# MILLER CONSTRUCTION, INC.

P.O. BOX 86 ASCUTNEY BLVD WINDSOR, VERMONT 05089-0086
**TELEPHONE (802) 674-5525 / FAX (802) 674-5245**

## TRANSMITTAL

| TO: Jennifer Fitch, PE<br>Project Manager<br>Vermont Agency of Transportation | DATE | PROJECT NO. |
|---|---|---|
| | 6/13/2014 | Brookfield<br>BRF FLBR (2) |
| | | |

XX WE ENCLOSE THE FOLLOWING: _____ UNDER SEPARATE COVER WE ARE SENDING THE FOLLOWING

| COPIES | NUMBER | DESCRIPTION | CODE |
|---|---|---|---|
| 1 | | FRP Test Sample Results - Rev 1 | H |
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CODE:

A FOR INITIAL APPROVAL
B FOR FINAL APPROVAL
C APPROVED AS NOTED-RESUBMISSION REQUIRED
D APPROVED AS NOTED-RESUBMISSION NOT REQUIRED
E DISAPPROVED-RESUBMIT
F QUOTATION REQUESTED
G APPROVED
H FOR APPROVAL
I AS REQUESTED OR REQUIRED
J FOR USE IN ERECTION
K LETTER FOLLOWS
L FOR FIELD CHECK
M FOR YOUR USE

BY: Paul

**Rev 1 Changes**

| Item | Description | Resolution |
|---|---|---|
| 1 | Testing facility is to be submitted for approval | UMaine ASCS ISO 17025 Certificate is attached along with their quality manual |
| 2 | Design calculations should be resubmitted to address changes in predicted properties | Design calculations Rev 4 is attached to include all computations with actual strength, stiffness, and thickness values |
| 3 | The 0.22” thick test laminate is not considered an equivalent partial thickness | See page 40 for a justification of the selected laminate and resolution |
| 4 | The true thickness of the laminate should be carried through the design calculations | Design calculations Rev 4 is attached – some variability, however minimal, is inherent in the fabrication process – minimum thickness used is 0.492”/0.950” |
| 5 | Testing is to occur at an ISO 17025 facility | UMaine has repeated the three physical test procedures and the report is attached |
| 6 | Minimum of 10 specimens shall be tested | UMaine has repeated the tests with a minimum of 10 specimens |
| 7 | Is grit blasting reproducible in a production environment? | Kenway will use the same media following the same procedure – see page 40 for resolution |

International Accreditation Service

# CERTIFICATE OF ACCREDITATION

*This is to signify that*

**ADVANCED STRUCTURES AND COMPOSITES CENTER, UNIVERSITY OF MAINE**

35 FLAGSTAFF ROAD
ORONO, MAINE 04469

Testing Laboratory TL-255

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ANS/ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing August 14, 2012, for the test methods listed in the approved scope of accreditation.

Patrick V. McCullen
Vice President

C. P. Ramani, P.E.
President

ACCREDITED

*(see attached scope of accreditation for fields of testing and accredited test methods)*

Print Date: 09/19/2012



This accreditation certificate supersedes any IAS accreditation certificate bearing an earlier date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation.
See the IAS Accreditation Listings on the web at www.iasonline.org for current accreditation information, or contact IAS directly at (562) 364-8201.

International Accreditation Service

# SCOPE OF ACCREDITATION

Advanced Structures and Composites Center, University of Maine TL-255

Advanced Structures and Composites Center, University of Maine
35 Flagstaff Road
Orono, ME 04469

Olivia Sanchez
ISO Coordinator
(207) 581-2052

| FIELDS OF TESTING | ACCREDITED TEST METHODS |
|---|---|
| Plastic Materials | ASTM Standards D 256, D 635, D 638, D 695, D 696, D 790, D 792, D 953, D 2765 (Test methods A and C), D 3846, D 4065, D 4812, D 6109 and D 6110 |
| Wood Products and Materials | ASTM Standards D 143 (excluding Sections 10 and 11), D 198 (excluding Sections 21-28 and 37-44), D 245, D 1037, D 2395, D 2555, D 3737, D 4442, D 4761, D 4933, D 5456 and D 6815 |
| Composite Materials | ASTM Standards C 393, D 2344, D 2584, D 3039, D 3410, D 3479, D 3518, D 4255, D 5379, D 5528, D 5766, D 6115, D 6641 and F 1679 |
| Adhesives | ASTM Standards D 905, D 1101, D 2339, D 2559, D 3165 and D 5868 |
| Structural Panels and Assemblies | ASTM Standards C 273, D 7032 (excluding Sections 4.8 and 4.9), E 72 (Transverse load only), E 564 and E 2126; Test methods referenced in Section 4.0 of ICC-ES Acceptance Criteria AC273 (excluding Section 4.2.8)<br>BS EN 408 |
| Fasteners | ASTM Standard D 1761 |
| Full-scale Structural Testing of WT Rotor Blades | IEC TS 61400-23 |

August 14, 2012
Commencement Date

ACCREDITED

C. P. Ramani, P.E.
President

Print Date: 09/19/2012



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See the IAS Accreditation Listings on the web at www.iasonline.org for current accreditation information, or contact IAS directly at (562) 364-8201.

# Advanced Structures & Composites Center
# QUALITY SYSTEM MANUAL
## Issue B Rev.5
**May 2014**

**Advanced Structures and Composites Center**
**35 Flagstaff Road**
**University of Maine**
**Orono, ME 04469-5793**
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**Important Notice:** Hard copies of this document are not controlled and may not be the document currently in effect. The current controlled copy is on the Center network.

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# Section 1: GENERAL OVERVIEW

## Scope:

This Manual describes the Quality System used by the Advanced Structures & Composite Center (Center) establishing policies for management, laboratory operations and client service which ensure:

- the delivery of quality services;
- compliance with contractual and statutory requirements; and
- systematic reduction, elimination and prevention of quality deficiencies.

The Quality System is based on the applicable requirements of ISO/IEC 17025:2005.

## Application:

The Quality System described in this Manual and supporting Standard Operating Procedures is applicable to all Center related work undertaken by Center personnel.

The Standard Operating Procedures and Work Instructions referenced in this document provide the procedures that put the quality system into effect.

Reference Documents:

ISO/IEC 17025:2005: General requirements for the competence of testing and calibration laboratories.

Unless otherwise specified, all standards referred to are the latest editions.

## Definitions:

**Service**: The result of activities or processes. The term "service" is used throughout the Quality System documentation to denote contract research, development, product testing/qualification or a combination thereof and applies to "intended service" only.

**Quality System**: The organizational structure, responsibilities, procedures, processes and resources for implementing quality management.

**Subcontractor**: Person or company engaged by the Center to conduct any of the work included in the Center's scope of work.

## Profile:

The Advanced Structures and Composites Center, a University of Maine research unit, is a global leader in research, development, and product testing/qualification of advanced structures and composites for public and private organizations. The Center conducts research leading to commercial development of the next generation of cost-effective, high-performance, composite materials.

The Center occupies an 84,000ft$^2$ complex at the University of Maine, Orono, Maine. In-house capabilities allow developing a composite material or structure from the conceptual stage through research, manufacturing of pilot- or full-scale prototypes, and subsequent, comprehensive testing and evaluation. The Center houses laboratories for composite materials manufacturing, polymer/interface science, nanocomposites R&D, environmental-durability testing, mechanical testing, nondestructive evaluation (NDE), advanced microscopy, resin infusion of composites and large-scale multi degree-of-freedom static and dynamic structural testing, as well as pilot plants for the manufacture of strand composites and wood plastic composites.

The 35,000ft$^2$ Offshore Wind Laboratory (OWL) has the capability of testing large high-performance hybrid composite structures. The OWL includes a structural test stand and other testing foundations required to test prototype composite components for wind energy applications, including wind blades, and floating structures up to 70 meters in length. The facility also contains environmental chambers and immersion tanks to perform durability testing of materials exposed to extreme marine environments.

Center faculty and research staff offer a wide variety of experience in multiple fields, including structural engineering, mechanical engineering, materials science, and composite manufacturing and testing. Current research initiatives include cutting-edge technology development for deepwater offshore wind, automated manufacturing, public infrastructure, consumer products, residential and light commercial construction, force protection, and homeland security.

The Center routinely conducts a broad menu of ASTM standard tests, as well as custom tests designed and performed to fill specific needs. These capabilities ensure that materials and structures under development receive an appropriately conceived and executed battery of evaluations.

ISO/IEC 17025:2005 quality systems, as outlined in this Manual, have been implemented to ensure that all client requirements are satisfied. The Quality System is applicable to all departments and to all activities undertaken by the Center.

## Quality Policy Statement:

The Advanced Structures & Composites Center is dedicated to research, development and education focused on the material science and structural applications of wood-nonwood hybrid composites. Center conducts contract research, development, and product testing/qualification for public and private organizations throughout the world.

The mission of the Center is:

- To develop the underlying science and engineering principles needed to produce low-cost, high-performance structural composites.

- To support current and emerging industries as well as government agencies that produce/use these products by providing testing, engineering and consulting services.

- To actively pursue commercialization, entrepreneurship, and job creation in Maine, and beyond.

To achieve the above objectives and satisfy client expectations, the Center is committed to implementing and maintaining a Quality Management System based on ISO 17025:2005.

Quality issues arising in various areas are to be identified and solved with speed, technical proficiency and economy. The Center focuses resources, both material and human, toward the prevention of quality deficiencies to satisfy the organizational goal of “right first time...every time". All employees are responsible for the quality of their own work and will not pass on work of inferior quality.

The successful operation of the Advanced Structures & Composites Center Quality System relies upon the cooperation and involvement of personnel at all levels. Our commitment to quality and continuous improvement will ensure the continued success of our Center and the satisfaction of clients and staff.

The Quality Manager is authorized to ensure that the requirements of this Quality System are implemented. Any problems that cannot be resolved are brought to management attention for final resolution.

This policy applies to all areas of the Center.

Habib J. Dagher, Ph.D., P.E.
Director

Stephen Shaler, Ph.D
Associate Director

# Section 2: Management System

## 1) Quality Policy:

The Director and Associate Director with executive responsibility for quality have formally issued the Quality Policy Statement (Section 1). Center management ensures that this quality policy is understood, implemented and maintained at all levels of the organization. This is achieved by:

**a)** the proper education of all personnel to the Quality System;

**b)** the display of the Quality Policy Statement at prominent locations;

**c)** regular reviews and audits of quality procedures (to verify their implementation and effectiveness).

The Quality System at the Advanced Structures & Composites Center includes ISO/IEC 17025:2005, the Quality System Manual, Laboratory Safety Plan Rev 10, and supporting Standard Operating Procedures (SOP).

## 2) Policy on Independence, Confidentiality, and Impartiality

It is the responsibility of all staff members to ensure that they understand the Advanced Structures and Composites Center and University of Maine's policies on Independence, Confidentiality, and Impartiality.

a. **Conflict of Interest:** A conflict of interest occurs when personal, family or financial interests interfere, or could appear to interfere, with the interests of the Center or the client thus preventing personnel from executing their duties and responsibilities in an ethical, professional and transparent manner. All staff members are to act in accordance with the University of Maine's conflict of interest policies, which can be found on the following University of Maine System websites.

http://www.orsp.umesp.maine.edu/ORSPDocs/Policies/ConflictofInterestinResearch.htm
http://www.umaine.edu/hr/policies/conflict.html
http://www.umaine.edu/purchasing/purchasing-policy/conflict-of-interest/

b. **Confidential and Proprietary Information:** Confidential information includes: client and employee records; research and technical data; manufacturing techniques and processes; other know-how, inventions and discoveries; financial results and information pertaining to clients served by the Center.

Any authorized communication of confidential information, internally or externally, should be limited to individuals who have a “need to know” for the purpose of fulfilling their role. As some confidential information held by the Center belongs to third parties, personnel must also consider what third-party consents may be required prior to any disclosure to persons outside the Center. All appropriate confidentiality agreements must be in place with third parties prior to sharing confidential information.

c. **Impartiality and Independence:** All activities carried out by Center staff are governed by the principles of independence, impartiality and integrity, so as to ensure that final results reported to clients are based on objective evidence and not influenced by other interests or parties.

## 3) Organization:

a) **Management Team:** The management team is comprised of the Director, the Associate Director, Center Operations Manager, Assistant Directors, and others at the discretion of the Director. Its purpose is to ensure that top management is provided with broad input representing the various interests of the Center in key decisions. This team ensures the continuing suitability, effectiveness, and integrity of the Quality Management System.

b) **Center Operations Manager** manages the day-to-day safety and activities of the Center and represents the management team on the Quality Council. Center Operations Manager:
   (1) approves SOPs;
   (2) ensures conformance with the Quality System; and
   (3) with the Quality Manager, ensures that actions identified during management review are implemented.

c) **Technical Manager:** The technical manager has overall responsibility for the technical operations and the provision of the resources needed to ensure the required quality of laboratory operations.

d) **Quality Manager:**
   (1) The Center's Quality Manager is responsible for and is given the authority to:
      i. ensure that the requirements specified in this Manual are implemented and maintained;
      ii. report on the performance of the Quality System to management. At a minimum, one annual review is held at a management team meeting for consideration during its annual Quality System review. The report will include the outcome of internal audits, a summary of corrective and preventive actions, assessments by external bodies, results of proficiency tests, client feedback, and complaints;
      iii. coordinate with various internal departments or external bodies on matters relating to the Center's Quality System.
   (2) The Quality Manager has direct access to the Director.
   (3) The Quality Manager has full organizational freedom to resolve any work or services not conforming to the requirements of the Quality System.
   (4) The Quality Manager serves as the chair of the Quality Council with responsibilities for calling meetings, preparing agendas, and bringing any other relevant matters before the Council.
   (5) The Quality Manager administers, controls, reviews and distributes the Quality Manual and Standard Operating Procedures.
   (6) The Quality Manager implements a protocol for internal audits including scheduling, training and assignment of auditors, and maintenance of audit results.

(7) The Quality Manager ensures the quality of test results by enrolling the Center in proficiency testing programs.
   i. The Quality Manager reviews the PT reports and if necessary, initiates a Corrective Action Request to investigate and resolve the cause of any outlying data.
(8) The Quality Manager serves as liaison with the International Accreditation Service (IAS).
(9) The Quality Manager maintains a register of controlled documents that identifies the current revision status of each.

**e) Quality Council** - The mission of the Center Quality Council is to create, maintain, enforce and evaluate the Quality Management System for the Center. This System provides the context and controls for excellence in all Center operations including research, product testing and development, and client service.

(1) Membership of the Quality Council:
   i. The Quality Manager serves as the Quality Management Representative and chair of the Quality Council.
   ii. The Center Operations Manager serves as the management team representative.
   iii. The Laboratory Operations Manager (LOM), the Manager of Funded Accounts (MFA), and the Communications Specialist all serve as ex officio members of the Council.
   iv. One or more faculty members will serve on the Council.
   v. A graduate student representative may be appointed by the Quality Council to act as an observer at Council meetings. These representatives will be recused during discussions of specific personnel-related non-conformances.
(2) Duties of the Quality Council:
   i. To maintain, review and periodically revise the Quality System.
   ii. To perform internal audits of the Quality System to ensure continual compliance with the Center quality documents and ISO 17025:2005.
   iii. To review non-conformance request reports to ensure that corrective actions have been implemented.
   iv. To assist the Quality Manager with preparation and implementation of periodic IAS audits.
   v. To educate all Center staff concerning the Quality Management System.
   vi. To attend scheduled Quality Council meetings.

**f) Center Personnel**

(1) The Center organization chart (page 18) shows the interrelationship of positions and functions within the Center and the paths of responsibility and authority in relation to quality.
(2) All Center employees are to adhere to the University of Maine Employee Responsibilities, Conflict of Interest, and Misconduct in Research policies.
(3) Personnel evaluations are conducted per University of Maine System Board of Trustees policy, appropriate collective bargaining agreements, and the University of Maine Employee Information & Resource Guide.

(4) The responsibility, authority and interrelationship of every person who manages, performs and verifies work affecting quality are defined in job descriptions. These are issued to all personnel and maintained in personnel files.
(5) All personnel shall, when required, delegate responsibilities and authority to others as specified in their job descriptions. All personnel have the authority to stop work on nonconforming services.
(6) All Center employees have the responsibility to initiate a Corrective Action or Preventive Action when they observe either a technical or management system nonconformity or an opportunity for improvement. AEWC SOP-05 is to be followed. In some cases, employees may be asked to assist in the implementation and verification of the effectiveness of the action taken to resolve the request.

## 2) Internal Audits:

**a) Frequency**. Internal quality audits are undertaken by members of the Quality Council and performed annually.

**b) Scheduling.** The Quality Manager schedules and assigns the internal audits with the auditors. Whenever possible, auditors are independent of the function being audited.

**c) Findings.** The Quality Manager prepares an internal audit findings report that is presented to the management team for the team's review.

**d) Follow-up**. Action reports generated from internal audits are resolved per AEWC SOP-05.

## 3) Management Review:

**a) Purpose.** Management reviews the Center Quality System annually to ensure its continued suitability and effectiveness in satisfying:
(1) Stated Center policy and objectives;
(2) Client expectations and needs; and
(3) Quality standard ISO /IEC 17025:2005

**b) Meeting**. The review is carried out during the first quarter of the calendar year and chaired by the Director and attended by the management team and the Quality Manager.

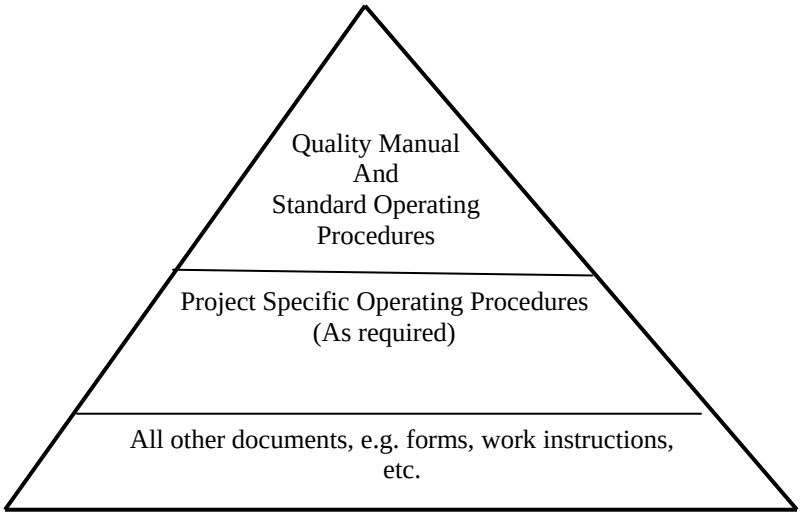
**c) Scope**. During the review, management will effectively utilize all available information, including internal and external quality audit results, client and third party complaints, quality targets (policy and objectives), non-conformance, corrective and preventive actions, to improve the system.

**d) Documentation**. Any corrective or preventive actions resulting from the meeting are documented per AEWC SOP-05 The personnel concerned implement the resulting decisions.

**e) Adequacy of resources and personnel** are reviewed annually. Resources and personnel requirements are also reviewed as part of contract or order review.

## 4) Document and Record Control:

**a) General.** Center Quality System ensures that only current, approved and valid documents are used for laboratory activities and records are maintained for those activities. Documents and records include: Quality Manual and SOPs; reports from internal audits; management reviews; work instructions; equipment calibration and maintenance records; as well as external documents including manuals and ASTM standards. This system produces a three-tier structure.




The Quality Manual and associated Standard Operating Procedures are the first-tier documents. They describe and include general management policy and procedures with regard to quality, organizational structure and responsibilities. It may be supplemented by project operating procedures. All employees are to ensure documents used are current prior to use.

**b) Documents.** Documents include the Quality Manual, Safety Manual, associated SOPs and associated forms. All Center documents included in the Quality System carry unique identifiers – date of issue, revision status, page numbering using page x of y, and issuing authority.

(1) The Center Quality Manager is responsible for the collection, indexing, filing, storage, maintenance and disposal of all Center Quality System documents; this authority will be delegated to project managers and/or other staff (LOM, Communications Specialist, Grants Manager, for instance) when appropriate.

(2) Document Approval and Issue – The Center Quality Council reviews, as needed, the document control system and revises, if necessary, to ensure continuing suitability and compliance with applicable requirements.

(3) Document Changes - Document changes shall be reviewed and accepted by the Quality Manager and approved by the Quality Council. Where practicable, altered or new text shall be identified. Hand amendments and changes are not allowed and will not be considered as an official document change. This policy also applies to documents maintained in electronic format.

The Quality Manager shall promptly remove invalid and/or obsolete documents to assure against unintended use; obsolete documents retained for either legal or knowledge preservation are archived.

To preclude the use of invalid and/or obsolete documents, the Quality Manager maintains a master list identifying current revision status. The Coordinator also determines the accessibility of documents based on need-to-know and ensures availability at all locations where operations essential to the effective functioning of Center laboratories are performed.

**c) Records**. The Center Quality System ensures the traceability of data and information concerning laboratory testing through its recordkeeping. Records include: action request reports; proposals, contracts and communication with clients; personnel records, training records, purchase orders, work notes, clients' notes and feedback, and technical reports.

(1) The Quality Manager stores records pertaining to the Quality System, including internal audit reports, external assessment reports, management review minutes, and action reports.
(2) The LOM maintains records pertaining to the operation, maintenance, calibration of laboratory equipment and laboratory training records.
(3) Project-related records are stored with project files by the responsible PI/PM. Records for each test shall contain sufficient information to establish an audit trail; to identify factors affecting uncertainty; and to enable repetition of the test under conditions as close as possible to the original.
(4) Financial records for projects are maintained by the MFA. This includes the project contracts, budget, and purchase orders.
(5) When computers or automated equipment are used for the acquisition, processing, recording, reporting, storage or retrieval of test data, software will be sufficiently validated.[1] Excel spreadsheets used to analyze data will be validated following AEWC SOP-02.

**d) Information Security.** All Center Quality System documents and records – relating to policy, operations, and client information- are stored on a Center server which is maintained and backed up daily by the University of Maine IT department. To prevent unauthorized access or amendment, records will be stored in password protected folders on the Center servers. The Project Manager and/or the Quality Manager determines the accessibility of the documents and records based on need-to-know. The Center's Information Security Procedure (AEWC SOP-04) provides information on what is required to be stored on the Center network and how it is maintained.

## 5) Impartiality and Conflict of Interest

**a)** The Advanced Structures and Composites Center follows the University policies and procedures to insure that employees are free from internal and external pressures that can affect the quality of the work. The purpose of the policy is to ensure continued confidence of the people of Maine in the

[1] Commercial software will be considered sufficiently validated; software developed by Center personnel will be sufficiently detailed and validated as adequate for use.

University, personnel engaged in extramurally funded work shall act at all times in a manner consistent with their public responsibilities to the University and shall exercise particular care that no detriment to the University results from conflicts between their personal financial interests and the interests of the University. The procedure for training all employees of the Center can be found in SOP –xx-yy

# Section 3: Laboratory Operations

## 1) Safety:

The Advanced Structures and Composites Center Laboratory Safety Plan ensures that the Center provides a safe work environment. The Center Safety Coordinator establishes and maintains this document in accordance with OSHA Guideline 29 CFR Part 1910.

a) **Safety Committee.** The Center Safety Committee chaired by Center Safety Coordinator with members from all sections of the Center meets as needed to discuss safety issues.

b) **Training.** The LOM maintains all training records relevant to working in Center laboratories.
   (1) Safety - Prior to working in any Center laboratories, faculty, staff and students must complete all safety training as outlined in the Laboratory Safety Plan.
   (2) Equipment – Personnel are to be trained on any designated, specialized equipment prior to operation of this equipment.
   (3) Testing – PI/PMs are responsible for ensuring personnel working on test projects have been trained to perform the ASTM tests requested by the client.

c) **Access.** A list of personnel authorized to work in the Center labs is maintained by the LOM. Center Laboratories are open from 7am to 5pm during normal business days. Requests for lab use after hours must be approved by the LOM using the After Hours Lab Request form (FM/AR/19).

## 2) Corrective and Preventive Action:

All Center employees are authorized and encouraged to file the appropriate form when they observe a non-conformance (corrective action) or a potential non-conformance (preventative action). AEWC SOP-05 is to be followed.

## 3) Facilities:

Testing, manufacturing, and other research and development activities are conducted in one of the ten task specific areas included in the 84,000-sq.ft Center building. These areas are:

- Offshore Wind Lab
- Structural Testing Lab
- Mechanical Testing Lab
- Wood-Plastic Composites Pilot Plant
- Strand Composites Pilot Plant
- Environmental Testing Lab
- Polymer and Interface Science Lab
- Micromechanics and Non-Destructive Evaluation Lab
- Microscopy Lab
- Resin Infusion Composites Reliability (RICoR) Lab

- Nano-composite Lab
- Wood Shop

## 4) Accommodations:

Environmental conditions are controlled and monitored by the LOM in the following areas:

- Mechanical Testing Lab
- Polymer and Interface Science Lab
- Micromechanics and Non-Destructive Evaluation Lab
- Microscopy Lab
- Resin Infusion Composites Reliability (RICoR) Lab

## 5) Equipment:

**a) Labeling.** All laboratory equipment is assigned a unique AEWC equipment number. A complete list of equipment is maintained by the LOM. All new equipment is assigned a unique number and logged into the equipment database by the LOM. When applicable, all equipment will be verified to ensure it operates as specified by the manufacturer before being released for general use by using the New Equipment Acceptance Checklist (FM/AR/37).

**b) Calibration and Maintenance.** Calibration records for equipment requiring periodic calibration can be found in the LOM's office. The LOM schedules all calibrations and maintenance with appropriate ISO 17025:2005 accredited calibration labs.

Maintenance records are kept in the LOM's office in the appropriate equipment folder.

**c) Storage and Handling of Measuring Devices.** The LOM will ensure that all measuring devices are carefully handled, preserved and stored such that accuracy and fitness for use is maintained, and are safeguarded from adjustments that would invalidate the calibration settings.

**d) Usage.** Only authorized personnel are allowed to use testing and manufacturing equipment. The LOM maintains the database of authorized personnel for applicable equipment.

## 6) Scheduling:

The LOM maintains the Center equipment schedule calendar on the University of Maine intranet.

## 7) Project Material: This includes material for use by the project purchased by the Center and material and test samples provided by the client.

**a) Receiving and Shipping:**

a. Standard shipments are received by the administrative assistant in the front office. The PI/PM/Laboratory staff that initiated the order will be notified. Project staff verifies the accuracy and condition of the materials/samples.
    i. Freight and chemical shipments are received via the lab by lab operations staff.
b. Upmost care will be taken to insure material shipped from the Center are protected and arrive at their destination in good condition.

**b) Labeling.** All project-related material is to be labeled upon receipt with the following information:
(1) PI/PM responsible
(2) Project number
(3) Contact phone number
(4) Date received
(5) Number of containers/packages, if more than one.
(6) Chemical label, if necessary (obtained from LOM)

**c) Storage.** The PI/PM should notify the LOM if the material is to be kept in an environmentally controlled room or in a secured location. Materials not requiring special accommodations are to be stored near the project site.

**d) Disposal.** All tested material will be disposed of at the completion of the project unless otherwise stated by the client. Any chemicals or chemical containers to be disposed of must follow the chemical hygiene plan outlined in the Laboratory Safety Plan, Section Four.

# Section 4: Project Lifecycle

## 1) General:

This section provides the general guidelines for establishing and conducting a project at the Center. AEWC SOP-12 outlines the procedures for establishing a project administered through the University of Maine Department of Industrial Cooperation. Procedures for establishing a federally funded project administered through the University's Office of Sponsored and Research Programs follow the University of Maine OSRP guidelines.

## 2) Request for Services:

Requests for services are received from either industrial clients, from state or federal agencies or other units of the University of Maine. The PI/PM receiving the request is to follow the appropriate proposal reviewing procedure as outlined in Section 3 below before submitting a formal proposal to any client.

## 3) Writing/Reviewing Proposals:

Proposals to be submitted to clients should include sufficient information to explain the service to be provided to the client, including scope of work, deliverables and cost. Prior to being submitted to the client, all proposals are reviewed by the MFA, Center Operations Manger, and the LOM to ensure the Center has all the necessary resources to perform the work requested by the client. Proposals must also follow appropriate University of Maine procedures as mandated by the Department of Industrial Cooperation or the Office of Research and Sponsored Programs, depending on the funding source.

Amendments or changes to the original scope of work must be approved by both the PI/PM and the client in writing.

## 4) Obtaining a Project Number:

Establishment of a project number authorizes the PI/PM to begin work on the project. This number is also used for tracking project material and supplies received through the life of the project. Project numbers are assigned by the MFA after the proposal for work has been signed by the client and returned to Center. If the PI/PM would like to begin work without the signed contracts, the PI/PM must provide an alternative, active project number to which incurred expenses will be charged in the event the PI/PM begins work without the client signature on the contracts.

## 5) Project Guidelines

a) **Sampling Plan.** The Center does not perform sampling.

b) **Training.** All personnel who work in the Center laboratories must be trained on the equipment to be used or test method to be performed as described in the Laboratory Operations, Section 3 (1)(b) of this Quality Manual.

**c) Traceability.** Client provided specimens are to be labeled upon receipt as described in Section 3, Clause 6b. Specimens that are fabricated as part of the project are to be labeled at the time of fabrication. The Specimen Preparation and Labeling Procedure (Center SOP-08) provides guidelines for both scenarios.

**d) Test Methods.** Unless requested by the client, current ASTM standards are to be used. Current ASTM standards can be obtained by the Quality Manager through the University of Maine Fogler Library.

- **i.** If the Center cannot perform the requested test method, the PI/PM must notify the client. The Center does not subcontract test methods the lab is unable to perform. In the event the client requests the PI/PM's assistance in obtaining a subcontract for such testing, Subcontractors used for testing are to be an ISO 17025:2005 accredited laboratory, unless stated otherwise by the client.
- **ii.** Datasheets created are to be reviewed and validated following AEWC SOP-02.
- **iii.** Measurement uncertainty is to be calculated at the request of the client or if a new test procedure is developed.

**e) Corrective Action Requests.** Work being conducted in the Center laboratories that is not following the required work instruction or test standard will be investigated. The PI/PM will be notified and, if necessary, the Non-Conformance online form will be filled out and resolved for the nonconforming work following the procedures outlined in AEWC SOP-05. The client will be notified when appropriate.

**f) Report Writing/Review.** Project reports are written by the Project Manager or his/her designee according to the requirements of the client as specified in the project contract. Prior to being submitted to the client, the report undergoes independent, internal review to ensure its compliance with the requirements of ISO/IEC 17025:2005, Section 5.10 and AEWC SOP-06. The project's PI/PM is authorized to issue the test report after it has undergone the review process.

## 6) Purchasing:

Purchases for supplies and services that affect the quality of service must be from approved vendors.

**a) Evaluation and Approval of Vendors.** The MFA maintains a database of approved vendors. Vendors are reviewed and approved based on one of the following criteria:

(1) Has a registered quality system (i.e. ISO 9001). Vendors used to calibrate Center equipment must be ISO 17025:2005 accredited calibration laboratories, with the item to be calibrated listed on their scope of accreditation. The LOM maintains records of all calibration laboratories used.

(2) Is a vendor of record.

(3) Is a vendor of reputation.
(4) Has been audited by Center for compliance with ISO 17025:2005.

The University of Maine Purchasing Department maintains a list of non-approved vendors. Reasons for placing a vendor on the non-approved list include, but are not limited to:

(5) Poor invoicing/billing terms.
(6) Poor client service.
(7) Repeat receipt of faulty material.

**b) Purchasing Process.** The Purchase/Reimbursement Request Form ("PRR", FM/AR/04) is to be used for all purchase requests for supplies and services. The request form is reviewed and approved by the PI/PM or delegate to ensure:

i. Use of proper project number;
ii. Proper service/supply is being ordered.

If applicable, the PRR form is to be reviewed and approved by the Chemical Hygiene Officer if chemicals are being ordered.

**c) Receipt of Purchased Material**

(1) Incoming items are delivered to Room 148, where the Administrative Assistant notifies the PI/PM of the shipment.
(2) The PI/PM or delegate verifies the order and logs the item into the purchase received binder.
(3) Chemicals received are subject to the safe handling and storage procedures outlined in Laboratory Safety Plan.

## 7) Client Feedback:

At the completion of the project, client feedback is sought so that the Center can continue to improve the Quality System. A client survey form is sent to clients via email by the Communication Specialist at the completion of a project. Periodic reports are given to the Quality Council and Management Team summarizing the results of the survey.

## 8) Complaints:

Client or personnel complaints received either as a result of client or personnel feedback or otherwise are to be documented and filed with the project file. For complaints that require a Corrective Action Request (CAR), the PI/PM will fill out the Non-Conformance online form for resolution of the complaint.

## 9) Project Completion:

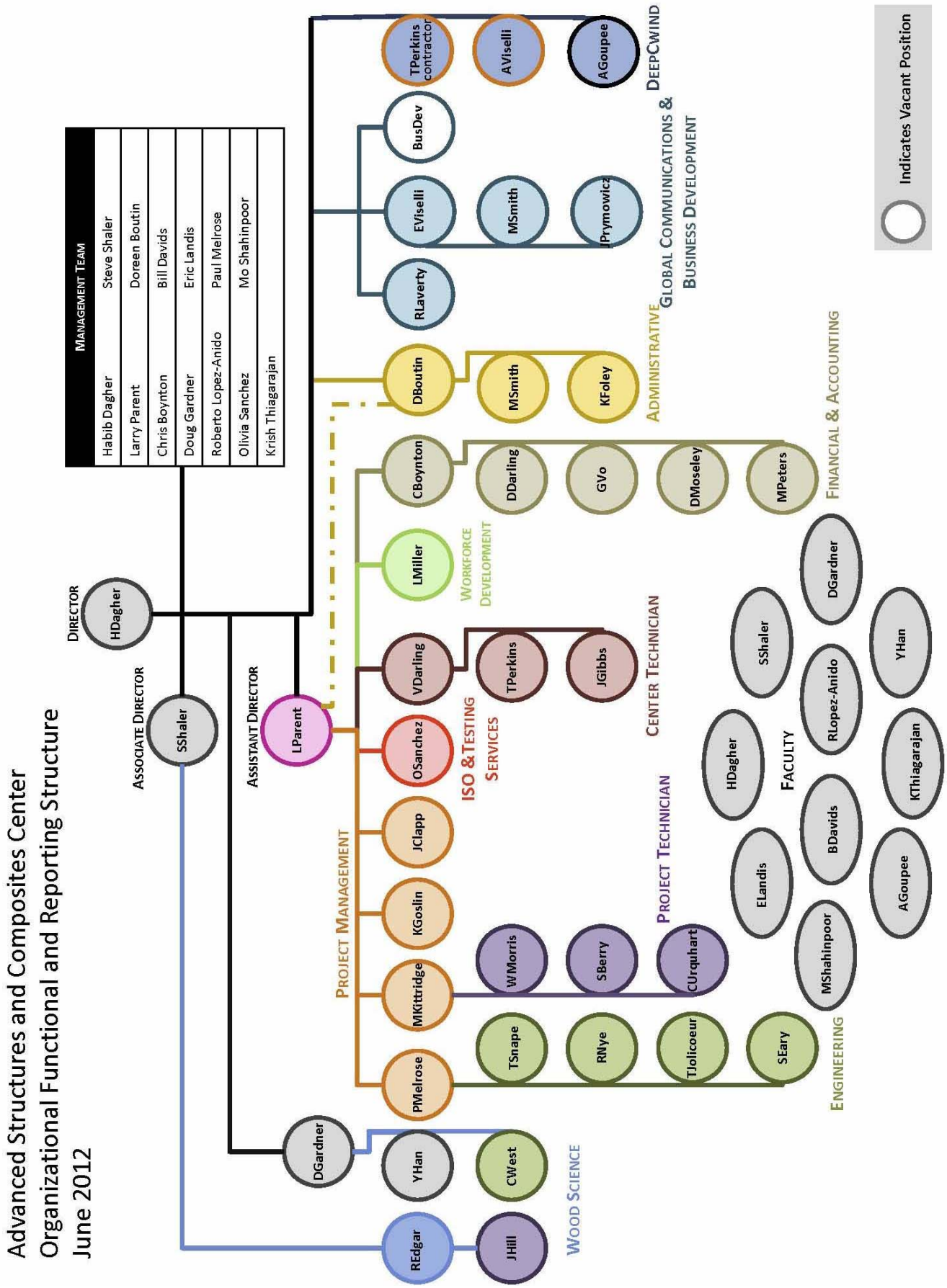
The Project Completion Form is to be filled out after the final report has been sent to the client. The form is completed by the PI/PM and LOM, authorizing the MFA to invoice the client and close the project.

### a) Material Disposal:

(1) **Test Specimens.** Unless otherwise stated by the client, all test specimens will be disposed of after the Project Completion Form has been filled out and the final report sent to the client. Samples may be kept for quality control testing.

(2) **Chemical Hygiene.** Any chemicals or chemical containers to be disposed of must follow the Chemical Hygiene Plan outlined in the project work instruction and/or the Laboratory Safety Plan.

# Section 5: Center Organization Chart


Advanced Structures and Composites Center
Organizational Functional and Reporting Structure
June 2012
Management Team
Habib Dagher Steve Shaler
Larry Parent Doreen Boutin
Chris Boynton Bill Davids
Doug Gardner Eric Landis
Roberto Lopez-Anido Paul Melrose
Olivia Sanchez Mo Shahinpoor
Krish Thiagarajan
Director
HDagher
Associate Director
SShaler
Assistant Director
LParent
Project Management
PMelrose
MKittridge
KGoslin
JClapp
OSanchez
VDarling
Wood Science
REdgar
JHill
YHan
CWest
DGardner
Workforce Development
LMiller
CBoynton
ISO & Testing Services
TSnape
WMorris
TPerkins
Project Technician
RNye
SBerry
Center Technician
TJolicoeur
CUrquhart
JGibbs
Engineering
SEary
MShahinpoor
ELandis
HDagher
Faculty
BDavids
RLopez-Anido
SShaler
DGardner
AGoupee
KThiagarajan
YHan
Financial & Accounting
MPeters
DMoseley
GVo
DDarling
Administrative
KFoley
MSmith
DBoutin
Global Communications & Business Development
RLaverty
EViselli
BusDev
MSmith
JPrymowicz
DeepCwind
TPerkins contractor
AViselli
AGoupee
Indicates Vacant Position

# Section 6: References

## 1) AEWC Standard Operating Procedures

| | |
|---|---|
| AEWC SOP-01 | Storage and Handling Measuring Devices Procedure |
| AEWC SOP-02 | Datasheet Creation-Validation Procedure |
| AEWC SOP-03 | Document Control Procedure |
| AEWC SOP-04 | Information Security Procedure |
| AEWC SOP-05 | Action Request Procedure |
| AEWC SOP-06 | Report Review Procedure |
| AEWC SOP-07 | Measurement Uncertainty Procedure |
| AEWC SOP-08 | Specimen Labeling Procedure |
| AEWC SOP-09 | Hourly Student Payroll |
| AEWC SOP-10 | Purchasing/Travel Procedures |
| AEWC SOP-11 | Project Management |
| AEWC SOP-12 | Creating a DIC Project |

## 2) University of Maine Administrative Practice Letters relevant to the Center

APL can be found on the University of Maine System website.
The full list of the APL can also be found on the University of Maine System website

| |
|---|
| **SECTION I - ACCOUNTING** |
| G.1. General Accounting for Capital Assets - FAQ |
| **SECTION II - ASSET MANAGEMENT** |
| A. Facilities Procedures |
| B. Motor Vehicle Administration and Guidelines |
| C. Withholding and Reporting for Personal Use of Vehicles |
| D. Waste Reduction and Recycling |
| E. Safety and Environmental Management System |
| **SECTION IV - GENERAL ADMINISTRATION** |
| B. Travel and Expense Procedures |
| J. Reporting Workplace Wrongdoing |
| K. Commercializing Research and Inventions |
| Draft in process |
| **SECTION V - Gifts** |
| A. Gifts of Stocks/Bonds |
| B. Gift Administration |
| **SECTION VI - INFORMATION TECHNOLOGY** |
| B. Information Security Incident Response |
| C. Information Security |
| E. Network Services |

**APL list, continued**

| **SECTION VII - PROCUREMENT** |
|---|
| A.1 FAQ for Purchasing Procedures |
| A.2 University of Maine System Purchasing Procedures |
| B. Procurement Standards of Conduct |
| C. Purchasing Cards |
| D. Cellular Telephone Acquisition, Use and Reimbursement |
| E. Sales Tax |
| H. Determining Employee vs. Independent Contractor Status |

**Rev 4 Changes**

[1]$C_M$ = 0.95 [2]$C_M$ = 0.85

**Rev 4 is being submitted to incorporate measured values from mechanical and physical testing**

| | $E_t$[1] (Msi) | $E_c$[1] (Msi) | $F_{tu}$[2] (ksi) | $F_{cu}$[2] (ksi) | G[1] (Msi) | $F_{su}$[2] (ksi) | 1/2" Lam. | 1" Lam. |
|---|---|---|---|---|---|---|---|---|
| Predicted | 3.11 | 3.11 | 44.54 | 29.67 | 0.67 | 12.16 | 0.509 | 1.017 |
| Measured | 2.94 | 3.18 | 39.69 | 48.22 | 0.60 | 12.28 | 0.492 | 0.950 |

**Bottom Plate**

**Maximum vertical bending moment on raft - Strength V (bottom in compression)**

$$M_u \le \lambda \phi M_n$$

*Rupture (evaluated as a composite section)*

$$M_n = \frac{F_C I}{y}$$

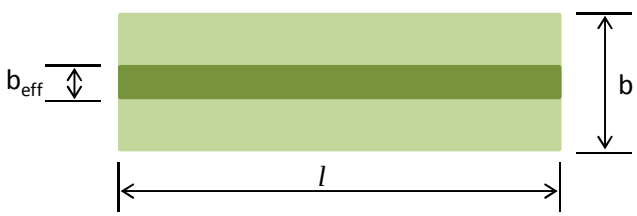
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F_C$ = | 48.22 | ksi | | $\lambda$ = | 0.90 | | |
| I = | 104,251 | $in^4$ | | $\phi$ = | 0.65 | | |
| y = | 20.65 | in | | | | | |
| $\lambda\phi M_n$ = | 11,868 | kip-ft | > | $M_u$ = | 1,612 | kip-ft | (Sheet 37) |

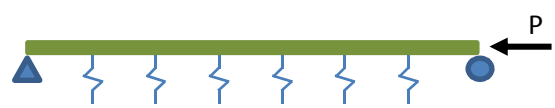
*Rupture (evaluated as a plate in compression)*

$$N_u^c \le \lambda \phi_c N_n^c \qquad N_n^c = F^c t \qquad N_u = \sigma t$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F_c$ = | 48.22 | ksi | | $M_u$ = | 1,612 | kip-ft | (Sheet 37) |
| t = | 0.492 | in | | y = | 20.40 | in | (N.A. to midplane) |
| $\lambda$ = | 0.90 | | | I = | 101,955 | $in^4$ | |
| $\phi$ = | 0.70 | | | $\sigma$ = | 3.87 | ksi | (ave. stress) |
| $\lambda\phi_c N_n$ = | 14.9 | kip/in | > | $N_u$ = | 1.90 | kip/in | |

*Buckling (evaluated as beam (strip of plate) on an elastic (foam) foundation)*




$$P_u = N_u b_{eff} \qquad P_{cr} = \frac{\pi^2 EI}{l^2}\left(1 + \frac{kl^4}{EI\pi^4}\right)$$

$$P_u \le \lambda \phi_c P_{cr}$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda$ = | 0.90 | | | $l$ = | 149.5 | in | |
| $\phi$ = | 0.70 | | | $E_L = E_T$ = | 3.18 | Msi | |
| $b_{eff}$ = | 12.0 | in | (strip width) | I = | 0.1191 | $in^4$ | (1 ft strip) |
| $N_u$ = | 1.90 | kip/in | (see above) | k = | 0.403 | ksi | (foam stiffness) |
| $\lambda\phi_c P_{cr}$ = | 575.1 | kip | > | $P_u$ = | 22.86 | kip | |

This will be conservative since it assumes the plate is simply supported on short ends only. Spray-in foam is bonded to plate and E is the same in compression or tension = 403 psi. Foam properties have been included with other data sheets.

**Top Plate**

**Maximum vertical bending moment on raft - Strength V (top in tension)**

$$M_u \le \lambda \phi M_n$$

*Rupture (evaluated as a composite section)*

$$M_n = \frac{F_T I}{y}$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F_t$ = | 39.69 | ksi | | $\lambda$ = | 0.90 | | |
| I = | 104,251 | $in^4$ | | $\phi$ = | 0.65 | | |
| y = | 15.35 | in | | | | | |
| $\lambda\phi M_n$ = | 13,141 | kip-ft | > | $M_u$ = | 1,612 | kip-ft | (Sheet 37) |

*Rupture (evaluated as a plate in tension)*

$$N_u^t \le \lambda \phi_t N_n^t \qquad N_n^t = 0.7 F^t t \qquad N_u = \sigma t$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F_t$ = | 39.69 | ksi | | $M_u$ = | 1,612 | kip-ft | (Sheet 37) |
| t = | 0.492 | in | | y = | 15.10 | in | (N.A. to midplane) |
| $\lambda$ = | 0.90 | | | I = | 104,251 | $in^4$ | |
| $\phi_t$ = | 0.65 | | | $\sigma$ = | 2.80 | psi | (ave. stress) |
| $\lambda\phi_t N_n$ = | 8.0 | kip/in | > | $N_u$ = | 1.38 | kip/in | |

*Top Plate Buckling (evaluated as a plate in compression - Strength V)*

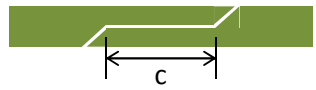
$$N_u^c \le \lambda \phi_c N_n^c \qquad N_n^c = F^{cr} t \qquad F^{cr} = \left(\frac{t}{b}\right)^2 \frac{\pi^2}{6}\left((4k_{cr} - 3)\sqrt{E_L E_T} + k_{cr} E_T \nu_{LT} + 2k_{cr} G_{LT}\right)$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $M_u$ = | 699 | kip-ft | (Sheet 37) | y = | 15.10 | in | (dist. from N.A.) |
| $\sigma$ = | 1.21 | psi | (ave. stress) | I = | 104,251 | $in^4$ | |
| $F^{cr}$ = | 2.82 | ksi | | $E_L = E_T$ = | 3.18 | Msi | |
| t = | 0.492 | in | | $G_{LT}$ = | 0.60 | Msi | |
| $\lambda$ = | 0.90 | | $N_u = \sigma t$ | $\nu_{LT}$ = | 0.20 | | |
| $\phi$ = | 0.70 | | | b = | 30.25 | in | (unsupported width) |
| | | | | $k_{cr}$ = | 1.1 | | (1.0 (pin) –1.3 (fixed)) |
| $\lambda\phi_c N_n$ = | 0.87 | kip/in | > | $N_u$ = | 0.60 | kip/in | |

Top plate seam at midspan - maximum moment at 0.5L on Raft 2

$$N_{LT,u} \le \lambda \phi_v N_{LT,n}$$

$$N_{LT,n} = F^v c$$




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F^v$ = | 1.60 | ksi | (MA560 TDS) | $M_u$ = | 1,377 | kip-ft | (Sheet 37) |
| c = | 3.00 | in | | y = | 15.10 | in | (N.A. to midplane) |
| λ = | 0.90 | | $N_u = \sigma t$ | I = | 104,251 | $in^4$ | |
| $\phi_v$ = | 0.50 | | | σ = | 2.39 | psi | (ave. stress) |
| | | | | t = | 0.492 | in | |
| $\lambda\phi_c N_n$ = | 2.16 | kip/in | > | $N_u$ = | 1.18 | kip/in | |

**<u>Longitudinal Bulkhead</u>**

**Maximum vertical shear on raft - Strength V**

$$V_u \le \lambda \phi V_n$$

| | | | |
|---|---|---|---|
| $V_u$ = | 80.8 | kip | (Sheet 37) |
| # webs = | 4 | | |

*Rupture (evaluated as a composite section)*

$$V_n = F_{LT} A_S$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F_{LT}$ = | 12.28 | ksi | | λ = | 0.90 | | |
| $A_S$ = | 17.5 | $in^2$ | (35 x 0.5) | ϕ = | 0.65 | | |
| $\lambda\phi V_n$ = | 126 | kip | > | $V_u$ = | 20.2 | kip | ($V_u$ / 4) |

*Rupture (evaluated as a plate in shear)*

$$N_{LT,u} \le \lambda \phi_v N_{LT,n}$$

$$N_{LT,n} = F_{LT} t$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | $V_u$ = | 80.8 | kip/in | (Sheet 37) |
| | | | | # webs = | 4 | | |
| $F_{LT}$ = | 12.28 | ksi | | λ = | 0.90 | | |
| t = | 0.53 | in | | ϕ = | 0.70 | | |
| h = | 35.0 | in | (36 - 2(0.5)) | | | | |
| $\lambda\phi_v N_{LT,n}$ = | 4.1 | kip/in | > | $N_{LT,u}$ = | 0.6 | kip/in | ($V_u$ / 4/35.0) |

*Web Buckling (evaluated as a composite section)*

$$V_n = f_{cr} A_S$$

$$f_{cr} = \frac{t_w^2 k_{LT} \sqrt[4]{E_L E_t^3}}{3h^2}$$

$$k_{LT} = 8.1 + 5.0 \frac{2G_{LT} + E_t \nu_{LT}}{\sqrt{E_L E_T}}$$

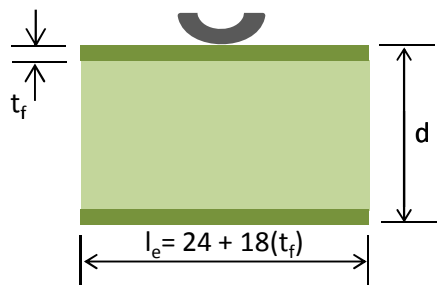
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $f_{cr}$ | 2.67 | ksi | | $V_u$ = | 80.8 | kip/in | (Sheet 37) |
| $A_S$ = | 18.6 | $in^2$ | (35 x 0.5) | # webs = | 4 | | |
| $k_{LT}$ = | 11.0 | | | | | | |
| $t_w$ = | 0.53 | in | | $E_L = E_T$ = | 3.18 | Msi | |
| $\lambda$ = | 0.90 | | | $G_{LT}$ = | 0.60 | Msi | |
| $\phi$ = | 0.80 | | | h = | 35.0 | in | (36 - 2(0.5)) |
| | | | | $\nu_{LT}$ = | 0.20 | | |
| $\lambda\phi V_n$ = | 35.7 | kip | > | $V_u$ = | 20.2 | kip | ($V_u$ / 4) |

*Buckling of longitudinal bulkhead due to tire loading*

$$N_u^c \le \lambda \phi_c N_n^c$$

$$N_n^c = F^{cr} t$$

$$F^{cr} = \left(\frac{t}{b}\right)^2 \frac{\pi^2}{6}\left((4k_{cr} - 3)\sqrt{E_L E_T} + k_{cr} E_T \nu_{LT} + 2k_{cr} G_{LT}\right)$$




$$N_u = \frac{W_u}{l_e}$$

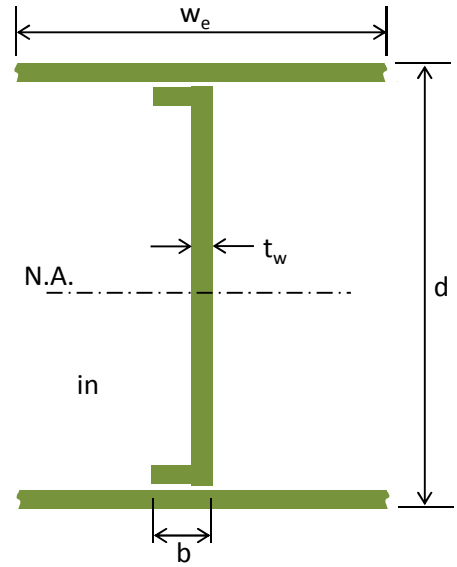
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $F^{cr}$ = | 2.10 | ksi | | | | | |
| t = | 0.492 | in | | | | | |
| $E_L = E_T$ = | 3.18 | Msi | | | | | |
| $G_{LT}$ = | 0.60 | Msi | | | | | |
| $\nu_{LT}$ = | 0.20 | | | | | | |
| $\lambda$ = | 0.90 | | | | | | |
| $\phi$ = | 0.70 | | | d = | 35 | in | (unsupported height) |
| | | | | $W_u$ = | 15.5 | kip | |
| $k_{cr}$ = | 1.1 | (1.0 (pin)→1.3 (fixed)) | | $l_e$ = | 32.9 | in | |
| $\lambda\phi_c N_n$ = | 0.65 | kip/in | > | $N_u$ = | 0.47 | kip/in | |

## Adhesive Bond Strength

*Shear transfer from longitudinal bulkhead to top/bottom plate - Strength V*

$$V \le \lambda \phi F_{LT}$$

$$V = \frac{V_u Q}{Ib}$$




| | | | | | | |
|---|---|---|---|---|---|---|
| $V_u$ = | 80.8 | kip | (Sheet 37) | | | |
| # webs = | 4 | | | | | |
| $V_u$ = | 20.2 | kip | ($V_u$ / 4) | | | |
| Q = | 218 | $in^3$ | | | | |
| $w_e$ = | 9.8 | in | ($20*t_w$) | | | |
| d = | 36.0 | in | | y = | 20.62 | in |
| $t_f = t_w$ = | 0.492 | in | | | | |
| b = | 3.0 | in | | | | |
| I = | 5548 | $in^4$ | | | | |
| $F_{LT}$ = | 1.60 | ksi | (MA560 TDS) | | | |
| $\phi$ = | 0.50 | | | $\lambda$ = | 0.90 | |
| $\lambda\phi F_{LT}$ = | 0.72 | ksi | > | V = | 0.26 | ksi ($V_u$ / 4) |

## Bolted Connections - Top/Bottom Flanges

$$R_u = \lambda \phi R_n C_\Delta$$

*Pin bearing*

$$R_{br} = t d_n F_L^{br}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | $\lambda$ = | 0.90 | |
| $d_n$ = | 0.875 | in | (bolt dia.) | $\phi$ = | 0.80 | |
| $F_{br}$ = | 45.07 | ksi | (brng stren.) | $C_\Delta$ = | 1.0 | |
| $\lambda\phi R_n$ = | 27.0 | kip | > | $R_u$ = | 19.40 | kip (Sheet 38) |

*Shear-out*

$$R_{sh} = 1.4\left(e_1 - \frac{d_n}{2}\right) t F_{sh}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | | | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | | | |
| $F_{sh}$ = | 12.28 | ksi | (shear str.) | | | |
| $\lambda$ = | 0.90 | | | $e_1$ = | 3.75 | in |
| $\phi$ = | 0.50 | | | $C_\Delta$ = | 1.0 | |
| $\lambda\phi R_n$ = | 53.6 | kip | > | $R_u$ = | 19.40 | kip (Sheet 38) |

*Net tension*

$$R_{nt} = \frac{1}{K_{nt,L}}(w - nd_n)tF_L^t$$

$$K_{nt,L} = C_L\left(S_{pr} - 1.5\frac{(S_{pr}-1)}{(S_{pr}+1)}\Theta\right) + 1$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | n = | 3 | | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | w = | 10.5 | (3 x g) | |
| $F_L$ = | 39.69 | ksi | (ten. stren.) | g = | 3.5 | | |
| $C_L$ = | 0.40 | | | $K_{nt,L}$ = | 2.24 | | |
| λ = | 0.90 | | | $S_{pr}$ = | 4.00 | (g/d) | |
| ϕ = | 0.50 | | | Θ = | 1.0 | ($e_1$/g ≥ 1) | |
| $C_\Delta$ = | 1.0 | | | | | | |
| $\lambda\phi R_n$ = | 58.23 | kip | > | $R_u$ = | 58.20 | kip | (Sheet 38) |

*Cleavage*

$$R_{cl} = 0.15((e_2 + 0.5g - d_n)F_{t,L} + 2e_1F_{sh})t$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| t = | 0.95 | in | (plate thk) | g = | 3.50 | in | | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | $e_1$ = | 3.75 | in | | |
| $F_{sh}$ = | 12.28 | ksi | (shear str.) | $e_2$ = | 2.25 | in | ($2e_{2,min}$)* | |
| $F_{t,L}$ = | 39.69 | ksi | (tensile str.) | λ = | 0.90 | | | |
| $C_\Delta$ = | 1.0 | | | ϕ = | 0.50 | | | |
| $\lambda\phi R_n$ = | 30.4 | kip | > | $R_u$ = | 19.40 | kip | (Sheet 38) | |

* since the edge distance in all joints is >> $e_{2,min}$, a value of 2 x $e_{2,min}$ has been used for $e_2$

**Bolted Connections - Vertical Webs**

Since the force per bolt acting on the webs is 12.3 kips (less than 19.4 kips evaluated for the flanges), the gage length and end distance is the same as above, and the material properties ($F_{t,L}$, $F_{t,T}$, $F_{sh}$, etc.) are the same, the bolted connections in the web are assumed to be satisfactory based on calculations performed above for the flanges in the longitudinal direction. However, bolt loading in webs is evaluated for load angles using equations for 5-90 degress from longitudinal.

$$R_u \le \lambda\phi R_n C_\Delta$$

*Pin bearing*

$$R_{br} = td_nF_L^{br}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | λ = | 0.90 | |
| $d_n$ = | 0.875 | in | (dia. +1/16) | ϕ = | 0.80 | |
| $F_{br}$ = | 45.07 | ksi | (brng stren.) | $C_\Delta$ = | 1.0 | |
| $\lambda\phi R_n$ = | 27.0 | kip | > | $R_u$ = | 12.30 | kip | (Sheet 38) |

*Net tension - force from 5-90 degrees*

$$R_{nt} = \frac{1}{K_{nt,T}}(w - nd_n)tF_T^t$$

$$K_{nt,T} = C_T\left(S_{pr} - 1.5\frac{(S_{pr}-1)}{(S_{pr}+1)}\Theta\right) + 1$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | n = | 3 | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | w = | 10.5 | (3 x g) |
| $F_T$ = | 39.69 | ksi | (53.6 x 0.85) | g = | 3.5 | |
| $C_T$ = | 0.50 | (transverse coefficient) | | $K_{nt,T}$ = | 2.55 | |
| λ = | 0.90 | | | $S_{pr}$ = | 4.00 | (g/d) |
| ϕ = | 0.50 | | | Θ = | 1.0 | ($e_1/g \geq 1$) |
| $C_\Delta$ = | 1.0 | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda\phi R_n$ = | 51.2 | kip | > | $R_u$ = | 36.90 | kip | (Sheet 38) |

**<u>Stainless Bolted Connections - Vertical Webs</u>**

$$R_u \leq \lambda\phi R_n C_\Delta$$

*Pin bearing*

$$R_{br} = td_n F_L^{br}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | λ = | 0.90 | |
| $d_n$ = | 0.875 | in | (bolt dia.) | ϕ = | 0.80 | |
| $F_{br}$ = | 45.07 | ksi | (brng stren.) | $C_\Delta$ = | 1.0 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda\phi R_n$ = | 27.0 | kip | > | $R_u$ = | 14.80 | kip | (Sheet 39) |

*Shear-out*

$$R_{sh} = 1.4\left(e_1 - \frac{d_n}{2}\right)tF_{sh}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | | | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | | | |
| $F_{sh}$ = | 12.28 | ksi | (shear str.) | | | |
| λ = | 0.90 | | | $e_1$ = | 3.5 | in |
| ϕ = | 0.50 | | | $C_\Delta$ = | 1.0 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda\phi R_n$ = | 49.5 | kip | > | $R_u$ = | 14.80 | kip | (Sheet 39) |

*Net tension*

$$R_{nt} = \frac{1}{K_{nt,L}}(w - nd_n)tF_L^t$$

$$K_{nt,L} = C_L\left(S_{pr} - 1.5\frac{(S_{pr}-1)}{(S_{pr}+1)}\Theta\right) + 1$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | n = | 3 | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | w = | 10.5 | (3 x g) |
| $F_L$ = | 44.54 | ksi | (ten. stren.) | g = | 3.5 | |
| $C_L$ = | 0.40 | | | $K_{nt,L}$ = | 2.24 | |
| λ = | 0.90 | | | $S_{pr}$ = | 4.00 | (g/d) |
| ϕ = | 0.50 | | | Θ = | 1.0 | ($e_1/g \geq 1$) |
| $C_\Delta$ = | 1.0 | | | | | |
| $\lambda\phi R_n$ = | 65.3 | kip | > | $R_u$ = | 44.40 | kip (Sheet 39) |

*Cleavage*

$$R_{cl} = 0.15\left((e_2 + 0.5g - d_n)F_{t,L} + 2e_1F_{sh}\right)t$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| t = | 0.95 | in | (plate thk) | g = | 3.50 | in | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | $e_1$ = | 3.75 | in | |
| $F_{sh}$ = | 12.28 | ksi | (shear str.) | $e_2$ = | 3.05 | in | (4-0.950) |
| $F_{t,L}$ = | 39.69 | ksi | (tensile str.) | λ = | 0.90 | | |
| $C_\Delta$ = | 1.0 | | | ϕ = | 0.50 | | |
| $\lambda\phi R_n$ = | 35.0 | kip | > | $R_u$ = | 19.40 | kip | (Sheet 38) |

*Net tension - force from 5-90 degrees*

$$R_{nt} = \frac{1}{K_{nt,T}}(w - nd_n)tF_T^t$$

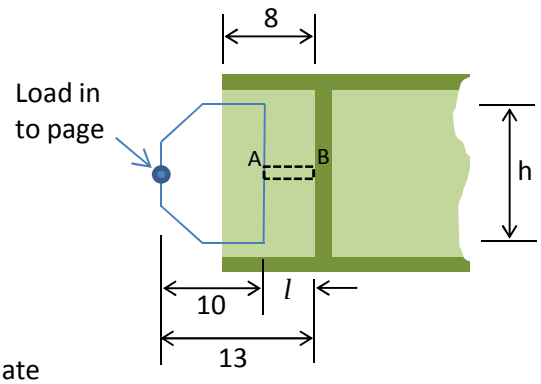
$$K_{nt,T} = C_T\left(S_{pr} - 1.5\frac{(S_{pr}-1)}{(S_{pr}+1)}\Theta\right) + 1$$

| | | | | | | |
|---|---|---|---|---|---|---|
| t = | 0.950 | in | (plate thk) | n = | 3 | |
| $d_n$ = | 0.938 | in | (dia. +1/16) | w = | 10.5 | (3 x g) |
| $F_T$ = | 39.69 | ksi | (53.6 x 0.85) | g = | 3.5 | |
| $C_T$ = | 0.50 | (transverse coefficient) | | $K_{nt,T}$ = | 2.33 | |
| λ = | 0.90 | | | $S_{pr}$ = | 3.50 | (g/d) |
| ϕ = | 0.50 | | | Θ = | 1.0 | ($e_1/g \geq 1$) |
| $C_\Delta$ = | 1.0 | | | | | |
| $\lambda\phi R_n$ = | 55.9 | kip | > | $R_u$ = | 44.40 | kip (Sheet 39) |

*Transverse load in line with HSS shelf*

1. Assume the transverse load is carried entirely by the three full depth webs = 20.2 kips/3 = 6.73 kips
2. First analyze a horizontal 1" wide strip of web at mid height of the pontoon for flexure stresses
3. Second analyze the adhesive joint at the top/bottom of the web for shear stresses

| | | | |
|---|---|---|---|
| P = | 6.73 | kip | |
| h = | 31.0 | in | (ht of plate) |
| $l$ = | 3 | in | (length of strip) |
| N = | 0.217 | kip/in | (6.73 / h) |
| $M_A$ = | 2.172 | kip-in | (N x 10) |
| $M_B = M_u$ = | 2.82 | kip-in | ($M_A$ + N x $l$) |




N = distributed load along height of support plate

$M_A$ = applied moment at point A due to load on support plate

$$M_u \le \lambda\phi M_n \qquad M_n = \frac{F_C I}{y}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| $F_C$ = | 48.22 | ksi | | $\lambda$ = | 0.90 | |
| I = | 0.071 | $in^4$ | ($1 \times 0.950^3/12$) | $\phi$ = | 0.65 | |
| y = | 0.475 | in | (0.950/2) | | | |
| $\lambda\phi M_n$ = | 4.24 | kip-in | > | $M_u$ = | 2.82 | kip-in |

4. For shear in adhesive, assume half the force is resisted at the top joint and half at the bottom joint

$$V \le \lambda\phi F_{LT}$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| P/2 = | 3.37 | kip | (6.73 / 2) | | | | |
| $A_s$ = | 24.0 | $in^2$ | (8 x 3) | $\lambda$ = | 0.90 | | |
| $F_{LT}$ = | 1.60 | ksi | (MA560 TDS) | $\phi$ = | 0.50 | | |
| $\lambda\phi F_{LT}$ = | 0.72 | ksi | > | V = | 0.14 | ksi | (P/2 / $A_s$) |

**Compression Loading due to Threaded Rods**

*Compressive strength of FRP blister*

$$P_u \le \lambda \phi F_c A_e$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Steel brng plt, $A_s$ = | 36.0 | $in^2$ | (6x6) |
| Axial force, P = | 55.0 | ksi | (Sheet 34) | $A_h$ = | 1.77 | $in^2$ | (∅1.5 hole) |
| Loaded area, $A_e$ = | 34.23 | $in^2$ | ($A_s$ - $A_h$) | $\lambda$ = | 0.40 | | |
| Comp. strength, $F_c$ = | 48.22 | ksi | | $\phi$ = | 0.70 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_m\lambda\phi_c P_n$ = | 486 | kip | > | $P_u$ = | 77.0 | kip | (1.4 x 55) |

*Compression strength of bulkhead*

$$P_u \le \lambda \phi_c F_c A_e$$

| | | | | | |
|---|---|---|---|---|---|
| Axial force, P = | 55.0 | kip | (Sheet 34) | $\lambda$ = | 0.40 |
| Blkhd xsec area, $A_s$ = | 18.6 | $in^2$ | (35 x 0.53) | $\phi$ = | 0.70 |
| Comp. strength, $F_c$ = | 48.22 | ksi | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda\phi_c P_n$ = | 250 | kip | > | $P_u$ = | 77.0 | kip | (1.4 x 55) |

*Buckling of transverse bulkhead*

$$N_u^c \le \lambda \phi_c N_n^c$$

$$N_n^c = F^{cr} t$$

$$F^{cr} = \left(\frac{t}{b}\right)^2 \frac{\pi^2}{6}\left((4k_{cr} - 3)\sqrt{E_L E_T} + k_{cr} E_T \nu_{LT} + 2k_{cr} G_{LT}\right)$$

Foam provides uniform bracing on both sides of the bulkhead. Therefore, the unsupported length of the plate, "b", is considered to be 0 and the bulkhead is not at risk of buckling.

*Shear and compression on MMA behind blister*

$$V \le \lambda \phi F_{LT}$$

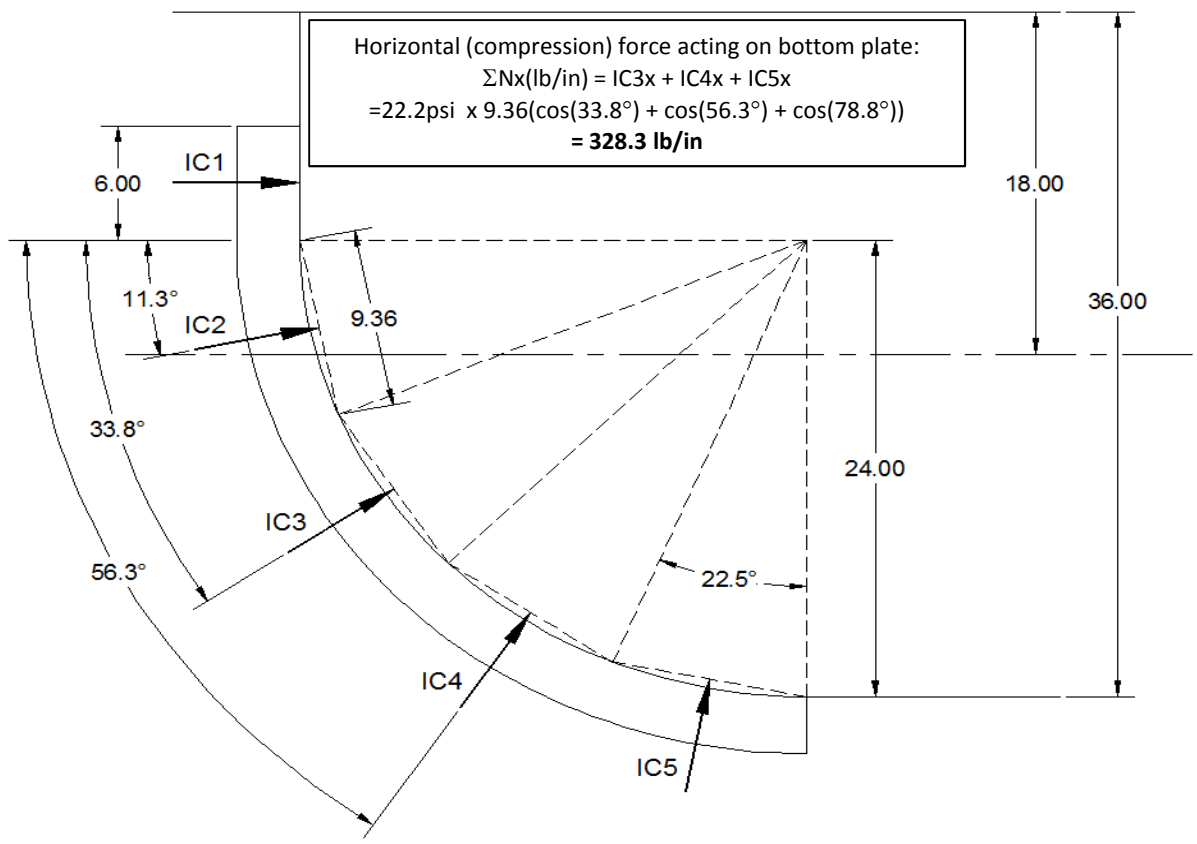
| | | | | | |
|---|---|---|---|---|---|
| $F_{LT}$ = | 1.60 | ksi | (MA560 TDS) | $\phi$ = | 0.70 |
| $F_c$* = | 4.23 | ksi | (MA560 report) | $\lambda$ = | 0.40 |

| | | | | |
|---|---|---|---|---|
| Shear component (55 kip x 1.4 x cos(75.4°)) = | 19.46 | | | |
| Comp. Component (55 kip x 1.4 x sin(75.4°)) = | 74.50 | | | |
| Loaded area, $A_e$ = | 64.25 | $in^2$ | ($A_b$ - $A_h$) | (use 8-1/8 x 8-1/8 plate) |

*Adehesive compressive strength is higher than tensile. However, since compressive strength is not listed in data sheet, the tensile value is used.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\lambda\phi F_{LT}$ = | 0.45 | ksi | > | V = | 0.30 | ksi | (P / $A_e$) |
| $\lambda\phi F_c$ = | 1.18 | ksi | > | V = | 1.16 | ksi | (P / $A_e$) |

**Ice loading**




*Combined compression (bottom plate - Extreme II + Ice)* $\phi$ = n/a per spec for ice

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $M_u$ = | 952 | kip-ft | (Sheet 37) | t = | 0.492 | in | |
| y = | 15.10 | in | (N.A. to mid) | σ = | 1.66 | psi | (ave. stress) |
| I = | 104,251 | $in^4$ | | $N_L$ = | 0.81 | kip/in | (σ x t) |
| λ = | 1.00 | (extreme event) | | $N_T$ = | 0.33 | kip/in | (from above) |
| $\lambda N_n$ = | 13.7 | kip/in | > | $N_T$ = | 0.33 | kip/in | (top plate) |
| $\lambda N_n$ = | 23.7 | kip/in | > | $N_L$ = | 0.81 | kip/in | (bot. plate) |

*Plate bending between bulkheads*

*Using beam on elastic foundation spreadsheet based on equations from "Formulas for Stress and Strain" R. Roark and W. Young (see next page)

$$f_u = \frac{M_u y}{I}$$

*Nominal 1" wide strip at 22.2 psi, w =* 22.2 lb/in

| | | | |
|---|---|---|---|
| I = | 0.010 | $in^4$ | ($0.492^3$/12) |
| $M_u$ = | 0.035 | kip-ft | (BEF sheet) |
| $f_u$ = | 10.41 | ksi | |

Compressive strength of foam = 37 psi at 5% strain. 5% strain over 35" thick foam = 1.75".
K = 37 / 1.75 x 0.85 = 17.97 lb/in²/in

| | | | | | | |
|---|---|---|---|---|---|---|
| $\lambda F_c$ = | 48.2 | kip/in | > | $F_u$ = | 10.41 | ksi |

**Test Laminate Variance vs. Bridge Laminate**

Kenway stands by the choice of laminate when fabricating test specimens for mechanical tests. An approximate thickness of 0.2” is required to perform strength and modulus testing per ASTM standards and within the physical limitations of the test equipment and instrumentation. The best combination of available materials was used to most closely match the percentage of fiber in the various orientations without going so far as to have custom fabrics manufactured at great expense. A summary of the bridge laminate and test laminate percentages is provided below.

| | CSM | ±45 | 0/90 |
|---|---|---|---|
| Bridge | 3 % | 17 % | 80 % |
| Test | 7 % | 17 % | 76 % |
| Delta | 4 % | 0 % | 4 % |

Kenway understands the 4% difference in mat and structural fiber will result in slightly higher strength and modulus values in the bridge laminate than were measured in the test laminate. Regarding the concern over exceeding the upper global stiffness limit in the specification, the measured tensile modulus was lower than design by 5.5% while the measured compression modulus exceeded design by 2.4%. The average change in modulus is 1.5% lower than design. If modulus values from the test laminate are adjusted to exactly match the percentage of fibers in each orientation in the bridge laminate, the predicted change in modulus following the rule of mixtures is shown below.

*Measured tensile and compression modulus per test laminate percentages:*

$$3.09 = 1.51 \cdot 7\% + 3.55 \cdot 76\% + 1.68 \cdot 17\% \qquad 3.35 = 1.75 \cdot 7\% + 3.82 \cdot 76\% + \cdot 1.91 \cdot 17\%$$

*Adjusted tensile and compression modulus per bridge laminate percentages:*

$$3.17 = 1.51 \cdot \underline{3\%} + 3.55 \cdot \underline{80\%} + 1.68 \cdot 17\% \qquad 3.43 = 1.75 \cdot \underline{3\%} + 3.82 \cdot \underline{80\%} + \cdot 1.91 \cdot 17\%$$

As a result, the average change in modulus is calculated as 0.9% higher than the assumed design value – 3,302 ksi vs. 3,270 ksi. This would result in a global raft stiffness of:

$327{,}035{,}000 kip \cdot in^2 = 3{,}302 ksi \times 0.95 \times 104{,}251 in^4$, which is less than the upper limit.

**Grit Blasting Process**

The test pieces were grit blasted as described in the report for approximately 1 min./ft$^2$. To ensure consistency, Kenway will follow the same process in full scale production, which will require approximately 2.5 hours to blast the entire 3 ft by 51 ft surface.

# Material Property Testing for Vtrans Floating Bridge (Addendum)

**Prepared for:**

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**Augusta, Maine**

**University of Maine's Advanced Structures and Composites Center**
**Report Number: 14-24-1267A (Addendum)**

June 12, 2014


**Prepared by:**

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**Reviewed by:**

Olivia Sanchez
ISO Coordinator



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ACCREDITED

*An ISO 17025 accredited testing laboratory, accredited by the International Accreditation Service.*

**Project Number:** 1267
**Project Date:** June 10, 2014
**Material:** E-Glass/Interplastics 8100-50 Vinyl Ester
**Date Received:** April 22, 2014

**Project Summary:** The following material property tests were conducted:

- ASTM D2583-13a - *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*
- ASTM D792-13 - *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*
- ASTM D3171-11- *Standard Test Methods for Constituent Content of Composite Materials*

The client provided a 48 inch by 48 inch composite panel with nominal thickness of 0.22 inches. The standard pontoon laminate will consist of (1) 4008 ±45, (7) 5400 0/90, and (1) 4008 ±45. This results in a total fabric areal weight of 474 oz./yd$^2$ (16 oz./yd$^2$ stitched mat (3%), 80 oz./yd$^2$ ±45 (17%), 378 oz./yd$^2$ 0/90 (80%) ) and a total thickness of 0.508 inches. The laminate schedule for the 0.22 inch test panels was derived to provide a similar ratio of fiber orientations while resulting in a thickness of less than 0.250." The test laminate consists of (1) 1708, (3) 5400, and (1) 1708, which has a total areal weight of 214 oz./yd$^2$ (16 oz./yd$^2$ stitched mat (7%), 36 oz./yd$^2$ ±45 (17%), and 162 oz./yd$^2$ 0/90 (76%) ). Due to the test laminate having a greater percentage of stitched-mat (non-structural fiber); mechanical testing will produce strength and stiffness values that are lower than the actual pontoon laminate and therefore conservative.

The specimens were cut from the 0.22 inch thick panel using waterjet abrasive machining. Final specimen drilling and machining was performed using a milling machine.

Prior to conducting the tests, the specimens were conditioned for a minimum of 48-hours in the laboratory's Mechanical Testing Lab at a standard environment of 70 ±3°F and 50 ±5% RH. The testing was also performed in this lab at standard environment.

The results of the various tests are summarized in the remainder of this document.

**Material Property Test:** Barcol Hardness
**Test Method:** ASTM D2583-13a - *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*
**Date Tested:** June 9, 2014

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**Test Setup:** Ten specimens were obtained from the panel at various locations in an effort to capture spatial variability of the properties. The nominal specimen size was 1 inch wide by 6 inches long. A Coleman GYZJ-934-1 Barcol Impressor was used for the hardness tests. Ten hardness measurements were made on each of the ten specimens.

**Results:** The results of the Barcol hardness tests are presented in Table 1. The table includes the mean value and coefficient of variation (CV) for both the individual measurements made on each specimen, and for the set of ten specimens.

**Table 1. Barcol Hardness Results**

| Specimen | Barcol Hardness | |
|---|---|---|
| # | *Mean* | *CV* |
| **1** | 58 | 11% |
| **2** | 62 | 13% |
| **3** | 63 | 10% |
| **4** | 61 | 11% |
| **5** | 56 | 18% |
| **6** | 58 | 11% |
| **7** | 56 | 9% |
| **8** | 60 | 12% |
| **9** | 59 | 18% |
| **10** | 57 | 11% |
| **Mean** | **59** | |
| **CV** | **3.9%** | |

**Equipment used:**

- Coleman Barcol Impressor AS# 893

**Material Property Test:** Density
**Test Method:** ASTM D792-13 - *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*
**Date Tested:** June 10-11, 2014

---

**Test Setup:** Ten specimens were obtained from the panel at various locations in an effort to capture spatial variability of the properties. The nominal specimen size was 1 inch wide by 6 inches long. Test Method A of ASTM D792-13 was used to perform these tests. The temperature of the water bath used for the wet mass measurements was 25.6°C (78°F).

**Results:** The results of the density measurements are presented in Table 2. The table includes the dry mass, the wet mass, the specific gravity, and the density for each specimen. In addition to the individual specimen results, the table includes the mean value and CV for the laminate properties.

**Table 2. Laminate Density Results**

| Specimen | | | | |
|---|---|---|---|---|
| *ID* | *Dry Mass* | *Wet Mass* | **Specific Gravity** | **Density** |
| *#* | *g* | *g* | | *g/cm³* |
| **1** | 40.5267 | 19.1596 | 1.897 | 1.891 |
| **2** | 40.0059 | 18.9190 | 1.897 | 1.891 |
| **3** | 39.9034 | 18.9470 | 1.904 | 1.898 |
| **4** | 40.0983 | 18.7892 | 1.882 | 1.876 |
| **5** | 39.6436 | 18.5603 | 1.880 | 1.874 |
| **6** | 39.4878 | 18.5932 | 1.890 | 1.884 |
| **7** | 40.5915 | 19.0975 | 1.889 | 1.883 |
| **8** | 40.0786 | 18.9575 | 1.898 | 1.892 |
| **9** | 40.7237 | 19.0448 | 1.878 | 1.873 |
| **10** | 40.1072 | 18.7600 | 1.879 | 1.873 |
| **Mean** | **40.117** | **18.883** | **1.889** | **1.883** |
| **CV** | **1.0%** | **1.1%** | **0.49%** | **0.49%** |

**Equipment used:**

- Ohaus Scale AS# 657
- Thermocouple Meter AS# 186

**Material Property Test:** Constituent Content
**Test Method:** ASTM D3171-11 - *Standard Test Methods for Constituent Content of Composite Materials*
**Date Tested:** June 10, 2014

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**Test Setup:** Ten specimens were obtained from the panel at various locations in an effort to capture spatial variability of the properties. The nominal specimen size was 1.0 inch wide by 1.5 inches long.

Test Method I, Procedure G from ASTM D3171-11 was used for this testing. A Fisher Scientific muffle furnace was used to burn off the resin. The specimens were placed in the furnace at a temperature of 565°C for a duration of 2.5 hours. This temperature and duration were sufficient for complete removal of the resin system.

**Results:** The results of the constituent content tests are presented in Table 3. The table includes specimen mass, constituent weight fraction, and constituent volume fraction. The volume fractions were computed using a resin density of 1.12 g/cm$^3$ [1] and a glass density of 2.55 g/cm$^3$. In addition to the individual specimen results, the table includes the mean value and CV for the set of ten specimens.

**Table 3. Constituent Content Results**

| Specimen | | Weight Fraction | | Volume Fraction | |
|---|---|---|---|---|---|
| *ID* | *mass* | *Fiber* | *Matrix* | *Fiber* | *Matrix* |
| # | g | % | % | % | % |
| 1 | 12.6779 | 70.75 | 29.25 | 51.51 | 48.49 |
| 2 | 12.6571 | 70.67 | 29.33 | 51.41 | 48.59 |
| 3 | 12.6494 | 71.26 | 28.74 | 52.13 | 47.87 |
| 4 | 12.4486 | 70.33 | 29.67 | 51.00 | 49.00 |
| 5 | 12.4452 | 69.73 | 30.27 | 50.30 | 49.70 |
| 6 | 12.3490 | 70.74 | 29.26 | 51.50 | 48.50 |
| 7 | 12.7131 | 70.65 | 29.35 | 51.39 | 48.61 |
| 8 | 12.5314 | 71.02 | 28.98 | 51.84 | 48.16 |
| 9 | 12.7216 | 69.73 | 30.27 | 50.29 | 49.71 |
| 10 | 12.5927 | 69.68 | 30.32 | 50.23 | 49.77 |
| **Mean** | **12.58** | **70.5** | **29.5** | **51.2** | **48.8** |
| **CV** | **1.0%** | **0.8%** | **1.9%** | **1.3%** | **1.4%** |

**Equipment used:**

- Ohaus Scale AS# 657
- Fisher Scientific Furnace AS# 180

[1] CoREZYN® Vinyl Ester Resins Data Sheet, Revision 10/05 A-006b, Interplastic Corporation, 2005.