The new football stadium roof in Saint-Petersburg, Russia

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Summary

The analysis of the new football stadium roof raised a bunch of analytical problems mainly connected with a large volume of information to be processed rather than the scale of the structure itself. The paper discusses some of those problems, methods of their solution as well as some tricks to decreasing the amount of data and improving the analytical performance for the structural analysis of large scale structures.

Keywords: stadium, roof, cable-stays, analysis.

1. Structural overview

The new football stadium in Saint-Petersburg, Russia (unofficially named Zenit-Arena in the media) has been under construction and design since 2007.

At the place where an artificial hill with a deep pit had once served as a hundred-thousand- seat stadium, a Spaceship shall land to be the home of football club Zenit, to host football players and fans within its comfortable hull beneath a roof sheltering from severe northern weather. That is said to have been the impression of the late Japanese architect Kisho Kurokawa, which became the new stadium concept with a rolling-out pitch and a sliding roof (Fig. 1).

As all these years have been passing by, the project has endured the change of many regulations, concepts, contractors, designers, and the customer as well. With every single modification the design proceedings had to be commenced again almost from scratch, sometime utilizing structural elements inherited from the previous session because some of those had been manufactured, brought to the construction site, and even installed.

Fig. 1: Artist's concept of the

According to the latest design concept, whose future is still uncertain, the grandstand is made of solid concrete which is worth an individual presentation at some reinforced concrete conference and won't be discussed here. The steel roof is a totally different matter. Having endured lots of design variants and even a construction attempt (part of the structure had been assembled and then dismantled), the roof now forms a low-pitched dome with 300 metres in diameter, the outer stiffness rim made of orthotropic plates, 150 metre inner truss rim, track girders to carry the sliding roof, radial and tangential trusses supported by outer rim bearings and hanging on eight 95-metre-high pylons with five cable-stays each.

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2. Cable force distribution

During the design, our objective was to get a structural solution which would suit the strict and conflicting requirements of older element capacity and new element weight. For example, the pylons had been already made and stored at the construction site. Their steel and foundation capacity of 52000 kN was sufficient to carry the previous version of the roof and could not be increased unless the pylons were made anew. But we found that we needed at least 73000 to minimize the entire roof weight.

Besides, inclined pylons and vertical cable-stays, a concept which might seem improper from the engineering point of view, caused the compression force to spread across the whole structure, particularly between the track girders, rather than to concentrate near the pylons. It could be possible to get rid of compression by introducing two more pylons, but the rolling-out pitch and sliding roof as well as the impossibility to establish foundations for the new pylons buried this idea. Thus, we had to go ahead with extra compression, augmenting the inner rim cross-section, increasing the structural mass and respecting the 18 000 ton limit.

3. Construction Stages

Construction is one of the most important periods in a structure's lifecycle. There are structures (at least some structural elements) which reach ultimate condition during their construction. This roof is one of those. Many variants of construction sequence were simulated to make sure the structural capacity complied with established requirements.

The scale of structure as well as the necessity to perform the analysis hundreds of times demanded giving up the traditional analytical models involving joints and elements and introducing long-forgotten approach of superelement to boost the analytical performance by removing unimportant data from the global stiffness matrix being solved during the analysis.

4. Sliding roof

From the very beginning the stationary and sliding parts of the roof were designed separately according to the assumption that the fixed roof is absolutely rigid against the moving parts and the moving parts are absolutely flexible against the fixed roof. In other words, reactions between the parts do not depend on the moving parts' location. Of course it is too far away from reality, but we had to commence the design proceedings. When the separate design of the roof parts was completed, the time came to make the entire roof model, which would enable us to simulate any sliding roof location. The problem itself is very similar to incremental launching and the solution comprises the generation of a certain amount of analytical models for any location with the further composition of member force envelopes.

What is the difference between incremental launching of a bridge superstructure and our sliding roof? In case of a bridge, the structure moves about an infinitely stiff and infinitely large rigid body of the external world along a straight or curved line, so we only have to determine which joints become supported at the next step. In the present case, two independent parts of sliding roof are rotated about a certain point and connected to a flexible substructure of the fixed roof.

5. Conclusions

From the analytical point of view, large scale structures are not that different from small ones. Time and huge amount of data are the only problems to cope with when you are working on such a structure. Following the modern tendency to increase the number of elements in analytical models can lead to coming against computational limits. Thus, in some cases you need to reduce the analytical model if the software allows you to do that.