Proceedings

Advanced Materials for Construction of Bridges, Buildings, and Other Structures III

Engineering Conferences International *Year* 2003

Histar High Performance Hot-Rolled Beams

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HISTAR HIGH PERFORMANCE HOT-ROLLED BEAMS

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ABSTRACT

The construction industry is continuously looking for superior building components. Innovative production processes are, in combination with tight quality control, the keys to structural steel grades with outstanding properties. Especially the thermomechanical treatment allows for combining material properties which were formerly thought to be incompatible: high yield strength for big material thicknesses, good toughness and excellent weldability.

This paper presents the Quenching and Self-Tempering (QST) process which allows for the production of heavy hot-rolled H-beams in high strength structural steel grades with excellent weldability characteristics. The new steel grades fully comply and even exceed the requirements of the European and American structural steel standards. The good toughness and ductility of these grades also make them very suitable for applications in earthquake areas. Ten years of experience in producing and commercializing heavy beams in high strength grades world-wide also allow to present the economical use of these products in various structures, such as long span trusses, high-rise buildings, bridges and offshore applications.

INTRODUCTION

Driven by strong competition, the H-beam market has developed over the last years towards sections with greater thicknesses and higher yield strength. High technology areas such as offshore structures and high-rise buildings require furthermore excellent toughness combined with improved fabrication properties.

The conventional method for producing high-strength steels consists in adding alloying elements to the steel and rolling at controlled temperatures. This thermomechanical (TM) rolling technique is however limited by:

- the mechanical power of the rolling mills as this process asks for high deformation rates at relatively low temperatures,
- the impossibility of substantially reducing the carbon equivalent (CE) value of the steel and, as a consequence, of improving its weldability.

So, until recently, the heavy structural H-shapes were only available in the market with yield strengths up to 345 MPa (50 ksi) and the need for preheating during welding operations. Nowadays, the QST process allows, in combination with the classical TM rolling, to overcome these limitations and to combine high yield strength, good toughness and excellent weldability for the whole range of available heavy H-beams. The corresponding steels are known in the market as HISTAR

(High-Strength-ARBED) grades. They fulfil and even exceed the requirements for structural and offshore steels according to European standards (EN10025, EN10113, EN10225) as well as American standards (ASTM A913, A992). Test programs have confirmed the outstanding mechanical and technological properties of the HISTAR steels.

MODERN PRODUCTION PROCESS FOR HIGH PERFORMANCE BEAMS

The QST process uses water and the rolling heat as working substances. A prerequisite for a successful QST treatment of heavy beams is the homogeneous temperature profile of the whole cross-section before entering the cooling bank. This condition is fulfilled by applying a selective cooling during rolling to the hottest part of the beam, namely the flange-web intersection (Figure 1). Doing so, substantial temperature differences over the entire flange width can be eliminated. This process considerably improves the grain sizes and reduces the residual stresses in the core area.

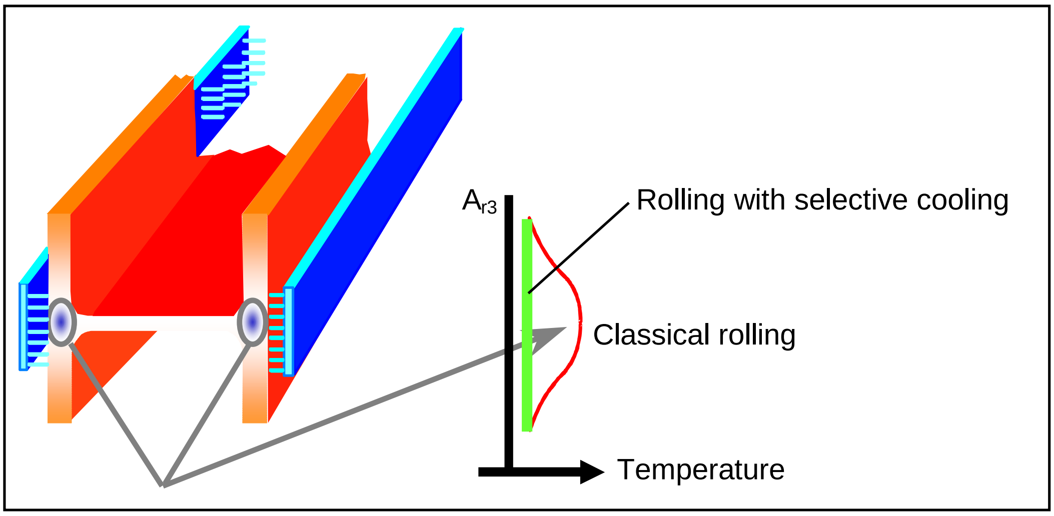

Figure 1. Selective cooling of heavy structural beams

After the last rolling pass, an intense water-cooling is applied to the whole surface of the beam. Cooling is interrupted before the core is affected and the outer layers are tempered by the flow of heat from the core to the surface (Figure 2). At the exit of the finishing stand, directly at the entry of the cooling bank, the rolling temperature of the beam lies typically at 850°C (1560°F). After the quenching over the whole surface of the section, self-tempering is achieved at 600°C (1110°F). The parameters of this industrial process are controlled by computer.

PROPERTIES OF HISTAR STEEL GRADES

The QST process considerably increases the yield strength and the toughness of the steel. Due to much lower carbon equivalent values when compared with conventional structural steel grades, the weldability and the ductility of the steel grades are significantly improved.

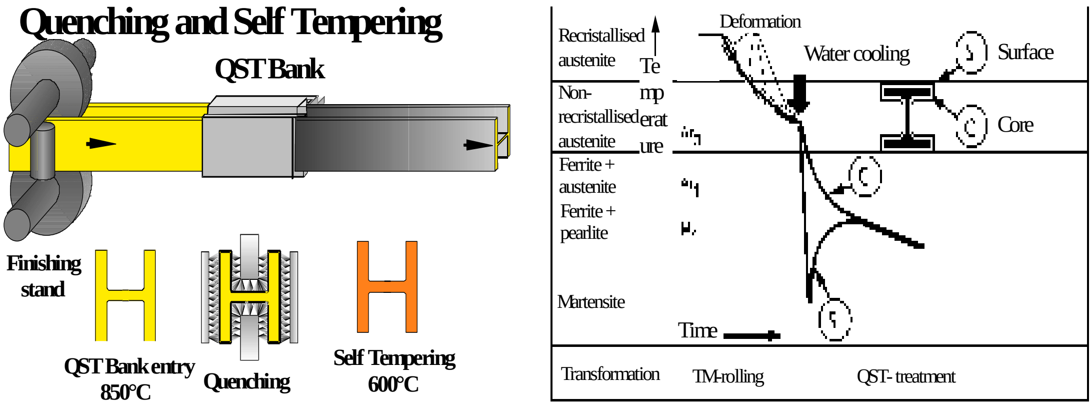

Figure 2. Schematic illustration of the QST-process

Mechanical properties

All HISTAR grades offer a constant guaranteed minimum value for yield strength over the whole range of product thicknesses. The main mechanical properties of these grades are given in Table 1 and Table 2. A comparison between the yield strength of HISTAR grades and conventional hot rolled fine grain grades in accordance with EN 10113-3:1993 is shown in Figure 3.

Table 1. Mechanical properties of structural HISTAR grades

	Tensile strength R_m [MPa]	Yield strength R_{eH} [MPa] $t_f \leq 125$ mm	Elongation A_5 [%]	Notch Impact test	
				Tempera-ture [°C]	Absorbed Energy [J]
HISTAR355	≥450	≥355	22	-20	40
HISTAR355L				-50	27
HISTAR420	≥500	≥420	19	-20	40
HISTAR420L				-50	27
HISTAR460	≥530	≥460	17	-20	40
HISTAR460L				-50	27

Table 2. Mechanical properties of HISTAR offshore grades

	Tensile strength R_m [MPa]	Yield strength R_{eH} [MPa] $t_f \leq 125$ mm	Through thickness tensile test	Elongation ($5{,}65\sqrt{So}$)	Notch Impact test	
			Z_z min (%)	Amin (%)	Longitudinal direction	Transverse direction
HISTAR355 TZO	460-620	≥355	25	22	-20°C ; ≥50J	-20°C ; ≥27J
HISTAR355 TZKO			35		-40°C ; ≥50J	-40°C ; ≥50J
HISTAR420 TZO	500-690	≥420	25	19	-20°C ; ≥60J	-20°C ; ≥27J
HISTAR420 TZKO			35		-40°C ; ≥60J	-40°C ; ≥50J
HISTAR460 TZO	530-720	≥460	25	17	-20°C ; ≥60J	-20°C ; ≥27J
HISTAR460 TZKO			35		-40°C ; ≥60J	-40°C ; ≥50J

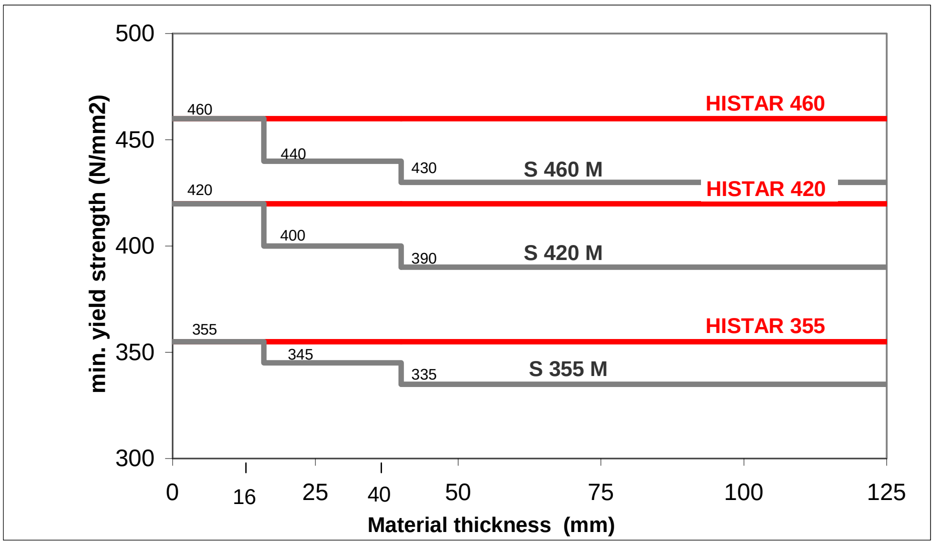

Figure 3. Min. yield strength R_{eH} of HISTAR steels versus structural steel grades in accordance with EN 10113-3:1993

Weldability

Figure 4 summarizes the relationship between chemical composition, product thickness and yield strength for the conventional rolling processes and the new QST process. In Europe, the grades HISTAR 355 to 460 have a maximum CE value of 0.39 %. In the range of normal heat inputs during welding (10-60 kJ/cm) and provided that low hydrogen filler metal and auxiliary products are used, a preheating is not necessary for temperatures of the structure over 0°C (32°F).

In the USA, Grade 50 and Grade 65 in accordance with ASTM A913 (HISTAR 355 and 460) have been introduced in the AWS (American Welding Society) codes D1.1 in a category "weldable without preheating" if welded with low hydrogen electrodes (< 8 ml/100g).

Toughness

Nowadays, it is well established that a certain level of toughness of the steel is required in order to avoid the propagation of cracks associated with brittle fracture in the base material during welding or during seismic loading from earthquakes. Figure 5 displays the Charpy-V impact energy values measured after welding at various locations of the heat affected zone (HAZ) for different welding energy levels. Obviously excellent toughness values are guaranteed, mostly in excess of 100 J.

In Europe, HISTAR 355 to HISTAR 460 are typically supplied with guaranteed toughness values of 47 J at 0° C. QST steels can also be supplied with better toughness at very low temperature. So, even a jumbo size HD 400x1086 kg/m (W14x730) in grade 460 MPa (gr 65) can be supplied with notch toughness values of 27J at –50°C ! This explains why beams in HISTAR grades are extensively used for the construction of offshore platforms, for instance in North Sea projects.

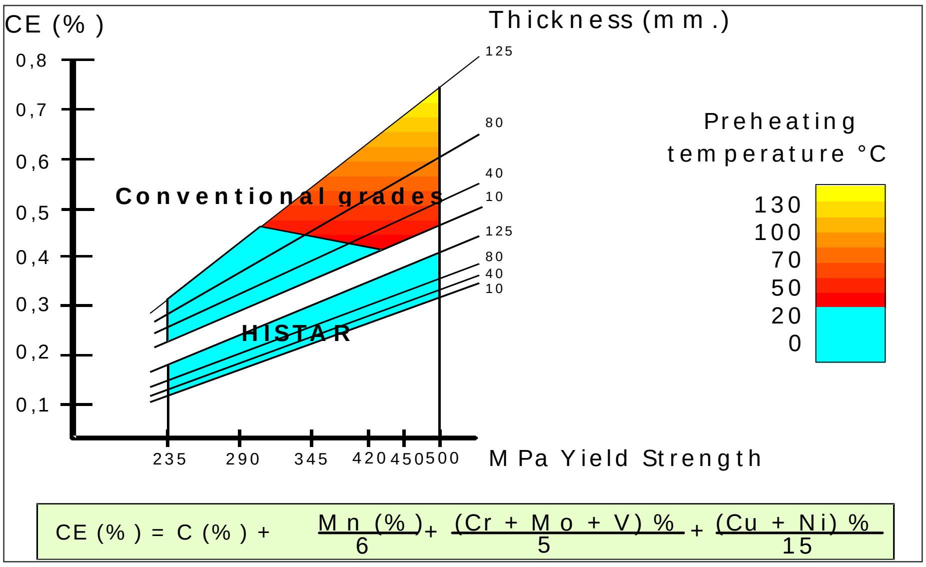

Figure 4. Weldability of HISTAR and conventional structural steel grades

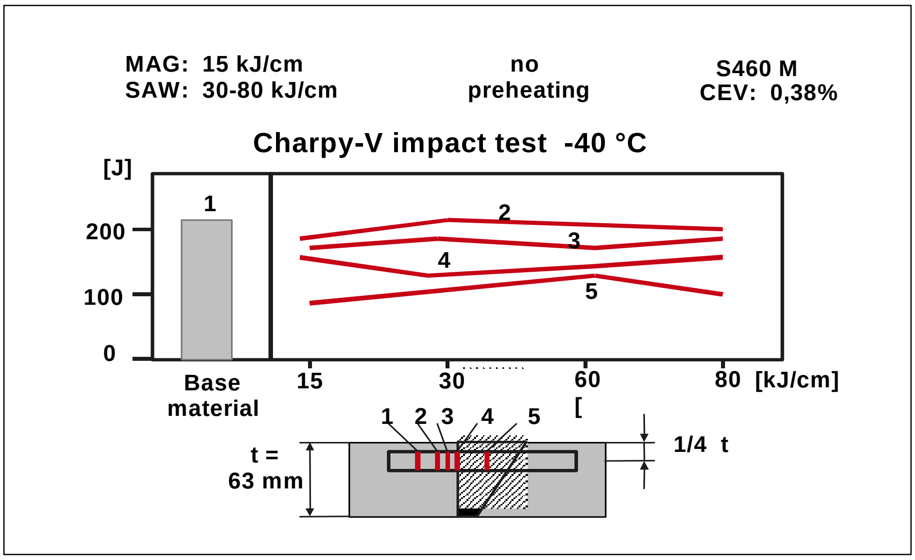

Figure 5. Toughness measured in the weld material and the heat affected zone of an H-beam in steel grade HISTAR 460 (gr 65)

In the USA, after the Northridge earthquake in California, the task group revising the existing standards on earthquake design recommends for base metal minimum toughness requirements of 20J at 21°C (70°F) for enclosed structures and 20J at 4°C (40°F) for exposed structures. This is the reason why QST grade 65 /ASTM A913 (HISTAR 460) is the only steel with a yield higher than 345 MPa (50 ksi) that can be used in California for the columns of moment resisting frames. This steel is used in order to achieve the 'strong column – weak beam' concept, which is the most economical way to design framed structures in seismic zones.

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Ductility

Bend test on HISTAR samples typically show no cracks in the steel after bending at 180°. This feature proves that QST steels have outstanding ductility which is a big advantage for seismic applications or any other applications requesting bending in the beams. Similar bend tests have also been performed after welding without preheating with different welding procedures and different heat inputs. In all cases, the conclusion is that welding does not affect the ductility of QST steels.

ADVANTAGES AND SAVINGS FOR TYPICAL HISTAR APPLICATIONS

When used as columns in buildings, for girders or as tension members in trusses, the new generation of HISTAR beams enables substantial savings in:

- structural weight,
- foundation costs,
- material costs,
- weld/fabrication costs,
- transportation and erection costs.

Typically, the extra cost for HISTAR 460 compared to grade S355 steel is only about 5%. In case full advantage can be taken from the higher yield strength, a HISTAR 460 beam is ~25% lighter than a comparable section in S355 so that the economical advantage on the material side alone is about 20%. The savings are even higher in case HISTAR 460 can be used instead of S235.

HISTAR steels should be used instead of conventional structural steels every time that the welding procedure requires preheating. For the same material cost, the steel fabricator can save the time and propane needed for the preheating of normal steels.

HISTAR application in high-rise buildings

When the design is not governed by drift or vibration problems, the use of high strength steel in gravity columns with normal buckling lengths (typically less than 5m or 16ft) allows the engineer to reduce the weight and the cost of the steel structure. Indeed, the use of HISTAR 460 results in weight reduction of the columns in average of 15-25 % when compared to S355 and of more than 45 % when compared to S235 steel columns. Because of the small extra of HISTAR 460, the steel fabricator can achieve substantial savings. Typically, the gravity columns of buildings featuring a concrete core which takes all the lateral loads can easily be designed with HISTAR 460 (Figure 6).

HISTAR application in long span trusses

For trusses, the use of HISTAR 460 is ideal in tension members such as the bottom chords and in compression members with short buckling length such as the top chords. The use of HISTAR 460 generally allows a weight reduction exceeding 15 % when compared to a solution using S355 grade (Figure 7). This reduction in weight is a function of the truss span and the importance of the dead loads. As an example, the weight savings for the 108m (355 ft) long span truss of the Boeing hangar in Seattle were about 35% when compared to a grade S355 solution. Besides, the use of HISTAR steels allows the fabricator to weld with low hydrogen electrodes without preheating.

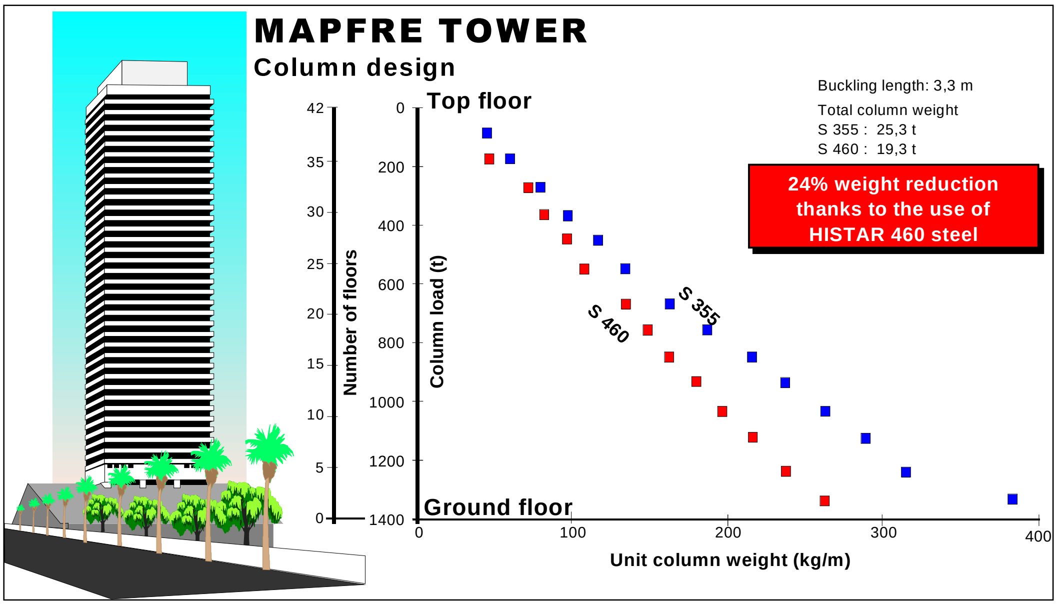


Figure 6. Weight savings in gravity columns through the use of HISTAR 460 steel grade

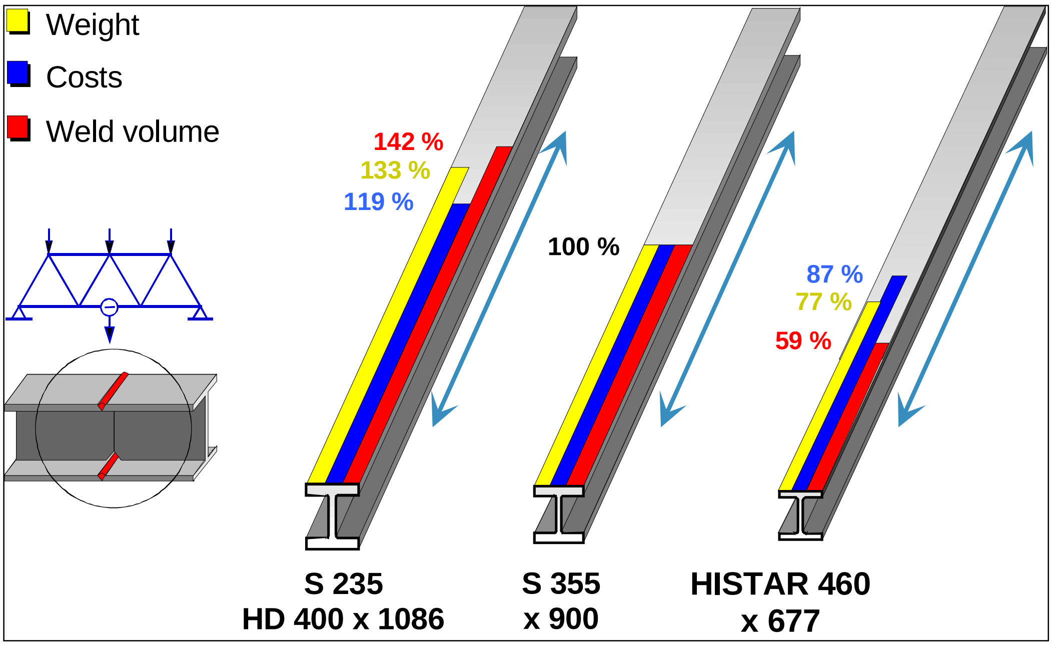


Figure 7. Cost savings in trusses through the use of HISTAR 460 steel grade

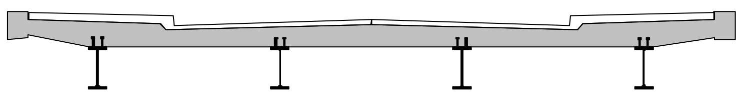
HISTAR application in bridge construction

Typically bridge structures carry heavy, dynamic and cyclic loads over long spans and during a long life. Safety and durability criteria result in stringent requirements for material quality. Therefore the achievements in material properties enabled by the QST process generates substantial benefits for bridge construction.

As a result of designing structural elements in high strength steel, the size of the cross section and especially the material thickness are reduced. Figure 8 shows the steel girder specification of comparative design in different steel grades for a typical small span composite bridge. In this case, the weight reduction from the use of S460 instead of S355 is as high as 25% and the material cost saving is 21%.

Beyond material cost advantage, the weight reduction eases transport and erection. Also, lower permanent loads need lower foundation bearing capacity. This fact is essential in the case of reconstruction of bridge decks on existing piers and abutments. Dead weight of movable bridges governs design of mechanical parts and high strength steel allows cost saving which exceed by far the material cost advantage.

Reduced material thickness is a great advantage in case of welded splices. Especially for highly stressed parts, weld volume reduction of butt splices is spectacular: 40% to 60% (V and double V full penetration).



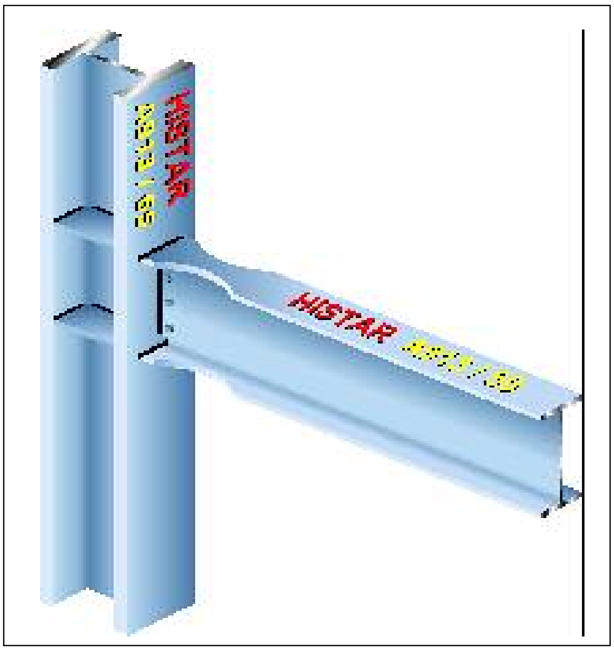
Steel grade	S235	S355	S460	S460
Section	HE 1000 M	HE 700 M	HE 800 A	HE 700 B
Construction depth (m)	1,38	1,09	1,17	1,08
Steel weight	+16%	reference	-25%	-20%
Material cost (beams)	+7%	reference	-21%	-17%

Figure 8. Comparative design of a 17m-span road bridge

HISTAR application in seismic areas

The use of HISTAR 460 and HISTAR 355 allows the engineer to design moment frame structures with the economical ‘strong column – weak beam’ concept which is commonly used on the West Coast of the United States. Only the use of this type of steel with yield higher than 355 MPa is allowed in the columns of moment frame structures located in a seismic zone. In addition, our company’s development of the so-called dog bone or reduced beam section (RBS), which consists in cutting a portion of the top and bottom flange of the beam, achieves a fuse in the structure

(Figure 9). During an earthquake, this special connection between the frame beams and columns absorbs substantial energy and provides major contributions to the displacement ductility demand with the creation of a simple plastic hinge. RBS moment frame connections are designed so that no plastification can occur in the column or in the connection. Many tests have been performed with good success and up till now, fabrication costs of this execution are considered the lowest when compared to other systems.



Figue 9. ‘Strong column-weak beam’ layout in combination with the ‘reduced beam section’ for seismic design

HISTAR application in offshore structures

HISTAR Offshore steel grades have been especially developed for offshore applications. In addition to their potential for the design of light offshore structures, they offer improved deformation properties in through-thickness direction with respect to the resistance of lamelar tearing as well as notch impact properties in transverse direction (Table 2).

CONCLUSIONS

Structural steel is considered nowadays an economical building material. In addition, new high performance steels such as the quenched and self-tempered HISTAR grades have recently been made available in the market. These steels offer a combination of properties that was impossible to achieve a decade ago:

- high minimum yield point up to 460 MPa (65 ksi) for heavy hot-rolled sections with a flange thickness up to 125mm (5 in),
- outstanding toughness up to –50°C (-58°F)
- low carbon equivalent resulting in improved weldability without loss of ductility.

Cost savings, resulting from weight reduction as well as ease of fabrication and erection, made the HISTAR high strength steels an immediate success in typical applications such as heavily loaded columns, truss members or bridge structures.

The use of these high strength steels within structural concepts such as the 'strong column–weak beam', and combined with the reduced beam section, offer additional reliable solutions for seismic design.

The favorable combination of high strength, high toughness at low temperatures and easy weldability also make these new steel grades very suitable for offshore applications.

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