Design of the Singapore Sports Hub Roof with High Strength Niobium Steel

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Summary

Singapore National Stadium roof structure is a highly efficient dome spanning 310 m with a rise of 85 m from the ground level. When complete, the fixed roof will be the largest clear span dome roof in the world and supports a symmetrical movable roof in 2 halves. The fixed roof structure is formed by a series of steel arch trusses that are supported by a post-tensioned concrete ring beam. The trusses are constructed from CHS elements and span in multiple directions to form a highly efficient braced dome structure.

This paper considers the potential savings in material use that could have been made if higher strength, high elongation steel had been economically viable and could have been competitively tendered. It is shown that it could be possible to make a significant saving on element steelwork if hot finished Niobium grain refined S500 can be adopted for similar projects in the future.

Keywords: Singapore Sports Hub, high strength steel, niobium grain refined steels.

1. Project Overview

The Singapore National Stadium will form the centre piece to the new Singapore Sports Hub and lies at the heart of the 35ha sports precinct.

1.1 National Stadium Roof Structure – Overview

The National Stadium (NST) consists of a 310 m diameter spherical steel dome roof. The roof rises to a height of approximately 85 m from pitch level, or 73 m from its supporting level 3 post-tensioned concrete Ring Beam. The roof comprises both a fixed roof and two movable roof components totalling approximately 8100 tonnes of structural steel excluding connections.

The fixed roof spans clear across the stadium with no support taken from the stadium seating 'bowl' concrete superstructure and supports the movable roof via a series of 'bogies' running on the parallel 'runway trusses' that span perpendicular to the pitch axis.

The structural dome form of the roof imparts large tensile forces into a post-tensioned concrete ring beam at Level 3, approximately 9 m from ground level, which acts to restrain the roof from spreading.

2. Optimisation Study

Initial studies looking at the impact on typical elements [1] indicate that S500 could provide a significant increase in capacity for many of the elements and hence a significant saving in tonnage.

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However, as the sectional area of the members decreases so do their stiffness. This leads to amplification of loading effects such as p-delta and resonant response to fluctuating wind loads which increase in importance as the stiffness of the structure decreases. Conversely, the change in weight of steel decreases the total dead load on the structure meaning that further savings are possible.

As a result of increases in load effects due to decreases in stiffness, it was not possible to fully realise all of the initial savings once these effects have been taken into account. The loading regime and the importance of stiffness in the structure are discussed in more detail in Companhia Brasileira de Metalurgia e Mineração (CBMM) *Singapore Sports Hub* Application of High Strength Niobium Grain Refined Steels to a re-design of the Singapore National Stadium roof [1].

3. Results of Optimisation and Discussion

The final design has found that for S500 steel with the same section library as the reference design, it has been possible to complete the fixed roof design with 4644 tonnes of steelwork for the fixed roof structure. As shown in Table 1, this amounts to a saving of nearly 15% on member size or 13.6% on total steel tonnage once the connections are accounted for. Therefore, using S500 steel for both the members and the connections it would be possible to save 855 tonnes of steel within the fixed roof structure. Further refinement of the design has been undertaken to further increase the tonnage saving and are illustrated in Table 1.

Table 1: Summary of fixed roof tonnages

Grade	Member		Connection		Total (tonnes)	% change from base design
	Mass (tonnes)	% change of design	Mass (tonnes)	% change of design		
S355 members and connections	5451	0.0	861 (16% allowance)	0.0	6312	0.0
HF S355 members and connections	5285	3.0	861	0.0	6146	2.6
S500 members and connections	4644	14.8	813 (18% allowance)	5.6	5457	13.6
S500 & S500 movable roof	4586	15.9	813	5.6	5398	14.5
S500 with movable roof and reduced section library	4171	23.5	813	5.6	4983	21.1

4. Discussion and Conclusions

When complete, the National Stadium roof structure will be an iconic structure of national and international significance utilising the latest innovations in wind engineering applied to parametric structural engineering design and optimisation to create a 310 m span roof with a structural weight per square metre of footprint that would be considered efficient for a 100 m span.

This study has shown that potential savings in material use could have been made if higher strength steel had been economically viable and the project could have been competitively tendered on this basis. This study has shown that if the design had been completed using hot finished S500 steel in place of cold-formed S355, a reduction of 13.6% of the total tonnage of steel within the fixed roof structure could have been realised. By extending the use of S500 to include the movable roof and revisiting the section library used, the saving could be increased to 21.1% of the total tonnage.

For a roof of this scale, the structure represents a significant proportion of the total cost and such savings demonstrate that if it can be shown to be economically viable S500 steel would have the potential to deliver improvements in the efficiency of future steel projects.

5. References

[1] Companhia Brasileira de Metalurgia e Mineração (CBMM) *Singapore Sports Hub* Application of High Strength Niobium Grain Refined Steels to a re-design of the Singapore National Stadium roof