ROUND ROBIN EXERCISE 2: INTERPRETATION OF BIAXIAL AND SHEAR TEST DATA

This is the second round robin exercise to be run by the TensiNet Analysis & Material Working Group (AMWG). The first exercise was a comparative study of analysis methods and results for a set of well-defined membrane structures. The results were published in 'Engineering Structures' and the full paper is available here: http://eprint.ncl.ac.uk/pub_details2.aspx?pub_id=184881
(click on link to 'Full text file 1' - no journal subscription required)
Round robin 2 will follow a similar format – a comparative exercise carried out by practitioners and Universities worldwide, with the anonymized results presented at conferences, in TensiNews and in academic journals. Contributors will be acknowledged in all disseminations.
The exercise is being organised by Dr Ben Bridgens and Prof Peter Gosling. The email address for correspondence, including return of completed submissions, is: tensinet.amwg@ncl.ac.uk.

1. What is a "round robin"?

A **"round robin"** exercise refers to an activity (e.g. measurement of properties, structural analysis, or physical experiment) performed independently by different groups, institutions, or companies. Each participant will provide an independent solution to a particular problem. Once the exercise is complete the solutions are reviewed and analysed. The collective outcomes are then used to produce a number of key conclusions and recommendations.

2. The purpose of the round robin exercises

Firstly, and most importantly, it should be noted that the round robin exercise is not a competition. The round robin exercise aims to determine the current state of activity in a particular field and to assist in the development of that field.

It is well known that coated woven fabrics exhibit complex, non-linear biaxial and shear behaviour. Variations in biaxial and shear test methods and interpretation of the results from these tests introduces considerable uncertainty in material properties for use in analysis. **This exercise will focus on the interpretation of biaxial and shear test data, i.e. the assessment of the stiffness of architectural fabrics and how these properties are represented in the analysis of a structure.**

The work of drafting a Eurocode for Membrane Structures by CEN/TC 250 Working Group 5 is underway. It is important that the EN standard accurately reflects the methodologies and practices used in the analysis and design of membrane structures. Interpretation of test data and the method of incorporating this information in membrane analysis is an important part of this. This is clearly important at the European level, and also for international practice for which the EN standard for Membrane Structures may be adopted. This is particularly relevant given the link between the CEN and ISO organisations through which CEN standards may be adopted worldwide.

3. Principles

The round robin exercise is proposed as a non-commercial activity. It is intended to serve the purpose of advancing scientific knowledge and engineering practice in the analysis and design of membrane structures. Participation in the round robin exercise is further based on the following principles:

- Involvement in the round robin exercise is voluntary,
- Completion of the round robin tasks is undertaken without fee and liability,
- The completed tasks will not be used outside the remit of the round robin exercise and will not be made available in a format that could be used for design purposes by a third party,
- The round robin outputs will be made anonymous in two ways: (I) participants will be acknowledged in all dissemination, but all results will be reported anonymously, (II) manufacturers who provide materials for the exercise will be acknowledged in all dissemination, but fabric materials will be described generically (e.g. Type III PVC-polyester) such that the results cannot be associated with a particular material.

4. Overview

Round robin 2 will operate in two distinct ways depending on the type of participant:

Route A: interpretation of 'typical' biaxial and shear test data provided by Newcastle University. Route A is for consultants, analysts, designers and fabricators who interpret biaxial test results provided by others. Newcastle University will provide data from 'typical' biaxial and shear tests. Participants will be provided with biaxial and shear test data for a selection of fabrics, in both graphical form and tables of stress and strain values (.csv and .xls formats). Full details of the Newcastle University biaxial and shear test equipment will be provided. In addition, participants will be provided with a description of the structure that the fabric is being used for, including stress plots, in case this information is required to inform their interpretation of the test data. Participants will report how the test data is analysed and incorporated in their analysis (see Section 4 below for details).

Route B: carry out biaxial and/or shear test and interpret results. Route B is primarily for test houses, but may also apply to consultants and analysts, whose method of interpretation relies on results from a particular test protocol. Participants will be provided with fabric samples, and a description of the structure that the fabric is being used in, including stress plots, in case this information is required to inform their testing and interpretation of the test data. Participants will carry out fabric testing and then provide details of how the test results are interpreted (see Section 4 below for details).

Participants may take part in both routes – providing interpretation of typical test data, and carrying out their own tests and interpreting those results. Alternatively it may be the case that an organisation follows one route for interpretation of shear results, and the other route for interpretation of biaxial results. The guiding principle is that participants should carry out whatever methodology they would usually use on a commercial project.

Note that Round robin 2 is **NOT** a comparative material testing exercise. We do not expect different organisations to repeat the tests detailed below (Section 6). Further testing (Route B) is only required if a particular method of interpretation relies on data from a particular test protocol.

5. Reporting of results

A standard form will be provided to report the results of the exercise, which will ask for the following information:

5.1 Route A: interpretation of 'typical' biaxial and shear test data provided by Newcastle University

A1. Describe how the biaxial stiffness of the fabric is incorporated in your analysis. A typical response may be specification of elastic moduli and Poisson's ratio, but we are also interested in other methods.

A2. Describe how you determined the biaxial stiffness parameters described in A1. For example, methods include the MSAJ strain minimisation approach or calculating gradients from stress-strain plots. Provide as much detail as possible – attach additional sheets as required. Report if and how the

details of the proposed structure (see Section 4) were incorporated in your interpretation of the test results.

A3. Describe how the shear stiffness of the fabric is incorporated in your analysis. A typical response may be: specification of shear modulus, but we are also interested in other methods.

A4. Describe how you determine the shear stiffness parameters described in A3. For example, methods include calculating gradients from stress-strain plots or using typical values based on biaxial stiffness. Provide as much detail as possible – attach additional sheets as required. Report if and how the details of the proposed structure (see Section 4) were incorporated in your interpretation of the test results.

A5. For each set of test results (PVC-polyester, PTFE-glass, and so on) provide the values that would be used to represent the biaxial and shear behaviour in the analysis. A typical response may be values of elastic moduli, Poisson's ratio and shear stiffness for each material, or other values as described in A1 and A3.

5.2 Route B: carry out biaxial and/or shear test and interpret results

B1. Describe the principles of operation of the biaxial test equipment that you have been used for this exercise.

B2. Provide details of the biaxial test protocol that has been used. This would typically take the form of a series of times and force values in warp and fill directions. Report if and how the details of the proposed structure (see Section 4) informed the details of the test protocol.

B3. Describe the principles of operation of the shear test equipment that you have used for this exercise.

B4. Provide details of the shear test protocol that you have used. This would typically take the form of a series of times and force values in warp and fill directions. Report if and how the details of the proposed structure (see Section 4) informed the details of the test protocol.

B5. Provide your biaxial and shear test results, in both graphical form and tables of stress and strain values (.csv and .xls formats).

B6. Complete A1 – A6 (above) to describe how the test results are interpreted.

6. Proposed biaxial and shear test protocols for Route A – for comment

The following test protocols are proposed as they are widely used in industry, but we welcome any comments or suggestions for modifications.

6.1 Proposed biaxial test protocol

Cycles	Description	Warp load (percentage of warp UTS)	Fill load (percentage of fill UTS)
1-3	1:1 conditioning	25%	25%
4-6	1:1	25%	25%
7-9	2:1	25%	12.5%
10-12	1:1 conditioning	25%	25%
13-15	1:2	12.5%	25%
16-18	1:1 conditioning	25%	25%
19-21	1:0	25%	Prestress
22-24	1:1 conditioning	25%	25%
27-29	0:1	Prestress	25%

Notes:
UTS = strip ultimate tensile strength (kN/m),
Values given are peak values, loads return to prestress between cycles,
Each cycle takes 10 minutes (5 minutes increasing load + 5 minutes decreasing load).

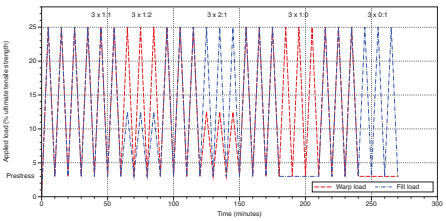

Figure 1. Proposed biaxial test protocol

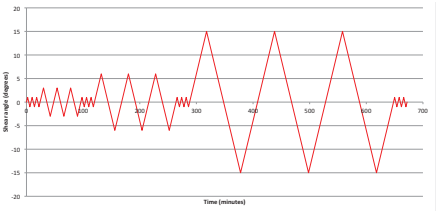

Figure 2. Proposed shear test profile.

6.2 Proposed shear test protocol

Cycles	Shear angle
1-3	+/- 1 degree
4-6	+/- 3 degrees
7-9	+/- 1 degree
10-12	+/- 6 degrees
13-15	+/- 1 degree
16-18	+/- 15 degrees
19-21	+/- 1 degree

Note: The shear test is displacement controlled – a shear angle is imposed and the shear force required to achieve this deformation is recorded.

7. Timeline

March 2015	**Round robin 2 is launched.** **Proposed test protocols are provided for comment.** **Manufacturers are invited to volunteer to provide fabric samples for testing.** We are looking for one medium weight example of each material – e.g. 1 x Type III PVC-polyester, 1 x PTFE-glass, 1 x silicone-glass, 1 x Tenara?, 1 x other interesting materials…? It is anticipated that no more than 10 linear metres of each fabric will be required, and the amount will be minimised once we know how many participants are taking Route B. **Participants are asked to register their interest in the exercise by emailing Dr Ben Bridgens at tensinet.amwg@ncl.ac.uk and to specify whether they want to take Route A or Route B** (in which case they will require fabric samples).
June 2015	Test protocols for Route A are finalised.
	samples are delivered to Newcastle University for testing and distribution to participants taking Route B.
August 2015	Full details of round robin 2 are circulated to participants including all test data and reporting forms.
October 2015	Deadline for return of results to tensinet.amwg@ncl.ac.uk
Nov 2015 – March 2016	Analysis and dissemination of results

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