MSAA/LSAA Conf Proceedings

FABRICATION AND INSTALLATION

OF TENSILE STRUCTURES

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STRUCTURFLEX

INTRODUCTION

This paper highlights the methods that Structurflex the fabricator/installer have developed to produce the structure required to fulfil not only the clients expectations but to also display the skills of engineer and manufacturer.
Obviously for the project to be a success all parties must be satisfied with the final product.

Hence in my opinion the manufacturer holds ultimate responsibility to ensure that a functional, well shaped, installed on time structure is achieved.

PRE - FABRICATION

For the entire project to be successful in every meaning of the word, all details pertaining to the job must be correct.

Unfortunately on a number of projects designed by a wide range of companies we have found inconsistencies in some aspects of the design whether it be with the shape finding (patterning) or hardware etc.

As no one is perfect we have had to implement a simple system to ensure that any mistakes or problem with the engineering or fabrication are dealt with before the construction begins.

The system comprises of a number of basic, common sense check sheets covering such points as checking cutting patterns, making models and querying anything that looks like it goes against the grain. The system of checks accounts for approximately 1/5 of the total allocated time for a project. You might think that this is alot of time, but these checks actually save time, as even a small mistake, once welded becomes a major event in rectification.

Refer MI 1

The project check sheet is fully completed before any manufacture can begin.

This checksheet and others form part of our Quality Management system under I.S.O 9002, for which we are currently working towards accreditation.

FABRICATION

As we do not solely fabricate fabric structures, but a wide range of fabric products, a training system is obviously needed to ensure that men working on the job actually have the skills and resources to fulfil the requirements of the specifications to manufacture a fabric structure.

Naturally a staff training programme was introduced to bring the men up to a competent level of manufacturing with minimum supervision.
All training is documented in detail so that for future projects we can assess the training requirements necessary i.e. new methods
new equipment

This programme also includes the development of techniques and equipment to enhance production and therefore produce a superior structure.

FABRIC SET OUT

Refer - production planning - section 5
- fabrication details - section 6

The marking/Cutting and assembly (welding) of the structure are critical processes, tight dimensional and quality tolerances must be maintained throughout.

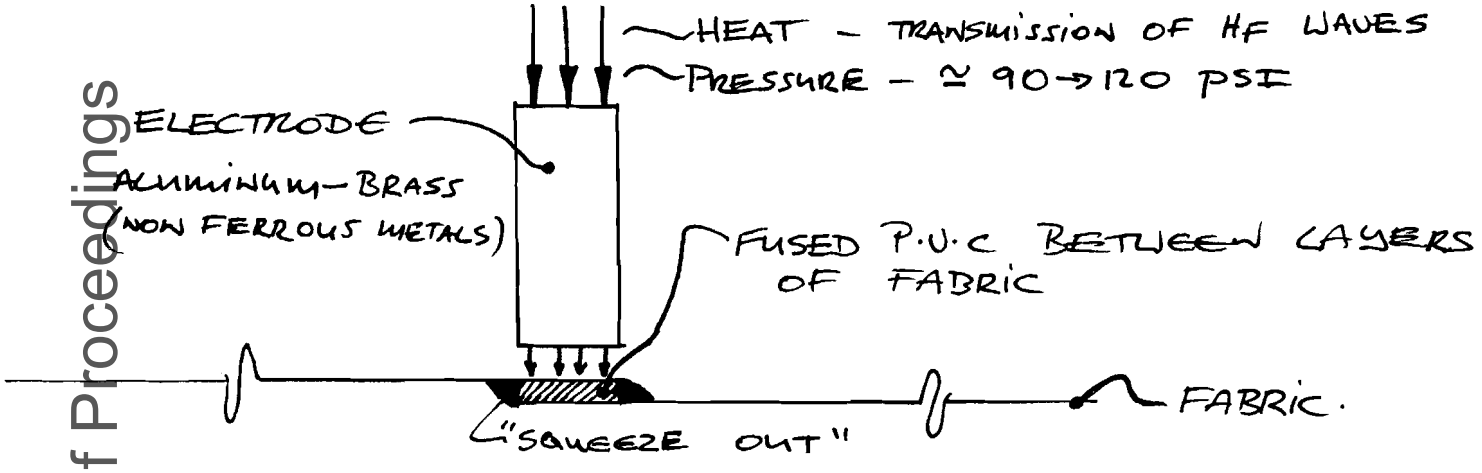
The set out of a typical fabric tensile structure is a relatively straight forward process when working from an engineered cutting sheet. **Refer MI 2**

Before the set out procedure begins all measuring tapes and squares are checked for accuracy and squareness.
Basically to achieve a highly accurate set out of node points, (without a computerised plotter) we use a two man mark/check and cut procedure where both men check each other's set out. This method eliminates gross and random errors from occurring.
Also a final check at both cutting stages is made by a supervisor - (This includes the panel marking and fairing, prior to panel cutting and perimeter cutting stages). **Refer MI 3.**

WELDING

(Highfrequency (HF) welding - the art of combining heat/pressure and time to fuse P.V.C coated fabrics together).

In basic an HF welder melts the P.V.C coating on the base fabric, and pressure to the weld, fuses the melted P.V.C from both surfaces together.
The heat and pressure is transferred from the machine to the fabric thru an electrode.



In order to truly test a welded seam (etc) a destructive test must be performed - "(A peel test)" when the weld is pulled apart the P.V.C shall be completely removed (100%) from either surface or in a combination from both surfaces, to expose the base fabric.

Obviously you can't test every weld to this extent, such tests are performed at regular intervals throughout the job on scraps of the same fabric.
(Refer 6.2 and 6.3)

Unfortunately with the majority of HF welders the operator has to manually set the machine for the correct proportion of power verses time (output) to produce an acceptable weld this setting must be manually maintained by the operator, almost exactly.
This is difficult to maintain throughout the job, and with many architectural type fabrics the amount of output is critical.

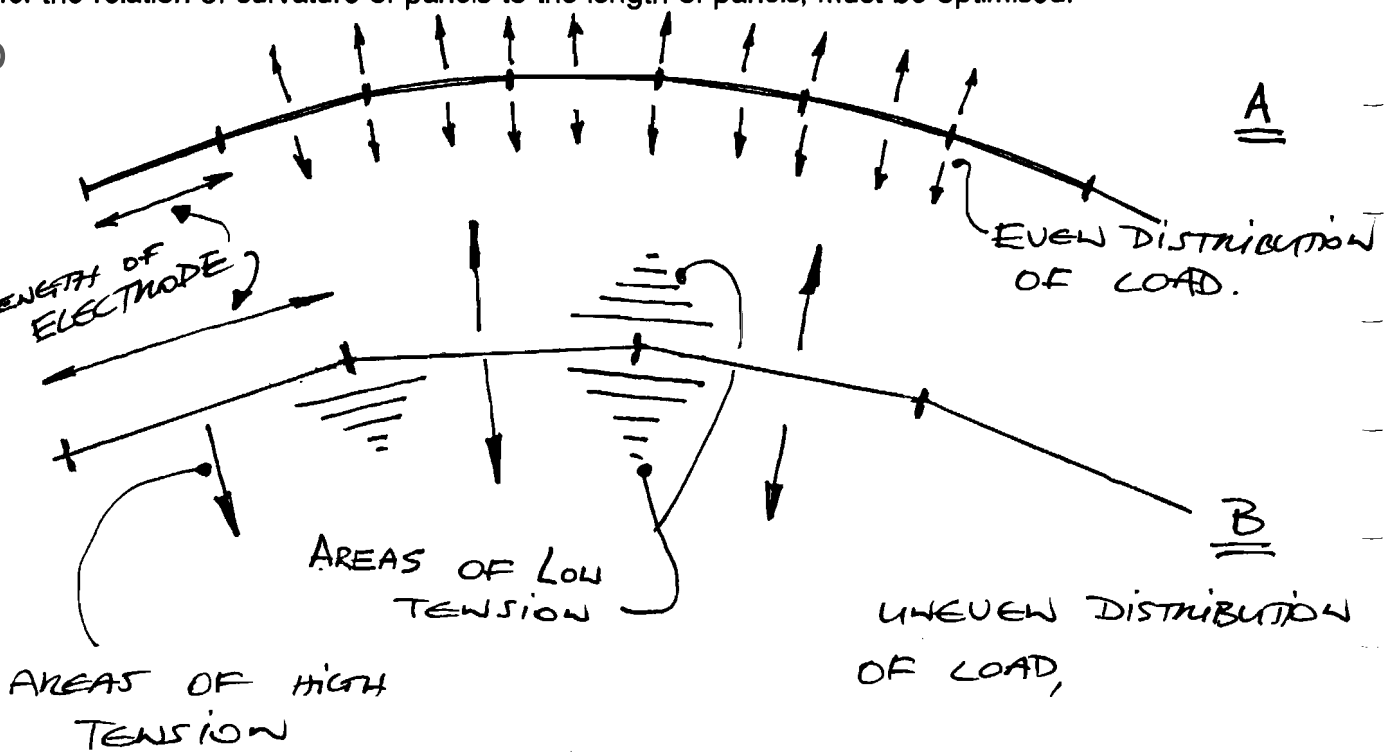
e.g.	slightly insufficient output	-	no weld just a lite bond, which to the operator may appear welded
	slightly excessive output	-	can result in severe damage to the base fabric and scorching of the surface, this can be so extreme that the fabric is cut or holed.

Hence how can you be sure that 100% welding has been achieved throughout the job.
To ensure this consistency, our HF technicians developed a computerised output control unit to emulate an output exactly time after time.
This unit is connected to the welder with servo driven controls which constantly maintain the output during the weld; sensors which monitor the electrical current generated by the valve regulate servo adjustment.

Hence we can now ensure that every weld is a true weld, just like a chain, the structure is only as strong as it's weakest weld.

ALIGNMENT

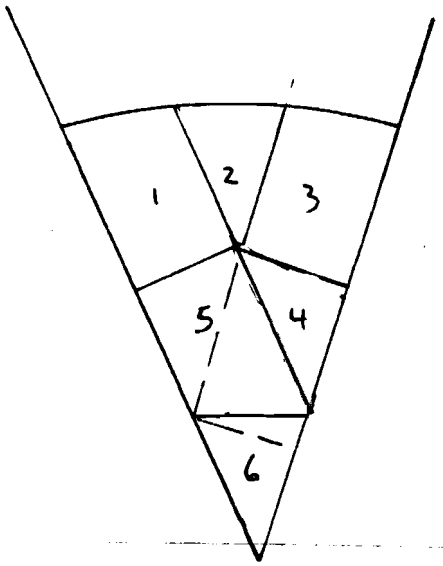
Naturally the alignment of panels by node points is critical but also another important alignment factor is bar length, as bar length also dictates the amount of shape to the structure. Obviously the more curvature in a seam the shorter the electrode length must be. Careful planning and experimentation is needed to ensure optimum shape is achieved without wasting time performing unnecessary welds.
i.e. the relation of curvature of panels to the length of panels, must be optimised.

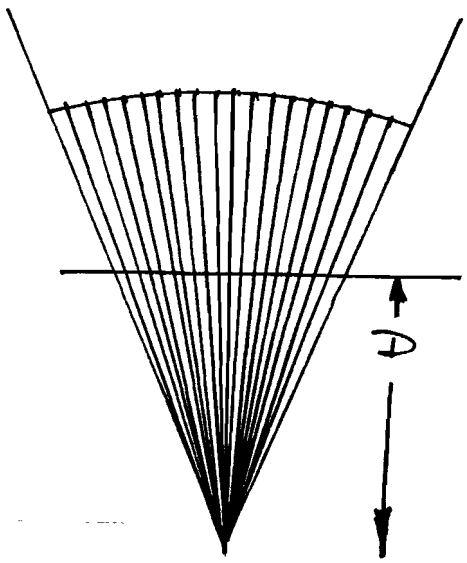


From the above diagram **A** has a much smoother shape compared to **B** therefore **A** has even loading throughout the seam where **B** has much higher loading at the centre of each weld. This can cause uneven tension and hence wrinkles will occur in this region of the structure.

REINFORCING

Reinforcing of certain areas of the structure are required to increase strength of the structure at connection points, and to beef up areas where chafe may occur.
This reinforcing, as well as being fully welded, must be performed in such a way so that it blends in with the smooth form of the rest of the structure.
We have developed large electrodes to enable the welding of e.g. 40° and a radius of 700mm to be welded in six hits maximum.
This is far superior to using small electrodes used in a radial setout to weld the same area. Which may require up to 40 welds to fully weld this area with a 50mm wide electrode.





Also the more welds required, produce large ridges of "squeeze out" (a bi-product of the weld). This forms a ridge to both sides of the weld. This traps dirt and can give moulds a rough surface to grip to.Over welding an area such as "D" above can considerably weaken the strength of the fabric - i.e. - all P.V.C is pushed away from weld and hence only base fabric remains this fabric has no weldability.

INSTALLATION

Refer Section 9

The three most important points to be covered are

Installation plan
Site check measurement (as built)
Weather

INSTALLATION PLAN

This covers all aspects of the installation, from folding and packaging the structure for transportation and installation, thru to calculating the final position of the structure i.e. the closure on adjustable tensioning devises.

A very important aspect of the installation plan to be considered is that due to site conditions, you can't always erect the structure the way that would be simplest.
In the majority of cases you have never seen the site, and only so much information can be read from site plans.
Therefore the installation plan is worked thru in conjunction with the site engineer.
This also highlights points as - scaffolding being too close to the structure for a safe (tear free) installation, and points that people would not bother to tell you if you didn't ask, such problems that cause delays on site are extremely aggravating, as time and weather become incredibly valuable at the deployment stage of installation.
Few people on site actually grasp the concept, of how fragile and susceptible the structure is during installation and great amounts of time are wasted ensuring that the area is snag free and clear of all hammer wielding workmen.

SITE CHECK MEASUREMENTS

An as built survey of the connection points is performed prior to installation. Any points which have been misplaced can therefore be RE-AFFIXED prior to the installation team arriving on site.
Usually points which are out by an insignificant distance or angle, can be absorbed by the recalculation of adjustment on the closure length of the adjustable threads on connection plates and or perimeter cables.

Never the less any discrepancies must be know prior to installation as it is very hard to figure out why the structure has a lack of tension or severe angular wrinkles once the structure is in place. And hours can be wasted tensioning different areas around the structure in an attempt to remove wrinkles that could be possibly caused by miss alignment of the connection detail.

WEATHER

Weather conditions are the biggest single concern to the installer.
As once the structure is unpackaged and deployment has begun, there is usually no turning back.

In order to have utmost control during the deployment stages thru to the primary connection to fixing points, we typically specify that for installation to proceed the following minimum condition must prevail for the estimated installation duration.

- Wind velocity not exceeding 7 knots within area of site.
- Clear Weather with no imminent threat of rain or frost.

The first conditions eliminates as far as possible and within reason, the chance of the structure flapping or flying away, which could cause damage to the structure or supporting structure, and endangering the workers. With clamp plates weighing up to 20kg, you don't want to be hit by one.

The second of these conditions allows for safe working conditions and eliminates the chance of water ponding and trapping the structure. As the direct run off or catchment area of a structure is usually large literally within seconds in heavy rain a structure can become immovable with the weight of the runoff.

Hence a few days prior to the installation, long range weather forecasts are studied daily and contingency plans are drawn up to cover the postponement or delay of installation. This is the part of the project where you have little control, and large sums of money can be wasted.

For example, on one of our larger jobs, (cover area approximately ¼ acre on an exposed site) the installation involved twenty five riggers, scaffolding at considerable expense, and multi million dollar development that could not proceed any further until the structure was installed, all this combined with two weeks of very unsuitable weather, heavy rain with 20 knot gusting south westerlies; this did not make the decision of when to proceed easy.

In the days of unions, we would have had to pay the riggers a minimum of 3 hours pay, weather they worked or not. Hence we could not afford to have them turn up and not install the structure at $18.00 per rigger per hour this would be a very expensive cancellation fee. Hence you can see the pressure that the installer is put under by weather conditions.

Finally when we could not afford to wait any longer, we received a weather report from the meterological office from just across the road.
at 11.30 pm we would have a calm period until 6 am the next day, which would be followed by heavy rain with strong squally winds again. We took the opportunity and all went well, followed by heavy rain and strong squally winds.
Unfortunately the weather being what it is, we had to take an expensive but well informed gamble.

The installer spends many sleepless nights wondering

- do we proceed
- will the weather hold
- what are the consequences if we wait

As the best time to install is at the crack of dawn, the decision to proceed is made in the darkness of the coming day and is based on experience, accurate weather reports, and the will of the gods.

Title	MANUFACTURE AND INSTALLATION OF TENSION MEMBRANE STRUCTURES		
Document No	SF 318	Issue	A
Page No	1 of 1		
Approved	OK	Date	14/5/93
Issued for use	Indefinite	Issue date	
Reason for issue			
Issued to		REF:STD\MKU1405.93	

PROJECT CHECK SHEET

MI 1

When sale of structure is complete and all specifications are dealt with and job sheet written up the project shall be passed to the supervisor in charge of structure manufacture.

			DATE	CHECK
		The following must be addressed:		
	1.	Visualisation of project - review sale file - pricing sheet		
	2.	Order cutting patterns and typical details (specify fabric type/width etc)		
	2a.	Check shape finding and send to client.		
	3.	Check all patterns and see (5) of section (6) PC 299.		
	4.	Establish schedule of quantities - price quantities (check against pricing sheet) - order quantities - specify delivery		
	5.	Critical path plan for entire project		

MANUFACTURING METHOD & QUALITY MANAGEMENT CONTROL

PRODUCT FABRIC STRUCTURES

Refer at all stages to full cutting pattern set out

Opertator is to visually inspect previous work and sign for this plus his work

MI 3

MARKING & CUTTING JOB #					This sheet is for one day Date			
MARKING & CUTTING					FAIRING		DIMENSIONS	
PANEL CODE	FABRIC INSPECTION AR3b ROLL #	PANEL SETOUT + CODE	SETOUT + CODE CHECK	CUT	EDGE CODE	FAIRED + CUT	EDGE CODE	CHECKED

MANUFACTURING METHOD & QUALITY MANAGEMENT CONTROL

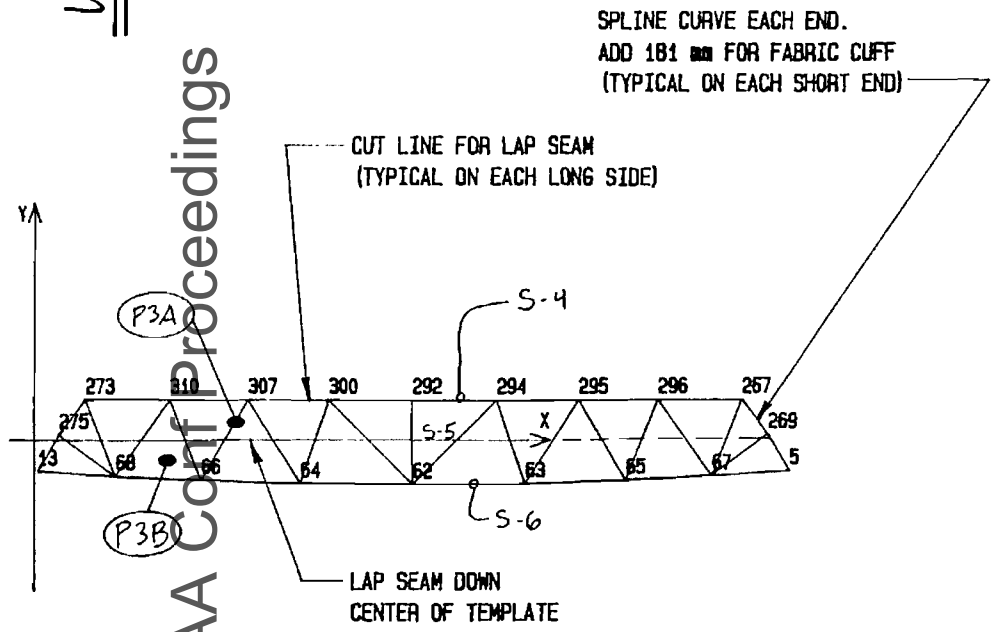
PRODUCT FABRIC STRUCTURES

Refer at all stages to full cutting pattern set out

Operator is to visually inspect previous work and sign for this plus his work

WELDING JOB#.....				This sheet is for one day Date.....	
SEAM CODES	TIME START	FINISH	WELD CHECK	TEST WELD TIME	TEST WELD NUMBER

MI 2



PATTERN NAME: P3.PAT
PATTERN DRWG NO: 9003
PATTERN TITLE: TEMPLATE P3
~~PLOT FILE NAME: P3.PLO~~
PATTERN DATE: 3 - 9 - 1990

MODEL FILE: HYP8.MCM
MODEL TITLE: [redacted]
PRESTRESS CHECK RUN

COMPENSATIONS: WARP = 0.300 %
FILL = 1.000 %

ORIENTATION NODES: 13 5

ROTATION ANGLE: 0.000
PATTERN WIDTH: 2.569
PATTERN LENGTH: 22.869
PATTERN AREA: 53.000

COMPENSATED PATTERN DATA

NODE	"X"	"Y"
273	1.447	1.284
310	4.009	1.277
307	6.420	1.272
300	8.883	1.269
292	11.434	1.267
294	13.986	1.269
295	16.452	1.272
296	18.858	1.277
267	21.422	1.285
269	22.213	0.227
5	22.869	-0.868
67	20.500	-1.020
65	17.891	-1.154
63	14.846	-1.250
62	11.434	-1.285
64	8.022	-1.250
66	4.978	-1.154
68	2.369	-1.020
13	0.000	-0.868
275	0.655	0.227

UNCOMPENSATED PATTERN DATA
(NOT FOR SHOP USE)

NODE	"X"	"Y"
273	1.451	1.297
310	4.021	1.289
307	6.439	1.284
300	8.910	1.281
292	11.469	1.280
294	14.028	1.281
295	16.501	1.284
296	18.915	1.289
267	21.486	1.297
269	22.280	0.230
5	22.937	-0.877
67	20.562	-1.031
65	17.945	-1.165
63	14.891	-1.262
62	11.468	-1.297
64	8.046	-1.262
66	4.993	-1.165
68	2.376	-1.031
13	0.000	-0.877
275	0.657	0.230

[redacted] CANOPY

TEMPLATE P3

SCALE: 1 : 150.0	MPAT VERSION 3.2		PATTERN: P3.PAT
			MODEL: [redacted]
	COMPENSATIONS:	WARP = 0.300	DATE: 3 - 9 - 1990
		FILL = 1.000	DRWG: 9003

Title	SPECIFICATION FOR THE FABRICATION AND INSTALLATION OF TENSION MEMBRANE STRUCTURES		
Document No	PC 299	Issue	C
Page No	1 of 9		
Approved		Date	18/6/93
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SPECIFICATION FOR THE FABRICATION AND INSTALLATION OF TENSION MEMBRANE STRUCTURES

1 General

The work covered is the cutting, fabrication and installation.

All work shall be done in strict accordance with the drawings and these specifications are subject to the terms and conditions of the contract. It is the intent of these specifications that a first quality finished product is provided.

2 Materials

Materials used shall comply with the specifications stipulated by the design engineers. Fabric shall be supplied by a recognised international supplier who has manufactured specialist architectural fabrics for a period exceeding ten years.

2.1 Fabric Physical and Mechanical Properties

The fabric shall comply with recognised standards for architectural fabric in relation to:-

Weight
Tensile Strength
Tear Strength
Adhesion
Seam Strength
Coating Thickness
HF Weldability
Cold Cracking
Temperature Resistance
Shrinkage after exposure to Water and Heat
Fire Properties
Colour Fastness
Resistance to Damage by Flexing
Resistance to Water Penetration
Resistance to Sea water Exposure
Abrasion Resistance
Dimensional changes at elevated temperatures
Biocide Additives
Resistance to Soiling and Cleaning Behaviour
Scratch Resistance
Water absorption

2.2 Fabric Visual Appearance

The fabric shall be viewed over a light table and defects that exceed the following are not permitted.

Any spot, stain, dire or foreign matter (contamination) that will not pick out. Size exceeding 3mm diameter.

Any coated over knots that will not leak - size exceeding 3mm diameter.

Any wrinkle that can not be removed by manual tension.

Any visible scratch or abrasion.

Any non-uniform embossing.

Any abnormal or strong odours.

Knots not coated over (bare).

Any hole, cut or tear.

Noticeable uneven coating or unbalanced face to back coating.

Any delamination.

Any uncoated or misscoated area.

Colour off shade, streaked, spotted or discoloured (burnt).

Folded over, scalloped or wavy edges precluding lay flat of fabric.

Width less than minimum.

Any tackiness (fabric must unroll readily).

3 **Clamping Systems, Corner Plates, Cables and other Hardware**

All hardware shall be made to specifications and design approved by the engineers. Suppliers shall be experienced in the type of fabrication required and have been in business supplying similar fabrication for a minimum of five years. Any welding or terminating of cables shall be carried out by qualified tradespeople.

4 Factory Fabrication of the Membrane

4.1 The Fabric Structure shall be fabricated by a supplier experienced in the fabrication of tension membrane structures who has completed a minimum of 5000m² tensioned membrane structures.
The supplier shall use machinery of modern design and minimum output of 15 KW capable of producing high quality welds with minimum number of strikes.

4.2 Work Area
The work area must be cleared of all obstacles, clear and free of all extraneous contamination. If multiple layers of fabric are to be moved on the floor a fabric skid must be used to protect the fabric from direct contact with the floor.

4.3 Fabric Storage
Incoming fabric shall be stored under cover at a similar temperature and humidity as that of the fabrication area.
All rolled goods, or partial rolls shall be clearly marked to indicate style and weight, and stored separate from unlike fabric.

4.4 Operators
Cutters and operators shall wear clean soft shoes whilst working on the material. They shall be skilled, experienced in the field and capable of high quality work.

4.5 Supervisor
The supervisor for the work shall have a minimum of two years experience in the fabrication of this type of structure and shall be responsible for fully implementing Quality procedures.

4.6 Handling
The fabrication shop shall be clean and dry. No scuffs, cuts, abrasions or permanent marks are to be made to the fabric. The material surfaces shall be clean, dry and folded prior to leaving the shop.
The fabrication area shall have smooth floors and only people wearing soft soled indoor shoes, which do not mark the fabric are permitted in the fabrication area.

4.7 Fabric Quality Control
The Fabricator shall inspect each panel of the material over a light table for any faults or marks which might be cause for rejection from the structure. Any such instances shall be reported immediately for inspection and determination of the appropriateness of these sections.

5 Production Planning

5.1 Prior to marking the supervisor will check all cutting patterns for discrepancies in adjacent panel lengths or other mismatches. A paper model of the structure will be made.
Any queries that arise must be answered before marking and cutting begin.

5.2 The supervisor shall document the complete cutting, fabrication, handling, folding and storage procedures before fabrication.
Calculations must be made as to weight and size of partially finished and finished structures to ensure that handling and folding is within the capacity of available space, plant, staff and equipment. These documents shall be retained as part of the quality records.

6 Fabrication Details

6.1 Patterns
Cutting patterns to be marked by a competent person experienced in marking. Marking to be checked by the Supervisor who will lay out spline and mark final cutting line.
All edges are to be marked and smooth curves are to be fitted prior to cutting. Panels shall be marked out to +/- 2mm accuracy and panel numbers and corner node numbers shall be marked for identification and registration.
All panel marks shall be made with a pen style which can be removed with a light cleaning agent which does not damage the fabric surface prior to folding and packing.
Any and all index points issued with the cutting patterns shall be used to obtain proper registration of panels during the welding process. In cases where index points are not issued with the cutting patterns, panels shall be assembled prior to welding and marked with suitable index points so that registration is assured.

6.2 Welding
All seams shall be high frequency welded to the dimension as indicated in the detail. All seams shall be 'shingle' laid in the appropriate manner to shed water away from a cut edge.
Care must be exercised in aligning and welding of adjacent panels and it is stated that wrinkling and puckering on one panel caused by the gathering of one side versus the other will not be acceptable.
Tension of adjacent panels must be set up evenly on the bench before welding commences.
All welds shall be continuous without gaps, holes or trap pockets.
All welds shall be performed such that the entry of air or water into the seams of fabric is prevented.

The welding bar used shall be checked for straightness and any irregularities shall be removed by machining prior to the welding process.
Two (2) sets of sample welds shall be performed and approved prior to commencement of fabrication.
Prior to commencement of welding on each day, a series of test welds shall be performed to a minimum number of six (6) so bar temperature is elevated from cold to an operating level.
The machine settings shall then be adjusted following the performance of a further five (5) welds to a final heated setting requirement.
At any time where a cessation of welding activity of more than ten (10) minutes occurs, reheating and adjusting of the bar shall be carried out. The Fabricator should not use the same settings throughout so that heating of the bar causes excessive frying of the surface PVC.
Welds shall be performed so that no excessive bleed of PVC occurs about the edges of the weld. Any exposure of the substrate is a cause for rejection.

6.3 Weld Testing

A properly performed high frequency welds shall be defined as one which when peeled apart, removes the PVC from one or both sides completely in an additive manner.

Tests shall be performed at two (2) hourly intervals or at the end of each seam and marked with the time, date and logged with data indicating the section of the structure being welded at that time.
These samples shall be a minimum 600mm long with a 300mm section of each delaminated to test for appropriate weld strength. The samples for the completed job shall be bagged and labelled and stored for ready referral during the life of the structure.
Any errors in welding shall be immediately reported to the supervisor for a decision as to the method of rectification.
Welding of sections must always be undertaken from the inside of a structure towards the outside edge.

All weld surfaces must be clean and free of foreign matter prior to welding. Cleaning materials used shall not damage the surface coating.
Special care and attention should be paid to seams of more than two (2) layers. These must be treated specially and not pressed into the thickness of the remainder of the surrounding work with consequent extreme bleed of the PVC coating.

6.4 Reinforcing

Unless noted otherwise, all reinforced areas shall be fully welded.
The fabricator shall weld such areas using specially made welding bars to minimise the number of strikes used to block weld. Unsightly and distorted finishes will not be accepted. Shrinkage in the weld zone is to be minimised by proper set up and machine adjustment.

7 Quality Management

A log book of original records must be maintained.

The following records are required with details of date and the operator who performed the work.

Fabric inspection
Cutting
Welding
Test welds
Fairing edges

8 Questions

The fabricator must if in doubt request specific instructions before proceeding.

9 Installation

A fully documented installation plan must be completed before installation of the fabric structure. This installation programme must be approved by the site engineer before the structure is delivered to site.

The following must be specifically addressed in the documentated installation plan.

Site Check (as built)
Packaging, delivery to site and storage on site.
Cranage or other lifting requirements.
Scaffolding or other personnel access requirements.
Control of installation.
Acceptable weather conditions including specific maximum permitted wind speed.
Estimated duration of installation process from point of no return to basic security of the structure.

THE FOLLOWING MINIMUM STANDARDS SHALL ALWAYS BE MAINTAINED:

The safety of the public and site personnel shall be paramount at all times.

Site assembly and erection shall be supervised by a suitably qualified person experienced in the scale of work and technology involved.

Both the design and erection procedures must be developed with prevailing site weather conditions in mind.

Qualified riggers shall be used where appropriate and Government Department regulations adhered to.

The Contractor shall have proof of current insurance for the project and the workmen involved.

The Contractor shall obtain approval of a qualified consulting engineer for footings and anchors prior to commencement of erection.

The Contractor shall not leave the structure in an unstable state at any time and shall plan the erection sequence in stages to ensure safety during and at the completion of each stage paying due attention to weather forecasts.

Removal or dis-assembly of membrane structures shall be properly planned and carried out to standards equal to those required for initial erection.