FABRIC AND MEMBRANE STRUCTURES

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1.0 SCOPE

This data sheet is applicable to fabric and membrane structures, hereafter referred to as fabric structures. These structures include tensioned fabric structures (tensile surface structures), tensegrity structures, fabric-covered (-clad) structures, cable-supported structures with fabric covering, pneumatic membrane structures, and air-supported structures.

1.1 Hazards

Major hazards for fabric and membrane structures are the following:

- Wind and Wind-Borne Debris
- Collapse: Snow and Ice
- Hail
- Fire

1.2 Changes

April 2021. This document has been completely revised. The following changes have been made:

A. Simplified the terminology and updated the scope statement and Appendix A definitions.

B. Modified the recommendations in Section 2.1 regarding where fabric structures should be installed.

C. Added recommendations related to ETFE.

D. Added the FM Global parallel panel test as a method to determine fire propagation properties.

E. Updated the Operations and Maintenance, and Human Factor sections.

F. Revised the figure and table numbering.

G. Revised the layout of Section 3.0.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

2.1.1 Use FM Approved equipment, materials, and services where they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide* and RoofNav, online resources of FM Approvals.

Use only FM Approved snow/ice melting systems, but do not reduce the design snow load on roofs.

2.1.2 Design fabric structures with adequate structural capacity to support automatic sprinkler protection systems per Section 2.4.

2.1.3 Consider use of fabric structures only if **all** of the following conditions are met:

A. Located within non-tropical cyclone-prone regions (this includes non-hurricane-prone and non-typhoon-prone regions).

B. Roof slope that meets one of the following criteria:

1. Shed (monoslope), gable, hip roofs with a slope greater than or equal to 15 degrees.

2. Curved/domed roofs with a vertical angle greater than or equal to 10 degrees where the vertical angle is measured between horizontal and a line drawn from the roof eave to roof crown.

C. Installed for use as temporary structures.

D. Contents and occupancy are noncombustible and low value.

2.2 Construction and Location

2.2.1 Wind

For loads on primary structural framing and main lateral force resisting systems, refer to ASCE 7 or other nationally recognized standard or code applicable to the jurisdiction.

2.2.1.1 Preface Recommendations

A. Determine the design wind speed from Data Sheet 1-28, *Wind Design*.

B. Enclosure Classification:

1. Classify *Open* buildings as Open.
2. Classify all other buildings as Partially Enclosed.

C. Use a wind load importance factor (I_w) of 1.15.

D. Dynamic Amplification:

1. If the fundamental natural frequency of the fabric structure is less than 2 Hz, evaluate dynamic amplification to wind loads using a method in accordance with recognized standards.

2.2.1.2 Determination of Design Wind Pressures

A. Determine wind design pressures based on atmospheric boundary layer wind tunnel tests in combination with the recommendations in 2.2.1.1 and 2.2.1.3 for the following situations:

1. Irregular building shapes
2. Fabric structures subjected to channeling or buffeting from adjacent or upwind structures or obstructions

B. Determine wind design pressures for regular building shapes in accordance with Data Sheet 1-28 in combination with the recommendations in 2.2.1.1 or using atmospheric boundary layer wind tunnel tests as described in 2.2.1.2A

2.2.1.3 Wind Tunnel Tests

A. Follow the wind tunnel recommendations in Data Sheet 1-28 for the use of wind tunnel tests and secondary framing and structural components.

B. Exception to enclosure classification: an Enclosed building model with prescriptively increased interior pressures may be used to represent the recommended Partially Enclosed condition.

2.2.1.4 Building Fenestrations

Determine design wind pressures on building fenestrations (e.g., windows and doors), per Data Sheet 1-28.

2.2.2 Roof Gravity Loads (Snow, Ice, Rain, and Roof Live Load)

2.2.2.1 Locate fabric structures to prevent any potential exposure to sliding or drifting snow load or falling or sliding ice. This includes snow drifts at low roofs, roof projections and parapets, roof valleys, or snow drifts due to adjacent structures or terrain features, as well as snow or ice from an adjacent high roof, rooftop equipment, exterior cables, or other overhanging support members. (This recommendation includes all types of sliding and drifting snow load, but does not include unbalanced snow load on hip, gable, curved, and dome roofs as described in Data Sheet 1-54, *Roof Loads and Drainage*.)

2.2.2.2 Determine design snow loads from a boundary layer wind tunnel test, water flume model, or other test or model for roof shapes not representative of standard roof shapes in DS 1-54.

2.2.2.3 Determine snow, ice, rain, rain-on-snow, and roof live loads for standard roof shapes per DS 1-54. For all fabric structures, including air-supported structures, use the recommendations in DS 1-54 with the following changes:

A. Use a Roof Slope Factor (C_s) for “Cold Roof” for all structures.

B. Use a Roof Slope Factor (C_s) for “All Other Surfaces” (not “Unobstructed Slippery Surface”) for all structures.

C. When determining the sliding snow load on a lower roof from an upper fabric roof, consider the upper fabric roof surface to be “slippery.”

2.2.2.4 For pneumatic systems with multilayer panels or cushions inflated by a mechanical air pressure system (***excluding*** air-supported structures):

A. Determine snow, rain, and ice loads based on conditions (1) and (2):

(1) Panels/cushions are inflated as designed.
(2) Panels/cushions are deflated to atmospheric pressure.

B. Include increases or concentrations of loads due to sliding, drifting, or ponding associated with conditions (1) and (2).

2.2.3 Hail

2.2.3.1 Install fabric with sufficient impact energy resistance for the hail hazard per Data Sheet 1-34, *Hail Damage*.

2.2.3.2 Install building fenestrations and any exposed equipment, such as rooftop equipment, with sufficient impact energy resistance or adequate hail damage protection (e.g., hail screens or hail guards) for the hail hazard per Data Sheet 1-34.

2.2.4 Bracing and Structural Stability

Install bracing for structural framing independent of the fabric. This includes bracing for both primary and secondary members and components.

2.2.5 Fabric Seams

2.2.5.1 Use high-frequency welded seams, heat-welded seams, or seam detailing with seam strength not less than the fabric tensile strength.

2.2.6 Safety Factor and Life Cycle Factor

2.2.6.1 Apply minimum safety factors per Table 2.2.6.1 for fabric strength at the start of service life (i.e., new fabric). Minimum safety factors are based on the condition that 75% of the initial strength of the fabric will be retained over intended service life of the structure (i.e., a life-cycle factor of 0.75).

Increase safety factors proportionally if less than 75% of the initial strength is expected over the intended service life.

The following equation describes the relationship between the life-cycle factor and safety factor for fabric:

$$\left[\begin{array}{c}\text{Safety factor at}\\ \underline{\text{end}}\text{ of service life}\end{array}\right] = \left[\begin{array}{c}\text{Safety factor at}\\ \underline{\text{start}}\text{ of service life}\end{array}\right] \times \left[\text{Life-cycle factor}\right]$$

Refer to Section 3.2.6 for an example showing the proportional increase of safety factor.

Table 2.2.6.1. Load Combinations and Safety Factors for Fabric Tension at the Start of Service Life (Life Cycle Factor of 0.75)

No.	*Load Combination*	*Minimum Safety Factor**
1	P + D	8.0
2	P + D + (L, S, or R)	5.0
3	P + D + W	5.0
4	P + D + T	5.0

Key:
P = pre-stress load for fabric
D = dead load (including collateral load)
L = live load
S = snow load (including ice load)
R = rain load
W = wind load (including 1.15 importance factor)
T = thermal expansion or contraction effects on self-restraining loads

*Safety factors do not include a life-cycle factor, but are based on the condition that at least 75% of the initial strength will be retained over the service life of the structure.

2.2.6.2 Apply life-cycle factors based on test data from the manufacturer and the judgment of the design engineer with the following upper limits:

A. A life-cycle factor no greater than 0.60 for fabric that will be subjected to repeated handling or folding (as with a deployable or seasonal structure).

B. A life-cycle factor no greater than 0.75 for all other fabric.

2.2.6.3 Apply minimum safety factors per Table 2.2.6.3 for fabric strength over the service life of the structure. Minimum safety factors include all life-cycle factors and need no further reduction.

Table 2.2.6.3. Load Combinations and Safety Factors for Fabric Tension During Service Life

No.	*Load Combination*	*Minimum Safety Factor**
1	P + D	6.0
2	P + D + (L, S, or R)	3.7
3	P + D + W	3.7
4	P + D + T	3.7

Key:
P = pre-stress load for fabric
D = dead load (including collateral load)
L = live load
S = snow load (including ice load)
R = rain load
W = wind load (including 1.15 importance factor)
T = thermal expansion or contraction effects on self-restraining loads

*Safety factors represent the minimum values that are acceptable over the service life of the structure.

2.2.6.4 Refer to Sections 2.2.7 and 2.2.8 for recommendations related to material tensile tests and mock-up panels to determine life-cycle factors.

2.2.7 Mechanical Testing

Perform the tensile strength, trapezoidal tear, elongation, and accelerated ultraviolet (UV) weathering tests listed in 2.2.7.1 through 2.2.7.3 on the fabric materials used in the fabric structure.

2.2.7.1 Tensile Strength Tests

Perform uniaxial or biaxial tensile tests on new and ultra-violet (UV) conditioned samples (including material assessment for creased, folded, warp and fill direction) in accordance with ASTM D4851 or another nationally recognized test standard specific to fabric structures, and per Table 2.2.7.1. Use a minimum of 10 test strips (5 in the warp direction, 5 in the fill direction) per roll sample.

Compare the test results of the UV conditioned material to the new material. Use a life-cycle factor based on the ratio of weathered to new tensile strength, but not to exceed 0.75. If UV weathering tests are not performed, assume a life-cycle factor of not more than 0.6.

Table 2.2.7.1. Mechanical Test Sampling Frequency for Fabric

Rolls of Material Used	*Number of Rolls Sampled for Testing*
1 to 3	All
4 to 24	4
25 to 50	5
Over 50	10% of the rolls, but need not exceed 10 rolls

2.2.7.2 Elongation and Tear Tests

Perform trapezoidal tear and elongation tests in accordance with ASTM D4851 or another nationally recognized test standard specific to fabric structures.

2.2.7.3 UV Weathering Tests

Perform accelerated ultraviolet (UV) weathering testing in accordance with either ASTM G151 or ASTM G154, or another nationally recognized standard specific to fabric structures, which is representative of the intended service life.

2.2.8 Mock-Up Test Panels

2.2.8.1 Install mock-up test panels of the fabric material from the same batch used on the structure. Use test panel material for periodic determination of the life cycle and safety factor condition over the life of the structure.

2.2.8.2 Construct sufficient test panels for sample harvesting over the projected life cycle of the structure. Install mock-up test panels using the same design with worst-case exposure conditions as the structure (i.e. material pre-stress; orientation of warp and fill yarns; exposure to sun, wind, and other environmental effects; etc.) It is not necessary to include curvature intended to represent the shape of the fabric surface of the structure. Permanently mark test panels with the month/year of construction.

2.2.8.3 Visually examine mock-up panels annually for obvious deterioration. Conduct tensile strength and tear resistance testing on a 5-year interval from the date of final construction. Perform testing following Section 2.2.7.1 and 2.2.7.2, except the total number of tensile tests need not exceed 20, 10 tests for each the warp and fill directions for each test. Establish test result criteria dictating when fabric replacement is necessary. Compare mock-up panel test results to fabric baseline prior to construction and trend results following each test cycle to identify deterioration. Accelerate testing for tensile strength and tear resistance where deterioration from baseline results are identified.

2.2.9 Exterior Fire Exposure and MFL Considerations

2.2.9.1 Follow the recommendations in Data Sheet 1-20, *Protection Against Exterior Fire Exposure*, with exceptions and modifications as follows:

A. Install fabric roofs with an ASTM E108 Class A Burning Brand rating.

B. When evaluating separation distances and other criteria based on combustible or noncombustible construction in Data Sheet 1-20, consider the following:

  1. For fabric structures part of an exposing building, direct exposure will occur from radiant heat of burning building contents.

  2. For fabric structures part of an exposed building, the contents will be directly exposed to fire.

2.2.9.2 Follow Data Sheet 1-42, *MFL Limiting Factors*, with the following considerations:

1. If the fabric structure is part of an ***exposing*** building, base the exposing fire hazard on the combustibility of the occupancy within the fabric structure.

2. If the fabric structure is part of an ***exposed*** building, classify the portion of exposed construction as combustible exposed. (regardless of the combustibility rating of the fabric)

2.2.10 Fire Resistance

Install fabric that meets 2.2.10.1 through 2.2.10.3.

2.2.10.1 Do not use fabric where fire resistance rated construction or a fire barrier is needed.

2.2.10.2 Install noncombustible fabric **or** fabric that will not self-propagate fire per A. or B., respectively.

A. Criteria for Noncombustible Fabrics

Fabrics can be considered noncombustible when the material has passed ASTM E136, ASTM E2652 with ASTM E136 pass/fail criteria. Both tests are applicable to materials made of fibers (yarns) that are not thermoplastic, laminated, or composite materials such as most films/foils or coated fabrics.

The following can be considered noncombustible:

1. PTFE-coated fiberglass

B. Criteria for fabric that will not self-propagate fire

Determine whether the fabric will self-propagate fire based on NFPA 701 (Method 2), or the FM parallel panel test.

The following can be considered to not self-propagate fire:

1. ETFE installed in either one-layer or multiple layers with an area density less than 1.4 lb_m/ft^2 (6.7 kg/m^2) inclusive of all layers.

2.2.10.3 Use fabric that has a flame spread index (FSI) of 25 or less in accordance with ASTM E84.

2.3 Occupancy

Do not use fabric structures for the following:

A. Occupancies with combustible storage or ignitable liquids.

B. High-value occupancies.

2.4 Protection

The recommendations in this section are based on sufficient structural capacity to support an automatic sprinkler protection system as recommended in Section 2.1.2.

2.4.1 In addition to the recommendations in this section, install automatic sprinkler protection as required for the hazard classification and the occupancy in accordance with the applicable FM Property Loss Prevention Data Sheets.

2.4.1.1 For concealed spaces formed by fabric, refer to Data Sheet 1-12, *Ceilings and Concealed Spaces*, Figure 2.2.2-1 for Suspended Ceiling construction classification.

Exception: For pneumatic systems with multilayer panels or cushions, it is not necessary to consider the air space between fabric layers as concealed spaces.

2.4.1.2 Install or provide **all** of the following:

A. FM Approved, quick-response, standard-coverage sprinklers having the lowest nominal temperature rating permitted by FM Property Loss Prevention Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*, based on the highest anticipated ambient temperature condition.

B. Slope of fabric roof or ceiling meeting the recommendations per DS 2-0.

C. Full-scale fire testing that confirms satisfactory sprinkler actuation (i.e. not delayed or otherwise adversely affected.) Testing should include proposed sprinkler orientation, temperature rating, and K-factor.

2.4.2 Install smoke or heat detection per Data Sheet 5-48, *Automatic Fire Detection*. Arrange the air-handling system to shut down upon activation of the smoke or heat detection system.

2.5 Equipment and Processes

2.5.1 Inflation Systems for Air-Supported Structures and Pneumatic Systems

2.5.1.1 Install **both** a primary inflation system and an emergency backup inflation system.

A. Each inflation system should have the capacity to maintain design inflation pressure with normal air loss. For air-supported structures, include air loss associated with the operation of the building entrances, exits, and emergency exits in the calculation of capacity for the inflation systems.

B. For air-supported structures, base the assumed normal air loss (leakage) on the provisions of Annex G of CSA S367-09, another nationally recognized standard, or calculations made by the design engineer.

2.5.1.2 Install an independent self-contained power source for the emergency backup inflation system.

2.5.1.3 Install an electrical interlock to ensure automatic operation of the emergency backup inflation system upon failure of the primary inflation system.

2.6 Operation and Maintenance

2.6.1 Re-tension fabric as recommended by the design engineer or manufacturer, or if billowing or other visible signs are evident that the proper level of pre-tensioning has not been maintained.

2.6.2 Re-tension cable bracing as recommended by the design engineer or manufacturer, or if there are indications that an adequate level of cable tensioning has not been maintained.

2.6.3 Provide one of the following, in addition to a contract for an available qualified repair/installation team, to facilitate prompt replacement of damaged fabric sections:

A. Maintain readily available spare quantities of fabric at the facility where the fabric structure is located or a nearby storage facility with adequate personnel, handling, and transportation to deliver within a short timeframe.

B. Identify a supplier with sufficient stock replacement fabric that can be delivered within a short timeframe.

2.7 Human Factor

2.7.1 Provide thorough inspection, testing, maintenance (ITM) of fire protection systems per Data Sheet 2-81, *Fire Protection System Inspection, Testing, and Maintenance*.

2.7.2 Provide testing and maintenance of fire detection systems per Data Sheet 5-48.

2.7.3 For pneumatic and air-supported structures, provide thorough ITM for the following systems:

A. Primary and backup inflation systems

B. Power source for the emergency backup inflation system including the interlock for the emergency backup inflation system

2.7.4 Ignition Source Control

Explore alternatives to all hot work in areas in close proximity of fabric roofs. Hot work is one of the most common ignition sources. Most hot work occurs during construction, alteration, or demolition (see Data Sheet 1-0, *Safeguards During Construction*). If there is no alternative to hot work, then use the FM hot work permit system (see Data Sheet 10-3, *Hot Work Management*).

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Introduction

3.1.1 Fabric Structures

Fabric yarns are generally oriented in either the warp or fill (weft) directions (Figures 1 and 2). When the fabric is tensioned in both directions, the warp yarns become more deformed and curved (i.e., more warped), while the fill yarns become straighter. The interaction between the warp and fill yarns has a significant effect on the mechanical properties of the fabric. The fabric is generally stronger in the warp direction than in the fill direction, and the percentage of elongation in the fill direction is generally greater than in the warp direction.

See Figure 3.1.1-3 for a typical large fabric-covered structure under construction. The fabric has not been installed at the near-side gable end wall, exposing the steel trust frame and the end wall steel posts and girts. Also note the inner layer (liner) of fabric, which is often used as an acoustical barrier or to create a space for mechanical, electrical, and/or plumbing systems

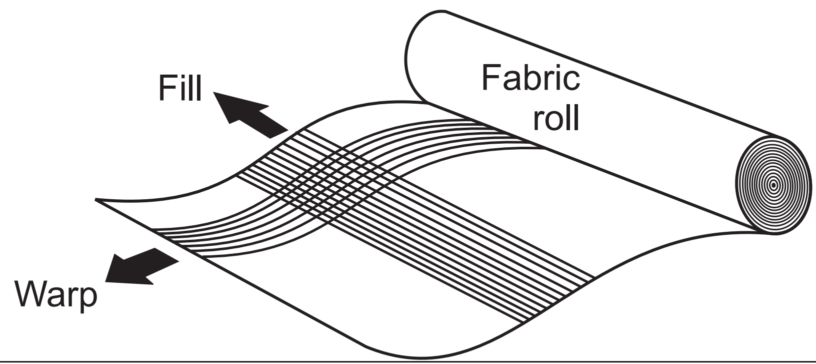

Fig. 3.1.1-1. Typical roll of fabric showing warp (machine) and fill (cross or weft) directions.

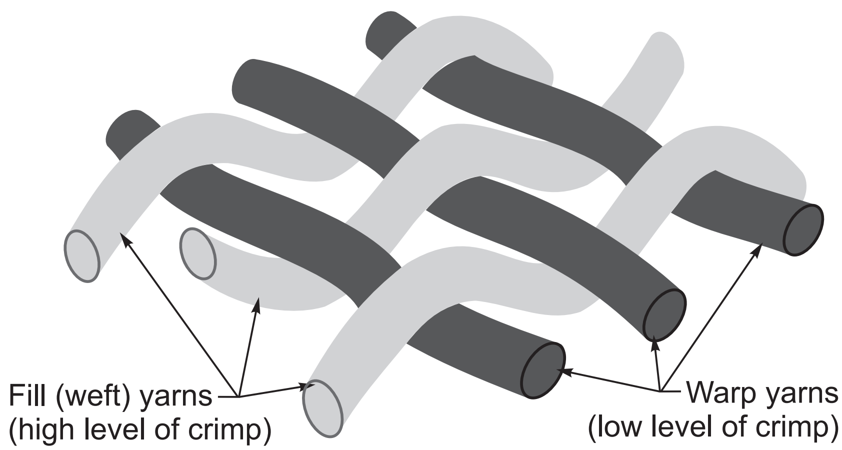

Fig. 3.1.1-2. Typical fabric yarns showing warp and fill (weft) orientation.

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Fig. 3.1.1-3. Fabric-covered structure under construction

Figures 3.1.1-4 through 3.1.1-7 show common shapes of tensioned fabric structures.

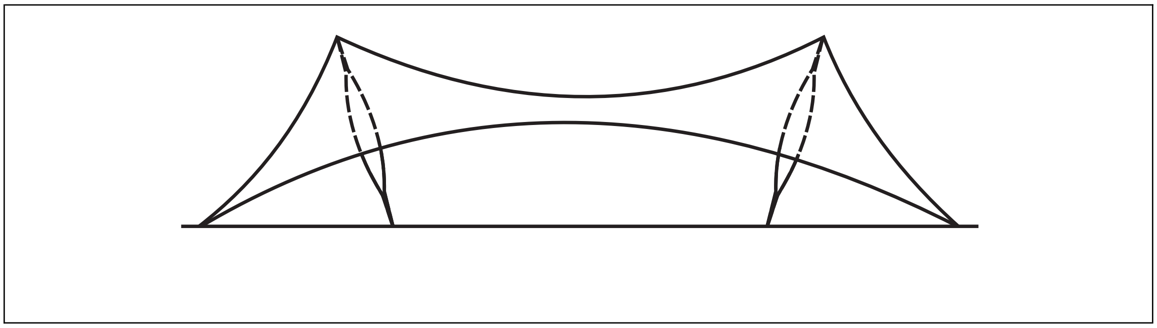

Fig. 3.1.1-4. Mast-supported tensioned fabric structure

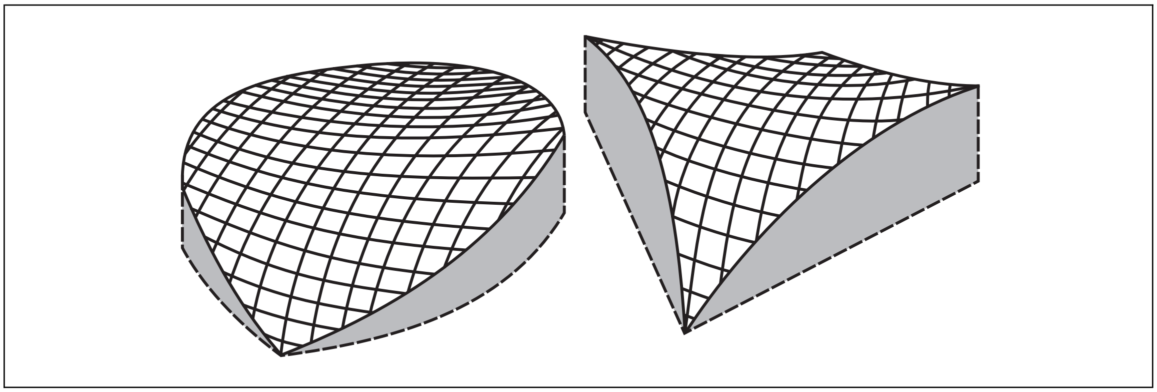

Fig. 3.1.1-5. Saddle-shaped (hypoid) tensioned fabric structures

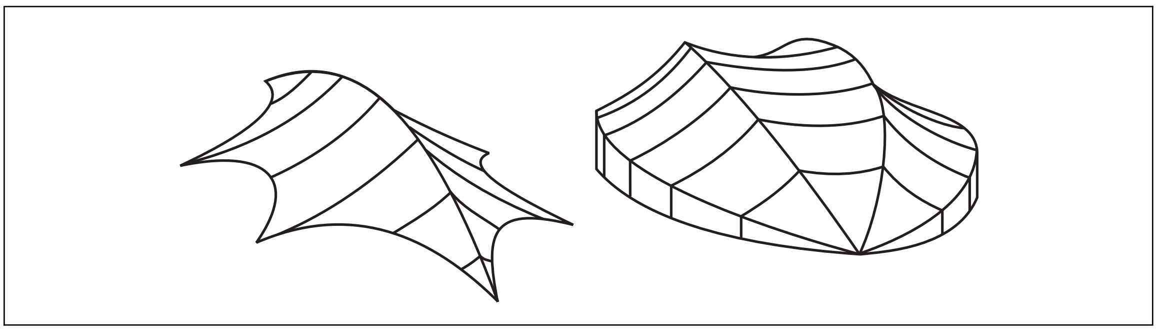

Fig. 3.1.1-6. Arch-shaped tensioned fabric structures

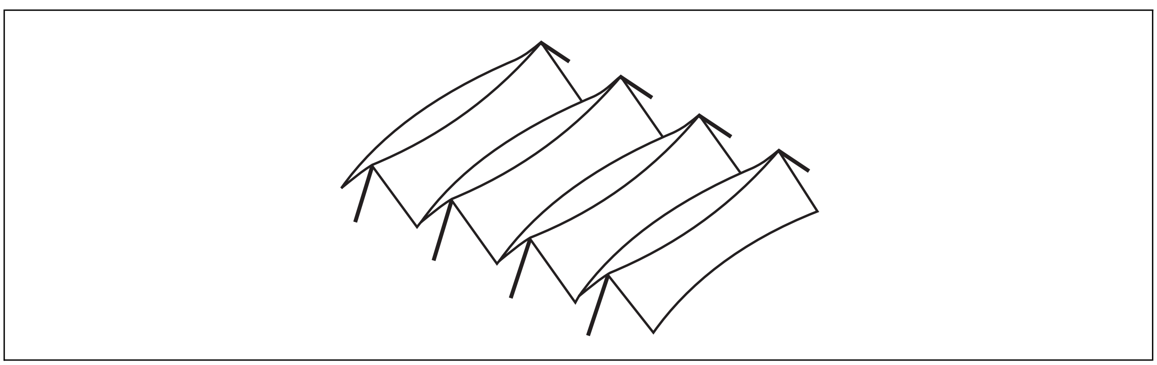

Fig. 3.1.1-7. Tensioned fabric structure with a folded configuration

3.1.2 Pre-Stressing and Re-Tensioning

Fabrics are typically pre-stressed (pre-tensioned) when first installed; this keeps the material taut, maintains the proper shape, and prevents the material from billowing when subjected to wind. Pre-stressing also helps to ensure the proper load distribution throughout the fabric. Under the sustained stress of pre-stressing, the material will generally relax over time; that is, it will elongate and therefore reduce the level of tension and tautness in the material. For this reason, many fabrics need to be re-stressed over the service life of the structure.

3.1.3 Air-Supported Structures

All air-supported structures (Figure 3.1.3) experience air loss to a certain degree when inflated with positive pressure. Pressure can be lost through the fabric skirt at the base of the building, fabric junctions at fenestrations (e.g., doors, ducts or vents), airlocks, and fabric seams. Leakage can be estimated based on calculations for a given building and inflation system. Or, leakage can be based on typical air loss rates provided in industry standards such as CSA S367 (for a given pressure). Leakage estimates are the minimum loss rates; variations occur under different service conditions.

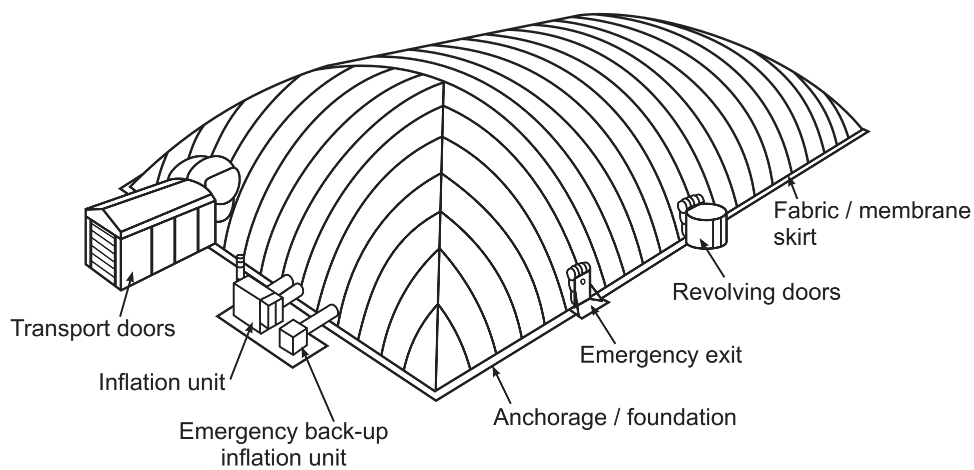

Fig. 3.1.3. Example of an air-supported building

In addition, air leakage increases significantly when people enter or exit; most buildings use rotating doors or air-locks to minimize leakage.

The normal operating pressure for most air-supported structures is approximately 5 lb/ft^2 (0.24 kPa), with a maximum operating pressure of approximately 10 to 15 lb/ft^2 (0.48 to 0.72 kPa).

3.2 Construction and Location

3.2.1 Wind

3.2.1.1 Wind Speeds and Loads

The recommended wind speeds in Data Sheet 1-28 are the design wind speeds. The wind pressures resulting from the design wind speeds are the characteristic wind pressures; that is, they are neither the factored wind pressures nor the ultimate limit states wind pressures.

3.2.1.2 Enclosed, Partially Enclosed, and Open Buildings

The recommendation to classify both “Enclosed” buildings and “Partially Enclosed” buildings as Partially Enclosed for all wind regions when calculating design wind pressures is based on the susceptibility of fabric to punctures and tearing; this may be from wind-borne debris or from deflecting fabric contacting internal supports or appurtenances.

The standard small and large missile tests for wind-borne debris exposure are intended for construction materials such as glass and glazing, metal wall panels, wood sheathing, and masonry, but are not intended for fabric structures where tearing continues after the initial puncture.

3.2.1.3 Wind Tunnel Tests

Fabric structures, particularly tensioned fabric structures, often do not conform to traditional building shapes that are addressed by building codes and standards. Accurate determinations of wind pressures on irregularly shaped buildings are best achieved by performing a boundary-layer wind tunnel study.

Most wind tunnel studies for fabric structures will not use aeroelastic models; that is, the model of the structure will be designed to represent the geometry and shape of the structures but not its physical and structural characteristics. For this reason, it will generally be necessary to use some prescriptive means of representing the dynamic effects of wind-structure interaction on wind pressures.

Wind-structure interaction can occur at two levels: global or local. The global level involves the movement of the building frame, while the local level involves the movement of the fabric spanning between structural supports. At the global level, a key characteristic is the rigidity or stiffness of the structure as represented by the fundamental natural frequency of the structure. Rigid structures have higher fundamental natural frequencies, while more flexible structures have lower frequencies. Fundamental natural frequency is measured in cycles per second or Hertz (Hz). The inverse of fundamental natural frequency is fundamental period, which is measured in seconds per cycle. Structures with shorter natural periods are relatively rigid while more flexible structures have longer natural periods.

The fundamental natural frequency of fabric covered structures will often be significantly less than that of a tensioned fabric structure of similar size. Therefore, it is common for fabric covered structures to be called flexible, non-rigid, or dynamic, while many tensioned fabric structures are called rigid or static.

For pneumatic membrane systems (e.g., pressurized multilayer ETFE panels), the inflated panels or cushions can deflate due to a malfunction or loss of power to the inflation systems, or from physical damage to the inflated panel or cushion (e.g., a cut, tear, or puncture of the membrane). Therefore, it is recommended that two scenarios be evaluated to determine the more demanding (least favorable) condition: snow, ice, or rain loads with the panels inflated as designed, and with the panels deflated. The deflated panel scenario in particular could allow for increased or concentrated loading, for example from sliding snow or ponding rainwater.

3.2.2 Roof Gravity Loads (Snow, Ice, Rain, and Roof Live Load)

3.2.2.1 Roof Live Load

Roof live loads specified for fabric structures by various codes and standards can be quite low (e.g., ASCE 7 specifies 5 lb/ft^2 [0.24 kPa] for fabric canopies and awnings) compared to the recommendations in Data Sheet 1-54.

3.2.2.2 Snow Load

A Roof Slope Factor (C_s) for “Cold Roof” is recommended because the loss of heating for a building, due to either the loss of electrical power or the loss of heated internal air from an opening (e.g., tearing or breaching) in the fabric covering, would negate the potential reduction in snow loads that could be applicable to a warm roof.

A Roof Slope Factor (C_s) for “All Other Surfaces” (not “Unobstructed Slippery Surface”) is recommended to account for the effects of aging (including roughening of the fabric surface or fabric fraying), local fabric deflection, actual roof shape (including valleys or other distortions created by support cables for example), or obstructions.

The recommendation to consider the fabric roof surface slippery when determining sliding snow loads (on a lower roof) is intended to account for conditions where the fabric is relatively new and has not been substantially roughened or frayed, and the fabric has not deformed due to loss of tension or creep deformation.

For fabric structures with two layers, the air space between the inner and outer layers is sometimes used as a plenum for heated air, which is intended to heat the outer layer to melt snow. This type of snow melting system should not be used to reduce snow or ice loads. ASCE 55 does not allow design snow loads to be reduced by using snow melting or removal methods for permanent structures.

3.2.2.3 Load Scenarios

For pneumatic membrane systems such as pressurized multilayer ETFE panels, the inflated panels or cushions can deflate due to a malfunction or loss of power to the inflation systems, or from physical damage (e.g., a cut, tear, or puncture to the inflated panel or cushion). The two scenarios given in Section 2.0 are intended for evaluation of the more demanding (least favorable) condition: snow, ice, or rain loads with the panels inflated as designed, and with the panels deflated. The deflated panel scenario could allow for increased or concentrated loading, for example from sliding snow or ponding rainwater.

3.2.3 Hail

Potential variations in composition and thickness among other parameters between manufacturers results in the recommendation for verification of hail resistance for each installation.

3.2.4 Bracing and Structural Stability

Fabric is not an appropriate material to provide bracing for structural framing, including primary framing (e.g., girders or columns) and secondary framing members and components (e.g., purlins, rafters, girts, or studs).

CSA S367-09 specifically prohibits consideration of the fabric as contributing to the structural strength or stability of the supporting structure or structural members.

3.2.5 Fabric Seams

Over the life of installed fabric, high-frequency welded seams and heat-welded seams typically retain more strength than sewn or adhesive seams.

If sewn or adhesive seams are used on lieu of welded seams, the retained seam strength could be as little as 50% of the retained strength of the fabric over the life of the fabric.

3.2.6 Safety Factor and Life Cycle Factor

The life-cycle factor accounts for the loss of initial material strength over the service life of the structure due to the effects of exposure, aging, weathering, handling, and folding.

Example: Fabric subjected to repeated handling or folding, as with a deployable or seasonal structure, where it could be expected to retain only 60% of its initial strength over its service life, apply a factor of 1.25 (75% / 60%= 1.25) to the safety factors in Table 2.2.6.1. However, if the safety factors in Table 2.2.6.1 are based on fabric tensile strength tests that already account for handling and folding (e.g., flex-fold test samples), then additional factors need not be applied to increase these safety factors.

Table 2.2.6.1 represents the minimum recommended safety factors for new (virgin) fabric (without a life-cycle factor) but is based on the assumption that the fabric will retain at least 75% of its initial strength. Table 2.2.6.3 represents the minimum recommended safety factors that should be sustained over the service life of the fabric structure. When the safety factors approach or reach the minimum safety factors in Table 2.2.6.3, the structure is nearing or has reached the end of its useful service life.

3.2.7.1 Tensile Strength Tests

For most structures, biaxial testing is a more appropriate representation of in-situ conditions where the fabric is subjected simultaneously to tensile forces in two orthogonal directions (i.e., warp and fill). Where uniaxial tensile testing is performed, it is typically performed in both the warp and fill directions.

Where fabric is expected to be creased or folded during installation, or while in service, it is appropriate to base the tensile strength on test samples that have been creased or folded prior to testing. Creased or folded tensile strength is a reasonable and conservative value to use in design unless the contractor or design engineer can demonstrate that the fabric will be installed without folding/creasing or will not experience folding or creasing during service.

Uniaxial or biaxial tensile tests can be used to determine the strength of fabric material subjected to ultra-violet (UV) weathering. The UV weathering process is intended to represent UV exposure over the design life of the structure. Therefore, a reasonable life-cycle factor can be calculated by taking the ratio of weathered to new tensile strengths.

3.2.8 Mock-Up Test Panels

Mock-up panels are intended to supply test samples of fabric that have experienced similar exposures as the fabric structure. The mock-up panel allows fabric test samples to be taken without the need for cutting the samples from the fabric structure itself (which would then require patching). Exposed fabric will lose strength over time, and the periodic testing is intended to monitor the loss of strength, and the effects on safety factor, at reasonable time intervals. Mock-up panels often can be incorporated into an architectural feature of or near the structure.

3.2.9 Exterior Fire Exposure

Fabric materials exposed to fire can ignite, soften, or melt early in a fire creating an opening in the building envelope that allows heat (hot gas) to vent outside or into the space between an interior fabric liner and the exterior fabric. These openings can delay activation of automatic sprinklers, allowing the fire to overwhelm the automatic sprinkler system and result in an uncontrolled fire.

Fabric structures are susceptible to fire damage from exterior sources since the fabric material can burn or melt away and expose building contents.

3.3 Reserved for Future Use

3.4 Protection

Fire-exposed fabric structures can impair automatic sprinkler systems or present conditions which are difficult to protect. Therefore, they are not appropriate for all occupancies.

Fabric materials that are exposed to fire can fail (lose integrity, melt, or burn through) and create holes or openings in the building envelope or ceiling that allow heat (hot gas) to vent. Automatic sprinklers rely on heat from fire exposure for proper actuation, and therefore venting can delay sprinkler response and result in inadequate protection. This is among the fire-related hazards addressed by the recommendations in Section 2.4.

For a two-layered system (e.g., an acoustical interior fabric liner in addition to the exterior fabric), the fabric liner typically acts as the ceiling when designing or evaluating automatic sprinkler protection. In addition to overwhelming the sprinkler system, two-layered systems can create a concealed space that may require additional automatic sprinkler protection.

Fabric structures often have substantial roof slopes or curvature in order to shed rain and snow, or for architectural or occupational purposes. These large slopes often exceed the maximum recommended slopes for some automatic sprinkler systems.

Fabric structures can be susceptible to fire damage from exterior sources since the fabric material can burn or melt away and expose building contents.

It may not be feasible to install automatic sprinkler protection in tensioned fabric structures due to the lack of adequate support structure, which is needed for the proper hanging, bracing, and restraint of automatic sprinkler system components.

Solar transmission through some fabrics can contribute to increased ambient air temperatures at the ceiling. If solar transmission is not accounted for by the building mechanical (HVAC) engineer, and coordinated with the fire protection engineer, the ambient air temperature could exceed the maximum recommended values in DS 2-0 for the specified nominal temperature rating of the sprinklers. Doing so would result in unintended sprinkler actuation.

Solar transmission could also affect flame detectors that are not properly arranged and shielded per DS 5-48, resulting in false alarms.

4.0 REFERENCES

4.1 FM

Data Sheet 1-0, *Safeguards During Construction*
Data Sheet 1-12, *Ceiling and Concealed Spaces*
Data Sheet 1-20, *Protection Against Exterior Fire Exposure*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-34, *Hail Damage*
Data Sheet 1-42, *MFL Limiting Factors*
Data Sheet 1-54, *Roof Loads for New Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 2-81, *Fire Protection System Inspection*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 10-3, *Hot Work Management*

4.2 Others

American Society of Civil Engineers (ASCE). *Air-Supported Structures.* ASCE 17-96.

American Society of Civil Engineers (ASCE). *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* ASCE 7.

American Society of Civil Engineers (ASCE).*Structural Applications of Steel Cable for Buildings.* ASCE/SEI 19-10.

American Society of Civil Engineers (ASCE). *Tensile Membrane Structures.* ASCE 55-10.

American Society of Civil Engineers (ASCE). Wind Tunnel Studies of Buildings and Structures. ASCE Manual No. 67.

American Society for Testing and Materials (ASTM). *Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer.* ASTM E2652.

American Society for Testing and Materials (ASTM). *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C.* ASTM E136

American Society for Testing and Materials (ASTM). *Standard Test Methods for Fire Tests of Roof Coverings.* ASTM E108.

American Society for Testing and Materials (ASTM). *Standard Test Methods for Surface Burning Characteristics of Building Materials.* ASTM E84.

Canadian Standards Association (CSA). *Air-, Cable-, and Frame-Supported Membrane Structures.* CSA S367-09.

Forster, B., and M. Mollaert. *European Design Guide for Tensile Surface Structures.* TensiNet, 2004.

National Fire Protection Association (NFPA). *Standard for Grandstands, Folding and Telescoping Seating, Tents, and Membrane Structures.* NFPA 102.

National Fire Protection Association (NFPA). *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films.* NFPA 701 (Method 2).

Shaeffer, R. E. (ed.). *Tensioned Fabric Structures: A Practical Introduction. Task Committee on Tensioned Fabric Structures.* ASCE, 1996.

APPENDIX A GLOSSARY OF TERMS

Air-Supported Structure: A structure supported by positive internal building pressure created by continuously operating fans blowing external air into the building instead of by structural members.

Building Envelope: The cladding and supporting components, as well as the fenestrations, which separate the inside of the building from the outside (sometimes called the building shell).

Cladding: Fabric that comprises the building, roof, or canopy surface.

Environmental Loads: A general category of structural loads that includes wind, snow, ice, and rain loads.

ETFE (Ethylene Tetrafluoroethylene): A synthetic fluoropolymer that has high transparency and is used as a film or foil covering, without a fiber/fabric reinforcing layer. Often used in a multilayer pneumatic system where the panels or cushions are inflated by an air pressure system.

Fabric:

(1) A material consisting of a polymer coating over a woven reinforcing base.

(2) The woven reinforcing base material that is subsequently coated with a polymer substance to form the first definition of "fabric."

Fabric Covered Structure: A structure where the fabric acts as cladding but is not an integral part of the structure's overall strength and stability. The fabric is tensioned enough to prevent wind flutter but the fabric tensile forces are not part of the structure's main force resisting system. The structural framing is usually conventional, consisting of metal frameworks, including columns, beams, trusses, and purlins. This may also be called: membrane (fabric) clad structure, or frame-supported membrane (fabric) structure.

Fabric Structure: A structure where all or part of the building envelope consists of fabric. This includes tensioned fabric structures, fabric-covered structures, and air-supported structures.

Fenestration: Any opening in a building envelope covered with systems or elements such as doors, windows, skylights, louvers, or similar.

Flat Roof (flat slope roof): A roof with a slope less than 5° (9%, or 1 on 12).

Fill: The fabric yarns that are initially crimped when not tensioned but straighten when tensioned; usually oriented at right angles to the warp yarns. Also known as weft, weft yarns, or cross direction, of a roll of fabric.

Life-Cycle Factor: The factor that represents the retained strength of fabric over its service life. The life-cycle factor is the ratio of tensile strength of exposed material (subjected to the effects of aging, weathering, handling, and stress conditions over its service life) to the tensile strength of new material.

Low-Slope Roof: A shed (mono-slope), gable, hip, and similar roof with a slope less than 15° (27%, or 3.2 on 12), but greater than a flat slope roof. A curved roof with a vertical angle from the roof eave to roof crown less than 10° (17.5%, or 2 on 12).

MEP: Mechanical, electrical, and plumbing systems. Usually in reference to the MEP load imposed on a building structure; often considered part of the collateral structural load.

Panel: A section of fabric area where the fabric is terminated, which allows the panel to be removed and replaced without damage to the adjacent panels or sections.

Parabolic Hyperboloid: A fabric shaped with positive curvature in one direction and negative curvature in the other direction; also known as a saddle shape, anticlastic, hypoid, or hypar.

Pneumatic Membrane System: A system with two or more layers (film or foil) forming individual pneumatic cushions or panels that are inflated by a mechanical air pressure system. The pneumatic membrane system is supported by structural framing.

PTFE (Polytetrafluoroethylene): A synthetic fluoropolymer used as a coating over a fabric base (e.g., glass fiber). An example is Teflon.

Structural Components: Structural members such as roof purlins and rafters, wall studs and girts, or cables that directly support the fabric.

Tensioned Fabric Structure: A structure where the fabric is part of the overall structural strength and stability. The fabric is tensioned so it is part of the structure's main force resisting system. Also known as a structure, tensile fabric/membrane structure, or tensile surface structure. These structures usually do not have a conventional metal framework.

Temporary Structure: A structure or building that is in place for no more than 180 days.

Tensegrity Structure: A tensioned fabric structure that uses cables and struts as tension and compression members, respectively.

Tropical Cyclone-Prone Region (also Hurricane-Prone and Typhoon-Prone): See glossary in Data Sheet 1-28, *Wind Design*.

Service Life: The life span of a structure over which adequate performance is provided. The service life should not exceed the intended design life.

Synclastic: A fabric shaped with positive curvature in both directions (i.e., a bubble or dome-shaped surface).

Unbalanced Snow Loading: The snow load due to wind-driven snow distribution on the windward (upwind) and leeward (downwind) roof areas of hip, gable, curved, and dome roofs. The unbalanced snow loading on the windward roof area will be less than the uniform snow load on the same area, while the unbalanced snow loading on the leeward roof area will be greater than the uniform snow load on the same area. Refer to DS 1-54 for additional details.

Warp: The fabric yarns that are initially straight or near straight (not crimped) when not tensioned, but bend or warp when tensioned; usually oriented at right angles to the fill (weft) yarns. Also known as the machine direction of a roll of fabric.

APPENDIX B DOCUMENT REVISION HISTORY

April 2021. This document has been completely revised. The following changes have been made:

A. Simplified the terminology and updated the scope statement and Appendix A definitions.

B. Modified the recommendations in Section 2.1 regarding where fabric structures should be installed.

C. Added recommendations related to ETFE.

D. Added the FM Global parallel panel test as a method to determine fire propagation properties.

E. Updated the Operations and Maintenance, and Human Factor sections.

F. Revised the figure and table numbering.

G. Revised the layout of Section 3.0.

October 2014. Interim revision to Section 2.3, *Fire Protection Systems* and Section 3.10, *Fire, Fire Protection, and Exterior Fire Exposure .*

October 2013. This is the first publication of this document.