ARCHITECTURALLY EXPOSED STRUCTURAL STEEL: CLEAR COMMUNICATIONS FOR A BETTER PROJECT

Terri Meyer Boake
tboake@uwaterloo.ca
School of Architecture, University of Waterloo, Cambridge, ON, Canada

Abstract

AESS sits squarely at the juncture between architecture and engineering. Of the many structural materials used for larger, non-residential buildings, it is the one that requires the highest level of technical knowledge from the architect and the highest level of design appreciation from the engineer. The fabricator is often caught in the middle, attempting to create steel that is simultaneously correct for aesthetic and stability requirements. In some instances AESS can be priced out of a project because the finish expectations have been placed too high – for the budget or the type of project.

This paper will speak to new standards that have been developed by the Canadian Institute for Steel Construction (CISC) for the design and specification of AESS that are centered around a “Matrix” that classifies AESS according to factors that include visibility, fit, finish and form. The paper looks at design for constructability as this affects the ability of the fabricator/erector to deliver the project on time and on budget.

Also addressed will be issues arising from the recent influence of 3D modeling software on the generation of buildings that are more easily rendered than fabricated. This would include projects that use curved steel and non-rectilinear forms. New detailing software is discussed that greatly assists with bringing some highly challenging projects to reality.

Keywords

AESS, Construction communication, Steel construction, Steel detailing

DEFINING AESS

Architecturally Exposed Structural Steel (AESS) is steel that must be designed to be both structurally sufficient to support the primary needs of the structure of the building, canopies, ancillary structures or pedestrian scale bridges, while at the same time be exposed to view, and therefore is a significant part of the architectural language of the building or structure. The design, detailing and finish requirements of AESS will typically exceed that of standard structural steel that is normally concealed by other finishes. AESS must be durable and maintainable. It must be able to resist corrosion if placed in a hostile environment and the design and finishes also resistant to urban pollution and general wear.[1] It calls for a different standard and style of detailing than standard structural steel.

AESS really only made its debut in North American architecture in the middle to late 1980s. The use of exposed steel grew out of the High Tech movement in England and parts of Europe during the 1970s and 80s. Much of the High Tech architecture of that period made use of highly elaborate structural steel systems that were based on modular construction, predominantly using the exposed steel as an exoskeleton. Most of the buildings had higher than normal budgets, crafting details that were not within the vision of Corporate North American clients. O'Hare International Airport in Chicago was the first Terminal to abandon expressive concrete in preference for steel. The detailing used by Murphy/Jahn was "between" the more elaborate High Tech details being used by Foster and Rogers and the use of expressed steel by Modernists such as Mies and Philip Johnson. The O'Hare structure was largely positioned on the interior of the envelope given the harshness of the climate, although it did express some steel on the exterior.

Hollow structural sections (HSS) only came into significant production in the late 1970s. They were immediately incorporated into High Tech buildings, and innovative connection design followed. The widespread use of HSS truly began to differentiate the exposed steel architecture of the late 70s and onward from that of the Modern Movement which had used a limited palette of wide flange, channel and angle type sections. Standard structural steel sections did not really lend themselves to expression in the newly expressed hinge and pin connections while HSS seemed well poised to encourage innovation in the same.

Fig. 1: Sainsbury Center by Foster (left) versus O'Hare International Airport by Murphy/Jahn (right). Sainsbury is rigorously modular where O'Hare begins to make more flexible use of a *family* of connection details.

The Issues

Without any specifications for the design and detailing requirements for AESS, architects and engineers were left on their own to decide upon appropriate standards. These tended to polarize at either end of the scale – with the use of exposed steel in "big box stores" at the lower end and "Calatravesque" projects at the high end. High-end AESS tended to defer to "glove smooth finishes" that were achieved with considerable grinding and filling. Mid range projects that selected finish standards at the high-end could be and were priced out of existence. There was not a *differentiated standard* that could be referenced by the team. This state was exacerbated by the reality that traditional engineering and architecture education does virtually nothing to help prepare either engineers or architects to design AESS, concentrating instead on the design of standard (concealed) structural steel. Fabricators are either engineers by training or trained on the job through an apprenticeship system. If a fabricator has not worked on a variety of AESS projects the firm may not have a body of AESS work to reference, leading to additional confusion regarding project expectations.

With AESS, the architect, structural engineer and fabricator need to form a triangle of communication, which can positively impact connections, their design and cost. This interactive design process is very different from the more linear process associated with "standard" structural steel that is hidden from view where the architect steps back from involvement in the process. When AESS is used, the architect sees the exposed connections as part of the design expression of the project.[2] The working relationship becomes smoother over time when the parties gain experience on a range of AESS projects, but can be difficult if one party has less experience or does not have good information with which to make decisions.

Fig. 2: Consider the case of these two "tree" structures. The structure for Reagan International Airport (left) uses more standard section types to create a very tactile aesthetic while the support at the right uses pipe and castings that have been carefully fabricated to support a high gloss finish. Two unique specifications were required.

Not All AESS Need be Created Equal

Decisions made in the design of Standard Structural Steel are very different from those required for AESS. The standard specification for structural steel also does not address the plethora of issues surrounding the detailing and erection of AESS. The bottom line is that not all AESS either needs to or should be fabricated to the same detailed requirements. Projects naturally vary by way of the use of the building, the distance to view of the steel, finish requirements (whether due to fire or corrosion protection), the desired aesthetic and the budget. More distant steel or that using a thicker intumescent coating would not benefit the expense of elaborate or finely finished details. Constricted sites can require innovation when it comes to erection – impacting the types of connections chosen.

There are primary factors that give 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)
- **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)

A set of documents was created by CISC: a specification for the engineers, an Appendix to the Code of Standard Practice for the fabricators, and an illustrated Guide for the architects that reflected the way the factors affected the "Form, Fit and Finish" requirements of the steel, and put the same into a language that was understandable by each discipline. A visual "matrix" was created that used language and terms that were common to all three documents and that acts as the central communication piece. (see Fig. 4) The specification and code focus on what you do TO prepare the steel and the guide elaborates on the impact of what you may put ON the steel.

Although the fabricators consulted were reluctant to commit, it was decided to include a range of cost premiums for the different categories of AESS as it was felt to be an important part of the decision making process, however approximate.

THE AESS CATEGORIES

The initial point of technical reference is Standard Structural Steel (SSS) as defined in as it is already an established and well-understood as a baseline in construction specifications.

AESS 1 – Basic Elements is the first step above Standard Structural Steel. This type of application would be suitable for ordinary elements that 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 the relatively large viewing distance as well as the lower profile nature of the architectural spaces in which it AESS 1 used. Surface preparation by commercial blast cleaning is the most important first requirement of all AESS, regardless of category.

AESS 2 – Feature Elements includes structure or “feature elements” that are intended to be viewed at a distance > 6m (18ft). This distance reflects the height of a high ceiling and is considered adequately out of visual range to appreciate finer finishes and also beyond touching. The process requires basically good fabrication practices with enhanced treatment of welds, connection and fabrication details, tighter 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.

Fig. 3: The AESS Categories: (top left) AESS 1, (top right) AESS 2, (bottom left) AESS 3, bottom right (AESS 4). AESS 1 and 2 are located beyond 6 meters where AESS 3 and 4 are within view range and touch.

AESS 3 – Feature Elements includes structures that will be viewed at a distance ≤ 6m (18ft). The closer distance means that the viewer can see and potentially touch the steel. 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. As this structure is normally viewed closer than six meters 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 centers, pedestrian bridges, hospitals or lobbies and could be expected to incur a moderate cost premium that could range from 60% to 150% over Standard Structural Steel as a function of the complexity and level of final finish desired. This is the Category where grinding to remediate surfaces and welds is first included. Beyond taking the sharp edges off of all AESS1 and 2 steel, no grinding is permitted in those Categories. The elimination of unnecessary grinding was essentially the starting point of the Canadian AESS Committee discussions as it was negatively impacting the viability of projects.

AESS 4 – Showcase Elements or "dominant" elements is used where the designer intends that the form is the only feature showing in an element. All welds are ground and filled and 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 C – Custom Elements was created to allow for a custom selection of any of the Characteristics or attributes that were used to define the other Categories. It allows flexibility in the design of the steel, and therefore requires a high level of communication amongst 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.

Table 1 - AESS Category Matrix

Id	*Category*	AESS C	AESS 4	AESS 3	AESS 2	AESS 1	SSS
		Custom Elements	*Showcase Elements*	*Feature Elements*	*Feature Elements*	*Basic Elements*	*Standard Structural Steel*
	Characteristics			*Viewed at a Distance ≤ 6 m*	*Viewed at a Distance > 6 m*		CSA S16
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	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	Retail and architectural buildings viewed at a distance	Roof trusses for arenas, retail warehouses, canopies	
	Estimated Cost Premium:	Low to High (20-250%)	High (100-250%)	Moderate (60-150%)	Low to Moderate (40-100%)	Low (20-60%)	None 0%

Fig. 4: The Matrix provides a systematic, additive approach to the relationship between the AESS Categories and their associated Characteristics.

The detailed Characteristics will not be addressed in this paper. The list is included in Figure 3. The Characteristics are additive, each AESS Category with increasingly stringent requirements. The intention of the list is to reflect the primary factors of influence, focus on the use and viewing distance, and remove requirements from the lower end categories that would be a waste of time and money to the project.

Worth noting is Characteristic 2.1, Visual Samples. These are common requirements for many projects when it comes to agreeing to specify finish materials and a potential problem for any AESS project as a full scale mock-up costs both time and money. Mock-ups are usually scrutinized very closely, at distances that are often much closer than in use. As the AESS in the project has become a critical element of the design and its finish is important, it is not surprising that architects and clients would like to see a sample prior to committing for the entire project. This characteristic highlights a variety of ways to satisfy this "need". It suggests alternate approaches that will save time and money. If a fabricator has experience in AESS other completed work can serve as the sample for the agreed nature of finishes. This can be accompanied by a 3D rendering showing how the particular details in question will be designed. Partial mock-ups of welded connections can be created to allow the architect and client to make a selection, without requiring the fabrication of a complete piece. In one instance where a very large unique element was required, it was actually incorporated into the final project although its finer details were different than the dozens of elements created for the project.

Fig. 4: The element at the left was the visual sample for the project. Given its size and expense, it was incorporated into the finished building. To find it on the right is akin to "Where's Waldo". Hence a cost and time saving that was worthwhile.

CONNECTION DESIGN

Connections in AESS projects *become* the architecture. They not only have to keep the loads happy, but they have an extremely important aesthetic role. Once the category of AESS has been determined on the basis of the building use, distance to view, budget and finishes, the actual detailed design of the connections and member selection comes into play. It is easier to weld in the shop and bolt on site, although site welding is possible, with the proper provisions. Shop painting is also preferred, although this infers greater care in handling during transportation and erection. The team must agree on site remediation methods for damage as it is likely to happen, regardless of level of care.

When designing steel connections with aesthetics in mind, one of the major choices will be to bolt or weld. Bolting is less expensive and more often found in lower-end AESS.

Generally speaking you will see more bolted connections in AESS 1 and 2, and more welded connections in AESS 3 and 4. A high level of communication is necessary, based on the core ideas of the Matrix, when the team is trying to combine the aesthetic "parti" with engineering loading requirements and fabrication/erection concerns. Bolted connections may prove the easiest to negotiate as the decision to bolt already agrees on a "technical appearance". The actual arrangement and numbers of bolts and the method of bolting will be guided by the types of members chosen (tube vs. shapes).

If the desire is for an all-welded look, decisions will get more complex as the shipping limitations will come into play. Larger elements will need to be broken into smaller pieces for transportation purposes. The team needs to clearly understand the route from the fabrication shop to the site, bridge and road clearances and how much "police escort" is to be afforded. Discreet or hidden bolted connections can be used as an alternate to a fully welded solution. Again the AESS documents and visual references in the Guide will assist the team by providing some suggestions for consideration.

Fig 5: These two images show three variations in creating bolted connections that work in conjunction with welded members. The simple plates bolted to the ends of the square HSS on the right are less streamlined but the splice plates can be more discreet.

A companion web site has been created to assist students and practitioners in creatively undertaking AESS connection design. The web based resource is able to accommodate a wider range of images and projects than the print media of the Guide. The pedagogy behind the selection of material for the web resources is to develop connections based upon an understanding of basic connection principles and methods.
http://www.architecture.uwaterloo.ca/faculty_projects/terri/SSEF1/

CONSIDERATION FOR FINISHES

When making decisions about fabrication details for AESS projects, the final finish must be known from the outset of the project. Whether the finish is selected on the basis of fire protection or corrosion, it will greatly impact detailing. The nature of the final finish should assist in determining the types and treatment of connections. An intumescent coating with a fairly thick finish, or a galvanized protection system would preclude the need for fastidious grinding of welds and might suggest AESS 1 or AESS2. A high gloss finish would work best with AESS 4. AESS 3 projects might be able to work with a variety of finishes and details according to the way the connections are detailed. Referring to the projects in Figure 2, the more tectonic "tree" at the left is finished in medium gloss paint and the smooth "tree" on the right finished in high gloss paint. A reversal of these finishes would have been inappropriate and a waste of fabrication time spent on the "smooth tree" as considerable time was spent bringing the surfaces of the mechanical pipe and castings to a point where their natural orange peel-like finish would not show through the paint.

Finishes is an area that falls outside of the Standard Structural Steel specification and also the normal scope of work for the Engineer, beyond an understanding of basic fire and corrosion protection methods. The Architect will often work with a Fire Engineer when determining Code and Exiting issues, and in this ascertain the required ratings for assemblies and the nature of fire protection or suppression systems. When creating the AESS Specification and Appendix to the Code of Practice for the Fabricators, it did not legally make any sense to include finishes as these are covered in detail in their own specifications. It was decided to address the "impact of finish selection" on AESS as an expanded part of the Guide as it was to be highly illustrated and could assist by showing photographs of details using a variety of finishes. Again it is critical to communicate the choice of finishes among the members of the project team so that the impact of selection is clearly understood.

FUTURE AESS: WORKING WITH COMPLEX GEOMETRIES

Improvements in the field of digital drawing over the last decade have radically improved the communication flow for projects and have also allowed for the inclusion of a wider range of complex geometries. Early High Tech projects such as the Sainsbury Center pictured in Figure 1 (left) made use of highly repetitive sections. Although the trusses were more complex than previous steel structures created from standard sections, some economy was achieved by the mass production of like elements – part of the theory behind the new architectural type. High Tech designs were typically based on repetitive geometries that relied on a simple linear expansion of modules/bays or an infinitely expandable grid, again using like elements. Although the buildings "looked" more complex than their Modernist counterparts and were more time consuming to fabricate, in reality the processes were akin to assembly line production in widespread use in other industries of the same period.

The development of BIM software has drastically changed what can be done in AESS designs. The software allows for an almost seamless flow of information from design through to detailing and shop drawings. The current detailing software can work with pretty well any 3D geometry that the Architect can invent. The 3D models created by the fabricator are able to form a visual basis for communication on the project. The connection details can be extracted as discussion items on joint design. Each structural member, truss or major connection can be extracted to form a shop drawing. Erection sequencing can also be extracted as separate 3D drawing sets.

Importantly the model can be used to drive CNC cutting equipment, enabling accurate cutting of complex shapes into plate material. Where multiple shapes of differing sizes are required to be cut from plate material, special "nesting software" is employed that will determine the least wasteful layout.

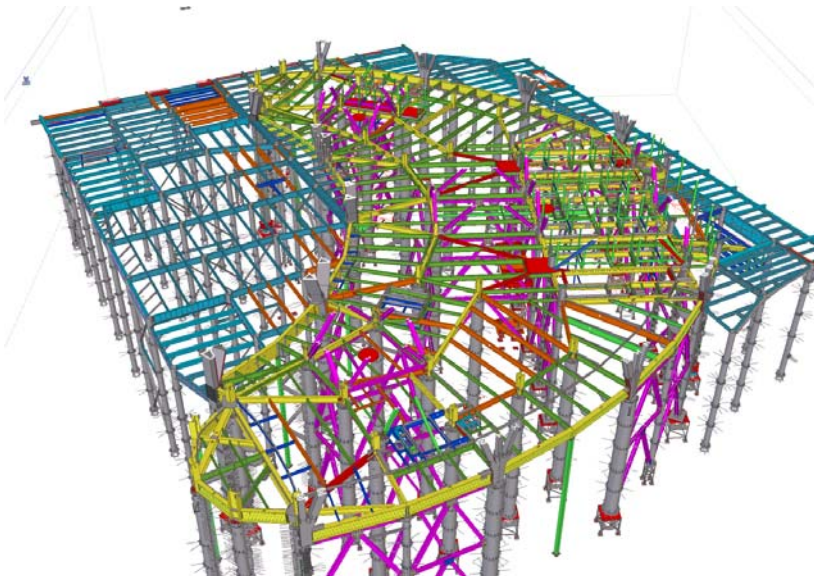

Fig. 6: This fabricator's drawing of the ground floor and basement framing of the Bow Encana Tower in Calgary, AB, Canada shows some of the complexity that can be handled easily by detailing software. Each connection is fully designed including bolting and welding information as responds to load calculations. The colors are indicative of function and construction sequence.[3]

The CISC suite of documents[4] was only fully released as of March 2011. Reports back of successes from the field are very positive and their use in projects is in part being driven by fabricator satisfaction. The flow on projects is smoother and discussions can focus on important details and issues and not on general levels of preparation. The suite has received International recognition and was revised for Australia and New Zealand and launched in November 2012. The construction industry has become a Global one, so this is viewed as very positive support for the CISC approach to the design and specification of AESS with an emphasis on improved communication for the team members.

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[1] Boake, Terri Meyer. "CISC Guide for Specifying Architecturally Exposed Structural Steel". March 2012.
[2] Boake, Terri and Sylvie Boulanger. "The 3 Cs of AESS". Modern Steel Construction. December 2011.
[3] Drawing of Bow Encana supplied by Walters Inc. of Hamilton
[4] The CISC Documents can be downloaded at: www.cisc-icca.ca/content/aess/

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All photos by author.