When It Comes To Moving A Roof Keep It Simple Stupid!

Uni-Systems

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All of us are probably familiar with the "KISS" principle and most of us would probably agree that it should be applied to our design efforts to the maximum practical extent. In fact, I believe that the ultimate compliment a design can receive is to be evaluated as a "simple design." However, to produce a design that is ultimately judged to be a "simple design" by the casual observer or by rigorous peer review; it can sometimes take a significant amount of sophisticated analysis, innovative thought, and design collaboration.

This is particularly true with regard to the design of retractable roof sport facilities. The integration of retractable roofs into sports venues has not been a completely trouble free endeavor. There are plenty of case studies to demonstrate that, if not well designed and delivered, these systems can end up being very complicated, extremely expensive to build, and unreliable to operate. However, there are also success stories of retractable roof systems that demonstrate, when the "KISS" principle is applied, retractable roof systems for sports facilities can be delivered at an economical cost, can be built on schedule, and can operate trouble-free.

One of the greatest challenges facing a retractable roof design team is the economical, effective, and even distribution of roof gravity loads to a series of wheels traveling over a set of rails. The following is a brief discussion of "dos" and "don'ts" of suspension design. The "dos" portion of this discussion includes a couple of examples where the "KISS" principle was successfully applied to the suspension design challenge resulting in retractable roof systems that were built economically, delivered on-schedule, and have operated trouble-free.

Let's start this discussion by defining the designer's challenge with regard to the design of the wheel suspension system. Generally speaking, the retractable roof systems of sports venues are long-span, heavy structures that can range in weight from a few million pounds to tens of millions of pounds. These roofs have typically been moved on steel wheels rolling on steel rails because of the low rolling resistance, or friction, this system offers. Due to the natural limitations of load carrying capacity of commercially viable steel wheel/rail combinations, there is a necessity to distribute the roof loads over a large number of wheels. These wheels are connected to, or part of, the retractable roof structure. These wheels and structure must move over a rail system that inherently has geometric deviations due to construction tolerances, structural deflections of its supports, and foundation settlements. The expected geometric variations vary from application to application and they can be in the range of a fraction of an inch to several inches. It is easy to visualized that the normal dips and high points in the rail would have the natural tendency to radically redistribute the wheel loads, if no suspension system were employed. To put it simply, if there were no suspension system, as a given wheel rolled over a high point in the rail it would become "high cen-

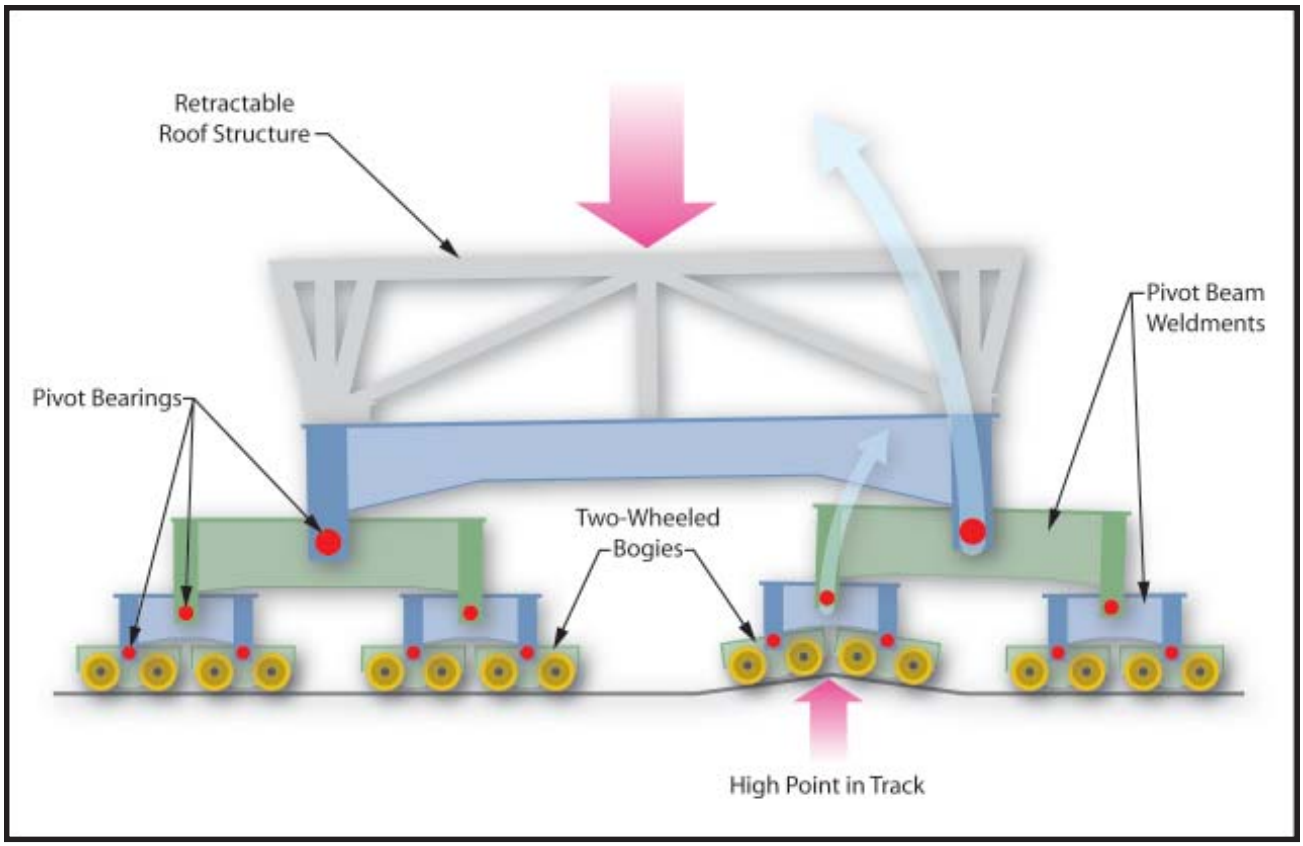

Figure 1 - Pivot Beam Suspension

tered" and that wheel, along with the local roof framing near it, would be forced to take an excessively high proportion of the total roof load. Therefore, the designer must ensure that there is a system in place to accommodate the geometric variations in the rail.

One classical suspension system that has been used in the gantry crane industry for decades is to have all wheels mounted to a series of load leveling pivot beams. Each pivot beam is pinned near the middle and loaded with a wheel or lower tier pivot beam on each of its ends. As the number of wheels is increased, these pivot beams must be stacked up to make the system work. See Figure 1 for a schematic illustration of a pivot beam suspension system. Although this system provides a technical solution to the suspension problem, it also has several disadvantages in its application to retractable roof systems. As stated earlier, most retractable roof applications require the use of many wheels and thus using the pivot beam suspension requires several levels of pivot beams. Each pivot beam is a large, heavy, structural weldment with precision bores for pivot bearings. These pieces are extremely expensive to manufacture and can significantly increase the cost of the retractable roof system. Because these pivot beams need to stack, the system height can grow to four or five times that of more simple systems. This excessive height can become a real detriment to the aesthetics of the building. For almost all applications, the pivot beam systems should be considered one of the "don'ts" of suspension design for retractable roofs.

A much more simple and cost effective alternative that can be applied to almost any application is an independent wheel spring suspension. See Figure 2 for a schematic illustration of an independent wheel spring suspension system. This is the type of system that was employed in the retractable roof system of Minute Maid Park (formerly known as Enron Field), the home of the Houston Astros. This system was delivered economically and

on schedule. Minute Maid Park has out performed all retractable roof systems in operation in North America.

Although the spring suspension does not provide completely uniform wheel loading; very modest wheel load variations, or load redistributions, can be attained with proper design. A reasonable goal for the performance of the spring suspension system would be to limit wheel load variations to plus or minus 25 percent, or less, of the nominal wheel dead load as the system travels over the maximum expected deviations in rail elevations, which can be in the range of plus or minus an inch or more. In the case of Minute Maid Park, this required extensive collaboration between the Engineer of Record for the roof, Walter P. Moore, and the mechanism designer and supplier, Uni-Systems. With careful detailing, proper spring design, and thorough structural analysis; a very simple, reliable, and cost effective system was delivered.

Even though the independent wheel spring suspension system can effectively be used in almost any roof configuration or application; designers should strive for even more simplicity and economy when possible. The design team of HOK Sport, Houston Stadium Consultants, Walter P. Moore, Birdair, and Uni-Systems achieved this goal in the Reliant Stadium retractable roof design. Reliant Stadium is the home of the Houston Texans and the Houston Livestock Show and Rodeo. It is the only NFL stadium with a retractable roof and it also has the distinction of being the only fabric covered retractable roof system in North America.

The Reliant Stadium roof design is a relatively lightweight and flexible roof system. The framing configuration and relatively low weight of the system minimized the number of wheels required to the point where only two wheels were required at each end of each retractable roof truss. This wheel arrangement combined with the flexibility of the framing and fabric

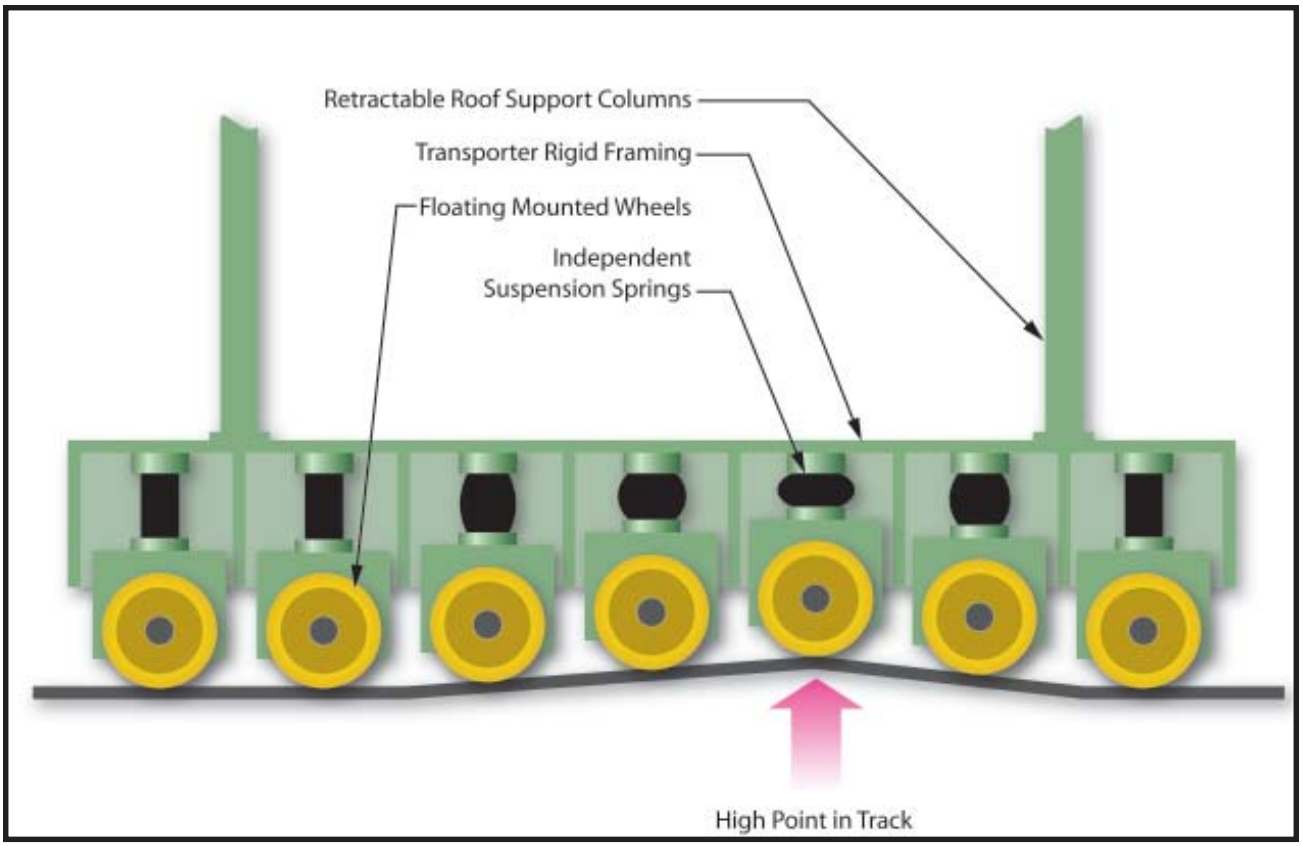

Figure 2 -Minute Maid Park Independent Wheel Spring Suspension

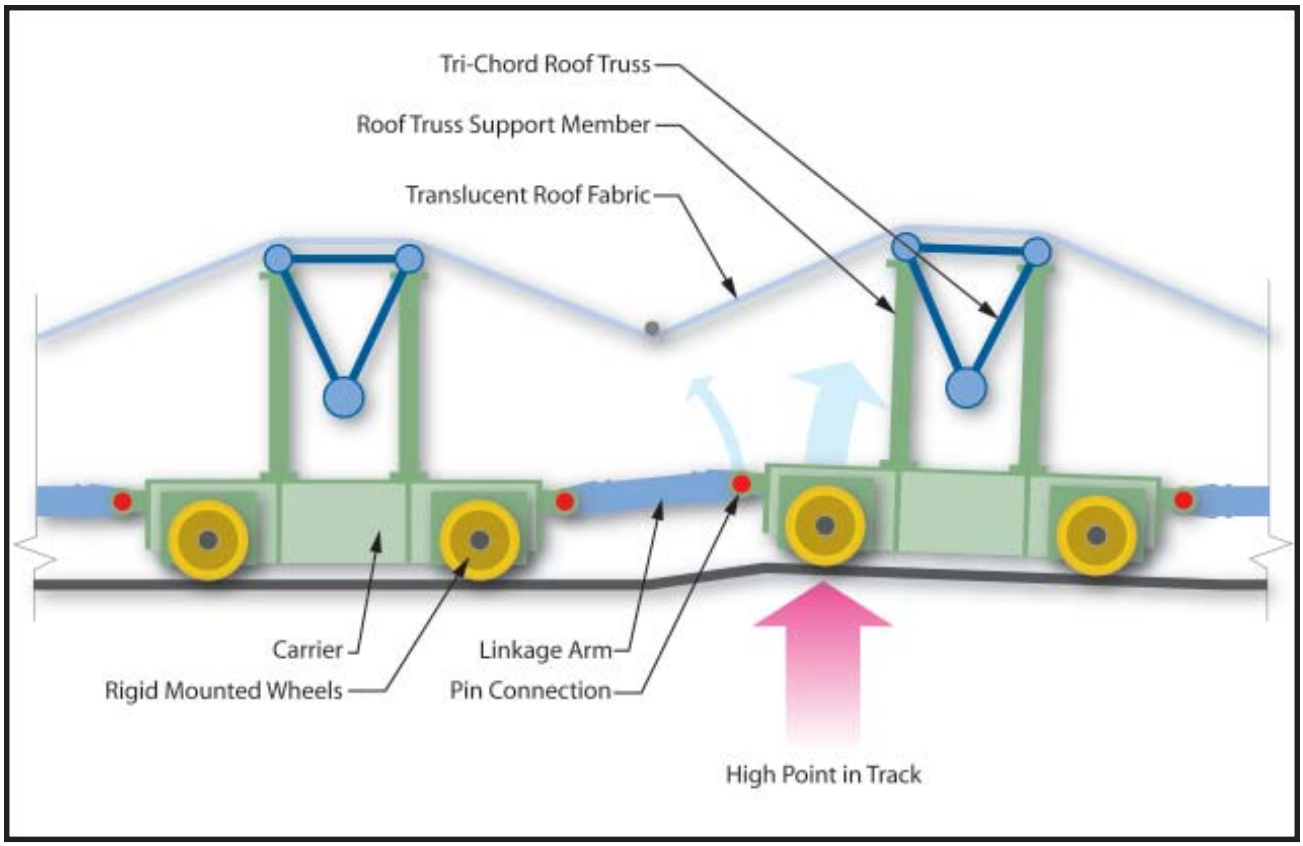

Figure 3 - Reliant Stadium Linked Carrier Suspension System

presented an opportunity to eliminate the need for a conventional suspension system altogether. See Figure 3 for a schematic illustration of the flexible structure and wheel configuration that effectively served as the wheel suspension system for the Reliant Stadium retractable roof system.

Since the stiffness of the roof framing, roof fabric, and carrier system all interact to determine to overall flexibility of the system; the structural engineer, fabric analyst, and mechanism designer had to work closely together in the analysis and detailing of the system. The end result was a roof and carrier system that was flexible enough to roll over the high points and low points in the rail without detrimentally redistributing the wheel loads. The design, analysis, and suspension characteristics were confirmed in the field by physical testing and load measurement after the installation was completed.

Obviously there are many advantages to simplicity and economy of being able to rigidly connect the wheels to the roof carrier system with no special suspension system. Even though the development of this design took a significant amount of sophisticated analysis, innovative thought, and design collaboration; it ultimately met the goal of producing a "simple design."

I hope that the case studies provided above demonstrate, when the "KISS" principle is applied, retractable roof systems for sports facilities can be delivered at an economical cost, can be built on schedule, and can operate trouble-free.