Advantages of Fabric Structures with Rigid Steel Frames

A white paper dispelling the myths of fabric building design

INTRODUCTION

With continuous improvements in performance, safety and speed of erection, fabric buildings are increasingly on the short-list of preferred building types. Fabric buildings adhere to the same engineering guidelines as other types of structures, and they have advantages that can't be matched with steel or wood buildings.

History of Fabric Buildings

Evidence has been found of structures dating back 40,000 years consisting of hides stretched over tree limbs. These structures are a precursor to modern fabric structures. These simple tents, lightweight and easy to move, supported the nomadic lifestyle prevalent prior to the rise of agriculture.

In the 1940s Walter Bird, an engineer with Bell Aeronautics, became interested in building with fabric. Bird established a roofing and membrane specialty contractor, and in 1957 the dome Bird built over a swimming pool was featured in a *Life* magazine cover story.

The first permanent membrane structure not supported by air was built in 1973 at the University of La Verne in California. The Sports Science and Athletics Pavilion is still in use today.

In the 1960s, NASA needed a non-combustible fabric, and they created polytetrafluoroethylene (PTFE), also known as Teflon-coated fiberglass, which they used for spacesuits. Today, PTFE is used for buildings. Pound-for-pound, it is stronger than steel and weighs less than 5 oz. per square yard. Most material used for modern fabric buildings weighs from about 12 oz. to 28 oz. per square yard.

One of the first high-profile modern fabric buildings was a stadium created by Frei Otto for the 1972 Munich Olympics. This corresponded with the dawn of the digital age, and was one of the first fabric buildings designed using computer modeling. That building is still in use today.

Figure I: Munich Olympic Stadium

Advantages

Fabric membrane buildings are weather-tight and designed to maintain a clean and consistent inside environment. Outside temperatures are moderated to keep the interior warmer in the winter and cooler in the summer. Because no screws or nails penetrate the roof, there are no places for rust to form and no holes that can become leaks. Superior ventilation in buildings keeps air fresh for commodity storage and other uses requiring fresh air. Furthermore, rodents, birds and mold can't use the fabric membrane and steel framework as homebuilding materials or feedstock.

Tension fabric buildings can be built to the exact length, width and height clearances as required even by aircraft. Fabric buildings on rigid steel frames have been created with clear spans over 300 feet wide, and exceeding 50,000 square feet in plan area. Engineered steel frames can support a variety of hangar doors, and ancillary equipment such as fire suppression systems, heating systems, and lighting equipment.

Trusses and Frames

Open web frames are typically made of tubular steel chords with tubular steel or angle iron placed intermittently between the chords to act as the "web." Rigid frames are made of solid plate steel.

Figure III: Open web trusses

Rigid steel frame construction employs a durable rigid frame in place of the hollow-tube, open web truss framing traditionally used for fabric buildings. Unlike hollow tube steel, solid structural steel beams are not vulnerable to unseen corrosion originating inside a tube. Additionally, the structural steel has multiple coating options, including hot dip galvanizing, oxide primer and powder coat or wet paint.

The strength of the structural steel frame provides several engineering advantages, most notably the flexibility to customize buildings beyond the confines of standard sizes to the exact width, length and height required. The design allows for much wider doors than is possible with web trusses, and adding side doors is simple as well.

Figure II: Customized fabric building

Structures may be modified to provide desired overhangs and interior columns. They can be engineered to handle additional loads for conveyors, sprinklers and even commodity loads on the sidewalls. The steel frame also allows for features such as offset peaks, lean-tos, variable sidewall heights and jack beams – which until recently were not available in fabric building construction.

Figure IVV: Solid steel beams

Materials, Engineering and Construction

High Performance Fabric

The fabric used for high-quality tension fabric structures is made of continuous filament polyester yarns that are woven together to create strong fabric, called scrim.

The scrim is coated with an adhesive coating compound that chemically bonds to the fabric. Bond strength is tested with a peel adhesion test. Sheets of fabric are then heat welded together. The heat welding process can be accomplished with a radio frequency welder, hot air impulse or hot wedge welder.

Seams can be produced at speeds of up to 20 feet per minute. The finished fabric has limited combustibility, which means it will burn when in the presence of flame but will self-extinguish once the flame is removed. Often this means that when there is a fire, the fabric will burn without damaging the frame or anything surrounding the building.

Colorfast pigments mean the building looks the same after years of use. There's also a top coating, which may contain a fungicide, helping the building to stay clean.

Uniaxial and biaxial elongation – or fabric stretch - is based on the yarn type, the weave pattern and coating. This determines the load strength of the fabric.

The fabric used in fabric building construction undergoes rigorous testing:

- Grab Strength - or Grab Tensile - and Elongation is the standard strength test used in the geotextile industry. It determines the force or load at which the geotextile breaks and how far it stretches or elongates before it breaks.

- Tensile Creep, applicable to geosynthetics including geogrids, is used in steepened slopes and retaining walls. Tensile or tension creep tests are performed by placing a load on a geotextile sample for up to 10,000 hours (417 days). The samples are gripped across their full width. The creep deformation or elongation – or strain of the sample is monitored over the test period.

- For the Trapezoidal Tear test, geotextile samples are cut in the shape of an isosceles trapezoid and then a small cut is made on one side of the trapezoid. The two non-parallel sides of the geotextile are gripped in parallel flat faced clamps in a manner which allows the tear to propagate as the jaws move apart and the required strain rate is applied. A continuous tear is propagated in this way and the maximum force recorded.

- UV Resistance is a measure of the potential for the deterioration of tensile strength in the fabric due to exposure to ultraviolet light and water. It is typically expressed at 500 hours exposure.

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Attachment of Fabric Tensioning System

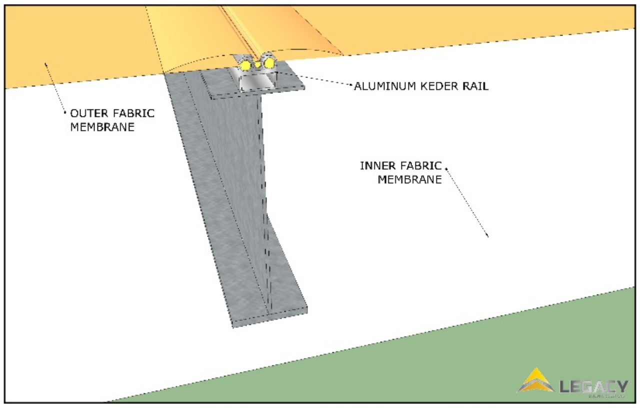

Figure V: Fabric attachment with keder system

Properly tensioned and secured fabric will last the longest and does not ever need to be re-tensioned. Panels should be tensioned horizontally and vertically. When fabric moves it accelerates the deterioration of the coating.

Kedered panels attached to every frame are the best practice for attachment. For optimal results, tension is applied to the width of the panel. To optimize biaxel stretch, it is then mechanically tensioned vertically.

Although many architectural fabric buildings may look the same, there are some critical differences in how the fabric is attached. Many fabric building covers are stretched over the entire building frame and attached only at the ends and bottoms. This overstresses the end frames of the structure and reduces fabric longevity.

In a kedered panel building, each roof panel is horizontally pre-tensioned and vertically tensioned. The top of each sidewall panel is also tensioned for a weather-tight, attractive fit. On the end walls, fabric is supported by girts, or “fabric stops,” which ensure proper attachment and add years to the life of the fabric.

Figure VI: Fabric building interior with steel I-beam frame

Engineering

There is a common misconception among designers that fabric buildings must adhere to different codes and different loadings than traditional metal buildings. In fact, the same tried-and-true engineering that has serviced the metal building industry for several decades is used by fabric building designers.

Overall the reactions from the rigid frame supporting a fabric structure are nearly identical to standard metal building reactions. Expectations for foundations should be the same for both types of buildings as they use the same wind, snow and seismic loads. Some fabric building suppliers claim that little or no foundations are required, but that should be a red flag that they are not applying their loads accurately.

Another misconception of fabric buildings is an expectation that the fabric will supply lateral support to the rigid frame top flange and in case of a loose fabric or a failed panel all lateral support will be lost to that flange. In fact, the rigid frames for fabric buildings are designed with purlins bracing the bottom flange and the flange braces come off of the purlins bracing the top flange at certain spacings. The fabric does not even have to be on the building in order for the rigid frame to have the lateral bracing it was designed for. Though the fabric does serve as a redundant lateral brace for the top flange, it is not relied upon for the stability of these structures.

Solid Web Frame Advantages

There are many advantages to specifying tension fabric buildings on rigid steel frames, from time to cost to safety and energy efficiency.

Figure VII: Jack beams allow for exceptionally wide side wall openings

Most fabric structures install 2 to 3 times faster than conventional buildings. A fabric structure requires .02 to .03 man hours per sq. ft. as compared to steel sheeting, which requires .04 to .07 man hours per sq. ft.

When considering the fabric membrane only, the install time is .01 man hour per sq. ft. as compared to .03 man-hours per sq. ft. for steel sheeting systems. The cladding is where the majority of the install efficiency is gained. It is far faster and safer to install fabric cladding over steel systems.

Fabric buildings are constructed as permanent structures, but they can be relocated. A typical, standard fabric structure can be dismantled in .015 man-hours per sq. ft. This makes for a very quick dismantle. Most of the materials may be re-used. Lightweight architectural fabric panels can be reused and shipped at a lower cost than conventional systems.

Rigid steel frames use proven engineering to handle collateral and hanging loads and may be engineered to hang cranes, catwalks, and conveyors. An engineered tension fabric structure is flexible enough for this type of addition because it will be designed to safely support the weight of the addition.

Over time, all-steel-clad buildings corrode, weaken, and become unsightly. All-steel buildings have exterior screw or nail holes that may leak moisture and are vulnerable to rust and corrosion, and once corrosion begins it cannot be ignored. Fabric buildings are rust and corrosion-resistant, even to salt, fertilizer and other materials that are harmful to steel.

Once professional crews install the building, only minimal maintenance is required from the building owner or operator. No painting, no replacing shingles, no loose siding to repair or replace. Fabric building maintenance does not require special tools and can be done from the ground.

Rigid steel framing provides the option to install alternative sidewall claddings, including steel, concrete or brick. The straight sidewalls created by a rigid frame also provide more usable interior space.

Fabric buildings are naturally non-conductive.

Figure VIII: Fabric panel installation

Figure IX: Fabric manufacturing building in Kansas

This will keep the inside of the building much cooler than the inside of a steel building on a hot day. Steel sitting in the sun will be warm, even hot, to the touch – even hours after the sun goes down. In contrast, fabric will not retain heat from the sun or the outside environment.

Furthermore, fabric will not conduct icy winter temperatures to the building's interior in the manner steel sheeting will. Before installation of heating or air conditioning systems, fabric buildings stay more than 10 degrees warmer on many cold days and almost 20 degrees cooler on most hot days.

Figure XI: Retail fabric building with glazing wall

Many fabric buildings contain recycled materials and can be recycled again after use. Some fabric manufacturers work with outside recyclers to process used membranes for use in new products. When a fabric membrane has reached its end of life, the manufacturer assists the customer in identifying an appropriate partner to recycle the membrane. The customer can arrange timing, shipping, and negotiate costs directly.

The use of fabric may help a project gain LEED points. And it's important to note that polyethylene fabrics are considered a low-toxin emitting material.

Figure X: Industrial storage building in Oklahoma

Conclusion

Fabric structures are becoming more common across a variety of industries. Combining durable fabric with a sturdy rigid steel frame creates buildings that have the strength of traditional construction with the benefits of fabric cladding. Fabric structures are engineered to last for decades in any environment. Being armed with a thorough understanding of fabric structure technology will keep engineers and architects well-prepared for future construction projects.