder) as the BCS mixture (in kg/m³). Use of alternative materials is allowed.
   ii. ACS must be designed with the same amount of total fine and coarse aggregates as the BCS mixture (in kg/m³). Use of alternative materials is allowed.

NOTE: All the inputs in the tool, such as materials, transportation distances, and the processing energy, must be based on reality and shall be explicitly presented in the report and poster presentation. In addition, all the identical materials in ACS and BCS (e.g. portland cement and virgin aggregates) must be supplied from the same source or plant.

After computing the environmental single score (SS) of each scenario (by the EcoConcrete Calculation Tool V2.01), a ratio is calculated, as presented in Equation 1, to highlight the relative environmental improvements from the base case to the alternative mix. A **minimum 15% improvement in the environmental impact score** is required for this competition.

$$SS_{Ratio} = \left(1 - \frac{SS_{ACS}}{SS_{BCS}}\right) x100 \geq 15\% \quad (1)$$

Where: SS_{ACS} = Single score of Alternative-Case Scenario
SS_{BCA} = Single score of Base-Case Scenario
SS_{Ratio} = Single score ratio

Such scenarios will allow comparing relative environmental improvement of each team and avoiding geographical distortion.

2.5.2 Calculating environmental impacts with the EcoConcrete Calculation Tool V2.01

The EcoConcrete Calculation Tool V2.01 provides a simple way for students to calculate and compare the environmental impacts of the concrete mixtures. The Instructions for this tool are provided in the "EcoConcrete calculation tool instruction" document provided on the competition website.

2.6 Resistivity Testing and Requirements

The durability of the concrete mixtures will be determined through conducting electrical resistivity tests on two concrete cylinders for each mix design during the competition. Electrical bulk resistivity demonstrates a good agreement with certain concrete transport properties, such as permeability and diffusivity. This test will determine the electrical bulk resistivity of the specimens and will be conducted by Giatec Scientific RCON equipment, or equivalent. An alternating electrical current of 1 kHz will be applied to the concrete

cylinders. The voltage and current will be determined to calculate the resistivity. Overall resistance will be used to generate a durability factor.

a. Specimen preparation:
   i. Two standard 100×200mm (4×8 in) cylindrical specimens for each mix design shall be prepared and cured for a minimum of 14 days according to ASTM C192.
   ii. The specimens of each mix design shall be cast from the same concrete batch.
   iii. Each specimen shall be labeled on the side by a permanent marker with the same four-letter designation stated in the report, along with a "1" and "2" to differentiate between the specimens. Marking is not permitted on the ends of the specimens.

b. Specimen submission and testing:
   i. Two specimens of each case shall be submitted in an SSD condition. Fully saturated specimens shall be wrapped in a plastic wrap to prevent drying of samples and submitted to the judges for testing between 8 a.m. and 8:30 a.m. at the competition area. If the examination shows that the specimens are not in SSD condition, the team will be disqualified.
   ii. Judges will transport the specimens to an offsite laboratory to conduct the required testing.
   iii. Judges will measure the diameter and height of the specimens.
   iv. Judges will place the specimens into water baths for a period of approximately 4 hours. All specimens will be submitted to the same preparation treatment prior to testing; as such, the order of testing will most likely be in the order of specimen submission.
   v. The specimens will be removed from the water and tamped surface dry by the judges. Judges will place the specimens into a Giatec RCON device for measurement of electrical bulk resistivity.
   vi. The voltage drop and current will be recorded by the judges.

c. Calculation of resistivity:
   i. Electrical bulk resistivity will be determined by the recorded current, voltage drop, and geometry of the cylinders.
   ii. The following formula will be used to compute the bulk resistivity ρ (kΩ.cm):

$$\rho = \frac{R.A}{L}$$

Where; R = Resistance of the concrete (kΩ);
A = Cross-sectional area of the cylinder (cm);
L = height of the cylinder specimen (cm).

d. Scoring
Teams will be ranked on the relative improvement in bulk resistivity of their specimen when comparing ACS to BCS. The team with the higher relative improvement in bulk resistivity will obtain the highest rank and a score of 100. Negative improvement will result in a score of zero in this category. The remaining teams will be awarded scores of an evenly graduated decrease according to the total number of teams competing.

2.7 Compressive Strength Testing and Requirements

Concrete compressive strength tests will be performed on the two concrete cylinders of each case, which were carried by teams to the competition place with the same dimensions noted above (100mm × 200mm (4" × 8")). Note that while a curing of at least 14 days is specified in Rules item 2.6 a., SCMs typically require 28 to 56 days to develop their compressive strength.

a. Calculation of compressive strength:
   i. Compressive strength shall be determined by the ultimate load and geometry of the cylinders
   ii. The following formula shall be used to compute the compressive strength in MPa

   $$\sigma_c = \frac{P}{A}$$

   where: P = Resistance of concrete (N)
   A = Cross-sectional area of the cylinder (mm^2)

b. Scoring
   Teams will be ranked on the relative improvement in compressive strength of their specimens, showing that how much increase in compressive strength was observed when using the ACS compared to BCS. Negative improvement will result in a score of zero in this category. The team with the largest improvement in compressive strength will obtain the first rank and a score of 100. Other teams will be awarded scores of an evenly graduated decrease according to the total number of teams (20 max).

2.8 Written Report

Teams shall submit a written report meeting the requirements listed below for the judges to review and score. An electronic version of the report shall be submitted as described below in standard PDF format. The electronic report due date is indicated in Section 5 below. A hard-copy version of the report shall be submitted to the judges at the competition. Teams failing to submit both the electronic and hard-copy versions of the report shall receive a zero in the written report section of the Final Score equation given in Section 3.

The judges will score each report using the indicated scoring percentages (based on a total of 100%). Each report shall contain the following (see the scoring sheet for more details):

a. Include a cover page containing the following: **– 5%**
   i. School name and department
   ii. Team members and faculty advisor name
   iii. 4-Character Team ID
b. Abstract **– 5%**
   In 300 words or less, the teams must provide the following information:
   i. Description of the goal.
   ii. Overview of constraints of the competition.
   iii. Overview about materials and mixture proportions of final mortar.
   iv. A brief description of the environmental, compressive, and durability results.

c. Introduction **– 5% (maximum one page)**
   i. Environmental aspect of concrete and its implications in sustainable development.
   ii. The importance of material and mix design in the environmental impacts of concrete, such as alternative sources of materials, mechanical properties, and durability of concrete.

d. Materials selection **– 25%**
   i. Provide a single figure representing all the materials used in the ACS concrete mixture grouped together prior to mixing.
   ii. Provide the concrete mix design chosen for the BCS and the ACS using saturated surface dried (SSD) densities (kg/m³). The mixtures presented in the written report shall correspond with those proposed in the EcoConcrete Calculation Tool V2.01 submitted by each team and the cylinders submitted for testing.
   iii. Identify each material category: cementitious materials, aggregates, chemical admixtures (if applicable) used in the mixture and their origin (main-product, co-products, by-product, recycled materials, etc.). A discussion about why they are selected as sustainable materials would be supportive.
   iv. Provide general and physicochemical information about each material used in the BCS and ACS concrete mixture if possible, including, but not limited to, the location, where each material is manufactured, particle size distribution curve(s), chemical components, fineness, etc. An example of a Material Technical Data Sheet (MTDS) is given in Appendix.
   v. Discuss environmental damage categories (human health, ecosystems quality, climate change, and resources) for each single material and the whole mixture (BSC and ACS)

e. Concrete mix design optimization **– 15%**
   i. Discuss the selected concrete mix design and how parameters are optimized in order to achieve the objectives defined in the introduction.
   ii. Provide data about performance results of the optimization process.

f. Provide a maximum of three pages on a discussion of the simplified LCA. **– 30%**
   The discussion shall include:
   i. Clear definitions of the system boundaries in the simplified LCA and how such boundaries affect results of an LCA (simplified or not).
   ii. Presenting the environmental impact results of BCS and ACS obtained from the Official Eco-Concrete Spreadsheet. A discussion on the importance of this aspect regardless of mechanical (compressive strength testing) and the durability (resistivity testing) performance in the mixture design process would be helpful.
   iii. Summary of major factors affecting the outcomes of the simplified LCA of the mixtures. For example, how components such as Portland cement, ASCM, SCM, water content, aggregate, and chemical admixtures affect positively and/or negatively the environmental burdens in distinct damage categories?

g. Conclusions **– 5% (maximum one page)**
   The key findings and lessons or insights of the mixtures must be explained.

h. References**– 5%**
   All external references cited using standard reference format (e.g., MLA, APA, etc.).

i. Formatting**– 5%**

The text must be written in the format of single spacing. 12 pt. font size. Times New Roman. (Applies to captions and fonts in figures and tables, as well.) The margins must be set to 1 inch all around. All the figures must be labeled with a number and title. In addition, all the pages must be numbered except the cover sheet

Considering all the described section in the report, the whole document shall not be longer than **20 pages**. Submit a PDF file of the report prior to the deadline. The hard copy submitted on the day of the competition shall be on standard letter size paper and bound together**.** All reports shall be scored between zero and 100%, with 100% being the best.

2.9 Poster Presentation

Teams must make a poster presentation at the competition prepared in the English language. The poster presentation must meet the requirements listed below for the judges to review and score.

a. Poster specification: **– 25%**
   i. The poster can be printed on any rolled medium but it must be light enough to be affixed to a wall or bulletin board using masking tape or pushpins.
   ii. The size of each poster shall be in A_0 size (85 cm × 120 cm) and the poster orientation shall be portrait.
   iii. An area of 15 cm wide × 10 cm high in the lower right-hand corner of the poster shall identify the team name, the team's school association, the same label shown on the team's specimens, the advisor's name, a contact phone number or e-mail for the advisor, and the names of the student team members.
   iv. All the poster content must be accessible without having to lift or turn a page. There may be no mechanical or electrical devices attached to the poster.
   v. Using a font size such that the minimum printed height of the font's capital letters is 6 mm.

b. Poster submission: **– 10%**
   i. Each poster must be submitted to the judges at registration and prior to the start of the competition.
   ii. Each poster presentation team shall submit one and only one poster.
   iii. Each poster shall be unique to a team.
   iv. Each poster will be presented during the Performance Category of the competition.
   v. At least two judges will evaluate each poster individually and provide a documented score for every poster.

c. Poster content: **– 45%**
   i. Each poster shall document the decision-making process and materials chosen for the mixture design used, and the simplified Life Cycle Assessment (LCA).
   ii. Each poster shall explain briefly the decision-making process. ***– 10%***
   iii. Each poster needs to fully identify the mixture used for Base-Case Scenario (BCS) and Alternative-Case Scenario (ACS) in the simplified LCA. ***– 15%***
   iv. Each poster shall present the major factors affecting the outcome of the Simplified LCA. **– 10%**
   v. Each poster shall present the importance of the simplified LCA in the decision-making process regardless of the durability (resistivity testing) and the mechanical capacity (compressive strength testing). ***-10%***

vi. Each poster presentation is designed to convey information but consideration should be given to doing this in a creative way.

d. Questions and answers: **– 20%**
   i. Each team should have a clear answer to questions of jury members at the competition.

e. Scoring
   Judges will score each poster appearance and presentation using the indicated scoring percentages (based on a total of 100%). All poster presentations shall be scored between zero and 100%, with 100% being the best.

3 FINAL SCORING

The final score will be calculated based on the following formula, inputting judges' scores for the written report and presentation, and the team ranking for strength and resistivity:

$$Final\ score = 0.25\ WR + 0.20\ PP + 0.15\ \ R_{\sigma_c} + 0.15\ R_{\rho} + 0.25\ R_{SS}$$

Where: WR is the overall score for the written report;
PP is the overall score for the poster presentation;
Rσ_c is the score according to the team ranking for compressive strength test;
Rρ is the score according to the team ranking for resistivity test;
R_{SS} is the score according to the team ranking for Single Score Ratio (SS_{Ratio}) from the simplified LCA.

Teams will be ranked based on the highest final score, and the highest (closest to 100) will be the winner. In the case of a tie, the winner shall be the team with the best resistivity testing score. A detailed table of scoring is presented in the appendix.

A team can be disqualified if the mix design does not respect the design rules as listed below;

- The Portland cement types specified in section 2.2.a;
- A maximum of 40 % of the binder may be non-portland cement material;
- Aggregates mass shall constitute at least 50% of the total mass of concrete mixture;
- The water-to-binder mass ratio is w/b = 0.43.

4 JUDGING

a. The judges will be appointed by ACI Committee 130 and the chair of S-801 as necessary. Judges may be different for each testing category.

b. The judges will make the final determination on compliance with the rules and penalties for rules violations. Disqualified entries shall not be included in the scoring or considered for awards. All penalties will be explained fully to the teams.

c. The decision of the judges will be final, and appeals will not be considered. Suggestions for improvement may be submitted to the ACI Subcommittee 130G.

5 REGISTRATION AND MATERIAL SUBMISSION

a. Advance registration is required. Teams shall register through the competition webpage on the ACI website by 11:59 p.m. Eastern Standard Time on 24 February 2019. It indicates the team's intent to enter the competition. Registration will be confirmed via email. This registration is the first of two required steps to participate in the competition.

b. The electronic report, as described above, shall be submitted no later than 11:59 p.m. Eastern Standard Time on 5 March 2019 through the official registration process link on the ACI website. The Excel format of the EcoConcrete Calculation Tool V2.01 completed shall also be attached. Receipt of the report will be confirmed. Failure to receive confirmation indicates incomplete submission.

c. The hard copy of the report for each entry shall be submitted to judges at the competition place in person at the established check-in time on the day of the competition. Check-in times will be sent to teams ahead of the competition and will also be posted in the exhibit area. Check-in times will likely be between 8:30 a.m. and 3pm on the day of the competition. Teams checking in past their established time will not be accepted for entry into the competition and will only be tested after the competition is complete, should time permit.

d. The competition will begin at 9:00 a.m. on the day of the competition, 24 March 2019.

6 COMPLIANCE WITH ACI ECOCONCRETE COMPETITION RULES

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 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 Subcommittee S-801 will further document recommendations to disallow the team, their advisor, and/or school/university from participation in future competitions.

Please review and adhere to additional General Competition Information found at https://www.concrete.org/students/studentcompetitions.aspx.

7. Contact Information

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E-mail: students@concrete.org

7 APPENDIX

See separate Appendix document