PERCEPTIONS
OF
FIRE AND FABRIC STRUCTURES
IN
BUILDINGS

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SYNOPSIS

The paper is as much about perceptions as about fact – the 'what is' and 'what should be'!

After dispensing with often exaggerated ideas about the behaviour of structural fabrics in a fire situation, their real behaviour both as a material and as part of a building is discussed.

Some notes on recorded fires are made as background to important fire test properties of fabrics as they relate to the requirements of the new Building Code of Australia.

It is noted that there are many opportunities for fabric structures within the code, however, where a relaxation or variation is sought, some guidelines are offered as to the rationale that should be followed.

PERCEPTIONS

After many years on the receiving end of telephone enquiries re the properties of fabrics used in structures it can fairly be said that there a lot of technical folk who picture the following when a fire starts below a fabric roof.

- flames licking up to the fabric which then burst out in all directions along the surface;
- sheets of burning fabric blowing around in the room; Globules of flaming plastic showering down all over;
- thick clouds of black smoke rolling into all parts of the building;
- currents of choking deadly fumes flooding down to kill every living thing in the block;
- finally the whole roof comes crashing down due to loss of structural integrity.

Overriding all this is the perceiver's ability to block out the idea of anything other than the fabric burning!

The Writer states that those perceptions have as much formal reality in them as holding one's breath under water for 3 minutes to cure hiccups!

THE FACTS

Let us look at each of the above as they relate to the fabrics normally used in structures, of which there are two principal groups:-

(i) Teflon coated glass (TG); and

(ii) PVC coated Polyester (PVC/P) with various top finishes.

Firstly, the perception that structural fabrics burst into flame in contact with a fire. They do not. It is necessary to maintain a flame onto the surface of PVC/P for a time before the PVC starts to burn. This localised burning will continue only while the external flame is kept in contact with the fabric.

As soon as the flame is removed the burning stops, leaving a charred hole in the area impinged by the external flame, and in that area only. High temperature air or gases may cause melting without burning.

With T/G fabrics much greater effort (higher temperatures and longer times) is needed to cause flaming - if it can be achieved at all.

How about sheets of burning fabric blowing around the room and onto other property? Again, this simply doesn't happen. As stated above neither fabric burns without contact of an external flame. Even if a weird combination of events caused a fire to burn out an intact panel of fabric this panel would simply fall away into the fire or onto the floor below without flaming edges. As its weight is only about 1 kg/m^2, the damage it would cause would be negligible compared with that already done by the fire that started the problem in the first place!

Globules of burning plastic raining down? No, structural fabrics don't do this. When ignited the PVC/P fabrics simply burn slowly at the flaming edge, the materials being converted into smoke and char. The fabrics remain intact and don't ball up like cellophane, or acrylic and polycarbonate sheets which do continue to burn as they drop away.

Comprising as they do hydrocarbons structural fabrics such as PVC/P produce black smoke if ignited. This smoke rises rather than falls due to their low density and the convective effect of the fire below.

There is one aspect of this, however, which must be noted, and that is related to smoke developed by the effects of the fire on materials in the space other than the fabric. Such smoke could originate from floor and wall coverings, paint, furniture, semi-structural elements, e.g. plywood panels, or more seriously, from inflammable goods in a shop. When the smoke reaches the roof of an enclosed space it matters little if the roof is of concrete, steel, fabric or anything else - the smoke is simply contained and circulated within the space by heat convections, air-movement systems, geometry of the space, etc. If the temperature of this smoke and the heated air generally rises sufficiently to cause local penetration of the fabric, or the fire develops to such a height to bring about the same thing, (200 - 300 degrees Celsius for PVC), the opening in the fabric roof will allow relief in the space by venting the heat and smoke to outside.

It is a quirk of reality that the PVC/P fabrics perform 'better' than T/G on this count since the former can burn through locally at much lower temperatures.

Does the same apply to fumes and invisible gases. Yes and no! Again, since the materials forming those structural fabrics contain hydrocarbons and sometimes hydro-fluorocarbons, gases can be formed and expelled from the fabrics at high temperatures and during burning.

Some of these are heavier than air and thus could permeate down to the floor. Many of them are highly toxic. In an enclosed space they would circulate with the heat and smoke. Should the fabric be penetrated some would be exhausted to outside, some not.

Now, a key point must be made absolutely clear lest one concentrates too narrowly on the performance of the fabric element in a fired space. For all of the above to be initiated a substantial and, usually, very destructive fire must have started in the space and developed to an advanced stage for sufficient heat and flame to reach and effect the fabric. Even before the fabric experiences increased temperature and the effects of hot smoke and flame much of the ultimate damage would have been done and the space already filled with fumes, poisonous gases and smoke.

This is a point almost universally overlooked when the effects of a fire in a fabric-enclosed space are assessed. The fabric element has never been reported as the 'prime source' of any fire of which the Author is aware. Furniture, wall coverings, equipment, stores and arson rank way ahead of the structural roof fabric as a source of fire.

You can't start a fire by placing a match, cigarette lighter, blow lamp or burning brand onto the fabrics. Dousing part of a fabric structure with burning petrol or the like may cause a local burnout but is more likely to result in a severe fire concentration in edge gutters, etc.

Then, finally, there is the perception that a fabric roof will come crashing down when a fire reaches it. Noting the several points made above, viz. negligible flame spread, very light weight, etc., it is fair to say that for a large fabric roof to collapse would require either a full burn-out of a structurally critical area, e.g. around the crown ring of a mast-supported cone roof, or burn-out of a majority of the roof, which in turn would occur only after development of an extensive fire burning for a significant amount of time. (In a strongly developing fire as little as 3 minutes can be a significant period of time!)

Small fabric roof structures are often essentially 'skylights', and their contribution to the overall damage is quite negligible. Larger structures are usually designed with built-in 'redundancies', i.e. secondary cables or rigid, self-supporting frames, etc. which would ensure safety from collapse of masts, arches, etc. in the event of fabric failure. Such structural arrangements are often essential to facilitate the initial erection sequence, and it is a criterion of good design that the possibility of loss of structural adequacy in the fabric resulting either from fire or other physical damage be catered for by redundancies in the structural support systems.

In short, therefore, fabric roof structures do not come crashing down in a fire unless the fire is so severe as to destroy the structural supports to the roof, and for that the fabric roof cannot be deemed the culprit.

The NFPA-701 test used in USA essentially requires that a 250mm x 70mm sample of the fabric be clamped vertically in a fire chamber and a bunsen burner applied to one side for 12 seconds. When the flame is removed the fabric must self-extinguish within two seconds to pass the test. The test also incorporates a weathering condition wherein a weathered sample is tested to confirm no loss of performance.

The AS1530 Part 3 test set up is only roughly equivalent to NFPA-701.

The AS1530 Part 1 test for combustibility is much more severe in that it demands immediate cessation of flame.

One recent fire involving a tension structure in Australia occurred at Surfers Paradise. Here an outdoor area adjacent a 2 storey restaurant was covered by a series of retractable fabric barrel vaults on timber beams. A fire started inside the building spreading quickly through its timber frame and out to the covered area. The fabric and its support timbers immediately adjacent the building were severely burnt; that further out being slightly charred but beyond that not effected at all.

This fabric was only 750 gsm^2 PVC/P with only minimal flame retardance. The result gave strong evidence to the claim that structural fabrics do not propagate a fire but merely react to a pre-established and externally sustained fire.

Some years ago in Brisbane the Author had the good fortune to witness two major fires in industrial buildings. One was a tram depot, the other a plastics foam plant. The old depot building was fairly open with extensive timber floors, while the foam plant was an enclosed modern building with concrete floor and brick walls. Both had steel framed and sheeted roofs.

The fires in each were very severe since both had substantial internal fire loads. The significant difference in performance of the two buildings is worth noting.

The relatively open depot building was able to vent heat and smoke easily so that at extinction, only parts of the floor and a small section of roof had collapsed.

The foam plant, on the other hand, contained the heat to the point where the entire steel roof simply collapsed into the fire pulling parts of the walls with it.

It is worth noting that both roofs would be classed as being 'non- combustible', which adds to the Author's contention that 'spread of flame', is the primary fire criterion for a roof and not 'combustibility' as is presently the case.

AUSTRALIAN APPLICATIONS

Of the several hundred membrane structures completed in Australia a small but by no means insignificant number have been installed in buildings where some degree of care is needed on the part of the approving Authorities.

Prime amongst these applications have been hotels, shopping centres and, to a lesser extent, office buildings. While the structures in the former two have usually provided a permanent roofing function to essential activity areas, such as service desks, restaurants, etc., their use in office buildings has been largely as skylights over an access way or atrium.

The buildings they cover are mostly one or two storey, but some, e.g. Myer Centre, Brisbane are up to five storeys. By and large T/G fabrics have been used, however, the number of PVC/P fabric roofs is increasing.

Experience is limited to about 10 years and, so far, there have been no fires in the fabric areas of any of these projects, so that no track record can be referred to.

What is notable, however, is that, as the number of fabric structures of this nature increase, the difficulties once perceived by Approval Authorities are slowly but surely dissipating. This is not to suggest that it is now or ever should be open slather season. It is, however, some gratification for those few pioneers in the industry who have patiently and carefully promoted the correct use of these structures.

THE BUILDING CODE OF AUSTRALIA

Soon the building industry throughout Australia will have a new, or more correctly, re-edited set of rules covering acceptable standards for structural sufficiency, fire safety, health and amenity in buildings.

The new Code varies somewhat in content and format from the several State Acts and Ordinances with which we have all been brought up.

It is worthwhile then to look at what the Code says about fire safety as it relates to fabric structures.

Firstly, it is noted that the Code specifically defines a 'sarking type material', which, fortunately has nothing to do with a structural membrane.

It makes specific reference to Atrium spaces and sets down rules for fire and smoke control. In addition, the Author noted that fabrics either non-combustible (T/G) or combustible (PVC/P) may be used for atrium roofs and that both require a sprinkler system to protect the covered space.

Reference is made to 'Rooflights" which, presumably, could be combustible even in an otherwise non-combustible roof, with an area limit of $14m^2$ per $70m^2$ of non-combustible roof.

In relation to the present common usage in Hotels, Offices and Shopping Centres, the Code's requirements have been summarised in Table 2.

TABLE 2

TYPES OF CONSTRUCTION REQUIRED FOR VARIOUS BUILDING HEIGHTS AND USAGE CLASSES

RISE IN STOREYS ABOVE GROUND LEVEL	BUILDING CLASS 3 (Hotel)	5 (Office)	6 (Shop)
4 or more	A	A	A
3	A	B	B
2	B (or C)	C	C
1	C	C	C

QUANTIFYING MATERIAL BEHAVIOUR

By and large there are two approaches to quantifying the behaviour of a material to fire. Both are referred to in the various Building Codes.

The first is the concept of 'Fire Rating' or 'Fire Resistance Level'. Here, a material in the form of a structural assembly such as a wall or floor panel is subjected to what is essentially a 'full scale' test with a controlled fire on one side. The fire is brought to a given temperature in a certain time interval in accordance with a standard ISO curve, approx. 1000 degree Celsius in 2 hours.

Observations of the test panel are made from the remote side to assess such things as retained structural adequacy, retention of integrity in resisting flame penetration, temperature rise, etc.

Generally speaking, the period in hours (or minutes) over which the assembly sustains its performance under the fire load is referred to as its Fire Rating or Fire Resistance Level (FRL). For example, a 140mm thick reinforced concrete slab would have a FRL of 180 minutes.

Now, it is patently clear that a structural fabric 1mm thick and containing large amounts of plastic materials could not perform anywhere near well enough to achieve even a 30 minute FRL. All structural fabrics will ignite at the very high temperatures reached in the test, but even if they did not, and T/G resists high temperatures much better than PVC/P in this regard, their minimal thickness provides negligible resistance to temperature build-up on the remote side. This ability to maintain a significant temperature differential is critical in achieving the desired FRL.

Therefore, recourse is made to the second concept for rating a material's fire performance, i.e. testing for 'Flammability' and for 'Early Fire Hazard'. These were initially developed to assess wall coverings, etc. and are strictly tests on small scale material samples.

AS 1530 defines the several components of each test with results for two typical PVC/P and T/G structural fabrics being shown in Table 1.

TABLE 1

LABORATORY FIRE TEST VALUES FOR STRUCTURAL FABRICS

FLAMMABILITY OF MATERIALS AS1530.2.1973		PVC/PVC Polyester Smelterite 8028FR 950 gsm	Teflon-Glass Sheerfill II 1530 gsm
Speed Factor	(0-60)	0	0
Spread Factor	(0-40)	1	0
Heat Factor	(0 up)	1	0
Flammability Index		2	0
EARLY FIRE HAZARD AS1530.3.1973			
Ignitability Index	(0-20)	16	0
Spread of Flame index	(0-10)	0	0
Heat Evolved Index	(0-10)	0	0
Smoke Developed Index	(0-10)	6	4

The three key properties relevant to structural fabrics referred to in Building Codes are:

- Combustibility
- Spread of Flame
- Smoke Developed Index

A fabric is defined by AS1530 Part 1 as 'Combustible' if samples flame in an air stream heated by coils maintained at 750 degrees Celsius.

Within this definition T/G fabric is considered non-combustible while PVC/P fabrics are considered to be combustible.

Where fabrics are allowed they are required to have Spread of Flame Index of 5 or less and a Smoke Developed Index of 8 or less. It can be seen that both fabric types easily meet these requirements.

This is fairly simplistic when one considers the complexity of a large fabric roof and the vagaries of a building fire. For example, one will note there is no reference to toxicity of fumes developed.

Unfortunately, structural fabrics usage places them somewhere between the two, i.e. neither the macro FRL type test nor the micro Flammability/Early Fire Hazard tests offer a fair measure of a full scale fabric structure in a fire situation.

Despite several attempts to develop a relevant and accepted test procedure for fabric structures the use of Flammability/Early Fire Hazard criteria has become firmly established in building codes.

It is well to note, however, that modern building codes are not all that penalizing of fabrics in building. A further period of proof in the field is required before any substantial relaxations can be expected beyond those which can at present be reasonably achieved. Any fire in a building full of people is a potential disaster, and anything that can be done to limit its severity must be taken seriously.

Conversely, with experience, full scale testing and rational thought should come opportunities to extend the present applicability of fabric structures in buildings consistent with society's balance of safety and economy.

FIRE HISTORIES

One of the best collated reports on fire performance of fabric structures was presented by Richard Seaman at the AFSI Symposium in 1984 Ref (i).

Some 30 years of experience with 'flame retardant' fabrics was reviewed with reference to documented fires in both air supported and tensioned structures, mostly in USA.

One of his summary comments is worth repeating:

> "In thirty years of actual field experience with millions of square yards of fabric and millions of square feet of building space, there is no record of a life-safety problem from fire exposure in membrane structures that were constructed utilizing flame retardant fabrics that meet the NFPA-701 test.
>
> In actual fire situations, these fabrics do not support combustion nor continue to propagate the fire. Because of their ability to melt away and open up, they vent dangerous smoke and fumes and rapidly dissipate the heat in a fire area. This helps to minimize the structural damage to the frame support systems. It also provides quick and easy access by firefighters to limit ongoing damage to life and property making flame retardant membrane structures very safe from a fire safety standpoint."

Type 'A' is the most fire resistant form of construction and allows only non-combustible fabric roofs in general areas. In this case sprinklers are required for Class 5 and 6 buildings, however, where the whole of the floor area of a Class 3 building is a sole- occupancy no sprinklers are required.

Both Types 'B' and 'C' construction are generally less fire resistant, and combustible material, e.g. PVC/P may be used for roofs.

Particular attention is drawn by the code to the need for sprinkler systems. It is notable that their need is related to space usage and floor areas and not to material used nor the combustibility or otherwise of the roofing over.

As stated earlier in the paper fabrics to be used structurally for roofs must have a Smoke Developed Index not more than 8 and a Spread of Flame Index not more than 5, which is easily achieved by today's good quality fabrics.

There are specific limitations, however, in connection with materials used around Fire-isolated exits and certain public areas, where a Spread of Flame index of 0 and Smoke Developed Index not more than 5 is required. T/G fabric would satisfy this rule.

However, one curious clause which requires interpretation by the Fabric Structures industry is C1.10/7 which states:

"7. Exempted building parts and materials.

The requirements in this Specification for a Spread-of-Flame Index, Smoke-Developed Index or Flammability Index do not apply to:-

(a) timber-framed windows;

— — — — — — — —

(h) any other material which does not significantly increase the hazards of fire."

There would be little question that the Industry considers its fabrics fit this definition!

It should be clear from this crude summary of the BCA that there are a great number of opportunities for fabric structures in buildings. We mentioned only hotels, shops and offices, but essentially similar rules apply to residential complexes, schools, factories, laboratories and public buildings.

RATIONALE OF FIRE SAFETY

As there will always be special cases and new usage functions for buildings and fabric structures it is as well to approach the design or, indeed, to assess the likely suitability of a fabric application against a proper rationale of fire safety.

Such a rationale should consider all of the following:

- limiting the potential for fire outbreak and spread.
- good housekeeping;
- early detection;
- effective alarm and warning;
- providing alternative escape routes; installation of sprinkler systems;
- designing in structural redundancies;
- providing effective smoke and heat exhaust systems;
- compartmentation or containment.

Generally, the rules of fire safety in buildings recognise the following criteria in order of decreasing preference:

- safety for people;
- prevention of damage to adjacent property;
- minimising damage to the fired building;
- minimising damage to the contents of the fired building.

By paying due attention to these and to the rules and intentions of the building code, Designers will find a great number of opportunities for safe and interesting fabric structures.

On occasion, the situation may warrant application to the Authority for a variation to the Code rules, and the above gives a good basis on which to approach such a variation.

CONCLUSION

While fabric structures have been around for well over a decade here in Australia, there are still many misconceptions in the building industry of their true performance in a fire situation.

Fortunately those are fading away and it is hoped the paper will hasten this and create, instead, a positive and confident building industry.

The small number of recorded fires involving fabric structures give a strong basis to the claim that they are no less fire safe than any of the long established structural systems that they now seek to compete with and replace.

The new Building Code of Australia not only recognises this but provides a significant range of building opportunities for both T/G and PVC/P fabrics.

There will always be places where fabric structures simply do not belong, but there are a great many others where they are freely approved, or after prudent and rational investigation can be shown to offer effective and fire safe alternatives in a highly competitive building industry.

REFERENCES

(i) Seaman R. 'Fire Performance History of Flame Retardant Membrane Structures' AFSI Conference, Orlando, 1984

(ii) The Building Code of Australia, 1988

(iii) Australian Standard AS1530, Parts 1, 2, 3.