Structural Engineering Documents

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Use and Application of High-Performance Steels for Steel Structures

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

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Foreword

Due to their good material and fabrication properties High-Performance Steels (HPS) are finding an ever increasing use in structural applications, especially in bridge design. However, the development and the code requirements of the various countries and regions in the world differ markedly from each other.

With this background, the members of Working Commission 2 of the International Association for Bridge and Structural Engineering (IABSE), especially Prof. Joel Raoul from SETRA, Paris, had the idea of preparing a state-of-the-art document on the use and application ofthis new generation of steel grades. This proposal, supported by the chairperson of Working Commission 2, Prof. Dr Ulrike Kuhlmann, was the starting point for the preparation of this document.

In comparison to existing Structural Engineering Documents which were written by only one or two experts, this document includes contributions from a number of experienced international authors showing the worldwide development of High-Performance Steels.

I wish to acknowledge the support given to the preparation of this document and express my thanks to all contributing authors and especially to Prof. Dr Bernt Johansson and Prof. Dr Chitoshi Miki for their support and involvement in organizing the contributions from the various countries. I also want to thank Prof. Joel Raoul who had the initial idea and Prof. Dr Ulrike Kuhlmann who gave me the opportunity and time to coordinate the whole document. Many thanks are also given to Dr Geoff Taplin, Dr Sylvie Boulanger, Dr Tomonori Tominaga and Dr Roger Pope who have spent much time in reviewing and rereading the whole document.

Finally I would like to thank IABSE for the publication of this Structural Engineering Document.

Stuttgart, October 2005

Hans-Peter Günther
University of Stuttgart

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Over 15,000 tonnes of "High-Performance Steel" (HPS) were used to build the Millau viaduct in France (see Fig. 5.5.12 and 5.5.13), in order to satisfy the performance criteria of the design team. Steel grades of that category generally lead to cost reductions, smaller sizes of components, lightweight structures and less welding work. Most importantly, these new grades contribute to a sustainable environment due to improved durability properties and reduced material use. For medium and long span bridges, weight reduction can reach 20%.

"High-Performance Steel" (HPS) is the designation given to steels that offer higher performance in tensile strength, toughness, weldability, cold formability and corrosion resistance compared to the traditionally used mild steel grades. In the past fifteen years, there have been significant improvements in steel making technologies, both in tenns of metallurgical advances, and rolling and heat treatment process developments. One of the important technologies in this context is the Thermo-Mechanical Control Process (TMCP) that adequately controls rolling and cooling within the steel plate production in order to generate fine microstructures. The TMCP technology has been instrumental in providing higher strength, better weldability and excellent toughness qualities. Only through these technological breakthroughs has it been possible to produce HPS for the construction industry.

The development of HPS goes a long way to address a new societal demand for slender lightweight structures for the design of medium to long span bridges and multistorey buildings. In such structures, there is a strong requirement to use high strength materials that can also meet erection and fabrication demands. HPS adequately fulfills these requirements leading to economical bridge and building structures with a great potential use for new effective and aesthetic structural solutions.

To encourage engineers to consider HPS in their designs, especially in the field of bridge construction, the deployment and sharing of specialized knowledge on this new steel grade was deemed essential. At the moment, current design codes do not contain sufficient guidelines to fully explore the properties of **HPS.** Hence, the scope of this document is to provide:

- information on the production process and its impact on steel quality,
- chemical composition and mechanical properties of **HPS** in terms of strength, toughness, weldability and corrosion resistance,

- design, fabrication and erection recommendations based on existing codes and research results,
- actual examples and technical solutions for various applications and
- a summary on the high-performance steel grades available in several countries.

The aim of the document is to provide an overview on the development and application of **HPS** at an international level. The document is not a monograph but an assembly of papers from different countries with a focus either on the material, the standard, or its use and application. Some of the papers have a research focus and others have a practical focus.
The design and application ofHPS often needs new design philosophies and advanced structural and technical solutions. The enclosed examples of applications should thus help to give more details and references based on existing experience. The reader will note that most of the examples relate to bridge structures, where one can take füll advantage of the improved properties of **HPS,** where reduction of weight is an important issue and deflection is in many cases not the governing factor in the design process. The document is divided into six chapters and includes North American, Japanese and European authors whose goals were to contribute a state-of-the-art review.

2 High-Performance Steels in the United States

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2.1 Introduction

In 1992, the U.S. Federal Highway Administration (FHWA) initiated an effort with the American Iron and Steel Institute (AISI) and the U. S. Navy (Navy) to develop new high-performance steels (HPS) for bridges. The driving force for this project was the need to develop improved higher strength, improved weldability, higher toughness steels to improve the overall quality and fabricability of steels used in bridges in the United States. lt was furthermore established that such steels should be "weathering". By this is meant the ability to perform without painting under normal atmospheric conditions. The Timeline of the HPS program is shown in Fig. 2.1.1.

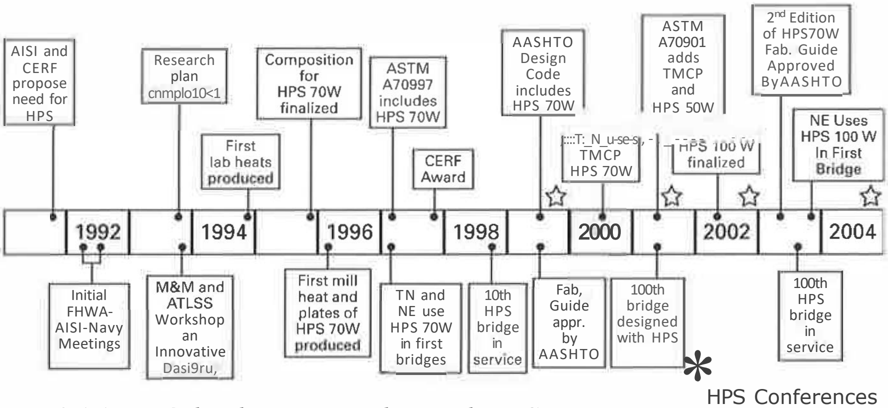

*Fig. 2.1.1: **HPS** development timeline in the U.S.*

In the United States, the principal steel specifications for bridges are American Society for Testing and Materials (ASTM) A709 and American Association of State Highway and Transportation Officials (AASHTO) M270. Currently, in these specifications, there are steel grades with minimum yield strengths (Y.S.) of 36, 50, 70, 100 ksi (250, 345, 485 and 690 MPa). These minimum yield strengths also serve as the grade identity. Furthermore, when the steel has a weathering capability, the letter "W" is at-

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3 Fatigue Research on High-Performance Steels in Canada

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3.1 Introduction

Compared to conventional structural grade steels, high-performance steel (HPS) provides higher strength, improved weldability, greatly enhanced fracture toughness, and comparable ductility, as well as having "weathering" properties. The improved characteristics of HPS are achieved through lower levels of carbon and other elements, in conjunction with advanced steel-making practices using either quenching and tempering or thermo-mechanical controlled processing. All of these properties make HPS highly desirable for bridge applications. Indeed, although its development spans only the past decade, it is rapidly gaining popularity for use in highway bridges and is becoming more widely available. Although many highway bridges have already been put into service in the United States, Canada has yet to implement this technology in bridges. Nevertheless, it is anticipated that the use of HPS will become common in the Canadian market in the near future.

Owing primarily to its enhanced strength, HPS has the potential to produce considerable cost savings and, in fact, this has been demonstrated in completed projects in the United States. Other benefits include the potential for reduced girder depths. However, several impediments to the effective use of HPS in conventional bridge girders exist, including the potential for global and local instability, excessive deflections, and fatigue failure due to the lighter structures that are possible with higher strength steels. To overcome these limitations, innovative bridge girder designs have been proposed [3.12], [3.13].

It was demonstrated early in the development of HPS technology [3.14] that utilizing the full benefits of HPS with higher yield strengths may not be possible because the fatigue limit state is likely to control the design. To address this limitation, the research focus has been largely on eliminating fatigue details associated with transverse stiffeners in conventional plate girders, particularly in regions subject to large stress ranges. This approach is based on the assumption that the fatigue performance of details made of HPS is the same as for conventional structural steels. The improved weldability of HPS (resulting in the reduced requirement for pre- and post heat treat-

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4 High-Performance Steels in Japan

4.1 Bridge High-Performance Steel (BHS) Concept

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Steel materials have been used for bridges for 150 years. Remarkable developments in iron- and steel-making technologies over the years have enhanced the properties of the materials dramatically and increased their applications for structural purposes. In addition, actual applications in structures such as bridges have continuously required higher performance steel materials.

Materials with a great variety of excellent properties have been developed recently. These properties improve the performance of bridges and help to reduce greatly their construction costs. We examined the required performance of bridges to identify what properties are needed in steel materials for bridge applications. As a result, we recommend "BHS" (bridge high-performance steel).

BHS must have various performance properties. The most important of all is high strength, of which BHS has already reached the required level. Today, BHS refers to a steel material with enhanced fracture toughness, weldability, fabricatability, formability and weathering resistance, in addition to excellent yield strength and tensile strength.

Bridge construction costs are divided into material costs, fabrication costs, transportation costs, and erection costs. The stronger the steel material, the lighter the structure, reducing not only the required amount of material, but transportation and erection costs as well. However, with conventional high-strength steel materials, the increased amount of carbon and alloy required for higher strength results in reduced weldability, fabricatability and formability. To make up for such shortcomings, fabrication costs, especially welding costs, have to be raised. Therefore a key issue is how to fabricate high-strength steel at the same cost as mild steel.

Especially high fatigue-resistant performance is required when high-strength steel is used for bridges. In other words, the fatigue strength of the welded structures does not depend on the strength of the steel material. In some cases, the fatigue strength of welded structures using high-strength steel becomes lower than that of mild steel, indicating an inverse relationship. Improving the fatigue strength of welded structures is extremely important in order to use high-strength steel in bridges.

One of the weak points of steel bridges is damage due to corrosion. Paint has been used on conventional steel materials to prevent corrosion. However, the average service life of paint is only 10 years and repainting costs account for a large portion of the life cycle cost (LCC) of steel bridges. Weathering steel was developed in the 1960s and has been widely used to reduce repainting costs. However, the material has not performed effectively under certain environmental conditions. Another urgent issue is the development of steel materials that are much more weathering resistant.

Lamellar tear resistance is especially important among the weldability properties for steel plates for bridges. High stress is often caused in the plate thickness direction in

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5 High-Performance Steels in Europe

5.1 Production Processes, Mechanical and Chemical Properties, Fabrication Properties

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5.1.1 Introduction

Since the first application of steel in steel structures in the 19th century the development of steel construction has been closely linked to the development in material properties and production methods. Significant achievements concerning strength, economy, design versatility, fabrication and erection techniques and service performance would not have been possible without the substantial improvements of steel. Especially with the application of "new" production processes for carbon steels such as the thermo-mechanical rolling and the quenching and tempering process, steel with a high construction strength but guaranteeing also good fabrication properties such as weldability was introduced into the construction market. Today, the application of these grades is driven by the following major reasons:

- Economy: By increasing the strength of steel, the structural section can be reduced depending on the structural problem. This may reduce fabrication and erection costs - an important task in high-wage economies.
- Architecture: The size of structural elements can be reduced, enabling special aesthetic and elegant structures, which embed in the environment in an outstanding manner.
- Environment: Construction with less steel means also a reduced consumption of our world's scarce resources.
- Safety: Modem high strength steel grades exhibit not only high strength values. Special grades combine this strength with excellent toughness so that a high safety both in fabrication and application of the structures is ensured. In particular, modern offshore steel grades performing at some of the lowest service temperatures are a good example.

lt should not be neglected that several other branches started with the application of high strength grades earlier. Mobile crane construction uses today steel grades up to a yield stress of 1100 MPa; in the offshore industry thermo-mechanically rolled steels in higher strength classes are likely to be the steel group the most often used for cold water applications. Even the shipbuilding industry has started to design with high strength steel. Nevertheless, this article focuses on the steel grades which are today used in steel construction (bridges, buildings, hydraulic steelwork) in Europe although we know that engineers in this field can profit a lot from the good experience made in other branches.

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6 Summary and Conclusions

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6.1 General

New steel production processes have lead to a remarkable improvement of steel products in the last couple of years and allows producing steels according to the desired mechanical and chemical properties. Developments in the USA, Japan and Europe showed a remarkable increase in the use of these steel grades for structural purposes, especially in the field of bridge construction. Within these countries, a variety of steel grades were developed according to the specified requirements and priorities. As this document is an assembly of papers from various countries with a focus on different aspects on **HPS**, the following sections give a short summary concerning research, developments and applications, and include an overview and comparison of the properties of the commonly used international HPS steel grades.

6.2 HPS Developments, Research and Applications

6.2.1 HPS in the USA

Within the USA a large research and development program was initiated in the mid 1990's in order to develop new high-performance steel grades for cost effective steel bridges, having high strength, improved weldability, higher toughness and better weathering and fabrication characteristics. Through a strong collaborative partnership and joint effort including various agencies such as FHWA, AASHTO, AISI, Navy and ASTM, fabricators, suppliers and universities the new steel grades HPS 50W, HPS 70W and HPS 100W were successfully developed matching the above mentioned criteria. The cost effective application of these new steels grades has already been demonstrated by the successful performance of about 200 in-service HPS bridges in over 40 states, as partly documented here. Significant progress has also been made in the AASTHO design codes to allow for more efficient use of high strength steels in bridges that can, for example, be attained by using the hybrid girder concept.

6.2.2 HPS in Canada

When high-performance steels are proposed for bridges, the utilization of the higher yield strength may often not be possible because the fatigue limit state is likely to control the design. In Canada research on HPS is thus underway focusing primarily on fatigue behavior. Initial research results from the University of Alberta could, for example, show that HPS base material does not generally exhibit better fatigue per-

Structural Engineering Documents

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Publisher

The International Association for Bridge and Structural Engineering (IABSE) was founded as a non-profit scientific association in 1929. Today it has more than 4000 members in over 100 countries. IABSE's mission is to promote the exchange of knowledge and to advance the practice of structural engineering worldwide in the service of the profession and society. IABSE organises conferences and publishes the quarterly journal Structural Engineering International, as weil as other monographs, including the SED series. IABSE also presents annual awards for achievements in structural engineering.

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Use and Application of High-Performance Steels for Steel Structures

New steel production processes have led to a remarkable improvement in steel products within the last few years, and now allows steels to be produced according to the desired mechanical and chemical properties. High-Performance Steel (HPS) is the designation given to this new generation of steels that offer higher performance not only in terms of strength but also toughness, weldability, cold formability and corrosion resistance, compared to the traditionally used mild steel grades.

The development of HPS goes with today's increased demand for slender lightweight structures, as for example in bridge design and the design of high-rise buildings, where there is a strong requirement to use high-strength materials in combination with good execution and fabrication properties. However, on the structural engineering side there is a need for knowledge on these new steel grades, and quite often design codes do not provide sufficient information to fully exploit the advantageous properties of HPS.

The present volume provides an overview of the development and application of HPS on an international level. This is done by giving information on, for example, the production process, the chemical and mechanical properties, the relevant design and fabrication standards and on recent research results. Approximately fifteen included examples of realised applications aim to provide detailed information based on existing technical solutions, and to point out the major benefits when using HPS in comparison to mild steels.

The document is thus not a monograph but an assembly of contributions from different countries. It is separated into chapters related to different countries, namely the USA, Canada, Japan and Europe, all of them providing a state-of-the-art report on HPS.