7th INTERNATIONAL CONFERENCE ON STEEL BRIDGES
Guimarães Portugal 4-6 June 2008

EFFICIENT AND ECONOMIC DESIGN OF COMPOSITE BRIDGES WITH SMALL AND MEDIUM SPANS

Oliver Hechler[a], Louis-Guy Cajot[b], Pierre-Olivier Martin[c], Alain Bureau[c]

[a] *ArcelorMittal Commercial Sections S.A., Long Carbon Steel Europe, Luxembourg*
[b] *Arcelor Profil Luxembourg, Centre de Recherche, Luxembourg*
[c] CTICM, *Saint-Aubin, France*

Abstract: Steel is increasingly present in the field of bridges as the material is guaranteeing a perfect combination between technical performances and safety. If steel is used in composite construction an additional economic potential is developed with the use of cost-effective construction techniques and advanced construction procedures. However these supremacies are not reflecting the market share for bridges with small and medium spans. As one main drawback, the lack of a tool for a fast pre-design of composite bridges using rolled beams has been identified. Consequently the pre-design software ACOBRI (**A**rcelorMittal **Co**mposite **Bri**dges) has been developed, which enables to propose competitive solutions for road, railway and footbridges in a very quick and interactive way. ACOBRI is a pre-design software for composite bridges with a superstructure based on rolled sections. The software applies to bridges with single as well as multi spans. Various alternatives of cross-section types like conventional deck, deck with prefabricated composite beams, box girder deck and filler-beam deck are included. The pre-design is carried out according to the French, German or Eurocodes (ENV) regulations. The software is available as French, English and German version.

1. INTRODUCTION

Steel has got a long tradition in the field of bridges. It is a well controlled material in terms of production, fabrication, construction, durability and design methods. Further with the design of composite construction an additional economic potential is developed with the use of cost-effective construction techniques and advanced construction procedures. With the choice of the appropriate steel grade and concrete quality the conditions for economic construction are provided.

For small and medium spans it is possible to use rolled sections as primary bearing elements in a series of bridge systems. They are industrially produced as well as available in a full range of sizes and steel grades, including high strength grades. The application field of the bridges composed of rolled sections covers spans up to a maximum of 40 meters depending whether it is a road, railway or footbridge and the construction type.

However these supremacies are not reflecting the situation for bridges with small and medium spans, which represent more than 80% of the bridge market. The market share of steel and composite bridges is 10% to 20% in Europe. If the share of rolled profiles in this steel share however is focused it has to be noted, that they are only representing 5% to 10% of the steel share, i.e. hardly 5000 tons in France, and less than 5000 tons in Germany [1].

2. PRE-DESIGN SOFTWARE OF COMPOSITE BRIGDES

2.1 Introduction

For composite bridges with small and medium spans the main competitors are concrete and more particularly pre-stressed concrete bridges. As drawback of the steel and composite solution the missing experience in many countries was identified; first, concerning the costs of a composite bridge and second, in pre-design, which resulted in a time-intensive process due to the flexibility of such a superstructure. The lack of a tool for a fast pre-design was obvious. Therefore ArcelorMittal, with the partnership of the CTICM, developed the pre-design software ACOBRI (**A**rcelorMittal **Co**mposite **Bri**dges) [2], which enables to pre-design competitive solutions in a very quick and interactive way for proposition to the customers.

ACOBRI is a pre-design software for composite bridges with a superstructure based on rolled sections. Moreover, the software provides information necessary to make a proposal (Pre-design, calculation note, drawings and bill of quantities). In addition ACOBRI can be used as a design checking tool.

The software applies to road, railway and footbridges with single as well as multiple spans up to 10 spans maximum.

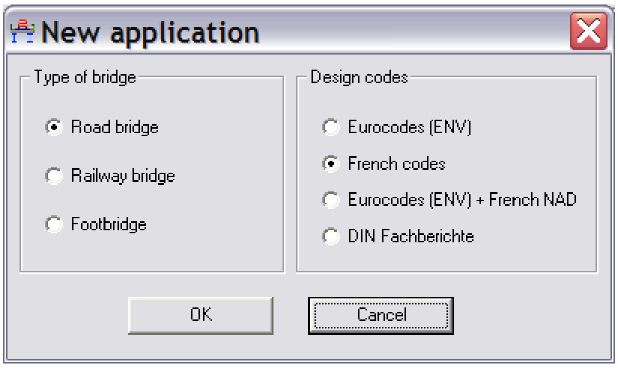


Fig. 1: Interface for the choice of bridge type and design standard

Calculations are carried out in conformity with the following standards: French Standards (2004), Eurocodes ENV, the French version of Eurocodes (ENV + French DAN), and finally German Rules (DIN Fachberichte). From end of 2008 also the Eurocode EN as well as the Eurocode EN with the French NAD will be implemented. The software is available as French, English and German version.

2.2 The interfaces

ACOBRI is very user-friendly pre-design software thanks to its Graphical User Interface. These are mainly based on interactive input windows for adding in the values for the definition of the bridge geometry and the loading, see figure 2. Thus windows are available for the input of:

- bridge references,
- the type of bridge deck,
- the concrete slab characterisation,
- material properties,
- support conditions (e.g. concrete cross beam on intermediate supports) and construction stages,
- diaphragms and changes in cross section,
- main beams and their strengthening,
- the definition of the cracked concrete zones,
- the loading on footway, roadways, tracks etc.,
- support settlements,
- calculation parameters and
- output and post processing of results.

In general standard values are proposed for each input parameter. E.g. the available steel grades are introduced into the input window "materials" by a drop-down menu which enables to choose S235, S275, S355 and S460 steel grade, see figure 2. For the steel grades S355 and S460, the HISTAR [4] can be selected as an option.

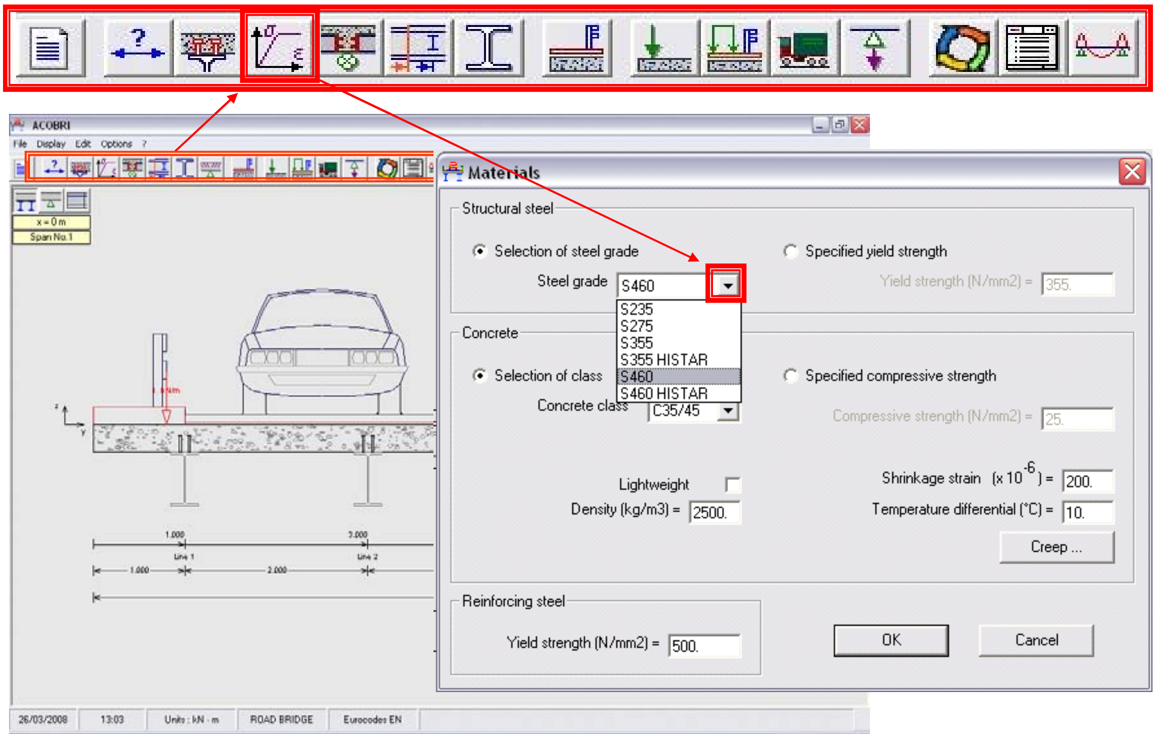
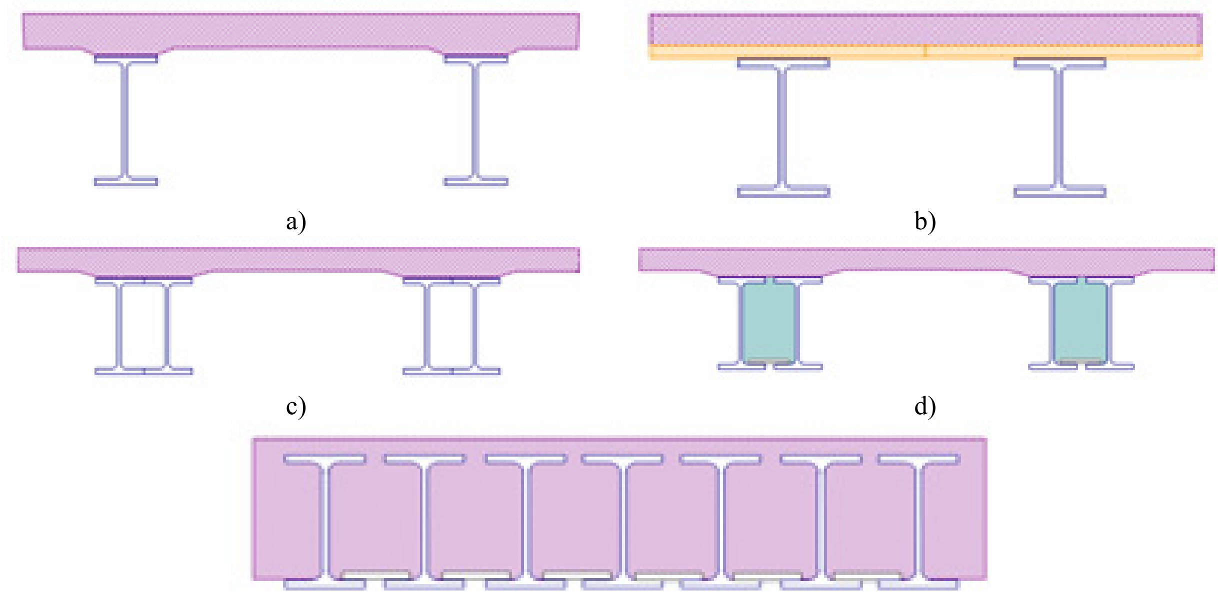


Fig. 2: User interface from ACOBRI

This enables the characterisation of the bridge in very efficient and self-explaining way, with a minimum of sources for input errors. Nevertheless the input values are always directly checked for plausibility.

2.3 Implemented types of bridge decks

All types of bridge decks implemented consist of longitudinal main beams limited to rolled I-profiles from the sales program of ArcelorMittal [3]. As bridge decks various alternatives are available in ACOBRI, see figure 3.



a) b) c) d) e)

Fig. 3: Cross section types

The first alternative is the conventional deck, see figure 3a). It consists of a concrete slab connected to the upper flange of the beams by shear connectors. The concrete slab can consist of a full slab, a slab with steel decking, or a slab using prefabricated elements. The Dolna Wilda bridge in Poznan, Poland, with 10 spans, shown in figure 4, is a recent example for this conventional bridge type with the use of prefabricated elements and concrete cross girder. The bridge was build in 2007 and is divided into two road bridges and a tram bridge. For the roadways HE800B and for the tram bridge HE700B in S355M have been used.

Fig. 4: Dolna Wilda brigde in Poznań, Poland

The second alternative is a superstructure from partially prefabricated composite beams, see figure 3b). This advanced construction method uses an extremely high degree of prefabrication. Therefore the use of partially prefabricated composite beams is an efficient method in construction and economic in design, as it enables to take into account the composite effect during the pouring of the residual complete slab.

The Horlofftal bridge in Germany is a good example for this type of superstructure. This bridge has 8 spans with an overall length of 236.2m; the single spans vary between 23.7m up to 35.9m. 5 spans have been built with rolled beams HE 1000 B with the steel grade S460M. The cross section consists of 4 parallel beams with prefabricated slab elements.
This large spanning bridge is crossing two German railway tracks, a former mining area and the river Horloff. Due to a strict environmental classification and to avoid any influence on protected areas scaffolding was not allowed. The most economic solution was the composite construction using prefabricated elements. The scaffolding for concreting the caps and the devices for the safety at work have also been prefabricated and fixed to edge beams before placing. Consequently the clearance has not been interfered at all. The placing of the prefabricated composite beams is shown in figure 5, the almost finished bridge in figure 6. The most critical construction step was the erection of the beams over the railway tracks, as railway traffic could only be interrupted during a few hours at night.

Fig. 5: Placing of the prefabricated composite beams

Fig. 6: Almost finished Horlofftal bridge

Further the pre-design of a box girder deck is implemented in the software, see figure 3c). This type of deck is similar to the conventional deck with the difference, that the beam is replaced by a box girder made of 2 identical beams whose flanges are welded continuously together. The motivation for this effort is the significantly increased torsional stiffness of the main beams, especially foreseen for complex construction stages and curved bridges. Another alternative to achieve an increased torsional stiffness, however without the effort (and costs) for welding the flanges, is the concrete-filled box girder, shown in figure 3d). Using prefabrication the advantages of box girders are also present in the construction stages.

The last type of superstructures included in the software is the well known and conventional filler-beam deck, see figure 3e). The deck thicknesses of filler beams are generally very small if compared to the span length. This feature is an essential advantage of filler beam construction. It allows for building slender decks which are best suited for projects with severely restricted construction depth. Further it is possible to cut significantly the maintenance efforts due to the high stiffness of the deck. In addition the fatigue performance is excellent due to the use of rolled beams. Overall filler beam bridges are a very robust type of superstructure.

For the highway bridge shown in figure 7 the clearance of the railway tracks imposed a construction depth of maximum 60cm. The filler beam deck construction fulfilled this condition. The slenderness ratio, i.e. span length divided by depth, is 42. At pre-design stage alternative solutions were analysed, such as half-through girder decks. However the filler beam deck showed to be by far the lowest cost option.

Fig. 7: Highway bridge in Luxembourg with a slenderness of 42

2.4 Loads

We already noted that the software is self-explaining for engineers familiar with composite bridges thanks to the use of input windows. An additional comfort to be mentioned is the implementation of the load models for road, railway and footbridges. Hereby the traffic load models of the standard used are already predefined. For the road bridges the traffic load models, fatigue, as well as the loading on the footway are implemented, see figure 8. For footbridges the loads and the vehicles circulating on the footbridge and for railway bridges the characteristics of the railway tracks, as well as the train load level are included, see figure 9. However it is possible to add the finishing loads and abnormal loads individually.

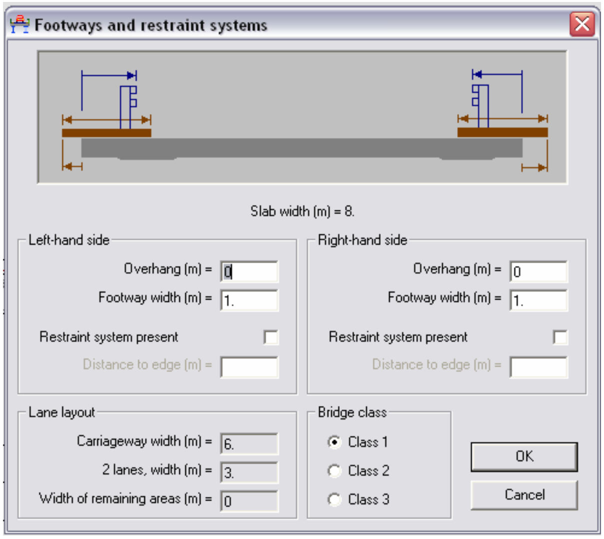


Fig. 8: Interface for the definition of the footways

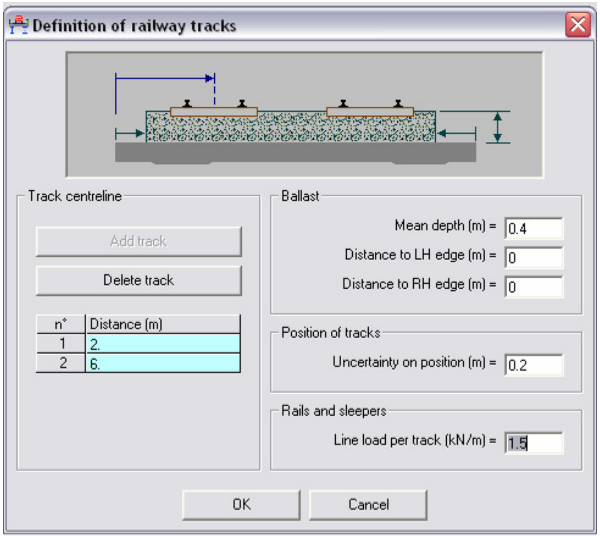


Fig. 9: Interface for the railway track definition

2.5 Running a calculation and print out the results

After the definition of the bridge and the loading follows the second step, running the calculation. First of all, it is possible to carry out the calculations according to two modes, a "checking“ mode and "automatic pre-design“ mode, see figure 10. For the checking mode the superstructure including the main beams are verified according to the standard defined, for the automatic pre-design mode software carries out iterations in order to select the sections in a chosen profile range to identify the optimal solution.

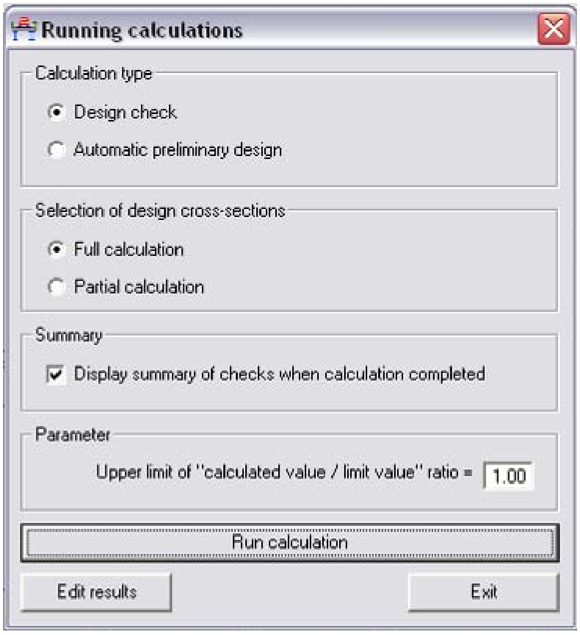


Fig. 10: Module for the definition of the calculation parameters and to run the calculation process

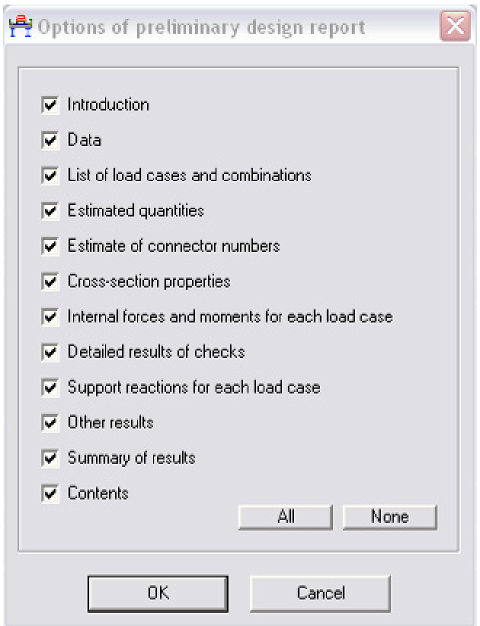


Fig. 11: Choice of chapters for pre-design report

For both modes the software starts with the calculation of the internal forces in the main beams for each elementary loading case based on the definition of the geometry, the materials and the loading specified. This analysis is carried out using a finite element solver on the basis of a grid model. Longitudinal and transversal influence lines are used to determine the position of the mobile loads producing the limit effects in the different sections.

In order to design the beams, the software calculates the main combinations of the internal forces of the bridge for which the ULS and SLS checks are carried out according to the selected standard. Finally the results of the analysis and the design checks are printed in a pre-design report appearing automatically on the screen and which can be printed. The final pre-design report comprehends:

- a summary of the input data,
- the list of the load cases and combinations,
- the estimated quantities,
- the number of required shear connectors,
- the cross section properties,
- the internal forces and moments for each load case,
- the detailed check results,
- the support reactions for each load case,
- other results, e.g. the natural frequency and,
- finally, a summary of the overall results.

It is possible to print the results altogether or to print each part of the calculation report separately, see figure 11.

2.6 Analyze and optimization of the pre-design

The information from the pre-design report are available for every beam in the cross section at various points of interest. Consequently the amount of information is large and, in many cases, not transparent enough to clearly interpret the results and to optimize the structure.

Consequently a module of post-processing of the results has been embedded in the software. This module enables to visualize the virtual models and its characteristic, e.g. loading see figure 12, and diagrams for a graphical output of the calculation results as:

- display of the influence lines,
- deflections or internal forces according to the loading type
- each design checking criterion,
- the connection,
- stresses due to fatigue and the resulting fatigue category, see figure 13.

This is a very powerful tool not only to check the input parameters but also to directly identify the weak points of the design of the composite bridge and to optimise the structure.

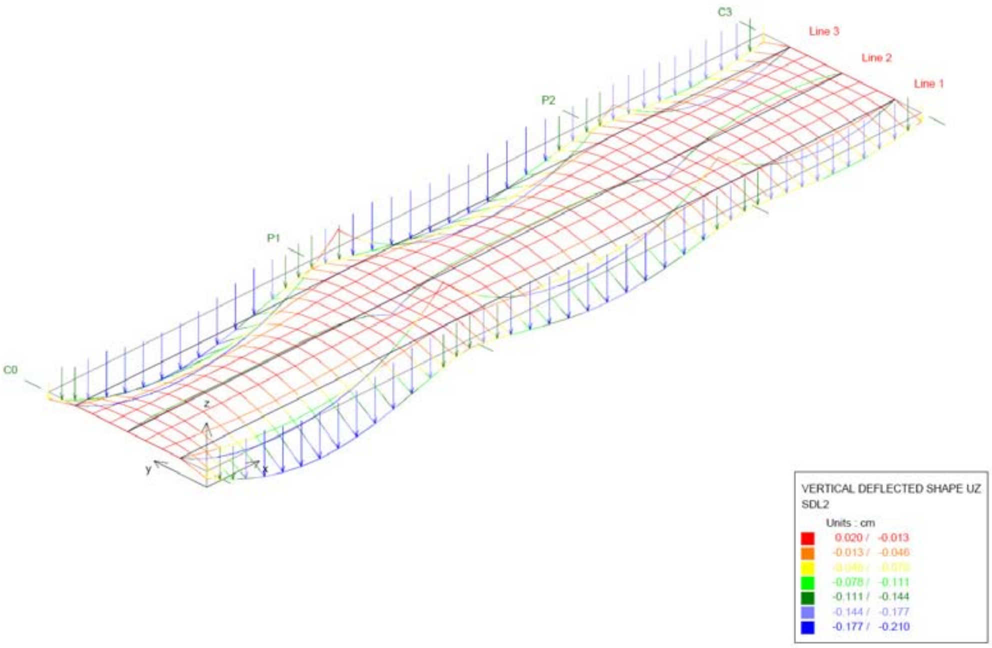


Fig. 12: Visualisation of the model in the post processor including loads, moments and deflected shape

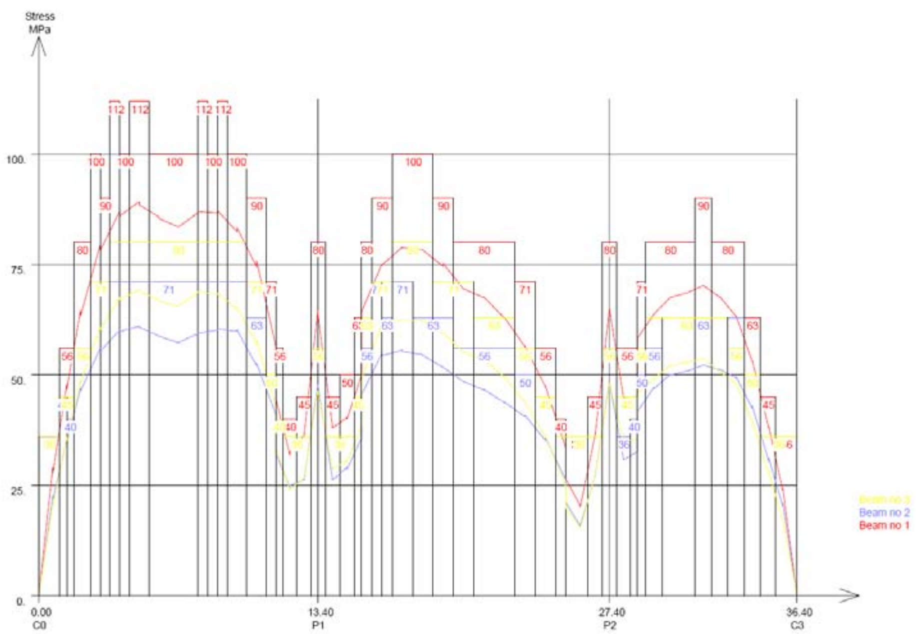


Fig. 13: Presentation of the results of the fatigue check in the post processor with the category to be respected

2.7 Help and validation to the software

The first priority for the software user is the trust in the calculation module, thus the trust in the results it produces. Therefore it is essential to first explain in detail the potential of the software, the input modules as well as the post processor and second to give the user the possibility check his results in the way that the "black box" software is made transparent.

Consequently a user manual, a validation manual and a technical manual are available, see figure 14. The users manual is available in French, German and English, the validation manual in English and the technical manual in French,

The user manual comprehends a short introduction to the scope and potential of the software. Further the description to all user interfaces in the pre-processor and post processor are included. In addition the calculation procedure is explained and the different options for calculation are discussed. Finally the technical background of the software is presented including the characterisation of the FE-model and all design checks. References are listed.

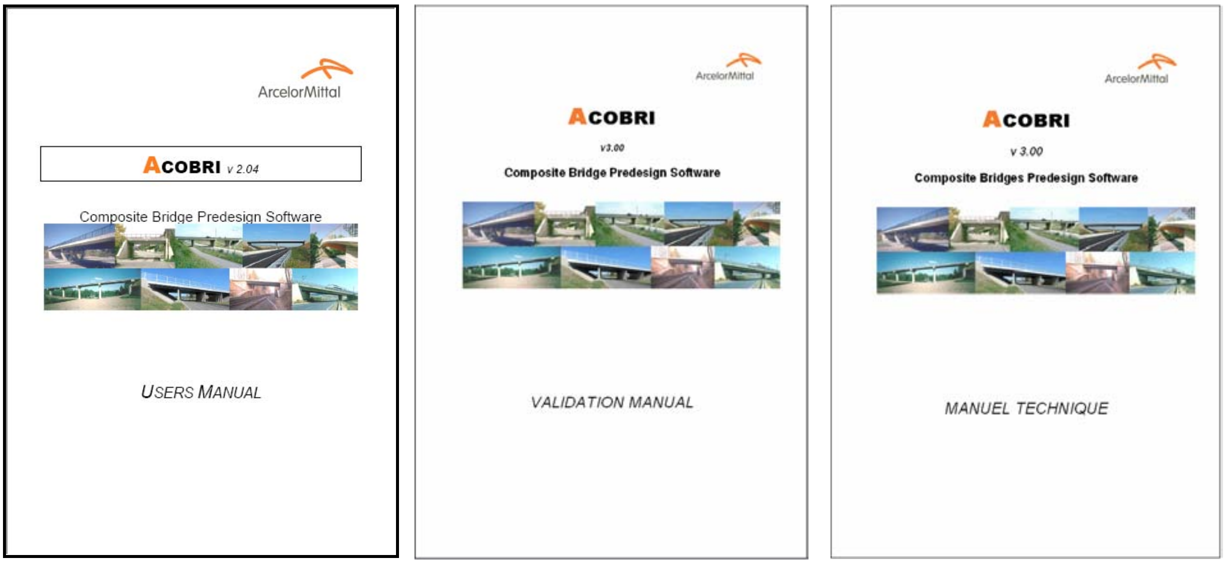


Fig. 14: Available manuals for ACOBRI

In the validation manual a full design of 2 reference bridges is presented. Further 15 additional case studies have been performed to cover all cases for validation. With the use of this manual the user is also able to see the potential of the software in an easy and explanatory way.

The technical manual discusses the design checks included in the software. It has been written to ensure that the content of the calculation module is transparent. It is technical and aims to record the knowledge implemented in the software and its further development.

7 Conclusions

It has been identified that one major drawback of the steel and composite solution is still the missing experience in many countries concerning the costs and pre-design of a composite bridge. As design offices are under time pressure and need to choose the way with less effort, the lack of a pre-design tool for composite bridges was obvious. Therefore ArcelorMittal, with the partnership of the CTICM, developed the pre-design software ACOBRI (ArcelorMit-

tal Composite Bridges) [2]. ACOBRI enables to pre-design competitive solutions for composite bridges in a very quick and interactive way for proposition to the customers.
ACOBRI has been used internally at ArcelorMittal, Commercial Sections, in the Technical Advisory department on a regular basis since 2006. In this department 117 bridges with nearly 30000t of steel in various countries, mainly Germany and France, have been calculated in the years 2006 and 2007 without any negative feedback. However it has been continuously improved. Further ACOBRI is now distributed in France and Germany extensively with a great level of acceptance. The software is free of charge.

References

[1] L.G. Cajot, F. Labory, O. Hechler, M. Haller: Nouveau logiciel de pré-dimensionnement de ponts mixtes ACOBRI. Journées Sidérurgiques Internationales (ATS) (Paris), 2006.

[2] ACOBRI, ArcelorMittal Composite Bridges, Version 2.05. To be downloaded for free at www.arcelormittal.com/sections/ . 2008

[3] Sections and merchant bars - Sales Programme. ArcelorMittal, Commercial Sections. www.arcelormittal.com/sections/. 2008.

[4] Langerzeugnisse aus warmgewalzten schweißgeeigneten Feinkornbaustählen im thermomechanisch gewalzten Zustand: HISTAR 355/355L, HISTAR 460/460L. Allgemeine bauaufsichtliche Zulassung Z-30.2-5. Deutsches Institut für Bautechnik. 2003.