INTRODUCTION

Fabric structures encompass a variety of building types – ranging from simple weekend projects to permanent, engineered industrial buildings. Before investing in a fabric structure, it’s critical to understand the design factors that will determine the structure’s longevity and lifecycle cost.

The objective of this white paper is to give the reader a basic understanding of how fabric structures work, with an emphasis on empowering the buyer to purchase a high-quality, permanent structure. This paper places particular emphasis on the value of engineered fabric structures on a rigid steel frame.

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Fabric Structure Overview

Modern tension fabric structures on a rigid frame use many of the same proven engineering principles as traditional metal buildings – the base reactions are typically identical, and the steel I-beam frames are similar. The greatest difference is in how the cladding material integrates with the frames: on a steel-clad structure, the steel creates an exoskeleton that structurally aids the frames. On a fabric structure the fabric cladding applies additional loads and stresses to the frames and secondary framing members, which must be properly calculated during the engineering process.

Understanding the basics of fabric structures, including the materials and engineering practices behind them, allows consumers to make educated decisions and select the highest-quality structure. There are numerous structural fabrics available in the marketplace. The most common are 12/13 oz. polyethylene (PE), 15 oz. PE, 20 oz. polyvinyl chloride PVC and 28 oz. PVC. The chart below shows the strengths and weaknesses of each fabric. Typically, heavier fabrics have a longer lifespan and increased initial cost.

<table>
<thead>
<tr>
<th></th>
<th>12 oz. PE</th>
<th>15 oz. PE</th>
<th>20 oz. PVC</th>
<th>28 oz. PVC</th>
<th>Unit of measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translucency</td>
<td>11.00%</td>
<td>7.00%</td>
<td>5.00%</td>
<td>5.00%</td>
<td>Numerical</td>
</tr>
<tr>
<td>Weld Strength</td>
<td>90-93%</td>
<td>95-100%</td>
<td>95-100%</td>
<td>95-100%</td>
<td>Numerical</td>
</tr>
<tr>
<td>Grab Tensile</td>
<td>350/350</td>
<td>350/350</td>
<td>400/400</td>
<td>700/700</td>
<td>Pounds per square inch</td>
</tr>
<tr>
<td>Self-Cleaning Ability</td>
<td>Great</td>
<td>Great</td>
<td>Good</td>
<td>Good</td>
<td>Visual</td>
</tr>
<tr>
<td>Longevity</td>
<td>15-20</td>
<td>20-25</td>
<td>23-28</td>
<td>20-30</td>
<td>Years</td>
</tr>
</tbody>
</table>

The unique characteristics of each fabric, including stretch and weldability, must be accounted for during manufacturing. For example, 28 oz. PVC requires a different pretension percentage than 12 oz. PE. This makes it important to verify that the building manufacturer has significant experience working with the fabric of your choice.
An indicator of quality is a fabric building manufacturer who fabricates the panels in house rather than subcontracting them to outside vendors. Fabric panels must be manufactured in a temperature- and humidity-controlled environment, and per industry standards numerous quality tests must be completed on each roll of fabric, on each fabric welder for each roll of fabric, and in different conditions. Only companies committed to the highest quality standards, including ISO 9001:2008, are sure to meet or exceed all guidelines.

Fabric Attachment

The largest determinant in a fabric structure’s quality and longevity is the fabric attachment. Even with the highest-quality engineering, framing and fabric, if the fabric is not properly integrated with the frame the result will be a low-quality structure with a limited lifespan.

The earliest fabric structures were constructed with monocover roofs, which comprise very large sheets of fabric attached to the end trusses and base of the structure. In a monocover system 100% of any additional forces applied to the cover during a wind event are placed only on the end frames and the base of the structure. Wind will cause suction to occur on the leeward side of the building, forcing the fabric cover to completely lift off the trusses. This lifting transfers the entire force of the wind onto the end trusses and the fabric.
Fabric is not designed to handle these excess forces without support; this is one of the most common reasons for fabric tearing and failure on a monocover building. Calculations have shown that the mono-cover design typically experiences triple the amount of stress specified in the fabric supplier recommendations.

Monocover roofs typically have a maximum width of about 70 feet because of the high failure rate. Some companies try to increase the longevity of monocover roofs by lacing the cover to purlins or secondary bracing. This may add marginal longevity to the cover, but it drastically reduces the effectiveness of the secondary bracing because during wind events the lacing pulls the secondary members out of plane while under compression. This renders the secondary bracing nearly worthless during wind events, precisely when they are the most critical in supporting the structure.

Despite the advances in fabric structure technology, monocover buildings remain a popular choice for simple applications including small or temporary buildings. Because there is no engineering and only minimal installation time required, monocover buildings have a lower initial cost. Some manufacturers prefer monocover systems because the manufacturing is very simple and no precision is required.

Disadvantages of Tek Screw Attachment

Higher quality buildings use individual bay roof panel systems. The most common practice in the fabric building industry is to use tek screws to attach an aluminum keder rail to the trusses or frames. This method can be supported with calculations that make it appear to be effective, but there are numerous factors that are overlooked. First, corrosion may cause failures of the connection detail due to small amounts of water that cause a corrosive reaction where zinc/galvanizing and aluminum are all in contact. It does not take long, typically just a few years, for corrosion to make 3/16-inch diameter tek screws completely ineffective, allowing the keder rail to lift off the trusses/frames during weather events, causing undue strain on the fabric and frames.
Tek screws are manually installed, requiring a great deal of precision to achieve the proper amount of torque. Installing thousands of tek screws on a building creates significant opportunities for human error. Under-torquing tek screws leads to a loose attachment, while over-torquing tek screws compromises the integrity of the screw – in both cases, drastically reducing their structural effectiveness.

Safety during installation is another major concern with the tek screw attachment. To achieve proper tension, fabric panels must be manufactured narrower than the bay width to allow the fabric to stretch and achieve proper tensioning. Since the keder rail is screwed in a fixed position, most manufacturers remove all secondary bracing supporting the top cord of the truss, then bend the truss approximately six inches horizontally to install the narrow panel. Without the supporting members, fabric buildings are vulnerable to collapse during a weather event.

Benefits of Kedered Panel Attachment

In 2010, Legacy Building Solutions introduced a new fabric attachment system using individual bay kedered panels. This system uses individual panels for every roof bay width and is the strongest available attachment system. The panels are attached to every frame using a kedered edge with keder rail.
The kedered panel attachment system has numerous structural and longevity advantages, in addition to the most visually appealing connection. The most significant advantage is that the system evenly distributes the pressures caused by wind, snow and fabric tension to every frame, not just the end frames. This even distribution places less stress on the fabric and the frames, increasing the system's longevity.

Another advantage of a kedered panel system is that if damage occurs, the manufacturer can replace just one panel, rather than the entire roof. Replacing one panel is much more cost effective than reskinning the entire building. Even if one panel of a kedered roof fails, the remaining panels will remain intact.

Many manufacturers avoid using kedered panels because the manufacturing process requires much greater precision. The panels must be built with tight tolerances, and the design must allow for pre-tension of both the width and length. To achieve proper tension, the panel is purposely manufactured a percentage narrower than the bay width and shorter than the designed length. Having panels made precisely with proper biaxial tension ensures the best longevity by preventing undesirable movement in the panels.

Advantages of the Legacy Building System

Legacy’s patented fabric attachment system uses ½-inch bolts to attach the keder rail to the frames. The new system has several advantages, the most obvious of which is the greater strength of the ½-inch bolts compared to 3/16-inch tek screws. Even if corrosion affects tek screws and heavier bolts at the same rate, the bolt will have greater longevity. Installing bolts is a relatively simpler process, eliminating the possibility of human error that often plagues tek screw attachment.

In Legacy’s system, the bolts are affixed at the base of the keder rail, as opposed to a tek screw at the center of the rail. This eliminates corrosion in two ways. First, the bolt is inside the building, protected from the elements and immune to moisture build up. Water pooling around the screwhead is a common source of galvanic reactions and corrosion that can lead to building failure. And second, adding a washer between the bolt and the keder rail prevents corrosion from occurring on the bolt head and causing bolt failure.
In addition to the increased strength of the bolt attachment, another significant advantage is how the system works. The keder rail is designed to move horizontally on the top flange of the frame while the frame itself remains in a fixed position. This system was created with the goal of rectifying two major problems in the industry: safety during installation, and lifespan of the fabric panel. The system is significantly safer during construction because all of the secondary framing supporting the bottom and top flanges remains 100% in place throughout construction. Even in the case of a wind event, the framing members are supported by the secondary bracing and will remain in place – along with any fabric panels that have been installed before the weather event.

The new system also allows for increased pre-tension on the designed width of the panels, which results in more horizontal tension and longer lifespan for the panels. This is possible due to the design which allows only the keder rail to move horizontally and proper tools that allow for mechanical horizontal tensioning of the panels. As an added bonus, greater vertical or “up and over” tensioning is achieved because there are no radiuses to tension the fabric around. Moving the keder rail horizontally also aids in vertical tensioning.

Separate Fabric

Another Legacy innovation is using separate panels for the roof, sidewalls, endwalls and soffits. Most manufacturers combine the roof and sidewall to save costs by manufacturing and installing one panel. Legacy has made it standard to offer overhangs or eave extensions on all buildings. By design this separates the roof panels from the sidewall panels, with a separate soffit panel installed to connect the two. This allows all fabric panels to be installed along flat planes, and it decreases the possibility of roof damage. The majority of the time, accidental damage on a building affects the sidewalls. Separating the sidewalls from the roof panel saves the customer a considerable amount of money and makes for a far more convenient replacement, if accidental damage occurs.

As a general rule, the smaller the fabric panel, the easier it is to tension and replace the panel should it sustain damage. More precise tension also increases the lifespan of the fabric panel. It is important to understand how the proper fabric panel tension is achieved for each panel. By design Legacy tensions panels horizontally by keder rails on the roof and sides and vertically by tensioning tubes. Sidewall panels are fed into a keder rail on the top edge and tensioned horizontally with keder rails on the vertical edges. Endwall panels include a keder edge on the top and sides and are tensioned mechanically in the center of the endwall and vertically using tensioning tubes.

Legacy exceeds industry standards by applying a second layer of fabric in all locations on the fabric panels where they will have direct contact with steel framing. This prevents long term wear on the fabric panels, because the framing only comes in contact with a single layer of fabric.
Figure VIII: Transfer of fabric pressure to the foundation

Design for Fabric Pressures

On a fabric-clad building, the fabric tension adds pressures to the frames and secondary framing. These added pressures cannot be ignored and must be properly accounted for during the design stage. A large percentage of these pressures are incurred by the end trusses or frames, especially at the top chord or flange. The fabric building manufacturer must know how to calculate these pressures, which are a combination of fabric panel pretension and wind and snow loads, so that no section of the end frame or truss deflects too far out of plane.

From there, these fabric pressures must be properly transferred down and into the foundation. Typically, the easiest way to transfer the pressure from the top flange of the end frame to the bottom flange of the second frame is with a support purlin. This support purlin must be a tension/compression member that is large enough to transfer the pressure forces. Once the force has been transferred to the lower flange it is common to use the combination of tension/compression purlins and cross bracing to transfer the forces to the foundation. This explains how the horizontal pressures are commonly addressed as applied to the end frames or trusses.

There are still vertical pressures to be properly accounted for. For example in the Legacy system the tension tube at the overhang is typically a 6”x3”x1/8” tube; when the fabric tensioning pressure is applied the tube will crown approximately 7/8” in the middle, weather depending. This is important to note because if a manufacturer is using a much smaller member to tension the roof they are either achieving significantly less tension or pulling the tensioning member dangerously out of plane with excessive crowning.

The other major tensioning devices are typically around the base of the structure, often termed tension tubes. These tension tubes need to be sized based on the fabric pretension, fabric type, height of the panel and the spacing of the tensioning devices. Fabric building manufacturers should be able to clearly explain how they design for fabric pressures before construction begins.
Secondary framing is another vital component of the fabric building system. Every purlin must be a tension/ compression member to account for the fabric pressure. Additionally, when flange braces apply forces to the purlins the purlins must be properly designed to account for the flange brace forces so the purlins do not deflect excessively under full design load. There are often scenarios where double flange braces need to be designed with certain purlin/flange brace locations to properly address the forces.

The cross bracing, typically cross cables or cross rods, are another critical component to transfer the loads down to the foundation. They must be properly sized and must not skip over any purlin fields. If they skip over a purlin they are not transferring the fabric pressures from that field to the foundation. Legacy makes it a standard practice to use solid steel cross rods for all corrosive material storage applications. There are other scenarios where tension/compression members should be used for cross bracing, especially for high seismic areas of South America (per code).

Conclusion

Before purchasing a fabric structure, it is critical that the buyer understand the differences between fabric and traditional metal-clad structures. The manufacturer must understand how the fabric pressures affect the primary and secondary framing so they can be properly accounted for. By giving equal consideration to the fabric, framing and attachment, the building owner will receive the highest-quality, longest-lasting structure possible.