



# CISC

## Guide for Specifying Architecturally Exposed Structural Steel



cisc icca

by Terri Meyer Boake



**CISC**  
**Guide for Specifying**  
**Architecturally Exposed**  
**Structural Steel**

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Front cover images courtesy Terri Meyer Boake

# **CISC Guide for Specifying Architecturally Exposed Structural Steel**

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Canadian Institute of Steel Construction



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## Acknowledgements

This publication would not have been possible without the input of many dedicated people in the steel industry. The CISC AESS Committee members from across Canada put many long hours into sharing their knowledge in order to help create a useful tool for designing, specifying or creating Architecturally Exposed Structural Steel.

Particular thanks go to Sylvie Boulanger for her assistance in working through the details of this publication, and to Walter Koppelaar for his encouragement and sharing his knowledge of the industry and its inner workings.

It is sincerely hoped that this guide will assist in leveraging the position and ease of use of Architecturally Exposed Structural Steel in the Canadian construction industry.

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### **Disclaimer:**

It is not the intention of the CISC AESS Committee that the projects and details included in this Guide should be replicated or necessarily represent “best practices”. They are included only to allow for a better understanding of the visual intentions of the practices and procedures outlined in the Guide and related specification documents, with the understanding that “a picture might be worth a thousand words”.

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# Foreword

The Canadian Institute of Steel Construction is a national industry organization representing the structural steel, open-web steel joist and steel plate fabricating industries in Canada. Formed in 1930 and granted a Federal charter in 1942, the CISC functions as a nonprofit organization promoting the efficient and economic use of fabricated steel in construction.

As a member of the Canadian Steel Construction Council, the Institute has a general interest in all uses of steel in construction. CISC works in close cooperation with the Steel Structures Education Foundation (SSEF) to develop educational courses and programmes related to the design and construction of steel structures. The CISC supports and actively participates in the work of the Standards Council of Canada, the Canadian Standards Association, the Canadian Commission on Building and Fire Codes and numerous other organizations, in Canada and other countries, involved in research work and the preparation of codes and standards.

Preparation of engineering plans is not a function of the CISC. The Institute does provide technical information through its professional engineering staff, through the preparation and dissemination of publications, and through the medium of seminars, courses, meetings, video tapes, and computer programs. Architects, engineers and others interested in steel construction are encouraged to make use of CISC information services.

This publication has been prepared and published by the Canadian Institute of Steel Construction. It is an important part of a continuing effort to provide current, practical information to assist educators, designers, fabricators, and others interested in the use of steel in construction.

Although no effort has been spared in an attempt to ensure that all data in this book is factual and that the numerical values are accurate to a degree consistent with current structural design practice, the Canadian Institute of Steel Construction and the author do not assume responsibility for errors or oversights resulting from the use of the information contained herein. Anyone making use of the contents of this book assumes all liability arising from such use. All suggestions for improvement of this publication will receive full consideration for future printings.

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# 1 The Challenge

## What Is AESS?

Architecturally Exposed Structural Steel (AESS) is steel that is designed for structural sufficiency to meet the primary needs of the building, canopies or ancillary structures, while at the same time remaining exposed to view. It is therefore a significant part of the architectural language of the building. The design, detailing and finish requirements of AESS will typically exceed that of standard structural steel normally concealed by other finishes.

## Why a Guide for AESS?

This Guide was developed to facilitate better communication among architects, engineers and fabricators. It was felt that visual references would help all parties understand the intent of the new AESS documents as applied to the design of structures.

The Guide serves as a companion to two other AESS documents: the Sample AESS Section in the Structural Steel Specification and the CISC Code of Standard Practice including the Category Matrix.

## For Whom Is It Intended?

This Guide was created primarily for architects but is also intended for all design professionals interested in AESS applications. In terms of the relationship between the new AESS documents and specific areas of practice, engineers have the Specification, fabricators have the Code, architects have the Guide, and all are linked by the Matrix of Categories and Characteristics. The Matrix sits at the centre of the suite and provides the connection that links all of the documents.

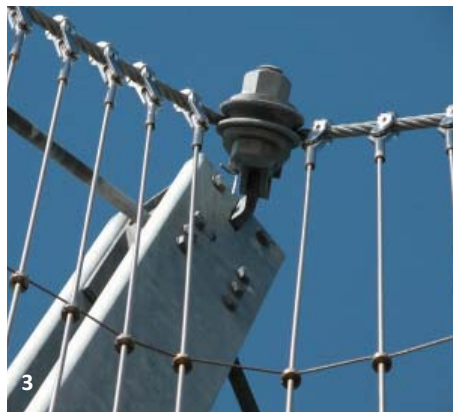
## Purpose of the Guide

The factors of influence were worked into the Categories (described in Section 2) and Characteristics (Section 3) as defined in the new AESS documents. It was felt that, in order for users of the new specification documents to understand more fully the Categories and Characteristics, an illustrated document was required. This Guide has been written to explain in detail the suite of CISC documents for the specification of AESS material. It provides visual references to help better understand the terms of reference. The buildings and connections included in this document are meant to be representative and to provide clear visual references supporting the key facts explained in the Guide. It is also hoped that the range of projects illustrated will inspire you by highlighting the wide range of possibilities available when designing with Architecturally Exposed Structural Steel.

It is not the intention of the Committee that the details included herein should be replicated or necessarily represent “best practices”. They are presented to allow a better understanding of the visual intentions of practices and procedures outlined in the Guide and related specification documents, with the understanding that “a picture might be worth a thousand words”. In addition, the projects and details are intended to help architects select appropriate Categories of AESS which range from AESS1 through AESS4 (see Section 2).

## Evolution of Architecturally Exposed Structural Steel

The basic understanding of steel construction lies in its roots as an assembled, largely prefabricated methodology. Steel construction is “elemental” in nature and its artistry reliant not only on the appropriate choice of members (shapes versus tubes), but also on the method of attachment. AESS steel design requires detailing that can approach industrial design standards when creating joints between members. The structural requirements of shear and moment resistance must be accommodated, along with tighter dimensional tolerances and other considerations such as balance, form, symmetry and economy. If the creation of connections requires an excessive degree of unique fabrication details, the designer can price the project out of existence. The method of preparing and finishing the connections can also radically increase costs. Specialized welds and unnecessary ground and filled finishes increase fabrication and erection expenses.



Much of the architectural enjoyment as well as the challenge of designing with AESS lies in the creation of key details and connections that give the structure its distinctive character. After the primary choice of member type and system (shape vs. tube), the challenge consists in determining the method of connection – welding vs. bolting, and ultimately designing the joint itself. Whereas designers tend not to be involved in connection issues for concealed structural systems, exposed systems become the architectural trademark of the building, hence requiring much involvement. Compositional issues usually necessitate the addition of extra steel at the joints to create a beautiful connection. Unfortunately not all designers are adequately informed regarding either the choice of appropriate methods of attachment or the cost implications of their choices.

The surge in the use of AESS has created a paradigm shift in the sequential communication that usually takes place in a more conventional building where the steel structure is hidden. The architect now wants direct access to the fabricator's shop to verify and comment on the edges and surfaces of the imagined product, and the engineer is dealing with aesthetic aspects that impact the structural integrity of the frame. That leaves the fabricator and the erector somewhere in the middle between aesthetic and technical requirements.

The paradigm shift centers on the simple fact that a “nice-looking connection” or a “smooth surface” has very different meanings whether you are talking to an architect, an engineer or a fabricator. Such a situation creates a misalignment of expectations in terms of what can be accomplished within specific budget limitations. Welds that are contoured and blended are not the same price as ASTM A325 hexagonal bolts, for example.



The Sainsbury Centre for the Performing Arts was designed and constructed by Norman Foster in 1977. The British High Tech movement brought exposed structural steel to the forefront of design, and with it an array of issues that had not been part of architectural discourse for more than a century. The project used round HSS members and a structure that was expressed on both the exterior and interior of the building.

## BACKGROUND

By 2003, AISC had produced its AESS Guide. During the same period, concerns about AESS were also emerging in several regions of Canada. Regional CISC initiatives eventually culminated in the national CISC Ad Hoc Committee on AESS in 2005. The idea was to create a dynamic industry dialogue including architects and engineers, in the hope of providing a series of documents that would assist in re-visioning the design, specification, and construction process for AESS.

In the following two years, CISC adapted components of what AISC had developed and also introduced an underlining Category approach and reduced its scope. The committee elaborated a Sample Specification (for engineers), an addition to the CISC Code of Standard Practice (for fabricators) and a Guide (for architects). Common to all these documents was a unique Matrix of Categories and Characteristics used by all.

In parallel, several roundtables were held in Montreal, Toronto and Vancouver, which typically involved architects, engineers and fabricators. Those sessions helped shape the orientation and direction of the Committee's work on the documents.

## Development of the New CISC AESS Documents

It was felt that the normal specification used for structural steel was incomplete when it came to serving the special needs of AESS. Therefore, CISC formed a national Ad Hoc Committee on AESS (*see Special Acknowledgments at the end of the document*) and focused on differentiating Categories because it became clear that not all AESS need be created equal(ly expensive). For example, viewing distances, coating thicknesses and connection types should matter, as they all impact the nature of the finish and detail required in exposed steel. The Committee established a set of Categories to define the nature of finish and tolerance in the steel. The Categories are further defined by a set of technical Characteristics. To facilitate communication among architects, engineers and fabricators, Categories and their associated Characteristics are presented in a Matrix to provide an easy graphic reference. In total, three AESS documents reference the Matrix: a Sample Specification, an addition to the CISC Code of Standard Practice and this Guide.

## Primary Factors of Influence That Define AESS

The Canada-wide discussion groups held by the CISC Ad Hoc Committee on AESS determined that there were primary factors giving rise to the differentiated Categories of AESS:

- **Connections mostly bolted or welded**  
(different aesthetics requiring differing levels of finish)
- **Tolerances required at fabrication and erection**  
(different as a function of scope and complexity)
- **Access to detail to perform required finish**  
(greater concern for workmanship may mean altering the detail or its location to allow access for different types of tools)



In its article on Architecturally Exposed Structural Steel Construction in Modern Steel Construction (May 2003), AISC cited the roots of the current trend of exposed steel and transparency in design to the Chicago O'Hare United Airlines Terminal designed by Helmut Jahn between 1985 and 1988. Indeed, airport architecture has succeeded in pushing the use of exposed steel to incredible heights.

- **Degree of expression**  
(complexity of structure and connections)
- **Size and shape of structural elements**  
(W sections and HSS have different detailing requirements and their use infers a different approach to detailing and finish)
- **Interior or exterior setting**  
(weathering issues, need to fire protect, potential for impact damage)
- **Paint finish, corrosion resistance, fire protection**  
(depending on the relative thickness of the finish material, more or less care may be required when preparing the surface, edges and welding of the steel)

## Form, Fit and Finish

The primary factors of influence can be further summarized as Form, Fit and Finish. Unlike standard structural steel that is hidden from view, Architecturally Exposed Structural Steel is a key element of the expression of the Architectural Design. A large amount of emphasis is placed on the Form of the steel in the design. The overall Form may vary greatly from regular framing and might often include curves, unusual angles or three-dimensional elements. Members and connections are designed with more attention to the way in which their details support the aesthetic intentions of the design. Bolted or welded connections may be chosen less for their structural capabilities or ease of erection than for their appearance within the overall intention and form of the design. This does not mean that their structural integrity is not a key consideration in the success of the design.

Highly articulated steel structures are by their nature more difficult to Fit. There is significantly less play in the connections, and accumulated errors can result in overall misalignment. This need to ensure accuracy, ease of fabrication, as well as bottom line constructability, puts greater pressure on the details and requires narrower tolerances throughout the entire project. Tighter tolerances will carry through when the exposed steel framing must coordinate with other trades, in particular areas of significant glazing and curtain wall. The use of stainless steel spider con-



Specialty glazing systems require tighter tolerances and a higher level of Fit on a project.



Composite structural systems require higher levels of coordination. The tolerances and construction practices of the other material must be taken into account.

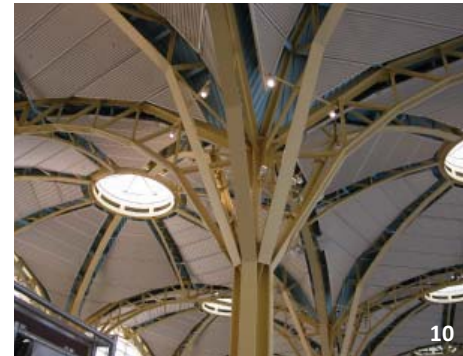
nections for structural glass systems puts additional pressure on allowable tolerances. If exposed steel is used with heavy timber or glulam systems, then the fit must also take into account the differential movements and erection idiosyncrasies of these other materials.

While the Finish might be the last phase of construction, *the selection of the Finish must take place at the beginning of the AEES design process*. Finishes will vary in exposed steel both as a function of the design intention and issues relating to weathering, interior or exterior exposure and fire protection. A high-gloss finish will reveal every imperfection and so will require more fastidious fabrication. A thicker intumescent coating will conceal many surface imperfections. Galvanizing itself has issues with consistency of finish, and its selection may accompany a less polished selection of details. The bottom line for the contract is that both time and money will be wasted if the level of fabrication care greatly exceeds the nature of the Finish.

## Exceptions

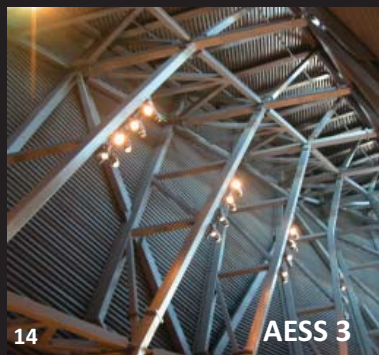
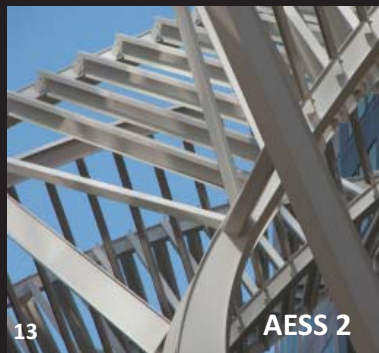
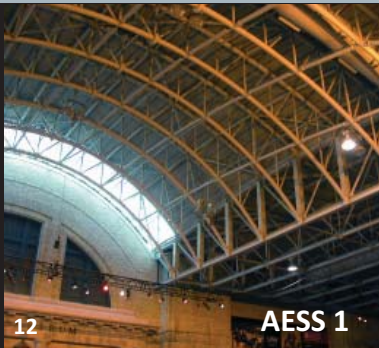
Form, Fit and Finish considerations will differ on projects whose intentions might fall outside of traditional Architecturally Exposed Structural Steel. Steel is often selected as the material of choice for large art installations. Here there needs to be a customized variation of the considerations presented in this Guide which form the basis of dialogue for the team. Where some artists might be looking for a very plastic appearance, others may wish to let the rough nature of the steel reveal itself.

Reused steel also requires a different set of considerations. Many projects seek to incorporate reused or salvaged steel for its sustainable qualities. In some instances the steel may be cleaned, but in others left with its original finish so that it can express its reuse. This type of application also demands a variation of the general intentions presented in this Guide.



Two different steel trees: one created using W shapes to create a very textured appearance; the other using mechanical pipe and specialty casting and striving for a seamless appearance using a high gloss finish. AEES specifications must be tailored to the overall design intentions of each individual project as they are all somewhat unique.





## THE CISC CATEGORY MATRIX FOR SPECIFYING ARCHITECTURALLY EXPOSED STRUCTURAL STEEL (AESS)

Table 1 - AESS Category Matrix				
Category		AESS C	AESS 4	AESS 3
		Custom Elements	Showcase Elements	Feature Elements
Id	Characteristics			Viewed at a Distance $\leq 6$ m
1.1	Surface preparation to SSPC-SP 6		✓	✓
1.2	Sharp edges ground smooth		✓	✓
1.3	Continuous weld appearance		✓	✓
1.4	Standard structural bolts		✓	✓
1.5	Weld spatters removed		✓	✓
2.1	Visual Samples		optional	optional
2.2	One-half standard fabrication tolerances		✓	✓
2.3	Fabrication marks not apparent		✓	✓
2.4	Welds uniform and smooth		✓	✓
3.1	Mill marks removed		✓	✓
3.2	Butt and plug welds ground smooth and filled		✓	✓
3.3	HSS weld seam oriented for reduced visibility		✓	✓
3.4	Cross sectional abutting surface aligned		✓	✓
3.5	Joint gap tolerances minimized		✓	✓
3.6	All welded connections		optional	optional
4.1	HSS seam not apparent		✓	
4.2	Welds contoured and blended		✓	
4.3	Surfaces filled and sanded		✓	
4.4	Weld show-through minimized		✓	
C.1				
C.2				
C.3				
C.4				
C.5				
Sample Use:		Elements with special requirements	Showcase or dominant elements	Airports, shopping centres, hospitals, lobbies
Estimated Cost Premium:		Low to High (20-250%)	High (100-250%)	Moderate (60-150%)



# 2 Categories

## THE CATEGORIES APPROACH

In the new AESS set of Specification documents, five Categories have been created that characterize five unique levels of finish related to AESS. These Categories reflect the primary factors of influence, form, fit and finish, and for the purpose of the Matrix, have been reduced to three main areas of concern:

- the viewing distance (greater or less than 6 metres)
- the type or function of the building (as this infers potential design requirements for finish)
- a range of percentage of potential cost increase over standard structural steel.

**Viewing Distance:** Six metres was chosen as a base dimension, as it began to differentiate whether an occupant would be able to scrutinize the finish from a close range and even touch the product. Six metres represents a normal height of a high ceiling. The ability to see the structure from a close range can impact the required level of workmanship of the finished product. It makes little sense to grind welds, for instance, on a structure many metres out of eyeshot. When designing atrium spaces, it is also important to use this measurement in the horizontal direction, as the view across a space is as critical as the view upward. In certain instances, this might also include the view down onto the structure. Where steel is viewed from above, care must be taken to detail the steel to avoid the buildup of grime and trash. Viewing distance can also impact the requirements of the surface finish on the steel members, as some natural blemishes in the steel from manufacturing, fabrication or mill processes will not be able to be seen at a distance. There are cost savings if such is recognized prior to specifying the steel.

**Type or Function of the Building:** The exposed steel over an ice rink and the exposed steel in an airport are likely to have different aesthetic and finish requirements. There are a range of degrees of finish between these two building types that are recognized in this document. It is also suggested that the program of the building and the range of spaces within a project be examined to assess whether there are in fact a number of types of AESS that need to be specified. The exposed roof trusses may be AESS 1, and the columns or base details may be AESS 3. If this is clearly marked on the contract drawings, then the fabricator can adjust the bid according to the appropriate level of finish.

**Range of Potential Cost Increase:** The percentage values noted on the matrix suggest a range of increase in the cost to fabricate and erect the AESS Categories over the cost to fabricate and erect standard structural steel. Additional time is involved in the fabrication processes associated with the specific characteristics of the higher levels of AESS. The erection costs will also increase as a function of the complexity of the steel, the degree to which this complex steel can be fabricated in the shop, transportation, access and staging area concerns, and increased tolerance requirements to fit the steel. The more complex the AESS and the higher the nature of the finish requirements, the tighter the tolerances become. This increases the time to erect the steel. For these reasons the range of increase is fairly wide. It is strongly suggested that, once the type of AESS has been selected and the Matrix completed, these documents be used as a point of communication and negotiation among the design and construction team.

Baselines have been established that characterize each of the five AESS Categories. A set of Characteristics has been developed that is associated with each Category. These are explained in detail under Section 3 Characteristics. Higher-level Categories include all of the Characteristics of the preceding Categories, plus a more stringent set of additional requirements. Each Category as illustrated within this Guide will be shown to be able to reference recognizable building types as a point of visual orientation.

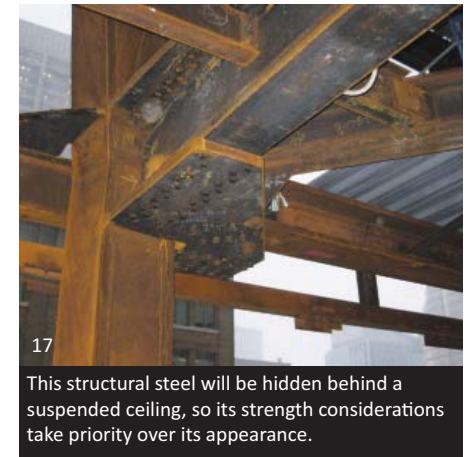
It is recognized that a wide range of AESS buildings is already in existence. The examples chosen to illustrate the points in this Guide are not meant to be either definitive or exhaustive, but to create a visual reference to assist in understanding both the intent of the AESS Categories as well as the nature of the finish and workmanship inferred by the Characteristics listed in the next section.

**Multiple Types of AESS, Same Project:** Different types of AESS can be in use on the same project. The choice of AESS category will vary according to the use of the space, viewing distance and types of members. The type of AESS will simply need to be marked clearly on the contract documents.

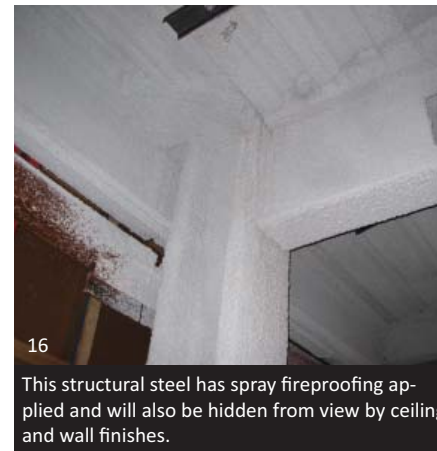
### Standard Structural Steel (SSS)

*The initial point of technical reference is Standard Structural Steel (SSS) as defined in CSA S16, as it is already established and well understood as a baseline in construction Specifications.*

Understanding the Categories of Architecturally Exposed Structural Steel begins by differentiating structural steel in terms of its degree of exposure. It is assumed that regular structural steel is either normally concealed for reasons of finish preference or for reasons of fire protection. The structural integrity of Standard Structural Steel is



17 This structural steel will be hidden behind a suspended ceiling, so its strength considerations take priority over its appearance.



16 This structural steel has spray fireproofing applied and will also be hidden from view by ceiling and wall finishes.

clearly the overriding concern of this material. In normal circumstances, because it will be either clad and/or fire protected, there is little or no architectural concern over the design of the details, connections and even necessarily the type of members chosen. Although some applications will be more complicated than others, and hence priced accordingly, this steel is not subject to the same considerations as an exposed product.

Architecturally Exposed Structural Steel will follow all of the same structural requirements as set out within CSA S16, and be subject to additional



requirements as defined by the assigned AESS Category (1, 2, 3, 4 or Custom) and the specific set of Characteristics associated with each AESS Category. In Architecturally Exposed Structural Steel, the steel, its materiality and method of connections are “expressed” and form a key part of the architectural design of the building or project.

**AESS 1 – Basic Elements** is the first step above Standard Structural Steel. This type of application would be suitable for “basic” elements, which require enhanced workmanship. This type of exposed structure could be found in roof trusses for arenas, warehouses, big box stores and canopies and should only require a low cost premium in the range of 20% to 60% due to its relatively large viewing distance as well as the lower profile nature of the architectural spaces in which it is used.

AESS 1 applications will see the use of fairly straightforward section types such as W, HSS, and often OWSJ and exposed profiled decking. Generally this type of framing might appear similar to basic structural steel applications, other than the fact that it is left exposed to view. And because it is left exposed to view, more care is required to ensure that the standard structural members are aligned in a uniform way, that spacing is kept consistent, and that the surfaces of the members are properly prepared to accept uniform finishes and coatings. A greater level of consistency in the use of connections, bolts, and welds is also required.

These types of applications may or may not require special fire protection design. This is determined as a function of the use of the space. In some situations the steel may be left completely unprotected or sprinklered, and so it will need to receive only a paint finish. Intumescent coatings could be found where the rating would be one hour or greater; however, this might not be a common choice due to the cost of the coating system. The detailing on AESS 1 elements should not be greatly impacted by the relative thickness or finish of the intumescent coating, as much of this type of steel will be located well above eye level and out of range of touch.

As it is anticipated that many AESS projects will specify more than one Category of steel, it will be common to specify AESS 1 for the ceiling elements of a design, where the distance to view is in the 6 m or greater range, and use a different class of AESS for those elements, like columns, that are located at a closer proximity.



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**Semiahmoo Library, Surrey, B.C.:** The project uses a very simple exposed structure comprised of W sections and OWSJ with a painted finish. Some extra care is necessary, in keeping with the library use of the facility, in the preparation and installation of the structure. The W sections are exposed to view and touch, but overall the ceiling elements are viewed at a distance. Had this project used custom trusses instead of OWSJ members, it would likely have fallen into AESS 2 Category Steel. In the case of the library, the steel has been left exposed to save on the use of finish material, which has helped in achieving credits towards a LEED Silver Rating. (lower cost premium with standard joists)

Alternatively, some specialty custom-designed steel may be specified but would be located at a distant view, so that the fabrication, finish of the steel and workmanship would not come under close scrutiny. Some of these specialty fabrications will be similar to those used in AESS 2, with the distance factor being the major point of separation.

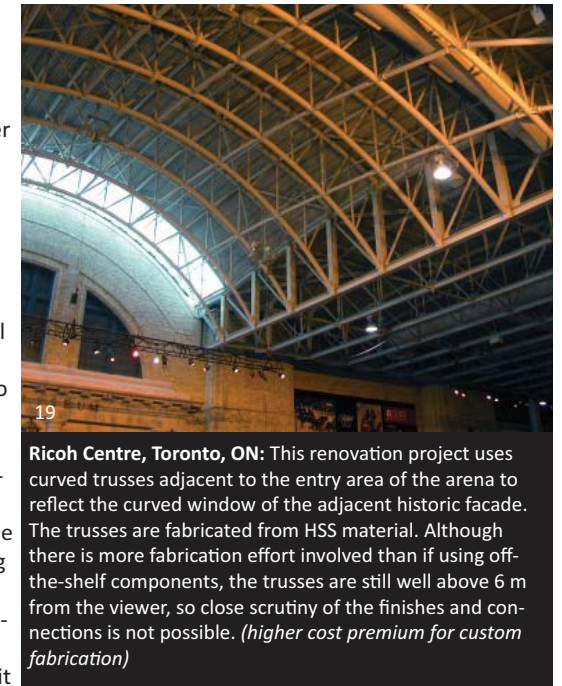
Another factor that will impact the decision to ask for AESS 1 versus AESS 2 steel for an exposed ceiling will be the nature of the lighting. In the case of Semiahmoo Library, the light level on the ceiling is high, and the ceiling height at the low range for this category. In the Ricoh Centre, the steel is more articulated using curved shapes and HSS members, but the ceiling is extremely high, and the lighting levels in the low range and additionally using a type of lighting that tends to conceal detail. If the curved steel trusses of the Ricoh Centre were to be brightly uplit with a more blue-white type of light that could accentuate the detail, this structure might need to fall into a higher Category.

Also important to consider when specifying AESS 1 for the ceiling will be the nature of the other elements and systems that will be incorporated into the ceiling plane. Is it “busy” with mechanical services? Do these need to run parallel or perpendicular to the main structural lines of the trusses or joists? Are the services to be painted out or accentuated? Typically you will see sprinkler runs and HVAC equipment integrated into most AESS 1 type ceilings. In the case of retail (big box) stores, you might also see a high level of signage that will serve to take the focus away from the steel systems and therefore allow for a lower level of finish and detailing.



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**Ricoh Centre, Toronto, ON:** Although the trusses that span the arena proper in the Ricoh Centre are somewhat closer to view, they fall into AESS 1 given their more roughly detailed design style as well as the less refined nature of the space. (low cost premium through the use of standard sections and connections that are removed from view)



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**Ricoh Centre, Toronto, ON:** This renovation project uses curved trusses adjacent to the entry area of the arena to reflect the curved window of the adjacent historic facade. The trusses are fabricated from HSS material. Although there is more fabrication effort involved than if using off-the-shelf components, the trusses are still well above 6 m from the viewer, so close scrutiny of the finishes and connections is not possible. (higher cost premium for custom fabrication)

Depending on the environment (moisture level in the case of rinks and chemicals in the case of swimming pools, industrial plants, etc.) this type of steel may need special coating treatment to prevent corrosion. This will impact the overall cost of the installation.



**AESS 2 – Feature Elements** includes structure that is intended to be **viewed at a distance > 6 m**. It is suitable for “feature” elements that will be viewed at a distance greater than six metres. The process requires basically good fabrication practices with enhanced treatment of welds, connection and fabrication details, tolerances for gaps, and copes. This type of AESS might be found in retail and architectural applications where a low to moderate cost premium in the range of 40% to 100% over the cost of Standard Structural Steel would be expected.

AESS 2 will generally be found in buildings where the expressed structure forms an important, integral part of the architectural design intent. The defining parameter of viewing distance greater than 6 metres will infer that you might find this sort of steel in high-level roof or ceiling applications. For this reason you might be specifying AESS 2 steel for the distant components of the structure and a higher grade of AESS for the low-level elements of the structure. These should be clearly marked on the drawing sets so that the treatments can be differentiated and the respective cost premiums separated out.

It will be more common to see W or HSS members specified for this category, rather than more industrial members such as OWSJ. This type of application may use a combination of bolted or welded connections. As the viewing distance is great, there is normally less concern about concealing the connection aspects of larger pieces to each other – hence no hidden connections.



**21 National Works, Vancouver B.C.:** The project uses a more articulated steel design, predominantly with W-sections. Much of the structure is located at ceiling height, so at a distance for viewing and therefore allowing for a lower level of detailing and fine finish. This structure interacts with wood, which will change aspects of its detailing and coordination during erection.



**22 National Trade Centre, Toronto, ON:** The project makes use of relatively standard steel sections, but the design and fabrication employ a higher standard in terms of arrangement and detailing. There is some section bending required which increases fabrication costs and can impact detailing. Much of the structure is still located in excess of 6 metres above view.

In the case of the National Works Yard, the use of exposed steel has reduced finishes and helped in achieving a LEED™ Gold rating. The predominant section choice is a W-shape, and the detailing has been kept fairly standard. The specialty details that support the roof structure and the Parallam wood beams remove the details from close scrutiny. The primary connection choice to join major sections is bolting; however, the elements themselves have been shop-welded prior to shipping. Although the steel can be viewed more closely from the upper floor level, a decision was made to maintain the tectonic of the W-sections and bolted connections consistent, given the use of the building as a

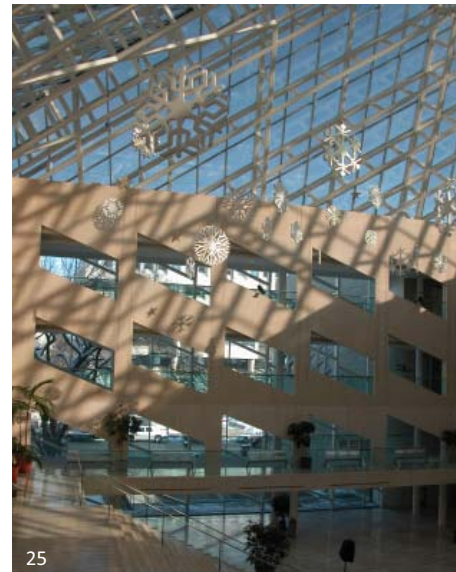


**23 Pierre Elliott Trudeau Airport, Montreal:** The trusses supporting this skylight are quite characteristic of AESS 2 type steel. The viewing distance is over 6 metres but the design needs something more than a standard joist or truss. The detailing is simple, and the viewer is not close enough to see the texture of the connection, only the form of the truss.



Works Yard Office. There are some specialty details added to the repertoire, centred around the support of the PV skylights and the wood structure.

Edmonton City Hall uses square HSS members to create a very complex high-level truss system to support a pyramidal skylight. The viewing distance has permitted a less fastidious level of fill and finish on the members, as these are not in close range of view or touch. The structure appears to use all-welded connections. For the straight-run truss elements, the square HSS sections align fairly cleanly. This becomes more difficult at the angled junctures of the roof. But given the pyra-



**25 Edmonton City Hall:** The trusses that support the pyramidal glass roof are created using square HSS sections. The viewing distance varies but is typically greater than 6 metres, even from the upper levels. An up-close inspection reveals many inconsistencies that are reasonable to leave “as is” due to the view distance. The extra expense to fill, grind and carefully align the members would be lost on users of the building.





midal shape, round HSS members were not deemed appropriate so a detailing compromise was required at the junctures, and the viewing distance made this workable.

**The cost premium for AECS 2 ranges from 40 to 100%.** There may be lower costs associated with the clean use of standard structural shapes with bolted or simple welded connections, and higher costs associated with the use of HSS shapes, complex geometries and a predominance of welded connections. As one of the common applications of AECS 2 will be for roof, skylight or ceiling support systems, the fire-protection method must be known from the outset of the project. If intumescent coatings are used, these can help to conceal any inconsistencies in surface conditions.

**AECS 3 – Feature Elements** includes structures that will be **viewed at a distance  $\leq 6m$ .** The Category would be suitable for “feature” elements where the designer is comfortable allowing the viewer to see the art of metalworking. The welds should be generally smooth but visible and some grind marks would be acceptable. Tolerances must be tighter than normal standards.



**O'Hare International Airport** in Chicago was the first airport to use AECS. Much of the steel is well within range of view and touch. A variety of steel shapes and connection types have been used. The complex nature of the sections and connections called for a tighter sizing tolerance and even finish application.

When AECS structural elements are brought into close range for view and potentially for touch, it is necessary for the team to come to a clear understanding about the level of finish that is both required and expected of the steel. The natural look of welds that would be out of view in AECS 2 steel will now be visible to the occupant in the space. Simple bolted connections may need to be designed to look more artful if they are to become part of the architectural language. Connections will come under closer scrutiny, so their design, tolerances and uniform appearance will become more important, and the workmanship required to improve these beyond both Standard Structural Steel and AECS 1 and 2 could have a significant impact on the cost of the overall structure. If the required attributes

*As this structure is normally viewed closer than six metres, it might also frequently be subject to touch by the public, therefore warranting a smoother and more uniform finish and appearance. This type of structure could be found in airports, shopping centres, hospitals or lobbies and could be expected to incur a moderate cost premium ranging from 60% to 150% over standard structural steel as a function of the complexity and level of final finish desired.*



**The Palais des Congrès** in Montreal uses specialty W sections with trimmed cutouts. Although the steel is all painted grey, and intumescent coatings are used, the coloured light through the curtain wall gives additional texture to this expression of steel.



**The Canadian War Museum** in Ottawa uses AECS to create a highly articulated and rugged expression of the steel in Regeneration Hall. In this instance a combination of welded connections and exposed plate-to-plate moment connections at the connection points between square HSS sections is the feature of the appearance. Due to the irregularity of the structure, tight tolerances are required. The profiled decking is also left exposed to view.

its smoothness and ensure that some of the natural finish on the steel and mill marks do not show through the paint.



**Ottawa International Airport:** The steel trusses and sloped column supports are within view and touch by the passengers. The geometry of the steel is complex, and the tolerances and finish requirements are characteristic of AECS 3 Feature Element type steel.

There may be more welded connections in AECS 3 steel. Where welds cannot be done in the shop, where conditions are more controlled and jigs can be used to ensure precise alignment of the components, it must be realized that large amounts of site welding of complex elements will result in cost premiums. Some site welds may not be of the same quality as can be expected of shop welds. It would be expected that the welds will be of a higher quality than those for AECS 2 structures where the welds would be out of view and touch due to their height. AECS 3 welds will be expected to have a very uniform appearance. Although some touch-up grinding of the welds may be required to ensure uniformity, complete grinding of all welds would not be included in this category of steel. It is assumed that good quality, uniform welds would be left exposed.

or characteristics of the steel are not thoughtfully considered, the AECS for the project can easily be priced higher.

The cost premium to be found in AECS 3 steel will depend greatly upon the types of members chosen, the nature of the connections, and the desire of the designer to either conceal or express the materiality of the steel itself. As can be seen later in this document under Characteristics, it is assumed that effort will be put into further surface preparation to increase



In the **Canadian War Museum** there are exposed welded and bolted connections. Square plates have been welded to the HSS members that provide surface for bolts on all sides of the connection to ensure a uniform appearance. Flat plates have been used for the lap-type hinge connections on the diagonal members, creating a degree of uniformity within the scheme.

Where bolted connections are employed, more care will be taken to ensure that there is an aesthetically based uniformity in the connections which will likely require more fabrication time and potentially more material. Simple approaches such as ensuring all bolt heads are located on uniform sides of the connections can greatly enhance the details with little extra cost. If bolted connections are required for erection ease but are visually unacceptable, concealed connections can be employed to give the appearance of a seamless or welded connection without the associated price tag. For these types of connections the attaching plates are kept within the general line of the members, so that cover plates can be attached over the bolted elements. If this is to be an exterior application, concealed connections must be made corrosion-resistant to prevent hidden rust.

Underlying AESS 3 steel is the idea that it is possible to change the appearance of the final product to make it smoother to the eye, but it is not always necessary to use more expensive fabrication techniques to arrive at this point. As will be seen under Characteristics, it is possible to use simpler methods to surface fill or provide the *appearance* of a continuous weld without actually welding.

**AESS 4 – Showcase Elements** or “dominant” elements is used where the designer intends that the form be the only feature showing in an element. All welds are ground, and filled edges are ground square and true. All surfaces are sanded and filled. Tolerances of these fabricated forms are more stringent, generally to half of standard tolerance for standard structural steel. All of the surfaces would be “glove” smooth. The cost premium of these elements would be high and could range from 100% to 250% over the cost of standard structural steel – completely as a function of the nature of the details, complexity of construction and selected finishes.

AESS 4 Showcase Elements represents the highest standard quality expectations of AESS products. The architectural applications of this category of steel included in the guide are very



**BCE Place in Toronto by Spanish Architect Santiago Calatrava** uses AESS 4 quality fabrication and finish on the lower portion of the tree supports in the Galleria space. All of the members use welded connections with a hand-smooth finish and no apparent blemishes. Given the articulation and complicated geometry, tolerances for this structure were even less than one-half standard fabrication. The “canoes” that form the support for the skylight are well above view level and use a combination of welding and bolting.

representative of the diverse nature of these projects. As can be seen, there is a wide variety of member types employed, each for their specific purpose within the structure or connection. Many of the column or spanning members have been custom-fabricated. In some cases this may be due to the very large size and structural capacity required of the member. In other cases it is due to the particular architectural style desired in the exposed structure. Many of the members tend to employ steel plate that has been custom-cut to odd geometries. Such geometries, when not based on a combination of simple circular holes and straight cuts, will increase the fabrication costs of the project.

On many of these projects the edges of the steel have been finished to be very sharp and precise. The straightness of the line of these members is a critical aspect of their fabrication that is a requirement of their architectural use.

AESS 4 makes extensive use of welding for its connections. In most cases the weld is ground smooth and any member-to-member transitions are filled and made extremely seamless in appearance. This type of finish will result in significant increases in fabrication cost, and so they are appropriate for use in this sort of high-exposure, upscale application.

Such special members often require additional care in transportation and handling, as the maximum amount of work is normally carried out in the fabrication shop to maintain the highest quality of work performed in controlled conditions and with more access to lifting equipment to position the elements for finishing operations. This type of AESS is often also painted in the fabrication shop, again to achieve the best quality finish. Protection of these members during transportation and erection is critical in order to prevent undue damage to the finish.



**Pearson International Airport in Toronto** uses a combination of AESS 4 for the columns and supports that are visible in the pedestrian areas, and Custom for the “wishbones” that form the supports for the roof trusses. The supports make use of more standardized shapes where the “wishbones” require significantly more effort on the part of the fabricator in the creation of specialty sections from plate steel.



**The Newseum in Washington, D.C. by Polshek Partnership** uses a combination of AESS 4 quality steel with some custom specialty elements in this inventive support system which forms the support and wind bracing for a large mullionless glazed wall at the front of the building. Stainless steel brackets hook on to parallel tension supports that are braced on either side of the façade by these vertical trusses fabricated from parallel sections of plate steel.

It is common in some showcase applications to see the use of stainless steel glazing support systems in conjunction with the use of AESS 4 regular carbon steel. Stainless steel is being used frequently to connect and support large glazing walls, often with quite innovative custom systems used to attach the spider connections to the steel. Such systems require even finer tolerances in order to achieve the proper fit between the structural members, glazing systems and AESS. Extra care in paint application is required to prevent overspill onto the adjacent stainless surfaces.



## AESS C – Custom

**Elements** was created to allow for a custom selection of any of the Characteristics or attributes used to define the other Categories. It will allow flexibility in the design of the steel but will therefore require a high level of communication among the architect, engineer and fabricator. The premium for this type of AESS could range from 20% to 250% over regular steel. A wide range may seem odd for “custom” elements, but the lower bound of this Category also includes specialty reused steel for sustainable purposes, and steel that might be purposefully less refined in its Characteristics.

The Custom Elements checklist in the Matrix will also allow design teams, which may have become familiar with the new AESS specification suite, to create their own checklist for a project so as to better reflect the nature of the project’s aesthetics or function. The Custom checklist also allows for the addition of extra fabrication criteria that must be agreed upon among team members and used to achieve particular or unusual finishes. This category will be suitable where specialty castings are used, as these require different handling and finishing than do standard steel sections due to their inherently different surface finish as a direct result of the casting process.



**University of Guelph Science Building Courtyard** uses special castings to cleanly join mechanical pipe and a structural tree that stands in the centre of the courtyard. The requirement for a seamless transition from the pipe to the casting required unusual welding and filling of the connection, as well as grinding of the surface of the casting so that its normal textured finish would match the surface condition of the adjacent pipe.



**Heathrow Terminal 5 in London, England by Sir Richard Rogers Architect** uses a range of AESS Category types throughout the terminal. These specialty connections use a combination of custom work for the central hinge, castings to connect the ends of the large HSS supports and truss members to the hinge, and showcase level of fabrication and finish for the legs/column supports. You need to be flying British Airways to come across this steel!

With increases in the reuse of steel for sustainably-minded projects, a unique set of criteria will come into play. Requirements will center around the presence of existing finishes, corrosion, inconsistencies between members, and whether the project needs to showcase the reuse or blend the material with new material. As some historic steel is fastened with rivets, different treatment may be required where new connections are mixed with old in order to create visual coherence.

The Custom Category will also provide the ability to create a checklist for members that may be

more sculptural in nature. In some instances the nature of the steel is intended to be a highlight of the finished project, and in other cases, the nature of the steel is to be concealed and the final product to look more “plastic” in nature. The former may require less care and the latter a higher degree of finish and workmanship than would be required even for structures in the AESS 4 range.

The use of stainless structural steel will also be addressed in this category, as this material has different specifications and particular issues that must be included to ensure a high quality of installation.



**Angus Technopole, Montreal** is a unique reuse application of a former locomotive shop as offices and commercial space. The riveted steel was left “as is”, with minimal cleaning and no repainting, to preserve the original look and feel of the building. Where new steel is required in this project, a custom specification is required in order to make it fit into the aesthetics of the old building.

**Mixed Categories** are to be expected on almost all projects. Generally no more than two categories would be expected. It will be very common to specify, based on the viewing distance, lower-level categories for roof/ceiling framing elements and higher-level categories for columns



**The Bow Encana, Calgary** uses an AESS 4 finish on the front two faces of this very large triangular section in order to achieve a very straight edge along the length of the member. As the rear face of the member will be hidden from view, it is finished as structural steel to save on fabrication costs. These members are shipped singly to prevent damage.

and sections that are nearer to view and touch. This will require that the Architect put a “cloud” note around sections or members on their contract drawings and clearly indicate the AESS Category.

It is also possible to mix categories on individual elements. This may be done for sections with a side exposed to view/touch and a side that is buried or otherwise hidden from view. In this case a high-level of finish may be required on the exposed AESS face, and a finish as low as Standard Structural Steel on the hidden face. This is of great financial benefit when finishing extremely large members. Again there should be a “cloud” drawn around the member and the specific combination of categories noted. When using the Categories to this level of detail, it is also advantageous to be sure that this is clearly and personally communicated to the fabricator prior to bidding the job. The fabricator may have some useful cost-saving suggestions which can positively impact the overall project.

# 3 Characteristics

## CHARACTERISTICS OF THE MATRIX

A set of Characteristics is associated with each Category. Higher-level Categories include all of the Characteristics of the preceding Categories, plus a more stringent set of additional requirements. The Characteristics listed below form the basis for differentiation of the AESS Categories and are listed in this order in the Matrix. It is suggested that, when using the suite of AESS documents, all of the Characteristics associated with each of the Categories be included in the contractual arrangements. For clarity, visual references in the form of steel samples (courtesy of the American Institute of Steel Construction) have been included in the ensuing descriptions. This Guide also includes visual references in the built context to assist in clarifying the intention of each bulleted point.

**AESS 1 – Basic Elements** would be the first step above Standard Structural Steel. AESS 1 fabrication and erection specifications would include Characteristics 1.1 to 1.5.

**1.1 The surface preparation of the steel must meet SSPC SP-6.** Prior to blast cleaning, any deposits of grease or oil are to be removed by solvent cleaning, SSPC SP-1.



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Fig. 1.1A Sample sheet showing the finish appearance for steel surface preparation standards. AESS starts assuming SP-6 finish. (Image courtesy of Dry-Tec)

Commercial blast cleaning is intended to remove all visible oil, grease, dust, mill scale, rust, paint, oxides, corrosion products and other foreign matter, except for spots and discolorations that are part of the natural steel material. By using this as a starting point, there should not be issues with the application of the range of finishes that would be required for AESS 1 through 4 type applications, as these are normally out of immediate eye range due to their typically high locations.

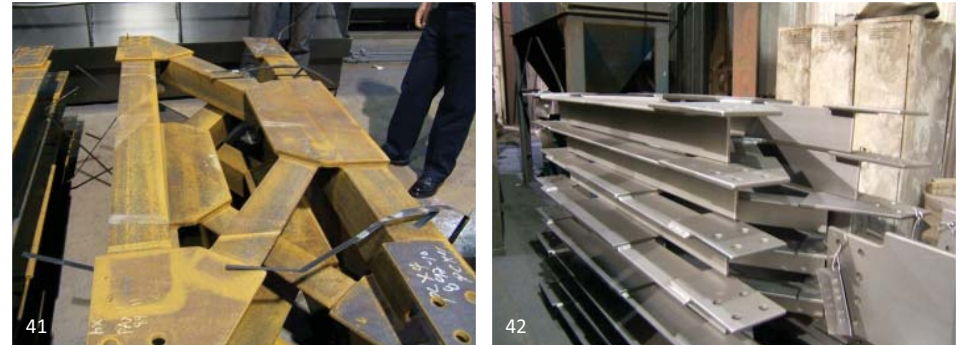


Fig. 1.1B As can be seen from the images above, shot blast cleaning can take what may appear to be rusted steel, and transform it into a product that is smooth in finish and ready to receive subsequent treatments and coatings.

It should be noted that one of the alternate surface preparation standards, SP-3, commonly used for structural steel elements, only provides for power tool type cleaning, and should not be relied upon to provide adequate cleaning for consistent-looking finishes in AESS applications.

**1.2 All of the sharp edges are to be ground smooth.** Rough surfaces are to be de-burred and ground smooth. Sharp edges resulting from flame cutting, grinding and especially shearing are to be softened.

Sharp edges, characteristic of standard structural steel, are considered unacceptable in any AESS application. Even if located out of close viewing range, as in AESS 1 type applications, this type of finish condition is not adequate in the final fabrication and installation.

**1.3 There should be a continuous weld appearance for all welds.** The emphasis here is on the word “appearance”. Intermittent welds can be made to look continuous, either with additional welding, caulking or body filler. For corrosive environments, all joints should be seal welded. The seams of hollow structural sections would be acceptable as produced.

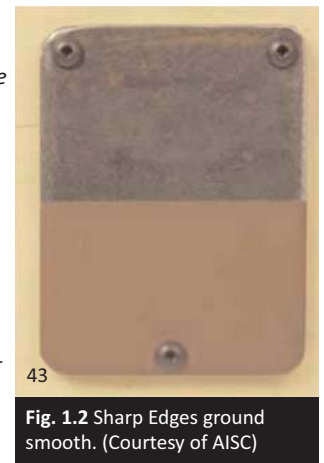


Fig. 1.2 Sharp Edges ground smooth. (Courtesy of AISC)



Fig. 1.3 Filling between the intermittent welds to give a continuous weld appearance

In many projects fabricators are often asked to create continuous welds when they are structurally unnecessary. This adds extra cost to the project and takes additional time and may create distortions. If not structurally required, the welds themselves need not be continuous. Prior to the application of the final finish, appropriate caulking or filler can be applied between the intermittent welds to complete the appearance. Filling between the intermittent welds also helps in the cleaner application of



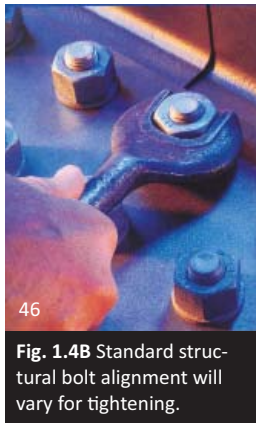
finishes and prevents the buildup of dirt in the joints which can be problematic to clean. Care should be taken in the application of fill materials so that the surfaces beneath are clean, adherence is ensured, and compounds are compatible with the type of finish application.

**1.4 It is assumed that bolted connections will use standard structural bolts.** When bolting, the heads should all be located on one side of the connection, but they need not be fastidiously aligned. There should also be consistency from connection to connection.

This characteristic requires that some additional care be given when erecting the structure. It is reasonable to expect that all of the bolt heads will be positioned on the same side of a given connection and all such connections will be treated in a similar manner, so that the look of the overall structure is consistent. It is *not* reasonable to expect bolts to be tightened with the heads identically aligned. The structural tightening of the bolts must take priority.



**Fig. 1.4A** Standard structural bolt components include the TC bolt.



**Fig. 1.4B** Standard structural bolt alignment will vary for tightening.



**Fig. 1.4C** Standard structural bolts are carefully aligned with nuts all facing the same direction.

**1.5 Weld splatters, slivers, surface discontinuities are to be removed** as these will mar the surface, and it is likely that they will show through the final coating. Weld projection up to 2 mm is acceptable for butt and plug-welded joints.



**Fig. 1.5** Natural splatter due to the weld process is to be removed.

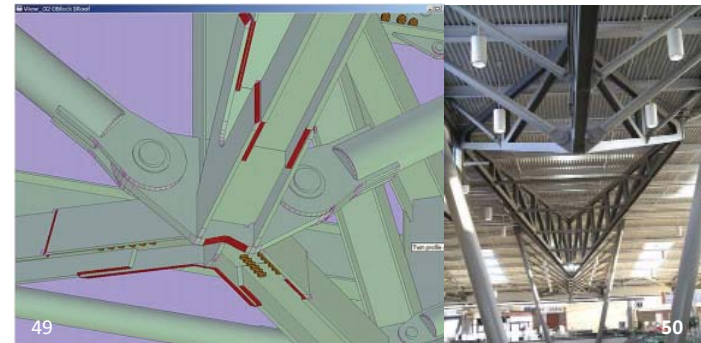
This expectation would hold for both procedures carried out in the fabrication shop prior to erection as well as weld splatter and surface continuities that might happen during or as a result of erection. Such a case would follow the removal of temporary steel supports or shoring elements used to facilitate the erection process. When these elements are removed, the marred surfaces should be properly repaired, and any oxidized surfaces repaired prior to final finish applications.

It was decided to include *all* weld splatter removal so as to avoid potential conflict in deciding on the minimum diameter or intensity of splatter to be removed.

**AESS 2 – Feature Elements** includes structures intended to be **viewed at a distance > 6m**. AESS 2 includes Characteristics for AESS 1, and also Characteristics 2.1 to 2.4.

**2.1 Visual Samples** – This Characteristic is noted as an optional requirement for this and all subsequent Categories due to issues of suitability, cost and scope.

Visual samples that might be used to validate the intention of the final installed product for AESS can take a variety of forms. Visual samples could be a 3D rendering, a physical sample, a first-off inspection, a scaled mock-up or a full-scale mock-up, as specified in contract documents. Visual samples could range from small pieces of fabrication which might include connections or finishes, to full-scale components.



**Fig. 2.1A** A digital mock-up was done for this connection. It allowed the client to understand how the detail would look. It was an efficient method that did not slow down the process. The image above is part of the fabricator's detailing package. Fully rendered 3D models can also be used as a point of clear communication between the parties, to speak more to the final finish appearance, including colour.

Not all projects would benefit from the construction of large-scale mock-ups, hence making this Characteristic optional. In some cases it is suggested that an agreement to incorporate full-scale mock-ups in the final project would make practical and economic sense. Again this decision would depend on the particular job requirements. It is very

important to bear in mind the potential for delay and additional costs when requiring physical visual samples in the timeline of the project. If a fabricator is expected to create a large element, this will delay the fabrication of similar elements until the approval is reached. There are costs associated with the creation of large physical mock-ups that must be integrated into the contract price. For projects with very complex details that are essential to defining the style and reading of the architectural intention, mock-ups can be essential to the AESS project.



**Fig. 2.1A** A special physical mock-up was made for Pearson International Airport. Although minor modifications were made to the detailing for subsequent elements, it was incorporated into the project without any issue.



**2.2 One-half standard fabrication tolerances, as compared to the requirements for standard structural steel in CSA S16, will be required for this Category. This is to recognize the increased importance of fit when assembling these more complex components.**

Large tolerances can lead to a sloppier appearance and lack of uniformity in the connections and, potentially, problems in the erection of complex geometries. This has a direct impact on the erection process and the potential cost implications of making site modifications to members that do not fit. This level of fit is essential for all structural members, plates, angles and components comprising the project. In highly articulated projects there is no play in the erection of the connections. Cumulative dimensional errors can be disastrous in the fitting of the final elements of each erection sequence.



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**Fig. 2.2** One-half standard fabrication tolerances are required for all elements to be incorporated into AESS 2 and higher.



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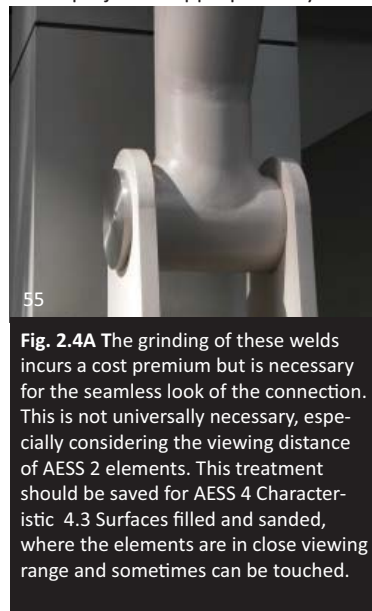
**Fig. 2.3** Fabrication marks not apparent. (Courtesy of AISC)

**2.3 Fabrication marks (number markings put on the members during the fabrication and erection process) should not be apparent, as the final finish appearance is more critical on these feature elements.**

There are different ways of making these markings not apparent. In some instances the marks could be left “as is” but located away from view. In other cases they may be lightly ground out. They could also be filled prior to finishing. The treatment of these might vary throughout the project as appropriate by member and location.

**2.4 The welds should be uniform and smooth, indicating a higher level of quality control in the welding process. The quality of the weld appearance is more critical in AESS 2, as the viewing proximity is closer.**

Quality welding is more stringent in AESS 2 categories and higher. This is a key characteristic, and ensuring good quality welds can save substantial cost in a project. If welds are uniform and consistent in appearance, there may be less need for grinding the weld. Too many welded connections are subjected to needless grinding, which can add substantial increases to a project budget. Welding is a natural condition of steel connections and, if neatly done, should be able to remain as part of the final product.



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**Fig. 2.4A** The grinding of these welds incurs a cost premium but is necessary for the seamless look of the connection. This is not universally necessary, especially considering the viewing distance of AESS 2 elements. This treatment should be saved for AESS 4 Characteristic 4.3 Surfaces filled and sanded, where the elements are in close viewing range and sometimes can be touched.

Ultimately this would indicate that more of the welds might be carried out in the fabrication shop to reduce site welding where the conditions may not be optimum. This can impact the design of joints as well as the transportation of potentially larger pre-assemblies and the erection on site. This does not infer that high quality site welding is not possible, only that it might incur a cost premium over shop welding.

**AESS 3 – Feature Elements** includes structures that would be viewed at a distance  $\leq 6m$ . This increased proximity in viewing distance begins to place the evidence of certain fabrication processes into close viewing range. Where some of the natural evidence of the materiality and connection methods of steel might be acceptable at a greater viewing distance, the same might not be acceptable “up close” where the final product can be both viewed and touched. In many cases these markings will need to be carefully positioned so that they cannot be seen, removed, or concealed.

**3.1 Mill marks are to be removed so as not to be visible in the finished product. Removal of these marks would typically be accomplished by grinding.**



57

**Fig. 3.1** Mill marks removed. (Courtesy of AISC)

**3.2 Butt and plug welds are to be ground smooth and filled to create a smooth surface finish. Caulking or body filler is acceptable.**

These kinds of welds can result in the presence of additional material or slight depressions in the members. These imperfections will be visible after finishing. If additional material is present, it should be ground smooth. If there are depressions, the voids can be filled with body filler and the surface ground smooth prior to finish applications.

**3.3 The normal weld seam that is the product of creating HSS shapes is to be oriented for reduced visibility. In general the seams are to be oriented**

**away from view in a consistent manner from member to member, or as indicated in the contract documents.**

Welded seams are a natural finish appearance which is part of the manufacturing process of HSS members. When choosing HSS, this is important to bear in mind. A seamless finish is not possible without significant added expense and time. There are other options to grinding the seams. The seams can be consistently located to give a uniform appearance. If HSS seams can be oriented away from direct view, this is an acceptable solution.



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**Fig. 2.4B** Welds are plainly visible but of good, uniform quality so complimentary to the structure.



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**Fig. 3.2** Butt and plug welds ground smooth. Right side shows groove weld ground smooth. (Courtesy of AISC)





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**Fig. 3.3A** The natural weld seams on these connecting HSS sections may have been better detailed if they had been aligned.



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**Fig. 3.3B** The seams on the square HSS sections have been aligned and, even on the outside face of the connection, seem in keeping with the overall design intention.



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**Fig. 3.3C** Given the complexity of the structure and the lighting conditions, the seams of the round HSS sections are not apparent to view.

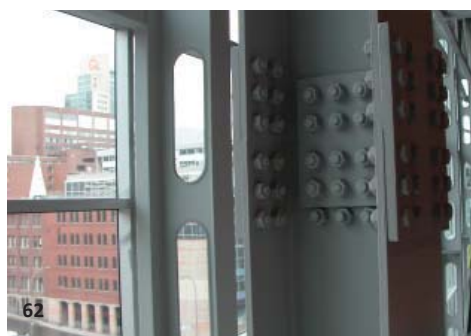
If the seams are located in members whose viewing angles are multiple, then greater care must be taken in detailing the members to achieve a consistent look. If two HSS members are joined (see Fig 3.3A), then ensure that the weld seams are aligned.

**3.4 Cross-sectional abutting surfaces are to be aligned.** *The matching of abutting cross-sections shall be required. Offsets in alignment are considered to be unsightly in these sorts of feature elements at a close range of view.*

Part of this characteristic may be enhanced by ensuring that the steel conforms to Characteristic 2.2, half standard tolerances, but this will not guarantee completely precise alignment of abutting members - particularly when using "off-the-shelf" structural sections that will have had little specialty fabrication work done to them (see Fig. 3.4). There may also be a need to shape or grind the surfaces at the point of connection to ensure that the surfaces are aligned. In some lighting conditions, shadow casting may be more problematic than others. Where the inconsistencies are small, be sure to incorporate advanced knowledge of the final finish coat as it may either help to conceal or exacerbate these slight misalignments.

**3.5 Joint gap tolerances are to be minimized.** *This Characteristic is similar to 2.2 above. A clear distance of 3 mm between abutting members required.*

The use of bolted connections is quite common in many AEES applications. Bolted connections may be advantageous for erection purposes or constructability, and might also suit the aesthetic of the project. In keeping with tighter tolerances on the members themselves, the reduction of joint gaps in bolted connections aids in ensuring consistency and tighter design.



62

**Fig. 3.4** This column splice is within touching range, but the column flanges do not line up and the connection plate seems too short.



63

**Fig. 3.5A** Joint gap minimized. The gaps on the left are standard structural steel, and on the right sized for AEES. (Courtesy of AISC)



64

**Fig. 3.5B** This exposed bolted connection is tightly designed and demonstrates uniformity in the joint gaps.

**3.6 AEES 3 Feature Elements may require all-welded connections.** *This is noted as optional; acknowledging that a particular aesthetic might purposefully call for bolted connections.*

This will be addressed in greater detail in Section 5, Connections, but much of the overall aesthetic intention of a project is held in the decision to use an all-welded structure over one that either uses some or all bolted connections. Welded connections are easier to fabricate in the shop. The erection condition on the site might require temporary shoring to hold the geometry in place while welding is completed. There may be additional work to repair surfaces that have been damaged due to the removal of temporary steel such as backing bars.

In some situations, whether due to access constraints or issues of time, welded connections might not be possible. Alternatively, if an entirely welded appearance is desired, hidden bolts may be considered as an acceptable solution (see Fig. 3.6A, where a bolted connection is concealed behind the cover plate). If this connection is used in an exterior environment, care must be taken to seal the joint to prevent water from becoming trapped.



65

**Fig. 3.6A** Pictured is a cover plate over a hidden bolted connection. The appearance of a completely welded structure is kept, but erection simplified.



66

**Fig. 3.6B** This design used all-welded connections, even for this anchoring detail of the truss to the base plate. Bolted connections were not desired.

**AESS 4 – Showcase or Dominant Elements** would be used where the designer intends the form to be the only feature showing in an element. The technical nature of the steel is to be hidden or downplayed. All welds are ground and filled edges are ground square and true. All surfaces are sanded and filled. Tolerances of these fabricated forms are more stringent, generally to half of standard tolerances for structural steel. All of the surfaces would be “glove” smooth.

**4.1 The normal weld seam in an HSS member should not be apparent.** *This may require grinding of the weld seam.*

If it is not possible to orient the natural weld seam in the HSS sections away from primary view, or if the viewing angles to the structure are from all sides and it is critical that the HSS appear more plastic, then the seams may need to be ground and filled. In some instances where there are numerous weld seams to conceal, it might be practical to choose mechanical pipe over round HSS. Mechanical pipe has the advantage of normally being seamless but has a surface texture more like an orange peel. It also has different physical properties and may require alternate approaches when fabricating details. In any case a change in sections must be approved by the structural engineer.

**4.2 Welds are to be contoured and blended.** *In addition to a contoured and blended appearance, welded transitions between members are also required to be contoured and blended.*

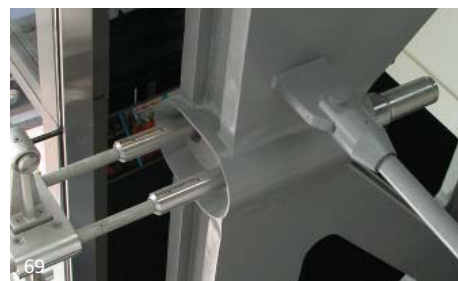
This type of detailing should be reserved for the most particular applications, those in very close proximity for view and touch and those whose form, fit and finish require this type of seamless appearance. Grinding and contouring welds is time-consuming and thereby very expensive. It is more easily done in the fabrication shop, in a controlled environment and where the pieces can be manipulated (by crane if necessary) so that the ironworkers can properly access the details. In situ high quality welding might require the erection of additional secure platforms to access the welded connections, which adds expense to the project. Therefore part of the negotiation for this type of detailing must begin by looking at maximizing the sizes of the pieces to



**Fig. 4.2A Welds contoured and blended.** The left-hand sample shows typical structural welds. The right-hand sample shows how they have been welded and contoured. (Courtesy of AISC)



**Fig. 4.1.** This project uses mechanical pipe instead of HSS, as the three-dimensional nature of the structure made positioning seams out of view difficult, and a seamless appearance was important. Grinding of the seams would have been prohibitively expensive as well as time-consuming.



**Fig. 4.2B** It is easy to see that this detail relies on a high level of finishing – including grinding and contouring of the welds to achieve its form, fit and finish.

allow for shop fabrication and minimizing site work. This brings in transportation issues and site access if the resultant members are very large. Also such pieces must be carefully handled and stored on the site to prevent damage.

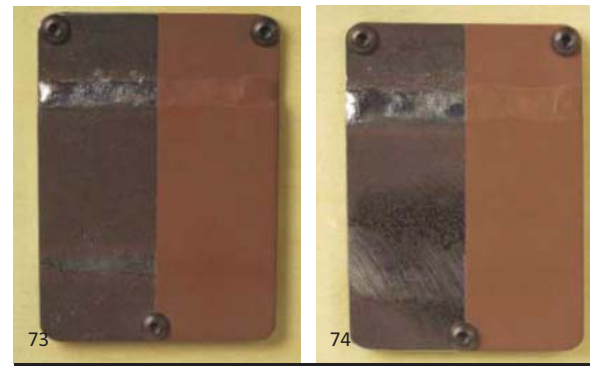
**4.3 Steel surfaces are to be filled and sanded.** *Filling and sanding is intended to remove or cover any steel surface imperfections, again due to the close range of view of the members. This particular point can incur a high cost premium and is a particular case in point that all AESS need not be created equal. Procedures such as this are not required where the members cannot be seen.*

Great care must be taken to ensure that the filled and sanded surface is consistent with the finished surface of the adjacent steel, or variations will be revealed after the finished coating is applied. Steel castings for instance have a different surface than adjacent HSS sections, so any joining surface treatment must mediate the two finishes.



**Fig. 4.3B Surfaces filled and sanded.** These three examples show very different applications of AESS 4 whose details require extra care and high-level consistency such that any and all imperfections are filled (typically with body filler) and sanded prior to the application of the finish coating. It is particularly important in the left and right images where a glossy finish is to be applied.

**4.4 Weld show-through must be minimized.** *The markings on the back face of the welded element caused by the welding process can be minimized by hand-grinding the backside of the weld. The degree of weld-through is a function of weld size and material thickness.*



**Fig. 4.4** Weld show through is minimized. The left-hand images show weld show-through from a connection on the far side of the plate. The right-hand image shows how it has been concealed. (Courtesy of AISC)

**AESS C – Custom Elements** was created to allow for a completely custom selection of any of the characteristics or attributes that were used to define the other categories. It would allow complete flexibility in the design of the steel, but would therefore require a high level of communication among the architect, engineer and fabricator. The premium for this type of AESS could range from 20% to 250% over standard steel. A wide range may seem odd for custom elements, but the lower bound of



this category also includes specialty reused steel for sustainable purposes, and steel that might be purposefully less refined in its characteristics.

It is strongly recommended that the team sit down with the Matrix and specification documents in hand and manually go through the list of characteristics. As is illustrated by the range of projects pictured, the complexity, size, level of finish and types of members used can greatly vary in custom projects, leading to a wide variation in the cost premium to be expected for this type of project.

The unusual areas of concern for AESS custom projects might include:

- oversized members
- extraordinary geometries
- curved members
- accessibility issues
- unusual finish requirements
- high levels of grinding and filling for connections
- transportation problems associated with member size
- difficult handling or extra care needed to protect pre-painted components



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Seamless curved structures have their own fabrication and erection concerns.



77

Very precise details require special fabrication, erection and handling.

### Working Outside of Canada

Projects located outside of Canada will bring their own unique issues to the table. An even higher level of communication and agreement will be required when working with team members that may include fabricators, erectors and ironworkers who may be unfamiliar with the level of expectation of AESS projects in Canada.

There is a high level of similarity and communication between Canadian and American systems, as well as a large number of Canadian fabricators and erectors accustomed to supplying steel to U.S. locations.

Some countries that have made AESS a part of their architectural tradition for the past decades boast highly skilled fabricators, erectors and ironworkers. Others clearly do not. When working in distant locations, caution is urged. Request to see sample projects as a demonstration of quality of workmanship. Ensure that local or site personnel are quite familiar with Canadian specifications and expectations. In many cases a certification may be needed.



75

In this project the artist very much wanted the rough nature of the steel to show through, so many aspects that would normally be removed in an AESS project were purposefully retained to enhance the understanding of the materiality of steel.



78

The quality of the ironwork, welding and finish on this museum in inner China was extremely low. The welds were sloppy. The intumescent coating appeared to have been applied when the project was still open to the weather, resulting in dirt streaks down all of the members. In spite of the overall creative energy of the design of the building, the lack of care in workmanship due in part to problems in communication, supervision and understanding of the role of AESS undermined this installation.



80



81

The Chinese National Theatre uses large plate steel members to create its trusses. These in turn are braced by solid rods that use a half-sphere to manipulate the curve of the connection. The form, fit and finish on the project are very high. This was undoubtedly the result of significant coordination and close supervision of the work.



79

Complex geometry, odd angles and extremely heavy elements add a cost premium to this project. The level of form, fit and finish on this project is exceptionally high. In the UK a high level of tradition of AESS has been established which has resulted in a highly skilled labour force.



82



83

The scale and complexity of this welded project meant high cost premiums and additional fabrication and erection time. The project was additionally complicated as a result of fabrication and erection in China. There is far less AESS work that is routinely made a part of Chinese construction, so skilled labour can be an issue. The sections were created using plates and, given varied lighting conditions, many of the welds were visible. The overall aesthetic of the project could accommodate this level of texture.

# 4 Coatings and Finishes

## GENERAL ISSUES

*The Matrix and AESS Specifications were intentionally designed to exclude coatings as a parameter or characteristic. The issue of coatings and finishes is a highly complex area of concern and one that may override the decision-making process regardless of the AESS Category.*

*The selection of coatings and finishes for AESS work needs to be known at the outset of the project. In many cases, the nature of the finish will begin to dictate the level of surface preparation required for the various elements of the structure as well as much of the fabrication detailing. The properties of different coatings can even begin to skew the decision-making process outlined within each of the distinct categories of the Matrix.*

**Generally speaking, coatings can be divided into two general categories:**

- those that reveal or exacerbate the surface conditions and potential imperfections in the steel (*thin coat or glossy finishes*), and
- those that conceal such surface conditions and potentially hide aspects of intended details (*thick coats and matte or mottled finishes*).

**Coatings will also be influenced by interior or exterior locations.** This will include issues of weathering, exposure to ice, snow and rain, as well as atmospheric pollution. Details will have to be designed to drain, shed water, and coatings chosen to prevent corrosion on both the exterior and interior of members. If similar members are being used on the interior and exterior of the project, consideration must be given to a coating selection that will work with the details in both places.

**The selection of the finish may be governed by fire protection** concerns rather than aesthetics. This would be the case with the choice to use intumescent coatings over a regular painted finish. Where some intumescent coatings are fairly thin and allow details to show through, others are by their nature quite thick. Spending project dollars on highly complex articulated details



Extreme care and highly specialized detailing was required to join the branches of this tree to the casting nodes. Mechanical pipe was selected for its seamless appearance and structural properties. The surface had to be perfect given the application of a glossy painted finish and focus lighting.



makes little sense if these are to be coated with a heavy material. Conversely, if an extremely glossy finish is desired, this might lead to design decisions that favour welded conditions over bolted ones given the inference of clean lines.

**Welded Versus Bolted Structures.** Different coatings, finishes, and types of texture of the coatings and finishes may be more or less appropriate as a function of the tectonic expression of the structure. Much of the tectonic character will be defined simply by the choice to use welded or bolted connections as the main method of attachment for the structure.

**Shop Versus Site Painting.** It may be much more expedient and desirable to pre-finish AESS structures in the fabrication shop. Controlled conditions can lead to a better final product. This is even more the case if the geometries are highly complex or if there will be accessibility issues in painting the structure on site. There are situations where the erection of scaffolding is prohibitively expensive or strategically impossible. If it is the intention to pre-finish members, then extra care will be required to transport the elements to the site as well as during the erection process. Even with extraordinary care, touch ups can be expected.

**Cleaning and Maintenance.** AESS installations might never look as good as on the day on which the building was opened. Seldom considered in many projects are issues related to the maintenance and cleaning of the structures. White is a fashionable colour for AESS, yet where it is installed in areas of high urban pollution, it can age quickly. Certain steel shapes can be more easily cleaned by high pressure washing than others. Flat surfaces and ledges can provide areas to collect debris. Both the details and the durability of the coatings must take into account the urban menace presented by pigeons. Their droppings are corrosive as well as a nuisance.



The white painted finish on this exposed steel exterior stair was not a good choice. Salt applied to the treads has resulted in rust stains on both the supporting steel and the concrete below.



The painted white structure at the TGV Station at Charles de Gaulle Airport in Paris has proven difficult to keep clean. Access is not possible over the full width of the station, leading to severe buildup of grime over part of the structure. The structure is easily viewed from above, making the surface condition even more obvious.



Ledges provide an excellent roosting place for pigeons. Remember to install pigeon-deterrent fences and surfaces to prevent roosting and the associated soiling of the structure and spaces below.



## DETAILS

### Surface Preparation

Surface preparation will be done in accordance with the chosen AESS category (1 through 4 or Custom). Where there are different AESS Categories used in the project, there may also be different surface preparations and different finishes required. In AESS applications, it is essential to apply the proper surface preparation. If the surface is not adequately cleaned prior to the application of the coating system, the coating system may fail or the surface deficiencies will show through.

**Finishes for exterior steel structures** will require special attention to prevent corrosion. Paint will not make up for design deficiencies. Even the most sophisticated epoxy and vinyl paint coatings cannot compensate for details that create opportunities for corrosion to occur. The basic selection of member type and connection detailing for exterior structures should ensure that there are no places where water and debris can collect or puddle. With some care and attention, orientation problems can be overcome. Beams and channels should be orientated with the webs vertical so that water cannot collect and stand for any period of time. Exposed steel on which moisture can collect should be detailed with a slope to ensure drainage. Drain holes can be added if the section cannot be orientated or sloped to drain.

When using hollow sections or composite members that create voids on exterior applications, it is also necessary to prevent corrosion of the interior surfaces. Seal welds are often specified to prevent the entrance of moisture or oxygen-laden air into the cavity. For architecturally exposed steel that is to be painted, seal welds may be specified to prevent unsightly rust bleeding.

Seal welds may be specified on parts to be galvanized to prohibit pickling acids and/or liquid zinc from entering into a specific region during the galvanizing process; however, a closed volume should *never* be galvanized as it will cause an explosion. Aired access should be provided for the molten zinc to reach all surfaces and therefore avoid explosions. For HSS, it is better simply to provide drainage at the bottom of the element to ensure that gasses do not get trapped. Proper communication is important when deciding on the method of prevention of moisture entry on sealed joints. Seal welds can alter load paths and are prohibited in some structural situations. It might be better to provide a vent space and also galvanize the interior of hollow sections. This will increase costs but will potentially provide a more durable exterior coating.

### Paint Systems

The selection of the paint or coating system should be done at the outset of the project, as both the colour and finish will impact detailing decisions and, therefore, cost. If a high-gloss finish is desired, it will reveal every minute imperfection in the steel. Flat finishes are more accommodating. Light-coloured paints will quickly reveal corrosion and dirt. Thin finishes will reveal surface imperfections. Thicker coatings, such as intumescent fire protection, can cover or conceal imperfections as well as fine details.



### General Notes About Painting

Steel exposed to view is generally painted for appearance. A one-coat paint system, such as performance specification CISC/CPMA 1-73a, is sufficient for standard warehouse structures that will not be top coated (Standard Structural Steel and AESS 1). Since the building environment is controlled, no corrosion occurs once the building is enclosed. These buildings perform adequately throughout the country. One-coat systems are referenced in Clause 28.7.3.3 of CSA Standard S16-09.

Steel buildings require *no* paint when the steel is hidden behind drywall and suspended ceilings. The humidity in such buildings is below the threshold limit for steel corrosion to occur (Clause 6.6.2 of CSA Standard S16-09). Buildings that have exceptionally high humidity, such as swimming pools and water treatment plants, are exceptions and should be treated as exterior exposed steel.

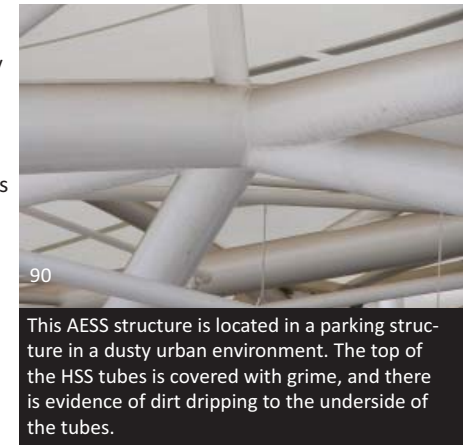
Steel exposed to view that will be top-coated for appearance (AESS 2 and above) requires a prime coat for adhesion. A fast-dry primer, such as CISC/CPMA 2-75, is sufficient to provide the necessary base. To ensure that this system will perform for longer periods, a greater degree of cleanliness is required by the specification. Hence AESS requires surface preparation to a minimum SP-6. *Consultants must ensure that the finish coats are compatible with the primer.* Each paint system often has its own primer. Alkyd primers are acceptable but epoxy primers are not. Once the building is enclosed, no corrosion occurs.

Structural steel that is exposed to view and the elements on the exterior of buildings require more thorough cleaning and finishing to ensure long-term performance. Higher degrees of cleanliness along with better quality multi-coat paints should be considered under these circumstances. Epoxy systems over compatible primers are usually most suitable. Urethanes should be used when wear is a consideration.

Tender documents should include the following information to ensure good quality coating systems:

- identification of members to be painted
- a specification for the degree of cleanliness required to ensure performance such as SSPC Surface Preparation Standards
- compatible primer, intermediate and finish paints and if applicable:
  - the manufacturer's product identification
  - the average dry film thickness per coat

It is recommended to review the painting with a local fabricator or supplier to ensure that the most suitable system is chosen for a specific application.



## Shop Versus Site Painting

The painting of an AESS structure can take place in the fabrication shop or on the site. Many fabricators can offer shop painting which can ensure a more consistent, higher quality finish. Naturally it is expected that the paint finish will be free of drips and runs. Access to the installed structure for paint applications can be a logistical issue. Shop-applied paint finishes will likely need to be touched up after erection, but this is less problematic than the complete painting of the structure on site which rarely occurs.

Pre-painted structures will require extra care and protection during transportation, handling and erection. Pre-painted structures will be more in need of “just in time” delivery to the site to prevent site-generated damage. Pre-painted structures may also require better staging areas on site – again to prevent damage to the painted finishes.

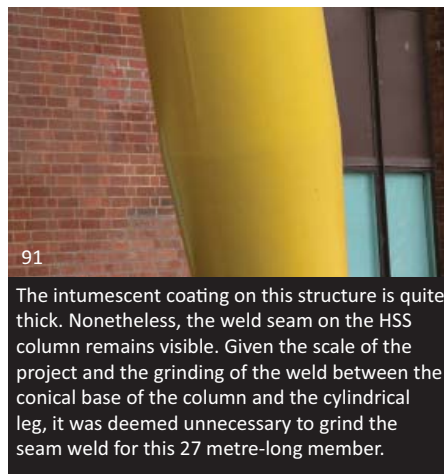
Careful preparation of the steel, including basic removal of sharp edges (Characteristic 1.2), will allow for a more even application of the paint and better coverage on the corners. The spray application of the product on sharp corners is difficult and, if these are not ground or rounded off, can lead to premature wear on the edges of the structure. In an exterior application, this can lead to corrosion.

## Primers

The selection of the primer will be a function of the choice of the finish coating. Not all finish coating systems take the same base primer, so revisions in the final finish type may require remedial correction of primers to ensure compatibility. Care in application of the primer is important as any drips and runs will show through both paint and intumescent coating finishes. Additionally, not all finish systems require a primer. If not required, this can represent a cost and time saving.

## Intumescent Coatings

Intumescent coatings simultaneously provide a fire resistance rating and a painted appearance to exposed steel. They contain a resin system “pigmented” with various intumescent ingredients which, under the influence of heat, react together to produce an insulating foam or “char”. This char layer has low thermal conductivity as well as a volume that is many times that of the original coating. The char layer reduces the rate of heating experienced by the steel, extending its structural capacity and allowing for safe evacuation. As this material can extend the fire resistance rating of exposed steel to a maximum of 2 hours, it has become quite popular for use with AESS applications. The fire resistance rating is in part dependent on the type and thickness of the coating as well as on the type of fire that might be anticipated in the building use. Increasing the fire resistance rating is usually achieved by applying multiple coatings of the product.



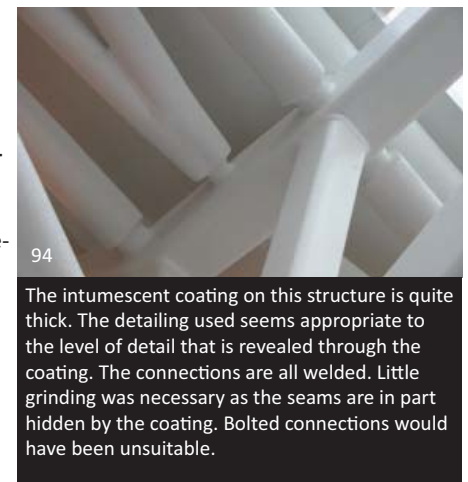
The required thickness of the coating is in turn determined by the thickness of the structural steel member. **Thin or light members will require more coats than heavier members.** It is sometimes more cost-effective to increase the thickness of the steel as it can decrease the number or thickness of the intumescent coatings – the increased cost of steel being significantly less than the extra cost to increase the thickness of the intumescent material. Structural steel is inherently a more sustainable material, so the reduction of the amount of coatings is preferable.

**Intumescent fire protection application is preceded by the application of an approved primer.** Not all primers can be used, so you must check with the intumescent coating supplier to determine an acceptable primer. If the wrong primer is applied, it will interfere with the successful application of the intumescent coating system.

Traditionally, intumescent coatings have been applied on-site to steel structures during the construction phase of the building. In-shop application is a more common practice as better control of application conditions is possible. Shop applications can provide for the controlled venting needed for solvent-based systems. Shop conditions can also provide more control of temperature and relative humidity, and hence better drying. Controlled drying in the shop means better finish as the coated steel sections cannot be moved until they are hard enough to resist damage. These members must be more carefully handled during transportation and erection as any damage must be properly repaired in order to preserve the integrity of the fire protection system.

**Intumescent coatings are either acrylic or epoxy-based.** Acrylic coatings can be either water or solvent-based, and they are field-applied. The water-based material is “greener” but takes somewhat longer to dry and is mostly used for interior applications. The solvent-based coating is more robust and can also be used on the exterior.

Epoxy coatings are normally shop-applied and can be used on interior or exterior applications. They are more durable than acrylic coatings and can also be used to provide corrosion protection.





The colour and texture of intumescent coatings are not the same as normal paint, so it is necessary to detail items like these columns to recognize that the finishes are not the same. Here a band of a different colour highlights the change.

Where access for finishing may be an issue, shop-applied epoxy coatings may offer savings.

Water-based coatings are typically applied when relative humidity is between 40% and 60%. Solvent-based coatings can be applied with relative humidity up to 85%. If there is concern about the presence of high VOCs on the project, a water-based product can be used if the humidity levels are kept low. It is important to allow the layers to dry thoroughly between coatings. Water-based products take longer to dry where humidity levels are high and temperatures are low. Solvent-based products can dry faster but can also strike back to dissolve prior layers if insufficient drying time is permitted between layers.

#### The intumescent coating system can include a top coat.

This provides a hard protective coating to the product. It is important to note that white or light colours will tend to yellow with time, so if colour matching is an issue, this should be taken into account when mixing intumescent and painted

finishes in a project. If combining intumescent and regular paint-finished steel, note that exact colour matches are not possible. The nature of the intumescent finish will alter the colour of the coating. It will be necessary to detail the structure to account for this slight change in hue or tone. Without a top coat, intumescent coating surfaces don't clean as well as with a top coat and will also show finger prints. Any portion of the structure at "hand" level should have a top coat for ease of cleaning and maintenance and to prevent permanent blotching and stains.

**Additionally there are two types of intumescent coatings: thin and thick systems.** A thin coating is considered to exist for thicknesses from 0.5 to 6 mm, and a thick coating for thicknesses up to 13 mm. Because the wet film needs to be relatively thick, of several hundreds of microns according to the particular formulation, intumescent coatings are often thick to avoid slumping and runs while still wet. Several coats may need to be applied to build up to a total dry coat thickness in order to give the required fire protection.

Although these coatings provide the appearance of a painted finish, the texture is not the same. Thin-coat intumescent systems will result in a finish that resembles an orange peel. The thicker system has enough substance to conceal some of the finer details that might go into the design of the AESS connections. If badly applied, a thick system can give a very uneven, textured appearance. Intumescent coatings, although allowing exposed steel use in an increased number of occupancies, are not *always* deemed by architects to be the best solution as they can sometimes result in a thick-looking finish that can obscure some connection details. The use of intumescent coating often precludes the need for fine finishing, as it is thick enough to cover up surface imperfections



This thick intumescent coating is constantly being repaired due to its high traffic location as well as repeated incidences of graffiti removal. The colour matching on some of the supports is more difficult to achieve.

that would be unacceptable if a standard paint finish were employed. If a very smooth high-gloss finish is desired, this system requires additional surface treatment.

Care should be taken when using thick coatings in high-traffic areas or where they can be subject to vandalism. The damaged intumescent coating must be properly repaired to maintain the required fire resistance rating. Colour matching can also be an issue.

### Cementitious/Fibrous Fire Protection

Although not the usual case for AESS installations, cementitious or fibrous fire protection might be used. This could be the case if the steel is located at a distance from view or touch, as in the case of AESS Categories 1 or 2. If such a finish is to be applied, there need not be the same level of surface preparation required, and the Matrix should be customized to remove characteristics very early on in the scheduling of the project to avoid wasted time and expense.

### Galvanizing

Galvanized finishes are increasingly seen in AESS applications. It is important to remember that in the view of the steel industry, galvanizing was not intended as a finish, but as a preventative measure against corrosion. The speckled grey finish is guaranteed to vary from batch to batch, even from the same manufacturer. It will also vary as a function of the application technique and the style, size and shape of the member to which it is being applied.

Achieving a good quality coating requires a surface that is free of grease, dirt and scale of the iron or steel before galvanizing. When the clean steel component is dipped into the molten zinc (approx. 450°C), a series of zinc-iron alloy layers are formed by a metallurgical reaction between the iron and zinc. When the reaction between iron and zinc is complete, there is no demarcation between steel and zinc but a gradual transition through the series of alloy layers which provide the metallurgical bond. This helps to make the galvanized finish highly durable as it cannot easily be chipped away. The thickness of the coating is determined by the thickness of the steel. The galvanized coating can be made thicker by roughening the steel, thereby creating more surface area for the metallurgical reaction to take place.

Galvanized coatings protect steel in three ways:

1. The zinc weathers at a very slow rate, giving a long and predictable life.
2. The coating corrodes preferentially to provide sacrificial protection to small areas of steel exposed through drilling, cutting or accidental damage.



Cementitious finishes can be commonly found on exposed steel used in parking garages. While not falling in a regular AESS category, care has been taken here with the design of the support system in the garage.



As can be seen in this galvanized exposed steel exterior shading system, a variety of finishes can be seen on the different hot dip galvanized members. This is to be expected in this sort of application.



3. If the damaged area is larger, sacrificial protection prevents sideways creep which can undermine coatings.

No post-treatment of galvanized articles is necessary. Paint or a powder coating may be applied for enhanced aesthetics or for additional protection where the environment is extremely aggressive.

The resistance of galvanizing to atmospheric corrosion depends on a protective film which forms on the surface of the zinc. When the steel is lifted from the galvanizing bath, the zinc has a clean, bright, shiny surface. With time this changes to a dull grey patina as the surface reacts with oxygen, water and carbon dioxide in the atmosphere. This forms a tough, stable, protective layer that is tightly bonded to the zinc. Contaminants in the atmosphere will affect this protective film. The presence of  $\text{SO}_2$  greatly affects the atmospheric corrosion of zinc.

Complex shapes and most hollow items can be galvanized, inside and out, in one operation. Where AESS is being installed in an exterior environment, it is critically important that all surfaces be coated. For HSS members, this will mean coating the interior of the shape as well – increasing the surface area for coating and potentially increasing the cost. Good member design requires:

- means for the access and drainage of molten zinc
- means for escape of gases from internal compartments (venting)

It is important to bear in mind that the steelwork is immersed into and withdrawn from a bath of molten zinc at about  $450^\circ\text{C}$ . This temperature can cause distortion in thinner steels. If the use of the galvanized coating is known early on during the design process, it may be decided to increase the thickness of the steel to prevent distortion.

Any features which aid the access and drainage of molten zinc will improve the quality of the coating and reduce costs. With certain fabrications, holes that are present for other purposes may fulfil the requirements for venting and draining; in other cases it may be necessary to provide extra holes for this purpose. For complete protection, molten zinc must be allowed to flow freely to all surfaces of a fabrication. With hollow sections or where there are internal compartments, galvanizing internal surfaces eliminates any danger of hidden corrosion during service.

From a design perspective, it will be important to understand the physical limitations of the galvanizer's facility. To be specific, what is the size of the bath? It is not usual to dip pieces that are 20 metres in length, but this limit must be verified as it impacts member size. This limit on the member size may result in the need for additional connections. Double dipping is not an effective solution.

## Metalizing

Metalizing is a substitute for painting structural steel that protects steel for significantly longer than paint alone. It is more expensive than galvanizing. Steel of every shape and size may be metalized either in-shop before construction or on-site instead as an alternative to painting. Metalizing is a very versatile and effective coating for protecting steel structures that are to be continuously exposed to weathering.

The metalizing process begins with proper surface preparation. Next, aluminum wire or zinc wire is continuously melted in an electric arc spray or gas flame spray gun. Clean, compressed



99 Seal welds have been used to connect the various components of this exterior galvanized steel feature railing. There is a large opening at the base of the square HSS post to allow any water that may enter the railing an opportunity to drain.



100 The base connectors for these hybrid steel and glulam timber members have been fabricated from galvanized steel. The position of the connector in the building put it at greater risk of moisture exposure, so painted steel was not desired.



101 Here galvanized steel members are mixed with zinc painted grey steel. It was decided not to galvanize some of the members due to the chance of deformation in the hot zinc bath and potential stress release of the welds.



102 One of the technical realities of using galvanizing as a finish lies in the inconsistency of the product. The difference in this photo is due to finishing temperatures. If galvanizing is used as a final coating on an AESS project, differentials in finish must be both understood and detailed into the project.



103 Galvanizing is a suitable finish for an exterior AESS structure that will be constantly subjected to weathering as in this expressive railing system.



104 Galvanizing is very popular as a finish, but remember that its basic purpose is as a corrosion-prevention coating. The nature of the finish will not be consistent from batch to batch.



105

This garden wall is made from weathering steel. Although durable in appearance, you can see the destructive markings on the surface made by users of the space. It is essential to detail these types of installations so that the run-off water does not stain surfaces below the wall.



106

This wall is made from weathering steel. The final colour of the steel will be slightly darker than what is pictured here. The material must go through a number of wetting and drying cycles for the coating to cure. It is not possible to select or carefully predict its final hue.



107

Care must be taken in detailing weathering steel to avoid having the natural oxidizing process create stains on the surfaces below the material.

air strips droplets of molten metal from the wire, depositing these particles onto the steel forming the protective coating. This sprayed metal coating is both a barrier coating and a galvanic coating in one. A single metalized coating can protect steel for 30 years or longer depending upon the application, coating thickness and sealing.

Metalizing is thought of as a cold process in that the aluminum or zinc is deposited onto steel by spraying rather than by dipping the steel into a bath of molten zinc as with galvanizing. The steel remains relatively cool at about 120°-150°C. This means that there is virtually no risk of heat distortion or weld damage by metalizing.

There are no VOC's (volatile organic compounds) in the metalized coating. There is no cure time or temperature to limit metalizing, so metalizing may be applied throughout the year, virtually regardless of temperature.

There are three types of wire that are used to create three specific coatings. **Sprayed aluminum** is preferred for use in industrial environments, particularly where there are high concentrations of sulfur dioxide and other pollutants. **Zinc** provides greater galvanic protection than aluminum. Its greater galvanic power protects gaps in the coating better than pure aluminum. It is marginally easier to spray pure zinc than pure aluminum by some flame or arc spray systems. **Zinc with 15% aluminum wire** combines the benefits of pure zinc with the benefits of pure aluminum in the metalized coating. It is very often used as a substitute for pure zinc because it is somewhat more chloride and sulfur dioxide-resistant than pure zinc, while retaining the greater electro-chemical activity of pure zinc.

### Weathering Steel

Weathering steel has a unique characteristic such that, under proper conditions, it oxidizes to form a dense and tightly adhering barrier or patina which seals out the atmosphere and retards further corrosion. This is in contrast to other steels that form a coarse, porous and flaky oxide which allows the atmosphere to continue penetrating the steel. The oxidized layer on weathering steel

in many climates does not consume a significant amount of steel in its formation. However, climate is important – the oxide layer will form provided there are wet/dry cycles.

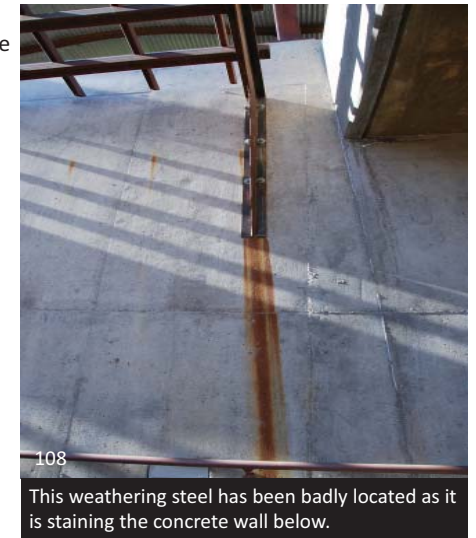
Words of caution: runoff of water from upper portions of a structure tend to produce long-lasting streaks or other patterns of redder oxide on lower portions. Therefore, special attention must be paid to the drainage of storm water (or condensate) to prevent staining of surrounding structures, sidewalks, and other surfaces.

Weathering steel is also available in sheets, for roofing and cladding. However, they were not meant for architectural applications. Weathering steel must be kept free from debris such as leaves, pine needles, etc. These waste products retard the wet/dry cycle necessary for weathering steel, and corrosion is accelerated. Also, in an accelerated environment, loss of material may be more significant and could cause perforation of very thin sheets. In addition, for green building design, one should know that a thin weathering steel roof has low solar reflectivity, i.e. it is a "hot roof".

In terms of availability, few steel service centres will stock a large inventory of weathering steel because of its specific bridge application. However, they will order it from the mill on request but usually for bridge applications. Unfortunately, when steel is needed for an exterior wall element, that usually represents low tonnage for a service centre.

After about two years, which is the time it takes to develop the oxide skin, the colour is going to be much darker and reddish brown. As we are dealing with "living steel", the colour will not be consistent from project to project or even within a project. In wetter climates the colour of weathering steel will generally have an overall redder cast relative to those exposed in drier climates. However, one can be most certain that the final colour will have a rich dark earthy tone and will be low-maintenance, durable and beautiful, provided one is careful about the details. If it is desired to use weathering steel in an interior application, it must be noted that the requisite wet/dry cycles are absent and it will not age (very quickly). If desired it can be pre-aged outside and then installed inside. Otherwise be prepared for the final surface state to take many years to develop.

Weathering steel is not readily available in W shapes and HSS from Canadian sources. It is not appropriate for green roofs. However, it is low-maintenance; no paint is required, and properly used vertically, it can add a distinct and green character to your project.



108

This weathering steel has been badly located as it is staining the concrete wall below.



109

These welded steel sections may look like weathering steel but they are actually fabricated from regular carbon steel that is coated with an applied "weathering steel finish". Although convenient, it will not provide lasting protection.



Weathering Steel Finish is a new coating that is available for use. This is a shop- and field-applied finish that gives the appearance of weathering steel but does not create the same oxidized layer as actual weathering steel. It is applied to standard structural steel materials. It provides a similar looking finish and so might be useful where certain sizes, shapes and thickness of material are not available. The coating must also be applied to site welds to result in a uniform appearance. This coating does not produce rust runoff.

### Stainless Steel

Stainless steel has the advantage of having its corrosion protection quite integral to the structural member. It is an iron-based metal that has at least 10.5% chromium as well as quantities of nickel, molybdenum and manganese that assist in resisting oxidation. The chromium combines with oxygen to create a barrier to the rust that would normally form due to the iron content. As a result, it has a remarkable finish and requires far less ongoing maintenance than does regular steel protected through methods of galvanizing, metalizing, or with painted or intumescent coatings.

There are significant cost premiums for stainless steel as a material, and from a structural perspective it also requires a different set of calculations as its behaviour is very different from regular mild carbon steel. Stainless steel has a very low carbon content. There are 50 different grades of stainless steel, of which five are most commonly used for structural applications. These vary due to their alloy content. **304** is the most commonly used for exterior architectural applications, being easy to form and fabricate and available in a variety of forms. **304L** is a low-carbon version of 304 and is specified where higher corrosion resistance is needed as well as the welding of heavy sections. **316** offers heavy corrosion resistance and is used in harsh environments. **316L** offers extra corrosion resistance and heavy welding. **430** is a chromium ferritic material that is used in interior applications. **305** and **410** are used for bolts, screws and fasteners.

Stainless steel is available in plate, wire, tubes, rods and bars. Extruded shapes are not common but can be fabricated by special order.

Only stainless steel fasteners should be used to join stainless steel members. Other metals can result in chemical reactions between the materials, which can lead to failure. Stainless steel is also readily welded; however, the welding rods and techniques are quite different from those involving regular carbon steel. Stainless steel castings can be fabricated to form connections between members.



110

The Domes at Robson Square in Vancouver have been fabricated from stainless steel tubular sections.

Only dedicated tools must be used to cut and finish the steel. Tools used with carbon steel will embed small particles of carbon steel in the stainless, causing rust spots to occur.

The fabricator chosen for creating an AESS structure from stainless steel should be experienced in the material.

## 5 Connections

### DETAILING REQUIREMENTS FOR AESS CONNECTIONS

#### General Issues

AESS structures, by their inherently exposed nature, put a greater than normal emphasis on connection design. The detailing language of the connections must feed into the overall aesthetic desired for the structure. Connection details must be constructable and within reason to erect. Although the details normally used for AESS structures include some fairly standard connection methods, these are mostly modified as a way of enhancing the architectural expression of the structure, and by their nature are likely to present challenges for both fabrication and erection.

**Connection types can be subdivided into structures that use shapes (such as W, C and L-shapes), and those that use hollow sections.** These typologies can be further subdivided into the choice of predominantly welding or bolting the connections. Plates can be worked into both types of connections. AESS connections will often incorporate specialty items such as rods and tensile connectors.

**In turn there are shop-fabricated connections and site-erected connections.** As a general rule, it is better to maximize the number of connections, particularly welded connections, that can be done in the shop over those, usually bolted, that must be done on site. There is more quality control in the shop. Jigs can be set up for repetitive assemblies to ensure consistency in appearance and finish. It is easier to turn and fix the members into position for welding with crane assistance. The application of primer and even finish painting is more efficiently done in the shop.

**In the end, the maximum size of member that can be transported to site will often determine the scope of shop-fabricated connections and the number and type that must be done on site.** Although it is possible to transport oversized pieces to the site with a police escort, it does increase the cost of the project. Likewise, when the site is constricted and the staging area either



111

Connection detailing must meet the end requirements of the AESS Category and also take into account the cost, constructability, fabrication and ease of erection.



112



small or non-existent, pre-assembling the pieces on site on the ground might also not be possible. Most urban sites will require “just in time” delivery of steel pieces and carefully planned erection to make the best use of the staging area as well as preserve an area for staging that might be required to the last moment of steel erection.

**Hidden or discrete connections can be used where there are transportation and erection limitations.** If a standard bolted connection is unsatisfactory from an aesthetic point of view, and a welded site connection is impractical and expensive, alternatives can be provided. Large pieces can be transported and erected efficiently using bolted connections that are hidden or made discrete.

### Connection Mock-Ups

The issue of mock-ups (Characteristic 2.1 - Visual Samples) plays heavily into the design issues related to connections. Most architects would ideally like to be able to see and feel specialty connections before they commit to their mass fabrication. This is not always possible or practical due to issues of timing and cost. The fabrication of large specialty items is expensive and time-consuming. Physical mock-ups can create delays, not only by their fabrication but also by requiring all parties to be present for approvals. Viewing distance also needs to be taken into account when looking at a physical mock-up. Normally those present are examining the sample at close range when in fact the in situ connection may be many metres out of range of view and touch. The AESS Category must be kept in mind when viewing physical samples. It may be possible to verify most of the appearance issues associated with the connections and receive design approval through the use of 3D drawings – a combination of those produced by the fabricator’s detailing software and the ones produced with 3D modeling software. This approach can save time and money. It may also be possible to reference a fabricator’s previous work to establish a baseline for discussion when using digital references.

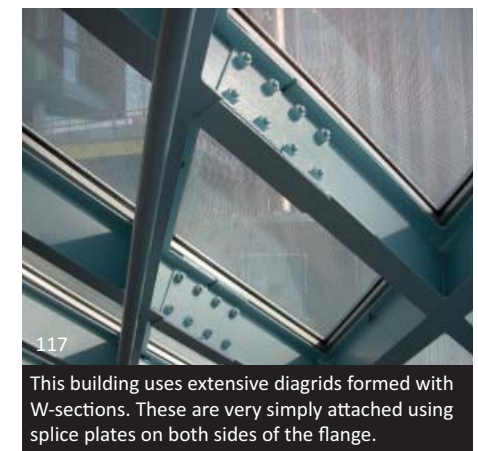
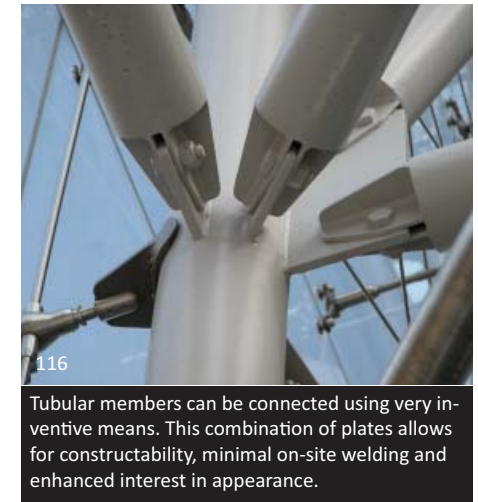
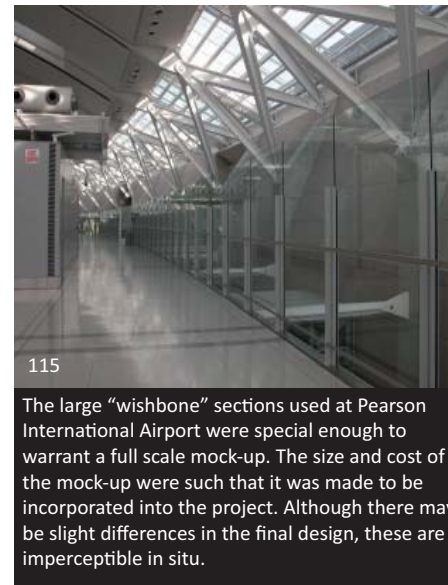
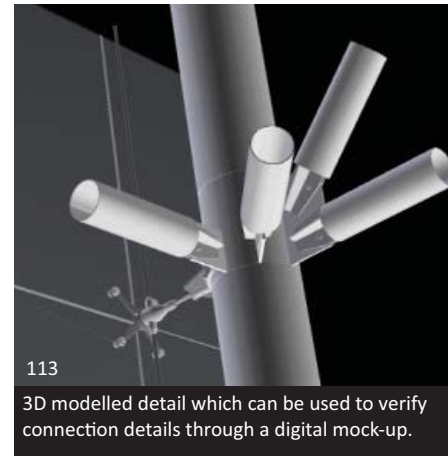
If 3D or other sorts of digital models are to be used as the basis of agreement for details, it is important to discuss the finer aspects of welding, bolting and finishing as these are likely not represented fully in the digital model.

A combination of smaller physical mock-ups of aspects of detailing and finish might be used to accompany digital representations to achieve a good level of communication about the expectations of the project details.

### Which Type of Connection Should I Choose?

The connection type will be dependent on the structural requirements of the assemblies, the shapes and types of steel members that are to be connected as well as the aesthetic that is desired. The type of connection that is most appropriate for a project might not be clearly evident from the outset. As previously mentioned, there are many different types of connections, and it may be necessary as well as desirable to use different types in a project as are suited to the specific range of requirements and AESS Categories (recognizing that viewing distances throughout a project may vary). For overall clarity of the design, these different connections may use a similar language and form a “family” of typical conditions.

As with any project, the overall structural considerations – loads, clear spanning requirements and support location – will form the starting point for the design. More pragmatic issues such as the type of project, use of the space, exposure to weather and atmospheric grime and choice



of fire protection method will begin to influence the choice of AESS Category. It makes little economic sense to invest in highly articulated details if the connections are either out of view or concealed in part by thicker intumescent coatings. If there is significant dirt present in the environment, or if cleaning and maintenance of the structure is difficult, it is best not to create ledges that will collect dirt and surfaces that will highlight lack of maintenance.

Transportation and access to the site will require breaking up the overall concept into smaller elements that may be shipped as well as fit into erection limitations on the site. The majority of site connections tend to be bolted. This does not preclude the use of welded connections on site. Site welding does mean additional costs to put temporary shoring or supporting pieces in place while welding is carried out, and to remove and make good surfaces when these are no longer required. It is also possible to suggest aesthetically pleasing bolted connections.

Budget will also directly impact detailing. If the project can be broken into different Categories of AESS, then the more visible areas can be more expensively detailed. Refer to the Matrix for suggested cost premiums for the AESS Categories, and discuss the same with your Fabricator.

### Bolted Connections

Bolted connections are normally chosen to achieve a more rugged aesthetic for AESS or as a result of erection issues and constraints. Bolted connections are often chosen when using W, C or L-shapes. The more industrial look of these section types seems more aesthetically suited to bolted connections. Often the detailing used on these types of bolted AESS connections is very close to the connections that would be used in standard structural steel. The organization and alignment of members is likely to be either more careful or more creative than is to be found in standard structural steel.

When designing bolted connections, attention should be given to specifying the type of bolt to be used (Characteristic 1.4) as well as the consistency of the side on which the bolt head is to be found. As the structural requirements of the bolted connection dictate how far it needs to be tightened, it is not reasonable to expect the rotation of all heads to align.

Bolted connections are also used with hollow structural members. The typical, practical HSS connection is to weld the intersecting HSS elements in the shop and create stubs with oversized end plates to facilitate erection. If these end plates are not aesthetically satisfying, cap plates and plates slit into the HSS can be detailed to make the connections more discrete. These details are automatically more expensive.

This can be seen in the connections of square HSS members for the Canadian War Museum (Fig. 124). Two types of bolted connections have been employed. One featured a set of overlapping plates (at the X intersection), and the other was designed to facilitate erection using a more standard approach where the plates are welded to the ends of the HSS members and then bolted. The aesthetic of the space and the desire to mimic a twisted war-torn landscape inspired these connections.

### Welded Connections

Shop-welded connections are used on a high proportion of AESS structures. Welding gives a clean, uncluttered appearance. Welding is often used on hollow structural shapes and less often for W, C or L-shapes. That is not to say that welding is not used with W-shapes. Both the National



119  
The aesthetic of this project included a high level of texture using standard structural shapes, and so bolting was chosen.



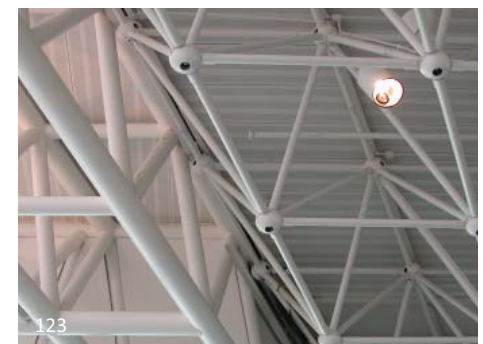
120  
Welded connections have been used here in conjunction with the selection of W-members to create a very technical feel for the Works Yard.



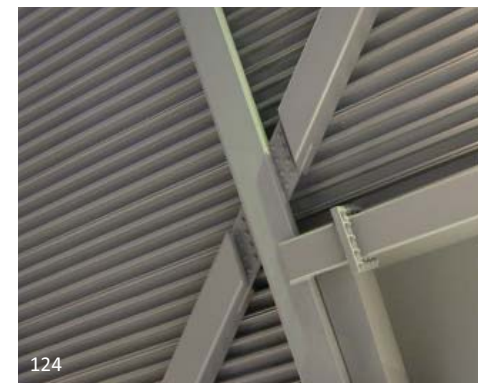
121  
Good quality welding should require no special after-treatment (grinding) for the majority of AESS applications (Categories 1 through 3). Grinding would be considered only for Category 4 applications if a seamless appearance is important.



122  
Although the overall form of this box truss appears complex, the 100% welded connections have been designed with simple geometries.



123  
Space frame systems used to be routinely used to connect large nodes of HSS members. This has given way to the use of all-welded connections in current AESS projects.



124  
These square HSS members are connected both by using overlapping splice plates as well as welded end plates for ease of erection.





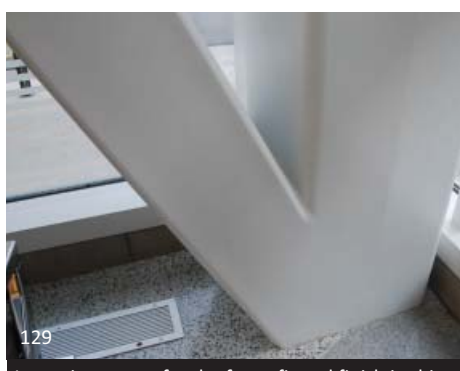
125  
Complex connections using square HSS members are very difficult when it comes to alignment. Circular members are more forgiving. This connection is located on a high-level skylight, so the alignment issue is not really visible.



128  
The large HSS members used on this bridge have helical welds. Although unusual in appearance, they were aesthetically worked into the design.



126  
These tubular members were welded, using both tube-to-tube connections as well as X-shaped plate fabrications to resolve the geometry of the transition.



129  
It was important for the form, fit and finish in this building to have a seamless transition between these two HSS members, so a welded connection was used. All evidence of the joining of the two members was concealed.



127  
Modern equipment makes precision cutting of these intersecting round HSS members much simpler.



130  
A higher cost is the result of this level of complexity for a welded connection. The reveal detail of the connection of the upper structure to the column makes the connection simpler to erect.

Works Yard (Fig. 120) and Art Gallery of Ontario (Fig. 101) incorporated welded connections within the larger portion of the shop-fabricated assembly, and bolted connections for the site work. In the Seattle Public Library (Fig. 117), bolted connections are used for splices between the larger shop-welded sections of the larger diagrid found in the building. In situ, these splices can hardly be differentiated from the larger welded expanses of steel.

Welded connections present different challenges for the fabricator as a function of the connection geometry as it is combined with the choice of member. For complex geometries to be more affordable and for better quality and alignment, it will be necessary to maximize the amount of work that can be done in the fabricator's plant so that proper jigs, lifting and clamping devices can be used to manipulate the materials. It will be necessary to understand transportation restrictions when working through the details of these connections. There will be a maximum member size that will be able to clear bridge overpasses and road widths to avoid clearance mishaps or frequent police escorts or road closures. Where highly articulated assemblies must be broken into smaller elements due to transportation and lifting limitations, it will be helpful to discuss the details of these more significant site connections with the fabricator if a totally welded appearance is the desired end result. It is possible to create site connections that give the appearance of being welded but that are discretely bolted, with the final connection concealed with cover plates.

When deciding upon the level of finish of a welded connection, it is extremely important that the viewing distance and AESS type and associated characteristics be respected. One of the major reasons for cost overruns in AESS has historically been the tendency of welded connections to be overworked. Welds are often ground, filled or smoothed out unnecessarily. Welds are structural, and overgrinding of welds can diminish their strength. Only in Custom or very high-end AESS 4 should grinding be considered as an option for welded connections. Except in the instance of structural necessity, or for seal welding to prevent moisture entry, welding may not even need to be continuous.

## Tubular Steel

Tubular steel – generally hollow structural sections or occasionally mechanical pipe – is often chosen when creating AESS projects. In the case of HSS, the section shapes can be square, rectangular, round or elliptical. Mechanical pipe is only produced round and cannot be used in seismic applications. The choice of the member shape will have a tremendous impact on the design and appearance of the connections. The geometry of the connection – planar, simple angle or multi-member intersection – will impact the cost and complexity of resolving multiple HSS shapes. In some instances the joint can be resolved by cutting and welding. In other instances plates may be needed to simplify the intersection and erection.

In general, HSS tends to be produced using a welding process, whereas pipe tends to be the result of an extrusion process. All HSS sections start out round and are formed to alternate shapes. There will be a welded seam along the HSS, whereas in pipes the shape will be seamless. When designing with HSS the AESS characteristics require that you look at the orientation of this weld seam in the design. A welded seam will tend to be visible even after grinding, depending on the coating process used, as one can only grind perpendicular to a surface. Although there is variance of final texture in extruded shapes and on the coating system used, the final look is likely to reflect the initial relief of the surface. As grinding may not completely conceal the weld seam, even after finish coatings are applied, it is preferable (and less expensive) simply to orient this



natural occurrence consistently or away from the dominant angle of view.

The surface of a welded HSS tends to resemble that of a rolled shape, whereas a pipe may exhibit a light texture akin to an orange peel. This textural difference may be significant if combining hollow section types with other structural shapes in an AECS application where a high level of consistency of finish is desired. Pipe sections are rarely used and are considered a backup plan for most applications.

There will be a variability in the availability of different section sizes, and it is not the same for different diameter ranges. Check with your local service centre for current availability. For large quantities (i.e. over 50 to 70 tonnes) an order can be placed directly to the structural tubing mill. HSS sections with a diameter greater than 400 mm generally require special ordering. Larger diameter tubes (diameter > 500 mm) will be custom-manufactured and will require a minimum 100-tonne quantity when ordering unless they can be bundled with another job. As helical welds are sometimes proposed for large tubular sections, it is important to discuss this with your fabricator and explicitly exclude these in your AECS specification documents if they are not acceptable.

Tapered tubes are not a regular manufactured product. They must be custom-fabricated from a trapezoidal plate that is rolled to form a tapered pole and the seam welded.

### Cast Connections

Cast connections are being used increasingly in projects in Canada. The characteristics of today's steel castings have nothing to do with its earlier cousin: cast iron. Steel castings are higher strength, weldable and more ductile. You generally see castings in conjunction with cable and glass structures, or in complex tubular joints for buildings or bridges. While they bring with them the added advantage of handling complex, curved geometries without the difficulties found using multiple combinations of tubes and plates, they do require a different level of engineering and testing expertise. Economy is found in the mass production of the elements. One-off castings or small runs can be very expensive.

For castings to work, a reason is needed. Is there repetition (so the cost of making the mould is partly amortized – a must)? Are there many elements coming to one point? Do you want to use castings in a high-stress zone? Is there a foundry in your area that has the expertise? Would castings provide aesthetic advantages? If the answer is yes for at least 3 of these questions, then maybe these are appropriate for your project. A rough rule of thumb is that, if the connection starts to cost four times as much as the material it is made of, then steel castings start to be economical.

A cast member has a different finish. This is due to the manufacturing process and a function of the material that creates the form for the casting. For example if a sand casting is used, the surface texture of the finished steel will have a rough sand-like appearance. Special finishing will be required if a seamless final appearance is sought between the casting and the adjacent tubular member. For higher levels of AECS categories, this can mean significant grinding and filling to smooth out the rougher finish of the casting, or remove casting mill marks.

Castings can be formed hollow or solid. Solid castings are usually found in smaller connectors like the ones used to form the terminus of tension rod-type structures. Hollow castings are used for larger members, as it would be difficult to achieve uniform cooling with solid castings and



131

This is a cast connector that would form the end condition of a round HSS section or pipe. You can see the “orange peel” like finish of the raw casting.



134

All of the primary connections on this project are fabricated from cast steel.



132

Custom castings are used to connect the timber columns to the concrete foundations.



135

These complex connections made appropriate use of castings to resolve complex geometries cleanly.



133

Castings used as tension anchors can vary greatly in size, from these pictured here to much smaller ones used to attach rods for stayed structures.



136

A large steel casting was used in this tree-like structure to join several mechanical pipe sections. The joints were filled and sanded to conceal them.

also more expensive. Non-uniform cooling can create internal stresses. Non-destructive evaluation of each casting, including 100% ultrasonic testing, should be considered as a minimum. When selecting a caster, be sure that appropriate testing will be performed.

Large specialty castings require specific testing to ensure that they are properly designed and capable of resisting stresses. Cast steel exhibits isotropic properties, making it quite suitable for transferring forces through the connections in a reliable manner, so as to resist shear, moment and torsional stresses. It accomplishes this by working the geometry as a function of variations in the wall thickness, independently of the finished form of the exterior. Unlike fabrications made from tubes or plates, the interior dimensions of the void in a casting do not have to match the exterior form of the object.

Solid castings are being effectively used in seismic installations.

#### References

- “Convenient Connections”, Carlos de Oliveira and Tabitha Stine, Modern Steel Construction, AISC, July 2008
- “Branching Out”, Terri Meyer Boake, Modern Steel Construction, AISC, July 2008



137

Although steel can be curved to very tight radii, it makes a difference if the steel shape is to be bent “the hard way” or “the easy way”. It will depend on the depth of the section and the curvature. If curves are very tight, some deformation is likely to occur. It is best to check with the fabricator early on in the design process when specifying curved steel.



138

The high profile and very exposed nature of the round bent steel tubes that support this pedestrian bridge meant extra care in bending, splicing and erecting the structure.



139

Steel bending is done at a special facility. The equipment and dies slowly push the steel into the desired curve after several passes through the machine.

## 6 Curves and Cuts

### DESIGNING FOR CURVES AND COMPLEX CUTS

Modern bending equipment, plasma cutters and CNC equipment allow for a wide range of interesting variations in AESS projects. As much of this work is highly equipment-dependent, and such equipment is very costly, it is a good idea to verify the capabilities of fabricators that might be bidding the job to ensure that their shop can handle the work on site, or that they can make arrangements to sub out work that they cannot handle.

#### Bending

Bending steel is a specialty subset of fabrication and is becoming increasingly popular in AESS work. Most steel fabricators do not own bending equipment and will subcontract this work out. Bending steel requires specialized equipment. There are also limits on the tightness of the radius that steel can be bent to as a function of:

- the diameter or overall section dimensions of the steel
- the thickness of the steel
- the type of section
- the direction of the bending (perpendicular or parallel to its weak axis)

In general terms, “easy way” is bending the steel around its weak axis and “hard way” is bending the steel around its strong axis.

If bending tighter than the advised tightness of radius, deformation or distortion will occur. If the deformation is small enough, and the steel is AESS 3 or 4, out-of-plane surfaces may be filled and sanded prior to painting to hide the defects. If the distortion is small and the steel is AESS 1 or 2, viewed at a greater distance, there may not be any need for corrective work.

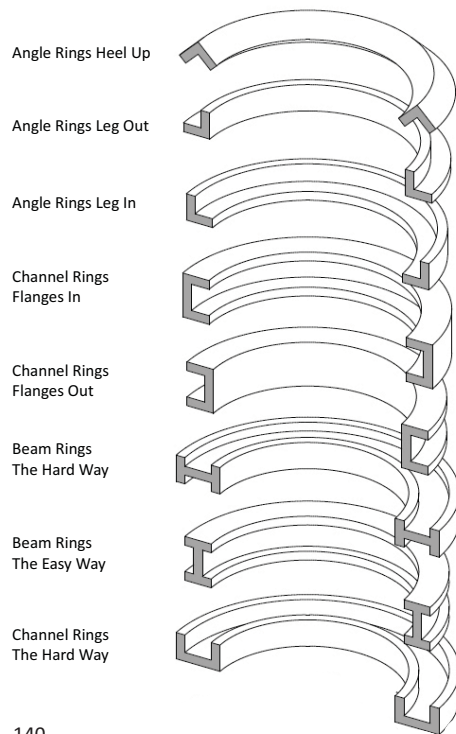
**It is preferable if the bent steel member can be designed to be continuous.** If splicing needs to occur to achieve a longer piece, or to join two sections of a complex project together, it is next to impossible to ensure that the pieces will align properly due to the natural distortion of the steel shape during the bending process. This is more easily done using W sections, but very difficult when designing with HSS shapes or pipe. It is important to be realistic about the expectations of the connected pieces. Connection styles may be considered that do not attempt to create the impression of flawless continuity.

A certain length of steel is lost to the bending process. The lengths of the member clamped at either end in the equipment are not bent. Extra steel will need to be purchased for each piece to ensure that the lengths delivered to site are long enough.

#### Reference

- “What Engineers Should Know About Bending Steel”, Todd Alwood, Modern Steel Construction, AISC, May 2006.





140

The minimum bending radius permitted will depend on the section type and its orientation.



141

Elliptical tubes are a new product that is seeing increasing use. These tubes are used to support a high curtain wall in an airport. The weld seam is located on the top of the member as the predominant viewing angle is from below.

## Elliptical Tubes

Elliptical tubes are relatively new to the AECS scene. Their use started in Europe and is making its way into North American architecture. EHS have greater bending capacity than circular hollow sections of the same area or weight, due to their strong and weak axis directions, but still maintain a smooth closed shape. There is also reduced visual intrusion compared to regular circular HSS, if the member is viewed from one predominant direction.

All EHS are produced, with major-to-minor axis dimensions of 2:1, as hot-finished hollow structural. They are produced as continuously welded sections, joined by high-frequency induction welding and finished to their final shape at extremely high (normalizing) temperatures, with the outside weld bead removed but the inside weld bead typically left in place. Due to the hot finishing process, EHS have a fine grain structure, uniform mechanical properties, excellent weldability, negligible residual stress, are suitable for hot-dip galvanizing and are applicable to dynamic loading situations. Elliptical tubes have similar material properties to regular HSS members, and similar connection methods can be used in their connection detailing. They are often used in front of glazing, as their shape is less obtrusive and blocks less of the view and light coming into the space.

## References

- "Going Elliptical", Jeff Packer, Modern Steel Construction, AISC, March 2008
- "Elliptical Hollow Sections – Three-Part Series, Part One: Properties And Applications", Jeff Packer, Advantage Steel No. 35, CISC, Fall 2009
- "Elliptical Sections – Three-Part Series, Part Three: EHS Connection Design", Jeff Packer, Advantage Steel No. 37, CISC, Summer 2010

## SPECIALIZED EQUIPMENT

When steel enters the fabrication shop, it is normally initially sized by sawing. New specialized equipment, often using robotics to control welding, cutting, drilling and punching, are additionally used to alter the steel. This specialized equipment allows for a very high level of precision when fabricating complex geometries. When examining bids for any job that might require the use of such equipment, it will be necessary to determine the shop capabilities of the fabricators bidding the job. Such equipment is very expensive. The use of such specialty equipment may enable increased fabrication speed and the inclusion of fine details but is likely to incur an increase in cost to the project. It is common for fabricators to sub out work to another shop that may own such equipment.

## Shearing

Shearing, also known as die cutting, is a metalworking process which cuts stock without the formation of chips or the use of burning or melting. If the cutting blades are straight the process is called shearing; if the cutting blades are curved then they are shearing-type operations. Sheet



This curved section is distorted at its splice, making a smooth welded connection difficult to achieve.

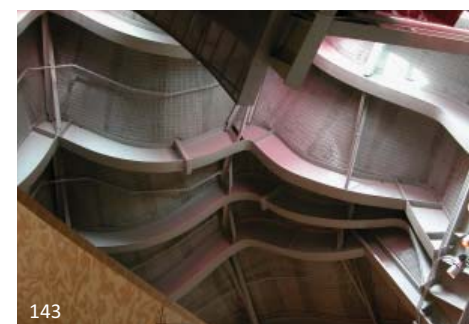
metal or plates as well as steel rods are commonly cut by shearing. The edges of sheared steel are typically sharp and will require finishing when used in AECS applications.

## CNC Cutting

A "Computer Numerical Controlled" device can be used to facilitate more complicated or repetitive cutting. The full potential of the device can only be realized if taking its instructions from CAD/CAM software. A CNC method can be used in conjunction with a number of different steel-cutting methods. These include torch cutting, routing, plasma cutting, water jet cutting and laser cutting. It can also be used to control hole drilling. CNC processes have become very commonly used in steel fabrication shops, particularly in AECS work.

## Plasma Cutting

Plasma is a gas in which a certain percentage of particles is ionized. Plasma cutting is a process for cutting steel of different thicknesses using a plasma torch. In this process, an inert gas (in some units, compressed air) is blown at high speed out of a nozzle; at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and



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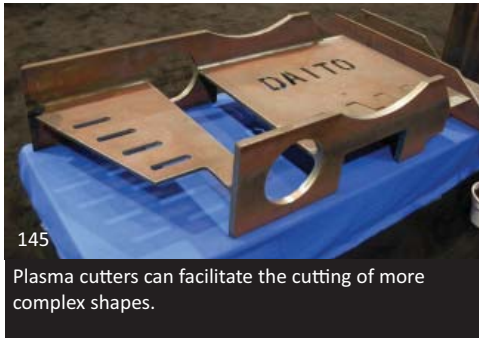
The curved steel W-sections in this exposed installation are joined with moment-resisting connections. The overall aesthetic is rougher, and with the steel located at a high ceiling level, the finish requirements would be less than for curved steel located at a more easily viewed level using welded connections and HSS members.





144

Modern hole-drilling equipment is clean, quick and precise.



145

Plasma cutters can facilitate the cutting of more complex shapes.



146

Plasma cutters combined with CNC equipment can achieve a very fine level of detail.



147

Grinding is done by hand to remove or smooth out the finish where operations must be concealed. This adds significantly to the time and, therefore, cost of the fabrication.



148

Automated torch cutting of a piece of steel plate. If torch cutting is used on AESS material, the edges will need treatment to make them smooth for even-finish applications.



149

Several kinds of cuts are required to connect this plate to the HSS member to create a pin connection.



150

The drilling of holes is an automated process. This ensures that holes are drilled with very even spacing on each member.

moves sufficiently fast to blow molten metal away from the cut. Plasma cutting is effective for material no greater than 50 mm.

### Torch or Flame Cutting

Torch cutting is also called oxy-fuel cutting. This process uses fuel gases and oxygen to cut the steel. In oxy-fuel cutting, a cutting torch heats metal to kindling temperature. A stream of oxygen is trained on the metal, and metal burns in that oxygen and then flows out of the cut as an oxide slag. Oxy-acetylene can only cut low- to medium-carbon steels and wrought iron. Since the melted metal flows out of the workpiece, there must be room on the opposite side of the workpiece for the spray to exit. This type of torch can be part of a large robotic device or a small portable handheld device.

The way that steel is cut will influence the level of detail as well as the amount of remediation required. Most cutting today is performed using CNC control although manual cutting can still be done. Manual cutting requires more clean-up depending on the skill of the operator and the level of AESS expected.

### Thickness limits:

- Plasma cutting: The thickness of steel with this method is typically  $\frac{1}{4}$ " to  $1\frac{1}{4}$ " (6 to 30 mm).
- Oxy-fuel cutting: This is the most common method and the thickness of material is unlimited.
- Water jet cutting: This method is less common and the limits on steel thickness are not known.
- Laser Cutting: This method is used on material in the range of  $\frac{1}{16}$ " up to a practical limit of  $\frac{3}{4}$ " (1.5 to 20 mm).

For exceptionally thick steel, in the range of 150 mm or greater, oxy-fuel cutting would normally be used. Plasma and oxy-fuel require moderate to heavy amounts of grinding if all cutting marks are to be eliminated from the plate edges. Laser and water-jet cut edges require minimal grinding. Any cut perpendicular to the material can be accomplished using CNC; however, plasma and oxy-fuel have limitations on width-to-thickness ratios of cuts. For example, you cannot practically oxy-fuel cut a hole with a diameter smaller than the thickness as this will result in too much melting and poor quality.

### Hole Punching and Drilling

Modern equipment has greatly improved hole punching and drilling, allowing for the high level of precision that is required in complex AESS structures. It is essential that the steel used in the project meet the half-standard tolerance characteristic of precision drilling in order to be of ultimate benefit to the project. Hole drilling can be done in conjunction with CNC equipment for greater precision and speed. For the cleanest results in hole punching, the plate thickness should be no greater than 1" (25 mm). The correct size relationship between the punch and the die hole will produce a cleaner top edge, straighter hole and minimum burr on the bottom edge. The hole size should be no greater than the plate thickness plus  $\frac{1}{16}$ " (1.5 mm) to the maximum of 1" (25 mm).

Although very complex shapes are possible using modern equipment, this does come at some cost to the project. It is good to remember that holes, circles and lines can be used in combination to make clean cut-outs which do not require the extra expense of specialized equipment.

# 7 Erection Considerations

## HANDLING THE STEEL

### Transportation Issues

As quality of finish and precision of installation are paramount with AESS, it is necessary to maximize the amount of fabrication and painting that can be carried out in the fabricator's shop. This may mean that members can become increasingly large and difficult to transport. It will be essential for the fabricator to map the clearances from the shop to the site to ensure that the pieces will fit for easy transport, including turning radii for narrow streets. It is obviously better (and less expensive) to avoid requiring an escort or street closures. The standard limit for size would be to ship on a flatbed trailer.

To prevent damage, members may have to be shipped separately rather than maximizing the allowable tonnage per trailer. More delicate members may require the use of temporary steel bracing to prevent distortion from road movement, off-loading and subsequent lifting.

### Sequencing of Lifts

Just-in-time delivery is needed to ensure proper sequencing and avoid damaging the pieces. Many sites are constricted and have insufficient staging area to provide holding for the steel. The erector will arrange lift sequences to minimize the amount of steel that is on the site at any time.

Construction sequencing for architecturally exposed steel members places further limitations on detailing and increases the challenge of erection. The 90-foot-long steel columns that support the upper structure of the addition to the Ontario College of Art and Design were pre-finished at the fabrication shop with a coloured fire-resistant intumescent coating. Not only was the street access extremely



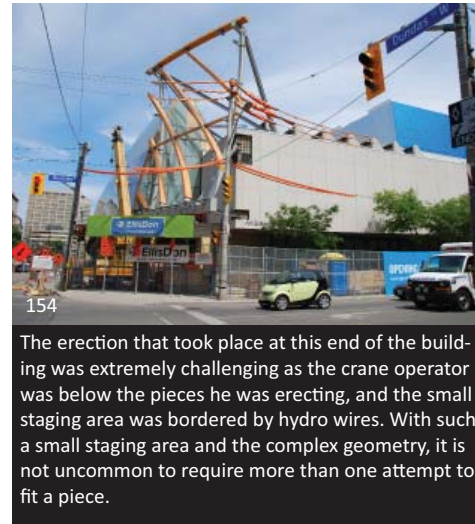
Only one piece of steel will be shipped on this truck to prevent damage to the piece.



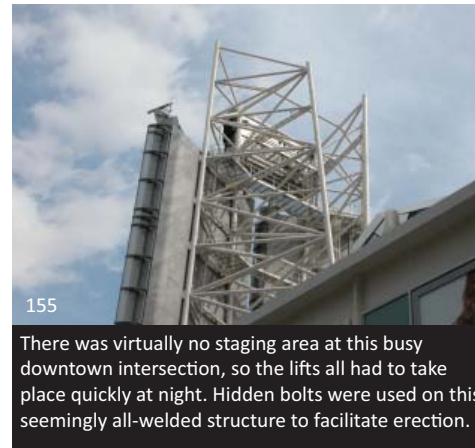
A temporary piece of steel joins the two points to stabilize the piece during shipping and erection.



These pieces were so long that they could not fit on a normal trailer bed but were fitted with separate wheels on the back. This configuration also allowed for these extra long members to navigate around difficult corners.



The erection that took place at this end of the building was extremely challenging as the crane operator was below the pieces he was erecting, and the small staging area was bordered by hydro wires. With such a small staging area and the complex geometry, it is not uncommon to require more than one attempt to fit a piece.



There was virtually no staging area at this busy downtown intersection, so the lifts all had to take place quickly at night. Hidden bolts were used on this seemingly all-welded structure to facilitate erection.



The blue frames are temporary supports that were constructed to shore up the sloped columns precisely, using padded support points so as not to damage the intumescent shop-applied coating.

restrictive, but also care had to be taken to preserve the integrity of the intumescent coating during handling and erection. A custom set of supports (blue) was constructed to hold the members in place until proper lateral bracing could be provided. The finish had to be touched up intermittently throughout the construction process due to unavoidable nicks and scratches, the result of routine construction processes – processes that would not cause extra expense on a more routine use of structural steel.

### Site Constraints

It is not uncommon for sub-assembly to occur on site in the staging area for oversized or geometrically complex members. The size of the staging area will figure into design decisions that will affect the types of connections that are employed in aggregating very large members. Where quality welding can be easily carried out in the shop, such will not be as easy in the staging area without benefit of jigs. If an all-welded appearance is desired, the design may need to make use of inventive hidden bolted connections to simplify erection.

Constricted sites are common in dense urban areas. Lane closures may be required on fronting streets to provide for staging and erection, particularly when building to the lot line.

### Care in Handling

AESS requires more care in handling to avoid damage to the members. Oddly shaped or eccentric members can easily be distorted or bent if improperly handled. Many of the members that come to the site might also be pre-finished (paint, galvanizing or intumescent coatings), so padded slings will be required to avoid marking the finish coat.

The more precisely fabricated the pieces, the less force will be required to fit them during erection.

Often steel will be shipped with temporary supports, backing bars or bridging attached to



prevent deformation during shipping and erection. These supports are removed after the steel is lifted into place and the weld marks removed prior to the application of finishes.

### Erection Issues

Erecting AESS will vary with the complexity of the project. If the steel members have been accurately constructed with no less than half the standard tolerances, fitting issues should be minimized but may not be eliminated.

With odd geometries and asymmetry of members, the lifting points will need to be more carefully pre-calculated. Standard structural steel elements tend to be more regular, with vertical columns and horizontal, relatively uniform beams. The lifting points are predictable and make assembly on site routine and quick. With diagonal or unbalanced members, gravity will not be of assistance and lifting points may require more calculation than normal. There may be erection delays in projects where each element is unique, as each will present a different challenge to be solved that may have no precedent. It is not unreasonable for some members to require more than one attempt due to alignment or geometry issues. There can be holes or small attachments to the steel strictly to facilitate erection. Care must be taken to minimize and remove these elements.

Where steel is pre-finished, extra care must be taken during erection so as not to damage the finish. In some cases padded slings will be used in conjunction with regular lifting chains to prevent damage to finishes. This might also be done with primed steel where a high-gloss finish is anticipated, again to prevent damage to the surface of the steel.

### Combining Steel with Timber

Steel is often used with structural timber. Pairing steel and wood in a single project can lead to unique assemblies of sustainable and aesthetically pleasing hybrid structures. The strength of steel lessens the bulk and provides an economy of structure that would not be possible with an all-wood design. The warmth of wood can add a welcoming touch to an all-steel building.

Steel and wood are two very different materials and combining them can be a challenge to designers. Steel is a manufactured product – strong, predictable and infinitely recyclable. Wood is a natural material – relatively weak, variable in strength but renewable. Temperature differentials cause steel to expand and contract but have little effect on wood; however, changes in humidity, which have little effect on steel, can cause wood to shrink and permanently change its dimensions. Wood is described as a heterogeneous, hygroscopic, cellular and anisotropic material. That means it is made up of a diverse range of different items, it attracts water molecules from the environment through absorption or adsorption, it has a cellular structure and its properties are directionally dependent.

Because of their different properties, connections between wood and steel can be difficult. A major issue is the different expansion and contraction coefficients when combining AESS with wood. Additionally, steel excels in tension while wood reacts much better to compression. There are analytical programs available now to help set up the structure needed when combining the materials, so in considering AESS with wood, make sure that the fabricator is familiar or has experience with the application. In some cases, slotted holes in the steel can allow for some movement of the wood. The important thing in creating a hybrid structural system is to remember the strengths of each material and in what context each of them works best. Because steel



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These special galvanized fittings work well with the glued-laminated timber system. Part of this canopy will be exposed to humidity and so corrosion protection is required. Also, the finish will last a long time and the connections would be difficult to access for refinishing.

is a much stronger material, a hybrid wood/steel truss design should have the wood on top of the truss (in compression) and the steel at the bottom chord (in tension). In this way, the wood elements butt against each other with very little bolting. This also avoids large connections at the bottom truss since steel is transferring the high-tension forces.

Both materials have issues with moisture. Steel is subject to oxidation while wood is subject to decay.

There are concerns where wood and steel come into direct contact with each other. Steel needs to be protected, by galvanizing or coating with a specific paint system, in order to resist the humidity changes in the wood. It also helps to use dry wood instead of green wood at the interface if possible because it moves less over time. Because it is important to limit the restraint imposed by the steel connecting elements, a bolted steel connection should not span the full depth of a wood element. On bridges, where timber decking is supported by steel girders, the two materials should be separated by a waterproof membrane.



158

The curved glulam facade of the Art Gallery of Ontario is entirely supported by a steel frame that takes its eccentric, twisting load back to the building. A combination of painted grey and galvanized steel is used.

Steel is a crucial element in the design of hybrid structures because it allows the use of slender, delicate profiles that would not be possible with wood alone.

When using steel and wood together, the designer has to be very aware of balance. On a primarily AESS structure, there has to be enough wood to warm up the building, and on a primarily wood structure, there has to be enough steel to provide some interest.



159

The steel and glulam arches of Brentwood Station were fabricated at the steel fabricator's plant to ensure proper fit and coordination of the erection process.

From a fabricator's perspective, a hybrid project can be carried out in the steel fabricator's shop. It is helpful if the fabricator has some experience with working with wood, as the processes and connection details differ from straight AESS work. There are concerns about damaging the wood in the shop, either through handling or by welding or heating steel too close to the wood in the structure. The use of a heat shield can protect the steel



from scorching during adjacent welding. The wood needs to maintain its protective covering until it arrives on site, only peeling away areas requiring work. The wood should not be walked upon, as is customary in working large steel, as damage can result. Covering saw horses with wood and carpeting and using nylon slings to move the wood beams rather than the chains and hooks usually used with steel will minimize problems. In selecting a fabricator it is important to make sure that everyone in the shop is aware of the differences in the materials.

The staging and erection of a hybrid system is similar to regular AESS with the exception that the wood must be handled more gently. Depending on the size and complexity of the members, the physical connections between materials can either be done in the fabrication shop, then shipped, or combined on site in the staging area. Precision in fit is even more important as wood members cannot be forcibly fit, or cracking will occur. Padded slings need to be used to lift the members so as not to damage the wood. Protective wrappings need to stay in place until well after the erection is complete to continue to provide weather protection.

Most importantly, someone has to take charge of the project. This is the only way to ensure a proper fit between the materials and to ensure coordination from start to finish. It is possible to have the steel fabricator coordinate shop drawings, delivery schedule and erection.

#### Reference

- “Steel and Other Materials, Part Two: Steel and Wood”, John Leckie, Advantage Steel No. 30, CISC, Winter 2007

### Combining Steel with Glass

New technological developments have both increased the options available and reduced the difficulties in designing, detailing and erecting AESS steel and glass buildings.

There are three basic ways to consider the way in which steel acts as a support system for



160 Steel connections are used to join this timber structure. It can be seen that the steel connection pieces are fitted with a plate that penetrates the end of the timber. Bolts through the assembly secure the plate to the timber. In this case the penetration slot is left exposed. These will often be filled or hidden to make the connections more mysterious.



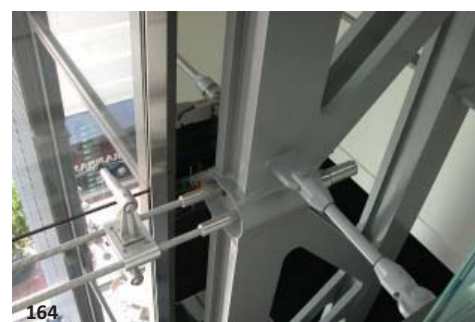
161 The heavy timber on this sculptural project is really “for show” as the main support system is all steel and the large square wood sections are used only to bulk out the form and provide a contrast with the steel used to support the glass.



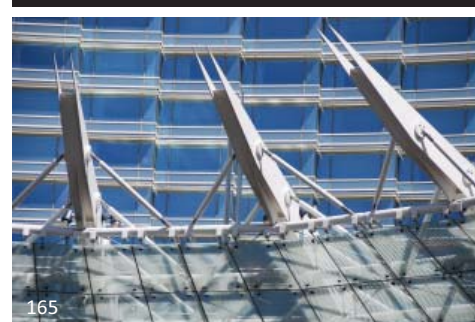
162 The large arches over the Richmond Speed Skating Oval are fabricated from a combination of steel and wood, with the majority of the steel hidden beneath the wood cladding of the arches.



163 The AESS system illustrated here uses a specialized vertical truss-like column formed from round HSS sections and plates, with holes cut into the plates to lighten the appearance of the system, to act as the lateral wind load support for this very tall expanse of glass at Pearson Airport. The thin profile of the steel appears as a simple extension of the curtain wall.



164 A highly articulated vertical truss at either end of a cable system is used to provide wind support for a large expanse of glass at the Newseum. Stainless steel clamps connect the spider connectors to the cables.



165 A suite of articulated steel arms cantilever out over a hotel drop-off area. Diagonal rods with stainless connectors support the glazed roof.

expansive glazed applications:

- The steel framework is used simultaneously as the structure and the method of holding the glass in place, whereby the glass is virtually in the same plane as the steel.
- Larger steel members are used directly behind (or in front of) the glass system to provide wind bracing; these members can be installed vertically or horizontally at the mullions and usually do not also support the floor loads above; structural steel sections, trusses or cable systems are used.
- The steel structure sits back from the glass to provide the lateral support and creates a separate, unique structure of its own; an interstitial support system (often cables) is used to connect the glass to the steel.

Tempered glass is most commonly used in these applications. Glass is tempered by heating it to 650 to 700° C and rapidly cooling it so the centre retains a higher temperature than the surface. As the centre cools, the resulting contraction induces compressive stresses at the surface and tensile stresses in the core which can produce a pane of glass four or five times stronger than annealed or float glass. Protection against breakage can be enhanced by laminated units where multiple layers of glass are bonded by a layer of plastic sheet material. The combination of different layers improves post-breakage behaviour of the glass and gives designers and building owners more confidence to use it in larger applications.

Many AESS and glass structures are designed as signature elements of the building. The steel interface elements of these signature structures transfer portions of the wind loads to the steel superstructure, hence the interface elements are generally small, but a much higher emphasis is placed on their visual appeal. The steel fabricator retained must be familiar with AESS, as the finishes and interface tolerances are more stringent than for standard structural steel.

Much of the supporting AESS used in these systems is welded for a cleaner appearance. Bolted connections are seldom chosen when

creating tall supporting systems for expanses of glass. Precision in the welding of the steel elements is particularly important as the welding process naturally distorts the steel. If more welding is required on one side of a long supporting member, it can result in bowing of the member.

One of the problems of working with steel and glass is the relative tolerances in producing the materials. Glass requires higher precision with tolerances of  $\pm 2$  mm while the tolerances for steel are  $\pm 5$  mm. The differences have to be accommodated during the installation in order to keep the glass panels properly aligned. Because the glass panels are normally aligned with the steel elements, poor alignment will be quite apparent.

There are a number of methods for connecting the glass panels to the structural supports. The most commonly used is the spider bracket which has one to four arms coming out of a central hub. Bolts through the glass panels are secured to the arms and the brackets are attached to the support structure. Angle brackets, single brackets, pin brackets or clamping devices are all alternatives that are used on occasion. The panels are usually secured at the four corners with an additional pair of bolts in the middle of each side for larger panels. In Europe particularly, bolted systems are slipping from favour and designers there tend to use a clip system where the panels are supported on the side, removing the need to drill holes in the glass.

It is critical to have a high level of communication between the architect, engineer and fabricator on these types of projects, as coordination must be very precise. Each project will have slightly different parameters, and it is possible to adjust the glass support system to suit the overall look of the balance of the AESS on the project. The AESS portion of the support system can be accomplished in a variety of ways, all capable of connecting to the stainless steel spider connectors. Methods include: vertical trusses, thin vertical columns, elliptical tubes, cable net systems, tension



166 Spider connectors are used to connect this mullion-less glass to a tubular steel frame at the top of the expanse of window of this Las Vegas Hotel lobby. The coordination for this detail is extremely tight, with little room for discrepancy given the proximity of the steel tube to the inside face of the glass.



167 Although the interior of this lobby would give the appearance of being supported in heavy timber, here we can see that the framing is steel with wood cladding. This permits the connection of spider connectors to the steel structure hidden inside.



168 This tubular steel framing system connects to the sloped curtain wall in a more traditional fashion with slim line supports being fairly concealed behind the profile of the HSS sections.



169 Alignment issues between the glass and steel support frame are taken care of by levelling mechanisms that are part of the glass connection system. These are located on the rear of the canopy and are not visible from the front, allowing for clean lines and uniformity on the public side of the system.



170 The steel supports for this double façade envelope use a system of clips to support the extra layer of glass. This alleviates issues of drilling of the glass and allows for better accommodation of differential movement between the systems.



171 Stainless steel cables are used in conjunction with laminated structural glass and stainless spider connectors to support this large glazed façade at a Berlin rail station.

rods, stainless steel tension systems (either by themselves or in conjunction with larger AESS carbon steel members). Structural glass fins can be used as the primary means of lateral/wind support or in conjunction with AESS systems.

The support system can also bear on the floor or be suspended from the floor above. More recently some cable systems are spanning across the width of the glazed façade and transferring the load to adjacent columns or vertical trusses.

In all cases a substantial amount of movement must be accommodated in the design of the system. Glazed façades are often subjected to high levels of solar gain, and so differential movement in the steel and glass will need to be accounted for due to temperature. Wind loads will cause differing deflections at the centre of the spans versus the top, bottom or side support points. Changes in floor loading both during construction and during the life of the building must be accounted for. Systems must also allow for vertical differential movement, often achieved by the use of slip joints that simultaneously allow movement up and down, while restricting the joint laterally for wind loads. Silicon is often used to fill the gaps between the panels once construction is complete.

Glass continues to be very brittle and sensitive to local stress concentrations. Hence, much attention has to be spent designing the interface between glass and steel to resolve issues of material compatibility, and reach the desired aesthetic objective.

As concerns about energy efficiency and preventing unwanted heat gain continue to grow, these sorts of facades promise to be even more challenging to design as external shading devices grow in use as a means of lowering cooling loads.

#### Reference

- "Steel and Other Materials, Part One: Steel and Glass", John Leckie, Advantage Steel No. 29, CISC Summer 2007



# 8 Special Acknowledgments

The AESS Story in Canada started in 2005 with the CISC Ad Hoc Committee. The idea was to create a dynamic industry dialogue, including architects and engineers, in the hopes of providing a series of documents that would assist in re-visioning the design, specification and construction process for AESS.

In the following two years, CISC adapted components of what AISC had developed, but it also introduced an underlining Category approach and reduced its scope. The committee developed a Sample Specification (for engineers), an addition to the CISC Code of Standard Practice (for fabricators) and a Guide (for architects). Common to all these documents is the unique Matrix of Categories and Characteristics to be used by all.

In parallel, several roundtables were held in Montreal, Toronto and Vancouver, which would typically involve architects, engineers and fabricators. Those sessions helped shape the orientation and direction of the committee's work on the documents.

We wish to acknowledge all the hard work from the committee members, the roundtable participants, CISC staff and the author, Terri Meyer Boake. Walter Koppelaar, chair of the committee, introduced the importance of a strong differentiation of Categories. Michel Lafrance suggested the step-like matrix of Categories, which became a central tool in the process. Rob Third was immensely active in the refinement stage of the documents. All CISC regions reviewed the documents and suggested changes.

Finally, our warmest thanks go to Terri Meyer Boake. It is with unsurpassed enthusiasm and a passion for teaching that Terri has travelled in Canada and around the globe to gain understanding and deliver beautiful, inspiring photos. She has asked thousands of questions and dug into the topic with the curious eyes of an architect, a teacher, a photographer, a writer, a detective and a friend of the industry.

So now the wait is over. The third of the series of CISC AESS documents is available in the form of this Guide. May all design professionals wishing to have fun with steel, to improve communication in order to satisfy aesthetic, economic and construction criteria use this Guide at work, at home, at school and start specifying AESS Categories in your projects. Enjoy!

Sylvie Boulanger  
CISC

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Harrison Wilson Ocean Steel Atlantic Region	Stéphane Rivest Bureau D'études Spécialisées (BÉS)
	Jacques White Université Laval School of Architecture



# 9 References and Image Credits

## REFERENCES

The following articles, journal publications and books were referenced in the creation of this Guide:

### **Advantage Steel | Ask Dr. Sylvie Column**

An excellent resource included in each Advantage Steel issue from Spring 2003 to Fall 2010

Advantage Steel issues are available online at:

<http://www.cisc-icca.ca/content/publications/publications.aspx>

### **The Canadian Matrix: A Category Approach for Specifying AESS**

A presentation of CISC's new Category Approach of AESS1 through AESS4 including a handy pull-out centerfold of the Category Matrix

by Sylvie Boulanger and Terri Meyer Boake

Advantage Steel No. 31 | Summer 2008

### **Steel and Other Materials, Part Two: Steel and Wood**

A detailed look at the technical aspects of effective design with composite steel and wood structures

by John Leckie

Advantage Steel No. 30 | Winter 2007

### **Steel and Other Materials, Part One: Steel and Glass**

A look at the detailed interaction of steel and glass in buildings

by John Leckie

Advantage Steel No. 29 | Summer 2007

### **Architecturally Exposed Structural Steel: How Is It Defined?**

by Terri Meyer Boake

A look into the design process and criteria that will be used to create the upcoming Canadian AESS Specification and Guide

Advantage Steel No. 22 | Spring 2005

### **A Categorical Approach: The Canadian Institute of Steel Construction Is Taking a New Approach to Specifying AESS Requirements**

by Sylvie Boulanger, Terri Meyer Boake and Walter Koppelaar

A detailed look at the new Canadian AESS Matrix.

Modern Steel Construction | April 2008

### **Architecturally Exposed Structural Steel: A Design Guide**

Modern Steel Construction | May 2003

### **Convenient Connections**

by Carlos de Oliveira and Tabitha Stine

Modern Steel Construction | July 2008

### **Branching Out**

by Terri Meyer Boake

Modern Steel Construction | July 2008

### **What Engineers Should Know About Bending Steel**

by Todd Alwood

Modern Steel Construction | May 2006

### **Going Elliptical**

by Jeff Packer

Modern Steel Construction | March 2008

### **Elliptical Hollow Sections – Three-Part Series, Part One: Properties and Applications**

by Jeff Packer

Advantage Steel No. 35 | Fall 2009

### **Elliptical Sections – Three-Part Series, Part Three: EHS Connection Design**

by Jeff Packer

Advantage Steel No. 37 | Spring 2010

### **Understanding Steel Construction: An Architect's View**

by Terri Meyer Boake, illustrations by Vincent Hui

Birkhauser, 2011

## IMAGE CREDITS

Front and rear covers and, unless otherwise noted, all photos by Terri Meyer Boake  
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# Appendix 1 - CISC Code of Standard Practice

## CISC CODE OF STANDARD PRACTICE – APPENDIX I Architecturally Exposed Structural Steel (AESS)

For a downloadable, electronic version of the CISC Code of Standard Practice, please visit:  
<http://www.cisc-icca.ca/aess/>

### 11. SCOPE AND REQUIREMENTS

**11.1 General Requirements.** When members are specifically designated as “Architecturally Exposed Structural Steel” or “AESS” in the Contract Documents, the requirements in Sections 1 through 7 shall apply as modified by this Appendix. AESS members or components shall be fabricated and erected with the care and dimensional tolerances that are stipulated in Sections 1.2 through 1.5.

**11.2 Definition of Categories.** Categories are listed in the AESS Matrix shown in Table I1 where each Category is represented by a set of Characteristics. The following Categories shall be used when referring to AESS:

- |                |   |
|----------------|---|
| <b>AESS 1:</b> | <b>Basic Elements</b><br>Suitable for “basic” elements which require enhanced workmanship.  |
| <b>AESS 2:</b> | <b>Feature Elements Viewed at a Distance &gt; 6 m</b><br>Suitable for “feature” elements viewed at a distance greater than six metres. The process involves basically good fabrication practices with enhanced treatment of weld, connection and fabrication detail, tolerances for gaps, and copes.  |
| <b>AESS 3:</b> | <b>Feature Elements Viewed at a Distance ≤ 6 m</b><br>Suitable for “feature” elements – where the designer is comfortable allowing the viewer to see the art of metalworking. Welds are generally smooth but visible; some grind marks are acceptable. Tolerances are tighter than normal standards. The structure is normally viewed closer than six metres and is frequently subject to touching by the public. |
| <b>AESS 4:</b> | <b>Showcase Elements</b><br>Suitable for “showcase or dominant” elements – where the designer intends the form to be the only feature showing in an element. All welds are ground, and filled edges are ground square and true. All surfaces are sanded/filled. Tolerances of fabricated forms are more stringent – generally one-half of the standard tolerance. All surfaces are to be “glove” smooth.          |
| <b>AESS C:</b> | <b>Custom Elements</b><br>Suitable for elements which require a different set of Characteristics than specified in Categories 1, 2, 3 or 4.   |

**11.3 Additional Information.** The following additional information shall be provided in the Contract Documents when AESS is specified:

- a) Specific identification of members or components that are AESS using the AESS Categories listed in I1.2. Refer to Table I1;
- b) Fabrication and/or erection tolerances that are to be more restrictive than provided for in this Appendix;
- c) For Categories AESS 2, 3, 4 requirements, if any, of a visual sample or first-off component for inspection and acceptance standards prior to the start of fabrication;
- d) For Category AESS C, the AESS Matrix included in Table I1 shall be used to specify the required treatment of the element.

### 12. SHOP DETAIL, ARRANGEMENT AND ERECTION DRAWINGS

**12.1 Identification.** All members designated as AESS members are to be clearly identified with a Category, either AESS 1, 2, 3, 4 or C, on all shop detail, arrangement and erection drawings.

**12.2 Variations.** Any variations from the AESS Categories listed must be clearly noted. These variations could include machined surfaces, locally abraded surfaces, and forgings. In addition:

- a) If a distinction is to be made between different surfaces or parts of members, the transition line/plane must be clearly identified/defined on the shop detail, arrangement and erection drawings;
- b) Tack welds, temporary braces and fixtures used in fabrication are to be indicated on shop drawings;
- c) All architecturally sensitive connection details will be submitted for approval by the Architect/Engineer prior to completion of shop detail drawings.

### 13. FABRICATION

**13.1 General Fabrication.** The fabricator is to take special care in handling the steel to avoid marking or distorting the steel members.

- a) All slings will be nylon-type or chains with softeners or wire rope with softeners.
- b) Care shall be taken to minimize damage to any shop paint or coating.
- c) If temporary braces or fixtures are required during fabrication or shipment, or to facilitate erection, care must be taken to avoid and/or repair any blemishes or unsightly surfaces resulting from the use or removal of such temporary elements.
- d) Tack welds shall be ground smooth.

**13.2 Unfinished, Reused or Weathering Steel.** Members fabricated of unfinished, reused or weathering steel that are to be AESS may still have erection marks, painted marks or other marks on surfaces in the completed structure. Special requirements shall be specified as Category AESS C.



**13.3 Tolerances for Rolled Shapes.** The permissible tolerances for depth, width, out-of-square, camber and sweep of rolled shapes shall be as specified in CSA G40.20/21 and ASTM A6. The following exceptions apply:

- a) For Categories AESS 3 and 4: the matching of abutting cross-sections shall be required;
- b) For Categories AESS 2, 3 and 4: the as-fabricated straightness tolerance of a member is one-half of the standard camber and sweep tolerance in CSA G40.20/21.

**13.4 Tolerances for Built-up Members.** The tolerance on overall section dimensions of members made up of plates, bars and shapes by welding is limited to the accumulation of permissible tolerances of the component parts as provided by CSA W59 and ASTM A6. For Categories AESS 2, 3 and 4, the as-fabricated straightness tolerance for the built-up member is one-half of the standard camber and sweep tolerances in CSA W59.

**13.5 Joints.** For Categories AESS 3 and 4, all copes, miters and butt cuts in surfaces exposed to view are made with uniform gaps, if shown to be open joint, or in uniform contact if shown without gap.

**13.6 Surface Appearance.** For Categories AESS 1, 2 and 3, the quality surface as delivered by the mills will be acceptable. For Category AESS 4, the steel surface imperfections should be filled and sanded.

**13.7 Welds.** For corrosive environments, all joints should be seal welded. In addition:

- a) For Categories AESS 1, 2 and 3, a smooth uniform weld will be acceptable. For Category AESS 4, the weld will be contoured and blended.
- b) For Categories AESS 1, 2, 3 and 4, all weld spatter is to be avoided/removed where exposed to view.
- c) For Categories AESS 1 and 2, weld projection up to 2 mm is acceptable for butt and plug-welded joints. For Categories AESS 3 and 4, welds will be ground smooth/filled.

**13.8 Weld Show-through.** It is recognized that the degree of weld show-through, which is any visual indication of the presence of a weld or welds on the opposite surface from the viewer, is a function of weld size and material thickness.

- a) For Categories AESS 1, 2 and 3, the members or components will be acceptable as produced.
- b) For Category AESS 4, the fabricator shall minimize the weld show-through.

**13.9 Surface Preparation for Painting.** Unless otherwise specified in the Contract Documents, the Fabricator will clean AESS members to meet the requirement of SSPC-SP 6 "Commercial Blast Cleaning" (sandblast or shotblast). Prior to blast cleaning:

- a) Any deposits of grease or oil are to be removed by solvent cleaning, SSPC-SP 1;
- b) Weld spatter, slivers and surface discontinuities are to be removed;
- c) Sharp edges resulting from flame cutting, grinding and especially shearing are to be softened.

### **13.10 Hollow Structural Sections (HSS) Seams**

- a) For Categories AESS 1 and 2, seams of hollow structural sections shall be acceptable as produced.
- b) For Category AESS 3, seams shall be oriented away from view or as indicated in the Contract Documents.
- c) For Category AESS 4, seams shall be treated so that they are not apparent.

## **14. DELIVERY OF MATERIALS**

**14.1 General Delivery.** The Fabricator shall use special care to avoid bending, twisting or otherwise distorting the Structural Steel. All tie-downs on loads will be either nylon strap or chains with softeners to avoid damage to edges and surfaces of members.

**14.2 Standard of Acceptance.** The standard for acceptance of delivered and erected members shall be equivalent to the standard employed at fabrication.

## **15. ERECTION**

**15.1 General Erection.** The Erector shall use special care in unloading, handling and erecting the AESS to avoid marking or distorting the AESS. The Erector must plan and execute all operations in a manner that allows the architectural appearance of the structure to be maintained.

- a) All slings will be nylon-strap or chains with softeners.
- b) Care shall be taken to minimize damage to any shop paint or coating.
- c) If temporary braces or fixtures are required to facilitate erection, care must be taken to avoid and/or repair any blemishes or unsightly surfaces resulting from the use or removal of such temporary elements.
- d) Tack welds shall be ground smooth and holes shall be filled with weld metal or body filler and smoothed by grinding or filling to the standards applicable to the shop fabrication of the materials.
- e) All backing bars shall be removed and ground smooth.
- f) All bolt heads in connections shall be on the same side, as specified, and consistent from one connection to another.

**15.2 Erection Tolerances.** Unless otherwise specified in the Contract Documents, members and components are plumbed, leveled and aligned to a tolerance equal to that permitted for structural steel.

**15.3 Adjustable Connections.** When more stringent tolerances are specifically required for erecting AESS, the Owner's plans shall specify/allow adjustable connections between AESS and adjoining structural elements, in order to enable the Erector to adjust and/or specify the method for achieving the desired dimensions. Adjustment details proposed by the Erector shall be submitted to the Architect and Engineer for review.

# Appendix 2 - Sample AESS Specification

## SAMPLE AESS SPECIFICATION FOR CANADA ARCHITECTURALLY EXPOSED STRUCTURAL STEEL (AESS) “AESS” Subsection of Division 5 “Structural Steel” Section 05120

For a downloadable, electronic version of the Sample AESS Specification, please visit  
<http://www.cisc-icca.ca/content/aess/>

### PART 1 – GENERAL

#### 1.1. RELATED DOCUMENTS

- A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 1 «Specifications» Section, apply to this Subsection.
- B. For definitions of Categories AESS 1, 2, 3, 4, and C as listed in the AESS Matrix (see Table 1), refer to the CISC Code of Standard Practice Appendix I.

#### 1.2. SUMMARY

- A. This Subsection includes requirements regarding the appearance, surface preparation and integration of Architecturally Exposed Structural Steel (AESS) only.

For technical requirements, refer to the other Subsections of Division 5 «Structural Steel» Section.

This Subsection applies to any structural steel members noted on Structural Design Documents as AESS. All AESS members must also be identified by their Category.

- B. Related Sections: The following Sections contain requirements that may relate to this Subsection:
  - 1. Division 1 «Quality Control» Section for independent testing agency procedures and administrative requirements;
  - 2. Division 5 «Steel Joist» Section;
  - 3. Division 5 «Metal Decking» Section for erection requirements relating to exposed steel decking and its connections;
  - 4. Division 9 «Painting» Section for finish coat requirements and coordination with primer and surface preparation specified in this Subsection.

#### 1.3. SUBMITTALS

- A. General: Submit each item below according to the Conditions of the Contract and Division 1 «Specifications» Section.
- B. Shop Drawings detailing fabrication of AESS components:
  - 1. Provide erection drawings clearly indicating which members are considered as AESS members and their Category;

- 2. Include details that clearly identify all of the requirements listed in sections 2.3 “Fabrication” and 3.3 “Erection” of this specification. Provide connections for AESS consistent with concepts, if shown on the Structural Design Documents;
- 3. Indicate welds by standard CWB symbols, distinguishing between shop and field welds, and show size, length and type of each weld. Identify grinding, finish and profile of welds as defined herein;
- 4. Indicate type, finish of bolts. Indicate which side of the connection bolt heads should be placed;
- 5. Indicate any special tolerances and erection requirements.

#### 1.4. QUALITY ASSURANCE

- A. Fabricator Qualifications: In addition to those qualifications listed in other Subsections of Division 5 “Structural Steel” Section, engage a firm competent in fabricating AESS similar to that indicated for this Project with sufficient production capacity to fabricate the AESS elements.
- B. Erector Qualifications: In addition to those qualifications listed in other Subsections of Division 5 “Structural Steel” Section, engage a competent Erector who has completed comparable AESS work .
- C. Comply with applicable provisions of the following specifications and documents:
  - 1. CISC Code of Standard Practice, latest edition.
- D. Visual samples when specified may include any of the following:
  - 1. 3-D rendering of specified element;
  - 2. Physical sample of surface preparation and welds;
  - 3. First off inspection: First element fabricated for use in finished structure subject to alterations for subsequent pieces.
  - 4. Mockups: As specified in Structural Design Document. Mockups are either scaled or full-scale. Mockups are to demonstrate aesthetic effects as well as qualities of materials and execution:
    - a. Mockups may have finished surface (including surface preparation and paint system);
    - b. Architect’s approval of mockups is required before starting fabrication of final units;
    - c. Mockups are retained until project is completed;
    - d. Approved full-scale mockups may become part of the completed work.

#### 1.5. DELIVERY, STORAGE, AND HANDLING



- A. Ensure that all items are properly prepared, handled and/or packaged for storage and shipping to prevent damage to product.
- B. Erect finished pieces using softened slings or other methods such that they are not damaged. Provide padding as required to protect while rigging and aligning member's frames. Weld tabs for temporary bracing and safety cabling only at points concealed from view in the completed structure or where approved by the Architect.

## **PART 2 – PRODUCTS**

### **1.1 MATERIALS**

- A. General: Meet requirements of Subsections of Division 5 "Structural Steel".
- B. Specialty bolts must be specified.

### **1.2 SPECIAL SURFACE PREPARATION**

- A. Primers: Primers must be specified.

### **1.3 FABRICATION**

- A. For the special fabrication characteristics, see Table 1 – AESS Category Matrix.
- B. Fabricate and assemble AESS in the shop to the greatest extent possible. Locate field joints in AESS assemblies at concealed locations or as approved by the Architect.
- C. Fabricate AESS with surface quality consistent with the AESS Category and visual samples if applicable.

### **1.4 SHOP CONNECTIONS**

- A. Bolted Connections: Make in accordance with Section 05120. Provide bolt type and finish as specified and place bolt heads as indicated on the approved shop drawings.
- B. Welded Connections: Comply with CSA W59-03 and Section 05120. Appearance and quality of welds shall be consistent with the Category and visual samples if applicable. Assemble and weld built-up sections by methods that will maintain alignment of members to the tolerance of this Subsection.

### **1.5 ARCHITECTURAL REVIEW**

- A. The Architect shall review the AESS steel in place and determine acceptability based on the Category and visual samples (if applicable). The Fabricator/Erector will advise the consultant the schedule of the AESS Work.

## **PART 3 - EXECUTION**

### **1.1 EXAMINATION**

- A. The erector shall check all AESS members upon delivery for twist, kinks, gouges or other imperfections, which might result in rejection of the appearance of the member. Coordinate remedial action with fabricator prior to erecting steel.

### **1.2 PREPARATION**

- A. Provide connections for temporary shoring, bracing and supports only where noted on the approved shop erection drawings. Temporary connections shown shall be made at

locations not exposed to view in the final structure or as approved by the Architect. Handle, lift and align pieces using padded slings and/or other protection required to maintain the appearance of the AESS through the process of erection.

### **1.3 ERECTION**

- A. Set AESS accurately in locations and to elevations indicated, and according to CSA S16-01.
- B. In addition to the special care used to handle and erect AESS, employ the proper erection techniques to meet the requirements of the specified AESS Category:
  1. AESS Erection tolerances: Erection tolerances shall meet the requirements of standard frame tolerances for structural steel per CSA S16-01;
  2. Bolt Head Placement : All bolt heads shall be placed as indicated on the structural design document. Where not noted, the bolt heads in a given connection shall be placed to one side;
  3. Removal of field connection aids: Run-out tabs, erection bolts and other steel members added to connections to allow for alignment, fit-up and welding in the field shall be removed from the structure. Welds at run-out tabs shall be removed to match adjacent surfaces and ground smooth. Holes for erection bolts shall be plug welded and ground smooth where specified;
  4. Filling of connection access holes: Filling shall be executed with proper procedures to match architectural profile, where specified;
  5. Field Welding: Weld profile, quality, and finish shall be consistent with Category and visual samples, if applicable, approved prior to fabrication.

### **1.4 FIELD CONNECTIONS**

- A. Bolted Connections: Make in accordance with Section 05120. Provide bolt type and finish as specified and place bolt heads as indicated on the approved shop drawings.
- B. Welded Connections: Comply with CSA W59-03 and Section 05120. Appearance and quality of welds shall be consistent with the Category and visual samples if applicable. Assemble and weld built-up sections by methods that will maintain alignment of members to the tolerance of this Subsection.
  1. Assemble and weld built-up sections by methods that will maintain alignment of axes. Verify that weld sizes, fabrication sequence, and equipment used for AESS will limit distortions to allowable tolerances.

### **1.5 ARCHITECTURAL REVIEW**

- A. The Architect shall review the AESS steel in place and determine acceptability based on the Category and visual samples (if applicable). The Fabricator/Erector will advise the consultant the schedule of the AESS Work.

### **1.6 ADJUSTING AND CLEANING**

- A. Touchup Painting: Cleaning and touchup painting of field welds, bolted connections, and abraded areas of shop paint shall be completed to blend with the adjacent surfaces of AESS. Such touchup work shall be done in accordance with manufacturer's instructions.
- B. Galvanized Surfaces: Clean field welds, bolted connections, and abraded areas and re-pair galvanizing to comply with ASTM A780.









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