Structural optimization of a bridge beam section subjected to instability of equilibrium

It is well known that in the design of thin-walled structures, extreme attention must be made to the instability of equilibrium problem. This phenomenon involves a performance characteristics loss of the element in which it is manifested, almost instantaneous. If the is a single structural element it can be called local instability"; If the problem is a full structure it can be called global instability". In both cases, the failure usually occurs suddenly with extreme danger.
In this work, starting from a typical steel bridge, the design optimization target was in relation to the instability of equilibrium phenomenon about the web of the main beams.
The starting structure is characterized by two main beams with 40 m of span and 2m of height. The beams are obtained by the union of three segments (one central and two lateral). The thicknesses of the flanges and web of the segments are modified, depending on the project needs.
The two main beams, following a classic constructive scheme, are internally connected together through a series of reticular substructures.
These transverse stiffening elements, in addition to stabilizing the beams during assembly, can also be used as reinforcement against the possible flexural-torsional equilibrium-type instability.
The web of the beams are further reinforced with welded ribbings. These panel types have variable sizes (typically smaller in the zones under a shear stress state joined to axial compression) depending by needs.

Optimization

In order to realize the optimization process of the initial design, 6 parametric models of the structure were created, using as parameters, with the assistance of the CAE software, ANSYS, respectively:

Design	disp	disp_an	stress	stress_an	i_mod	l_sald
Optimum 1	15,32%	-1189,09%	92,54%	85,72%	5	192310mm
Oprtimum 2	4,38%	-0,74%	102,66%	18,14%	0	71450mm
Oprtimum 3	14,60%	-28,14%	23,84%	87,22%	5	192310mm
Optimum 4	9,10%	-21,51%	19,83%	56,59%	4	138550mm
Oprtimum 5	7,65%	-20,82%	-3,85%	39,07%	2	104380mm
Oprtimum 6	15,24%	-28,96%	94,89%	-95,93%	5	192310mm

Table 1 - Percent of performance improvement compared to initial design

- thickness of the transverse stiffening elements;
- thickness of the beam;
- tensions equivalents;
- tensions of the main beam web;
- total displacements of the structure;
- lateral shift of the single web.

Each model also presents a different number of transverse stiffening elements.
Due the complexity of the problem, some static simplifications were made in the analysis parametric model phase.
However, these changes weren't influenced significantly the overall structural behavior.
The optimization was made using the multidisciplinary multiobjective software modeFRONTIER. In order to evaluate simultaneously the dependence on multiple parameters, the use of the genetic algorithm MOGA II (Multiobjective Genetic Algorithm) was needed. Through this algorithm were generated a series of models composed by models generated with recursive method.
These models offer all of the best features of the previous generations. Because of the number of models used in optimization and the high number of parameters that each model has got in the creation of modeFRONTIER workflow, a logic node "switch" was used.

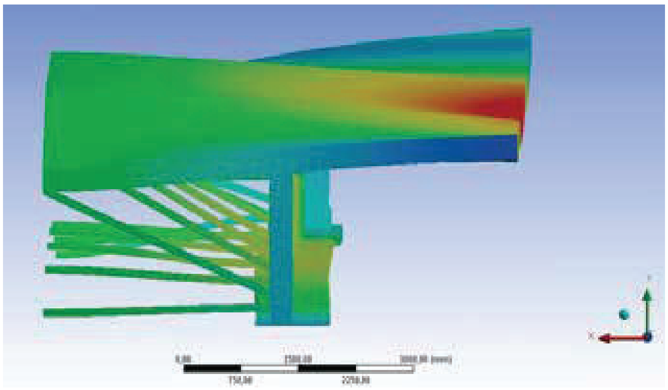

Fig. 1 - Deformation response of optimum design, front view

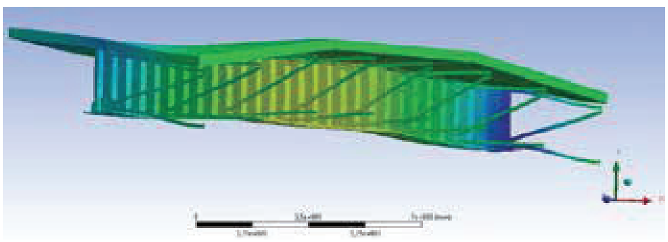

Fig. 2 - Deformation response of optimum design

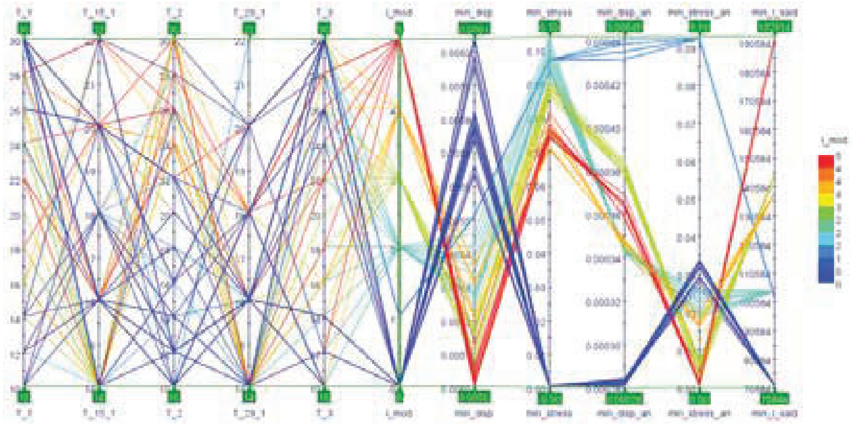

Fig. 3 - Parallel Coordinates Chart of Pareto design

Design	T_1	T_2	T_3	T_agg	i_mod
Initial	16	14	16	/	0
Oprtimum 1	28	26	28	18	5
Oprtimum 2	28	30	28	/	0
Oprtimum 3	24	24	24	16	5
Oprtimum 4	10	30	10	/	4
Oprtimum 5	10	30	10	/	2
Oprtimum 6	30	24	30	16	5

Table 2 - Optimum design table (T_1, 2, 3 spessore dei conci d'anima della trave, T_agg thickness of theaddictional transverse stiffening elements placed between the longitudinal stiffener and the lower flap of the beam upper flange, i_mod reference model)

Through the appointment of a specific value of input variable associated, allow the software to do a univocal choice on the model to be used in the optimization process.
Furthermore, for the quantification of the economic impact resulting from this process, was used the total length of the welds for the fixing of the stiffening elements to the main structure.

Optimum solution

The optimization process has produced a large number of design solutions that has been greatly reduced through the use of the Pareto Frontier. The remaining solutions are all to be considered "optimal" and for this reason a sensitivity analysis was performed to study various hypotheses made on the output parameters. This was done to determine a global optimum solution.
these solutions have characteristics which optimizing the selected output parameters:

- minimum total displacement and of the web alone of the beam;
- minimum tension in the web of the beam
- minimum equivalent stress state in the entire bridge,
- minimum values of the length of the weld.

It was observed that each model has a constant value of the weld length, therefore minimizing this parameter means to choose the design that have the minimum number of transverse stiffeners.
We used the Parallel Coordinates Chart to do a selection between the Pareto designs, obtaining six possible optimal solutions.
It wasn't possible to define an absolute optimum solution.

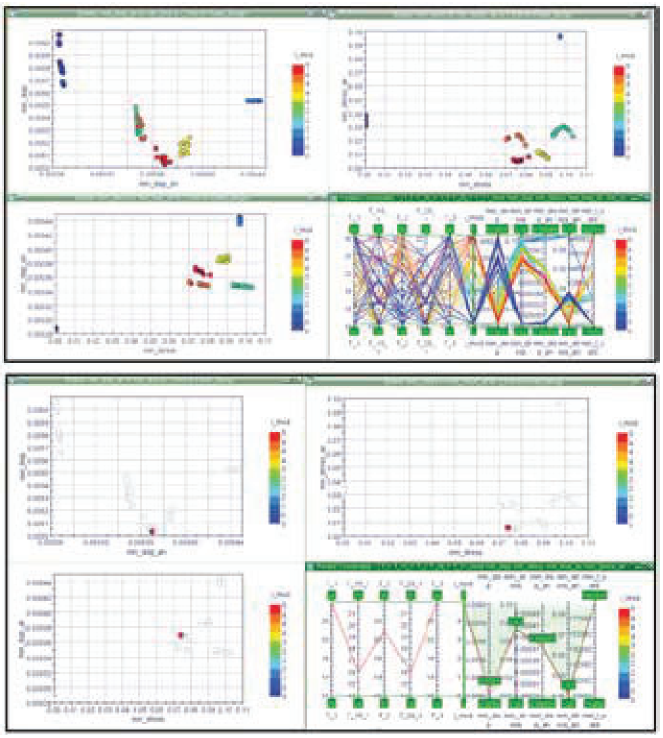

Fig. 4 - Synchronized view of Parallel coordinates chart and Bubble chart (upper picture), variation of the parameter values (lower picture)

Conclusion

The final optimum solution has been chosen through static and economic considerations. The use of parameters such as a weld length, number of stiffening elements and the beam's web thickness have directed the design choice to a good compromise of the improvements vs cost.

The selected final design is characterized by a mean value of the total improvements obtained by the various solutions founded.
The use of modeFRONTIER helped obtain important information about:

- change of geometry
- change of cross-section;
- reaction of the structure.

For example, the existence of a high number of transverse stiffening, associated with the presence of additional stiffening elements placed in the compressed portion of the beam produce an increase of the web displacements.
This increase is due to a low inertial state in longitudinal direction compared to a high inertial state in transversal direction.

Luca Candito, Giorgio Zavarise - Università del Salento

Ask the expert in the bridge structural optimization
Vito Primavera, EnginSoft
v.primavera@enginsoft.it