ICC EVALUATION SERVICE

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February 10, 2009

**TO:** PARTIES INTERESTED IN EVALUATION REPORTS ON STRUCTURAL COMPOSITE HYBRID SYSTEMS (SCHSs) CONSISTING OF STRUCTURAL STEEL, PRECAST CONCRETE AND CAST-IN-PLACE CONCRETE

**SUBJECT:** Acceptance Criteria for Structural Composite Hybrid Systems (SCHSs) Consisting of Structural Steel, Precast Concrete and Cast-in-place Concrete, Subject AC407-0209-R1 (DZ/BG)

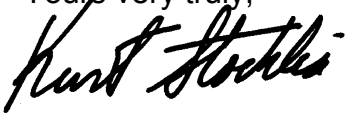
Dear Madam or Sir:

Enclosed is a copy of the subject new acceptance criteria approved by the ICC-ES Evaluation Committee on February 5, 2009, effective March 1, 2009. This new proprietary product criteria covers various types of structural composite hybrid systems (SCHSs), which are specific forms of composite steel and concrete structural systems. SCHSs consist of various types of composite steel and concrete flexural members (SCHS beams) and conventional structural steel columns. The SCHS beams are different from the code-recognized composite steel and concrete flexural members.

The acceptance criteria applies only to products that have the same characteristics as the product described in AC407. We recognize there may be other companies that have similar products but whose characteristics may not be the same as those described in AC407. Subsequent applicants may either comply with the subject criteria, request a revision to the criteria to include their product, or be considered under a new acceptance criteria, as determined by the Evaluation Committee.

If you have any questions, please contact David Zhao, Senior Staff Engineer, at (800) 423-6587, extension 3722. You may also reach us by e-mail at es@icc-es.org.

Yours very truly,



Kurt Stochlia, P.E.
Vice President

KS/DZ/gh/raf

Enclosure

cc: Evaluation Committee

ICC EVALUATION SERVICE

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# ACCEPTANCE CRITERIA FOR STRUCTURAL COMPOSITE HYBRID SYSTEMS (SCHSs) CONSISTING OF STRUCTURAL STEEL, PRECAST CONCRETE AND CAST-IN-PLACE CONCRETE

**AC407**

**Approved February 2009**

**Effective March 1, 2009**

## PREFACE

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the International Building Code® reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

This acceptance criteria has been issued to provide all interested parties with guidelines for demonstrating compliance with performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the ICC-ES Evaluation Committee, and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from the previous edition, a solid vertical line (|) in the margin within the criteria indicates a technical change, addition, or deletion from the previous edition. A deletion indicator (→) is provided in the margin where a paragraph has been deleted if the deletion involved a technical change. This criteria may be further revised as the need dictates.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria set forth in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise demonstrate compliance with the performance features of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

***Acceptance criteria are developed for use solely by ICC-ES for purpose of issuing ICC-ES evaluation reports.***

# ACCEPTANCE CRITERIA FOR STRUCTURAL COMPOSITE HYBRID SYSTEMS (SCHSs) CONSISTING OF STRUCTURAL STEEL, PRECAST CONCRETE AND CAST-IN-PLACE CONCRETE (AC407)

## 1.0 INTRODUCTION

**1.1 Purpose:** The purpose of this acceptance criteria is to establish requirements for structural composite hybrid systems (SCHSs) to be recognized in an ICC Evaluation Service, Inc. (ICC-ES), evaluation report under the 2006 *International Building Code*® (IBC). The basis of recognition is IBC Section 104.11.

The reason for the development of this criteria is to provide guidelines for the evaluation of alternative composite steel and concrete structural systems, where the codes do not provide requirements for testing and determination of structural capacities, reliability and serviceability of these structural composite hybrid systems.

**1.2 Scope:** This acceptance criteria applies to structural composite hybrid systems (SCHSs), which are specific forms of composite steel and concrete structural systems. SCHSs consist of various types of composite steel and concrete flexural members (SCHS beams) and conventional structural steel columns. The SCHS beams are different from the code-recognized composite steel and concrete flexural members.

**1.3 Description:** The SCHS beams consist of rolled wide flange steel shapes, with the bottom flange and/or portion of the web of the steel section partially encased, by precast concrete, which is mechanically anchored, by headed stud shear connectors, to the bottom flange of the steel shape only. The top of the precast concrete is below the top of the steel section. Portions of the steel reinforcements of the precast concrete are exposed and extended beyond the top of the precast concrete, and mechanically connect the precast concrete with the cast-in-place concrete slab, which is placed, at the construction site, on top of the precast concrete. The components of the SCHS beams (steel shape, precast concrete, and cast-in-place concrete) are interconnected by mechanical connectors and steel reinforcement, to act as composite structural members. This criteria sets forth requirements for test and performance, so the SCHS beams can be designed in accordance with the current code provisions, with supplements, as applicable. The connections between SCHS beams and conventional steel columns are limited to simple connections, as specified in Section B3.6a of AISC 360, and shall be designed according to the current code provisions. The SCHS system is limited to supporting gravity loads only.

**1.4 Codes and Referenced Standards:**

**1.4.1** 2006 *International Building Code*® (IBC), International Code Council.

**1.4.2** AISC 360-05, *Specification for Structural Steel Buildings*, American Institute of Steel Construction.

**1.4.3** ACI 318-05, *Building Code Requirements for Structural Concrete,* American Concrete Institute.

**1.4.4** ASCE/SEI 7-05, *Minimum Design Loads for Buildings and Other Structures, Including Supplement No. 1*, American Society of Civil Engineers.

**1.4.5** AWS D1.1-04, *Structural Welding Code-Steel*, American Welding Society.

**1.4.6** AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges*, March 18, 2005, American Institute of Steel Construction.

**1.5 Definitions:** Definitions in the IBC, AISC 360, AISC 303 and ACI 318 apply to this criteria. In addition, the following definitions, with revisions and amendments to the code provisions, apply to this criteria:

**1.5.1 Limit State:** Condition in which a structure or component becomes unfit for service and is judged either to be no longer useful for its intended function (serviceability limit state) or to have reached its ultimate (peak) load-carrying capacity (strength limit state); or an event which marks the demarcation between two behavior states, at which time some structural behavior of the element or member is altered significantly.

**1.5.2 Mechanical Connector (or Shear Connector):** Headed stud welded to a steel member and embedded in concrete of composite steel and concrete member to transmit shear forces at the interface between the concrete and steel.

**1.5.3 Full Interaction:** The composite action, due to the mechanical connectors, between steel and concrete, such that there is no measureable relative movement (slip) at the steel/concrete interface. It relates to compatibility of deformation at steel/concrete interface, and represents a stiffness criterion.

**1.5.4 Full Shear Connection:** The composite action, due to the mechanical connectors, between steel and concrete, such that the shear connection strength exceeds the tensile yield strength of the steel section or the compression strength of the steel section and/or concrete, so the flexural strength of the composite section can be fully developed. It relates to equilibrium of forces within a composite member, and represents a strength criterion.

**1.5.5 Structural Composite Hybrid System (SCHS):** A structural framing system composed of SCHS beams, as defined in Section 1.5.6 of this criteria, and conventional steel columns, together with a proper simple connection between the SCHS beams and steel columns, for supporting gravity loads only.

**1.5.6 SCHS Beams:** For purposes of this criteria, the SCHS beams, as described in Section 1.3 of this criteria, are subdivided into the following types:

**1.5.6.1 Rectangular-shaped SCHS Beam:** An SCHS beam with the bottom flange and lower portion of the web of the steel section encased by a rectangular-shaped precast concrete member. Refer to Figure 1 of this criteria for an illustration.

**1.5.6.2 U-shaped SCHS Beam:** An SCHS beam with only the bottom flange of the steel section mechanically attached to a U-shaped precast concrete member. The void space between the U-shaped precast concrete and the web of the steel section is filled with cast-in-place concrete at the construction site during the concrete slab placement. Refer to Figure 2 of this criteria for an illustration.

**1.5.6.3 Flat-shaped SCHS Beam:** An SCHS beam with only the bottom flange of the steel section mechanically connected to a flat rectangular-shaped precast concrete member, which is located below the bottom flange of the steel section. Refer to Figure 3 of this criteria for an illustration.

**1.5.7 SCHS Fabricator:** An entity that fabricates SCHS beams, as defined in Section 1.5.6 of this criteria, at an off-site facility, but is not involved in the design nor installation of an SCHS system.

**1.5.8 SCHS Erector:** An entity that installs a complete SCHS system, including SCHS beams, steel columns, connections between beams and columns, and any other constructions necessary, so as to form a complete structural framing system.

## 2.0 BASIC INFORMATION

**2.1 General:** The following information shall be submitted:

**2.1.1 Product Description:** A detailed description of the SCHS system, including information concerning material specifications, dimensions, the manufacturing process, and restrictions or limitations on use. Information shall be provided on, but shall not be limited to, the following items:

1. Precast and cast-in-place concrete: type of SCHS beams, as defined in Section 1.5.6 above; concrete constituents; concrete mix design; concrete compressive strength; detailed dimensions of concrete cross section; and sectional properties.

2. Wide flange steel shapes: referenced specifications, grades, shapes, member dimensions and sectional properties.

3. Steel reinforcements: referenced specifications, grades, sizes, locations and clear concrete covers.

4. Shear connectors: types, grades, sizes and welding requirements. The connectors shall comply with Sections A3.6 and I1.3 of AISC 360.

5. Miscellaneous items: Embedded plates and shapes, bolts, etc, shall be defined with corresponding reference standards (such as ASTM) and applicable installation requirements.

**2.1.2 Packaging and Identification:** A description of the method of packaging and field identification of the SCHS system. Identification provisions shall include the name of the report holder, the ICC-ES evaluation report number and the name or logo of the inspection agency.

**2.1.3 Field Preparation:** A description shall be provided, as part of the installation instructions, of the methods of field modifications such as cutting or bending, if applicable, surface preparation, application and finishing. Field preparation shall be subject to approval of the registered design professional and the code official.

**2.1.4 Installation Instructions:** Instructions shall include the following items:

**2.1.4.1** A description of how the product or system will be used or installed at the project site, including field preparation methods noted in Section 2.1.3 of this criteria.

**2.1.4.2** Procedures for quality control at project sites during installation.

**2.1.4.3** Requirements for product handling as identified in Section 7.6 of this criteria.

**2.1.4.4** Welding, bolting or connector installation to structural elements, if required.

**2.2 Testing Laboratories:** Testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

**2.3 Test Reports:** Test reports shall comply with AC85. Detailed descriptions of the test setups, test methods and test procedures, including load application rate, shall be provided in the test report.

**2.4 Product Sampling:** Sampling of the SCHS beams for tests under this criteria shall comply with Section 3.1 of AC85. The fabrication of the test assemblies shall be witnessed by or verified by the testing laboratory.

## 3.0 STRUCTURAL DESIGN

**3.1 Structural Design Method:** The structural design method for determining the nominal strength of SCHS composite sections shall be based on the Strain-Compatibility Method, as specified in Section I1.1b of AISC 360, which is a method for determining the stresses in a composite member considering the stress-strain relationship of each material and its location with respect to the neutral axis of the cross section. This method is based on the design assumptions identified in Section 10.2 of ACI 318; with the amendment that Section 10.2.4 of ACI 318 also applies to structural steel section.

**3.2 Structural Design Requirements:** The structural applications of the SCHS system shall address the following items:

**3.2.1** A complete description of the SCHS system as identified in Section 1.5.5 in this criteria.

**3.2.2** Details on how the SCHS complies with Chapters 19 (with reference to ACI 318) and 22 (with reference to AISC 360) of the IBC, including conformities and deviations. Details shall clarify the following: the sections of Chapters 19 and 22 of the IBC with which the SCHS complies; the sections of Chapters 19 and 22 of the IBC with which the SCHS does not comply; and the sections of Chapters 19 and 22 of the IBC with which the SCHS complies but with revisions and/or amendments, along with revisions and/or amendments identified in the structural design process, as described in Section 3.2.4 of this criteria.

**3.2.3** The concrete/steel interface shall comply with the requirements for either full interaction or full shear connection, as defined in Section 1.5 of this criteria.

**3.2.4** A complete description of the structural design process, which shall provide detailed steps and examples, including engineering plans and calculations, showing how the SCHS is analyzed and designed. The description shall include formulas, with procedures and properties necessary for design and analysis.

**3.2.5** The structural design shall specify design provisions for each applicable limit state, including, but not limited to, the following:

**3.2.5.1** Local buckling of a steel compression element within a cross section.

**3.2.5.2** Strength and slip capacity of shear connectors, with consideration of the state of stresses (tensile or compressive) in concrete adjacent to shear connectors.

**3.2.5.3** Strength and slip capacity of shear-friction reinforcements (stirrups) in SCHS beams.

**3.2.5.4** Failure of concrete element due to concentrated dowel loads imposed by the shear connectors.

**3.2.6** The structural design procedures shall be substantiated by the qualification tests and design criteria report described in Sections 4.0 and 5.0.

**3.2.7** When structural calculations are performed using computer software, a description of the printout is needed indicating the input and the output as well as an explanation of the headings, symbols, formulas, etc. A general program operation description is also needed in the form of a flow arrangement of all of the steps taken and the design formulas used, in order to verify compliance with the design specifications. Hand calculations are needed for each type of SCHS system, as a minimum, demonstrating that the computer-based results are verifiable.

**3.2.8** Structural design drawings and specifications, shop drawings and erection drawings shall comply with Section A4 of AISC 360, AISC 303, Section 1.2 of ACI 318, and Section 1603 of the IBC.

## 4.0 QUALIFICATION TESTS

**4.1 Qualification Test Plan:** The intent of testing is to verify the design equations and assumptions used in the engineering analysis. All tests described in this section shall be specified in the test plan. The test plan shall be a complete document, which includes, but is not limited to, the conformation details noted in this section. The test plan shall be submitted to ICC-ES staff for approval prior to testing.

Overall, qualification testing must provide data on material properties, force and deformation limit states, including failure modes, to support a rational analysis procedure. The specimens shall be constructed under conditions specified by the SCHS fabricator, including curing. Sampling of the specimens shall be in accordance with Section 2.4 of this criteria. Tests must simulate the anticipated loading conditions, loading rates, load levels, deflections, and support conditions.

### 4.2 Shear Connectors

**4.2.1 Configuration:** The specimen shall be configured to induce shear connector–related limit states. It shall represent applications in both SCHS beams, including strain and stress levels, both in the shear connectors and their surrounding concrete, where concrete adjacent to shear connectors is under either tension or compression. Extremes of dimensional characteristics, reinforcing (including shear-friction reinforcing), structural steel shapes, shear connectors, and material strength parameters shall be considered.

**4.2.2 Procedure:** For gravity loading application, the load may be monotonically applied. The limit states shall be determined based on material properties, including strains and stresses in both shear connectors and surrounding concrete, and post cracking dowel strength.

### 4.3 SCHS Beams

#### 4.3.1 Flexural Tests

**4.3.1.1 Configuration:** Beam spans shall be configured to induce all applicable limit states such as limit states corresponding to bending moment and shear force. Beams shall be simply supported. Extremes of dimensional characteristics, reinforcing (including shear-friction reinforcing), structural steel shapes, shear connectors, and material strength parameters shall be considered.

**4.3.1.2 Procedure:** For gravity loading application, the load may be monotonically applied. The limit states shall be determined based on material properties, including strains and stresses, and the transition from uncracked to cracked concrete.

#### 4.3.2 Shear-friction Reinforcements

**4.3.2.1 Configuration:** The specimen shall be configured to induce shear-friction reinforcement-related limit states. It shall represent strain and stress levels of both the shear connectors and their surrounding concrete, where the concrete adjacent to shear connectors is under either tension or compression. Extremes of dimensional characteristics, reinforcing (including shear-friction reinforcing), structural steel shapes, shear connectors, and material strength parameters shall be considered.

**4.3.2.2 Procedure:** For gravity loading application, the load may be monotonically applied. The limit states shall be determined based on material properties, including strains and stresses, the physical condition of the interface between precast concrete and the cast-in-place concrete, and anchorage of shear-friction reinforcement at both sides of the shear plane.

## 5.0 FINAL SUBMITTAL

**5.1** The final submittal for an ICC-ES evaluation report will consist of a test report or test reports, and a design criteria report, as described in this section. The final submittal shall include the data described in Sections 2.0 and 3.0 of this criteria. Contents of the final submittal are described in the following subsections:

**5.2 Test Report:** The testing laboratory shall report on the qualification testing performed according to the approved test plan. In addition to the information required in Section 2.3 of this criteria, each test report shall include the following:

**5.2.1** Information noted in the reference standards.

**5.2.2** Description of test specimen.

**5.2.3** Description of test setup.

**5.2.4** Rate and method of loading.

**5.2.5** Deformation and strain measurements.

**5.2.6** All applicable limit states, including modes of failure.

**5.2.7** Properties of concrete and steel materials used in tests.

**5.3 Design Criteria:**

**5.3.1 Design Criteria Report:** The report shall include a complete analysis and interpretation of the qualification test results presented in the independent laboratory test report or test reports. Design strength and flexural stiffness for SCHS systems shall be based on the analyses, but shall not be higher than specified in Section 5.3.2 or 5.3.3 of this criteria. Design strength and stiffness shall be based on a characteristic value approach verified by test data.

**5.3.2 Acceptable Design Criteria:** The nominal strength, as specified in Sections B3.3 and B3.4 of AISC 360, and flexural stiffness for deflection calculation as required by Section L3 of AISC 360, Sections 17.2.7 and 9.5 of ACI 318, and Section 1604 of the IBC, shall comply with the following requirements:

$$P_m > 1.0 \text{ and } V_p < 0.06$$

where:

$R_t$ = tested capacity for each specimen.

$R_a$ = predicted capacity by theoretical formulas as indicated in Section 3.0.

$$P = R_t / R_a$$

$P_m$ = Average (mean value) of the *P* values.

$V_p$ = coefficient of variation of the *P* values.

Determination of SCHS beam deflection shall include effects of slip due to shear connector/shear-friction reinforcement (if applicable), concrete creep, and shrinkage, as identified in Section L3 of AISC 360.

**5.3.3 Alternate Acceptable Design Criteria:** As an alternative to requirements in Section 5.3.2, design provisions, including formulas, shall be revised to justify that the reliability index (or safety index) of SCHS system, as determined from Section 3.0 and with adjustments in accordance with the tested values, shall be equal to or greater than the code requirements.

**5.4 Quality Control:** Qualify control documents as described in Sections 6.1, 6.2 and 6.3 shall be submitted.

## 6.0 QUALITY CONTROL

**6.1** The products shall be manufactured under an approved quality control program with inspections by an inspection agency accredited by the International Accreditation Service (IAS) or otherwise acceptable to ICC-ES. The inspection agency inspections shall comply with Sections 1.3 and 1.4 of the ICC-ES Acceptance Criteria for Quality Documentation (AC10).

**6.2** Quality documentation complying with AC10 shall be submitted.

**6.3** Fabrication and assembly work requiring special inspection is permitted to be done on the premises of approved fabricators. The quality assurance program for fabrication practices shall be documented and comply with the IAS Accreditation Criteria for Fabricator Inspection Programs for Reinforced Concrete (AC157) and the IAS Accreditation Criteria for Fabricator Inspection Programs for Structural Steel (AC172). In addition, the quality assurance program shall address specific requirements for the SCHS system, including, but not limited to, stud welding.

**6.4** Jobsite quality assurance shall conform to IBC Section 1704, applicable portions of the ACI 318 and AISC 303.

**6.5** All installations shall be done by SCHS erectors approved by the proponent of the SCHS system. Special inspection shall be provided in accordance with Sections 1704.3 and 1704.4 of the IBC. Duties of the special inspector shall be included in the evaluation report.

## 7.0 EVALUATION REPORT RECOGNITION

The following information shall be included in the evaluation report:

**7.1** Information described in Section 2.1 of this criteria.

**7.2** Structural design procedures described in Section 3.0 of this criteria.

**7.3** Limitations of the SCHS system and the scope of the evaluation report as described in Sections 1.3, 1.5, 2.1, and 3.0 of this criteria.

**7.4** Details of the fabrication program as described in Section 6.3.

**7.5** Provisions for quality assurance and special inspection as described in Sections 6.4 and 6.5 of this criteria.

**7.6** It shall be a condition of use in the evaluation report that product handling shall comply with applicable code, including Section 16.9 of ACI 318, and shall be subject to the approval of the registered design professional and the code official.

**7.7** Performance of fire protection of the SCHS system is beyond the scope of the evaluation report.

**7.8** The SCHS system is limited to support gravity load only. ■

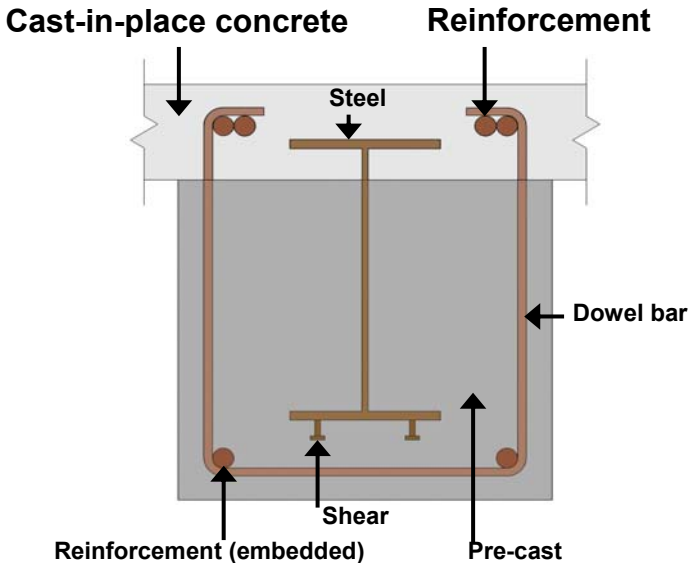


**FIGURE 1—RECTANGULAR-SHAPED SCHS BEAM**

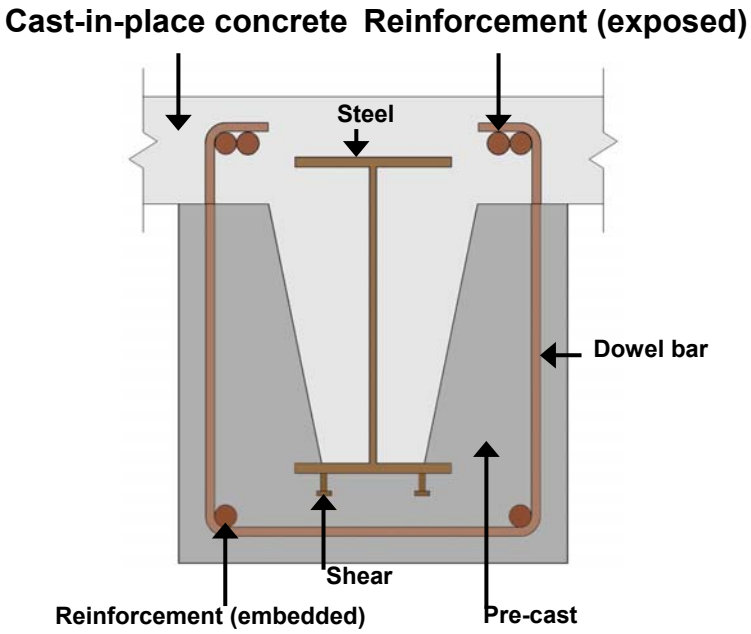


**FIGURE 2—U-SHAPED SCHS BEAM**

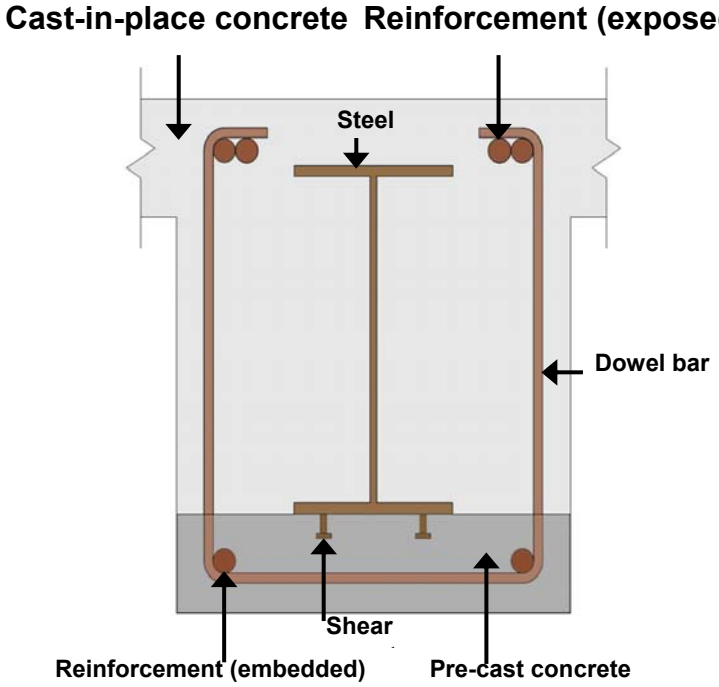


**FIGURE 3—FLAT-SHAPED SCHS BEAM**