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Berger

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[54] **RETRACTABLE STADIUM ROOF SYSTEM WITH RECTANGULAR OPENING**

[76] Inventor: **Horst L. Berger,** 18 Chestnut Dr., Hastings-on-Hudson, N.Y. 10706

[*] Notice: The portion of the term of this patent subsequent to Jul. 28, 2004 has been disclaimed.

[21] Appl. No.: **76,120**

[22] Filed: **Jul. 21, 1987**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 913,520, Sep. 30, 1986, Pat. No. 4,682,449.

[51] **Int. Cl.**[4] **E04B 1/346**

[52] **U.S. Cl.** **52/66;** 52/6; 52/83

[58] **Field of Search** 52/66, 64, 83, 6

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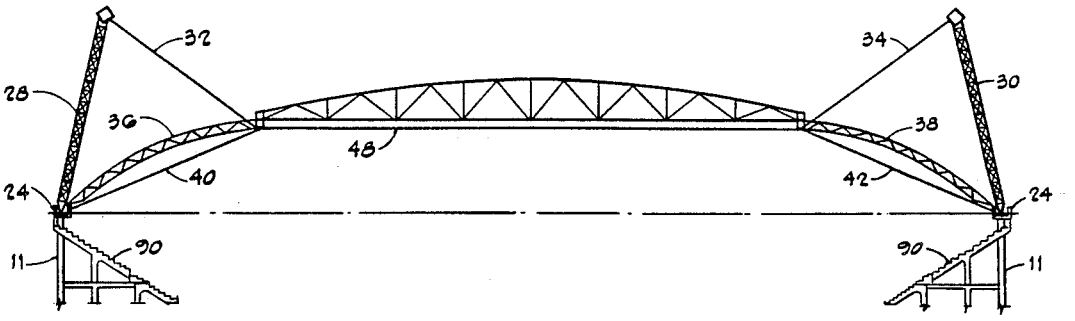
Primary Examiner—Henry E. Raduazo
Attorney, Agent, or Firm—Cooper & Dunham

[57] **ABSTRACT**

A structure, such as for a full-size stadium roof, which has a retractable central portion capable of opening up about one-half of the total roof area. Two retractable roof panels, rectangular in plan, cover an area that can be larger than a football field, and move in the direction of the main axis of the stadium.

4 Claims, 11 Drawing Sheets



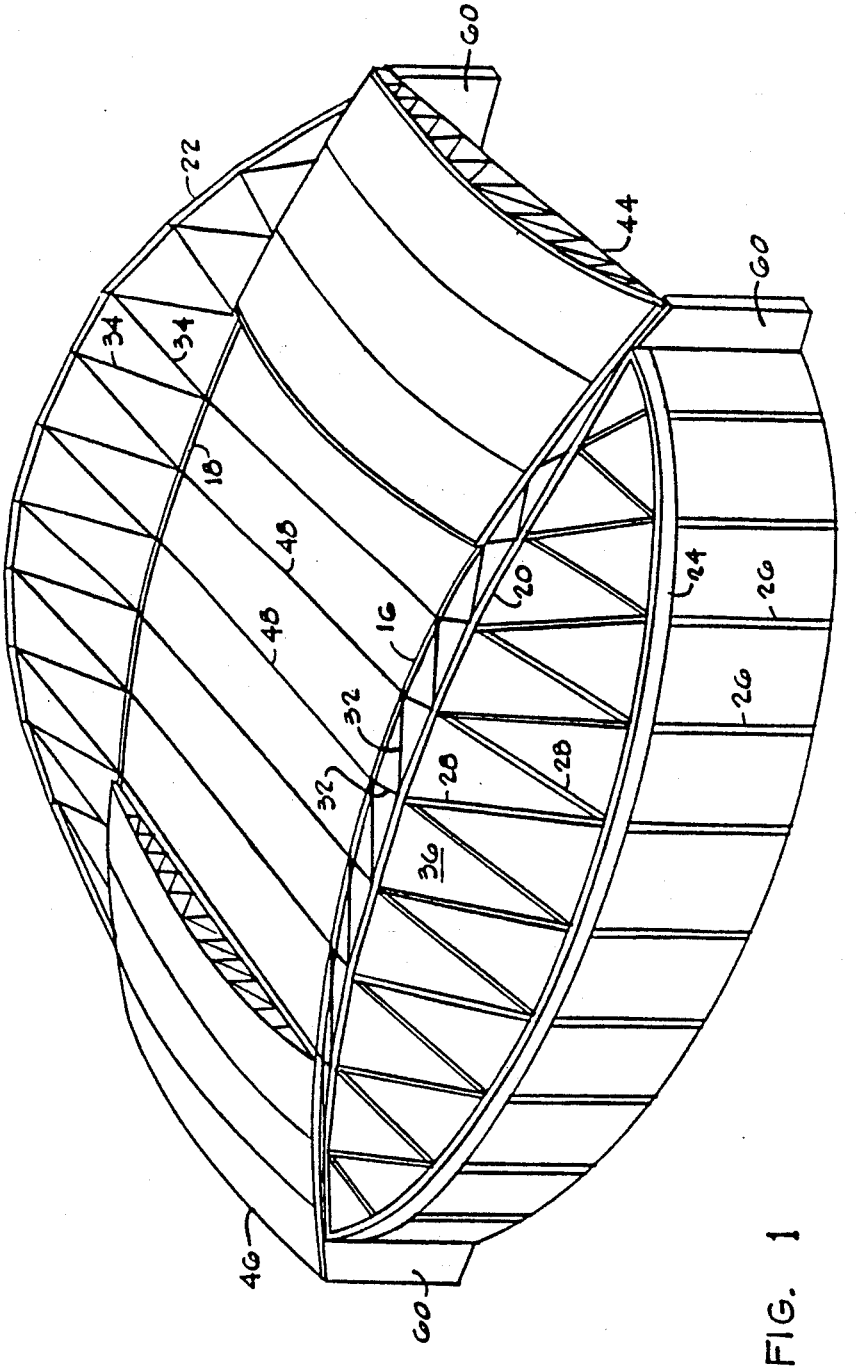


FIG. 1

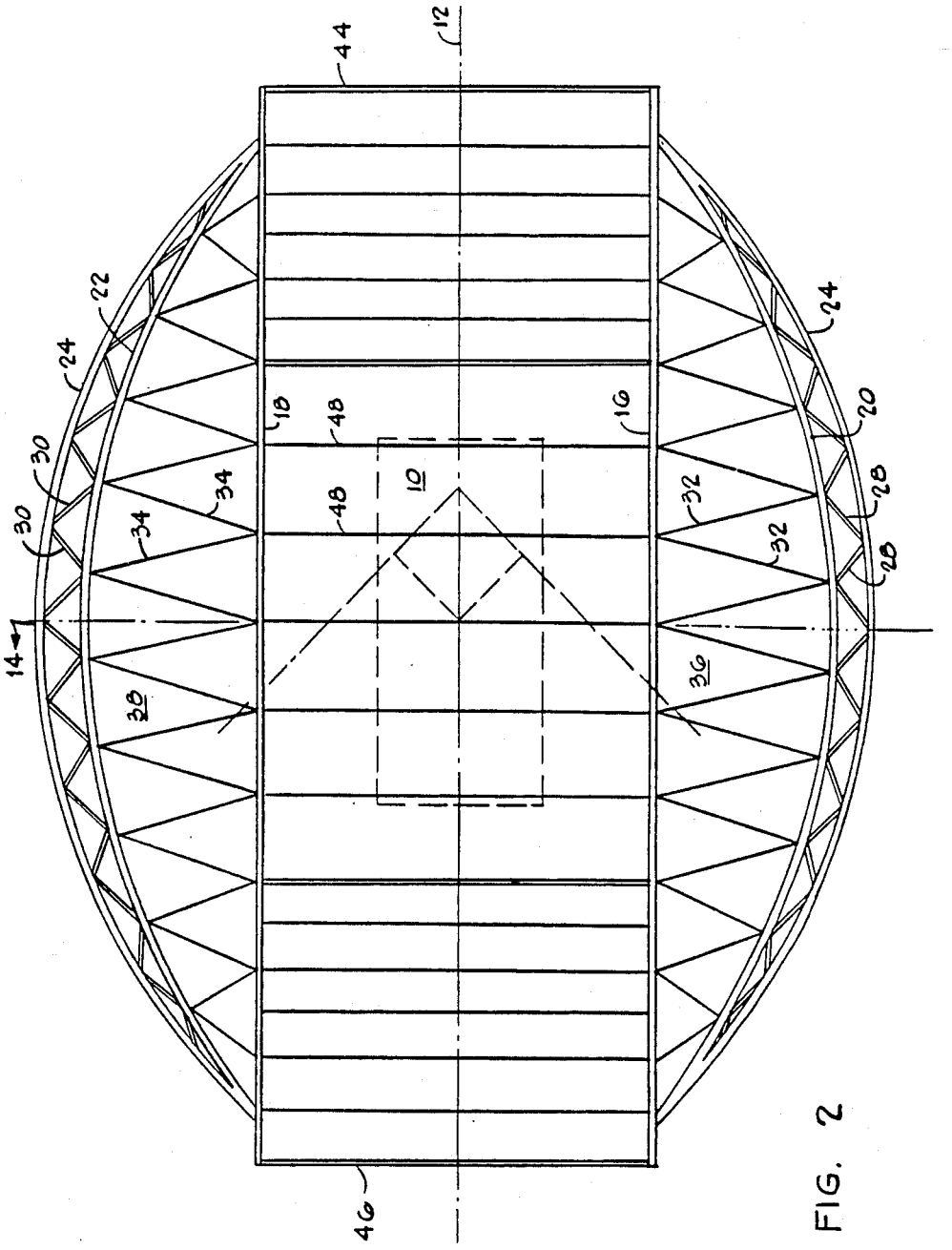


FIG. 2

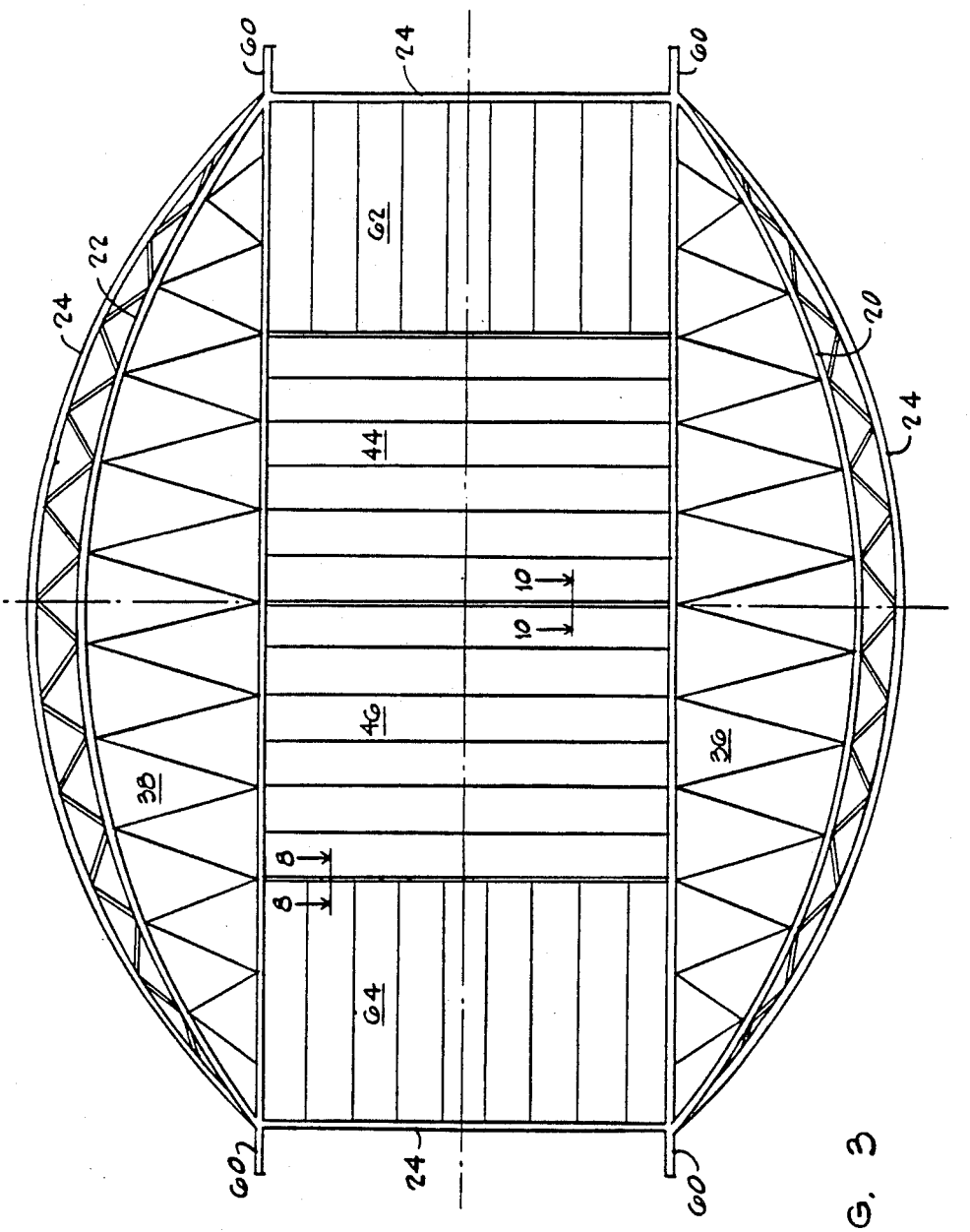


FIG. 3

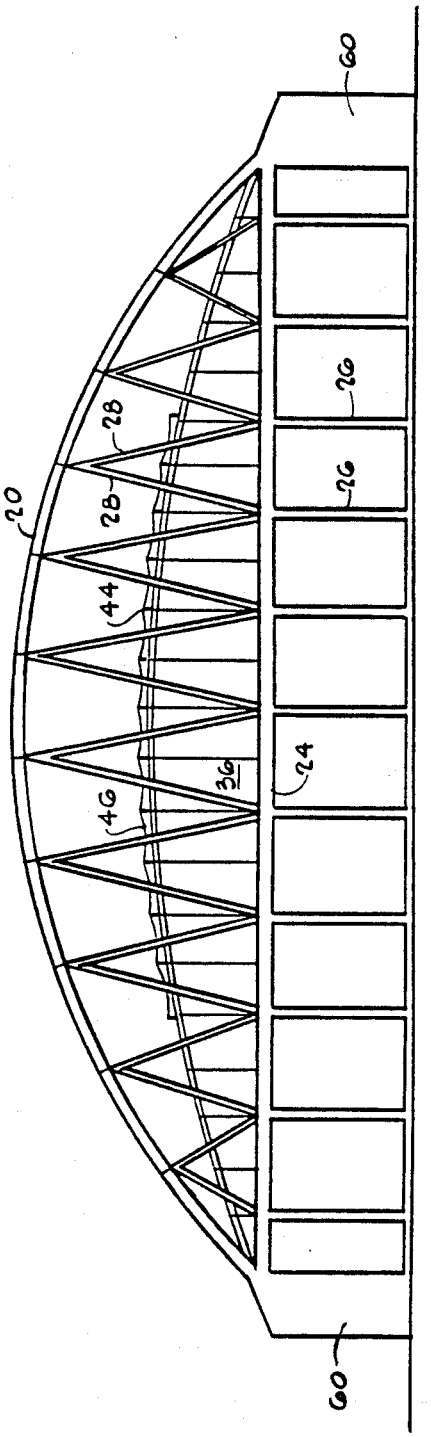


FIG. 4

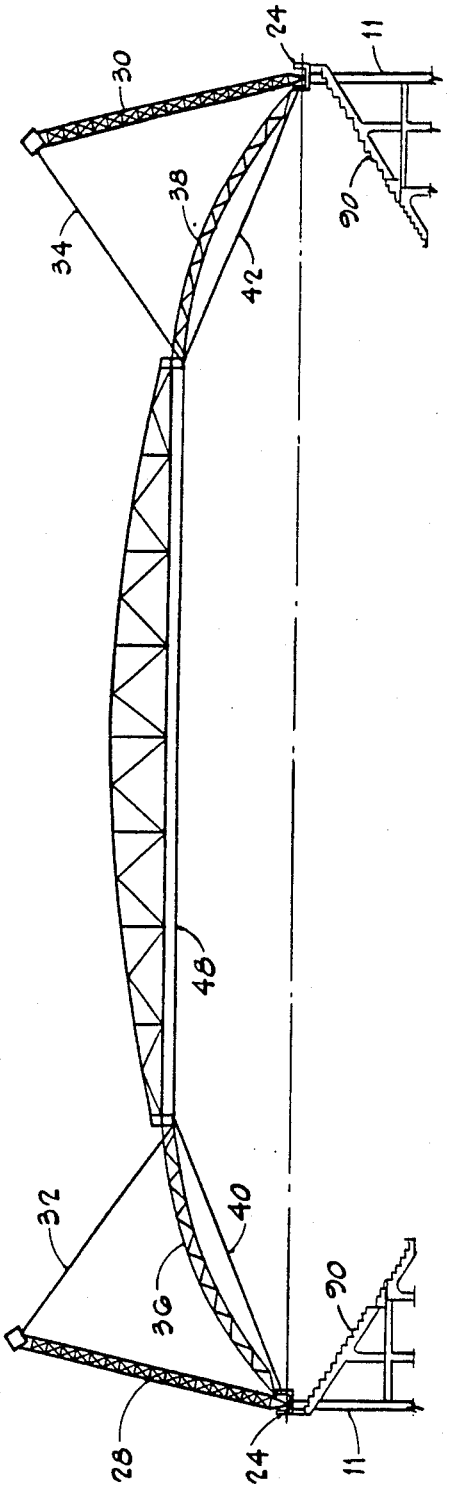


FIG. 5

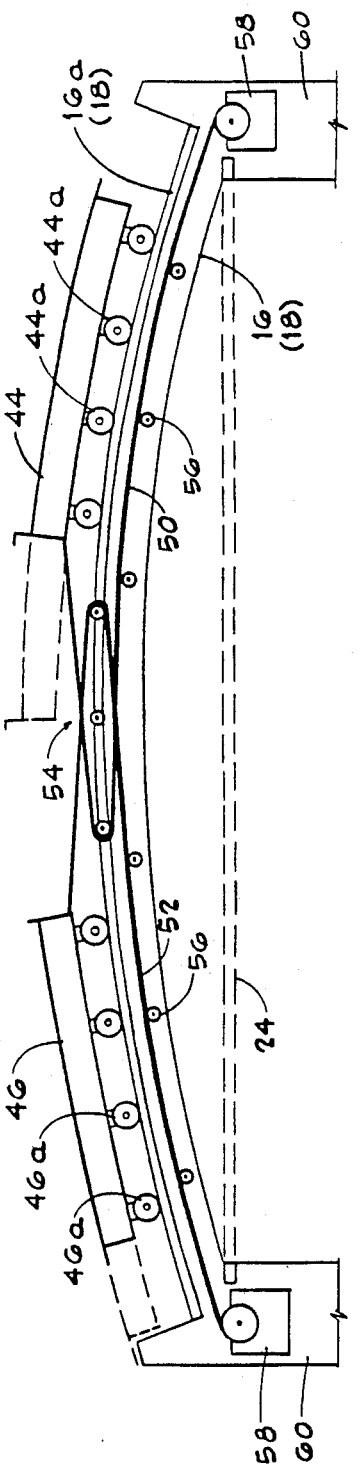


FIG. 6

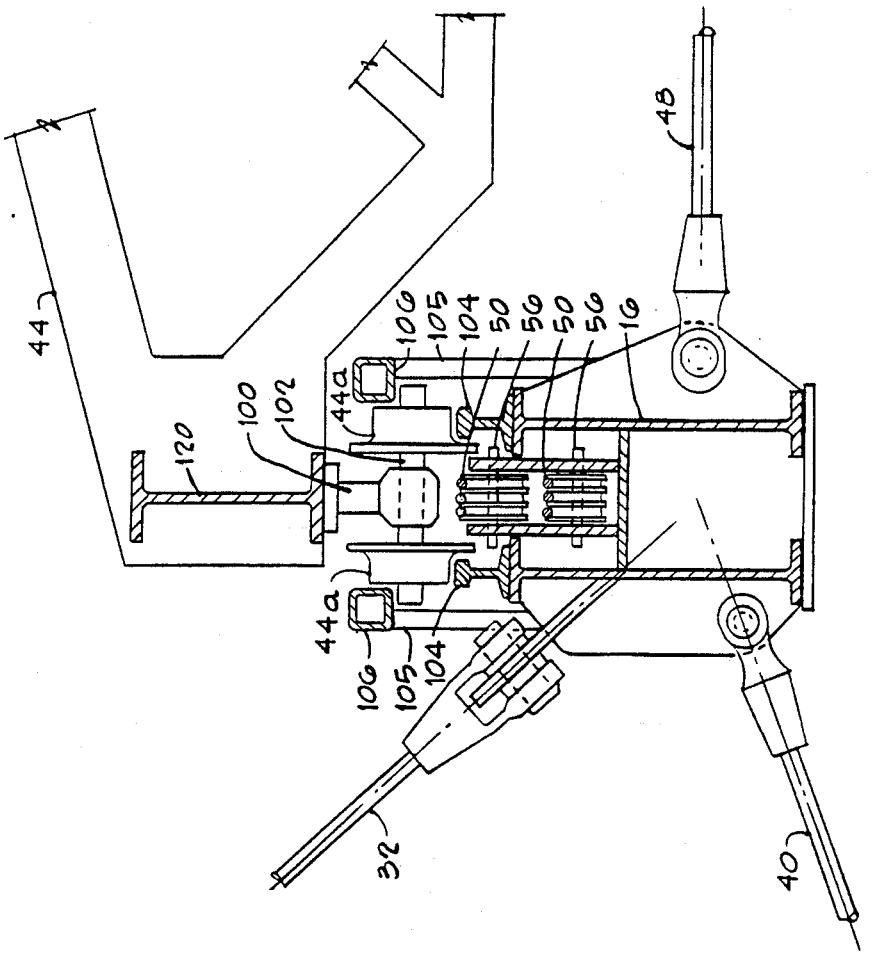

48
44
106
105
104
50
56
50
56
16
44a
100
102
120
44a
106
105
104
32
40

FIG. 7

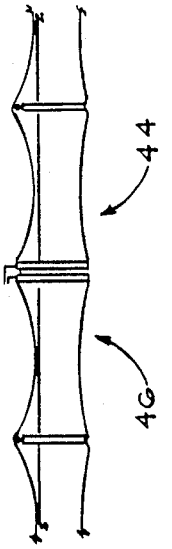


FIG. 10

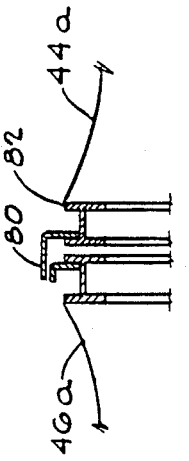


FIG. 11

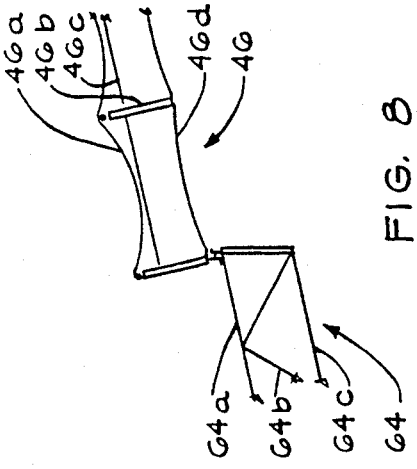


FIG. 8

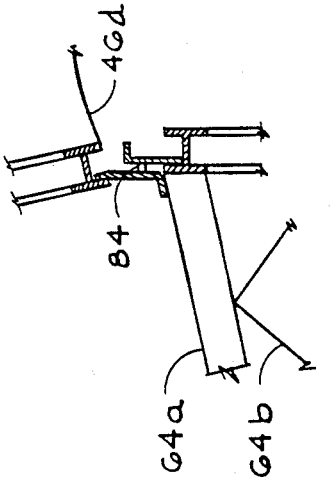


FIG. 9

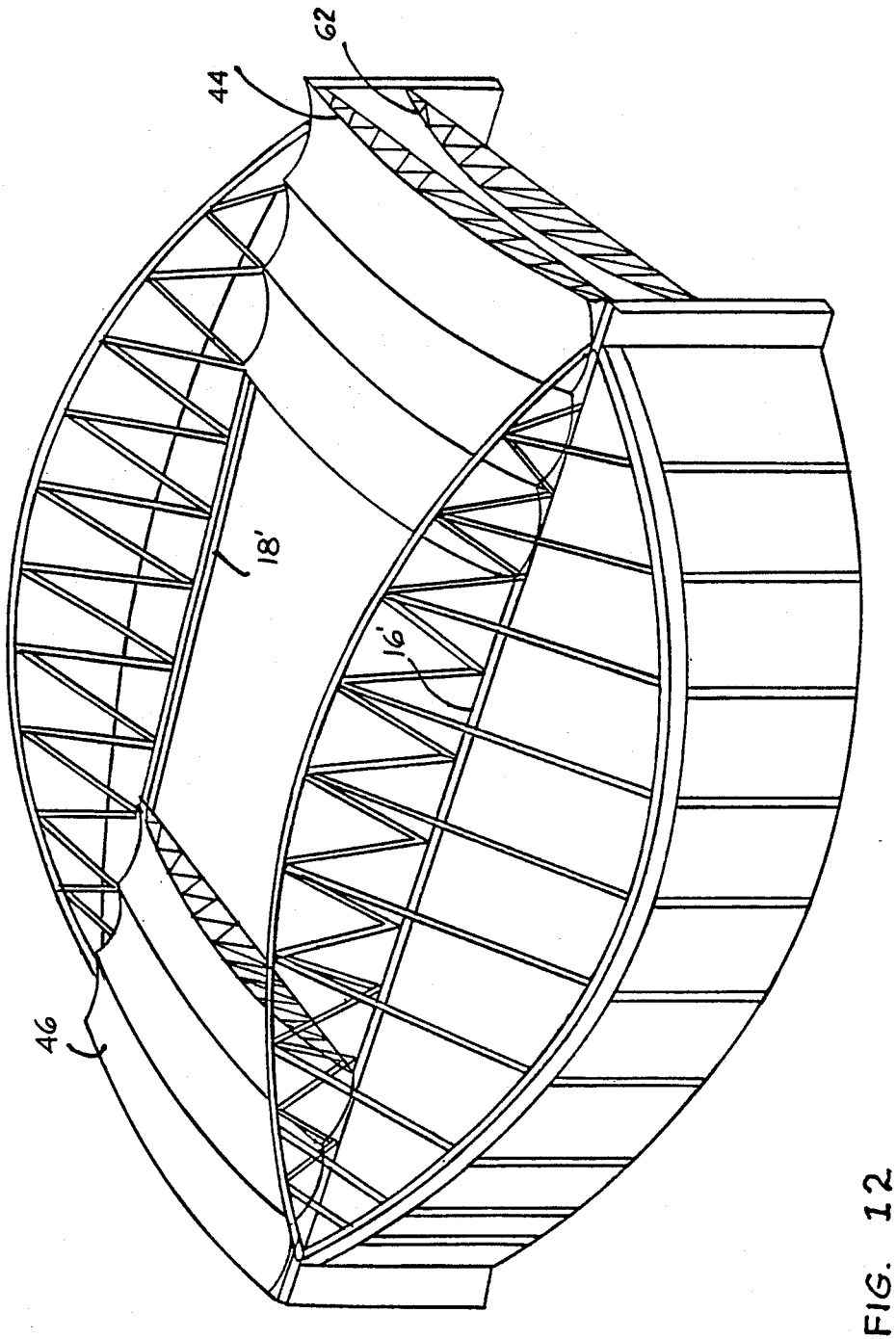


FIG. 12

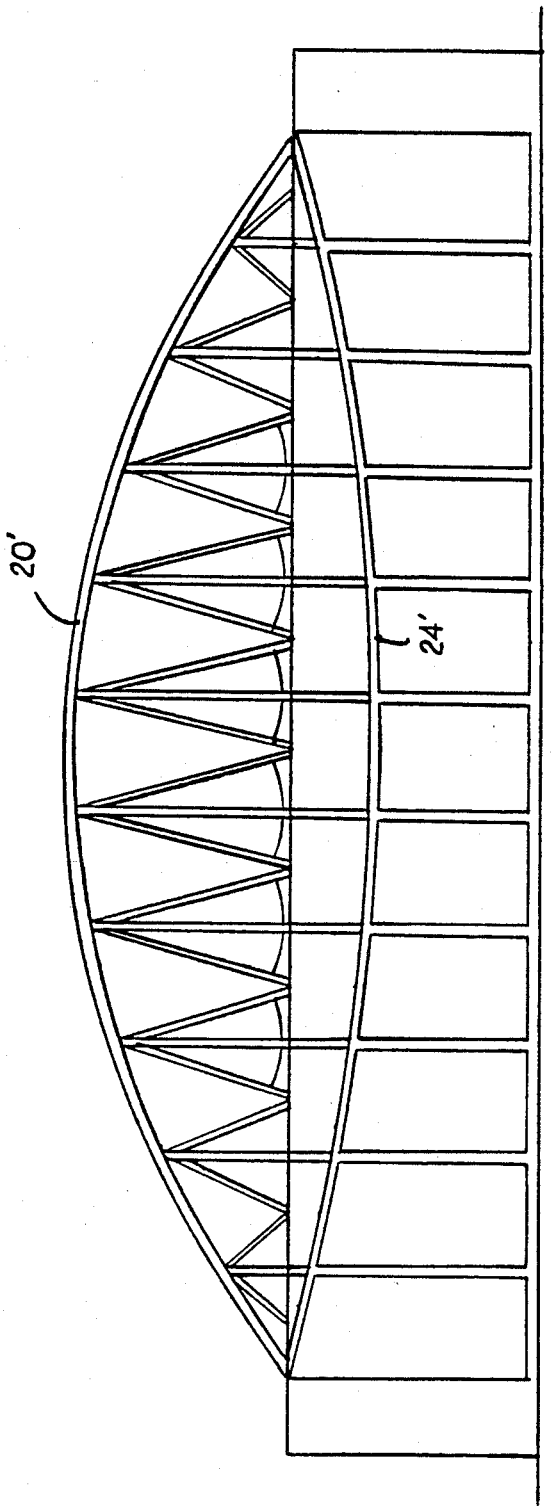


FIG. 13

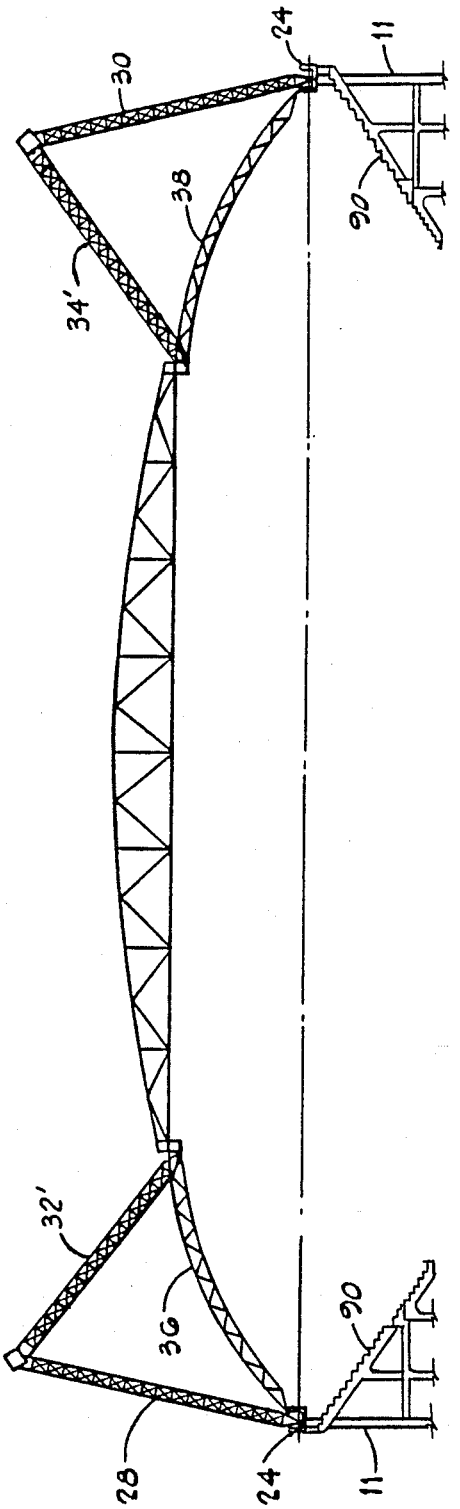


FIG. 14

RETRACTABLE STADIUM ROOF SYSTEM WITH RECTANGULAR OPENING

REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of my earlier application Ser. No. 913,520 filed Sept. 30, 1986, to issue on July 28, 1987 as U.S. Pat. No. 4,682,449. The entire disclosure of said earlier application is hereby incorporated by reference in this application.

BACKGROUND AND SUMMARY OF THE INVENTION

The invention is in the field of structures for covering large areas, such as a full size stadium, and is particularly directed to a structure having a retractable roof. A structure having a partially retractable roof is illustrated at FIG. 6 of U.S. Pat. No. 4,581,860, in which the applicant herein is the inventor and which is hereby incorporated by reference. Other large-span structures for enclosing stadium-size spaces are discussed in a presentation of the inventor herein to the International Symposium on Spatial Roof Structures at Dortmund, Germany, Sept. 10, 1984 entitled "A Decade of Fabric Tension Structures for Permanent Buildings," and in the 12 references cited at pages 19 and 20 of the presentation. The presentation and its 12 references are hereby incorporated by reference in this specification.

It is believed that there is an increasing demand for covered full-size stadiums and similar structures to make sports and other events independent of the weather. On the other hand, there is a desire to retain the outdoor character of certain events whenever possible, which leads to the demand for retractable roofs. A major difficulty in designing and building a stadium-size structure with a retractable roof is the combination of size and movable parts. Full-size stadiums require free-span roof areas in the area of several hundred thousand feet, and roofs of this size and span to be economically and practically built and used require special structural techniques. In particular, structures of this type can make use of efficient geometries such as domes, saddles, etc., which have a circular, elliptic, or super elliptic boundary condition. Making the roof, or at least the central part of the roof, retractable generally makes those closed structural shapes difficult to implement, although one implementation of a partially retractable roof is shown in said prior U.S. Pat. No. 4,581,860 of the inventor herein. A further consequence of a retractable design is that the movable sections of the roof have to fit the geometry of the structure both in the open and in the closed positions, and this requirement can tend to dominate the geometry choices. One such requirement can be that the edges of the movable roof panels run on straight lines or circles. A further such requirement can be that the superimposed loads, such as wind and snow, have to be safely supported in the open and closed positions, and preferably in any intermediate state as well. Also, rain water has to run off in any position. The combined difficulty of these and other considerations is underscored by the fact that to the knowledge of the inventor herein no retractable stadium roofs have been built so far.

This invention provides a functional, structurally efficient, and economical solution for a full-size stadium roof which, in one nonlimiting example, has a retractable central portion which can open up approximately one-half of the total roof area. This is achieved by the choice of a unique geometric configuration and a unique combination of structural systems, materials and construction methods.

In one exemplary embodiment a central rectangular opening of the roof is covered by two retractable roof panels which are rectangular in plan and can cover an area substantially larger than a football field. The panels are substantially rigid, using trussed steel construction or similar rigid lightweight framing. They are covered with a structural fabric membrane or other lightweight roofing system, and move in the direction of the main axis of the stadium (in the case of a football or soccer field, the main axis is along the long direction of the field, and in the case of baseball it is a line through home plate and third base). In at least one elevation the roof panels are high in the middle and low at the ends, thus allowing water to run off in any position of the panels. In the direction of the main axis the retractable panels in a first embodiment follow a slight circular curve, to thereby ride on similarly curved tracks supported on track girders. In a second embodiment the retractable panels move along straight, horizontal lines to open and close the roof. Rollers between the panels and the track girders are arranged to resist downloads, uploads (e.g. from wind uplift), and lateral loads. In the first embodiment the movement of the panels is generated by a hoist system similar to that of an elevator or cable car, with cables running along the track girders, which form the inboard edges of two fixed portions of the roof that flank the sides of the stadium field. Two other fixed portions of the roof flank the ends of the stadium field, and are under the curve along which the retractable panels move to their open positions. In the second embodiment the roof panels ride along straight, horizontal girders, on wheels driven by electric motors synchronized as those on electric trains. The track girders are the main longitudinal support members of the roof, running the total length of the stadium. They are suspended from the arches by respective cable systems similar to those used in a stay cable bridge, or by respective rigid struts. The upper support points of these suspension cables or struts are a part of an arch which gathers the loads from all of the cables or struts on one side, spanning over the length of the structure. Each arch in turn is laterally supported by a triangulated set of inclined struts which rest on an edge ring at the stadium perimeter. The edge ring can be horizontal in the first embodiment, and in the second embodiment can be concave in each elevation. Horizontal tie cables can extend between the two track beams to provide continuity of the system, spanning across the opening in the retractable portion of the roof.

An exemplary first embodiment of the invention comprises two tracks which in plan view are parallel to each other and to a first axis of the stadium field, and in elevational view along the first axis are convex and conform an arc of a circle. In a second exemplary embodiment of the invention the two tracks in plan view are parallel to each other and to a first axis of the stadium field, and in elevational view are horizontal. Two arches in plan view are convex and circumscribe the tracks such that each track is along a chord of a respective arch. In elevational view along the first axis the arches are convex and have curvatures greater than those of the tracks in the first embodiment to thereby extend above them. A substantially rigid, laterally extending edge ring in plan view generally follows the

outline of the arches and in the first embodiment in elevational views along the first axis extends along chords of the arches and tracks. In the second embodiment the edge ring is concave in each elevation. A support, such as a system of columns, can be used to raise the edge ring above grade. The ends of the arches rest on rigid abutments which carry the arch forces into the foundations. Between these abutments the arches are laterally braced by two respective sets of triangulated, inwardly inclined struts, such as steel struts, which rest on the edge ring. In the second embodiment the arches can be supported in the same way, or the horizontal track girders can serve as tie beams for the arches, thereby doing away with the need for the abutments. The track girders are suspended from the arches by two respective triangulated sets of cables or by rigid struts. Horizontal tie cables can span from one track girder to another, and two respective sets of stabilizing cables or rigid struts can connect the track girders to the edge ring. This system can be prestressed and, together with the track girders, can form a sufficiently rigid support for the tracks. The roof panels form substantially rigid space frames covered with fabric or other lightweight roofing material shaped to drain water laterally onto the rigid, fixed portions of the roof at the sides of the stadium field. In the first embodiment (curved, convex tracks), a system of hoist cables and winches is provided to selectively move the roof panels toward and away from each other along the tracks, to thereby close or open the roof of the structure. In the second embodiment (horizontal tracks) there is no need for such a system, and the roof panels are mounted on and are moved along the tracks by wheels powered by electric motors in a manner similar to that used in electric train cars.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a first embodiment of the invention.

FIG. **2** is a plan view showing retractable roof panels in their open positions.

FIG. **3** is a plan view showing the retractable roof panels in their closed positions.

FIG. **4** is an elevational view along a first axis.

FIG. **5** is a sectional view along a second axis.

FIG. **6** is a sectional view along a track girder.

FIG. **7** is a sectional view across a track girder.

FIG. **8** is a partial sectional view taken at line **8**—**8** in FIG. **3**.

FIG. **9** shows a detail of FIG. **8**.

FIG. **10** is a partial sectional view taken at line **10**—**10** in FIG. **3**.

FIG. **11** shows a detail of FIG. **10**.

FIG. **12** is a perspective view of a second embodiment of the invention.

FIG. **13** is an elevational view along a first axis of the second embodiment.

FIG. **14** is a sectional view along a second axis, showing rigid struts in place of cables used in either of the second embodiments.

DETAILED DESCRIPTION

A retractable roof structure embodying a first example of the invention covers a stadium field **10**, such as a football, soccer or baseball field, and has a first axis **12** and a second axis **14**. In the plan view of FIG. **2**, track girders **16** and **18** are parallel to each other and to axis **12** and are spaced from each other by a substantial distance, which can be greater than the width of a football field. As best seen in FIGS. **1** and **6**, in elevational view along axis **12** each track girder is convex and forms an arc of a circle. Track girders **16** and **18** are suspended from the respective arches **20** and **22** by respective sets of suspension cables **32** and **34**, which are arranged in respective triangulated (or parallel) and outwardly inclined patterns, as best seen in FIGS. **1** and **5**. Track girders **16** and **18** are stabilized by two respective sets of stabilizing cables **40** and **42**, which are anchored to edge ring **24**. The horizontal components of forces on the suspension cables and the stabilizing cables are balanced by a set of horizontal tie cables **48**. In plan view, as seen in FIG. **2**, arches **20** and **22** are convex and circumscribe track girders **16** and **18** such that each track girder is along a chord of the respective arch. In an elevational view along axis **12**, as seen in FIG. **4**, arches **20** and **22** also are convex, and have curvatures greater than those of track girders **16** and **18** to thereby extend above them. A substantially rigid, laterally extending edge ring **24** in plan view generally (but not necessarily exactly) follows arches **20** and **22** (as seen in FIG. **2**) and in elevational view along axis **12** ring **24** extends along chords of the arches and track girder (as seen in FIG. **4**). The ends of the arches are supported by abutments **60** which also form the anchor points of track girders **16** and **18** and of edge ring **24**. These abutments **60** carry the resultant loads from the components anchored thereon into the foundations. A support, e.g. comprising columns **26**, can be used to raise edge ring **24** above grade. Edge ring **24** can be polygonal, or elliptic at the sides of the stadium field and straight at the ends of the field. It need not be a complete ring if elements of the supports for stadium seats **90** are designed to carry the required loads from the roof system. Two sets of substantially rigid struts **28** and **30** extend up from edge ring **24** to the respective arches **20** and **22**. Struts **28** and **30** can be in triangulated sets, as illustrated in FIGS. **1**–**4**, or can be in parallel sets. Fixed side roof portions **36** and **38** extend generally laterally from the side portions of edge ring **24** to the respective track girders **16** and **18**, and end fixed roof portions **62** and **64** extend from the ends of the roof structure to the rectangular opening for retractable panels **44** and **46**. Retractable panels **44** and **46** run on tracks **16***a* and **18***a* of girders **16** and **18** on rollers **44***a* and **46***a*, which in plan view overlap the track, and in elevational view along axis **12** are on rotational centers on loci matching the curvature of the tracks, as best seen in FIG. **6**. In elevational view along axis **14**, as seen in FIG. **5**, roof panels **44** and **46** are convex. Retracting means are provided for selectively moving the roof panels **44** and **46** toward and away from each other along track girders **16** and **18** to thereby close or open the roof of the structure. These means comprise hoist cables **50** and **52** trained over sheave wheels **54** and guide wheels **56** and moved in the desired direction by winch systems **58** housed at abutments **60**, to form a system similar to those used in cable cars and elevators.

FIG. **7** illustrates the retracting system at track girder **16** and roof panel **44**, but the same method is used for the other girder and roof panel. Suspended on struts **100** from an edge beam **120** of panel **44** are axles **102** each carrying rollers **44***a* which are similar to railroad wheels and ride on tracks **104** supported on girder **16**. Upper tracks **106** are affixed to girder **16** through posts **105** and overlap the outboard ends of axles **102**, to prevent lifting of panel **44** under extreme uplift loads. The forward

and return runs of hoist cables **56** are carried by guide whels **56**. Some relative lateral movement is allowed between panel **44** and girder **16** by allowing strut **100** to ride on axle **102**, but its extent is restricted by wheels **44***a*.

FIG. **8** illustrates the joint between the fixed end roof portion **64** and the retractable panel **46** when in its closed position; the joint between **66** and **44** is similar. Each fixed roof portion can comprise a truss structure, such as the structure of truss memebers **64***b*, and can have roof skin such as at **64***a* and a black-out curtain such as at **64***c*. Similarly, each retractable roof panel can comprise a truss structure of members such as **44***b* and truss members such as **44***c*, covered with roof skin such as **44***a* and if desired using a black-out curtain such as **46***d*. As seen in FIG. **9**, the joint can be maintained watertight by ensuring that the edge member of the retractable panel overlaps the fixed roof end portions, for example by using the edge members illustrated in FIG. **9**. FIG. **10** illustrates the joint between retractable panels **44** and **46** when they are in their closed positions. As visible in the detail of FIG. **11**, a ledge member **80** on panel **44** overlaps the edge member of panel **46**, and a compressible rubber tube **82** can be used to complete the seal. A similar tube **84** can be used for the same purpose in the joint illustrated in FIG. **9**.

The structure can be erected using generally conventional construction materials and methods. For example suitable foundations are provided and columns **26** and abutments **60** are erected, using reinforced concrete. Edge ring **24** is cast, preferably one segment at a time. Each arch is erected in sections, starting at an abutment **60**. For example, starting at one abutment, the two nearest struts **28** are erected on edge ring **24**, using structural steel frames, and are joined at a top node and held at the corect inward inclination, for example by temporary bracing cables or struts. A section of an arch steel frame is then assembled and moved into place to span from its anchor point on the abutment to the strut node. The next two struts **28** are then similarly erected and held in place, and another steel frame section of the arch is used to span between the two strut nodes, and so on until the steel frame of an arch is completed. Concrete can then be pumped into forms supported on the steel frame of the arch, using the frame as reinforcing steel. The track girders can be assembled on the ground, preferably in sections, and lifted in position using the completed arches as support points, and the sections affixed to each other to complete the girders and tracks. Tie cables **48** can then be strung and prestressed. The fixed roof portions can be erected using conventional truss techniques. The retractable panels can be assembled on the ground, one truss span at a time, lifted in position by canting them relative to tie cables **48**, and the assembly and attachment of roof skin completed in place.

A second example of the invention is illustrated in FIGS. **12** and **13**. It is generally similar to the first example, described in detail above, differing mainly in that it uses straight, horizontal track girders **16'** and **18'** (and tracks **16***a'* and **18***a'*) in place of the convex track girders **16** and **18** (and tracks **16***a* and **18***a*) in the first example. All other differences flow from this use of straight, horizontal track girders and tracks. Thus, there is no need for hoist cable and associated equipment to move roof panels **44** and **46** along sloping tracks, as in the first embodiment. Since tracks **16***a'* and **18***a'* are horizontal in the second embodiment, motion of retractable roof panels along the tracks can be effected simply by driving at least some of rollers **44***a* and **46***a* by means of electric motors (as schematically illustrated at M in FIG. **7**), in the manner used to propel electric train cars by means of synchronized electric motors. Of course, since in this embodiment the tracks are straight and horizontal, fixed roof panels **62** and **64** are identical in any section along a vertical section parallel to axis **12**, and similarly retractable roof portions **44** and **46** are identical in the same section. The only other major difference between the first and second embodiments is that the second edge ring is concave in elevation parallel to axis **14** (as seen in FIG. **13**), to ensure that it meets arches **20** and **22** at an angle and to ensure that there is adequate slope for water runoff. Note that because track girders **16'** and **18'** are straight in the second embodiment, they can be used as tie beams for arches **20** and **22**, respectively, thereby taking the end loads of the arches and removing the need for abutments **60** and carry these loads to the foundation.

In either embodiment, rigid struts **32'** and **34'** can be used in place of cables **32** and **34** in the first embodiment, and therefore stabilizing cables **40**, **42** and **48** can be omitted in the second embodiment. Rigid struts **32'** and **34'** can be truss members similar to struts **28** and **30** in the first embodiment. This can make erection of the arch structure easier, as an arch segment can become self supporting when joined to a pair of such rigid struts.

I claim:

1. A retractable roof structure for covering a field having a first axis and a second axis comprising:

two tracks which are parallel to each other and to the first axis;

two arches which in plan view are convex and circumscribe the tracks such that each track is along a chord of a respective arch, and in elevational view along the first axis also are convex and extend above the tracks;

a substantially rigid, laterally extending edge ring which in plan view generally follows the arches;

a support which supports the edge ring above grade;

two sets of substantially rigid arch support struts which extend up from the edge ring to the respective arches;

two sets of track suspending members which extend down from the arches to the respective tracks;

two fixed roof portions which extend from the edge ring to the respective tracks;

two retractable roof panels having runners which in plan view overlap the tracks and match the tracks in elevational view along the first axis, wherein the roof panels are convex in elevational view along the second axis;

means for selectively moving the roof panels toward and away from each other along the tracks to thereby close or open the roof of the structure.

2. A retractable roof structure as in claim **1** in which the tracks are substantially straight and horizontal.

3. A retractable roof structure as in claim **1** in which the track suspending members are substantially rigid truss members.

4. A retractable roof structure as in claim **1** in which the edge ring is concave in at least one elevational view.

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