EVALUATION OF THE INFLUENCE OF AMBIENT TEMPERATURE ON HIGH FREQUENCY WELDED SEAMS WITH VARYING PIGMENT DENSITIES

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The study of material properties is broad and challenging to the designer of membrane structures. This paper documents interesting research work carried out by the authors into the influence ambient temperature has on surface temperature of various colored membranes and the consequent impact on seam strength.

BIOGRAPHICAL DATA ABOUT THE AUTHORS:

DR. D. DeSILVA

Dr. deSilva is a materials scientist at the Scientific Services Branch of the Department of Housing & Construction in Port Melbourne. He obtained his PhD at the Australian National University in 1978 and his work concentrates on building materials, specifically plastics.

DAVID McCREADY

David McCready is a Director of Geodome Space Frames Pty. Ltd., Spacetech Pty. Ltd. and Connell Barrow McCready Pty. Ltd., three specialised companies devoted to specific tasks in the field of membrane structures' design and contracting in Australia. He has been involved in this field for the last twelve years and was one of the prime movers for the development of the M.S.A.A. He has been on the Executive almost since its inception and has held the post of Technical Subcommittee Chairman for the last two terms.

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During the design detailing of the Australian Bicentennial Exhibition fabric structures, studies were made into the effect fabric color has on surface temperature and the surface temperature maxima likely during the tour along with the consequent influence on welded seam safety.

The designers felt that a properly executed high frequency welded seam of adequate width would develop the full strength of the fabric and that there should be no need for additional sewing to supplement the welded seam strength. Accordingly, a study was undertaken of seam strengths at elevated temperatures to ascertain whether there would be any loss of strength at the anticipated high surface temperature conditions during the tour.

The Bicentenary Travelling Exhibition comprises a series of structures of different design and utilizes a PVC coated polyester material in a series of varying colors. These colors range from cream to deep green and it was anticipated that the deeper tone ranges would reach extremes in surface temperatures at ambient levels predicted at around 40 degrees C.

The Exhibition tours through twelve months travelling to thirty-four sites around Australia whereupon temperature extremes of this order would be achieved.

The work was carried out by the Scientific Services branch of the D.H.C. at Port Melbourne in Victoria under the control of Dr. D. DeSilva and was directed by John Robertson of D.H.C. Melbourne in conjunction with David Mccready of Geodome Space Frames Pty. Ltd.

The full range of varying colors were exposed to sunlight for recording of their surface temperatures in conjunction with ambient and the results present interesting data for designers of fabric structures. The samples were largely shielded from wind influence which presents almost a worst case scenario for fabric structures with regard to surface temperature.

The brief submitted to the Scientific Services Branch detailed the test parameters summarised below:

1. Colors of fabrics to be tested: Red/Red, Dark Blue/Yellow, Mid Blue/White, Cream/Cream, Light Blue/Light Blue, Light Blue/White.

2. PHASE I

   i. Expose fabric to direct sunlight

      A. open on both sides with full influence of wind movement,

      B. enclose on the underside, perimeter sealed, influence of wind on upper surface only,

      C. open on both sides, upperside partially shielded from wind and

      D. enclosed on the underside, perimeter sealed, upperside partially shielded from wind.

   ii. Samples should be placed 20 - 25 degrees off horizontal from the north-south meridian and along the east-west direction to achieve maximum solar exposure at midday.

   iii. Monitor temperatures of upper and lower panel surfaces and the exposed and shade ambient temperature using thermocoples, (T/C).

3. PHASE II

   Carry out tests on welded seams at elevated temperatures equivalent to those reached in Phase I. It was anticipated that as the temperature exceeds 50 degrees C, failure in the seam will start to be more predominant rather than failure in the base material.

INVESTIGATION:

Special exposure frames were fabricated from 7mm plywood for Phase I experimental work. These project a 300 x300mm surface of the fabric either flush with the upper plane of the frame or counter sunk 100mm below and with an open or covered base to simulate the required exposure conditions. Figure I shows a general view of the samples under test conditions.

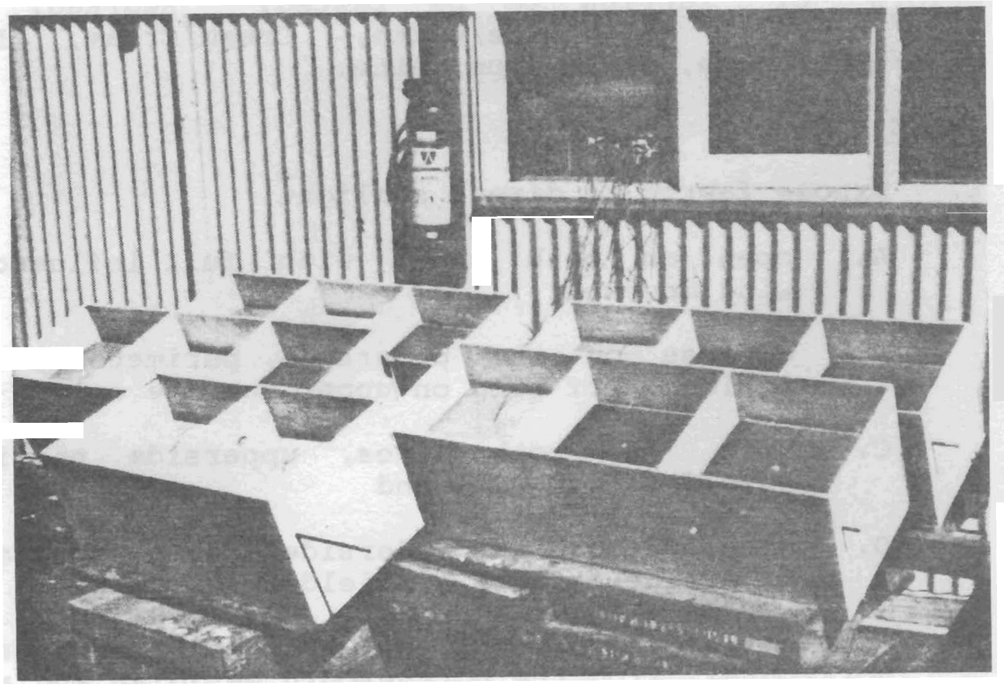


Figure I: View of exposure frame with samples inset

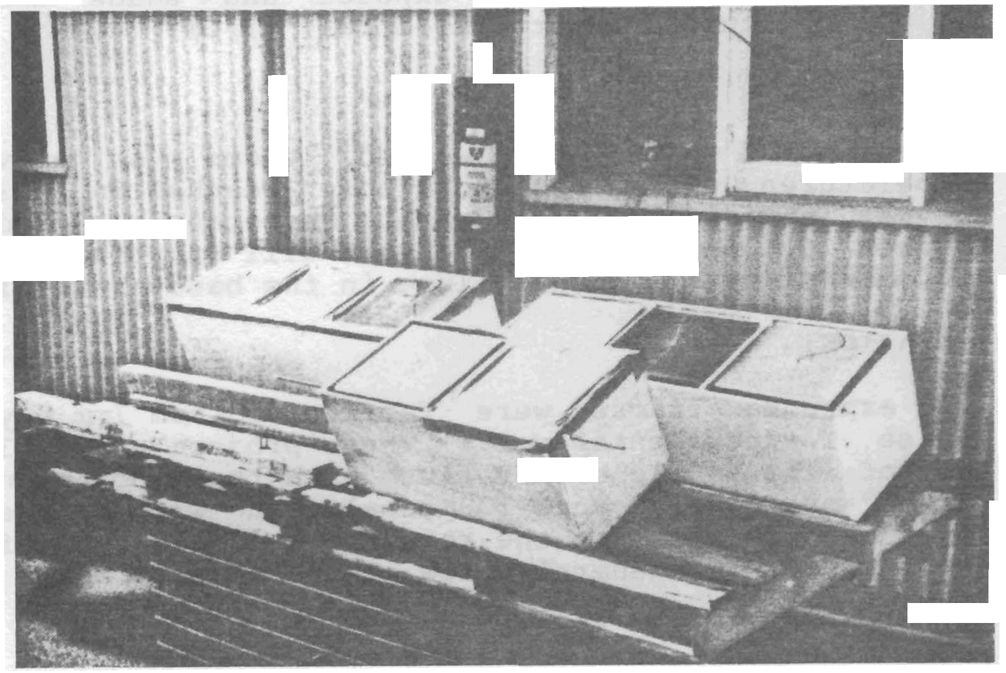


Figure II: View of exposure frame with samples surface mounted.

The fabric perimeter was sealed with masking tape to create the unvented condition required in 2(B) and 2(D). Iron-constantin T/C's were attached with cyano-acrylate adhesive to the centre of each panel. The upper T/C was covered with silicon sealant and painted white to prevent heating by self-exposure. The TC's were connected to a YEW 8088 30 point chart recorder that simultaneously monitored 14 samples and two ambients. The instrument produces a continuous trace of the temperature registered by each T/C and a print out of temperature measured on the hour every 2 hours. A summary of the results on the hottest day and a typical chart recording are presented in appendices 1 and 2.

In the initial exposure period from 13 to 20 February, the samples were in the semi-shielded state, i.e. counter-sunk 100mm below the upper plane of the frame. The highest ambient temperature during this period was 38 degrees C on 19 February. From 23 February to 11 March, the samples were in the non-shielded state, i.e. flush with the upper plane and the corresponding highest recorded ambient temperature was 34 degrees C on 27 February, but panel temperatures on that day were slightly depressed due to cloud and wind. Maximum panel temperatures in the latter period were recorded on 3 March at 14:45 hours when the ambient was 30.5 degrees C.

Phase II experiments were conducted on two types of welded specimens with 80mm seam width, i.e. green/green fabric with the seam parallel to the weft direction and the yellow/dark blue fabric with the seam parallel to the warp direction. An Instron 1122 testing instrument equipped with a high temperature cabinet was used for the extension tests. The specification was to pretension the sample to 1.5kN/m for 4 hours at 55 degrees C, 60 degrees C and 65 degrees C and to determine the residual seam strength after the samples had cooled down to room temperature.

However after testing one sample at 65 degrees C it was evident that the conditions specified had no effect on the seam. Therefore subsequent tests were carried out on samples subjected to higher stresses, i.e. 33 kN/m pretension load for 4 hours at 65 degrees C. These test results and strength test results on the base materials are presented in Appendix 3.

DISCUSSION:

PHASE I

As anticipated, a significant variation in surface temperature in panels of different colors was evident throughout the experiment, the darker colors heating to a higher degree than the lighter colors.

However the effects of changes in wind velocity and cloud density were greater than expected. The temperature recordings demonstrate that even the semi-shielded panels under relatively steady ambient conditions have significantly variable temperatures due to fluctuations in wind velocity and cloud density. Appendix 4 illustrates this situation for the green/green fabric which over a 3 hour period varied between 45.6 and 65.5 degrees C while the shade ambient was a relatively steady 35.2 to 38.9 degrees C. On account of the influence of these secondary factors on panel temperatures a direct comparison of temperatures between the two panel orientations under similar ambient temperatures is imprecise.

However from a detailed study of the chart recordings it is estimated that under cloudless, hot ambient conditions, i.e. 37 to 38 degrees C, most of the semi-shielded panels, vented and non-vented, will exceed 55 degrees C and a few will even exceed 60 degrees C, i.e. green, dark blue and mid blue. Under comparable conditions the non-shielded light colored panels will be cooler by 2 to 4 degrees C and the dark colored panels an additional by 1 to 2 degrees C. In essence on hot days under moderate cooling conditions, nearly all the fabrics will exceed the 50 degrees C threshold temperature and over half will exceed 55 degrees C. The highest temperatures reached will be around 65 degrees C for the dark colors under cloudless, still air conditions.

PHASE II

The base fabrics irrespective of color had breaking strengths (at 23 degrees C) in the order of 115 to 120 kN/m in the warp direction and 85 to 90 kN/m in the weft direction. The exception was the cream fabric which was weaker, 75.8 kN/m and 52.0 kN/m respectively.

The seams of the welded specimens were stronger than the material when tested under ambient conditions and remained so without significant change after the specimens were subjected firstly to the specified pretension at 65 degrees C and secondly to the higher stress of 33 kN/m at 65 degrees C. Importantly the integrity of the seam was unaffected and in all tests, failure was limited to the fabric. The marginal reduction in strength after pretensioning is attributed to thermal effects on the fabric.

In view of the inability of higher stress conditions (33 kN/m at 65 degrees C) to induce seam failure on the samples tested, it is unlikely that the condition of the seam will deteriorate under the specified test conditions (1.5 kN/m at 50, 55 and 60 degrees C). Therefore it was agreed not to proceed with the full series of extension tests at those stresses.

CONCLUSION:

On hot days the temperature of most of the different colored PVC fabrics will exceed 50 degrees C, the dark colored fabrics even approaching 60 degrees C. However, these temperatures will not affect the integrity of the welded seams pretensioned to 1.5 kN/m. Nor will the seams fail when the stress conditions are increased to 33 kN/m pretension at 65 degrees C.

The results point out an interesting anomaly with the temperature readings on cream and light blue where it would be anticipated that higher values should be found with blue than cream. Some of the materials used for the Exhibition utilized a carbon black interlayer to prevent light transmission and the cream fabric was of this sort, while the light blue was translucent and presumably the higher results recorded by the cream material indicate the lack of transmission.

The experiments were carried out in Melbourne, Australia and generally reflect conditions Australia-wide as solar energy per square metre between north-west Australia to southern Tasmania will differ by only a factor of 2. The tests were conducted during relative temperature maxima for Melbourne, a level which is close to maxima throughout Australia.

The tests represent a worst case scenario as the panels were largely shielded from wind and were mostly unvented from below. The chart trace of temperature effects indicates the fluctuations due to cloud and wind, the effects of which would have an ameliorating influence on surface temperature.

APPENDIX 1 (2D)

TEMPERATURES OF SEMI-SHIELDED PANELS, °C

19 February 1987 Official High 37 "C

	PANEL COLOUR	T/C Number	11.00	12.00	13.00	14.00	15.00	16.00	17.00	Panel Profile
1 CLOSED BASE	Green Top Surface Under Surface	1 2	46.1 45.5	-	59.4 58.0	62.5 60.8	65.5 62.2	62.4 57.7	46.0 46.5	Green/ Green
	Red Top Surface Under Surface	3 4	43.1 43.7	-	55.0 55.3	56.6 57.3	60.9 59.0	57.2 54.0	43.9 44.4	Red/ Red
	Yellow Top Surface Under Surface	5 6	42.2 41.1	-	52.3 51.0	53.4 52.9	58.6 54.5	54.7 50.5	42.9 43.2	Yellow/ Dk Blue
	Mid Blue Top Surface Under Surface	7 8	43.8 43.7	-	57.4 56.1	61.1 58.6	63.2 60.2	60.5 55.8	46.0 46.2	Md Blue/ White
	Cream Top Surface Under Surface	9 10	39.2 38.6	-	50.9 48.5	54.1 50.5	56.4 51.7	55.3 48.1	41.9 41.5	Cream/ Cream
	Dark Blue Top Surface Under Surface	11 12	45.4 46.7	-	58.1 60.0	60.2 62.4	63.8 65.4	60.5 60.3	45.4 49.2	Dk Blue/ Yellow
	Lt Blue Top Surface Under Surface	27 28	41.5 40.3	-	51.3 51.1	51.8 52.6	54.5 53.9	53.1 52.3	43.2 43.6	Lt Blue/ Lt Blue

1 - Sealed perimeter, no venting of the underside

2 - 20 mm gap on perimeter

TEMPERATURES OF SEMI-SHIELDED PANELS, °C

19 February 1987 Official High 37°C

	PANEL COLOUR		T/C Number	11.00	12.00	13.00	14.00	15.00	16.00	17.00	Panel Profile
2 OPEN BASE	Green	Top Surface	13	41.2	–	51.7	53.1	57.7	56.5	43.7	Green/
		Under Surface	14	39.9		51.1	53.9	57.0	56.7	42.2	Green
	Red	Top Surface	15	40.5	–	49.3	50.0	54.4	52.7	41.7	Red/
		Under Surface	16	39.0		48.2	50.2	51.4	50.9	40.2	Red
	Yellow	Top Surface	17	40.0	–	48.8	49.4	53.0	51.7	41.5	Yellow/
		Under Surface	18	36.4		44.4	46.8	48.5	48.4	39.6	Dk Blue
	Dk Blue	Top Surface	19	41.8	–	52.9	55.5	58.4	56.9	43.8	Dk Blue/
		Under Surface	20	40.1		49.6	52.8	54.3	53.4	41.9	Yellow
	Cream	Top Surface	21	38.8	–	47.4	49.1	50.8	51.3	41.4	Cream/
		Under Surface	22	34.5		41.3	43.1	43.3	44.1	38.3	Cream
	Mid Blue	Top Surface	23	41.7	–	52.7	55.0	56.0	55.8	42.7	Md Blue/
		Under Surface	24	40.2		51.1	53.6	54.5	54.8	42.0	White
	Lt Blue	Top Surface	29	38.8	–	48.2	49.2	49.8	50.9	39.9	Lt Blue/
		Under Surface	30	36.2		45.2	47.0	45.4	47.5	38.2	Lt Blue
	Ambient – Shade		25	31.7	–	35.9	37.6	38.1	38.8	36.5	
	Ambient – Exposed		26	33.9		38.2	37.9	41.4	41.6	37.5	

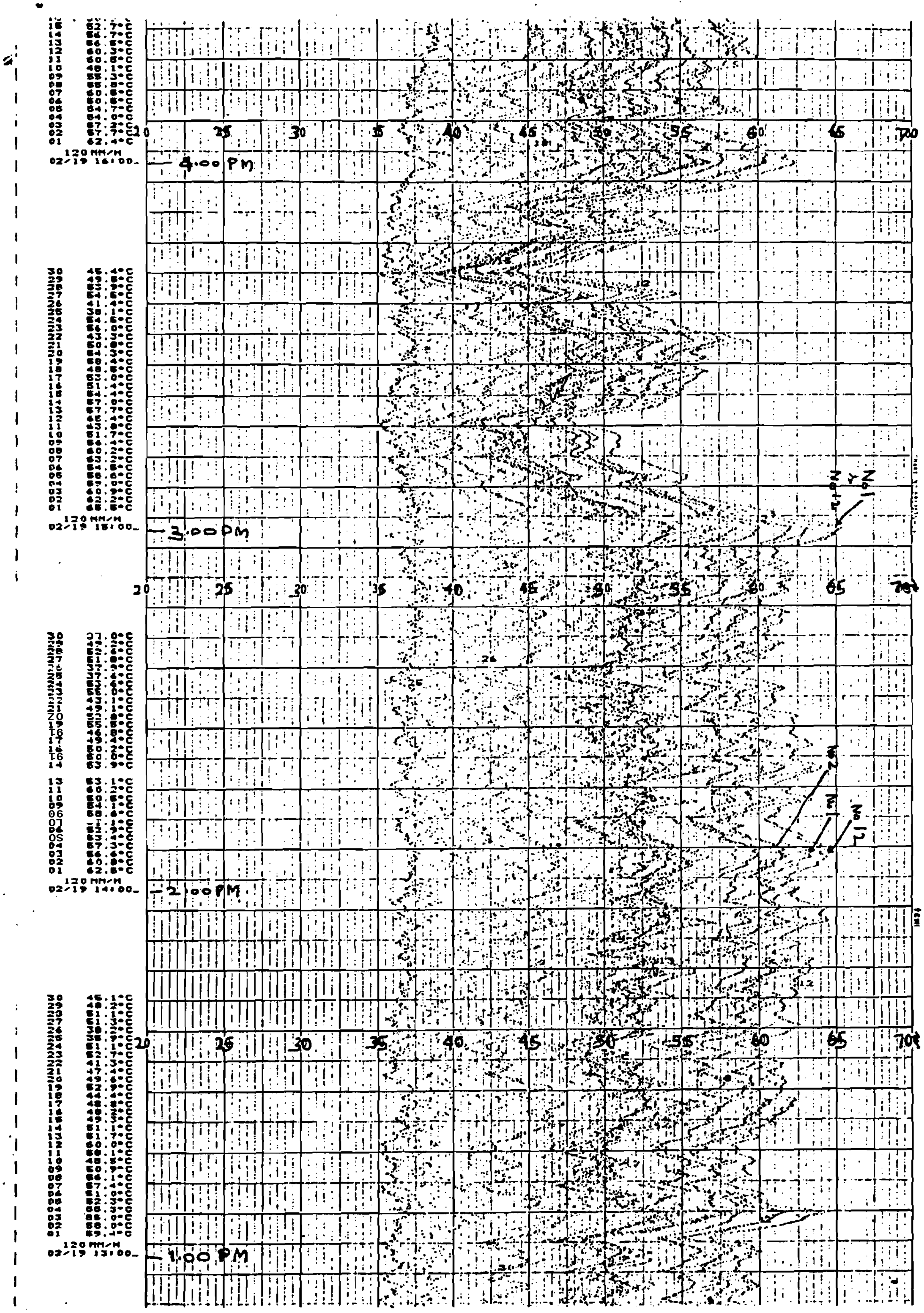
1 – Sealed perimeter, no venting of the underside

2 – 20 mm gap on perimeter

APPENDIX 2

Typical Chart Recording

(See Appendix 1)



APPENDIX 3

Tensile Strength of Fabrics. kN/m

Colour	Warp	Weft
Yellow/Blue	123.2	90.0
Green/Green	117.4	91.6
White/Lt Blue	117.8	85.5
Lt Blue/Lt Blue	116.3	82.1
White/Mid Blue	115.1	91.8
Red/Red	117.2	86.4
White/White (Cream) (Cream)	75.8	52.0

Tensile strength of seamed Fabrics kN/m

Colour	No conditioning. Room Temp,	Conditioned for 4h, 40 kN/m, 65°C
Green/Green (Warp direction)	122.5	114.0
Yellow/Blue (Weft direction)	85.5	85.0

Note: Fabric failure in all samples. Seams not affected.

APPENDIX 4

Temperature Fluctuation due to cloud and wind

(See **Appendix 1**)