



Reliant Stadium, Houston, TX. Photo by Russ Anadorka

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**W**e hear a lot about the harmful effects of too much stress in our everyday life. Owners, designers, and constructors of sports venues can benefit from taking heed of this advice and applying it to the design and construction of retractable roof systems. Integrating stress relief mechanisms into a retractable roof design might be the single most beneficial decision a design team can make. These stress relief mechanisms can generally be grouped into two categories: suspension systems for distribution of gravity loads and thrust-release systems to eliminate lateral loads. The following brief discussion focuses on the importance and benefits of integrating thrust release systems into mechanized roof structures.

When a design team begins schematic design of a retractable roof sports venue, they are undertaking a challenge that few designers successfully conquer. These mechanized structures are a significant design challenge because they fall outside the norms of both conventional mechanism design and conventional structural design.

Mechanism designers usually work with precision-made, small elements. Thermal expansion, construction tolerances, structural deflections, and thrust loads from frame action are not usually significant design considerations. Structural engineers typically do not have to consider the tight tolerances required for moving parts nor the economic consequences of transferring high-thrust loads through mechanisms. The design of retractable roofs for sports venues presents unique design challenges that must be addressed with innovative solutions.

The goal of the design team is to design a system that optimizes aesthetics, economy, safety, mechanical reliability, and ease of operation. Some externally-applied lateral loads such as wind and seismic loads are unavoidable. The roof-drive system and the structure must take them down to the building foundation.

However, other thrust loads are undesirable and avoidable. The roof design team must be keenly aware of the potential sources of these undesirable thrust loads. One source is thrust reactions resulting from rigid frame action. Another is lateral loads generated from

Innovative stress-relieving solutions eliminate unwanted thrust forces to make today's long-span, retractable roof systems possible.

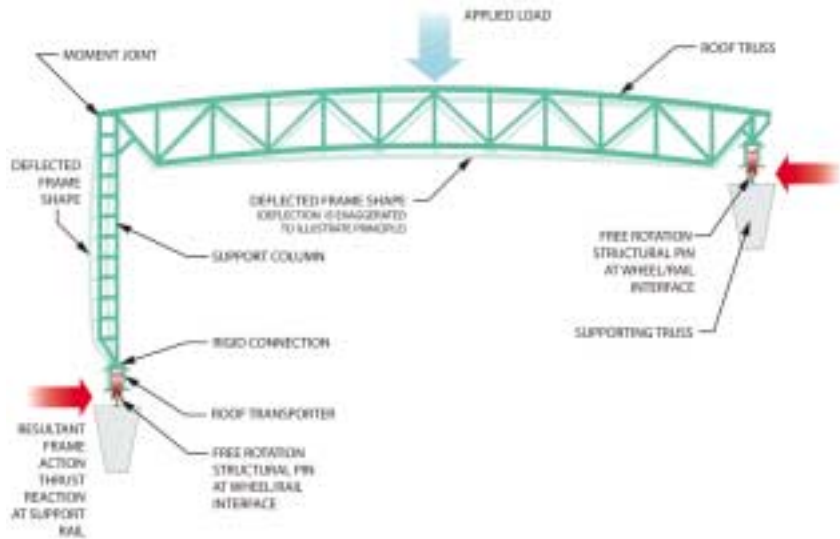


Fig. 1. Thrust reactions from frame action.

the normal variations in the geometry of buildings associated with thermal expansion, structural deflections, foundation settlements, and normal construction tolerances. Figures 1 and 2 illustrate sources of thrust loads.

It is impractical to burden the roof-drive mechanism with any more thrust load than is absolutely required. Rigid frame action and attempts to restrain the geometry variations described above can generate thrust loads several times greater than those imposed by externally applied wind or seismic loads. In the past, attempting to take these thrust loads has driven designers to use a separate system of wheels and rails orientated specifically to the task. At best, this has resulted in an unnecessarily difficult system to build with an unnecessarily high system cost. At worst, this has resulted in problematic and unreliable system operation.

The preferred design approach is to eliminate undesirable thrust loads and design the system to accommodate only more modest thrust loads generated by externally applied wind and seismic forces. Typically the thrust loads generated by externally applied loads can easily, safely and economi-

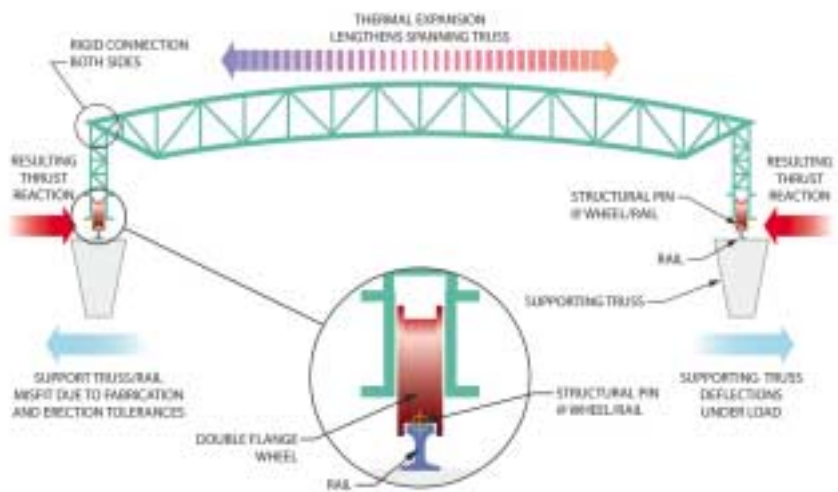


Fig. 2. Thrust reactions from geometric variations.

cally be distributed from the roof structure to the supporting structure via the flanges of gravity wheels riding on vertically oriented rails.

The elimination of undesirable thrust loads can be accomplished without sacrificing economics, aesthetics, safety or mechanical reliability. This is done by adding strategically located release mechanisms in the system. Integrating these release mechanisms can also provide significantly relaxed construction tolerances and beneficially impact the overall cost of the structure. See Figures 3 and 4 for examples of the integration of thrust-release mechanisms into a structure.

Figure 3 is a schematic representation of the thrust-release mechanism used in the roof structure of Minute Maid Park (formerly known as Enron Field), the home of the Houston Astros. Engineers integrated a structural hinge at the top of the tall vertical wall on the west side of the structure. A second structural hinge is provided at the interface between the wheel tread and rail head in the transport system. The head of the rail is crowned so the wheel tread can pivot up to about two degrees with no detrimental effects.

These two hinges allow the west end of the roof truss to move freely without generating stresses. This elim-

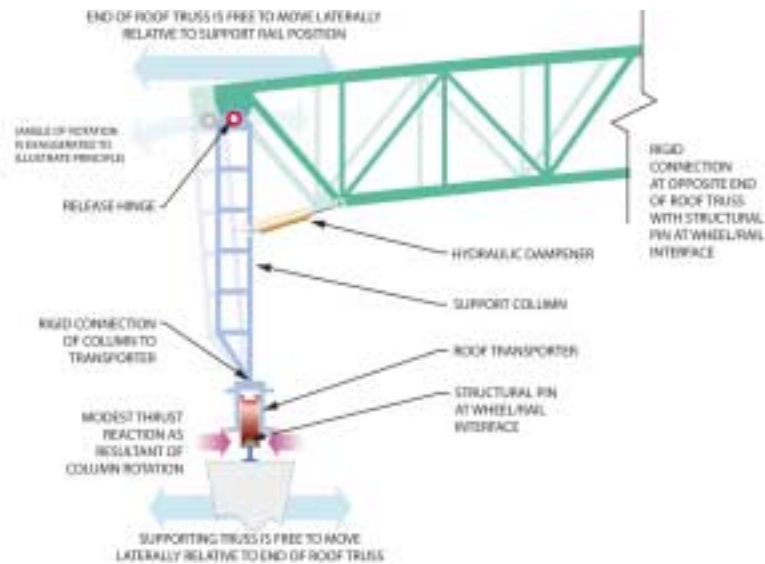


Fig. 3. Minute Maid Park thrust-release hinge.

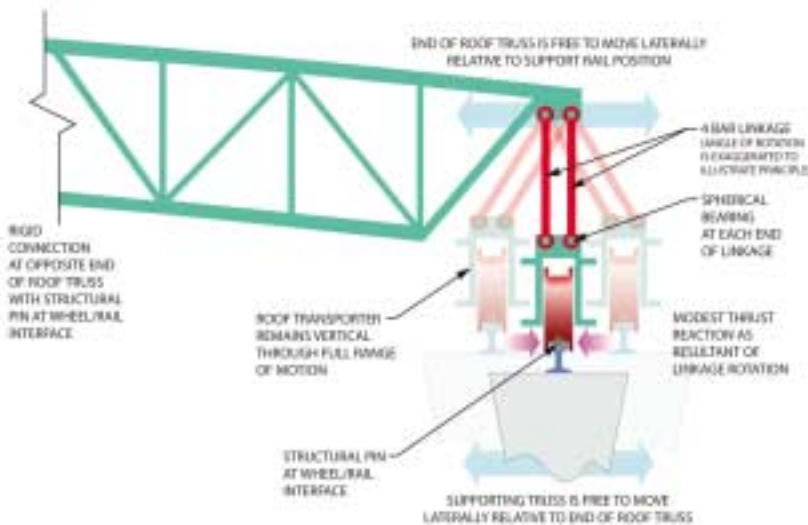


Fig. 4. Reliant Stadium's four-bar linkage.

inates any thrust at the transport wheels from frame action, thermal expansion, and geometric variations due to structural deflections and construction tolerances.

Figure 4 is a schematic representation of the innovative thrust-release mechanism incorporated into the roof design of Reliant Stadium, the home of the Houston Texans and the Houston Livestock Show and Rodeo. The Reliant Stadium design, as conceived by architects HOK Sport and Houston Stadium Consultants, presented significant lateral-release challenges. The roof

structure was designed to ride on rails supported by a supertruss that spanned 600 ft, which permitted the rails to experience significant lateral deflections under load at mid-span. The design team also assumed that the truss could not be built to a mid-span lateral location tolerance of less than plus or minus 3 in. When all expected tolerances and deflections were added up, the design team concluded that one end of the truss had to be able to move laterally plus or minus 21.5 in. relative to its supporting rail position.

This lateral motion had to be accommodated in a relatively short vertical distance of about 10 ft. Thus, the hinge-type release used at Minute Maid Park could not be used because it would generate an intolerable contact angle at the wheel-to-rail interface.

Uni-Systems worked with engineers to design and integrate an innovative linkage system into the roof structure. At the east end of the retractable roof tri-chord trusses, a four-bar linkage was integrated to form the connection of the end of the truss to the transport carriers. This linkage allows free lateral movement of the east end of the retractable roof tri-chord trusses while keeping the transport carrier wheels vertical and producing only very modest thrust loads. Walter P. Moore designed the linkage arms. Uni-Systems designed, tested, and manufactured the maintenance-free linkage bearings. This linkage system provided an economical, easily-constructed solution to a challenging design problem.

The examples above are a small sample of the many means of releasing undesirable thrust loads in structures. The challenge for the retractable roof design team is to develop the most economical and simple solution for the specific application. While there are no generic solutions, the information in this article should provide some insight into potential sources of unwanted thrust loads and a keen awareness of the need to eliminate them.

Remember, if you want your retractable roof to have a long and reliable life cycle; release those thrust loads and live the stress-free life!

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