The role of wind in steel megastructure erection

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SUMMARY

In the erection design of civil steel megastructures—namely bridges, stadia and mega-roofs—wind plays a peculiar role, not so much because of the gradual change in the shape of the construction, but rather because of changes in several fundamental parameters with non-obvious consequences on the static and dynamic response of the structure throughout the route to its final in-service configuration, for which the designer has originally arranged his work.

While the need for calculations and wind tunnel testing for the service life of structures is well established, it remains far less clear what the erection designer is expected to do. Companies often have schedules and budgets that take no account of the issue or of the associated risks, standards are essentially lacking, and third parties tend to formulate requests based on whatever can be found on the web, without any consistent framework.

Well-known examples of contemporary structures are reviewed in this regard, an issue still part of the regulatory debate—a debate mostly focused on load-to-check questions rather than on general yet incisive prescriptions that could eventually lead to effective design solutions.

Keywords: wind, erection, megastructures

1. INTRODUCTION

When the disciplines of erection, heavy transport and heavy lifting are applied to megastructures—namely long bridges, stadia with special erection issues, or very large roofs—handymen, last-minute professionals and casual advisors disappear from the picture. The erection design of a megastructure can easily exceed a few hundred drawings, including phases and sub-phases, details, customised equipment such as lifting, pulling and pushing machines, and interfaces with the ground, with existing foundations, but also with quays, barge decks, operational cranes, ship decks and so on, in a continuously changing engineering scenario.

What really plays a special and underrated role, even among professionals, is the effect of wind during erection. For a building, the height changes; for a stadium or a roof, however, height is no longer the dominant parameter, since the direction of exposure becomes critical, together with the relative arrangement of skeleton and cladding—mixed situations that change continuously, sometimes without any feedback being relayed to the erection designer. At this point, professionals may envisage some form of analysis to be performed over a number of partial construction configurations. Shape variation also alters other fundamental parameters, with non-obvious consequences on the static, dynamic and safety response of the structure and on the safety of the people working on it, inside it, beneath it and nearby, throughout the complex route to the final structural configuration. In fact, while the need for analysis, calculations and wind tunnel testing for service life is well established, it is far less clear how far the erection designer should push his investigations, given that companies operate within schedules and budgets that are not required by standards, clients or their third parties to include further wind analysis. At times, third parties with no background in specific wind problems turn to the web for a random list of phenomena to be investigated.

This contribution presents real-world experiences gathered by the author as erection analyst and erection designer of contemporary megastructures—some well-known, others confined to highly specialised circles—with the aim of putting forward proposals on the matter, still part of the regulatory debate, which remains mostly focused on load-to-check questions rather than on general yet incisive prescriptions capable of leading to effective design guidance.

2. OLYMPIC OAKA STADIUM ATHENS ERECTION

In 2004, in the absence of an established Eurocode, the Calatrava Roof of the Athens Olympic Stadium was modelled by means of FEM accounting for the temporary erection phases. Due to the 90m temporary towers and the unusual evolving shape, and following the design wind tunnel test, wind during construction was the principal concern of the erection engineers, with no truly innovative tool available except for the reduced return period, which provided a reduction factor on the wind action.

Figure 1. A view of the construction site a few months before the opening ceremony

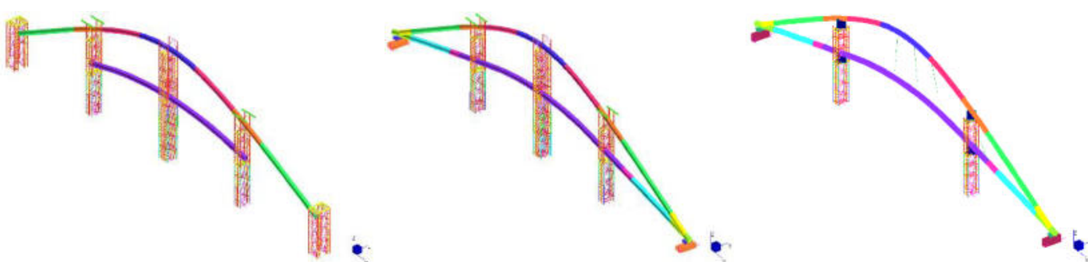
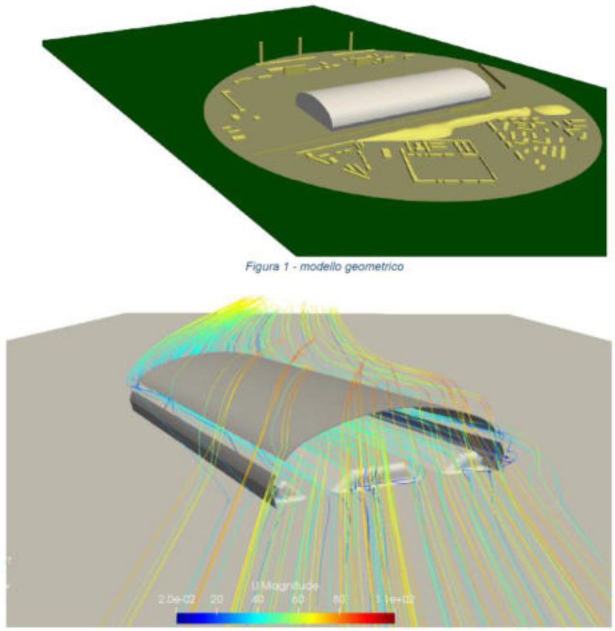
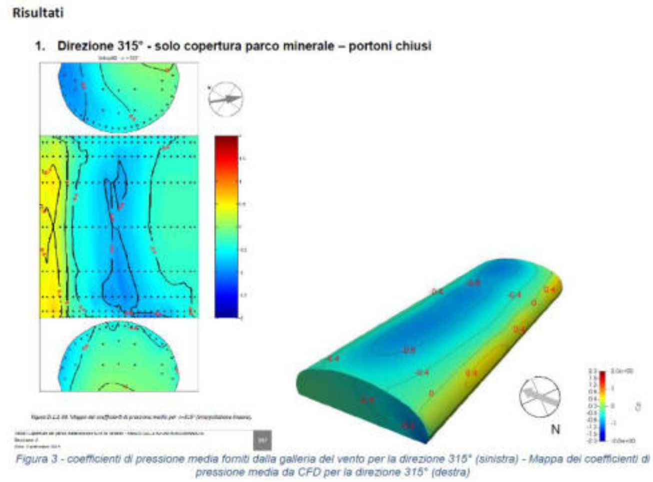


Figure 2. FEM models accounting for the structural evolution of the temporary towers throughout the erection sequence

3. ILVA TARANTO COAL AND IRON MINERAL PARKS MEGAROOFS ERECTION

In 2018, entirely new investigation tools were employed for the construction of the two mega-roofs of the mineral and coal parks. The two wind tunnel tests (the 700m version by Prof. Solari, UniGe, and the 400m final version by Prof. Bartoli and Prof. Mannini, UniFi) provided a sound basis regarding geometries, wind site analysis and dome behaviour, and supplied the benchmark for the CFD analyses dedicated to the temporary erection phases under wind action. The CNR-DT 207 standards represented an advancement as a reliable guide on many points, yet provided no support for critical decisions concerning wind during construction. As a design measure, for instance, a strip was introduced in the cladding to allow wind to flow through, thereby reducing the forces on the translation rollers.





Confronto forze risultanti

LIFT Sum (Z)	DRAG Sum (XY)		LIFT Sum (Z)		TOTAL	
	(t)		(t)		(t)	
GALLERIA	3060		10790		11220	
CFD	2780	-9%	11460	6%	11790	5%

Figure 3. Geometry, WTT and CFD benchmark

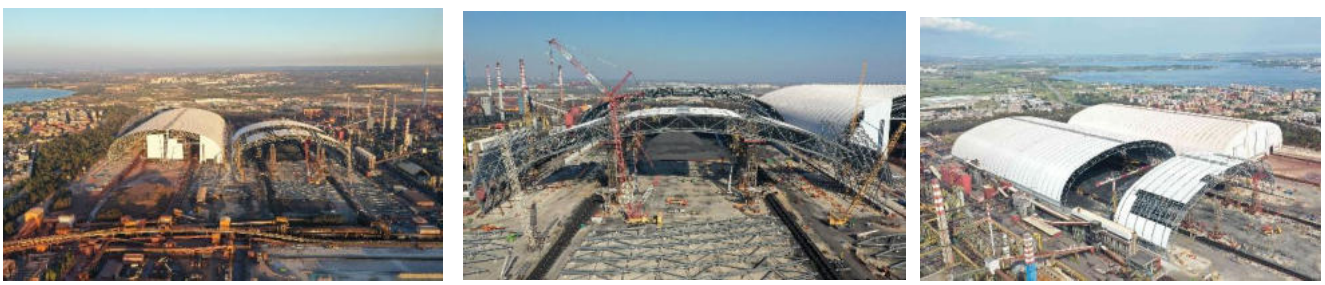
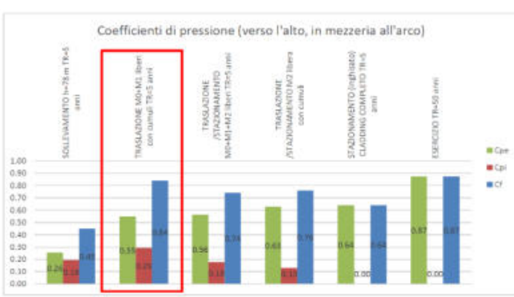


Figure 4. 3000t module lifting, translation, cladding phases

Caso	SOLLEVAMENTO h=78 m TR=5 anni	TRASLAZIONE M0+M1 liberi con cumuli TR=5 anni	TRASLAZIONE /STAZIONAMENTO M0+M1+M2 liberi TR=5 anni	TRASLAZIONE /STAZIONAMENTO M2 libera con cumuli	STAZIONAMENTO (inghisato) CLADDING COMPLETO TR=5 anni	ESERCIZIO TR=50 anni
TR (anni)	5	5	5	5	5	50
Cpe	-0.26	-0.55	-0.56	-0.63	-0.64	-0.87
Cpi	0.19	0.29	0.18	0.13		
Cf	-0.45	-0.84	-0.74	-0.76	-0.64	-0.87
		Situazione da evitare				



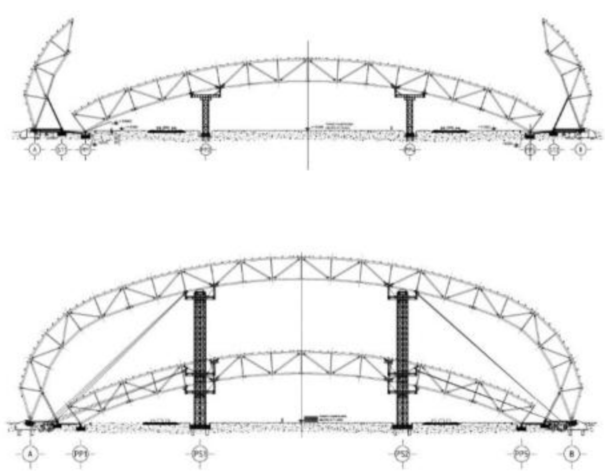
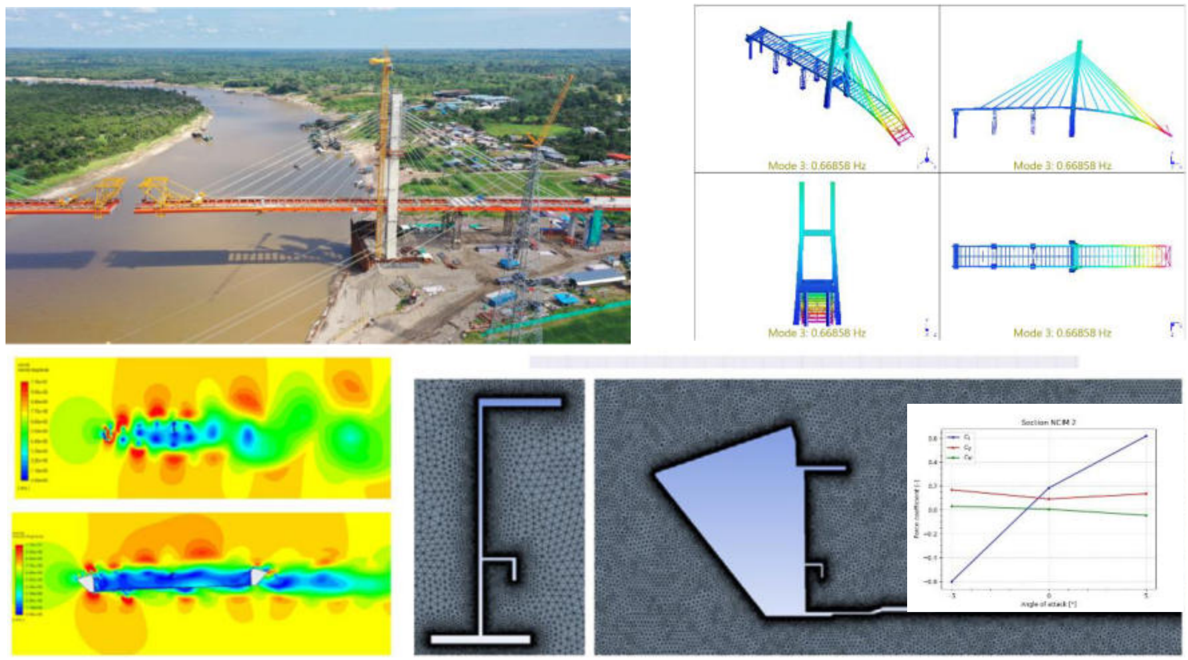


Figure 5. Desktop CFD analyses enabled multiple investigations aimed at mitigating or ruling out dangerous situations

4. NANAY CABLE STAYED BRIDGE IN PERU

Since the only available WTT for the construction phase proved inadequate, all analyses for the Nanay Bridge in Peru—including vertical galloping and torsional divergence—were carried out on desktop, also capturing flutter and the aerodynamic derivatives.



This procedure permits to conclude the new calculations during production and transportation of the segments on site, with just a contained design budget increment to fulfill checkers will.

Figure 6. Full set of aerodynamic instabilities investigated through desktop analysis

5. CONCLUSIONS

In erection design, wind is the most sophisticated and impactful issue. It is, however, often subsumed under the more general assumption that assembly and construction need not be designed, calculated and planned with their fixed and mobile equipment across all foreseen phases, but can simply be addressed through on-site arrangements improvised before execution. Many further real cases could be presented to demonstrate, to the contrary, that the challenges are highly engineering-intensive, with their difficulty amplified by time constraints, by the lack of standards guidance and by the close scrutiny of those funding the work.

Acknowledgments: Cimolai S.P.A.

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