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CBD 137

Air-Supported Structures

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D.A. Lutes

Please note

A wide variety of structures that use pressurized air to stiffen or stabilize a thin envelope of pliable material to form a structural shape may be included in the description "pneumatic structures." The single-wall or balloon-like structure filled with air maintained at a pressure slightly above ambient was originally called an air-supported structure and is frequently referred to as an air-structure. Double-wall structures where the skin is shaped into tubular or cellular compartments pressurized to develop structural stiffness (the usable space, in contrast, is not pressurized) are generally called air-inflated structures.

This Digest will discuss single-wall, air-supported structures consisting of four basic components: envelope, anchorage, inflation equipment, and doors (Figure 1). These components must be selected in accordance with carefully specified design criteria to provide for and ensure adequate safety and operation.

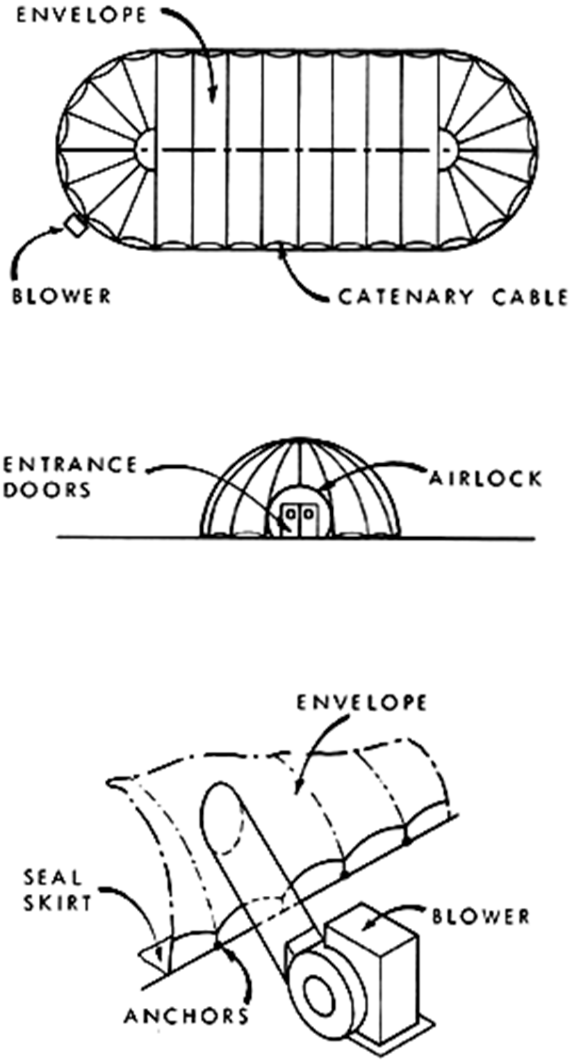

Figure 1. Typical single-wall air-supported structure

Historical Development

The first proposal for an air-supported structure was probably made in the 1917 patent of F. W. Lanchester in England.

In the U.S. the Air Force in 1946 needed a new way to house the large radar antennae planned for the Arctic. Walter Bird, an aeronautical engineer, directed a team that designed, built, and successfully tested prototypes of radar domes which became known as radomes. By 1954 hundreds of these bulbous structures were scattered across the U.S. and Canada.

Ten years later in 1956, Bird and a few of his colleagues set up a manufacturing company and air-supported structures were further developed and produced commercially. Other manufacturers entered the field and an industry association, the Air Structures Manufacturers and Suppliers Association (ASMSA), was formed in the United States to establish standards.

Major Applications

The air-supported structure is one of the most efficient structural forms available in terms of weight of material, although not necessarily of cost, for it combines the inherent tensile strength of materials with the structural efficiency of the shell form. There are some disadvantages, however. An uninterrupted air supply must be available, people and equipment must enter and leave the building through air-locks, and the life of available skin materials is generally shorter than that of more conventional building materials.

Few other types of structure have the same ability to provide free-span coverage for so large an area. Supported by air. requiring no columns or beams, these structures can attain great roof heights. A dome erected at Andover, Maine, could enclose a 16-storey building.

Existing uses of air-supported structures include antennae shelters (radomes), temporary warehouses, on-site storage shelters for construction materials, construction enclosures, swimming pool enclosures and other recreational shelters, social activity shelters, and disaster shelters. These uses, by their nature, illustrate two major features: portability, and speed of erection and dismantling.

Envelope Shape and Design

Shape

It must be recognized that there are limitations on the shape of air-supported structures. Every point in the surface of the envelope must be in equilibrium under the loads imposed. If these conditions are not provided by design and patterning, the envelope will wrinkle and distort until equilibrium conditions are established. Distortion of this type results not only in poor appearance but also in stress concentrations that could result in failure of the structure.

The most conventional shapes include hemispheres or half cylinders capped at each end by hemispherical elements, but an air-supported structure is adaptable to a variety of shapes, generally surfaces of revolution about at least one axis.

Structure

The major loads acting on an envelope are internal inflation air pressure and wind (aerodynamic) loading. Pressure differences occur across the envelope due to stack effect (**CBD 107**), but these become significant only in relation to the design of very high structures heated in cold weather. Many air-supported structures have been designed on the basis of a crude stress analysis and a large factor of safety to ensure an envelope capable of withstanding a design wind load. Concern for more economical structures, however, has created a need for a more refined analysis of stresses. Fabric stress distributions have been determined using wind-tunnel-measured pressure distributions and suitable shell theory for many basic shapes. Such basic design data are presented in reference [1], and detailed derivation may be found in reference [2]. Stress values are those for the design wind load. In selecting a material to meet design stresses, allowance must be made for other factors such as uniformity of product, weathering resistance, handling and stress-strain characteristics of the fabric and its ultimate rupture strength. In situations where detailed information on these factors is not available reference [3] recommends that a safety factor of 3 be used. Instability, defined as the condition at which structural deflection and oscillation combine to produce objectionable structure motion, has been studied with respect to fabric porosity and enclosure pressure [3]. The tests indicate that when the enclosure pressure is equal to or greater than the dynamic or stagnation pressure of the wind, both high stability and very good deflection characteristics are obtained. Experience has shown, however, that for many uses satisfactory performance characteristics (including acceptable deflections) can be obtained with somewhat lower inflation pressures (see Inflation System).

Material

The material of the envelope of an air-supported structure has a most important influence on the performance of the structure. Certain combinations of properties are required to ensure satisfactory performance and a long service life and characteristics to be considered in materials for air-supported structures include: tensile strength in both warp and weft of the fabric; tear resistance to reduce accidental damage; coating adhesion to the fabric under all conditions of operation; weathering resistance, including resistance to ultra-violet degradation, abrasion resistance and retention of physical properties after long periods of exposure;

suitability of the material for jointing in order to develop the full strength of the base material; pliability to prevent damage during packing, storage and handling at cold temperatures; flame spread resistance to meet fire codes where applicable and prevent propagation of flame; translucence or opacity, as application requires. The relative importance of each characteristic may vary with the application, but all should be carefully evaluated.

Among the materials available for envelope construction one of the most satisfactory for commercial applications appears to be vinyl-coated nylon, in which heavy nylon fabric is coated on both sides with a specially compounded polyvinyl-chloride elastomer. The fabric provides the strength, the vinyl coating the weather protection. The vinyl is compounded with certain additives to retard mildew and fungus growth, and to provide pliability, weather resistance, toughness, flame spread resistance, colour or opacity, and ultra-violet absorption.

Use of other fibres or elastomers, although not common at this time, may be acceptable if the requirements indicated above can be met. Dacron and glass fabrics have been used; polyethylene and hypalon elastomers, as well as others now in development, may prove to be acceptable.

Materials may be joined by electronic welding, cementing or sewing, but because a structure can obviously be no stronger than its joints, minimum joint strength performance is specified in the ASMSA Standards [4] to ensure reliability.

Many manufacturers recommend that only a heat-sealed joint should be used for all load-carrying joints; when properly done this process results in seams actually stronger than the material itself. Sewn joints often offer poor service life. In tents and awnings, for example, the sewn joint has long been recognized as the weak link. Cemented joints are acceptable when properly made but must develop the full strength of the fabric.

Inflation System

Air-supported structures need only small pressures to hold them up, i.e. approximately 1 inch of water static pressure or 0.036 psi. To visualize how low a pressure this represents, consider that when one puffs ones cheeks with air about 30 inches of water static pressure can be created inside the mouth, or that an automobile tire carries about 800 inches of water static pressure. Only when opening the door can anyone entering an air-supported structure know that air pressure is involved.

The greater the inflation pressure, the better the ability of the envelope to resist wind loadings without significant deformation. In practical terms, therefore, the pressure required will be a function of the prevailing design wind speed.

Based on extensive wind tunnel and full-scale tests, the minimum inflation pressure for air-supported structures recommended by the ASMSA Standards [4] is 50 per cent of the dynamic wind pressure. In the United States air-supported structures are usually designed to withstand a minimum wind velocity of 60 or 70 mph. (This requires an inflation differential pressure of approximately 1 inch of water.) In Canada the National Building Code requires that buildings be designed to withstand the wind load specified for the particular location under consideration. This may be more or less than the speeds quoted above and may require correspondingly different pressures.

Blower capacity should be designed to allow for

1. anticipated maximum leakage at the base, around doors and through vents (the total leakage air must be replaced by air from the blower at the design inflation pressure; experience indicates that conservatively estimated leakage losses -- assuming a differential pressure of 1 inch of water -- are 10 cu ft/min per linear foot of base perimeter, 200 cu ft/min per door assembly, and 2400 x A cfm for vents where A is the total vent area in square feet;
2. a ventilation airflow of at least 30 cu ft/min per person; and
3. an initial inflation time specified by the design requirements.

Initial inflation requirements will generally dictate the blower capacity required for structures having a floor area of more than 30 sq ft per person. Structures that provide less than 30 sq ft per person may require additional blower capacity to accommodate a greater number of occupants owing to the increase in number of doors and vents, and anticipated leakage or ventilation flow may dictate the blower requirements.

It is recommended that blowers should be capable of providing at least twice the calculated airflow. The National Building Code requires that structures classified assembly occupancy should be furnished with two blowers, each with sufficient capacity to supply the required air. The standby unit is set to turn on automatically in the event of mechanical or electrical failure in the operating unit. An automatic starting power generator is normally provided for this purpose.

Each blower is normally equipped with a backdraft damper to prevent air loss when it is inoperative. To prevent over-pressurization, backward, curved-blade centrifugal blowers that deliver a variable air volume at a specified pressure are recommended. All blowers should provide adequate protection for personnel, for example inlet screen and belt guards, and require protection from the weather to ensure operation at all times.

Anchorage

Air-supported structures must be firmly attached to the ground around the entire perimeter to resist the combined total lift of inflation pressure and wind. Stack effect would be a consideration for high structures. Such anchorage usually consists of ballast anchorage or positive ground anchorage, depending on the erection base. Ballast anchorage is a satisfactory method of securing an air-supported structure to a deck. Bagged sand, concrete blocks, bricks or other high density material are suitable. Water ballast systems are acceptable only if individual compartmentation prevents loss of anchorage over more than 5 linear feet of base. A spherical air-supported structure (30-foot radius) designed to withstand a dynamic wind pressure of 60 mph with an inflation pressure of 1 inch requires a minimum ballast load of 234 lb per ft of perimeter.

As for ballast anchorage, a positive ground anchorage system must distribute the anchor loads uniformly to the envelope so that excessive stress concentrations will not occur. Common systems used for this purpose include: provision of a catenary cable system between anchor points, insertion of metal pipes into the base skirt, clamping of the envelope to the foundation by a channel. If the method of anchorage does not prevent air loss around the perimeter, a simple seal skirt may be provided as an integral part of the envelope. Various masonry anchors or soil anchors similar to those used by utility companies have been used.

Doors

The number and type of doors to be provided for an air-supported structure will be dictated by the size of the structure and its particular occupancy. The National Building Code of Canada requires that exit doors for air-supported structures conform to Section 3.4 "Requirements for Exits."

The most widely used type of door for high or continuous traffic applications is the revolving door. Its advantage for air-supported structures is that resistance to rotation does not noticeably increase with increasing internal pressure and pressure difference can be negotiated easily. Air-locks also are used to provide access for people, goods and vehicles. Every air-lock requires a two-door system in which only one door can be opened at a time so that there is no loss of pressure.

It is possible, by providing excess blower capacity, to have fairly large openings in air-supported structures without air-locks to permit the direct entry and exit of trucks. Additional blower capacity is not, however, a practical solution since to maintain pressure at 1 inch of water pressure requires blower capacity of about 48,000 cfm (10-hp fan) for even a 3- by 7-foot door opening.

Accessory Equipment

Air-supported structures often require accessory equipment such as ventilators, lights, windows, air conditioners, and heaters. Such equipment will usually not affect safety or reliable operation, provided nothing is done to increase air leakage or to disrupt continuous inflation. Equipment is not normally suspended from the fabric envelope, and all envelope openings must be reinforced or otherwise designed to avoid stress concentrations.

Snow Removal

Because of their shape little or no snow will normally accumulate on air-supported structures except for heavy wet snow during periods of calm. A snow load on properly designed air-supported structures does not add to the stress in the fabric envelope and may even relieve it. No sudden collapse can endanger the occupants because the gradual sagging that takes place with increasing snow depth can readily be observed well in advance of any danger stage.

The snow can be removed in several ways: by heating the side of the structure until the snow slips from the dome; by deflating the structure 5 to 10 per cent of its volume so that ice and frozen snow crack as it goes limp, then reinflating it so that the expanding movement thrusts the load off; on a smaller structure by running a rope tossed across it along its top so that snow and ice are broken up.

Code Coverage

Most code regulations established for conventional structures cannot easily be applied to air-supported structures because their design and manufacture involve new and unusual techniques. Special requirements concerning fire safety, separation, exits, flame spread, and blower capacity are contained in the 1970 edition of the National Building Code.

Conclusion

Air-supported structures are becoming more common and are providing shelter for a number of different activities. Such structures are limited, however, in their ability to provide a controlled environment under the climatic conditions that exist in some areas of Canada. Their cost and limited life may also be a deterrent where the portability and speed of erection and dismantling cannot be fully exploited.

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