EFFECTS ON ELASTIC CONSTANTS OF TECHNICAL MEMBRANES APPLYING THE EVALUATION METHODS OF MSAJ/M-02-1995

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Summary. The non-linear load-deformation behaviour of textile membranes highly depends on the ratio of the applied membrane forces in warp and weft direction (called load ratio hereafter). In practice, usually for each membrane structure the biaxial material behaviour is determined experimentally. The Japanese Standard MSAJ/M-02-1995 describes a standardized biaxial testing procedure. To achieve input parameters for the structural design process, the commentary to this standard explains some methods how to evaluate one set of fictitious elastic constants based on the experimental results which, simultaneously, envelop different load ratios and do not reflect the non-linear material behaviour anymore. Different approaches of determining such simplified, fictitious elastic constants have been investigated in the present contribution, with mainly two conclusions: firstly, to have one set of elastic constants by means of which all types of structures under all types of loading can be treated is a highly disputable objective and secondly, the values of the determined elastic constants react quite sensitively on the underlying determination option, which should be defined by the users themselves.

1 INTRODUCTION

Typical coated woven fabrics used in membrane structures are made of Glass/PTFE or Polyester/PVC. Both fabrics show an extremely nonlinear load-deformation behaviour under biaxial tension, which is the common loading condition of textile membranes.

The structural design of membrane structures depends on this load-deformation behaviour, which can vary even for one membrane type of one fabricator from batch to batch. Due to this fact biaxial tensile tests are usually performed for each membrane structure to determine its specific load-deformation behaviour as source for realistic input parameters for the design calculation.

From the engineering point of view an international standardized testing and evaluation procedure is desirable for the determination of the load-deformation behaviour of membrane materials. A standardized procedure should allow the comparison of different membrane materials on an objective base. The Membrane Structures Association of Japan developed such a standardized biaxial testing procedure, which was published 1995 in the standard MSAJ/M-02-1995 "Testing Method for Elastic Constants of Membrane Materials"[1]. This excellent standard has been more and more internationally accepted during the last 15 years and has been used increasingly as a basis for contractual arrangements between design engineers, contractors, manufacturers and/or fabricators.

The main characteristic of the MSAJ/M-02-1995 testing procedure is that five different load ratios for the membrane forces in warp and weft direction have to be applied in a precisely defined sequence. Herewith, different non-linear load-strain-paths are measured depending on the applied load ratios.

Usually, the design calculation of a membrane structure is performed using modern software packages which are based on finite elements and which are able to handle global geometric non-linearity as well as material non-linearity, although the latter only in terms of the membrane's inability to carry in-plane compression. For simplicity, the load-deformation-behaviour of the membrane in tension is usually treated linear-elastically, which means that the non-linear load-deformation-behaviour is not considered in the design process. There seems to exist a great lack of knowledge how to simulate and herewith how to include the non-linearity of the membrane material in the design process.

The main topic of the MSAJ/M-02-1995 is the standardized biaxial testing procedure in order to deliver realistic information on the load-strain behaviour. Optimally, for each loading condition the specifically measured non-linear load-strain-characteristics would directly be introduced into the design calculation. However, up to now this is not feasible. The commentary to MSAJ/M-02-1995 therefore explains exemplarily some methods how to simplify the non-linear load-strain behaviour in order to achieve certain fictitious elastic constants which shall approximately describe the membrane material.

The simplified evaluation of the experimental load-strain-paths according to the commentary of MSAJ/M-02-1995 has already led to intensive discussions, e. g. by Bridgens & Gosling[3]. In addition to their investigations, the aim of this contribution is firstly, to discuss the application of the simplified methods on principle and secondly, to present and discuss results of different options for the simplified determination of such fictitious elastic constants. The quantitative effects of these different determination options on the resulting sets of elastic constants will be investigated by means of exemplary test data.

2 BIAXIAL TESTING APPLYING MSAJ/M-02-1995

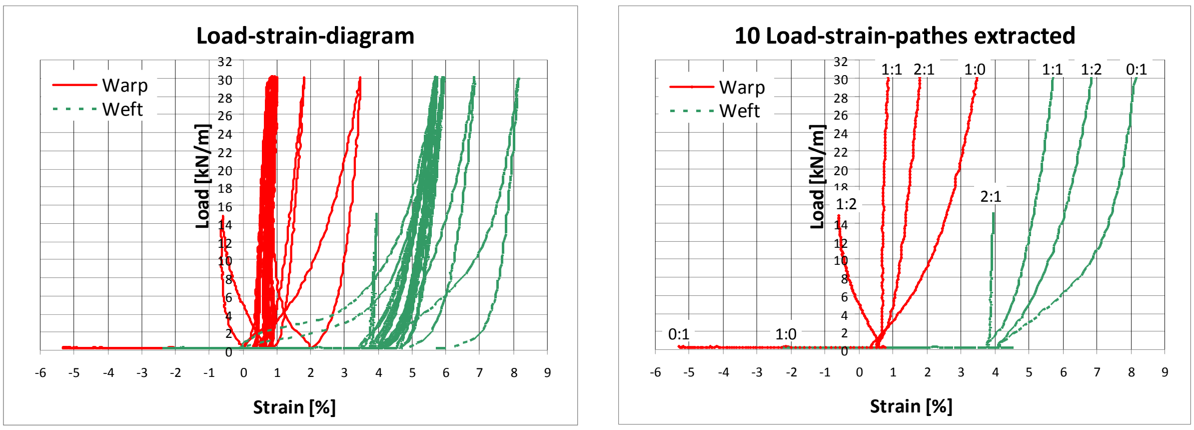
As already mentioned, MSAJ/M-02-1995 principally describes a standardized biaxial testing procedure for woven membrane materials. The scope is to obtain the non-linear load-strain relationship. The biaxial tests are performed applying tensile loads in the warp and weft direction on a cross-shaped specimen for five different defined load ratios of the membrane forces in warp and weft direction, see figure 1 and table 1. Figure 1 shows one of the biaxial testing machines of the Essener Labor für Leichte Flächentragwerke of the University of Duisburg-Essen, which has maximal loads of 50 kN in each direction.

Direction of yarn	Load ratio				
Warp direction	1	2	1	1	0
Weft direction	1	1	2	0	1

Table 1: Load ratios applied during biaxial tensile testing starting with 1:1 and ending with 0:1

Figure 2 (a) shows a typical load-strain-diagram as a result of a biaxial test according to MSAJ/M-02-1995 of a Glass/PTFE material, type G6 according to the European Design Guide for Tensile Surface Structures[4]. This load-strain-diagram consists of ten load-strain-paths: one load-strain-path each for the warp and weft direction at five load ratios, see figure 2 (b). The two zero-load-paths for the load ratios 1:0 and 0:1 appear as horizontal straight lines in this particular way of plotting.

Figure 1: Biaxial testing machine of the Essener Labor für Leichte Flächentragwerke at the University of Duisburg-Essen with a maximum load of 50 kN in each direction



(a) (b)

Figure 2: (a) Load-strain-diagram as a result of a MSAJ biaxial test on Glass/PTFE material Type G6, (b) ten load-strain-paths (warp/weft at five load ratios), as extracted from the diagram

Architectural fabrics are woven from single yarns and coated afterwards. The yarns lay crimped in the fabric matrix. The crimp value depends on the stress in the warp and weft direction that is applied during the weaving process [4]. As the stresses in warp and weft direction usually do not have the same values, due to the crimp interchange the fabric shrinks differently in both directions. Herewith, woven membranes behave orthogonal anisotropic, see figure 2.

3 DETERMINATION OF ELASTIC CONSTANTS APPLYING THE COMMENTARY OF MSAJ/M-02-1995

In design practice, the membrane material is considered as a linear-elastic orthogonal anisotropic two dimensional plane-stress structure. For this reason, the commentary of MSAJ/M-02-1995 describes several possibilities how to determine a set of fictitious elastic constants for the use in practical design, which consist of the stiffness, E_x and E_y, and Poisson's ratio, ν_{xy} and ν_{yx}, each in warp and weft direction. The defined set of constants meets the requirements of constitutive equations for linear-elastic, orthotropic materials used for numerical simulations, see exemplary Münsch & Reinhardt [2]. This set of constants describes an optimized approximation while using specified load-strain-paths considering the full range of experimental load values for the evaluation. The sets of elastic constants have to be treated as "fictitious" elastic constants because firstly, they shall estimate the non-linear load-deformation behaviour of the material and secondly, they shall envelop all load combinations in warp and weft direction.

On the basis of the afore described simplifications, the commentary of MSAJ/M-02-1995 proposes to express the relationship between load and strain with the following equations

$$\varepsilon_x = \frac{n_x}{E_x \cdot t} - \nu_{xy} \cdot \frac{n_y}{E_y \cdot t}, \tag{1}$$

$$\varepsilon_y = \frac{n_y}{E_y \cdot t} - \nu_{yx} \cdot \frac{n_x}{E_x \cdot t}. \tag{2}$$

Hereby, ε describes the strain, n is the load, E is the stiffness and ν is the Poisson's ratio with ν_{xy} is the transverse strain in x-direction caused by a load in y-direction and ν_{yx} is the transverse strain in y-direction caused by a load in x-direction. The x-direction corresponds to the warp direction of the fabric, the y-direction to the weft direction. The number of unknowns in these equations is four: the two stiffnesses and the two Poisson's ratios. The further idealisation of the membrane material to a linear-elastic orthogonal anisotropic plane stress plate with a symmetric stiffness matrix leads to the constraint

$$\frac{E_x \cdot t}{E_y \cdot t} = \frac{\nu_{yx}}{\nu_{xy}}, \tag{3}$$

which is referred to as the "reciprocal relationship" in the commentary of MSAJ/M-02-1995. This additional constraint reduces the number of unknowns to three, but it does not necessarily correspond to the behaviour of woven membrane materials. Modelling of the membrane by assuming a linear-elastic orthotropic plane stress is well known to be a rather rough structural model for a coated woven fabric with its above-mentioned nonlinear load-strain behaviour. Over all, it must be aware that this way of modelling of the load-strain behaviour is just a vague approximation.

The determination of the fictitious elastic constants from the load-strain-paths has to be performed stepwise in a double step correlation analysis. In the first step each curved loading path has to be substituted by a straight line. In the second step the slopes of the straight lines obtained in the first step have to be modified in such a way that they satisfy the equations of the assumed linear elastic plane stress behaviour and describe all experimental loading paths for all five load ratios optimally by just one set of four fictitious constants. The commentary of the MSAJ-Standard recommends to use eight of the ten measured loading paths omitting the two zero load paths, although, four paths would be sufficient to determine a set of four fictitious elastic constants. Bridgens & Gosling [3] already have discussed the significantly different results in the determination of the elastic constants when using all ten paths instead of the eight paths as recommended in the MSAJ-Standard.

To determine the optimum set of elastic constants the commentary of MSAJ/M-02-1995 proposes the "least squares method", the "best approximation method" and other simplified methods. The "best approximation method" and the other methods are not presented here. The "least squares method" is known from the determination of regression lines in statistic calculations and has been used in the present investigations. The scope is to minimize the sum of squares of errors in a certain subject interval [a, b] between a continuous function $f(x)$ and an approximation equation $y(x)$:

$$S = \int_a^b [f(x) - y(x)]^2 \, dx \rightarrow min \, . \tag{4}$$

The errors can either be defined as the vertical differences (load errors S_σ) or the horizontal differences (strain errors S_ε). For the determination of the elastic constants this means that either the load term or the strain term can be minimized: $S_\sigma \rightarrow$ min or $S_\varepsilon \rightarrow$ min. For clarification see figure 3 (a) and (b), each showing three exemplary errors - load and strain, respectively - between an experimental load-strain-path and an arbitrary line. The commentary of MSAJ/ M-02-1995 recommends the application of various methods to determine the elastic constants and to use the most satisfactory combination of constants. It has not to be noted here, that this procedure does not fit with a "standardized procedure" and will lead to variable values depending on the chosen procedure of the user, too.

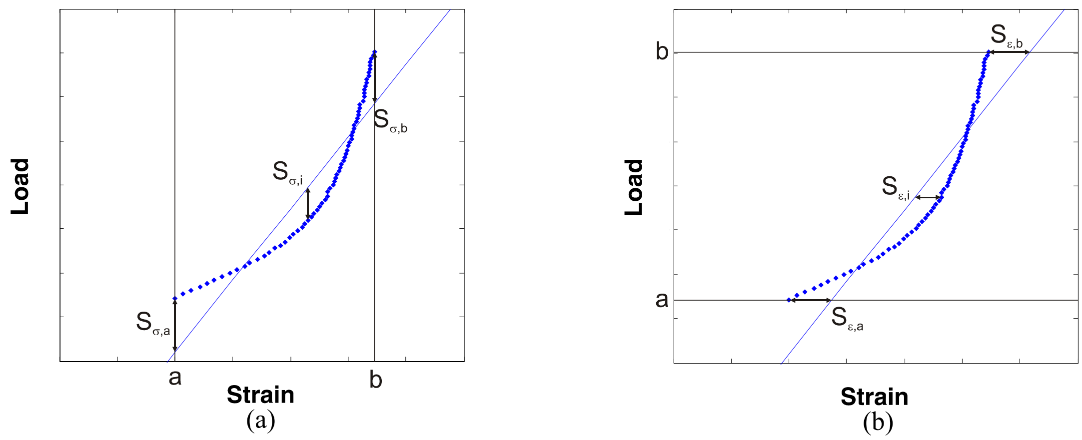


Figure 3: (a) Vertical errors are calculated in order to minimize the load term, (b) horizontal errors are calculated in order to minimize the strain term

In the design process for a membrane structure the residual strains are taken into account in the process of compensation. This means that the membrane material is shortened by the value of the residual strains before installation. Usually, the residual strains are not included in the static calculation of a membrane structure. Therefore, it is reasonable to remove the residual strains from the test data for the determination of the elastic constants.

The commentary of MSAJ/M-02-1995 recommends to use straight lines connecting the point of 2 kN/m (for Glass/PTFE membranes) and the point of the maximum experimental load for the determination of the constants. Herewith, the fictitious elastic constants and the corresponding lines are determined with the aim to reflect the strain at the maximum experimental load in the best way. Although this procedure satisfies the desire for standardization, the service loads of the most membrane structures do not reach the maximum experimental loads during their life time. Herewith, this procedure might not be sufficient for practical design efforts.

4 ROUTINE FOR THE DETERMINATION OF ELASTIC CONSTANTS

For the determination of the fictitious elastic constants from test data a correlation analysis routine was programmed by using the commercial software MATLAB [5]. The basis of the routine is the calculation of regression lines using the least squares method as proposed in the commentary of MSAJ/M-02-1995. A regression line in a load-strain-diagram follows the linear equation (5), in which n is the load, m is the slope, ε is the strain and b is the intersection point of the regression line with the load-axis at zero strain:

$$n = m \cdot \varepsilon + b\ . \tag{5}$$

In a first step, the routine evaluates the regression lines for all experimental load-strain-paths. Herewith, ten regression lines and their values for m and b are determined so that each of the ten load-strain-paths is fitted optimally. A regression line for an arbitrary experimental load-strain-path is shown in figure 4. It is the nature of a regression line to reflect the slope of the path in a good manner. Usually, the regression line has another intersection point b with the load-axis at zero strain than the test data path itself. To describe the stiffness of a linear-elastic material in a load-strain-diagram the intersection point of the regression line is not important but the slope. To provide the typical illustration of a linear load-strain behaviour, the intersection point of the regression line may be switched into the intersection point of the test data path for the plots, see figure 4.

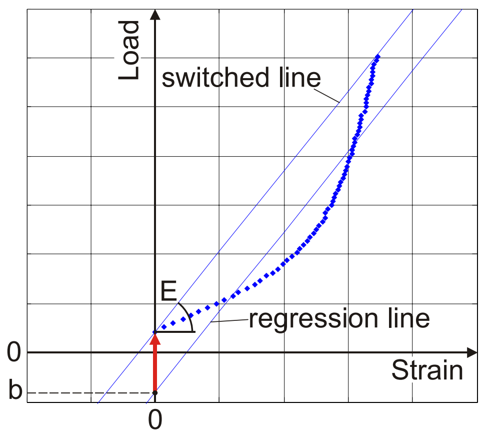


Figure 4: Regression and switched lines for a test data path

In order to set up fictitious straight load-strain-lines the programmed routine generates in a second step all possible combinations of the four fictitious elastic constants within limit values and increments established by the user. The increments may be quite rough in a first step of the analysis. They can be set to smaller values in an adjacent fine analysis, which will be conducted in the periphery of the best fit result of the rough analysis. In case that the reciprocal relationship, see eq. (3), is applied, only those combinations are taken into account that satisfy this constraint within arbitrary limits. In the investigations for this contribution the limits are set to

$$\frac{\nu_{yx}}{\nu_{xy}} - 0.005 < \frac{E_x}{E_y} < \frac{\nu_{yx}}{\nu_{xy}} + 0.005 , \quad (6)$$

which seems to be precise enough.

In a third step, the strain values of the fictitious load-strain-lines are calculated for one arbitrary load level at each load ratio according to equations (1) and (2) inserting the generated constants. Knowing the strain values enables the evaluation of the slope of the fictitious load-strain-lines. Each fictitious load-strain-line j is related to the load-strain-path j of the test data. The slopes of the fictitious load-strain-lines j are calculated with equation (7) at the various load ratios using arbitrary values for n_x and n_y. The only constraint is that the ratios of n_x and n_y satisfy the respective load ratio.

$$m_j = \frac{n_j}{\varepsilon_j} \quad (7)$$

For the further procedure the intersection point of each load-strain-line at the load-axis at zero strain is set to the respective value b of the related regression line. This ensures that those load-strain-lines with a slope that approaches the slope of the respective regression lines lead to the “least squares”. In order to calculate the strain values for a fictitious load-strain-line j for each existent test data point i of the related load-strain-path j, equation (5) has to be transformed into equation (8)

$$\varepsilon_i = \frac{n_i - b_j}{m_j} . \quad (8)$$

Finally, the sum of squared strain errors over all n test data points and m load-strain-paths considered in a determination of constants can be calculated using the following equation

$$S_\varepsilon = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(\varepsilon_i - \bar{\varepsilon}_i \right)^2 , \quad (9)$$

in which ε_i is the result of equation (8) and $\bar{\varepsilon}_i$ is the value of the related test data point, respectively. The value S_ε is the sum of all squared horizontal differences explained in figure 3 (b). The optimum set of constants in the meaning of the commentary of MSAJ/M-02-1995 is the one combination of elastic constants with the minimum value S_ε.

The programmed routine was validated with the exemplary test data presented in the commentary of MSAJ/M-02-1995. Hereby, very similar results were achieved by using the least squares method minimizing the strain term compared to the presented ones in the commentary of MSAJ/M-02-1995.

5 EXEMPLARY EVALUATION OF TEST DATA

Based on the afore mentioned evaluation procedure, the influence of different "determination options" on the resulting elastic constants has been investigated. For this purpose, test data of 70 biaxial tests on the Verseidag-Indutex membrane material B 18089 were considered. This is an often used and well-proved Glass/PTFE material type G6[4] with nominal tensile strength values of 140/120 kN/m in warp/weft direction.

All mentioned tests had been conducted in the context of real projects in the last three years at the Essener Labor für Leichte Flächentragwerke of the University of Duisburg-Essen. In order to get an insight into how much even for one type of material produced by a manufacturer with high quality management level the calculated values of fictitious elastic constants might inevitably vary, three tests were systematically selected out of the 70 biaxial tests – in the following referred to as T1, T2 and T3 – with the aim to cover approximately the whole realistic spectrum. Within the relatively narrow range of observed behaviour characteristics, Test T2 represents the average, while Test T1 shows a somewhat stiffer behaviour in warp direction combined with a somewhat softer one in weft direction, and Test T3 behaves the other way around (somewhat stiffer in weft and softer in warp direction). The maximum test load was max. n = 30 kN/m.

Table 2 shows the calculated elastic constants using eight differently defined "determination options". All results were calculated using the least squares method minimizing the strain term as described in chapter 4. The first four determination options make use of all five load ratios applied in the standardized MSAJ test, see table 1. Calculations have been performed either using eight load-strain-paths as proposed in the commentary of the MSAJ-Standard (i.e. omitting the zero-load-paths), see options 1 and 2, or using all ten load-strain-paths as proposed by Bridgens & Gosling [3], see options 3 and 4. Additionally, a differentiation was made with regard to applying the reciprocal relationship (yes or no), see options 1, 3 versus options 2 and 4.

The last four determination options 5 to 8 in table 2 have been defined by the authors to simulate reasonable decisions of rationally thinking structural design engineers with regard to their specific membrane structure. For a synclastic structure with almost identical membrane forces in warp and weft direction under design loading, the determination might reasonably be conducted using the load ratio 1:1, combined with either 2:1 or 1:2 (at least four load-strain-paths are needed for the determination of the unknowns). For an anticlastic structure with predominant warp stressing under the critical design load case, the load ratios 2:1 and 1:0 might be reasonable (option 7), and for the opposite type of stressing the load ratios 1:2 and 0:1 (option 8). For all determination options 5 to 8, the reciprocal relationship is applied as proposed in the commentary of the MSAJ-Standard. Furthermore, in determination options 7 and 8 three load-strain-paths are used omitting the zero-load-paths.

Figure 5 exemplarily shows the experimental load-strain-paths of Test T2 together with the theoretical straight lines obtained with the fictitious elastic constants from determination option 1 in table 2, i.e. using eight load-strain-paths in compliance with the commentary of MSAJ/M-02-1995 and applying the reciprocal relationship. Figure 6 shows the corresponding results for determination option 3 in table 2, i.e. using all ten load-strain-paths and also the reciprocal relationship applied. In figures 5 and 6 the strains are plotted against the „leading membrane force ", which is meant to be the larger one at each load ratio. This form of plotting was chosen to avoid meaningless horizontal lines for the zero-load-paths.

	Determination options	Test data	Stiffness [kN/m]		Poisson's ratio [-]		S_ε	Note
			E_xt	E_yt	ν_{xy}	ν_{yx}		
1	All load ratios - 8 load-strain-paths - reciprocal relationship applied	T1	1322	718	0,55	1,01	41,06	MSAJ original
		T2	1292	816	0,57	0,90	32,72	
		T3	1122	884	0,68	0,86	24,64	
2	All load ratios - 8 load-strain-paths - reciprocal relationship not applied	T1	1212	766	0,71	0,74	27,94	MSAJ modified
		T2	1188	864	0,73	0,69	23,09	
		T3	1066	924	0,79	0,71	20,96	
3	All load ratios - 10 load-strain-paths - reciprocal relationship applied	T1	918	544	0,82	1,38	696,66	MSAJ modified as in [3]
		T2	914	610	0,83	1,24	637,19	
		T3	756	660	1,00	1,15	520,31	
4	All load ratios - 10 load-strain-paths - reciprocal relationship not applied	T1	888	558	0,89	1,28	690,59	MSAJ modified
		T2	860	634	0,94	1,08	625,49	
		T3	766	658	0,99	1,19	519,63	
5	Two load ratios: 1:1 / 2:1 - reciprocal relationship applied	T1	1580	798	0,45	0,89	4,89	practical approach (synclastic)
		T2	1600	924	0,48	0,83	2,14	
		T3	1566	1074	0,55	0,80	0,45	
6	Two load ratios: 1:1 / 1:2 - reciprocal relationship applied	T1	1600	738	0,55	1,19	7,96	practical approach (synclastic)
		T2	1336	824	0,60	0,97	4,42	
		T3	1250	920	0,65	0,88	3,05	
7	Two load ratios: 2:1 / 1:0 - 3 load-strain-paths - reciprocal relationship applied	T1	520	770	0,88	0,59	0,67	practical approach (anticlastic)
		T2	520	894	1,33	0,78	0,62	
		T3	500	1083	1,43	0,69	0,35	
8	Two load ratios: 1:2 / 0:1 - 3 load-strain-paths - reciprocal relationship applied	T1	522	372	0,75	1,05	0,23	practical approach (anticlastic)
		T2	500	732	1,40	0,96	0,98	
		T3	540	500	0,74	0,80	0,29	

Table 2: Elastic constants from three biaxial tests of the same Glass/PTFE material Type G6 obtained using different determination options

Using the determination options based on the commentary of MSAJ/M-02-1995 – fully original or modified, options 1 to 4 – results in an "alarmingly" great variety of values for the calculated elastic constants: $E_x \cdot t$ varies between 756 kN/m and 1322 kN/m, $E_y \cdot t$ between 544 kN/m and 924 kN/m, ν_{xy} between 0.55 and 1.00, and ν_{yx} between 0.69 and 1.38.

It can be seen from figure 5 that for determination option 1 the calculated load-strain-lines match the experimental load-strain-paths, in particular the points of maximum experimental load quite well – of course except for the zero-load-paths of the load ratios 1:0 and 0:1, because they were omitted from the correlation process. Bridgens & Gosling [3] propose to take into account these zero-load-paths, too, because they contain relevant mechanical information regarding the load bearing behaviour of anticlastic structures. However, it may be concluded by plausibility from figure 5 that, in order to achieve an improved matching of the two calculated zero-load-lines with their experimental counterparts, smaller theoretical values for ε_y at 1:0 and ε_x at 0:1 would be necessary. This would imply smaller values for the stiffnesses and higher values for the Poisson's ratios, as becomes obvious from eqns. (1) and (2). For example: at 1:0, with $n_y = 0$, the strain ε_y in eq. (2) decreases if ν_{yx} increases and $E_x \cdot t$ decreases.

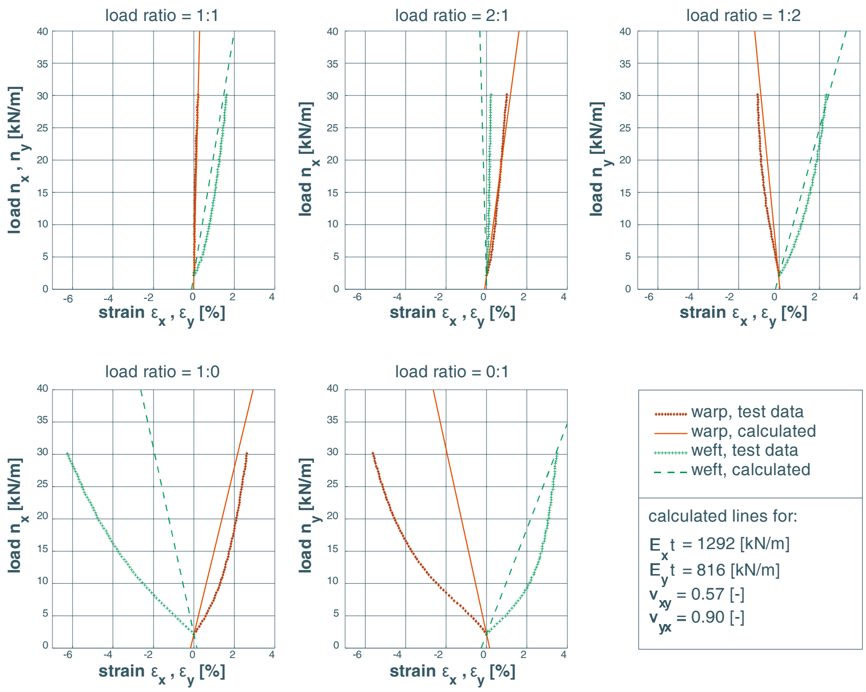


Figure 5: Results for Test T2, 8 load-strain-paths, reciprocal relationship applied (det. opt. 1)

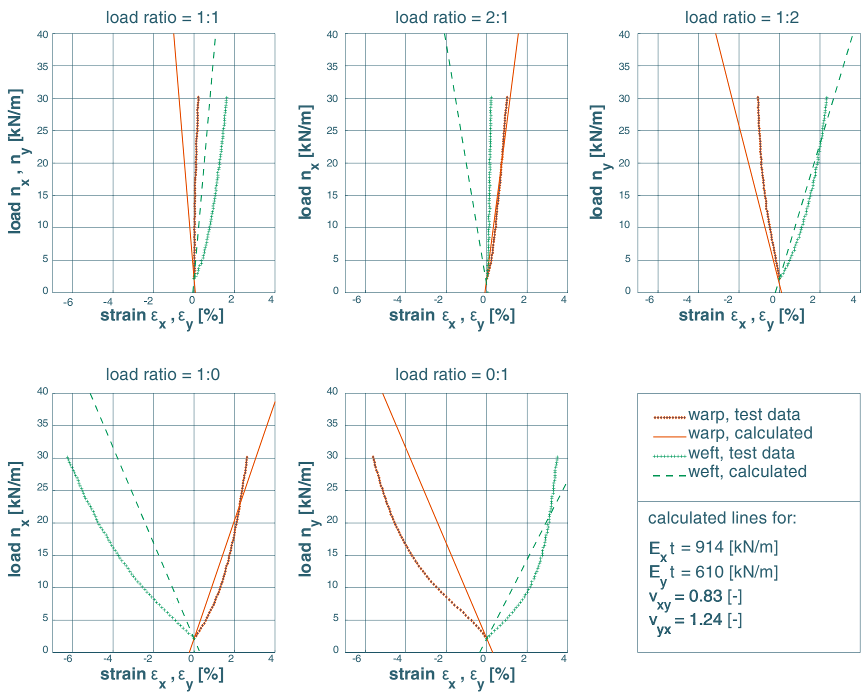


Figure 6: Results for Test T2, 10 load-strain-paths, reciprocal relationship applied (det. opt. 3)

Figure 6 shows that – using determination option 3 – the two calculated zero-load-lines fit indeed somewhat better with their experimental counterparts, but for the "price" of greater disagreement for all other calculated load-strain-lines. This effect is reflected by the results in table 2, comparing options 1 and 2 with options 3 and 4. For example, the calculated stiffness $E_x \cdot t$ decreases dramatically from values greater than 1000 kN/m to values smaller than 1000 kN/m when the zero-load-paths are taken into account. Attention should be paid to the much worse correlation measure S_ε for the determination options 3 and 4 (column 8 in table 2).

A comparison of the determination options 1 and 2 shows, that applying the reciprocal relationship has a significant influence on the calculated constants if only eight load-strain-paths are evaluated, especially on the Poisson's ratios. Applying the reciprocal relationship increases the values of ν_{yx} and decreases those of ν_{xy}, e.g. for Test T2 from 0.90 to 0.69 and from 0.57 to 0.73, respectively. The influence of the reciprocal relationship is smaller if ten load-strain-paths are evaluated, as can be seen from the results for determination options 3 and 4: For Test T2, ν_{yx} decreases from 1.24 to 1.08 and ν_{xy} increases from 0.83 to 0.94.

If a practical, i.e. a structural design engineer's approach is used for the determination of the fictitious constants, see determination options 5 to 8 in table 2, the results vary even more. Especially, the stiffness values reach extreme values: $E_x \cdot t$ varies from 500 kN/m up to 1600 kN/m and $E_y \cdot t$ varies from 372 kN/m up to 1083 kN/m.

It can be summarized, that the values of fictitious elastic constants evaluated from one and the same biaxial MSAJ-test depend extremely on the underlying determination option – even if, as performed in the present investigations, only one numerical correlation method is applied (here: the least squares method minimizing the strain term), and if the calculated lines are optimized only for one load range (here: between minimum and maximum experimental test load).

6 CONCLUSIONS

The Japanese Standard MSAJ/M-02-1995 describes first and foremost a standardized experimental biaxial testing procedure. It is the main feature of the procedure, that the specimens are loaded in warp and weft direction with a precisely defined consecutive sequence of five different load ratios. In the authors' opinion this is the primary merit of MSAJ/M-02-1995.

The secondary (and highly ambitious) scope of the MSAJ-Standard is to provide the design engineer with information how to transform the observed biaxial load-strain-behaviour into ready-to-use stiffness parameters for his design calculations. The commentary of the MSAJ-Standard idealizes the membrane material for this purpose as a linear-elastic orthotrophic plane stress material, which may be described by only three fictitious elastic constants, but which is known to be a rather rough structural model for woven membranes with their highly nonlinear load-strain-behaviour. On this basis, the commentary gives recommendations how to extract an optimum set of these elastic constants from the biaxial test data.

Disregarding the roughness of the model, the effects of different determination options on the resulting sets of fictitious elastic constants were investigated in this contribution. To determine the optimum sets of elastic constants, a MATLAB correlation analysis routine was programmed using the least squares method minimizing the strain term, which is one of the proposed methods in the MSAJ/M-02-1995 commentary. Three real test data sets were investigated with this tool using several determination options. They represent, on the one hand, the evaluation proposals of the commentary of MSAJ/M-02-1995, both in their original version and in the modified version according to Bridgens & Gosling, and, on the other hand, thinkable design engineer's approaches aiming at covering the actual load bearing behaviour of typical membrane structures.

It could be demonstrated that a great variety of values for the elastic constants can be obtained for one and the same material, only depending on the different determination options. Having the roughness of the underlying structural model in mind, the question arises, if it is not a disputable objective of the commentary of MSAJ/M-02-1995 to determine only one single set of fictitious constants by means of which all types of membrane structures under all types of load cases shall be treated. In the design practice it might be more reasonable to use constants which are determined for specific load ranges and load ratios depending on the project's needs. Further, concerning the design practice, it might be recommendable in the light of the great variety of the constants' values to calculate membrane structures with two limitative sets of elastic constants instead of using only one single set.

Nonetheless, from an engineering point of view an international standardized procedure for testing and evaluating the biaxial load-strain-behaviour is desirable to enable the comparison of materials on an objective base. However, it is not reasonable to evaluate values for fictitious elastic constants with an ostensibly high accuracy considering the rough character of a linear approximation of the material behaviour and the variety of possible determination options and evaluation methods.

7 ACKNOWLEDGEMENT

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