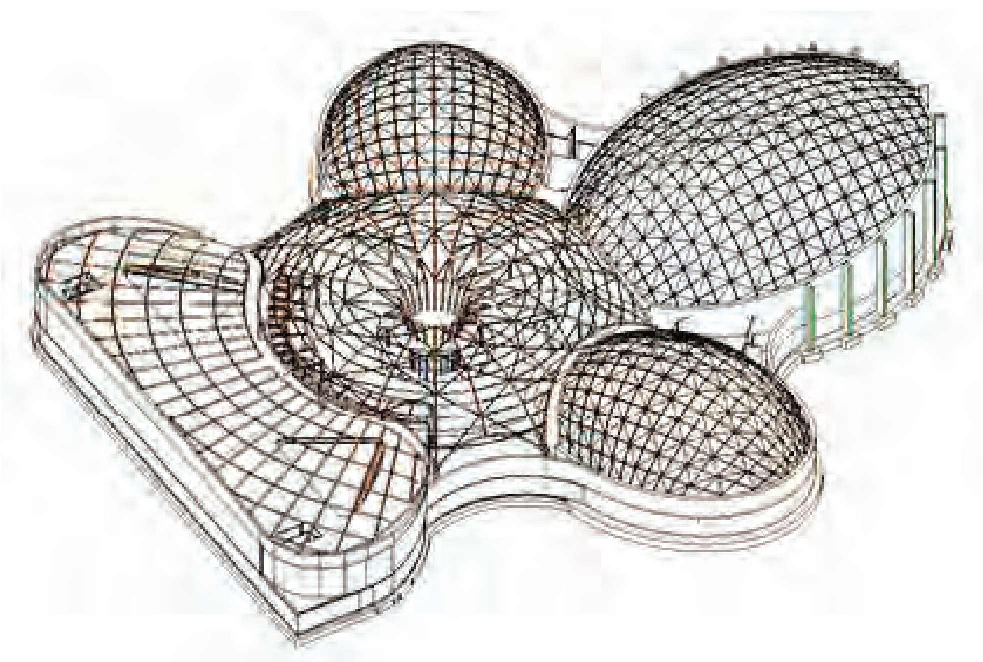
ATC 75

Improvements to BIM structural software interoperability



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The Applied Technology Council (ATC) is a nonprofit, tax-exempt corporation established in 1973 through the efforts of the Structural Engineers Association of California. ATC's mission is to develop state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. ATC also identifies and encourages needed research and develops consensus opinions on structural engineering issues in a non-proprietary format. ATC thereby fulfills a unique role in funded information transfer.

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ATC-75

Improvements to BIM Structural Software Interoperability

by

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Preface

In September 2007 the Charles Pankow Foundation awarded the Applied Technology Council (ATC) a Research Grant for the Development of Industry Foundation Classes (IFCs) for the Structural Domain (ATC-75 project). The goal of the ATC-75 project was to develop a basis for incorporating and integrating structural design parameters, codes, analysis tools and methods into the Industry Foundation Class (IFC) data model, an open-source object-oriented exchange language (file format) that is being developed by the International Alliance for Interoperability (IAI) for Building Information Modeling (BIM) software. The IFC data model is viewed as a critical component of the building industry's efforts to save time and money by enabling software platforms to "talk to each other" intelligently.

The project development effort included the formulation of a Strategic Work Plan early on in the project, and the conduct of a variety of critical tasks, including (1) documentation of structural engineering business processes, (2) development of IFC exchange requirements, (3) the conduct of benchmark and validation tests, and (4) the conduct of an information dissemination effort to distribute project results and encourage their use, all of which are described in detail in this ATC-75 Report.

The ATC-75 project was carried out by leading available design professionals, industry representatives, and software developers. Edwin Dean, Thomas R. McLane, and Michelle Kernen served, respectively, as Project Technical Director, Project Manager, and Project Administrator. A broadly based Project Management Committee (PMC), chaired by the Project Technical Director, formulated and managed the practical direction of the Project. This group consisted of Thomas Liebich, (IFC Consultant), Erleen Hatfield (Lead Engineering Consultant), Aaron White (Engineering Consultant), Wai Chu, Santanu Das, Brad Douglas, Luke Faulkner, Raoul Karp, Robert Lipman, Ken Murphy, Chi Ng, Herman Oogink, Stacy Scopano, Paul Seletsky, Matthew Senecal, Dennis Shelden, Douglas Sordyl, Rasso Steinmann, Rob Tovani, Frank Wang, Tom Williamson, and Angel Velez. Overview and guidance were provided by a Project Advisory Panel consisting of François Grobler (Chair), Chuck Eastman, Dan Frangopol, David Hutchinson (ATC Board Representative), James Jacobi, Steve Jones, Paul Mlakar, and Deke Smith. Peter Mork created the project web site and assisted in the preparation of this project report. The affiliations of these individuals are provided in the list of Project Participants

ATC gratefully acknowledges the funding provided by the Charles Pankow Foundation, the support and guidance provided by the Foundation's former and current Executive Director's, Robert Tener and Mark Perniconi, respectively, and the encouragement and support by the Industry Advocate for this project, Charles Thornton (former ATC Board President). The services of the industry representatives and software developers, who served without compensation on the Project Management Committee, are also highly appreciated.

Christopher Rojahn
ATC Executive Director

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Chapter 1

Introduction

1.1 Definition of BIM

Building Information Model, or BIM, is a 3-Dimensional virtual database-driven digital modeling system used by the architecture, engineering, and construction industry in the planning, design, and construction of buildings. BIM can also be defined as a computer model containing 3D "objects" that have properties. Objects are anything that can be represented in 3D; for example, beams, columns, walls, braces, bolts, footings, doors, windows and ceilings modeled in 3D are all objects. Figure 1-1 shows an example of a BIM used to document a stadium and Figure 1-2 shows the final built construction.

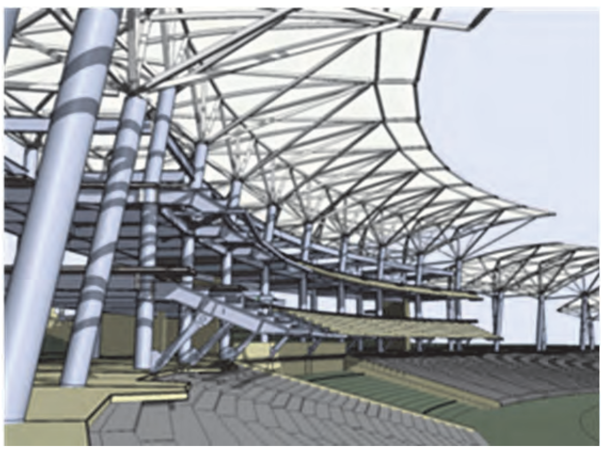


Figure 1-1 Stadium BIM.

Figure 1-2 Final built construction.

To illustrate the difference between BIM and traditional 2D computer aided drafting (CAD), see Figure 1-3, a screen shot of a traditional 2D AutoCAD framing plan and Figure 1-4, a screen shot of a BIM framing plan. In addition to going from 2D to 3D, a major difference between traditional 2D drafting and 3D BIM modeling is that BIM objects have additional data or properties attached. These data are often referred to as meta-data, properties or attributes. Figure 1-5 is a dialog box from Revit Structure (BIM) software that shows a column; in the dialogue box, we see many column properties including that it is a sized as W14x90 and is A992 grade steel. If this column were drawn in traditional 2D Computer Aided

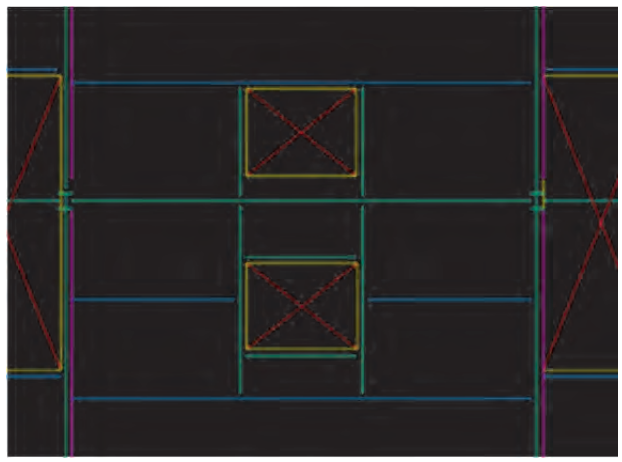


Figure 1-3 Screen shot from 2D framing plan drafted in AutoCAD.

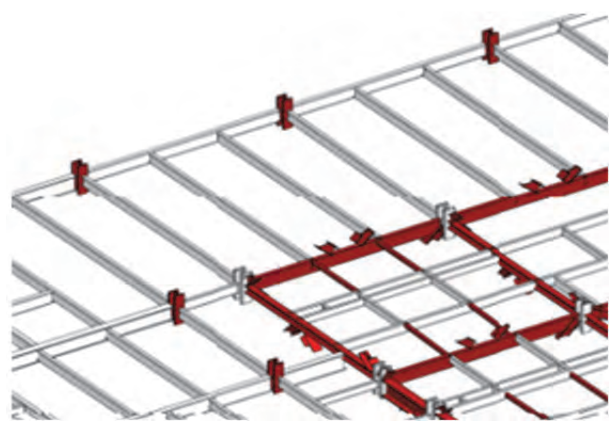


Figure 1-4 Screen shot from 3D BIM.

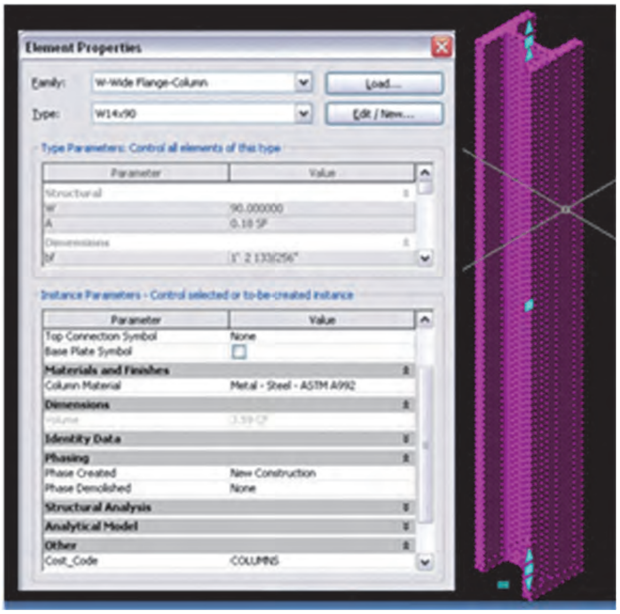


Figure 1-5 Screen shot from Revit Structure showing property settings.

Design (CAD) software, it would be represented merely as 2D line work, and to determine the size and grade of steel, one would reference a schedule or notes elsewhere in the CAD file. The 3D visualization, along with additional data attached to objects, makes BIM a very powerful tool for the design and construction of buildings.

1.2 BIM Adoption

BIM has been emerging as a useful tool in the design and construction industry for several decades, and is now viewed as an important means to improve efficiency and productivity and to identify construction conflicts during the design process. The National Institute of Building Sciences (NIBS) has recognized BIM as a critical element in reducing design and construction industry waste, adding value to industry products, decreasing environmental damage, and increasing the functional performance of building occupants (NIBS, 2007).

Several years ago McGraw-Hill Construction published a *Smart Market Report on Building Information Modeling* (McGraw-Hill, 2009) that indicated that almost half (49%) of the design and construction industry participants (architects, engineers, contractors and owners) they surveyed in North America had adopted BIM, and the majority of those companies predicted that over 60% of their projects would be using BIM within two years. The level of BIM adoption has been growing every year, partially driven by the productivity gains offered by BIM, the improved coordination made possible by using BIM, and by savvy owners requiring BIM to be used during the design and construction of their projects.

In today's software, BIM is implemented through object-oriented databases of information shared among project participants, and the amount of information contained in the models continues to grow as the project progresses through design, construction and operation.

1.3 Interoperability

The ability to translate BIMs between different software programs is referred to as "interoperability." The need to translate models from one software package to another arises when the various participants on a project wish to share their models. Model sharing can occur because the design team is composed of many participants with different areas of expertise and different disciplines, so it is common that all participants on a project are not using the same software. For instance, a mechanical engineer may use specialized software to analyze air flow, while a structural engineer may use software to determine lateral loads on a building, and these different software packages most likely do not allow the most basic transfer of geometry from one to another, let alone more complex meta-data. So the first issue of interoperability is one of sharing BIMs with other project participants or other disciplines using different software.

Another issue of interoperability is sharing files within one discipline. For instance, structural engineers use different software to analyze, design and document a project, for a number of reasons, including personal preferences, the unique benefits of a particular software, existing knowledge of a software, and project-specific requirements. Prior to the conduct of the ATC-75 project, BIM models often did not translate from a BIM software used for design or construction documents to structural analysis software used for engineering calculations.

The lack of interoperability has caused reduced productivity and increased time because of the need to manually re-enter data for each software program, or to re-model the building. In addition when any manual process is introduced, significant additional time is required to check for errors.

A major obstacle for BIM to reach its fullest potential and gain widespread adoption has been the lack of interoperability. Since most software programs on the market today have proprietary file types that cannot be opened or saved into formats other their own, the ability to share models has been greatly limited.

1.4 Inpetus for the ATC-75 Project

The state of the industry in 2008 was a lack of trust by many structural engineers that a BIM created in one software package could be exported successfully to another software package. Many types of interoperability problems existing at that time seemed an overwhelming task to try to overcome. Such problems were a deterrent for some to begin using BIM, and for others, the problems were a deterrent to get the most benefit from BIM. Problems such as lack of data transferring (i.e., missing data), incorrectly translated data (objects appearing differently in different software, see Figure 1-6) and files that simply would not open in a different software, created the perception that time would be wasted recreating models and that BIM was not a viable method for analysis, design and documentation of the structure of a building.

As early as 2004, interoperability was identified as a major concern for the entire design and construction industry. In the National Institute of Standards and Technology (NIST) GCR 04-867 Report, *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry* (Dettbarn et al, 2004), annual interoperability costs were estimated at $15.8 billion for the capital facilities industry. Also noted in the NIST study was that in 2002, the value of capital facilities completed in the United States was $374 billion. Based on these data, it was recognized that even small improvements in efficiency could potentially represent significant economic benefits.

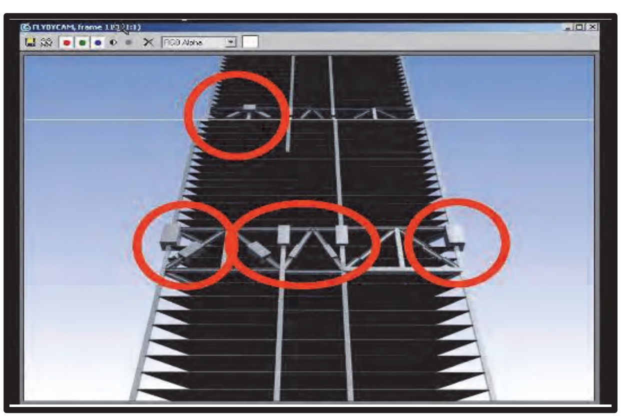


Figure 1-6 Screen shot showing miss-translated objects.

The lack of interoperability between structural software was the principal reason for the formation and conduct of the ATC-75 project. Without a method to transfer from one software application to another, the growth in the use of BIM and all of its associated benefits would be limited. Finding a method to improve interoperability between BIMs, which in turn would improve productivity, appeared to provide an opportunity for tremendous cost saving benefits.

1.5 Industry Foundation Classes (IFCs)

Around the time of the issuance of the NIST report in 2004, a neutral and open BIM file type that could be shared between different software was being developed called Industry Foundation Class (IFC), with the file extension of .IFC. IFC is similar to BIM in that it is an object-based building data model that is, however, non-proprietary.

The Industry Foundation Class (IFC) file type represents a means for sharing construction and facility management data across various software packages used in the architecture, engineering, and construction industry and the facility management industry. IFC is an object-oriented data schema based on class definitions representing the objects (such as building elements, spaces, properties, and shapes) that are used by different software applications used in a construction or facility management project. The IFC file type is based on a neutral and open file specification that is not controlled by a singular vendor or group of vendors. It is freely available on the Internet. IFC is an open specification, supported by an international, non-for-profit organization and it is registered with the International Organization for Standardization (ISO) as ISO16739.

The need for a means to share models from one software package to another was recognized by a number of industry groups, including the buildingSmart International a non-for-profit industry alliance established in 1995. BuildingSmart has copyrighted the IFC specification and continuously develops and maintains IFCs as part of its mission. The IFC logo (Figure 1-7) is often shown when software can export or import IFC files.

buildingSMART® International home of openBIM

Figure 1-7 buildingSmart logo.

Industry Foundation Classes (IFCs) are critical components of BIM file sharing. IFCs are defined by buildingSmart as data elements representing the parts of buildings (objects), or elements of the design and construction process, and containing relevant information about those parts or elements. IFCs are used by computer software to assemble a computer-readable model of the facility that contains all the information of all of the parts (and process elements) and their relationships to be shared among project participants.

Practically speaking, Industry Foundation Classes are the means to exchange data related to buildings that software vendors have agreed to use when their software system exchange data. The systems are said to be interoperable when the meaning of the data, and how the data are assembled, have been agreed upon in advance, so that different software can exchange, interpret and use the data correctly. In other words, IFCs are analogous to words in a neutral language used by two foreigners to communicate. For example a Swede and a Nigerian may choose to communicate in English. The words have defined (i.e., agreed upon) meanings that could be put together, in ways defined by the language rules, to communicate complex thoughts. Similarly, complex structures of building, facility and life-cycle information are assembled and clearly communicated using IFCs.

1.6 Project Concept

The ATC-75 project was conducted to improve upon the poor state of interoperability between BIM software packages. Rather than create a new exchange file type or start from scratch, the project team decided to build upon and update the structural domain of the IFC exchange standards. A co-lateral objective was to entice stakeholders in the architecture, engineering, and construction industry to utilize more fully the tools available in BIM related to IFC exchanges. By involving stakeholders in the project and advertising its progress, it was envisioned that stakeholders would embrace the results.

The project approach was based on the then current state of affairs between the various software vendors and their software programs. Because so many software vendors had independently developed their own software products, there has been a lack of interoperability between the software products of different vendors. Many vendors had multiple software programs that worked together well, but only a few had software that was able to translate accurately with competing software. Additionally, there was a lack of industry or technical leadership to establish standards or guide software programmers in tailoring their work for the needs of practitioners.

The project team also recognized that the National Institute of Building Sciences (NIBS) and its buildingSmart Alliance, through the *National Building Information Model Standard* (NIBS, 2007), as well as many international groups and the International Alliance for Interoperability (IAI), had pioneered an overarching standardization process. The goal was to follow an approach in project development that was consistent with that standardization process. As a result, the *National Building Information Model Standard* (NBIMS) was a key resource throughout the ATC-75 project developmental efforts.

1.7 Project Planning and Execution

At the outset of the project, the project team developed a draft Strategic Work Plan that identified the following work products and activities:

- *A Users Requirements and Business Process Report* to delineate attributes that are important in defining characteristics specific to structural components and to describe interactions between the various players from the architecture, engineering, and construction industry on a given project;
- *Exchange Requirements* to capture the objects and attributes that (1) are contained in the BIM model that are to be exchanged between software platforms; (2) explain the exchange in terms used by the profession and align it with the very specific definitions, which are required for software programmers to execute via IFCs;
- *Model View Definitions* that flow from the Users Requirements and Business Process Report and define Exchange Requirements in both plain language and IFC language;
- *Benchmark Testing* to evaluate and compare the interoperability of output IFC files for an idealized structural model, created in several popular BIM software packages;
- *Validation Testing* to validate updated, improved output IFC files developed two years after the initial benchmark testing; and
- A *Dissemination Plan* and a *Diffusion Summary Report* to describe both the ATC-75

project results dissemination strategy and the effectiveness of the dissemination process.

The Strategic Work Plan became a guide for the group, as well as a means of advertising the project to a wider community. As a result, the Plan was instrumental in drumming up early enthusiasm for the project and developing a wider network of participants.

The ATC-75 project initially was envisioned as an IFC update effort for the structural domain. However, as the project progressed and participants dug deeply into the current state of structural domain IFCs, and examined the exchange points and pathways, the direction was refined to focus on a key area of need in the structural engineering domain—the need to transfer primary objects. They found that the transfer of secondary objects (such as bolts, reinforcement, and pour stops), were not the most immediate need for interoperability. They also found that IFC based file transfers were capable of conveying most of the information that a structural engineer needs to input and output. However if one IFC object did not translate, doubt would be shed on the entire translation process and it was considered an unsuccessful translation. The ATC-75 team then engaged a software code writer (IFC consultant) familiar with IFCs to determine the reasons for the underlying inconsistency problems in IFC transfers.

After much study, the project team determined that it is the usage and application of the IFC structural domain instructions by different software vendors that has been inconsistent, causing inconsistency in the translations, which led practitioners to believe that the exchanges were unsuccessful. In many cases, as evidenced by the Benchmark Testing, the information was partially exchanged but not completely accurate and often not with the intent to be used by the receiver with the same intent as the originator. Therefore, one of the project tasks was tightening the usage and interpretation of existing IFC coding instructions. Through multiple rounds of discussion and feedback, an exchange requirement document was created to identify a unit of information and take the reader through the use of that unit, from the practitioner's language to the software programmer's language. As a result, additions to the IFCs coding instructions were identified and written with the intent to be included in the next IFC release update.

1.8 Report Contents and Organization

This report summarizes the activities involved in the development of this project and highlights the accomplishments that were achieved in the years of its evolution. Interoperability and the development of IFCs is a broad and complex process, even when limited to the structural domain. This project was a first step in providing guidance and development of IFCs that will in turn provide better instructions to the software vendors and ultimately promote interoperability in the structural domain. Improved interoperability will lead to meaningful improvements in the BIM users' ability to reliably and consistently exchange BIM data between different model platforms.

The remaining chapters and appendices describe key results. Chapter 2 discusses the structural engineering business processes that a BIM model needs to represent in the design and construction phases of a project. In Chapter 3, the process for developing and testing needed Industry Foundation Classes for key structural elements is discussed. Chapter 4 describes the strategy for dissemination of the project results, along with a discussion of the successful implementation of that dissemination strategy. And finally, in Chapter 5, an overview summary of the report and the conclusions of the ATC-75 project team are provided, including perspectives on the importance of BIM and IFCs to the architecture, engineering, and construction industry.

The appendices consists of Appendix A: Example IFC Exchange Requirements; Appendix B: Example Structural Member Properties Defined and Used by Vendors for Exchange (IFC Binding); Appendix C: IFC Model View Definition Diagrams; Appendix D: IFC Structural Testbed Validation for Bentley Structural Software, Version 8i; Appendix E: IFC Structural Testbed Validation for Digital Project Software, Version 1 r8; Appendix F: IFC Structural Testbed Validation for Revit Structure 2008 Software; and Appendix G: IFC Structural Testbed Validation for Tekla Structures Software, Version 16.0. Following the appendices are a Glossary, References, list of Project Participants and their affiliations, ATC Projects and Report information, and a list of ATC Directors.

Chapter 2

Structural Engineering Business Processes

2.1 Structural Engineering Exchange Points—Process Diagrams

Structural engineering involves the overall process of planning, designing, analyzing and constructing load-bearing systems for building projects. Structural engineers develop systems for stability and serviceability under normal circumstances, environmental conditions, and disaster-related stresses.

Structural engineers exchange information with other groups during the design, analysis and construction lifecycle through the interface of three main purpose-built models, which are shown in the process map of Figure 2-1 as (1) the architectural model, (2) the structural model, and (3) the construction model. The interface of the structural model with the architectural and construction models takes place at many junctures.

The process within the structural engineering domain is described in Figure 2-2. The structural engineering domain contains both a structural engineering design model and a structural engineering analytical model. The structural engineer is given a design architectural model by the architect, imports it into their BIM software package, and adds structural information as the structural systems are defined and detailed. The analytical model is treated as a separate entity used for engineering analysis.

The structural design model can then be returned to the architect as an enhanced version of the original architectural model, or the combination of an architectural and a structural

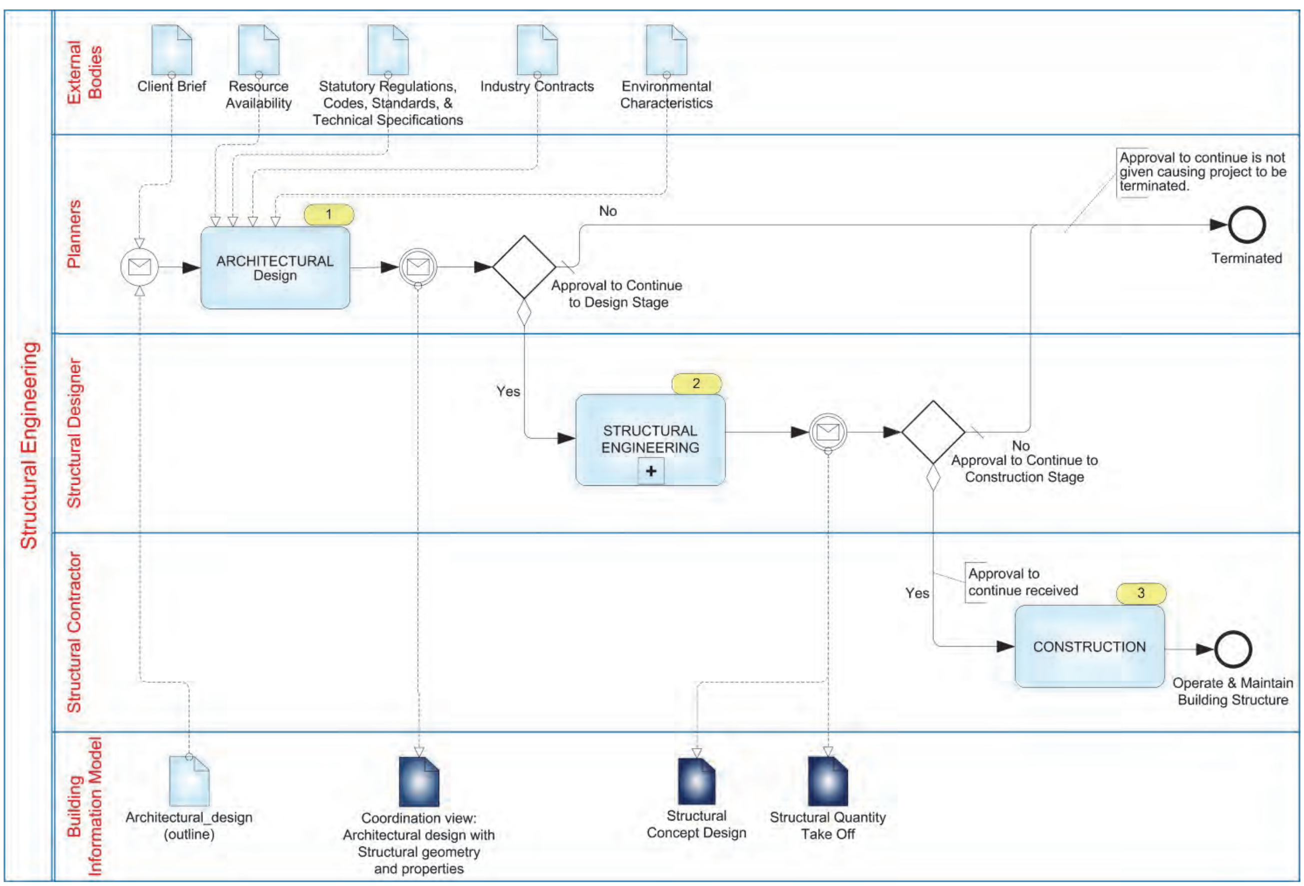


Figure 2-1 Top level business processes diagram.

design model. This process takes considerable interaction, back and forth model transferring to converge on a final architectural and structural design. The design model can be used to produce final architectural and structural drawings, specifications, and material quantity estimate information.

These four primary tasks are considered to be the process stages within the structural domain:

- Define the structural systems.
- Develop the structural model.
- Perform structural analyses for verification.
- Extract structural drawings and specifications.

At a detailed level, for each of the structural processes, there are many sub-processes. Within the definition of the structural system (see Figure 2-2), there are sub-processes, 2.1, 2.2, 2.3, and 2.4.

The structural engineer will add structural framing information to the physical model (see Figure 2-3) to show the floor and roof framing layout (2.2.1), the column layout (2.2.2), the lateral load resisting system (2.2.3), and the foundation system (2.2.4). At the completion of these tasks, the *Structural Concept Design* and *Quantity Take-off* can be exchanged with other users, preliminary drawings and specifications can be produced, and material quantity estimates can be extracted, to evaluate alternative structural systems from a cost perspective.

Process 2.3, structural analyses, and process 2.4, extract structural drawings and specifications, were not considered to be within the scope of this project.

2.2 Coordination View Case

The structural engineer exchanges information formally through pathways of a BIM model, but these pathways are affected by the general accuracy of the geometry and properties of structural elements. An architectural model seldom provides an engineer with the type of objects or elements that a structural engineer will find useful. Subsequently, the model created by the engineer will combine the initial contents from the architect and the structural components created by the engineer. It will be returned to the architect for review, or it will be passed along to the detailer or the construction contractor. All users rely on the proper identification of element geometry and properties.

The first use case addressed by the ATC-75 project team was the joint use case used by the architect and the structural engineer called the coordination view. The coordination view includes the architectural design plus the structural element geometry and properties (Figure 2-1, BIM item 1) and Structural Concept Design (Figure 2-1, BIM item 2). In terms of the business process diagram, each consultant will touch each piece of the model's life in some way. The requirement in a broad sense is that the structural engineer (identified for this project as the user) must trust the fidelity of the exchange of model from the architect in the *Coordination View: Architectural Design with Structural Geometry and Properties* in order to avoid re-building the model in its entirety; and on the other side, in the *Structural Concept Design*, the information must be transferrable back to formats that the other stakeholders utilize. The interoperability and trust of the fidelity of the models are key. Through the participation of the major software vendors in North America, the ATC-75 project team developed an increased understanding of, and agreement on, convention, that future upgrade software releases could incorporate more reliably. Structural engineers will receive the architectural model as a template, will add structural framing information and properties, and will then return the model to other stakeholders in the process (the architect, the detailer, the construction contractor). This process takes considerable back and forth interaction until a project is complete.

In Revit software, for example, this convention works because Revit software is broken into software pieces, such as, Revit Architecture (for architectural elements), Revit Structure (for structural elements) and Revit MEP (for mechanical or electrical elements). The different files can all be combined together and can also be separated apart seamlessly. The different disciplines involved on a given design and construction project can all work on their piece of the model and then the model portions can be combined to create a multi-discipline model. The multi-discipline model can be used to detect clashes or coordination issues between disciplines.

Example details of the structural engineering business process considered can be found in Appendix A, which formats the exchange requirements in a more standardized template, as established by the BuildingSMART Alliance (NIBS, 2007). In Figures 2-1, 2-2, and 2-3, it is apparent that there are numerous points within the structural engineering business process where information is exchanged as other parties check or

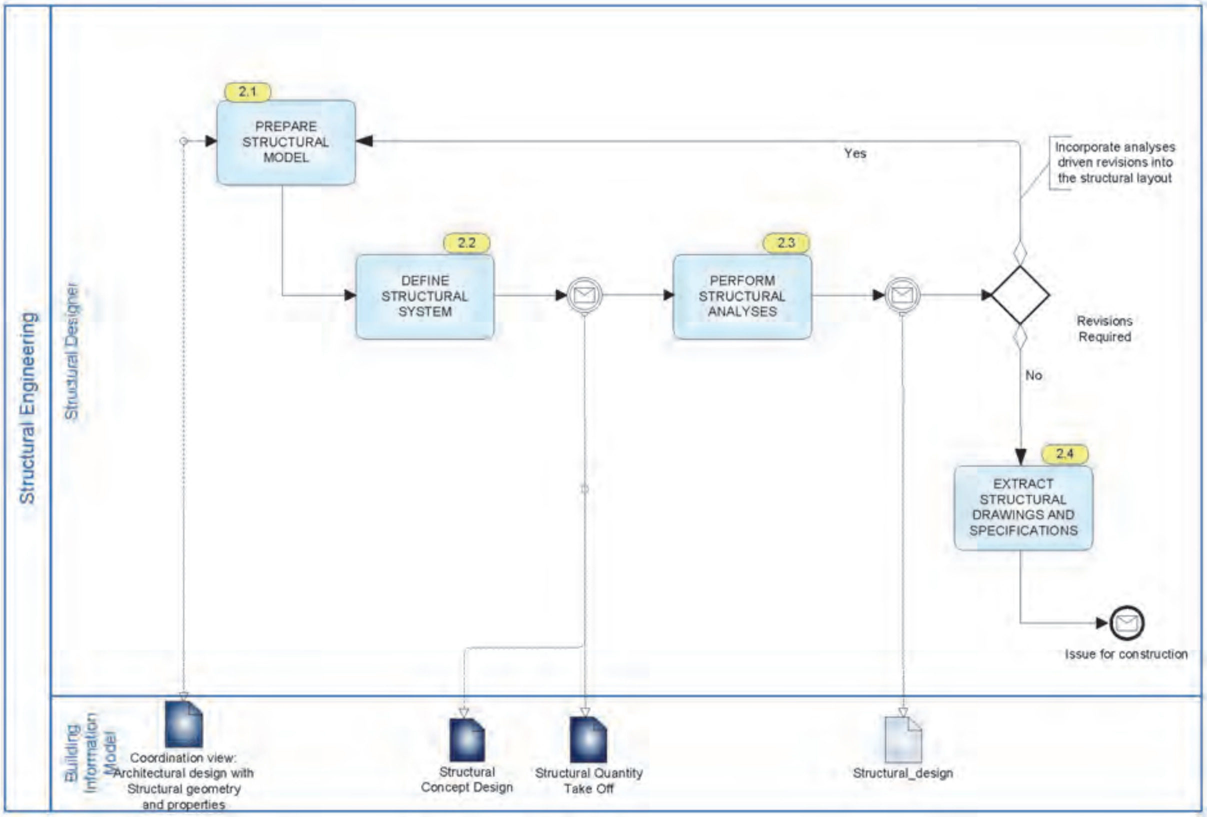


Figure 2-2 Structural engineering domain diagram.

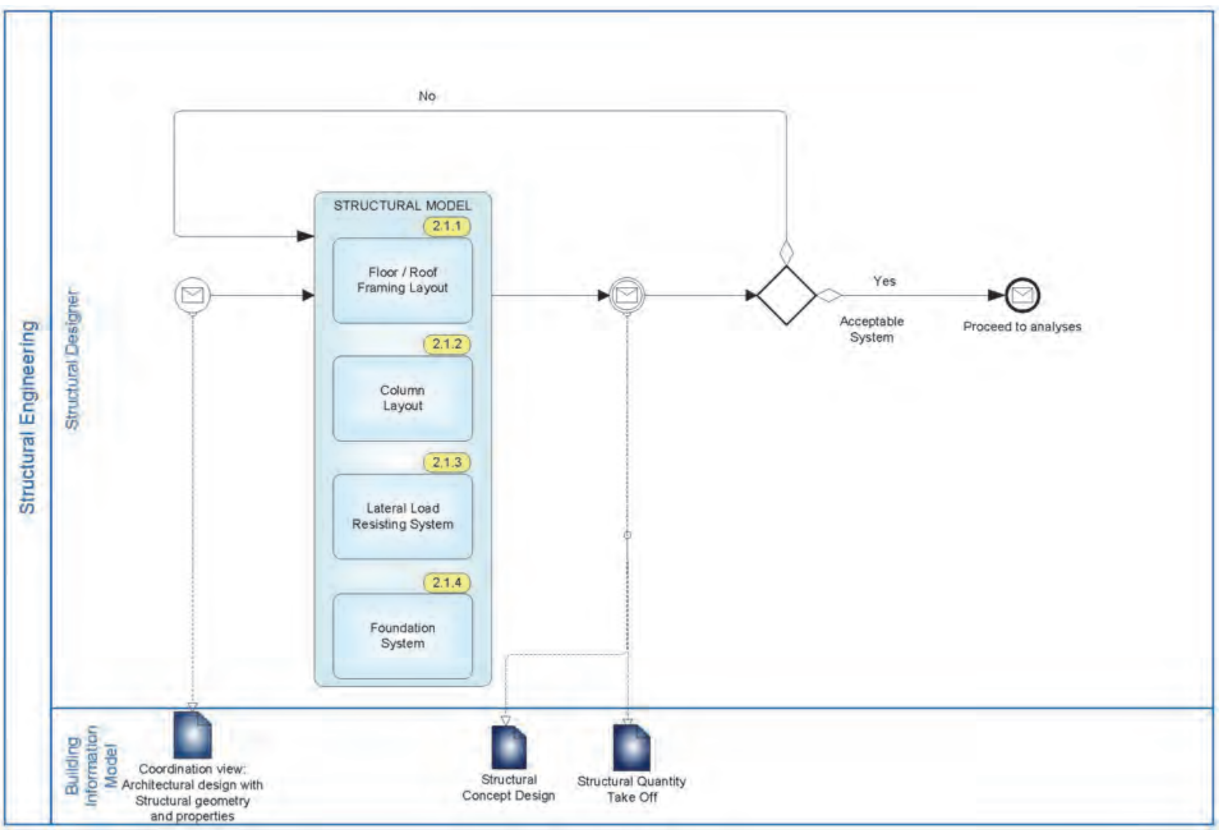


Figure 2-3 Structural system subtasks diagram.

utilize the work done by the engineer. Everywhere that "structural design" appears as a BIM component, the geometry and properties information is exchanged.

2.3 Material Quantity Take-Off Case

The improvement in the exchange of model geometry and properties leads to an opportunity to utilize structural and architectural information to estimate material quantities and costs. BIM is primarily used for architectural and sub-consultant design, and the preparation of construction documents. However, the information can be used to estimate material quantities, and costs, and to aid in construction processes. It is possible to formalize the use of material properties, and quantities, to estimated costs, by including cost information into the database of elements with similar material and cost data. By performing preliminary material cost estimates, it is feasible to make informed choices about structural systems and to evaluate alternative structural systems in terms of cost and schedule implications. In Figure 2-2, the material quantity take-off is identified as a co-result with the structural model, a scenario that is made possible by the approach of the ATC-75 project team. Since BIM software can analyze data, and industry foundation class (IFC) categories exist to hold different classes of data, the use of model data to perform material quantity take-off and cost estimates is a powerful tool.

2.4 Analysis Model Case

Work has been done internationally to allow engineers to exchange information from physical BIM models to analytical models, and there is great value in this type of exchange. However, the ATC-75 project team determined that practicing engineers are unlikely to trust analysis model exchanges until substantial improvements are made translating models between BIM and analysis software vendors. Expanding the IFC, or increasing its consistency of use, will not address differences in logic between BIM physical models and structural analysis models. This is caused because of the different purposes of the models. A BIM design model is developed to inform a contractor of what should be constructed, using drawings and specifications developed within the BIM model, and from review of the physical 3D model that includes a depiction of the materials and geometry. A structural analysis model is developed using structural modeling techniques that cause mathematical analysis to estimate anticipated structural behavior most accurately. Sometimes structure geometry is modified for a structural analysis model to include joint offsets or flexibilities, or element stiffness modifications, which will increase the accuracy of a structural analysis procedure. There are aspects to structural modeling that are inherently different, and the pure geometry or element properties between the two models could be different.

To best utilize the resources of this project, the Analysis Model Case has not been considered beyond the improvement of geometry and property exchange. When a structural engineer imports the structural BIM model to a structural analysis software program, the basic information will be correct, and the time spent modifying the model for analysis will be time spent adding information and mathematical interpretation, rather than correcting basic errors of geometry, shape and object type.

2.5 Structural Engineering Exchange Requirements

Details of each structural engineering business process and sub-process considered by the ATC-75 project team, and their input and output, are provided in Table 2-1. All functions that take place within the structural model, as opposed to the analysis model (item 2.3), are dependent on imported geometry and properties (items 2.1 and 2.2, including all sub-items). The analysis model contains a mathematical definition of the objects, including geometry and material properties imported from the physical BIM structural model. All coordination between the structural engineer and other stakeholders is affected by geometry and property improvements in the exchange.

The Structural Engineering Exchange Requirements considered under this project, as derived from the business processes described above, are provided in Table 2.2. These Structural Engineering Exchange Requirements defined the overarching processes considered in the development of IFC Exchange Requirements, as described in Chapter 3.

Table 2-1 Structural Engineering Process Overview—Detailed Descriptions

ID	*Type*	*Name*	*Description*	*Process Model*	*Input*	*Output*
1	Model	Architectural Model	The objective of the handoff of the Architectural Model to the Structural Engineer is to provide the design-level concept for the structure, as well as desired materials and usage information to the Structural Engineer for the development of Structural Systems	1	Architectural Design	Coordination View: Architectural Design with Structural geometry and properties
2	Model	Structural Model	The objective of the creation of a Structural Model by the Structural Engineer is to detail the structural systems within the building for detailed analysis and production of structural drawings.	2	Coordination View: Architectural Design with Structural geometry and properties	Structural Concept Structural Design Material Quantity Take-off
2.1	Task	Prepare Structural Model	The structural engineer adds structural framing to the Architectural Model to create a Structural Model for use throughout the structural engineering domain.	2	Coordination View: Architectural Design with Structural geometry and properties	Structural Concept Structural Design Material Quantity Take-off
2.2	Task	Define Structural System	The objective of defining the structural system is to determine the best system for the project, at a broad level. The system can be compared to other alternative systems for cost-effectiveness through analysis of the quantity take-off information that can be extracted.	2	Structural Model	Structural Concept Structural Design Quantity Take-Off
2.2.1	Sub-process	Floor/Roof Framing Layout	The objective of the floor/roof framing layout is to provide the detailed layout of horizontal structural members; layout produces data for analysis (2.3).			
2.2.2	Sub-process	Column Layout	The objective of the column layout is to provide the detailed layout and orientation of vertical structural members; layout produces data for analysis (2.3).			

Table 2-1 Structural Engineering Process Overview—Detailed Descriptions (Continued)

ID	*Type*	*Name*	*Description*	*Process Model*	*Input*	*Output*
2.2.3	Sub-process	Lateral Load Resisting System	The objective of the lateral load resisting system design is to provide detailed layout of the lateral load resisting system; layout produces data for analysis (2.3).			
2.2.4	Sub-process	Foundation System	The objective of the foundation system design is to provide detailed layout of the building foundation system; layout produces data for analysis (2.3).			
2.3	Task	Perform Structural Analyses	The objective of the performance of structural analyses is to determine whether the system as designed is adequate for building environment and uses; this activity is a cycle with activity 2.1, refining until analysis yields satisfactory results.	2	Structural Concept Design	Structural Design
2.4	Task	Extract Structural Drawings and Specifications	The objective of the extraction of structural drawings and specifications is to provide output from the structural activities for permitting and construction use and archival records.	2	Structural Design	Structural Drawings and Specifications
3	Model	Construction Model	The objective of the handoff of the Structural Model to the Construction Model is to enable the construction process to directly utilize Structural Model along with the Architectural Model to produce a complete construction directive.	3	Structural Model	

Table 2-2 Structural Engineering Exchange Requirements

Name	*Description*	*Exchange Discipline*
Coordination View: Architectural Design with Structural Geometry and Properties	The architectural designer exchanges a basic or conceptual physical model of the project's architectural elements and form. This exchange includes geometry and material property information usable by the structural engineer.	Architect and Structural Engineer
Structural Concept Design	The result of this exchange is a 'finalized' version of the structural concept design, which includes structural form, framing layout, stability provision, material selection and sizes.	Cyclical between Structural Engineer and Architect
Structural Quantity Take-off	This exchange includes a basic measurement of building materials, with types of measurement depending on the variables relevant to the construction type. Rough scheduling data are also included for time-dependent cost factors.	Structural Engineer and all other stakeholders; can be cyclical
Structural Design	This exchange requirement is the result of the Structural Design, which has been refined through structural analysis and coordination with the architect and other sub-consultants. It represents the final detailed structural design, ready for construction.	Structural Engineer and all other stakeholders, is cyclical

Chapter 3

Development and Testing of IFC Exchange Requirements

When the ATC-75 project commenced in 2008, buildingSmart International (NIBS, 2007) had already adopted the Industry Foundation Classes (IFC) file structure, an existing open source schema designed for the transfer of building information between different software definitions to facilitate building model transfers. The Applied Technology Council's goal, in conducting the ATC-75 project, was to develop an extended set of IFC definitions for structural components to improve the success rate of structural model transfers using the IFC technology. The approach adopted by the ATC-75 project team was to incorporate the then-current state of structural design processes, analysis tools and documentation methods into useable, reliable IFC based model transfers.

This chapter provides an overview of the IFC exchange requirements development and testing process.

3.1 Scope

The scope of the IFC development efforts consisted of identifying the IFC exchange pathways for the structural domain and prioritizing those that are most important, that would lead to the greatest benefit, within the constraints of the project. The diagram in Figure 3-1 conceptually illustrates the IFC exchange pathways that are common to the structural domain.

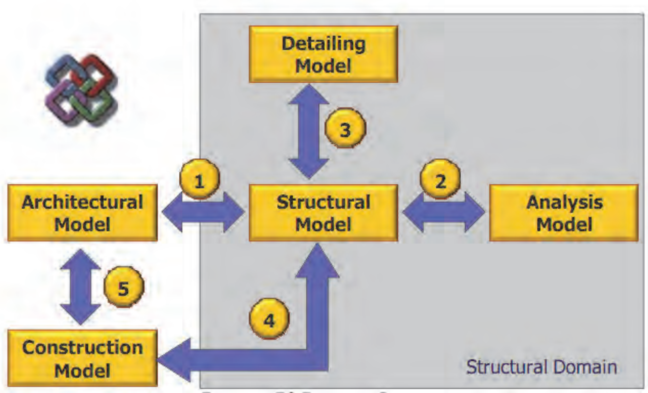


Figure 3-1 IFC exchange pathways for the structural model.

Much consideration was given to the importance of each of the potential pathways and their relative importance to each other, as well as their value to interoperability with other domains. The consensus of the project team was that all of these pathways were important to the seamless interoperability across the myriad of platforms potentially involved in a project. However, the most important parameter by far was basic geometry.

The project team limited the scope of transferred structural objects to primary structural elements defined as beams, columns, braces, walls, floors, roofs, and foundations and their corresponding properties. The geometry of these objects needed to be able to transfer in either orthogonal or non-orthogonal orientations. The original scope was much broader and included items considered as secondary objects such as bolts, gusset plates, reinforcing bars, and prestressing tendons but this extended scope was deemed to be too much detail for the size and scale of this project.

3.2 Development of IFC Exchange Requirements

The framework through which the structural engineering profession exchanges interoperable data was defined through documentation of the structural engineering business processes, as described in Chapter 2 (ATC, 2009). The process models identified in the documentation of business processes determined the required data that needed to be exchanged to serve these processes. The resulting exchange requirements were defined in a process and format prescribed in the *National Building Information Modeling Standard* (NBIMS) (NIBS, 2007). Each IFC exchange requirement was tied to associated business rules that define the constraints for their use. This work phase followed the NBIMS process to ensure wide industry participation and to create accepted industry processes.

The exchange requirements identify the objects and properties contained in the BIM model that are needed to be exchanged between software platforms. Structural object attributes (e.g., story elevation) addressed by the project were described in terms used by the structural engineering profession and were exemplified for software programmers in language that enables them to execute a software exchange using the IFC process.

Appendix A of this report provides example exchange requirements for several of the nine categories of structural elements addressed in this project (story, grid, column, beam, brace, wall, slab, footing, and pile) and identifies their properties and how the elements (objects) should be treated by users and by software. The priority set by the ATC-75 project team for developing IFC exchanges for each attribute is also provided. Properties in engineer/practitioner language are provided under the column heading, "*Explanation*", and information in terms meaningful to software vendors is provided under the column heading, *Examples*. The information provided in Appendix A illustrates the communication mechanism between practitioners and the software programmers. This information was developed at early project work sessions, and refined over successive teleconferences. The exchange requirements were reviewed in detail with the representatives of software companies who were engaged throughout the development of the project.

As part of the IFC exchange requirements development and implementation process, the project team also kept track of pertinent information to IFC exchange implementation. This information was documented in the "IFC Binding," which is exemplified in this report in Appendix B. Like Appendix A, Appendix B provides example information for several of the nine categories of structural elements (objects) addressed in this project (story, grid, column, beam, brace, wall, slab, footing, and pile). For each attribute, information is provided on (1) the priority for developing IFC exchanges by the ATC-75 project team, (2) the IFC representation of the exchange, (3) the status of IFC implementation, (4) the name of the relevant Model View Definition (see below), (5) recommendations for implementation by the ATC-75 project, and (6) recommendations for further development.

3.3 Model View Definition

Once the exchange requirements were clearly defined, the project's IFC consultant determined and mapped their representation in IFC file diagrams, pinpointing where and how different software is to store particular IFC data upon export and draw it in upon import. In cases where the IFC did not contain a compatible data placeholder, new language was written to expand it. Some iteration in the software mapping process required consultation with the project team and collaboration with industry representatives.

The mapping process, including identification of new and modified IFC structural elements, was integrated into an IFC data model designed to ensure interoperability across diverse domains. The results of this effort are documented in the Model View Definition (MVD), which is a complete set of software data elements for enabling data exchanges, in this case for the structural engineering domain.

For illustrative purposes, Appendix C to this report contains the Model View Definition (MVD) Diagrams that have been developed in the format established by the International Alliance for Interoperability (IAI). Not included in Appendix C, but generated during the ATC-75 project and available on the ATC website (ATC, 2008), is the software coding information that accompanied the original MVD Diagrams.

3.4 Lack of Naming Conventions for Structural Materials

As the IFC exchange requirements were developed, a trend emerged that construction material industries (such as steel, concrete, wood, and masonry) did not have complete digital based naming conventions for the size and shape of the products they represent. The structural steel industry, through the American Institute of Steel Construction (AISC), does have a published guide on the digital naming of steel members entitled, *Naming Convention for Structural Steel Products for Use in Electronic Data Interchange (EDI)* that was issued in 2001. Unfortunately, the nomenclature chosen for steel angles and HSS hollow tubes included the back slash "/" character that has a conflicting meaning in computer programming, and therefore could not be used. Other construction material industries do not have standard digital naming conventions.

This problem may seem trivial, but the IFC consultant was hesitant to determine naming conventions and felt strongly that material industries should provide guidance. An example of a problem created is the definition of a concrete beam, which is customarily defined in the United States as width x depth. However, some software packages defined it is depth x width, creating a discrepancy when passed from one software to another. Without industry-approved standards, the IFC consultant was reluctant to define naming convention because it may cause software vendors to change their software based on IFC definitions. This was also a problem when defining material name, type and grade properties. This stumbling block was overcome by a consensus process on the typical industry naming approach by the project participants. However, each material industry is encouraged to develop a digital naming methodology for their products for use by the engineering software industry.

3.5 Benchmark Testing

In order to guide improvements to the use of the IFC data, it was necessary to determine how well the IFC transfers worked between the most commonly used software packages. To execute such an interoperability evaluation, the project team devised a testing program that involved the collaboration of software vendors who had volunteered to be involved in the project. The first testing program was carried out in June 2008, followed by a second validation testing program two years later (in June 2010). The program required that the collaborating software vendors modify, as necessary, their software to enable the exchange of structural data elements as defined by the domain experts and documented in the Model View Definitions developed under the ATC-75 project for the structural domain.

At the outset of the first testing program, the engineering practitioners on the project team interacted with software vendors to ensure that the structural data exchange requirements were correctly understood and implemented in a two-tiered testing program. First, the IFC *Structural Model View* was implemented in the software, and an International Alliance for Interoperability (IAI) testing program was conducted to certify that *Structural Model View* data was correctly implemented in accordance with NBIMS (NIBS, 2007) and IAI (1999) guidelines. Secondly, the project engineering team and other members of the engineering community validated the effective exchange of structural data elements in the defined processes from a user perspective through a benchmark testing program.

The benchmark testing program involved the use of a benchmark test model that was created by the project team, with the advice of an external specialist in IFC file exchanges. The benchmark test model (see Figure 3-2) represented an

Figure 3-2 Benchmark test model.

idealized structure derived from a portion of a stadium project that included a broad range of content of different structural materials, elements and configurations. The model contained straight and curved beams, straight and sloped columns, encased steel columns in concrete, and slabs and walls.

The model was generated independently in four common BIM software platforms, and exchanged amongst the software, with common engineering analysis software, and with the IFC viewer. The initial purpose was to systematically quantify the state of interoperability in a methodical and comprehensive format, namely a spreadsheet matrix that graded the success of transfer from one software to another, based on the accuracy of:

- Geometric coordinates transfer,
- Material properties transfer,
- Curved and shaped geometric transfer, and
- Sloped geometric transfer.

To qualify for an acceptable transfer (as scored in the benchmark tests) the following conditions had to be met for each category:

1. Geometry—the element location as determined by endpoints must have been correct and the element must have been displayed accurately in the model view.
2. Properties—the element size and orientation and material profile must all have been correct.
3. Curved elements—element curves or radii in plan (horizontally) or in space (horizontal, vertical or combination) must have been displayed accurately in the model view.
4. Sloping elements—element inclined at an angle greater or less than 90 degrees (vertical) must have been displayed accurately in the model view.

Representatives of the software vendors involved in the testing program were given an opportunity to review and improve upon the results during the two year elapsed time between the initial benchmark tests in 2008 and the final validation tests in 2010. This approach also enabled vendors to ensure that the benchmark testing was not skewed by user error, and reflected the best performance of their software.

The following software products were included in the benchmark testing:

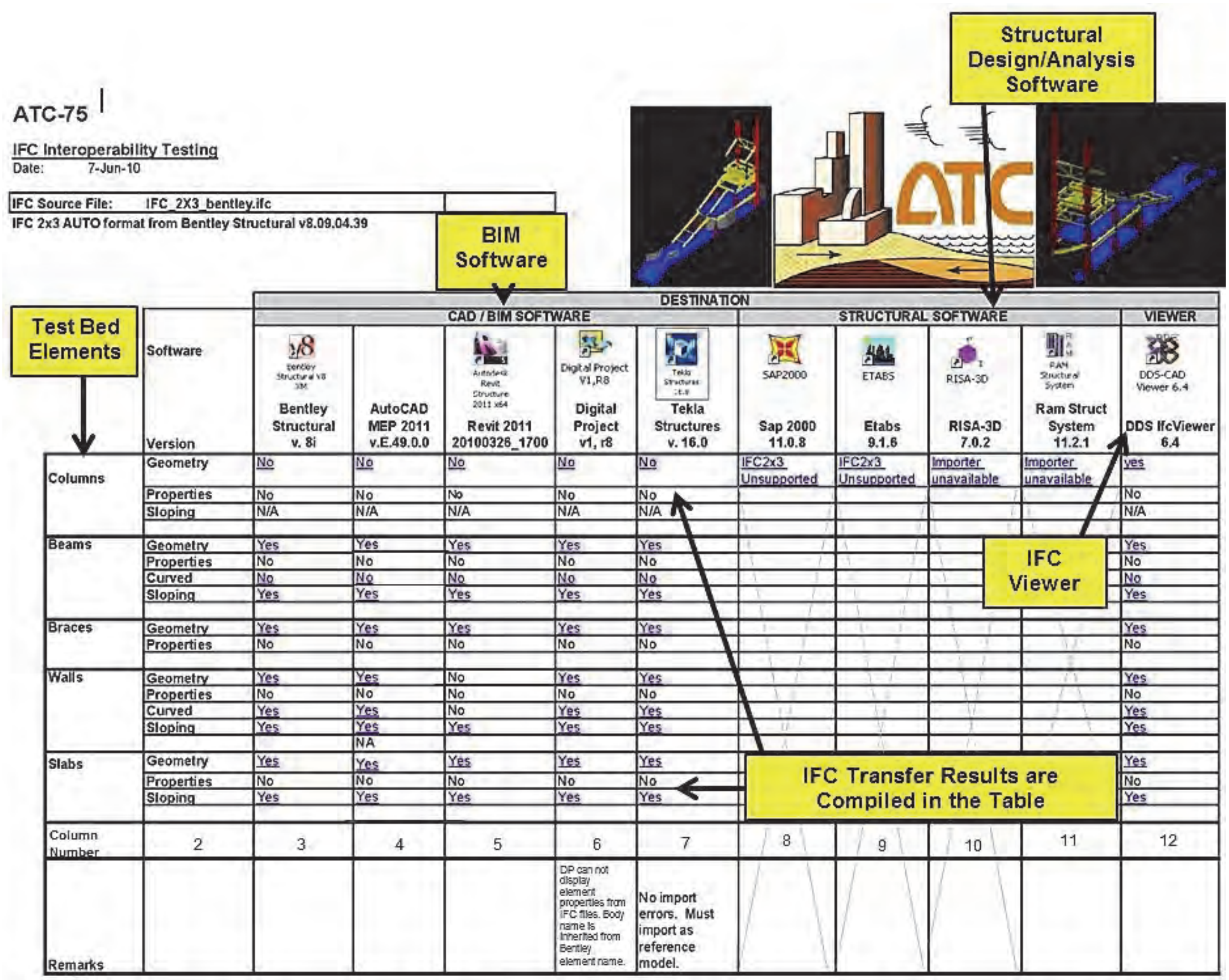
- Bentley Structural, Version 8.9
- AutoCAD 2008, Service Pack 1, b219.0
- Revit Structure 2008, Build 0101_2345
- Digital Project, Version1, r8
- Tekla Structures, Version 13.0
- Sap 2000, Version 11.0.8
- ETABS, Version 9.1.6
- RISA-3D, Version 7.0.2
- Ram Structural Systems, Version 11.2.1

At the outset of the testing program each BIM software vendor who participated was advised that the testbed validation would involve the following components and activities:

- A common source model to testing the IFC exchange;
- A description of the test model based on the structural modeling elements and attributes used;
- A description of test criteria against which the result would be validated;
- A realization of the same test model in (at least) two structural modeling applications;
- A set of IFC export files (from the source applications) with well documented export options;
- A set of success/failure descriptions for external neutral test tools:
    - In IFC syntax checker;
    - In IFC validation tools; and
    - In IFC viewer;
- A matrix of success/failure descriptions for import into other software:
    - Matrix based on test criteria and importing software; and
    - Importing software is either:
        - Other BIM tools (architectural/ structural modeling software), or
        - Structural analysis software.

As indicated above, initial benchmark tests were conducted in 2008, with final validation tests in 2010. For each software platform tested, the following information was documented: the software version and date of the test; perspective views of the benchmark test model (Figure 3-2); and detailed views of the various structural elements (objects) exported to IFC (i.e., various column, beam, brace, wall, and slab types and configurations) and the properties of these elements (i.e., size, material, grade, length, and roll).

The instructions provided to each BIM software vendor who participated indicated that the benchmark testing consisted of the following steps: (1) exporting the IFC file; (2) verifying the IFC file for a correct header; (3) verifying the IFC file within a syntax checker; (4) verifying the IFC file for basic information (e.g., units, other properties), and (5) verifying the IFC file within a free viewer.



	Software / Version	Bentley Structural v. 8i	AutoCAD MEP 2011 v.E.49.0.0	Revit 2011 20100326_1700	Digital Project v1, r8	Tekla Structures v. 16.0	Sap 2000 11.0.8	Etabs 9.1.6	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.4
Columns	Geometry	No	No	No	No	No	IFC2x3 Unsupported	IFC2x3 Unsupported	Importer unavailable	Importer unavailable	yes
	Properties	No	No	No	No	No					No
	Sloping	N/A	N/A	N/A	N/A	N/A					N/A
Beams	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Braces	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
Walls	Geometry	Yes	Yes	No	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	Yes	Yes	No	Yes	Yes					Yes
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
			NA								
Slabs	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Column Number	2	3	4	5	6	7	8	9	10	11	12
Remarks					DP can not display element properties from IFC files. Body name is inherited from Bentley element name.	No import errors. Must import as reference model.					

Figure 3-3 IFC transfer summary for example software platform, for final validation benchmark test in 2010.

3.6 Results of Benchmark Testing

The benchmark testing provided verifiable results to understand the state of interoperability in the BIM and structural software industry. An example summary of the output for one set of IFCs for one tested BIM software platform is provided in Figure 3-3. For each of the four tested BIM software platforms (3rd, 5th, 6th, and 7th columns from left in Figure 3-3), the summary indicates, for each element (column, beam, brace, wall, and slab, as shown in the rows), whether the IFC passed or failed (in yes or no terms) transferring geometry, properties, curved elements and sloped elements.

The software documentation and benchmark test data for the final validation testing in 2010 are summarized in Appendices D through G for each of the four BIM software platforms tested: (1) Bentley, (2) Digital Products, (3) Revit and, (4) Tekla.

Appendix D contains documentation on the IFC transfer validation testing of Bentley Structural software, Version 8.9. The results of the benchmark tests were that the IFCs were exported successfully and were imported correctly. The geometry was transferred correctly, but the properties of each element were not transferred correctly. Sloping columns were transferred into beams after IFC transfer. These issues were to be corrected in subsequent releases of the software.

Appendix E contains documentation on the IFC transfer validation testing of Digital Project software, Version 1 r8. The results of the benchmark tests were that the IFCs had some transfer errors. Column, beam, walls, braces and slabs did not have properties transfer correctly. Some columns were transferred as beams into

Digital Project. Sloping columns were not able to transfer. These IFC transfer issues were to be corrected in subsequent releases of the software.

Appendix F contains documentation on the IFC transfer validation testing of Revit Structure 2008 software. The results of the benchmark tests were that the IFCs had some transfer errors. The columns were read as arch columns. Column, beam, walls, and slabs did not have properties transfer correctly. Braces did not transfer into Revit at all. Sloping columns were transferred into beams after IFC transfer. These IFC transfer issues were to be corrected in subsequent releases of the software.

Appendix G contains documentation on the IFC transfer validation testing of Tekla Structures software, Version 13.0. The results of the benchmark tests were that the IFCs were exported successfully and needed to be imported as reference objects. The geometry and grade of beams, columns and braces were transferred correctly. The thickness of walls and slabs, however, did not transfer correctly. Sloping columns were transferred into beams after IFC transfer. These issues were to be corrected in subsequent releases of the software.

During the course of the ATC-75 project, it became evident that the general dissatisfaction with software interoperability by structural engineers was a systemic problem caused by the lack of successful transfers between the software tested. Some software products were not able to accurately transfer (either into or out of) something as basic as a straight beam or column. However, most BIM software products could transfer many of the beams, columns, slabs and walls in the benchmark test model. In discussions with practicing structural engineers, the lack of accuracy of element transfers has led to a lack of faith in the entire model fidelity. Often with 3D models, trying to find the elements that did not transfer properly can be as difficult as remodeling the entire 3D model. This can cause engineers to forego model transfers and to completely re-model in the software they wish to transfer to.

At the conclusion of the benchmark tests, the results were used to gauge the progress of the software platforms to exchange information using the ATC-75 generated IFCs. Improvements have not been as rapid to develop as the project team had hoped. Software vendors have acknowledged user demand and were willing to work with groups like ATC-75 team to meet it. Even in cases where the particular points of ATC-75 were not entirely integrated to the latest software releases, the vendors felt the need to incorporate improvements in future releases. In the project meetings, programmers expressed gratitude that practitioners had created consensus definitions for them to use and implement. In the past, software vendors have encountered difficulty anticipating the needs of their customers, and this project has created a template for cooperation between disciplines to achieve the maximum improvement possible. Some vendors are more rapid to implement desired improvements than others. Regardless of timing, the BIM software industry has continued to implement the ATC-75 project objectives with each new release. The benchmark test results are mixed; however, there has been major improvement since the project started. There were clear improvements in exchanges with the Data Design System (DDS) IfcViewer and notable improvements in Digital Projects software.

The IFC exchange of BIM with engineering analysis software is still largely unsuccessful. The need for further progress in development of reliable IFC exchange in the structural domain is evident; however, there is a great deal of progress to be made.

3.7 Implications of the Validation Testing

The need for interoperability between the various software tools in the BIM industry is unquestioned. The ATC-75 project was a catalyst for building industry consensus that IFCs are the preferred transfer file type for interoperability for the structural domain. Programmers for software vendors expressed gratitude that practitioners created consensus IFC definitions for their use. Due to the schedule and timing of software releases, implementation of the recommendations of ATC-75 has progressed over time. The software vendors have all committed to incorporate the ATC-75 framework in subsequent software releases. The process of advancing a software industry that is used by many disciplines is difficult, and ATC-75 and other projects have helped to the lay the foundation for continued progress.

Chapter 4
Results Dissemination

4.1 Dissemination Work Plan

At the end of the ATC-75 project in 2011, the project team developed a Diffusion Summary Report (summarized herein) that reflected on the effectiveness of the dissemination process by summarizing the diffusion successes, documenting the implementation of the dissemination strategy, and seeking out measures to quantify the effectiveness of the Dissemination Work Plan written at the outset of the project.

Dissemination, both of the IFCs themselves and of the message of the opportunities and benefits of interoperability they provide, were an important product of this endeavor. The strategic planning effort by the project team laid out a dissemination scheme that was intended to demonstrate the value that this technology brings to the architecture, engineering, and construction industry, thereby creating a need for the technology in the broad group of stakeholders. The Dissemination Work Plan defined the strategies to be implemented to market and distribute the development of the IFCs to stakeholders—engineering practitioners, the construction industry and software creators. The strategy also addressed the "human factors" of implementation of new technology to the user group to allow them to be accepting and accommodating of the technology. The strategy was multifaceted, reaching a wide variety of avenues, including:

- internet platforms;
- professional associations;
- engineering journals;
- engineering periodicals; and
- industry seminars/conferences.

The ATC-75 project was commissioned by the Charles Pankow Foundation as an effort to establish structural domain IFC exchange standards. Part of the objective of the project was to entice stakeholders in that arena to more fully utilize the tools available in BIM related to IFC exchanges. By involving stakeholders in the project and advertising its progress, it was hoped that the industry at large would embrace the results.

Because so many software platforms have independently and competitively innovated, there has historically been a lack of interoperability between them. Many vendors have multiple programs that work together well, but few were able to translate accurately with competing software. Additionally, there was a lack of industry or technical leadership to establish standards or guide software programmers in tailoring their work for the needs of the practitioners. The *National Building Information Model Standard* (NBIMS) (NIBS, 2007) and the buildingSMART Alliance in the United States, as well as many international groups and the International Alliance for Interoperability (IAI), have pioneered an overarching standardization process; in the meantime, independent work groups like the one established for the ATC-75 project have begun to work on fleshing out and standardizing specialized domains of data.

4.2 Dissemination Objectives

The benefits of interoperability among a multitude of software platforms are immense. Interoperability creates the opportunity for the seamless integration of design activities in the workflow and the bridge to the vertical integration of design/construction/operation of a given facility. Industry Foundation Classes (IFCs) serve to provide non-proprietary, open exchange of data between different programs. The development of IFCs for the structural domain created the opportunity to foster the interoperability between software platforms for structural systems.

The objective of this project's dissemination was twofold: first, to reach the largest possible audience of practitioners and encourage their belief in and demand for functional interoperability; and second, to reach software programmers and sales representatives and facilitate their involvement in a community effort to enable full, robust, trustworthy interoperability.

4.3 Dissemination Avenues

Several avenues were utilized by the project team to distribute information about the project, its goals, and opportunities for involvement by a broader section of the design and construction industry. Described below are some of the activities that were undertaken.

4.3.1 Internet Platforms

The internet provided the most accessible platform for project dissemination. The principle platforms used were the ATC-75 project website and the buildingSMART alliance (bSa) project website.

- www.atcouncil.org/Projects/atc-75-project.html. This site—the project storehouse—contained the entire project resources developed and published for this project. The site provides the most extensive repository of project products, including workshop reports, detailed test data compiled during the benchmark testing as well as the actual Model View Definitions for the IFC exchanges.
- www.buildingsmartalliance.org. The ATC-75 project was one of the original projects listed on the buildingSmart Alliance active projects list. This list is used to provide a collaboration space that identifies the myriad of BIM projects that are being undertaken or contemplated.

The model view definitions were also published on the International Alliance for Interoperability (IAI) Model View Definition (MVD) collaboration site called the IFC Solution Factory. When the project was completed in 2011, there were also a wide array of links from other websites and electronic publications, including:

- *Development Of IFCs For Structural Concrete Strategic Plan* by the Strategic Development Council of the American Concrete Institute (www.concretesdc.org/BIMStrategicPlan.pdf);
- *Masonry BIM and the Structural Domain* by N. O. Nawari (2011);
- *The Role of National BIM Standard in Structural Design* by N. O. Nawari and M. Sgambelluri (2010); and
- *Assessment of Conformance and Interoperability Testing Methods Used for Construction Industry Product Models* by R. Lipmana, M. Palmera, and S. Palacios (2011).

4.3.2 Professional Associations

- *American Concrete Institute (ACI)*. The ATC-75 Project Technical Director and Lead Engineering Consultant joined, as members, the newly established committee ACI-131, Building Information Modeling. The committee was formed to develop and promote data exchange standards for concrete, among other reasons.
- *American Institute of Steel Construction (AISC)*. The ATC-75 Project Technical Director and Lead Engineering Consultant were participants at several AISC eConstruction Roundtable discussions.
- *Strategic Development Council of the ACI Foundation*. The ATC-75 Project Technical Director and Lead Engineering Consultant participated in various Strategic Development Council conference meetings.

4.3.3 Engineering Journals

- *Journal of Building Information Modeling*, Abstract submitted: "IFC-BIM for Structural Engineering, Applied Technology Council (ATC) Project Team" by Francois Grobler. Article not accepted for publication.

4.3.4 Industry Seminars and Conferences

- ACI Foundation Strategic Development Council, Session #23, April 22, 2008, Omni Mandalay Hotel, Irving, Texas
    - Presentation, "ATC-75 IFC's for the Structural Domain, Project Overview" by E. Dean
- ACI Foundation Strategic Development Council, Session #24, October 9, 2008, Palm Harbor, Florida
    - Presentation, "Changing Process with BIM" by E. Hatfield
- ACI Foundation Strategic Development Council, Session #26, October 1, 2009, Inverness Hotel & Conference Center, Englewood (Denver), Colorado
    - "ATC-75 Status Update" by E. Dean
    - "ATC Project: Developing a Strategic Plan for BIM and Structural Concrete (ATC-81)" by E. Dean

- ACI Foundation Strategic Development Council, Session #27, May 6, 2010, Intercontinental Hotel, Kansas City, Kansas
  - "ATC-75 Status Update" by E. Dean
  - ACI Foundation Strategic Development Council BIM Initiative Strategic Planning Session (ATC-81)
- AISC/NASCC Convention, eConstruction Roundtable, April 1, 2008, Nashville Convention Center, Nashville, Tennessee
  - "ATC-75 Update to the eConstruction Roundtable" by E. Hatfield
- AISC/NASCC Convention, eConstruction Roundtable, March 31, 2009, Convention Center, Phoenix, Arizona
  - Presentation, "ATC-75 IFC's for the Structural Domain" by E. Dean

4.4 Dissemination Successes

The ATC-75 project was a seminal effort to seed the future development of interoperability across a broad spectrum of BIM platforms. The effort to accomplish this is only beginning. The dissemination of the project goals met with some success, but was also limited in the reach that was achieved. The team prepared a work plan to identify the strategy to be used to achieve the desired objectives:

> *to reach the largest possible audience of practitioners and encourage their belief in and demand for functional interoperability; and to reach software programmers and sales representatives and facilitate their involvement in a community effort to enable full, robust, and trustworthy interoperability.*

The project was successful in making the work produced broadly available through the project website. The project team worked to reach practitioners through their participation in professional associations and presentations at conventions and conferences. A clear measure of success in this dissemination was the posting of the MVDs at the IFC Solution Factory making them available to programmers worldwide. The ATC-75 exchange protocols are beginning to appear in the discussions with the software developers, but their implementation has been slow. The implementation has been slowed by the compounding effects of poor economic conditions that have continued for several years, which has hampered research and development funding at the software firms and may have slowed the adoption of BIM in many design offices. The human factors, or the inherent resistance to change that exists in many industry professionals, is a definite head wind to the broader adoption of BIM technologies. It is difficult to know to what extent this project was influential in being an agent of change for those resistant to adopting BIM technology. Nonetheless the project was successful in laying a foundation for future efforts as evident by the establishment of a BIM committee at ACI and their effort to plan for the development of IFCs for structural concrete as one of their future Critical Industry Technologies using the ATC-75 project as foundation for that plan. The ATC-75 effort is sure to spawn other such technology investments in the structural domain and the true measure of the effort's success will be seen in the future developments that result.

Chapter 5
Summary and Conclusions

The Applied Technology Council (ATC) has developed extended sets of Industry Foundation Classes, IFCs, for inclusion in the International Alliance for Interoperability (IAI) as a part of the buildingSmart alliance, *National Building Information Modeling Standard* (NBIMS) (NIBS, 2007). This project has improved productivity in the design and construction industry by taking the lead in developing a basis for incorporating and integrating structural design, codes, analysis tools and methods into IFCs, the neutral, object-oriented exchange language for Building Information Modeling (BIM) software.

The objective of the project was to entice stakeholders to utilize more fully the tools available in BIM related to IFC exchanges, and by involving stakeholders in the project and advertising its progress, it is hoped that they will embrace the results.

Because many software platforms have independently innovated their products, there has been a lack of interoperability between them. Several years ago, many vendors had multiple programs that worked together well, but few were able to translate accurately with competing software. Additionally, there was a lack of industry or technical leadership to establish standards or guide software programmers in tailoring their work for the needs of the practitioners.

NBIMS and the buildingSmart alliance in the United States, as well as many international groups and the IAI, pioneered an overarching standardization process. Additionally, independent work groups like the one established for the ATC-75 project have worked on fleshing out and standardizing specialized domains of data.

5.1 Report Summary

This report summarizes the activities involved in the development of the ATC-75 project and highlights the accomplishments that were achieved in the years of its evolution. Interoperability and the development of IFCs is a broad and complex process, even when limited to the structural domain. This project was a first step in providing guidance and development of IFCs that will promote interoperability in the structural domain and lead to meaningful improvements in the BIM users' ability to reliably and consistently exchange parametric data between the same or different model platforms.

5.1.1 Project Planning and Execution

The ATC-75 project began with a strategic planning session to define the project goals and objectives and establish a direction for the project. The participants, including the Project Management Committee (PMC) and the Project Advisory Panel (PAP), worked to determine the relevant and necessary data at each exchange point for the various stakeholders in the structural design process. They ranked the exchange data by priority, determining that basic geometry was the highest priority item to tackle; they then began the task of organizing and defining all of the relevant aspects of structural geometry.

The initial planning efforts were documented in the Strategic Work Plan, which became a guide for the project team, as well as a means of advertising the project to a wider programming community. The Plan was instrumental in drumming up early enthusiasm for the project and developing a wider network of participants.

The ATC-75 project initially was envisioned as an IFC update for the structural domain. However, as the participants dug deeply into the state of structural IFCs and examined the exchange points and pathways, the direction was refined toward improved interoperability. They found that the IFC is, for the most part, capable of conveying the information that a structural engineer needs to transfer. It is the usage and application of the IFC units that were inconsistent, which led the practitioners to believe that the exchange can be unsuccessful. In most cases, as evidenced by the benchmark testing conducted during the project, the information was exchanged but not used by the receiver with the same intent as the originator. Therefore, tightening the usage and interpretation of existing IFC data was important.

5.1.2 Documentation of Business Processes

As one of the first major project tasks, the project team documented how structural engineers exchange information with other groups during the design, analysis and construction lifecycle through the interface of three main purpose-built models: (1) the architectural model (architectural design); (2) the structural model (structural design), and (3) the construction model (construction). By documenting the processes that involve structural engineering data as a subset of the total project life, the project team was able to pinpoint the types of data that each stakeholder requires, who inputs that data, and what form the data should take. The documentation of business processes, which is described in Chapter 2, is a way of formalizing expectations, so that the software can perform at the level that users require. In a longer view, formalization of these processes can help improve standard industry practices. Where, in the past each professional would work in the way that best suited their needs and style, to fully realize the potential power of BIM, users needed to conform to the style of work for which BIM is optimized. At the very least, users need to understand where their process deviates from standard BIM usage in order to compensate and still benefit from the power of BIM and integrate with other BIM project groups.

5.1.3 Development of IFC Exchange Requirements

The IFC exchange requirements, as documented in Appendix A of this report, were developed and refined over successive teleconferences of the project team. The exchange requirements were captured in practitioner language, with the goal of defining each item clearly, and then used as a means to guide the conversation from engineering language to software language, removing ambiguities and clarifying specifics, such as units and methods of measurement.

Once the exchange requirements were clearly defined, the project's IFC consultant determined their current representation in an IFC Binding (see Appendix B), which pinpoints where and how the software is to store that particular data upon export and draw it from upon import. In cases where the IFC did not contain an adequate data placeholder, new language was written to expand it.

5.1.4 Model View Definitions

Model View Definitions, which flow from the structural engineering business processes and the IFC exchange requirements, are a complete set of software data elements for enabling data exchanges, in this case for the structural engineering domain. Stated another way, a Model View Definition (MVD) represents an exchange point in the design project at which the data are viewed by a certain user for a certain purpose.

For illustrative purposes, Appendix C to this report contains the Model View Definition (MVD) Diagrams that have been developed (on this project) in the format established by the International Alliance for Interoperability (IAI).

5.1.5 Benchmark Testing

In order to guide improvements to the use of the IFC data, it was first necessary to determine the state of IFC transfers between the most commonly used software packages. The project team developed a small benchmark test model from a portion of an existing project that contained all of the elements that the project identified as exchange priorities, while keeping it simple enough to be manually tracked and reviewed. That benchmark test model was then used as the primary means for testing the ability of IFC exchanges to transfer information in four common BIM software platforms: Bentley, Digital Products, Revit and Tekla.

The benchmark test model was generated independently in each of the above-specified four common BIM software platforms, and exchanged amongst the software, with common engineering analysis software, and with the IFC viewer. The initial purpose was to systematically quantify the state of interoperability in a methodical and comprehensive format, namely a spreadsheet matrix that graded the success of transfer from one software package to another, based on the accuracy of:

- Geometric coordinates transfer,
- Material properties transfer,
- Curved and shaped geometric transfer, and
- Sloped geometric transfer.

Representatives of the software vendors involved in the testing program were given an opportunity to review and improve upon the results during the two year elapsed time between the initial benchmark tests in 2008 and the final validation tests in 2010. This approach also enabled vendors to ensure that the benchmark testing was not skewed by user error, and reflected the best performance of their software.

The software documentation and benchmark test data for the final validation testing in 2010 are summarized in Appendices D through G for each of the four BIM software platforms tested.

The benchmark testing provided verifiable results to understand the state of interoperability in the BIM and structural software industry.

5.1.6 Dissemination Work Plan and Diffusion Summary Report

A crucial aspect of the project was development of the Dissemination Work Plan and the Diffusion Summary Report, which are summarized in Chapter 4. The purpose of this overall dissemination effort was to determine how project information could best be passed to the architecture, engineering, and construction industry, and then to implement those dissemination options. The effort included speaking assignments and technical presentations by key project participants, and publication of project information on websites and elsewhere.

5.2 Conclusions

The extent to which the ATC-75 project can be deemed successful is based on several factors: real-world improvements in IFC application; increased awareness of IFC among practitioners; and increased momentum for IFC development and use in North America. The software providers were able to implement changes that have made IFC a more effective means of transporting data from one platform to another, and will continue to do so in successive releases. Software vendors are motivated to improve their IFC import and export because their customers are becoming more aware of IFC transfer capability. Practitioners who do not use IFC are bound to custom translators, a narrow field of software choices or laborious rebuilding of models in various formats. Practitioners who have begun to use IFC recognize the capabilities and are a powerful customer base.

BIM has become the standard of care in the architecture, engineering and construction industry, evidenced not only by the community of users but also by the growing number of project owners requiring BIM deliverables. When BIM was primarily used by large multinational firms, software vendors wrote custom software for these large customers to translate models from platform to platform. As BIM use has spread to most architecture, engineering and construction companies, demand for IFC interoperability has become necessary. Public awareness has grown to a point that practitioners know that interoperability is important, whether they know to call it IFC or not. The ATC-75 project team has helped to educate many practitioners, which has created a great deal of excitement about the potential for the use of BIM in the architecture, engineering and construction industry.

The need for interoperability between the various software tools in the BIM industry is unquestioned. Software vendors acknowledged demand for the vendors to improve interoperability. The ATC-75 project was a catalyst for building industry consensus that IFCs are the preferred file transfer method for interoperability for the structural domain. In the project working group meetings, programmers for the software vendors expressed gratitude that the practitioners agreed to create consensus definitions for development and use, and these consensus definitions have been implemented into the major BIM products. Due to the timing of updated software releases, along with the continued development, immediate implementation of the ATC-75 recommendations was not possible. However, the vendors participating in the ATC-75 project all committed to incorporate the IFC framework in their future releases. The process of reforming and advancing a BIM industry that affects so many architecture, engineering and construction firms is time-consuming; however, the ATC-75 project and others like it have helped to lay the foundation for improvement.

There is also another type of success that this project has generated: an effective project format for IFC work. Based on the ATC-75 project model, the Applied Technology Council worked with the American Concrete Institute on a subsequent ATC project (ATC-81), with the goal of improving interoperability through the development of IFCs for structural concrete components. The unique project participant combination, the extremely effective IFC exchange requirements development process, and the network developed for dissemination of the project's goals and progress combine to a very successful format for development.

Interoperability through IFC has become a powerful movement. While there are discrete improvements in implementing IFCs that can be made by software providers, the larger picture shows an entire industry being remade to realize the promise of BIM. The ATC-75 project brought together the BIM product programmers and practicing engineers to work together in a forum that allowed progress in a collaborative environment. Similar groups can tackle additional aspects of interoperability in the future and work with international groups to further advance interoperability and to expand the potential of BIM.

Appendix A

Example IFC Exchange Requirements

Table A-1 Exchange Requirements for Object Category 1: Story

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Story Elevation (Priority 2)	Absolute elevation for story; the name "story" is preferred over "level", as level is used, for example, in Revit beyond the meaning of story – (i.e., for any horizontal reference level). There are two elevation values for each story: - the relative elevation of the story against the reference height of the project. - the absolute elevation of the story against the relevant sea level (or geographic height datum).	Typically, elevations for a project are all relative to a base elevation that is generally set to +100'-0". So, in Florida, +100'-0"' might be 3' above sea level. In Denver, Colorado, +100'-0" might be 5300' above sea level.	It is sufficient to have the relative elevation as an explicit measure for each story, and the absolute "above sea level" elevation once at the building to which all stories reference. The absolute elevation of each story can then be calculated by the receiving system.
Story Name (Priority 2)	Associated name for the story.	Typical names are, e.g., "foundation", "basement", "1st and 2nd story".	

Table A-2 Exchange Requirements for Object Category 2: Grid

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Grid Element (Priority 2)	Grid element exists in the exchange. The requirement for grids in the structural exchange is to have a 3 dimensional grid, based on grid planes.	A structural grid is a vertically-oriented plane and therefore has 3-dimensional characteristics. A grid system is a collection of 3-dimensional planes. However, this could be simulated by multiple 2-dimensional grids assigned to the stories in a building.	A grid based on 2-dimensional lines on a base plane is already needed in the exchange. A full 3-dimensional grid based on planes, rather than lines, is not widely supported by software. So, 2-dimensional lines are sufficient but must be in multiple grid planes (at varying elevations) that define levels in order to provide a "3-dimensional grid".

Table A-2 Exchange Requirements for Object Category 2: Grid (Continued)

Attribute Name	Explanation	Examples	Further Comments
Grid Layout (Priority 2)	Geometric layout of the grid; set of horizontal and vertical planes with intersection between them.		
Grid Numbering (Priority 2)	A string attached to each grid plane (or line) representing the plane (or line) label.	E.g., "A", "B", "1", "2".	
Reference to Story (Priority 2)	Reference to the story where the grid planes (or lines) appears.		The 2-dimensional grid is assigned to each story where it is valid. For now, it is necessary to copy the grid to each story.

Table A-3 Exchange Requirements for Object Category 3: Column

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Column Axis (Priority 1)	Definition axis of the column, used, e.g., for determining the Cardinal point and, as a first assumption, for the linear structural member representing the column for structural analysis.		
Profile Name (Priority 1)	Name of the profile (or cross section) of the column. The naming convention, when applicable, should follow American Institute of Steel Construction (AISC) naming convention.	Profile name is a string that represents a standard naming convention from a manual, handbook, or other external reference. It is common in the steel industry to use AISC or Canadian Institute of Steel Construction *(*CISC*)* standard profile name. Some precast profiles have standard naming conventions, but most concrete profiles are not standardized. Name examples are (W14X90, 24X24).	For non-AISC profiles, is it required to also pass the profile table (or profile standard) name? Currently the best way to pass the profile information is by including it into a property set.
Material Name (Priority 1)	Name of the material of the column. It should be an indicator of the type of material (steel, concrete, timber) and not any specific material name (e.g., "lightweight concrete type ABC"). Only the material name should be exchanged, not the material properties, like density or specific weight.	Examples for type of material are: concrete, steel, timber, glass.	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.

Table A-3 Exchange Requirements for Object Category 3: Column (Continued)

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Grade (Priority 1)	Grade is a further classifier for a particular material. It often refers to items from external standards such as those promulgated by the American Society for Testing and Materials (ASTM), e.g., ASTM 36.	Examples are: A36, ASTM36, GRADE36. The question is whether a standard expression is available.The receiving application, therefore, must be capable to interpret all kinds of expressions.	Is grade considered as specific property of material, or of the element (or profile). Is just a grade value sufficient, or a value with reference to a standard?
Length (Priority 1)	Member length is a software generated value that may be redundant to the length parameter embedded in the geometry representation. There are different length measurements, best described as quantities: - logical length between two joints - physical length of the actual column body; since these can be redundant to the geometry representation, it is important to keep them consistent and to guarantee that there is no inconsistency. They are provided in addition to the geometric representation.	The logical length is a real length measure between two joints and equal to the length of the column axis. The physical length is the length of the extrusion body (not taking cut-out's into account). Having explicit real values is particularly important, if the geometry is not an extrusion (e.g., a boundary representation).	Is there a specific definition of how the length is measured? Is it the physical or cut length, or the logical length between two joints?
Roll (Priority 1)	Member roll is a software generated value that may be redundant to the placement and placement orientation parameters embedded in the geometric representation. Roll is the rotation of the column profile (and body) about a vertical axis for columns. Since these can be redundant to the geometry representation it is important to keep them consistent and to guarantee that there is no inconsistency. They are provided in addition to the geometric representation.	For example, for a 24x30 cast-in-place column, the orientation or roll of the column is needed to know if the 30" dimension is pointing along the x-axis or the y-axis (or somewhere in between).	Roll is handled for analytical models, but not (yet) for physical models. Is it needed for physical models as well?

Table A-3 Exchange Requirements for Object Category 3: Column (Continued)

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Cardinal Point (Priority 1)	Offset of profile from longitudinal axis; essentially, it is the justification of the cross-section relative to the working line between the two end joints.	Cardinal point "lower-left", "center-right".	Propose to rename it from insertion point to cardinal point to make it similar to the CIS/2 concept. The CIMSteel Integration Standards (CIS/2) is a product model and electronic data exchange file format for structural steel project information (source: www.aisc.org).
Element ID (Priority 1)	Unique identifier for element. Element ID is only for indexing model elements and used to uniquely identify elements that may have identical properties (length, profile). Element ID is typically defined by the modeling tool and the user should not be able to change this to ensure uniqueness.		Is it a piecemark for structural steel? However, piecemarks are not necessarily unique across the entire model. There might be many identical assemblies with the same parts with the same piecemarks. Or is it a GUID, a unique software ID that keeps identity across applications?
Schedule Mark (Priority 2)	Identifier for scheduling same profile elements. Schedule marks do not need to be unique. Schedule mark is typically defined by the user and named based on the element's location on a grid and/or the properties of that element (depth, length, number of reinforcing bars).	This is generally a short string that is provided on a plan adjacent to a column (for example, "CC12"). The "CC12" is then defined in the column schedule. It is generally used as a unique identifier in the plans. So, a CC12 would be at a specific gridline (or gridlines) and is not the same as a CC11 or other mark.	Unsure whether this is different to the Element ID and if both identifiers are needed.
Base Reference Story (Priority 2)	Base location; reference to the story where the start point of the column resists. Start point is the lower point of the column axis.	This is, e.g., a level as defined in "0. Level", from which the member starts.	
Top Reference Story (Priority 2)	Top location; reference to the story where the end point of the column resists. End point is the upper point of the column axis.	This is, e.g., a level as defined in "0. Level", at which the member ends.	

Table A-3 Exchange Requirements for Object Category 3: Column (Continued)

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Base Offset (Priority 2)	Offset from base level.	This is a length describing the distance above a given level where a column starts. For example, steel columns when spliced are generally cut ~4'-0" above a floor level. So, the column above the splice would have a +4'-0" offset at its start.	Does this information need to be exchanged as a redundant additional offset value, as it is already captured in the column position?
Top Offset (Priority 2)	Offset from top level.	Also a length. In the example in the cell above, the lower column would have a top offset of +4'-0".	Does this information need to be exchanged as a redundant additional offset value, as it is already captured in the column position and column geometry?

Table A-4 Exchange Requirements for Object Category 6: Wall

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Thickness (Priority 1)	Dimensional thickness of the wall, applicable to the standard wall, having a unique, not-changing thickness along the wall axis. Typically, a structural engineering package does not support multiple layers for wall objects. Two walls would be defined separately.		
Material Name (Priority 1)	Name of the material of the wall; it should be an indicator of the type of material (steel, concrete, timber) and not any specific material name (e.g.,"lightweight concrete type ABC"). Only the material name should be exchanged, not the material properties, like density or specific weight.	Examples for type of material are: concrete, steel, timber, glass. It is assumed that structural walls are single layer walls.	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.
Grade (Priority 1)	Grade is a further classifier for a particular material. It often refers to items from external standards such as ASTM, e.g., ASTM 36.	Examples are: A36, ASTM36, GRADE36. The question is whether a standard expression is available. The receiving application, therefore, must be capable to interpret all kinds of expressions.	Is grade considered as specific property of material, or of the element (or profile)? Is just a grade value sufficient, or a value with reference to a standard?

Table A-4 Exchange Requirements for Object Category 6: Wall (Continued)

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Wall Axis (Priority 1)	Definition of the wall axis used, e.g., for determining the alignment and as a first assumption for the linear structural member representing the wall for structural analysis.		
Alignment (Priority 1)	Alignment of the wall body relative to the wall axis.	Values could be an enumeration, like centerline, interior, exterior face, or an absolute value.	
Base Reference Story (Priority 2)	Base location; reference to the story where the start point of the wall resists. Base story is where the wall axis resists.	This is, e.g., a level as defined in "0. Level", from which the member starts.	
Top Reference Story (Priority 2)	Top location; reference to the story where the end point of the column resists.	This is e.g. a level as defined in "0. Level", at which the member ends.	
Base Offset (Priority 2)	Offset from base level	This is a length describing the distance above a given level where a wall starts.	Does this information need to be exchanged as a redundant additional offset value, if it is already captured elsewhere (e.g., in the column position)?
Top Offset (Priority 2)	Offset from top level	This is a length describing the distance above (or below) a given level where a wall ends.	Does this information need to be exchanged as a redundant additional offset value, if it is already captured elsewhere (e.g., in the column position and column geometry)?
Load Bearing (Priority 2)	Attribute associated to the wall as a disciplinary setting, indicates that the wall is designed to be load bearing.	Boolean value TRUE or FALSE for the wall.	

Table A-5 Exchange Requirements for Object Category 7: Slab

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Thickness (Priority 1)	Dimensional thickness of the slab; applicable to standard slab, having a unique, not-changing thickness. The thickness is the perpendicular thickness between the two upper/lower faces, not the extrusion thickness. Typically, a structural engineering package doesn't support multiple layers for slab objects.		
Material Name (Priority 1)	Name of the material of the slab. It should be an indicator of the type of material (steel, concrete, timber) and not any specific material name (e.g., "lightweight concrete type ABC"). Only the material name should be exchanged, not the material properties, like density or specific weight.	Examples for type of material are: concrete, steel, timber, glass. It assumes that structural slabs are single layer slabs.	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.
Grade (Priority 1)	Grade is a further classifier for particular material. It often refers to items from external standards such as ASTM, e.g., ASTM 36.	Examples are: A36, ASTM36, GRADE36. The question is whether a standard expression is available. The receiving application, therefore, must be capable to interpret all kinds of expressions.	Is grade considered as specific property of material, or of the element (or profile)? Is just a grade value sufficient, or a value with reference to a standard?
Base Reference Story (Priority 2)	Base location, reference to the story where the slab resists.	This is e.g. a level as defined in "0. Level", from which the member starts.	
Base Offset (Priority 2)	Offset from base story level. Base story offset is measured to the reference plane of the slab.	This is a length describing the distance above a given story where the slab reference level is located.	Does this information need to be exchanged as a redundant additional offset value, if it is already captured elsewhere (e.g., in the column position)?
Span Direction (Priority 2)	Structural span direction; the span direction, in this case, is defining the orientation of the area object relative to the z-axis.		Different bearing types (e.g., fixed edge, one-way, or two-way) are not to be exchanged.

Table A-6 Exchange Requirements for Object Category 8: Footing

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Footing Type (Priority 1)	A type classifier for footings that further specifies the subtype (or functional type) of the footing.	Examples are: pad, strip, mat	
Material Name (Priority 1)	Name of the material of the footing. It should be an indicator of the type of material (steel, concrete, timber) and not any specific material name (e.g., "lightweight concrete type ABC"). Only the material name should be exchanged, not the material properties, like density or specific weight.	Examples for types of materials are: concrete, steel, timber.	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.
Grade (Priority 1)	Grade is a further classifier for particular material. It often refers to items from external standards such as ASTM, e.g., ASTM 36.	Examples are: A36, ASTM36, GRADE36. The question is whether a standard expression is available. The receiving application, therefore, must be capable to interpret all kinds of expressions.	Is grade considered as specific property of material, or of the element (or profile)? Is just a grade value sufficient, or a value with reference to a standard?
Top Reference Story (Priority 2)	Top location, reference to the story where the end point of the footing resists. End point is the upper face of the footing. Note: Similar to top reference story for columns. See screen shot in column section above.	Quote: "I don't understand how it would be queried from the shape. Is the footing object defined by multiple end joints. As opposed to having, say, a center point, a length, width, thickness and orientation."	
Bottom Elevation (Priority 2)	Dimensional elevation or thickness of the footing	Quote: "I don't understand how it would be queried from the shape. Is the footing object defined by multiple end joints. As opposed to having, say, a center point, a length, width, thickness and orientation."	

Table A-7 Exchange Requirements for Object Category 9: Pile

Attribute Name	*Explanation*	*Examples*	*Further Comments*
Pile Type (Priority 1)	A type classifier for pile that further specifies the subtype (or functional type) of the footing.	Examples are: pile, caisson	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.
Material Name (Priority 1)	Name of the material of the pile. It should be an indicator of the type of material (steel, concrete, timber) and not any specific material name. Only the material name should be exchanged, not the material properties, like density or specific weight.	Examples for type of material are: concrete, steel, timber.	Agreement is needed on an enumeration of applicable type of material to reduce unnecessary string interpretation.
Grade (Priority 1)	Grade is a further classifier for particular material. It often refers to items from external standards such as ASTM, e.g., ASTM 36.	Examples are: A36, ASTM36, GRADE36. The question is whether a standard expression is available. The receiving application, therefore, must be capable to interpret all kinds of expressions.	Is grade considered as specific property of material, or of the element (or profile)? Is just a grade value sufficient, or a value with reference to a standard?
Top Reference Story (Priority 2)	Dimensional elevation Note: Similar to top reference story for columns.		Quote: "This is just like the top and bottom levels above for columns.
Bottom Elevation (Priority 2)	Dimensional elevation or thickness of the pile		Quote: "This is just like the top and bottom levels above for columns.

Appendix B

Example Structural Member Properties Defined and Used by Vendors for Exchange (IFC Binding)

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 3: Column

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Column Axis (Priority 1)	Additional IFC Shape Representation with Representation Type = Axis. The IFC Geometric Representation Item is a single IFC Polyline (or IFC Trimmed Curve with Base Curve IFC Line , or IFC Circle)	Currently not enforced in the coordination view.	"Axis Definition"		

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding) Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Profile Name (Priority 1)	For all parametric profiles and all extrusion based profiles it is currently provided as a single string value: IFC Profile Definition. Additional agreement is needed where a section designator (plus eventually a section table name) goes in the IFC file for any type of geometry representation, e.g. in case of Boundary Representation (BREP) or Surface Models.	The entity, IFC Profile Definition (its subtypes) is already required as part of the coordination view and certification. Filling the attribute Profile Name (with sensible values) is, however, not yet enforced. It should be enforced, if such information is available in the authoring tool.	"Profile Definition"; see also "Single Value Property Definition"	Use the "Profile Definition" agreement for all swept solids. Agree to use AISC naming convention as far as applicable. Add to implementation scope as an enforcement of the coordination view.	Add a general place to find a profile name and section table name independently of the profile geometry. For now, profile names should be passed as a property set, as it cannot be added to a boundary-representation column. Better support to be added in IFC2x4
Material Name (Priority 1)	IFC Material. Name. It is currently the only string value applicable for material name. There is no distinction between a material name, as a general name, and material category (steel, column, timber)	Support of IFC Material. Name is part of the coordination view and enforced. A separate field for the material category is not yet provided.	VBL-345 VBL-265	Add support of material name to implementation scope as an enforcement of the coordination view.	Add a second attribute in IFC2x4 to differentiate a user name for any material and the material category.

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Grade (Priority 1)	Currently there is no specific attribute for grade; it should be handled by material classification (grade name "36 "and referenced standard "ASTM"). It would be represented by IFC Material. (INV) Classified As and IFC Classification Reference.	Not part of the coordination view. Can be added for this testbed.	"Material Grade"	Add support of material classification to implementation scope.	

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding) Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Length (Priority 1)	Length is perceived in IFC as a quantity, i.e., it is a measurement taken from the geometry that should be exchanged in addition to the geometric representation. Such quantities should be added for downstream applications (not having their own geometric kernel). In this use case, it could be expected from the receiving application to re-establish: - (physical) length from the extrusion length - logical length from the length of the axis representation Simple Quantity (using IFC Quantity Length with the Name 'Length'); optionally a "Logical Length" can be supported in addition.	Exports of quantities are part of the quality take off (QTO) view, which is an add-on to the coordination view (and not a part). Export of an additional axis representation of the column is currently optional in the coordination view.	"Single Quantity" also see QTO implementation guide.	Export of quantities is in scope of the QTO add-on view. It should be added to implementation scope.	

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding) Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Roll (Priority 1)	Roll is a redundant information given in addition to the geometric representation, but helpful for analyzing the model; it should be provided as a property, similar to the Span property in Pset_ Column Common	Should be added as a new property. Can be added for this testbed.	"Single Value Property Definition"	Single Value Property Definition is needed here; property name would be 'Roll' with a value of the type IFC Plane Angle Measure.	Add Roll to for IFC2x4
Cardinal Point (Priority 1)		The cardinal point is currently not supported in IFC2x3; its support is already proposed for IFC2x4.	- Not in 2x3 -	Not included, new schema IFC2x4 is required to support it.	Add Cardinal Point to IFC2x4 as part of the new material-profile definition.
Element ID (Priority 1)	The element-id is not identical to the globally unique identifier (GUID), it is a unique number, given by the exporting software system, like a handle. The IFC representation is IFC Column Tag; see its Tag is the tag (or label) identifier at the particular instance of a product, e.g. the serial number, or the position number. It is the identifier at the occurrence level.	Currently supported in an ambiguous way, e.g., as part of the IFC Column. Name; needs to be unified.		Provide an unambiguous way to export the element ID; recommended is IFC Column Tag.	

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding) Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Scheduled Mark (Priority 2)	The schedule mark is also regarded as reference id, or construction type id; it is already included in IFC as Reference.	Currently not supported in an unambiguous way.		Provide an unambiguous way to export the schedule mark by using reference.	
Base Reference Story (Priority 2)	Base Reference Story is used for the containment information, i.e., the assignment of building elements (e.g., column, beam, wall, slab) to spatial structure elements (typically the building story).	Supported by the coordination view. It might not show up in the GUID of the receiving application; in this case implementation has to be improved.	"Spatial Container"	Include and verify this attribute.	
Top Reference Story (Priority 2)	Top Reference Story is used for the containment information and the spatial structure; requires following some references and checking the geometry (length and offset of the column, reference high of the building stories).	Not currently supported in the coordination view; the IFC relationship, IFC referenced In spatial structure, would support it, but would need to be added to the coordination view.	"Referenced in Spatial Structure"	Propose an addition to the view definition with an implementation guideline for capturing the top reference story.	

Table B-1 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 3: Column (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Base Offset (Priority 2)	The offset can be calculated from the element geometry. Building elements (e.g., column, beam, wall, slab) are typically placed relative to their spatial container (see Base Reference. Story) so that offset calculation is often very simple. However, the most general case might require a sum of some offsets: (1) offset of the base reference to the local placement of the building story; plus (2) offset of the local placements of the building story and the building element; plus (3) offset of the base level of the building element to its local placement) and coordinate transformations.	The information itself (reference to story, relative placement to story and placement of column extrusion body within the object placement) is part of the coordination view. It has however not been verified or enforced to be interpreted as vertical base offset.			
Top Offset (Priority 2)	See Base Offset and Top Reference Story	Depends on the clarification of the above requirements			

Table B-2 Structural Member Properties in Software Vendor Terms (IFC Binding) Object Category 8: Footing

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Footing Type (Priority 1)	Defined by IFC Footing. Predefined Type; the following types are available: - FOOTING_ BEAM - PAD_FOOTING - PILE_CAP - STRIP_FOOTING - USERDEFINED - NOTDEFINED	Included in the coordination view, but correct setting of the pile enumeration is not enforced.		Check the current setting to the pile type in IFC exchanges for benchmarking.	
Material Name (Priority 1)	IFC Material. Name; it is currently the only string value applicable for material name. There is no distinction between a material name as general name and material category (steel, column, timber.)		VBL-345 VBL-265	Include and verify this attribute.	
Grade (Priority 1)	Currently there is no specific attribute for grade; it should be handled by material classification (gradename "36" and referenced standard “ASTM”). It would be represented by IFC Material. (INV) Classified As and IFC Classification Reference.		"Material Grade"		

Table B-2 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 8: Footing (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Top Reference Story (Priority 2)	This attribute is used for the containment information i.e., the assignment of building elements (e.g., column, beam, wall, slab) to spatial structure elements (typically the building story). It is the reference story (the term "top" is not preserved in the exchange)	Supported by the coordination view. It might not show up in the (GUID) of the receiving application; in this case implementation has to be improved.	"Spatial Container"	Include and verify this attribute.	
Bottom Elevation (Priority 2)	Equal to the extrusion length parameter of the footing				

Table B-3 Structural Member Properties in Software Vendor Terms (IFC Binding)
Exchange Requirements for Object Category 9: Pile

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Pile Type (Priority 1)	Defined by IFC Pile. Predefined Type; following types are available: - COHESION - FRICTION - SUPPORT - USERDEFINED - NOTDEFINED	Included in the coordination view, but correct setting of the pile enumeration not enforced.		Check the current setting to the pile type in IFC exchanges for benchmarking.	

Table B-3 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 9: Pile (Continued)

Attribute Name	*IFC Representation of the Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Material Name (Priority 1)	IFC Material. Name; it is currently the only string value applicable for material name. There is no distinction between a material name, as general name, and material category (steel, column, timber.)		VBL-345 VBL-265	Include and verify this attribute.	
Grade (Priority 1)	Currently there is no specific attribute for grade, it should be handled by material classification (grade name "36" and referenced standard "ASTM"). It would be represented by IFC Material. (INV) Classified As and IFC Classification Reference.		"Material Grade"		

Table B-3 Structural Member Properties in Software Vendor Terms (IFC Binding)
Object Category 9: Pile (Continued)

Attribute Name	*IFC Representation of The Exchange*	*Status of IFC Implementation Model View Definition, Certification Process*	*Model View Definition Name*	*Recommendations for ATC-75 Implementation*	*Recommendations for Further IFC Development*
Top Reference Story (Priority 2)	This attribute is used for the containment information, i.e., the assignment of building elements (e.g., column, beam, wall, slab) to spatial structure elements (typically the building story). It is the reference story (the term "top" is not preserved in the exchange)	Supported by the coordination view. It might not show up in the (GUID) of the receiving application; in this case implementation has to be improved.	"Spatial Container"	Include and verify this attribute.	
Bottom Elevation (Priority 2)					

Appendix C

IFC Model View Definition Diagrams

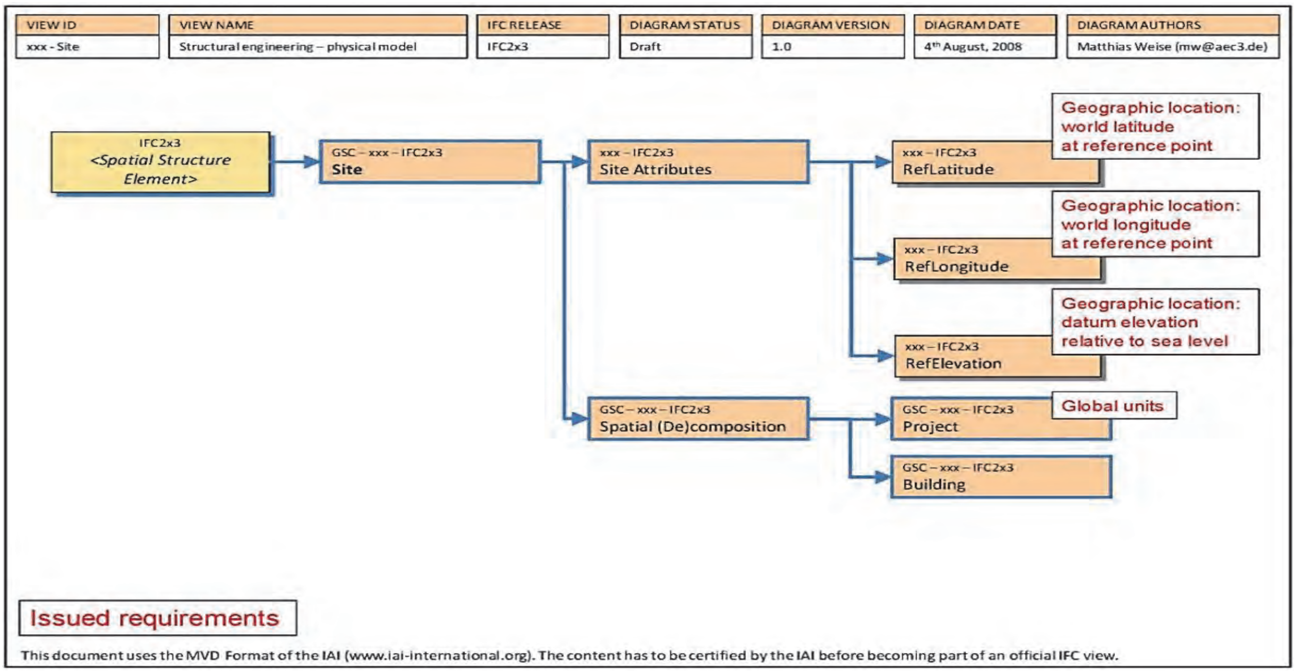


Figure C-1 IFC model view definition diagram: site.

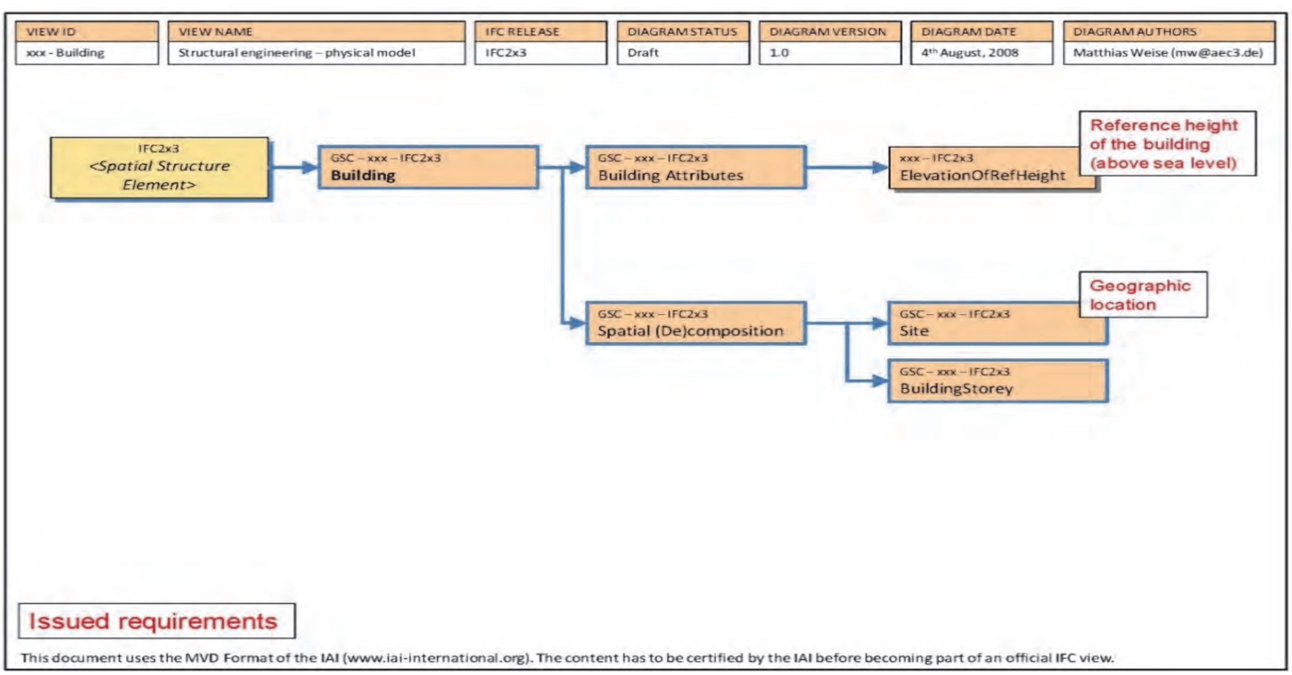


Figure C-2 IFC model view definition diagram: building.

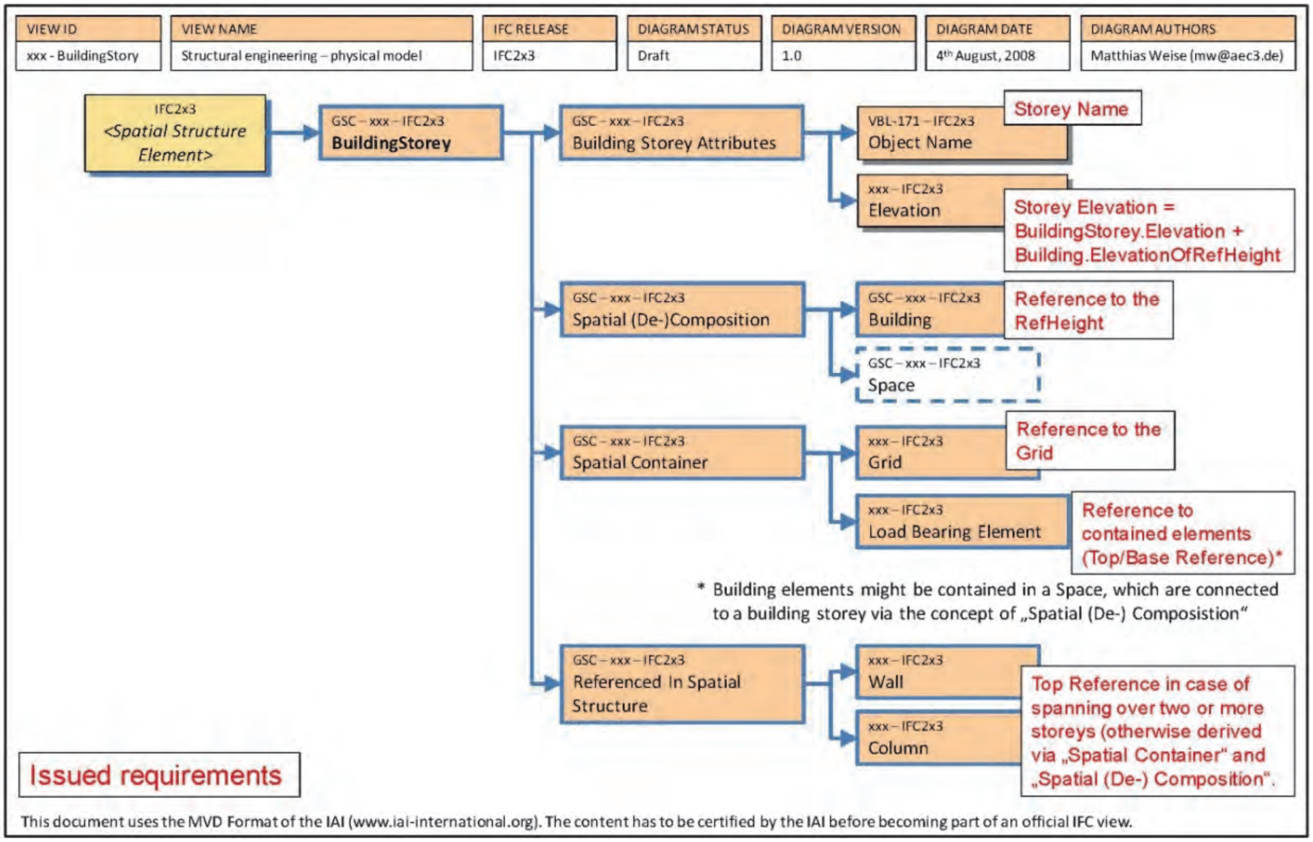


Figure C-3 IFC model view definition diagram: building story.

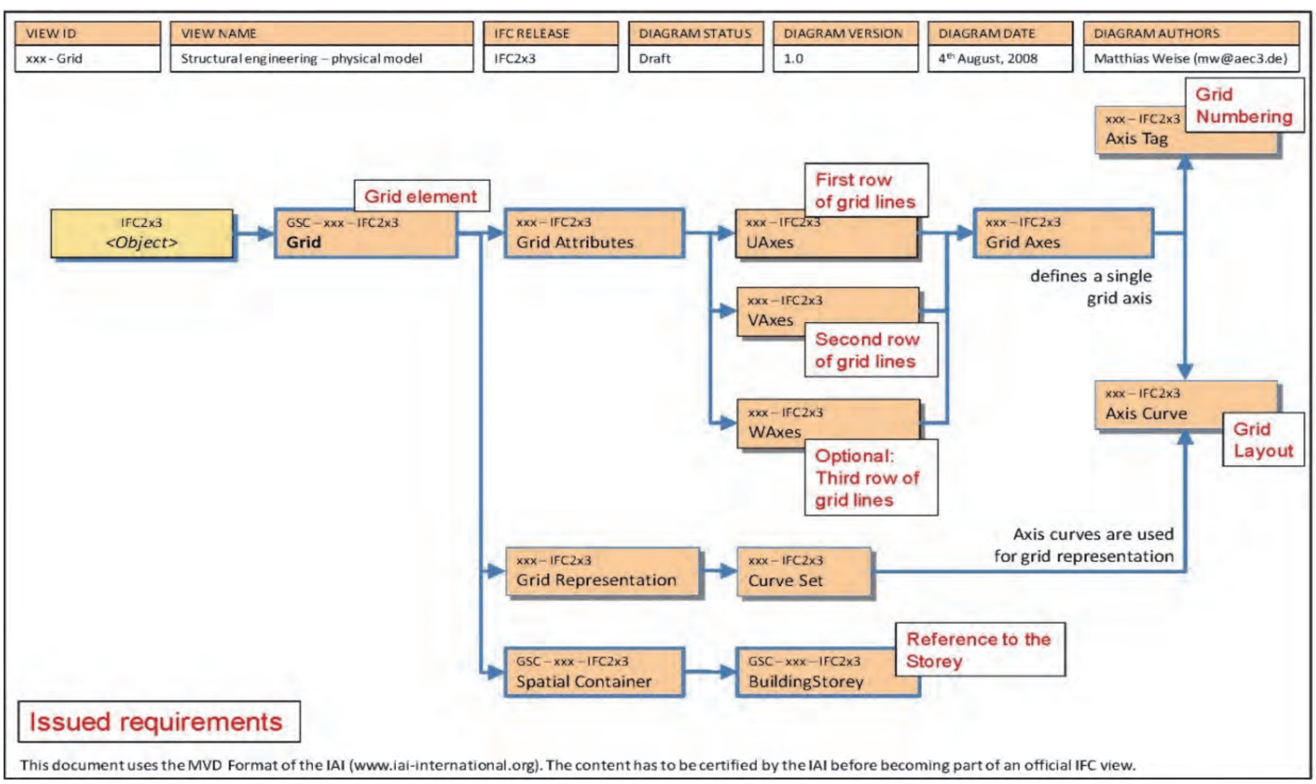


Figure C-4 IFC model view definition diagram: grid.

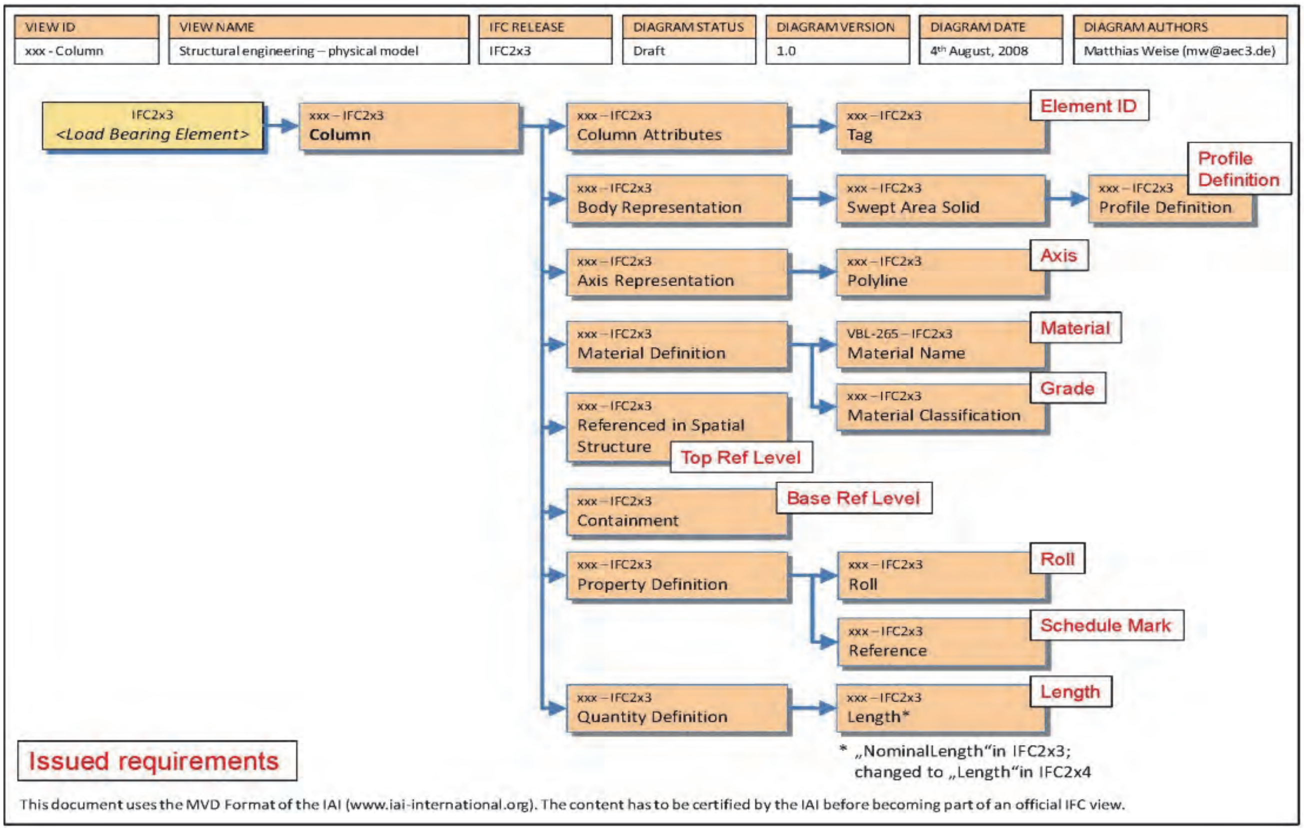


Figure C-5 IFC model view definition diagram: column.

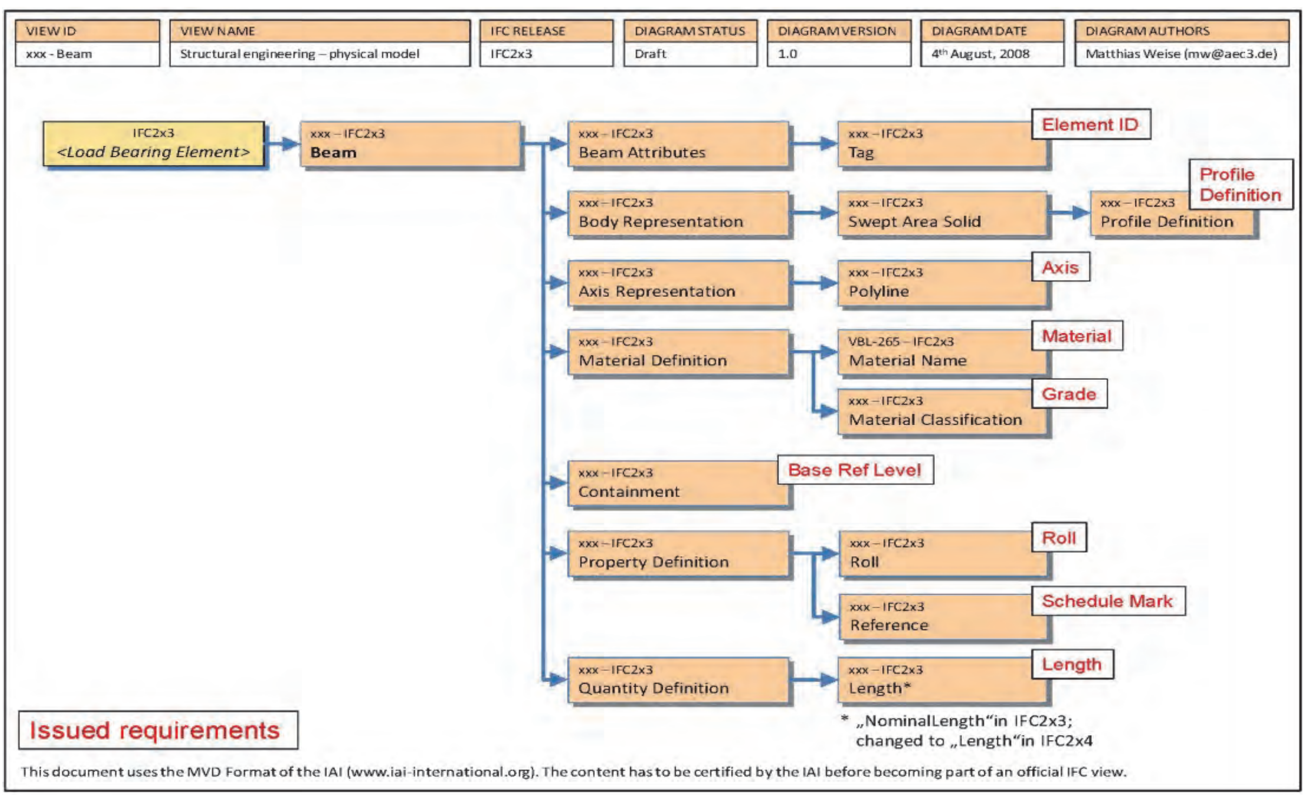


Figure C-6 IFC model view definition diagram: beam.

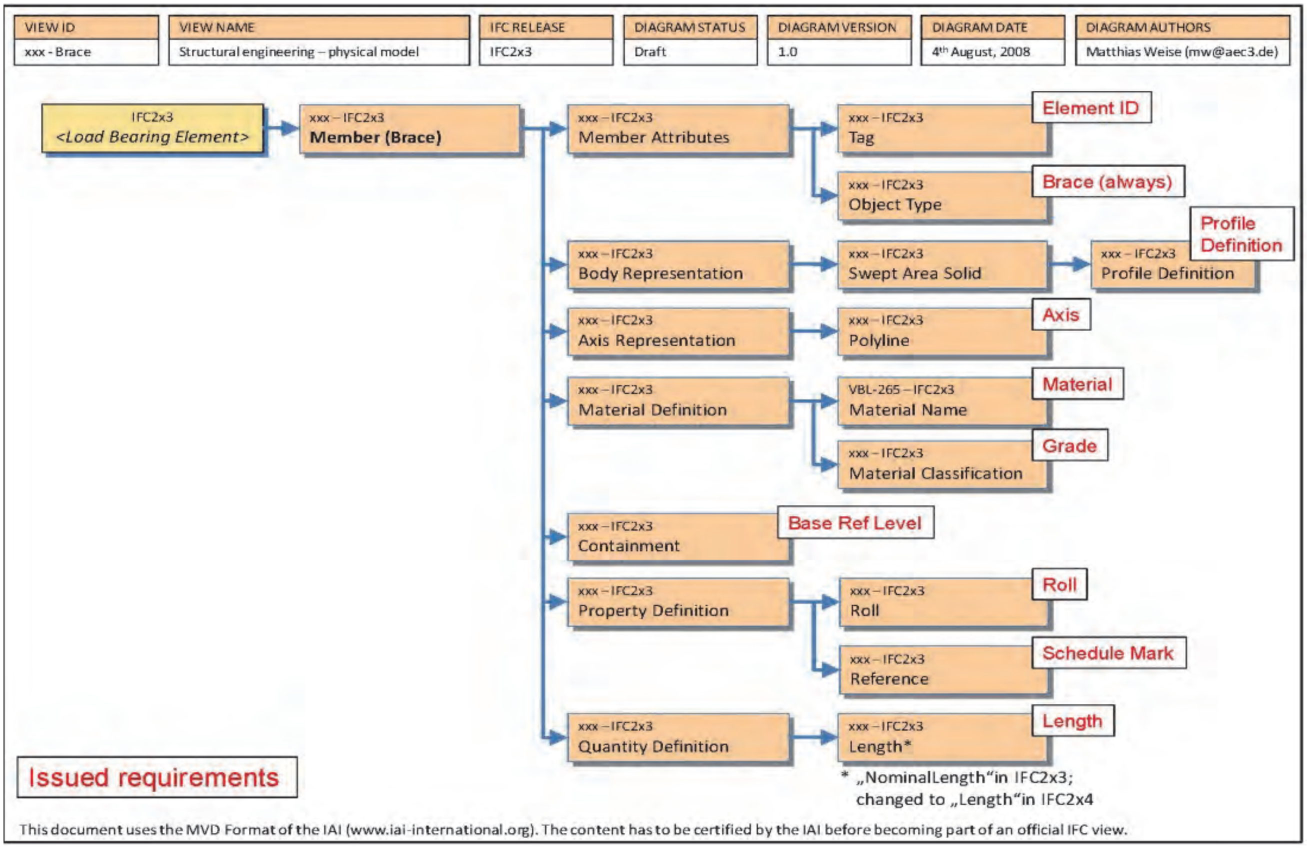


Figure C-7 IFC model view definition diagram: brace.

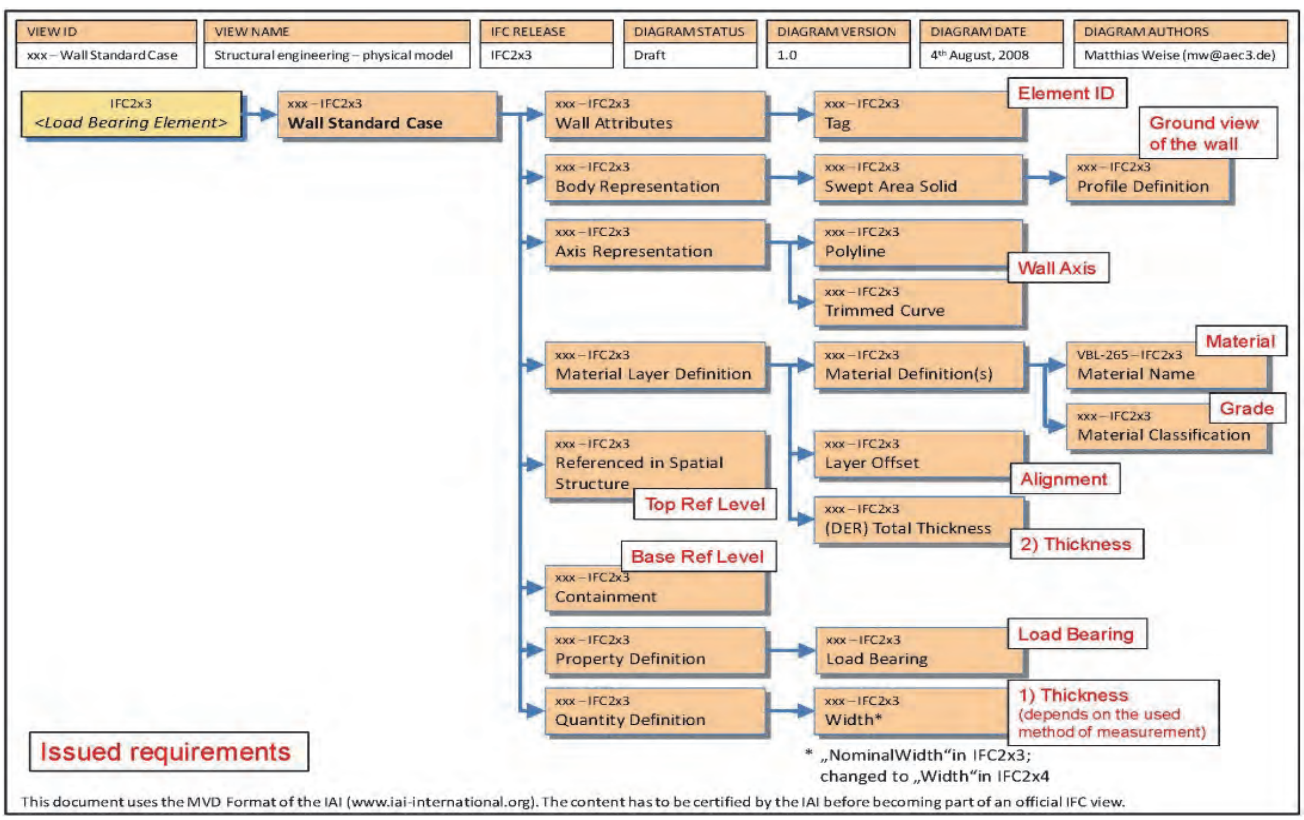


Figure C-8 IFC model view definition diagram: wall standard case.

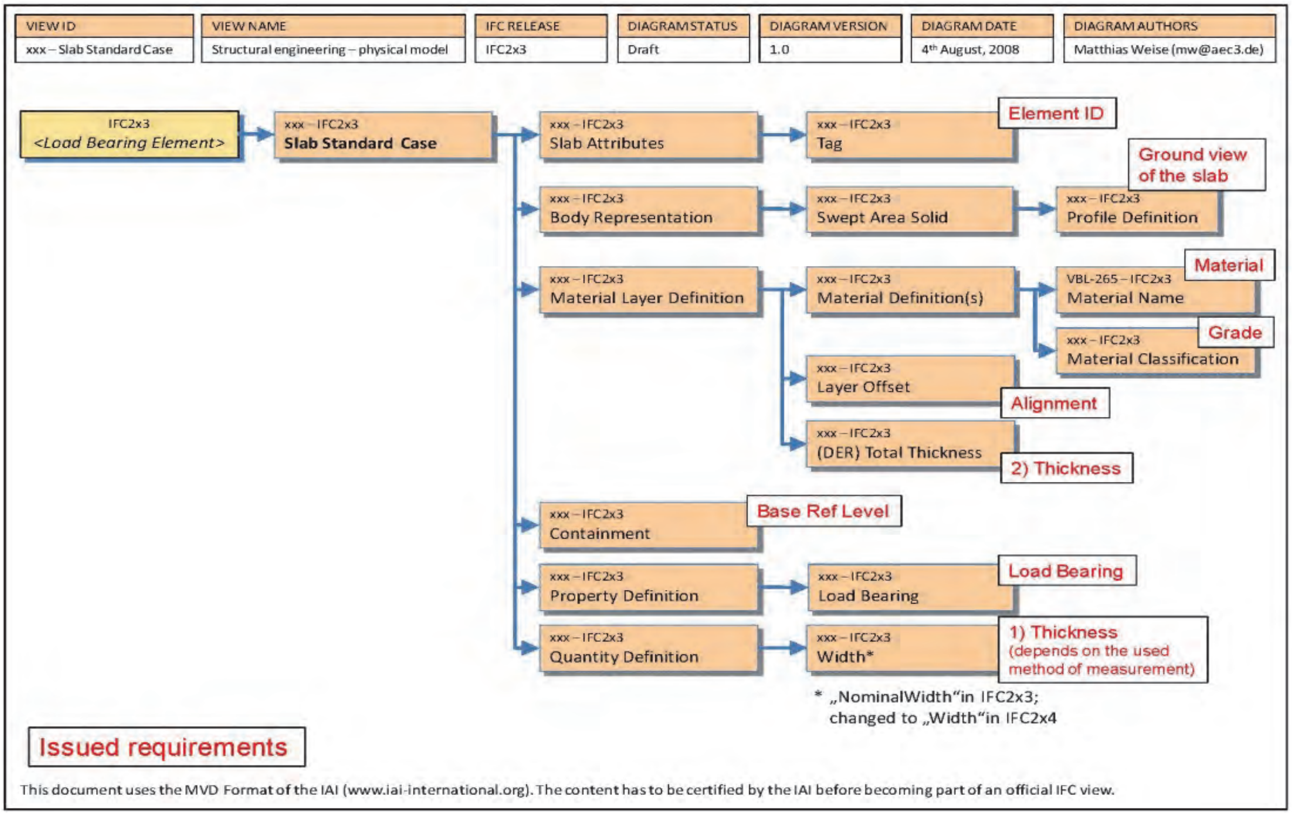


Figure C-9 IFC model view definition diagram: slab standard case.

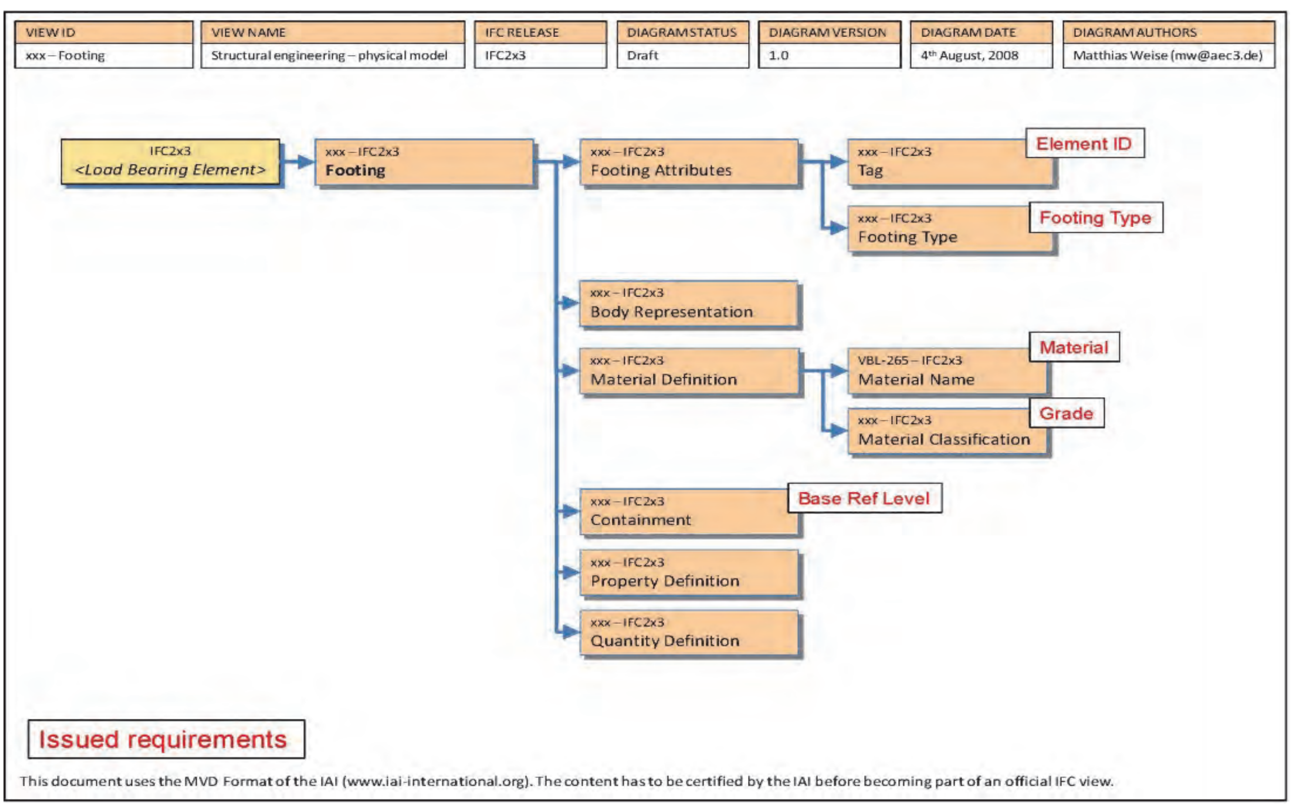


Figure C-10 IFC model view definition diagram: footing.

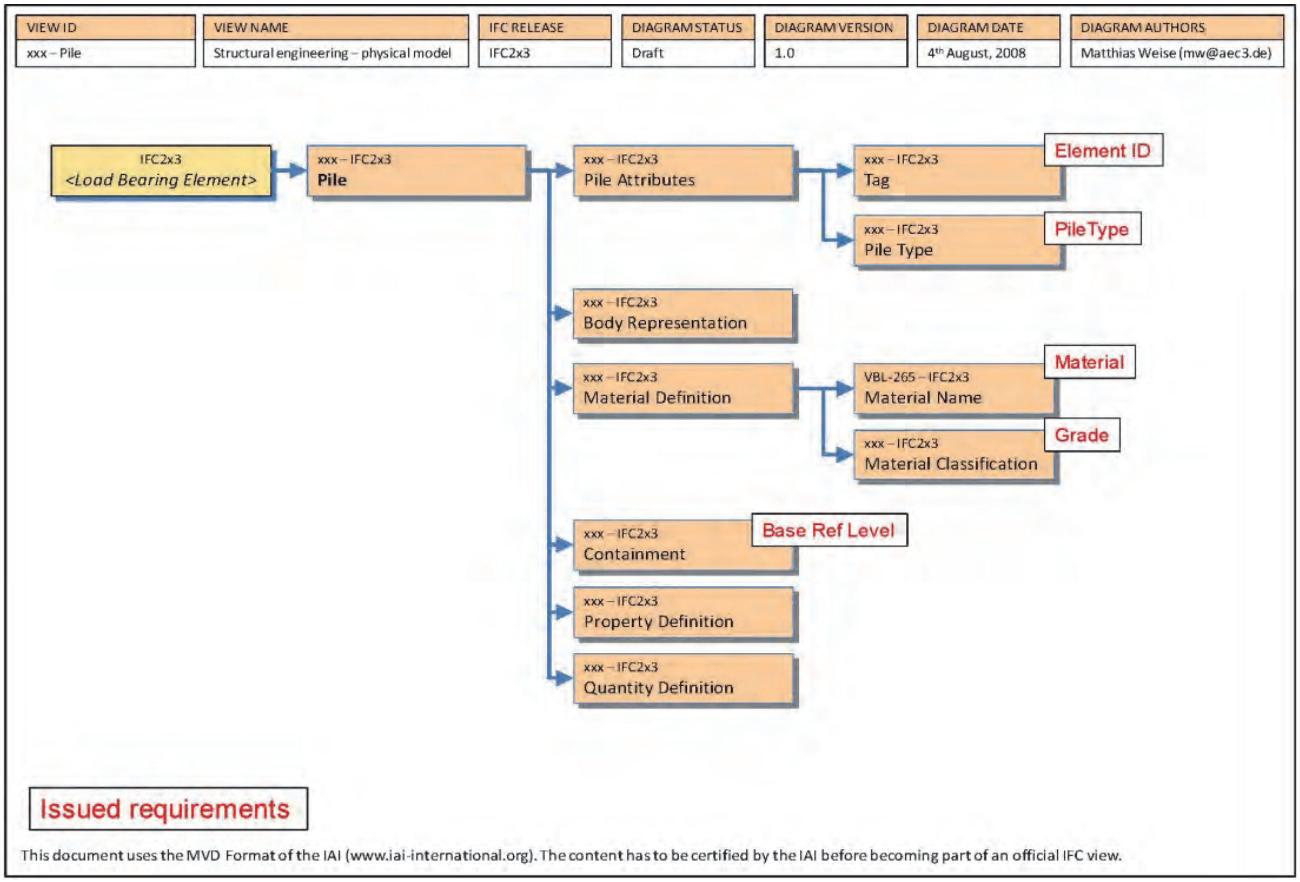


Figure C-11 IFC model view definition diagram: pile.

Appendix D

IFC Structural Testbed Validation: Bentley Structural v8i

D.1 Testbed Description

The structural testbed is based on a modified original design of a stadium, where one section had been cut-out and additional element types had been added. It should represent a fair portion of elements used in structural modeling.

The testbed comprises:

- A common source model to testing the IFC exchange
- A description of the test model based on the structural modeling elements and attributes used
- A description of test criteria against which the result is validated
- A realization of the same test model in (at least) two structural modeling applications
- A set of IFC export files (from the source applications) with well documented export options
- A set of success/failure descriptions for external neutral test tools
    - In IFC syntax checker,
    - In IFC validation tools,
    - In IFC viewer
- A matrix of success/failure descriptions for import into other software
    - Matrix based on test criteria and importing software
    - Importing software is either:
        - Other BIM tools (architectural/ structural modeling software), or
        - Structural analysis software

D.1.1 Test Model Description

The first test model has been created in Bentley Structural. It deals with the main elements:

- Column
- Beam
- Brace
- Wall
- Slab

The original test model has been created and exported to IFC using:

Table D-1 Test Model Description

Name of application	*Version number*	*Export options*	*Remarks*
Bentley Structural	v. 8i	IFC2x3	File name: IFC_2X3_BentleyStructural.ifc

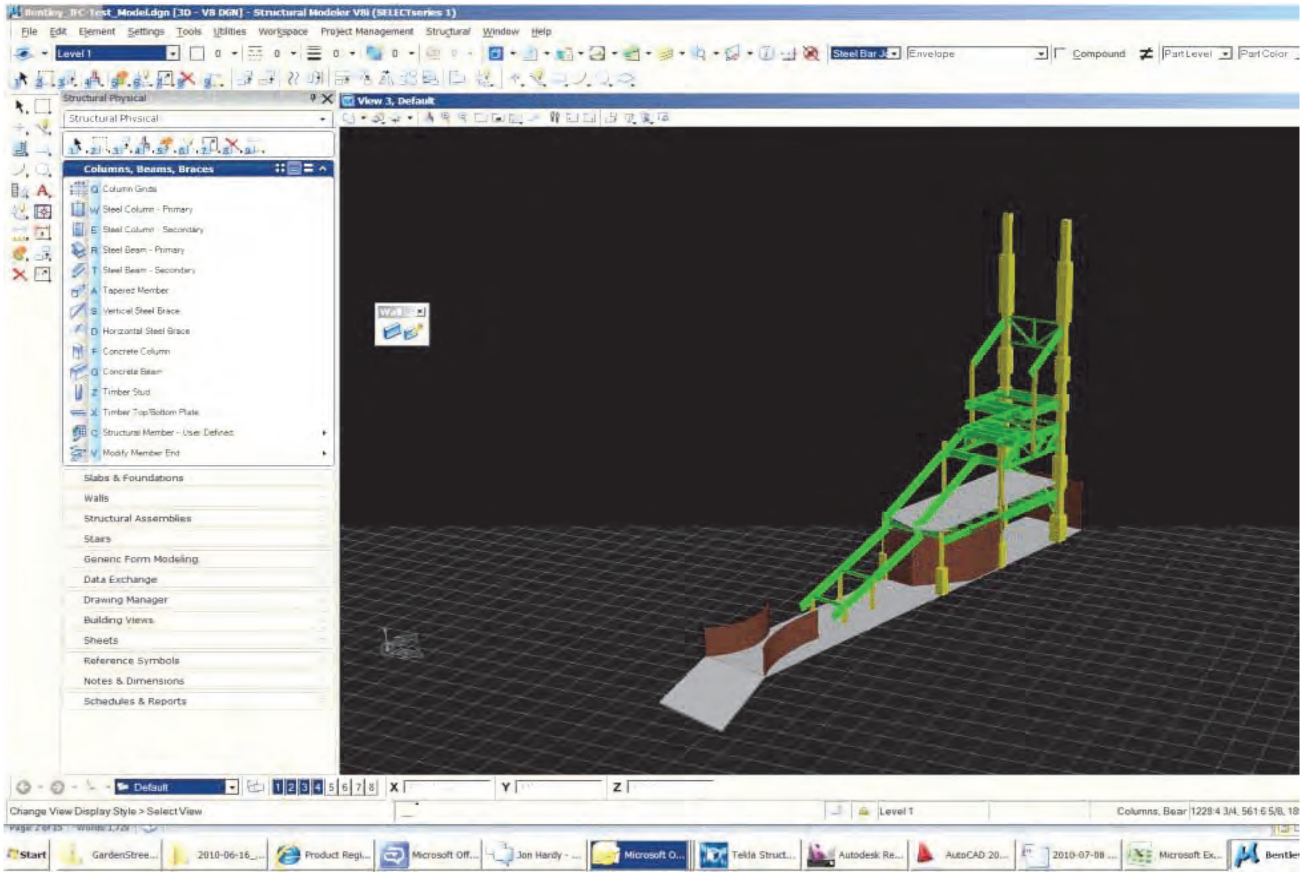


Figure D-1 Perspective view of the test case 1.

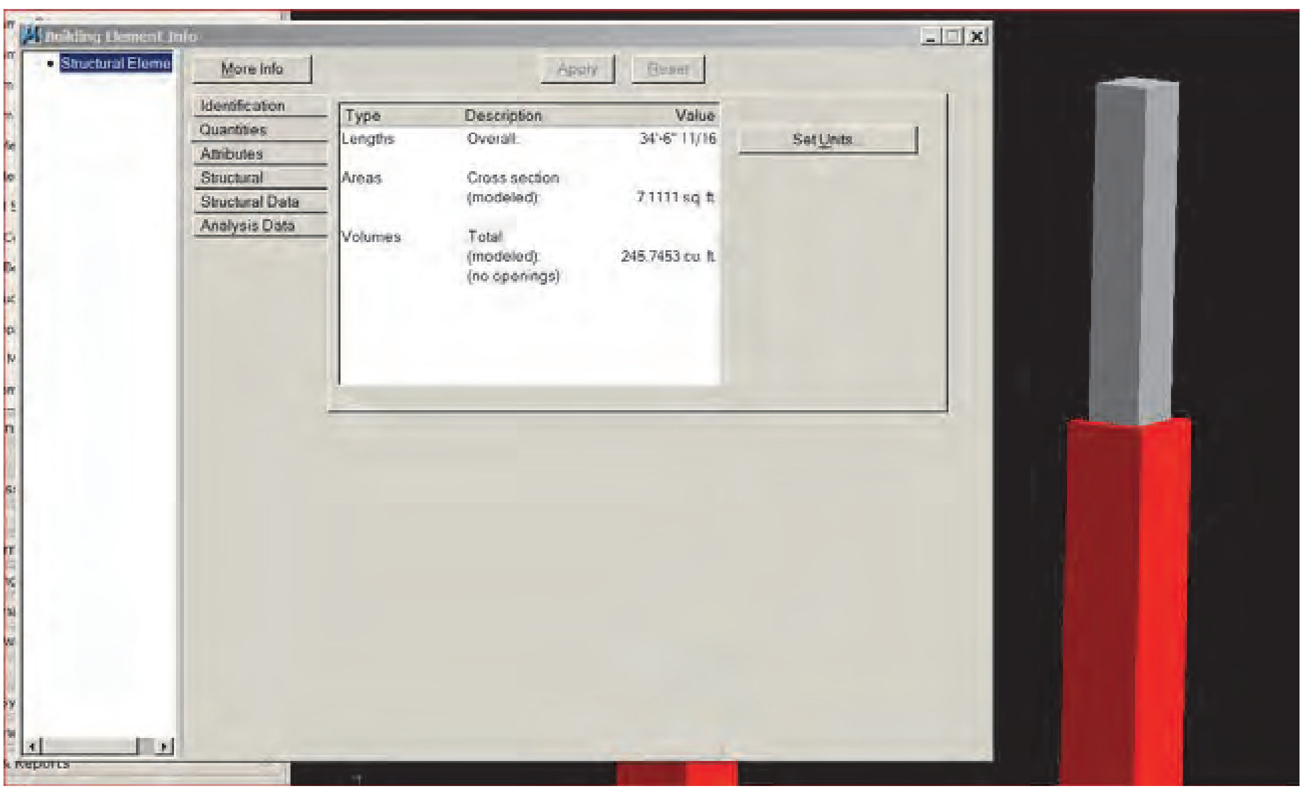


Figure D-2 Detailed view of built-up column with properties.

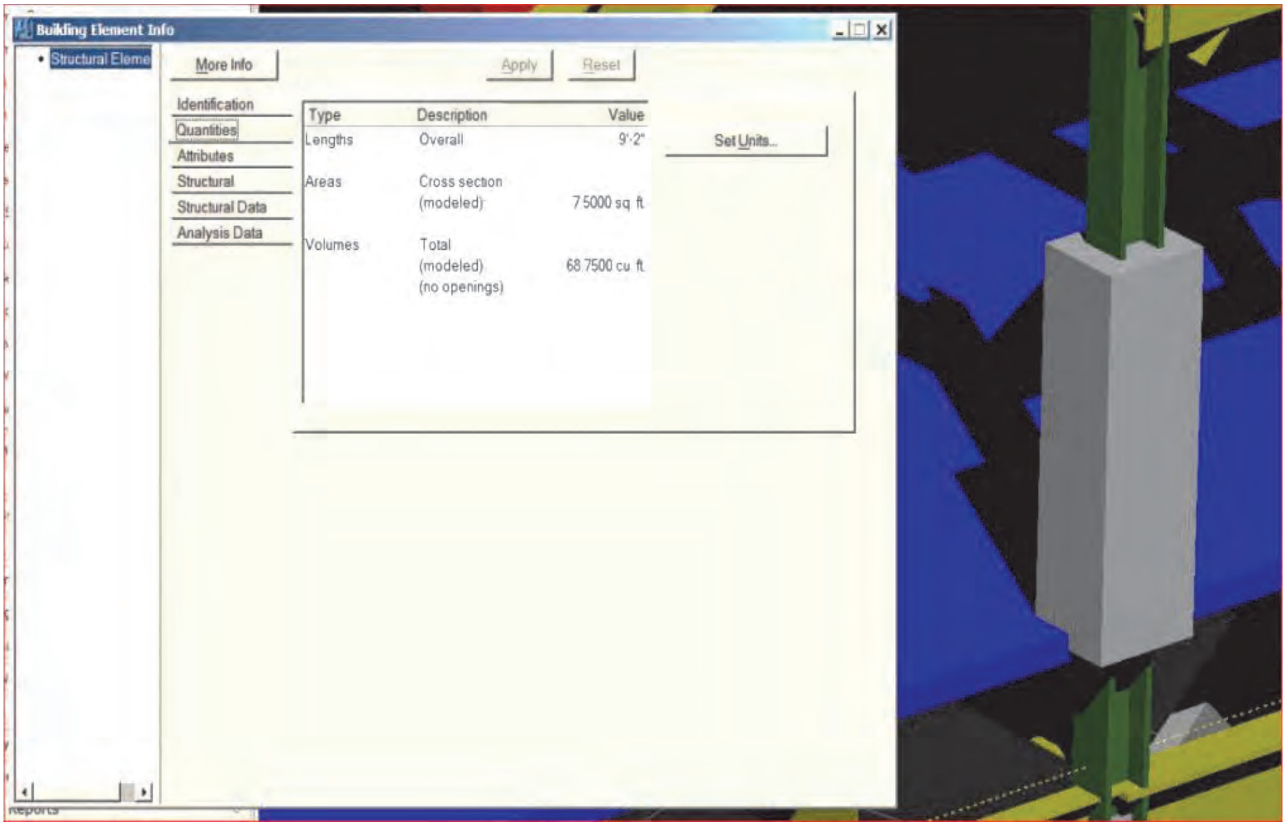


Figure D-3 Detailed view of concrete column with properties.

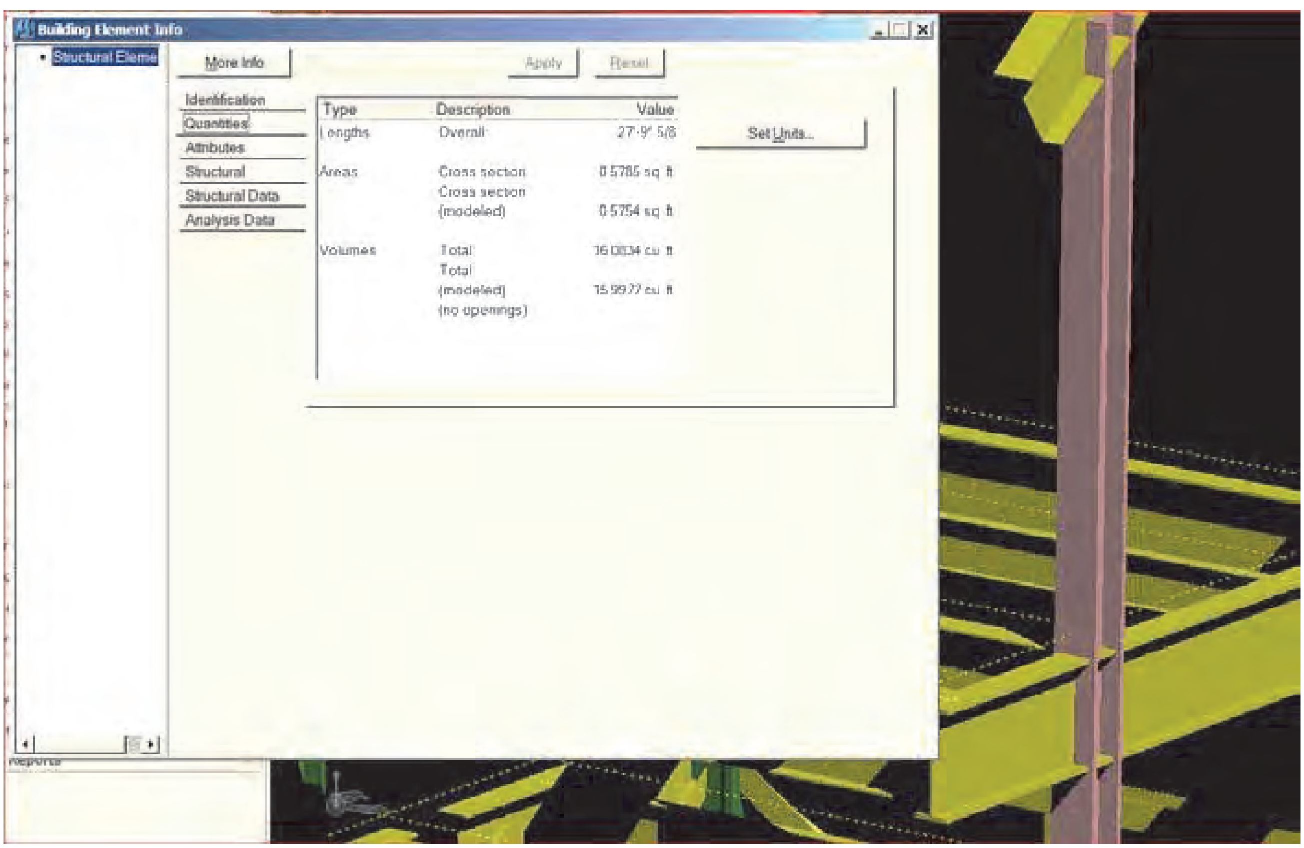


Figure D-4 Detailed view of wide flange column with properties.

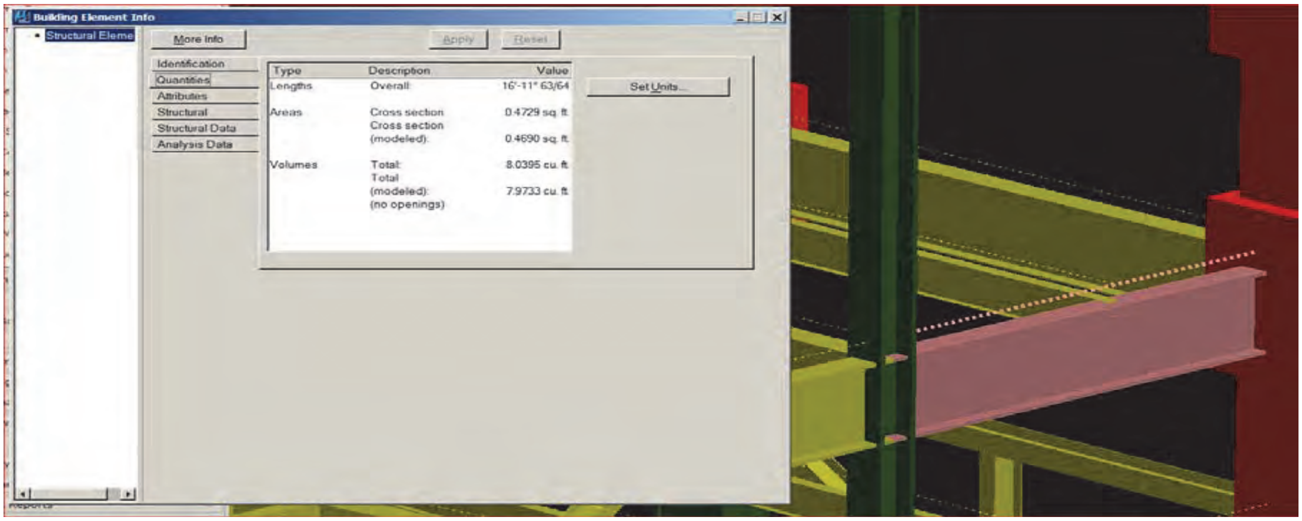


Figure D-5 Detailed view of wide-flange beam with properties.

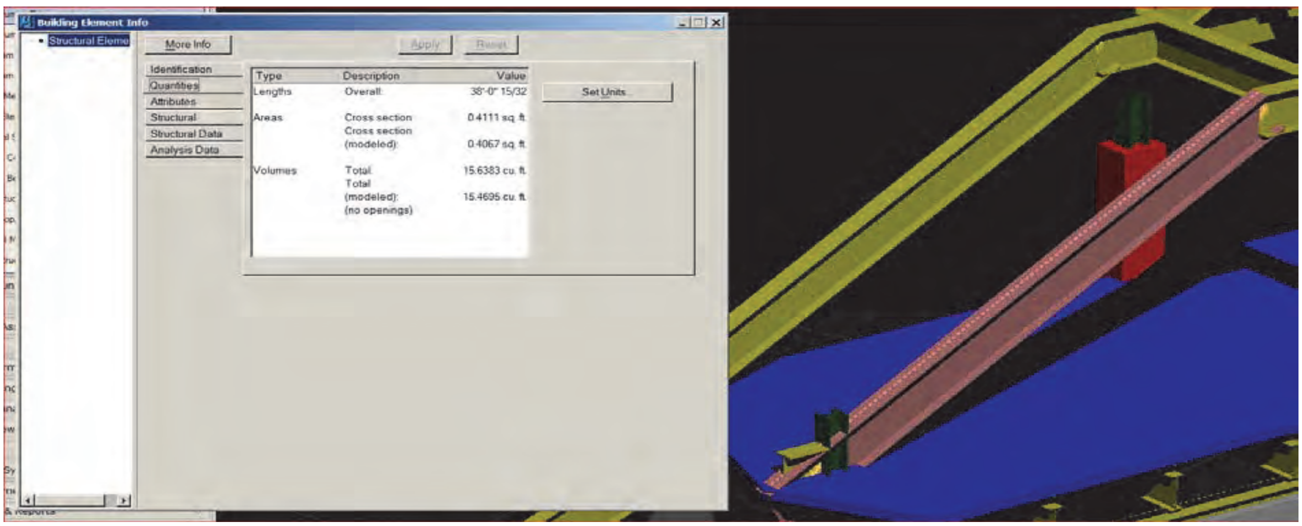


Figure D-6 Detailed view of sloped wide-flange beam with properties.

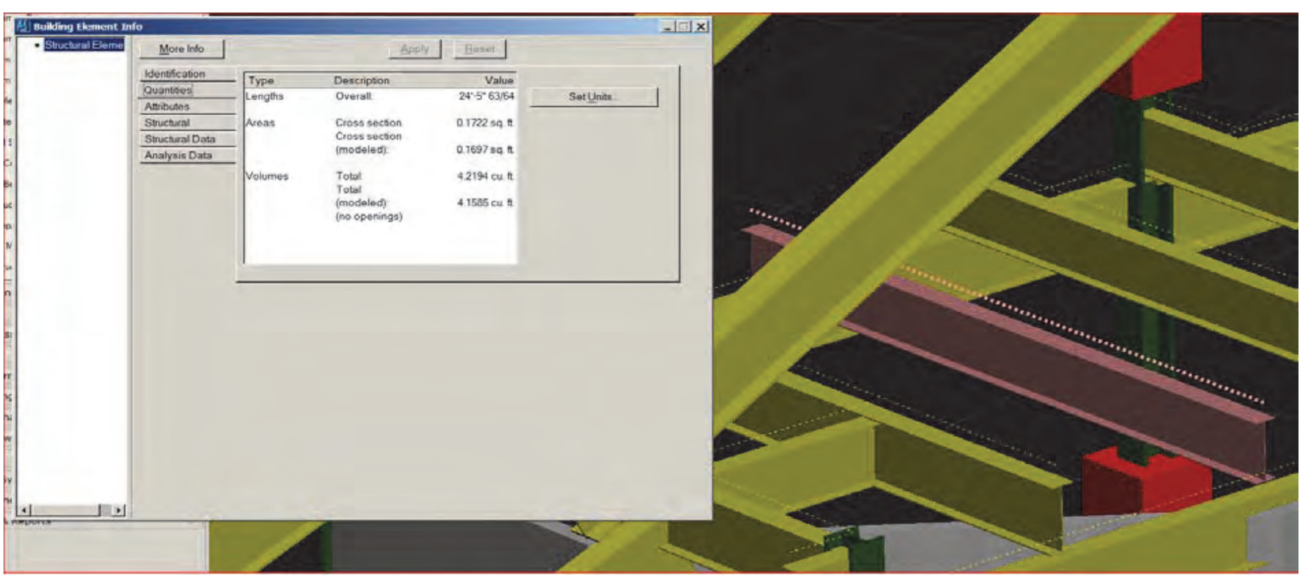


Figure D-7 Detailed view of wide-flange beam with properties.

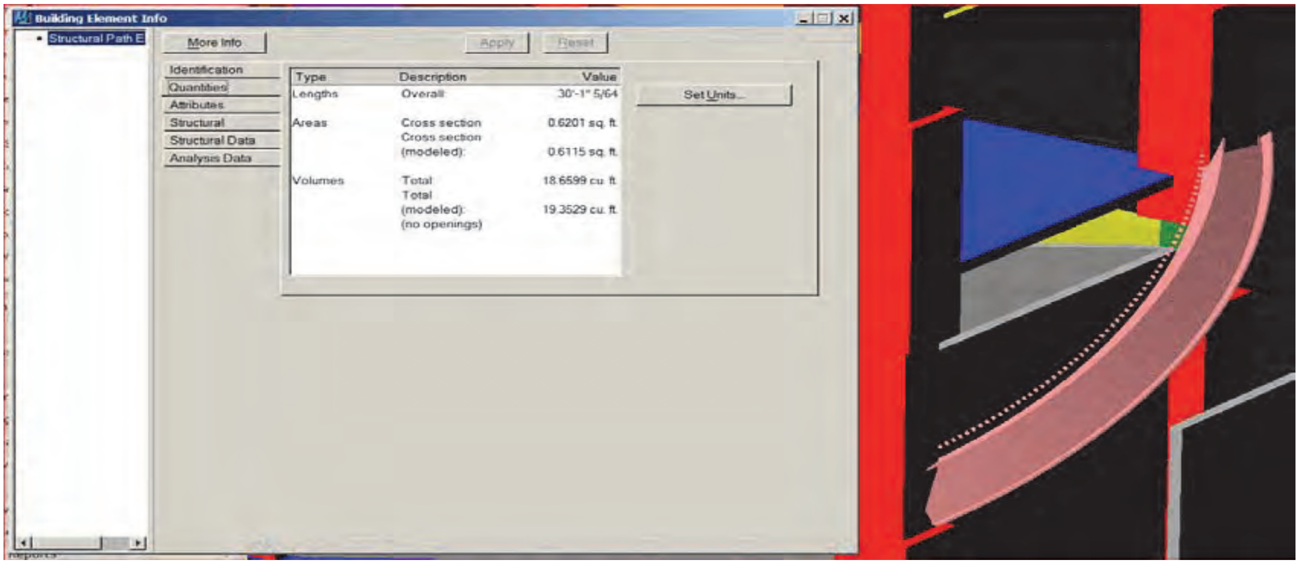


Figure D-8 Detailed view of curved wide-flange beam with properties.

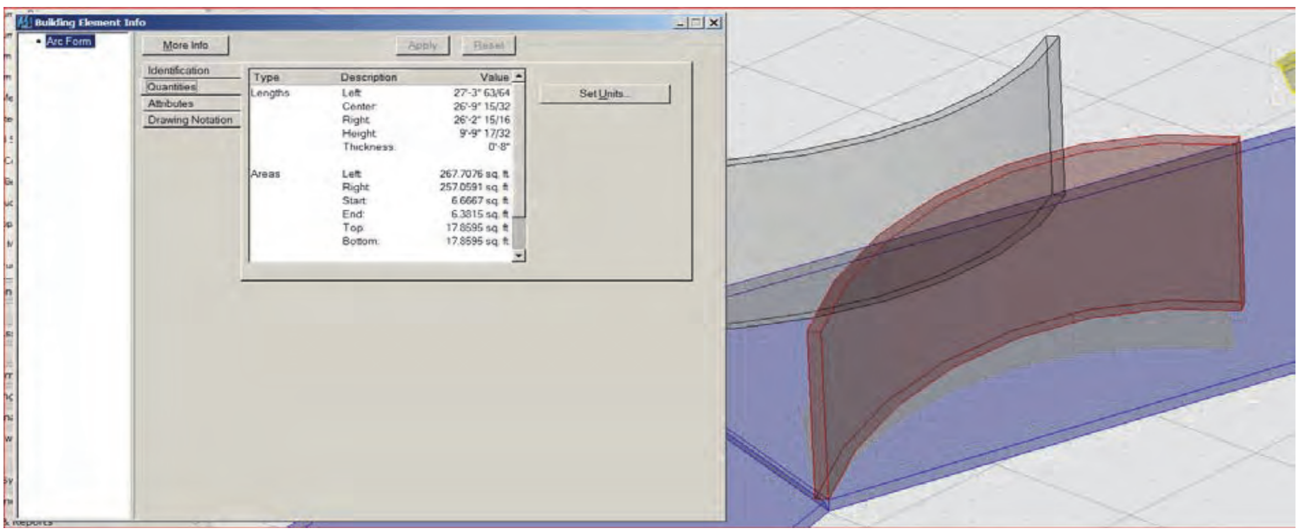


Figure D-9 Detailed view of curved wall with properties.

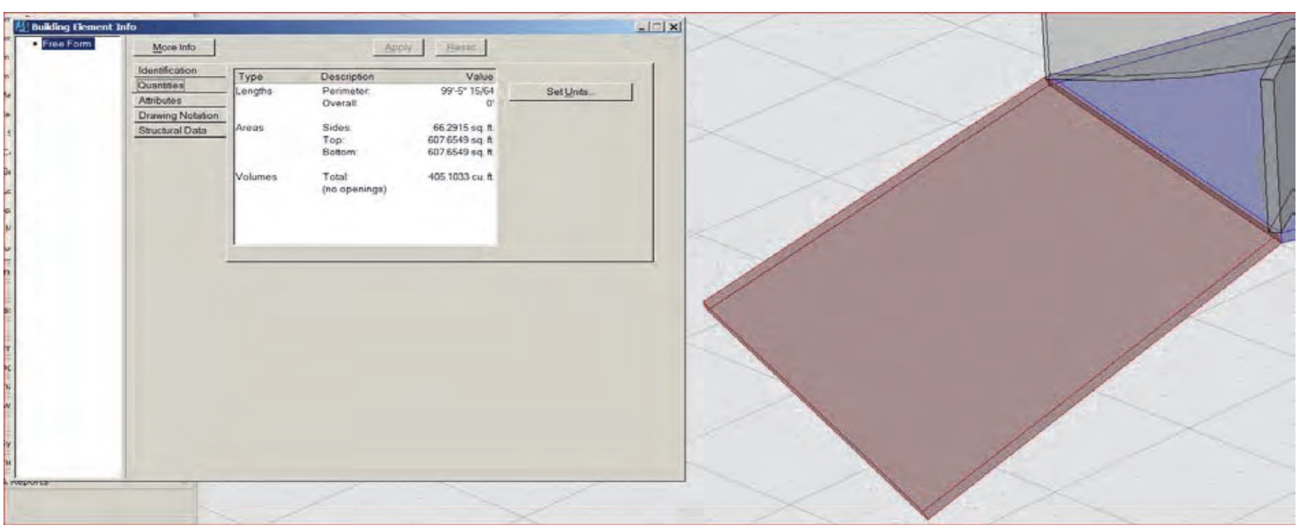


Figure D-10 Detailed view of sloped slab with properties.

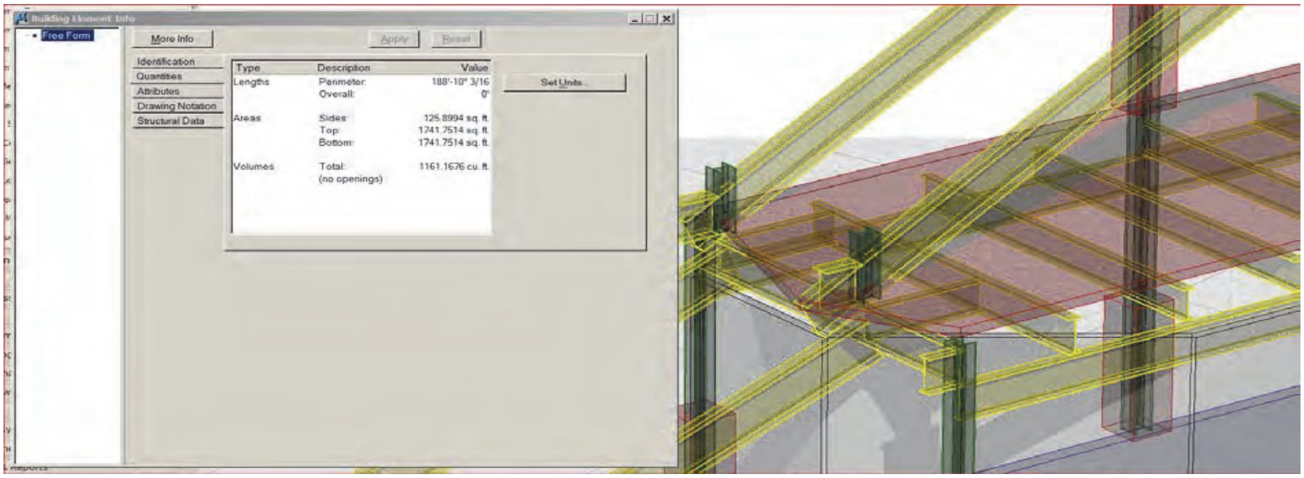


Figure D-11 Detailed view of flat slab with properties.

D.1.2 Description of the Test Model

The content of the test model and the important element and attribute information should be documented here. The testbed should later test that those exchange requirements are correctly exported and imported using the IFC protocol.

D.1.2.1 Building Elements Used

Main element types for the test model are described in the following tables:

Table D-2 Building Elements Used: Beams

Position (Origin X,Y,Z coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
(1139'-5", 518'-2"1/8, 82'-3"1/4)	W36x232	Steel	A992	16′-11″63/64	0
(1116'-9"3/8, 467'-0"7/8, 49'-11"3/8)	W33x201	Steel	A992	38′-0″15/32	0
(1105'-11"5/8, 489'-11"1/2, 49'-0"1/4)	W27x84	Steel	A992	24′-5″63/64	0
(1143'-10"5/8, 536'-10"3/4, 39'-0"1/4)	W36x302	Steel	A992	30′-1″5/64	-17.93
(1119'-10", 541'-7"1/2, 114'-8"3/4)	W14x61	Steel	A992	24′-5″63/64	90

Table D-3 Building Elements Used: Columns

Position (Origin coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
(1119'-8″, 541'-0"7/8, 120'-3"1/4)	BB36x796	Steel	A572	34′-6″11/16	-17.01
(1134'-10", 498'-2"1/8, 52'-4")	RECT30X36	Concrete	4000	9′-2″	75
(1138'-1"1/4, 517'-9"3/4, 74'-10"3/8)	W14x283	Steel	A992	27′-9″5/8	-179.86
(1144'-3"1/4, 533'-1"1/8, 120'-3"1/4)	32″x32″	Concrete	5000	34′-6″11/16	165
(1107'-2"1/2, 431'-7"1/2, 28'-0")	W14x90	Steel	A992	6′-10″27/32	165

Table D-4 Building Elements Used: Braces

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
(1139'-4"5/8, 517'-9"1/8, 67'-3"3/4)	W14x90	Steel	A992	11′-8″1/16	-90
(1143'-3"3/8, 535'-4"1/8, 75'-10"3/8)	W14x61	Steel	A992	14′-7″9/16	-90

Table D-5 Building Elements Used: Walls

Position (Start/End coordinates)	*Profile*	*Material*	*Height*	*Length*
(1103'-3"5/8, 385'-3″7/8, 28'-0")	120″x8″	CMU	9′-9″17/32	26′-9″15/32
(1143'-4", 534'-8"3/4, 28'-0")	240″x8″	CMU	20′-0″	115′-10″57/64

Table D-6 Building Elements Used: Slabs

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*
(1103'-3"5/8, 385'-3"7/8, 27'-4")	8″	5000	
(1119'-8", 541'-0"7/8, 52'-0"1/2)	8″	5000	

D.1.2.2 Attribute Content

In addition to the proper export/import of building elements the additional attribute content should be tested. Therefore a minimum of attributes relevant to the design phase should be created.

Table D-7 Building Elements Used

Object Category	*Attribute name*	*Remark*
Column	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Beam	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Brace	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Wall	Thickness	Dimension in the shortest direction (typically horizontal), taken normal to the surface defining wall height; may vary along length.
	Material	Timber (stud), concrete, CMU, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)
	Alignment	Location of wall insertion point in relation to its x-sectional centroid (center, left, right, etc.)
Slab	Thickness	Dimension in the shortest direction (typically vertical); may vary along length
	Material	Concrete (typically)
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)

D.2 Export Test of the Test Model

The export test contains various test procedures and criteria that should be performed by the applicant before submitting the test case for validation and approval. It includes the following steps:

- Export the IFC file
- Verify the IFC file for a correct header
- Verify the IFC file within a syntax checker
- Verify the IFC file for basic information, e.g. units, etc.
- Verify the IFC file within a free viewer

D.2.1 Verify the Correct IFC File Header

The IFC header has to contain the basic information about the application that created the exchange file. The IFC header can be accessed by opening the IFC file with a simple text editor.

Table D-8 Content of IFC File Header

Content of the IFC file header	*Check correct information*
IFC_2X3_bentley.ifc ISO-10303-21; HEADER; /* Generated by software containing ST-Developer * from STEP Tools, Inc. (www.steptools.com) */ FILE_DESCRIPTION(/* description */ ('IFC2X_PLATFORM', 'MicroStation Triforma generated IFC File', 'Triforma IFC version 8.9.4.33','*Comments*'), /* implementation_level */ '2;1'); FILE_NAME(/* name */ 'IFC_2x3_bentley', /* time_stamp */ '2008-05-27T10:59:18-04:00', /* author */ ('SDoolan'), /* organization */ ('TT'), /* preprocessor_version */ 'ST-DEVELOPER v8', /* originating_system */ 'WinNT', /* authorisation */ 'Admin'); FILE_SCHEMA (('IFC2X3')); ENDSEC;	Export date/time correct Correct IFC Schema

D.2.2 Verify within a Syntax Checker

Run the generated IFC file against a syntax checker. Make sure that there are no syntax errors against the IFC schema. If you are uncertain if a certain syntax error is produced erroneously, report the error together with the FC export file.

Example for a syntax checker is the *IFC Object Counter*.

See http://www.ifcwiki.org/index.php/Free_Software.

Table D-9 Syntax Check

Name of the IFC syntax checker	*Version number ,IFC schema version used*	*Results of the syntax check*
IfcObjectCounter V2.9a	IFC2x3	No Failures

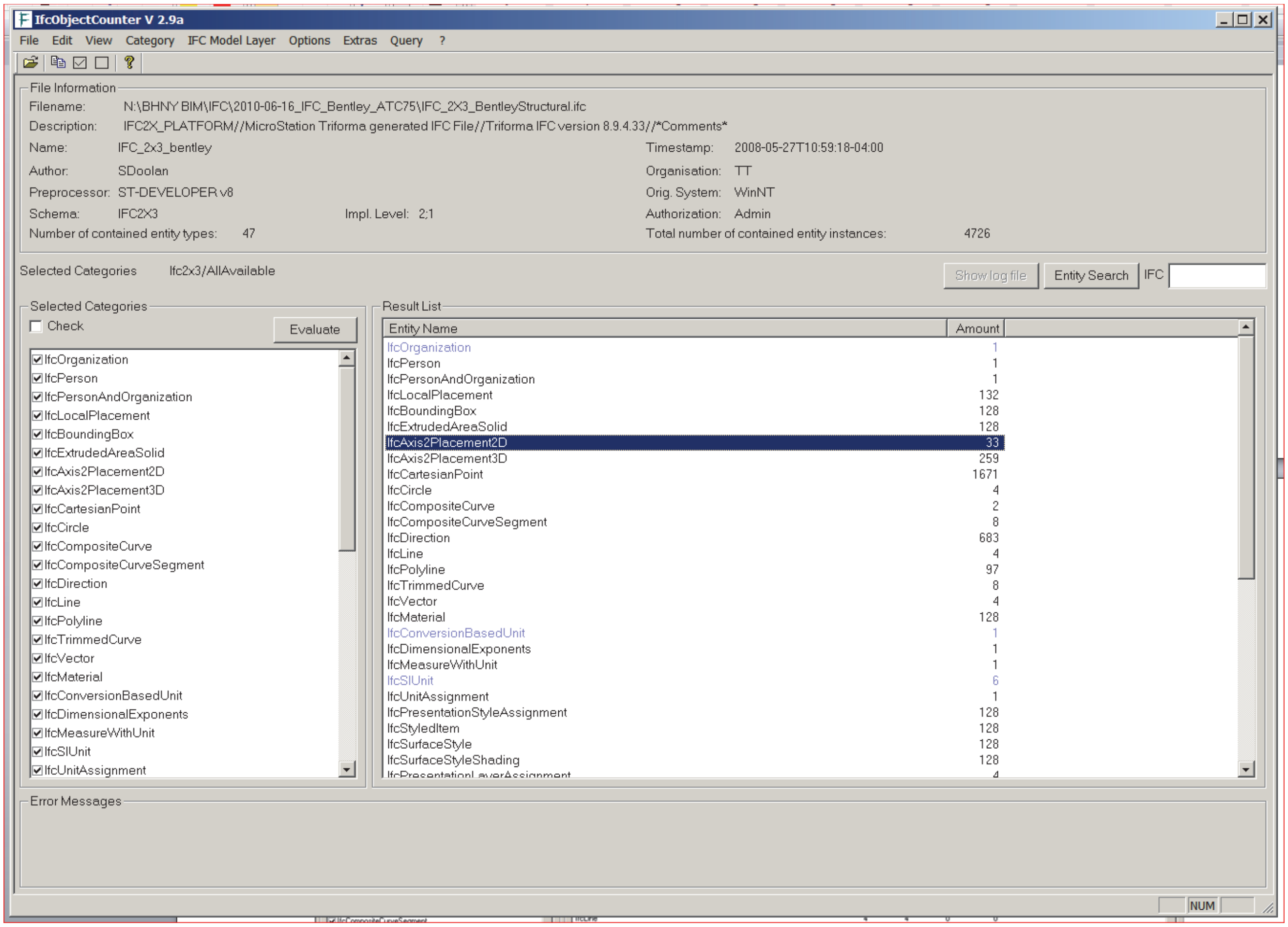


Figure D-12 IFC object check.

D.2.3 Verify within a Viewer

Choose one or several IFC viewers to verify the result. Verify both the geometry of the result, as well as the spatial structure and the attribute content.

Examples for a free viewer are the IFC Storey View, the DDS Viewer or the IFC Engine Viewer.

See http://www.ifcwiki.org/index.php/Free_Software

Table D-10 Test Results Summary for DDS Viewer

IFC viewer used	*DDS viewer Version 6.4*	
Check performed	*Checking results*	*Remarks*
Columns	Geometry does not import correctly	Built-up column is geometrically incorrect; material property imported to “name” field
Beams	Geometry does not import correctly	Curved beam is geometrically incorrect; material imported to “name” field
Brace	Geometry imports correctly	Imports as beam; material property imported to “name” field
Wall	Geometry imports correctly	Only properties available is material and thickness; no other properties available
Slab	Geometry imports correctly	Material imported to “name” and “material name” fields; no other properties available

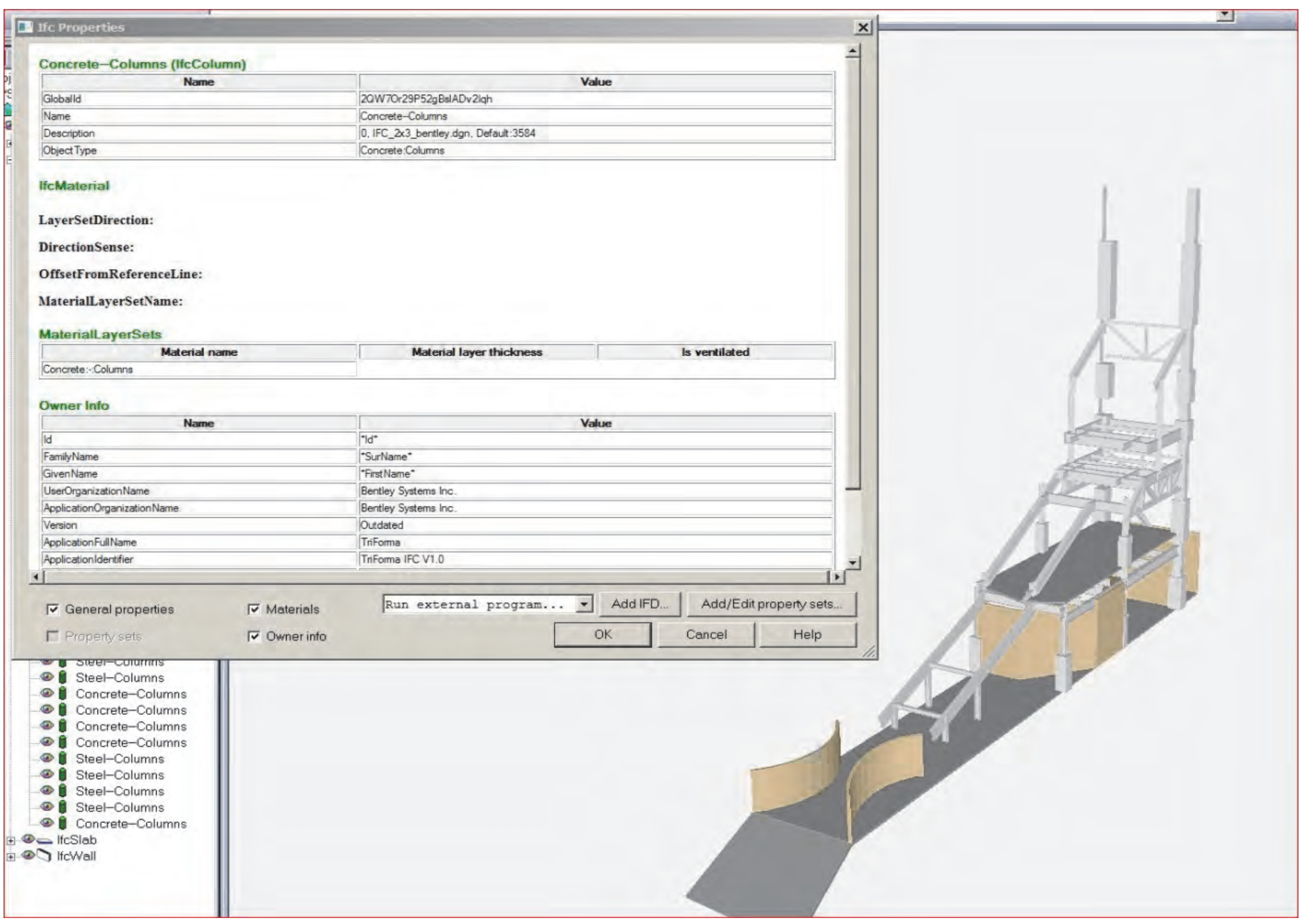


Figure D-13 View of geometry with properties in DDS-CAD Viewer 6.4.

D.3 Import Test of Test Model in Target Application

The export file should be tested in a target application.

- An extended validation tool that includes the rules to check the conformance against the selected IFC view and the agreed implementer agreements for that IFC view.

- A series of import tests by importing the exported test case into other IFC certified applications (or applications that participates in the certification process).

D.3.1 Series of Import Tests

The content of the export file can be tested independently in viewers, the own application and by the validation tool. However in order to make sure, that the exchange with the appropriate target applications actually works, it needs to be checked manually by importing into target applications and by validating the information received by and made available to the target application.

D.3.1.1 Import into Revit

Table D-11 Import Test Result to Revit Structure 2008

Version number	*IFC built*	*Remarks*
Autodesk Revit Structure 2011.0.0	IFC2x3 (IFC_2X3_bentley.ifc)	Error message on Import. Model units are incorrect.

Table D-12 Import Test Results Summary in Revit Structure 2008

Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly	All elements imported as architectural types with no properties except IFC guide
Beams	Geometry imports correctly	All elements imported as architectural types with no properties except IFC guide
Brace	Geometry imports correctly	All elements imported as architectural types with no properties except IFC guide
Wall	Geometry imports correctly	All elements imported as architectural types with no properties except IFC guide
Slab	Geometry imports correctly	All elements imported as architectural types with no properties except IFC guide

D.4 Final Test Matrix

Table D-13 Final Test Matrix for Bentley Structural v8

ATC-75

IFC Interoperability Testing

Date: 7-Jun-10

IFC Source File:	IFC_2X3_bentley.ifc

IFC 2x3 AUTO format from Bentley Structural v8.09.04.39

		DESTINATION									
		CAD / BIM SOFTWARE					STRUCTURAL SOFTWARE				VIEWER
	Software / Version	Bentley Structural v. 8i	AutoCAD MEP 2011 v.E.49.0.0	Revit 2011 20100326_1700	Digital Project v1, r8	Tekla Structures v. 16.0	Sap 2000 11.0.8	Etabs 9.1.6	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.4
Columns	Geometry	No	No	No	No	No	IFC2x3 Unsupported	IFC2x3 Unsupported	Importer unavailable	Importer unavailable	yes
	Properties	No	No	No	No	No					No
	Sloping	N/A	N/A	N/A	N/A	N/A					N/A
Beams	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Braces	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
Walls	Geometry	Yes	Yes	No	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	Yes	Yes	No	Yes	Yes					Yes
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
			NA								
Slabs	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Remarks					DP can not display element properties from IFC files. Body name is inherited from Bentley element name.	No import errors. Must import as reference model.					

To qualify for a YES the following must be met for each category:

1. Geometry = element location as determined by endpoints must be correct and the element must be displayed accurately in the model view.
2. Properties = the element size/profile, material and orientation must all be correct
3. Curved = element radiused in plan (horizontally) - we have noted any difference between this and a straight member.
4. Sloping = element inclined at an angle less than 90 degrees vertically

Definitions:

1. Errors = Error messages on import and general model issues (i.e. scaling affecting element properties)

Appendix E

IFC Structural Testbed Validation: Digital Project v1 r8

E.1 Testbed Description

The structural testbed is based on a modified original design of a stadium, where one section had been cut-out and additional element types had been added. It should represent a fair portion of elements used in structural modeling.

The testbed comprises:

- A common source model to testing the IFC exchange
- A description of the test model based on the structural modeling elements and attributes used
- A description of test criteria against which the result is validated
- A realization of the same test model in (at least) two structural modeling applications
- A set of IFC export files (from the source applications) with well documented export options
- A set of success/failure descriptions for external neutral test tools
    - In IFC syntax checker,
    - In IFC validation tools,
    - In IFC viewer
- A matrix of success/failure descriptions for import into other software
    - Matrix based on test criteria and importing software
    - Importing software is either:
        - Other BIM tools (architectural/ structural modeling software), or
        - Structural analysis software

E.1.1 Test Model Description

The first test model has been created in Bentley Structural. It deals with the main elements:

- Column
- Beam
- Brace
- Wall
- Slab

The original test model has been created and exported to IFC using:

Table E-1 Test Model Description

Name of application	*Version number*	*Export options*	*Remarks*
Digital Project	8.09.04.39	IFC2x3	File name: 100616_ATC75_DP.ifc

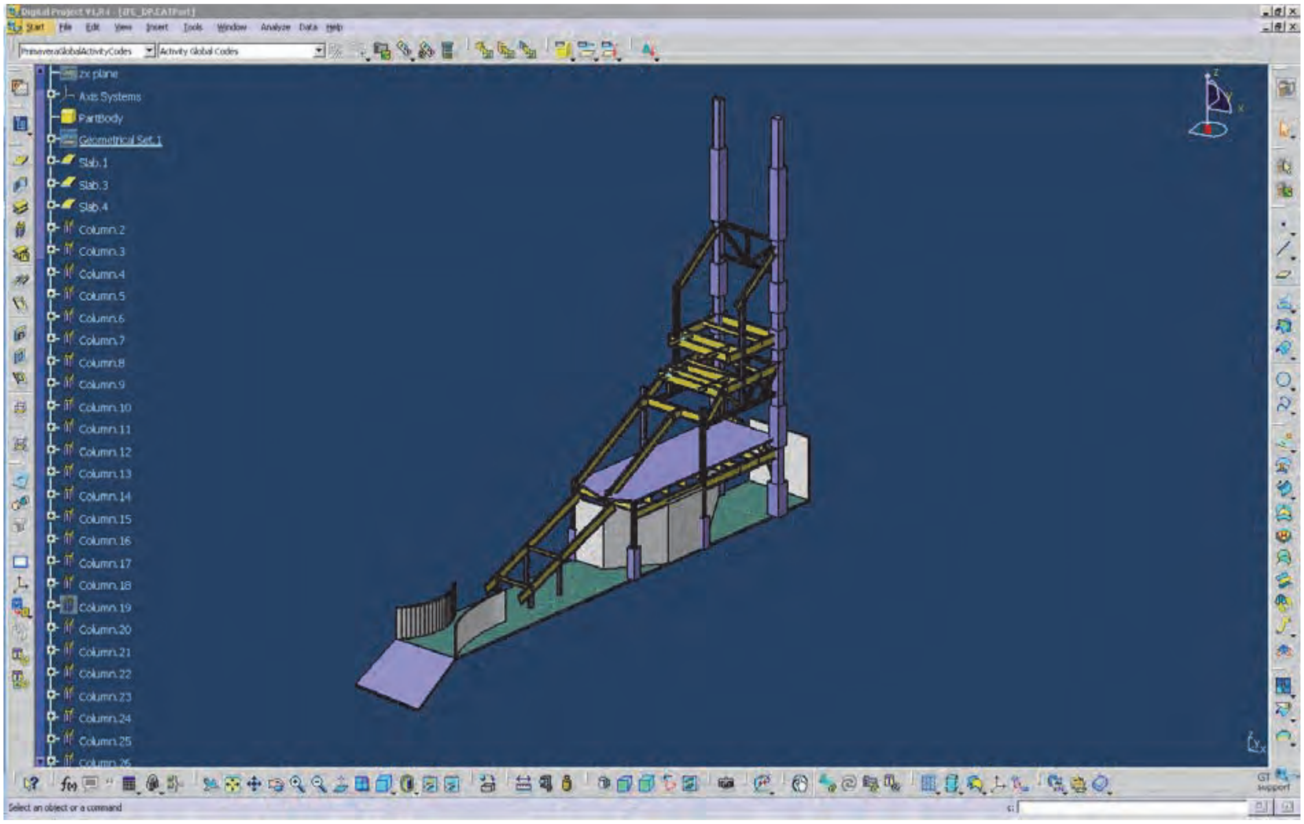


Figure E-1 Perspective view of the test case 1.

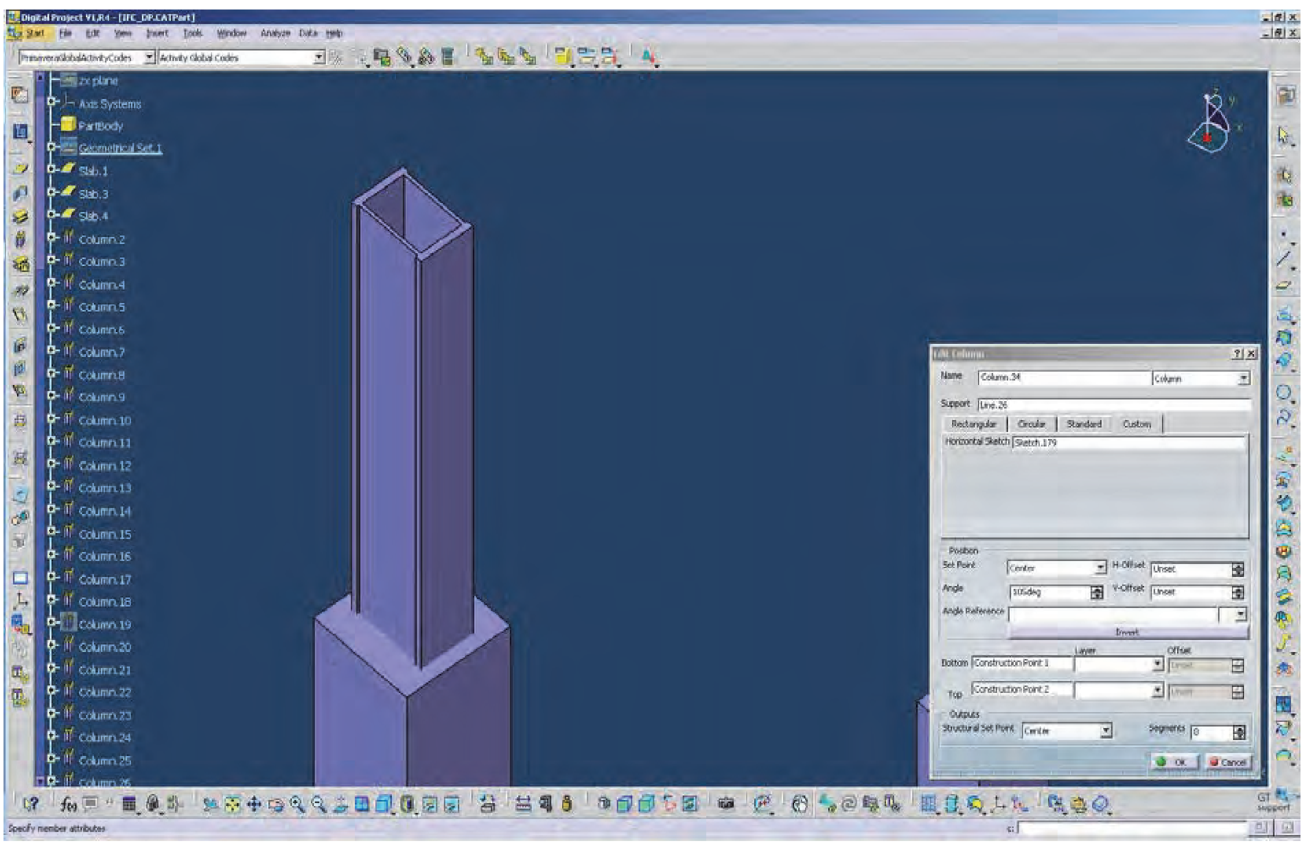


Figure E-2 Detailed view of built-up column with properties.

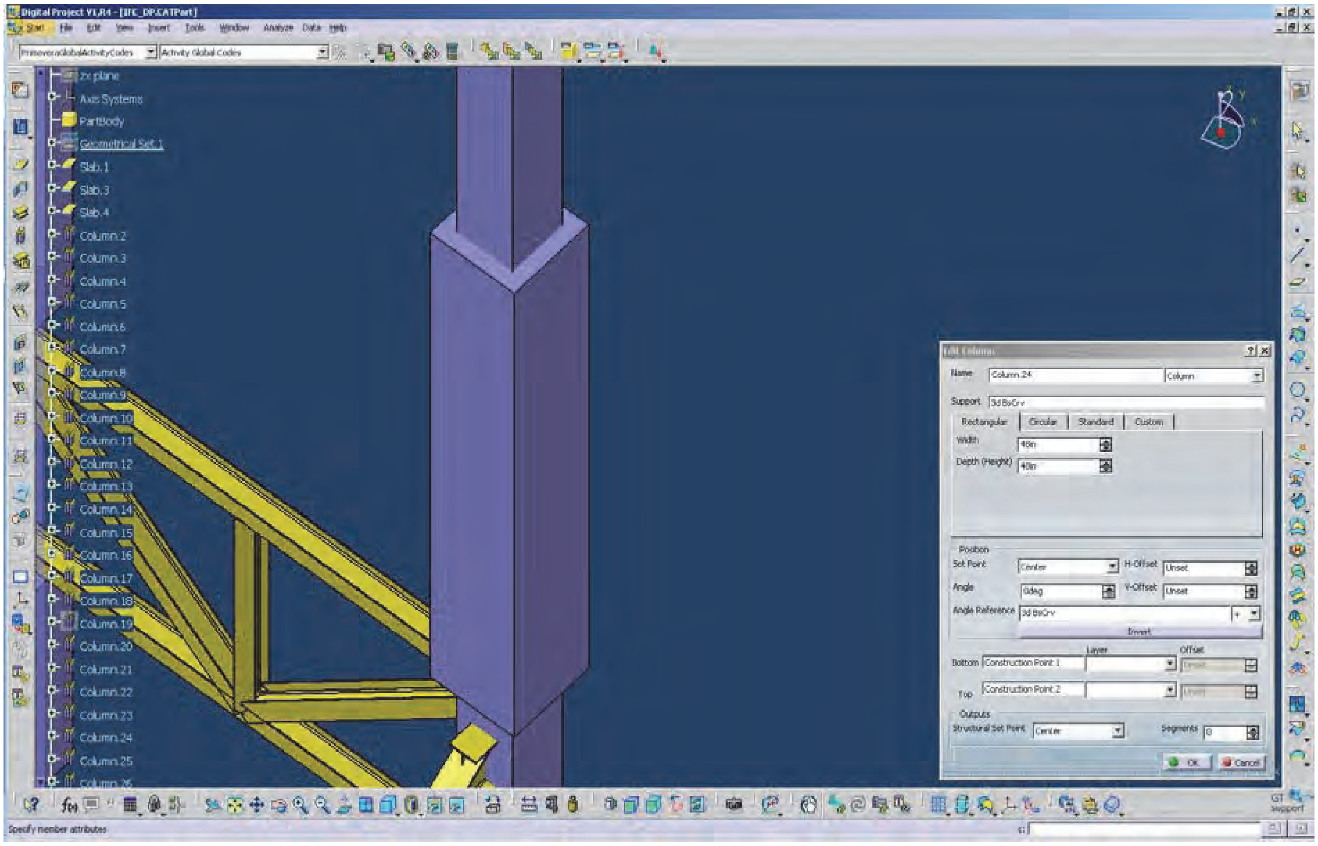


Figure E-3 Detailed view of concrete column with properties.

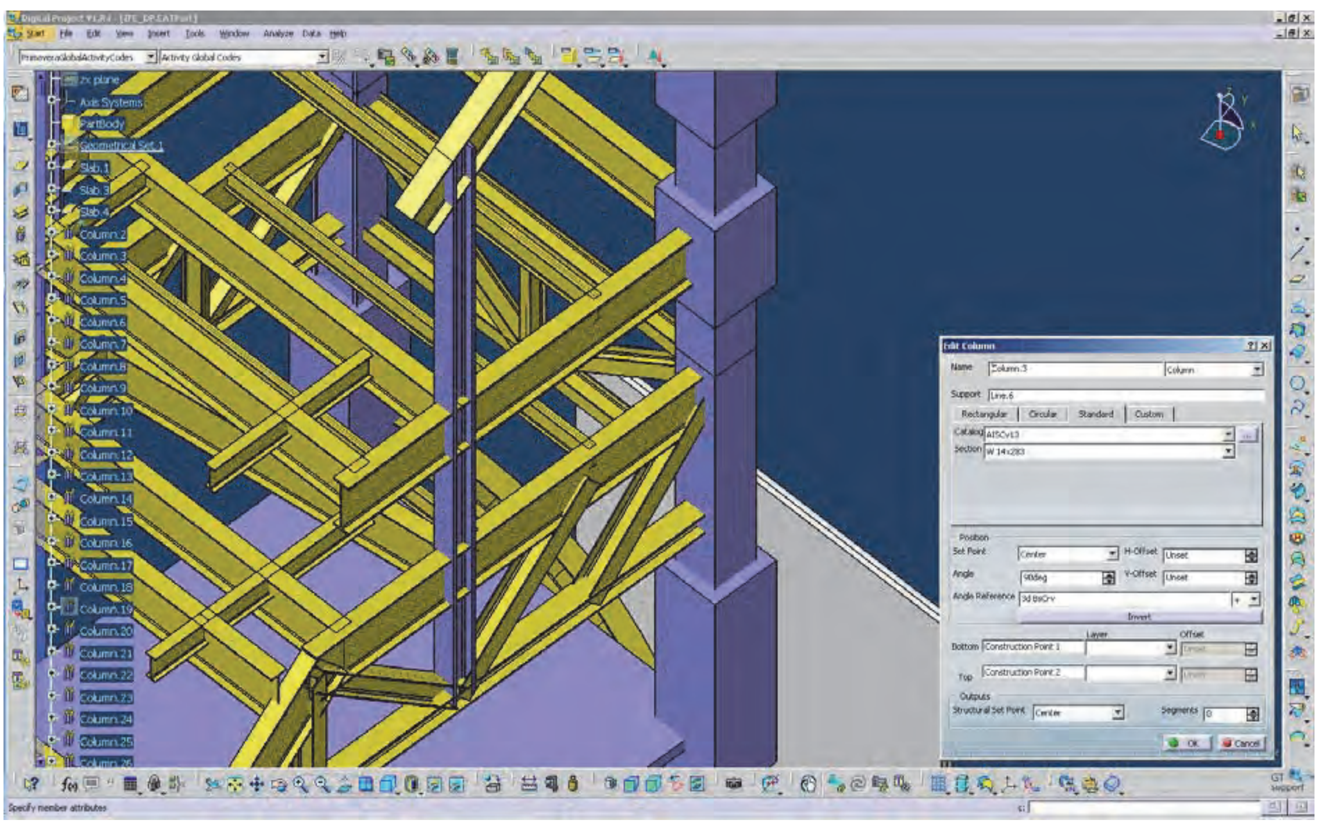


Figure E-4 Detailed view of wide flange column with properties.

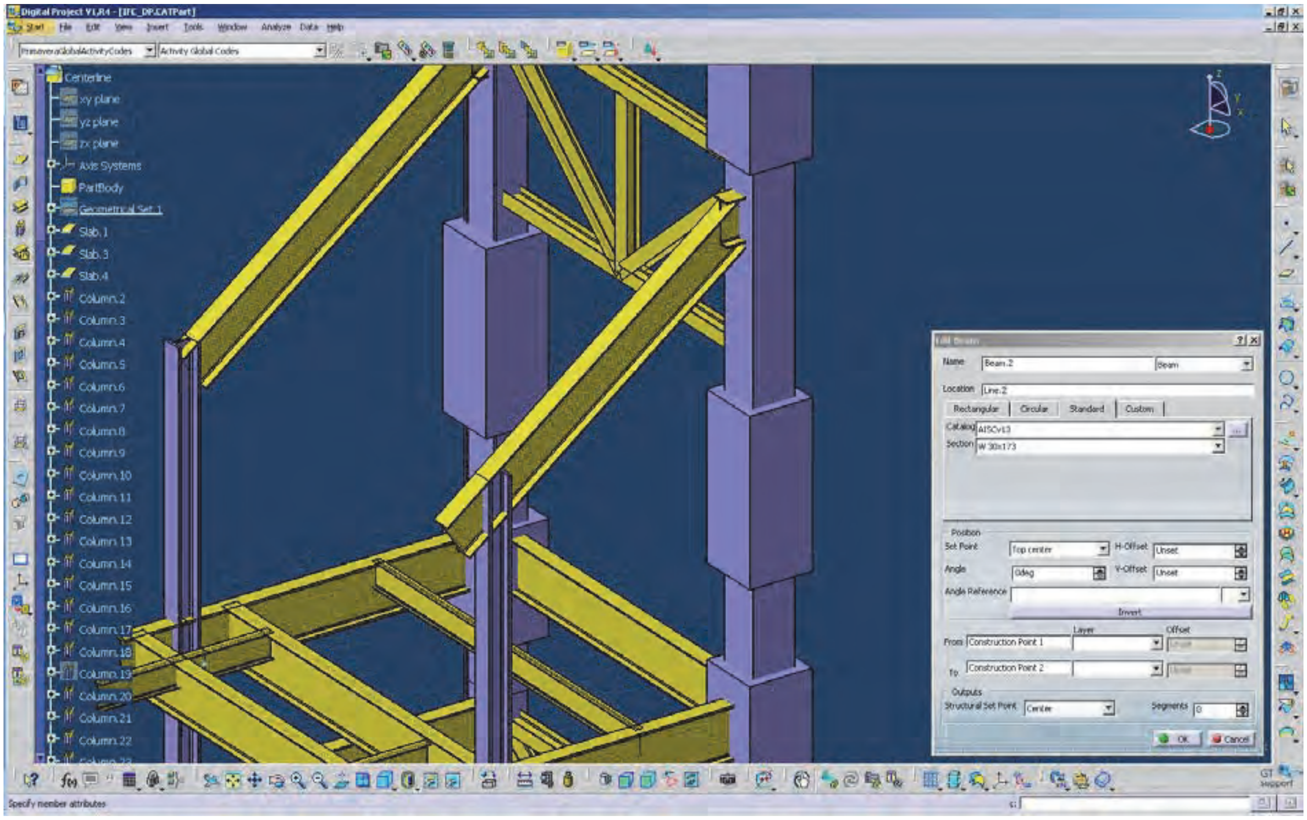


Figure E-5 Detailed view of sloped wide-flange beam with properties.

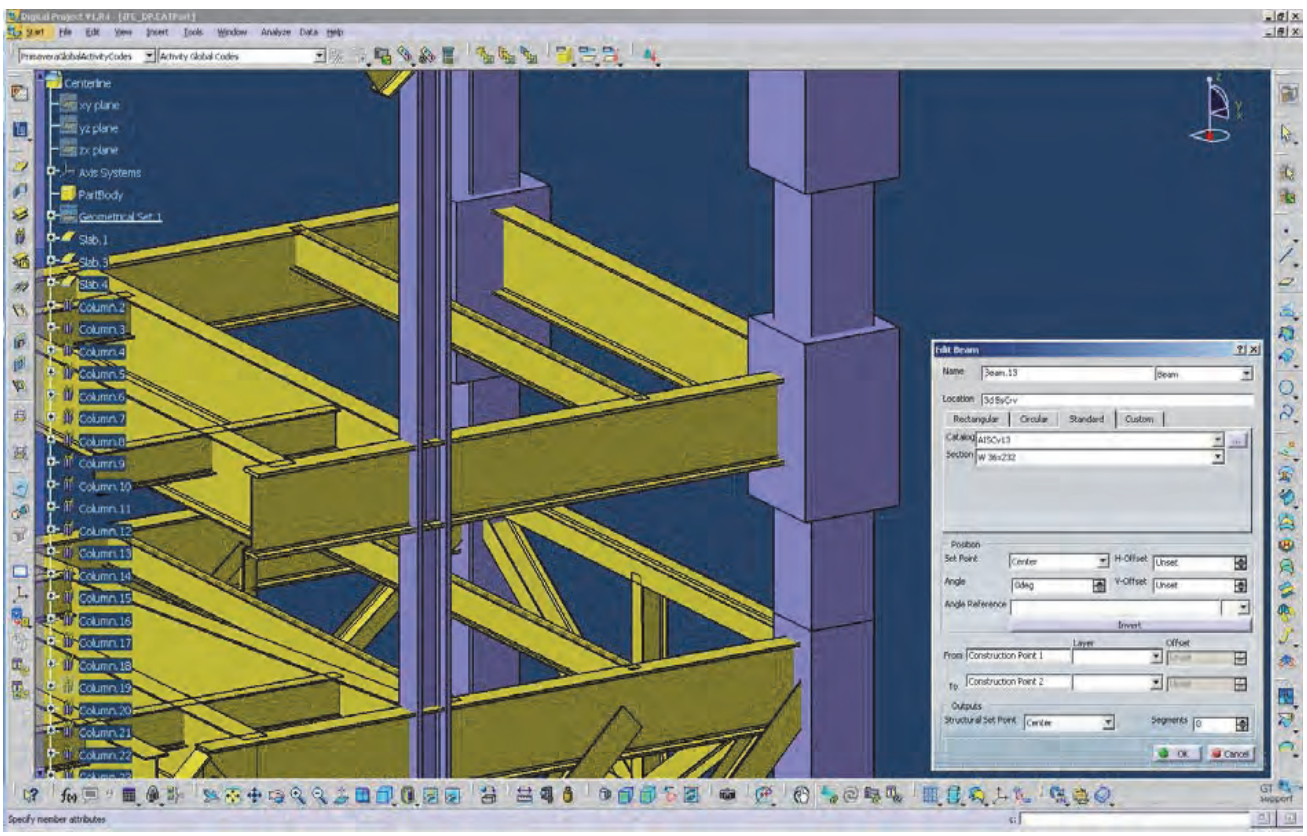


Figure E-6 Detailed view of wide-flange beam with properties.

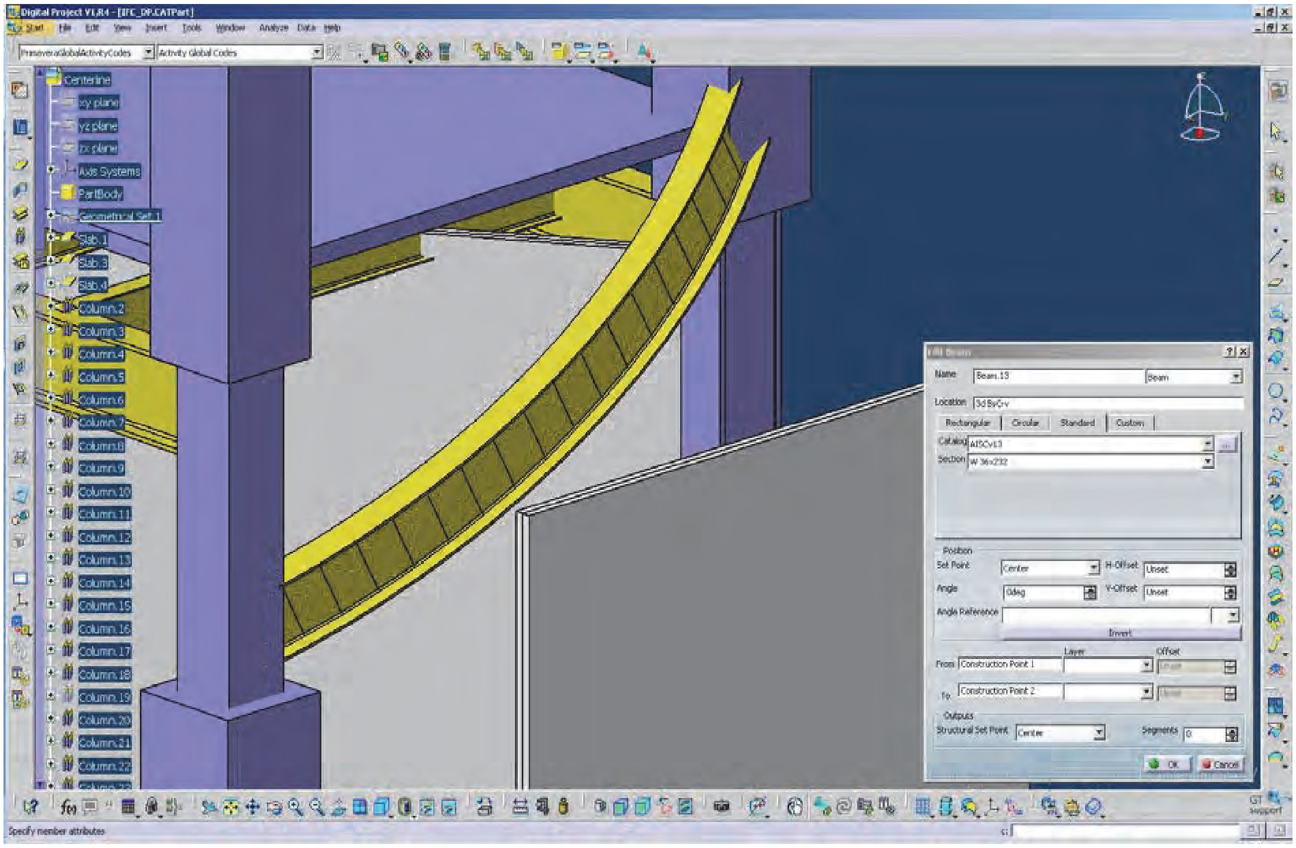


Figure E-7 Detailed view of curved wide-flange beam with properties.

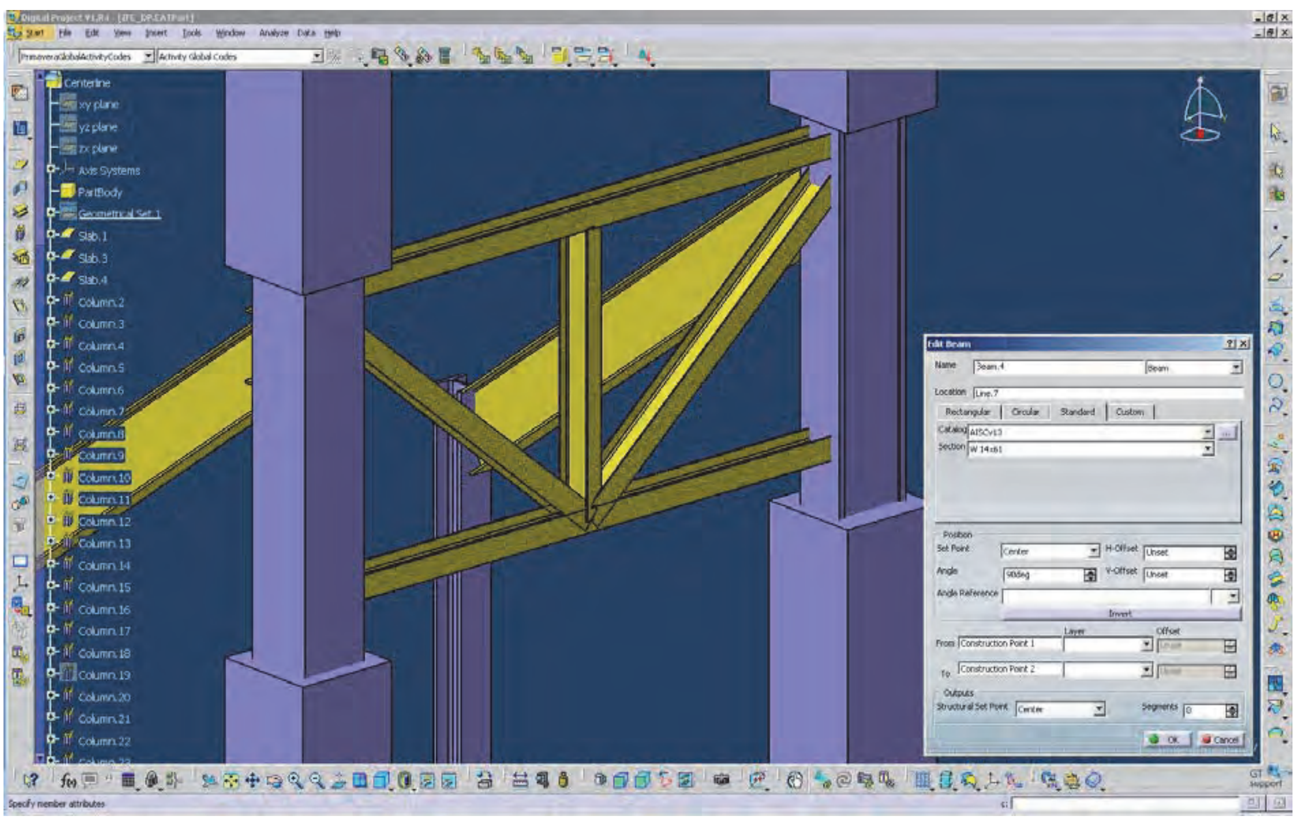


Figure E-8 Detailed view of wide-flange beam with properties.

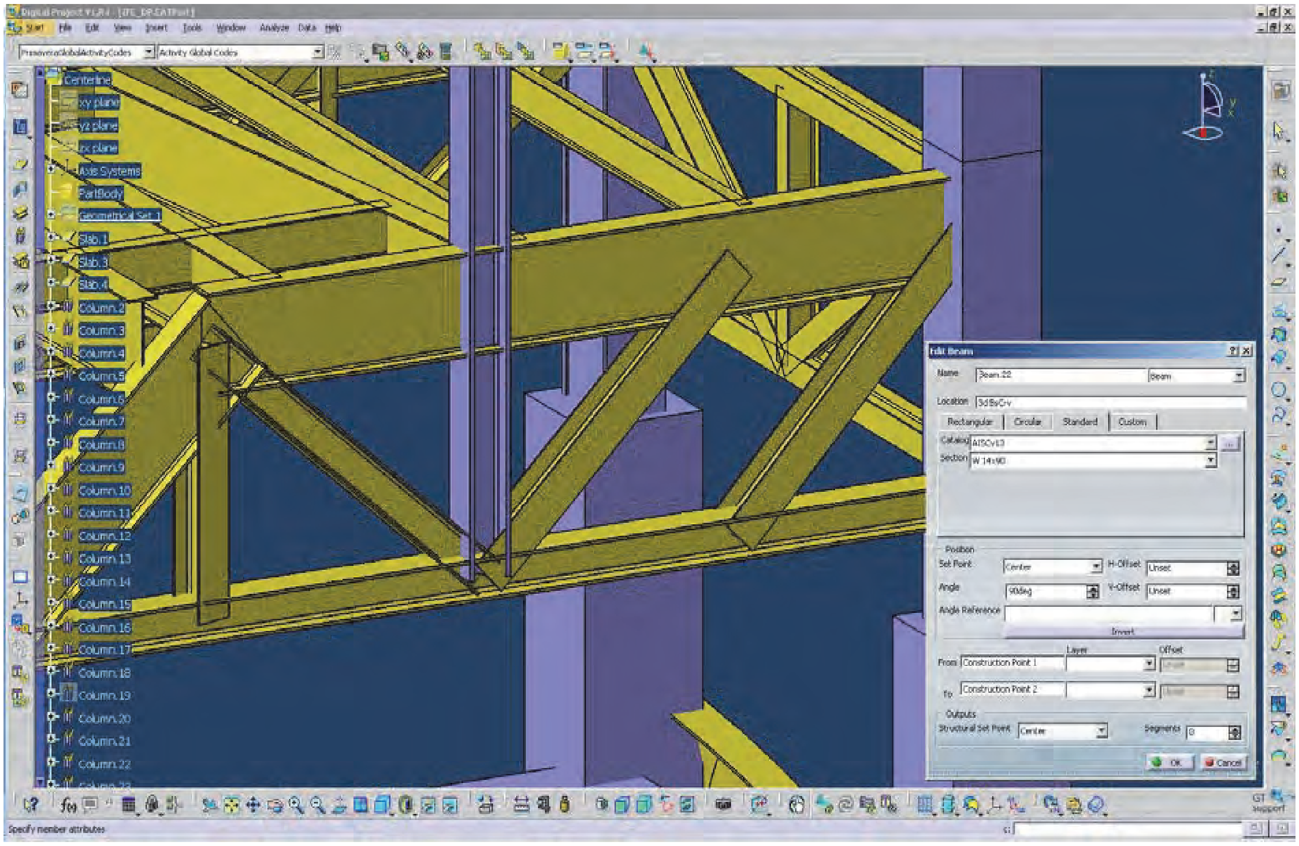


Figure E-9 Detailed view of wide-flange brace with properties.

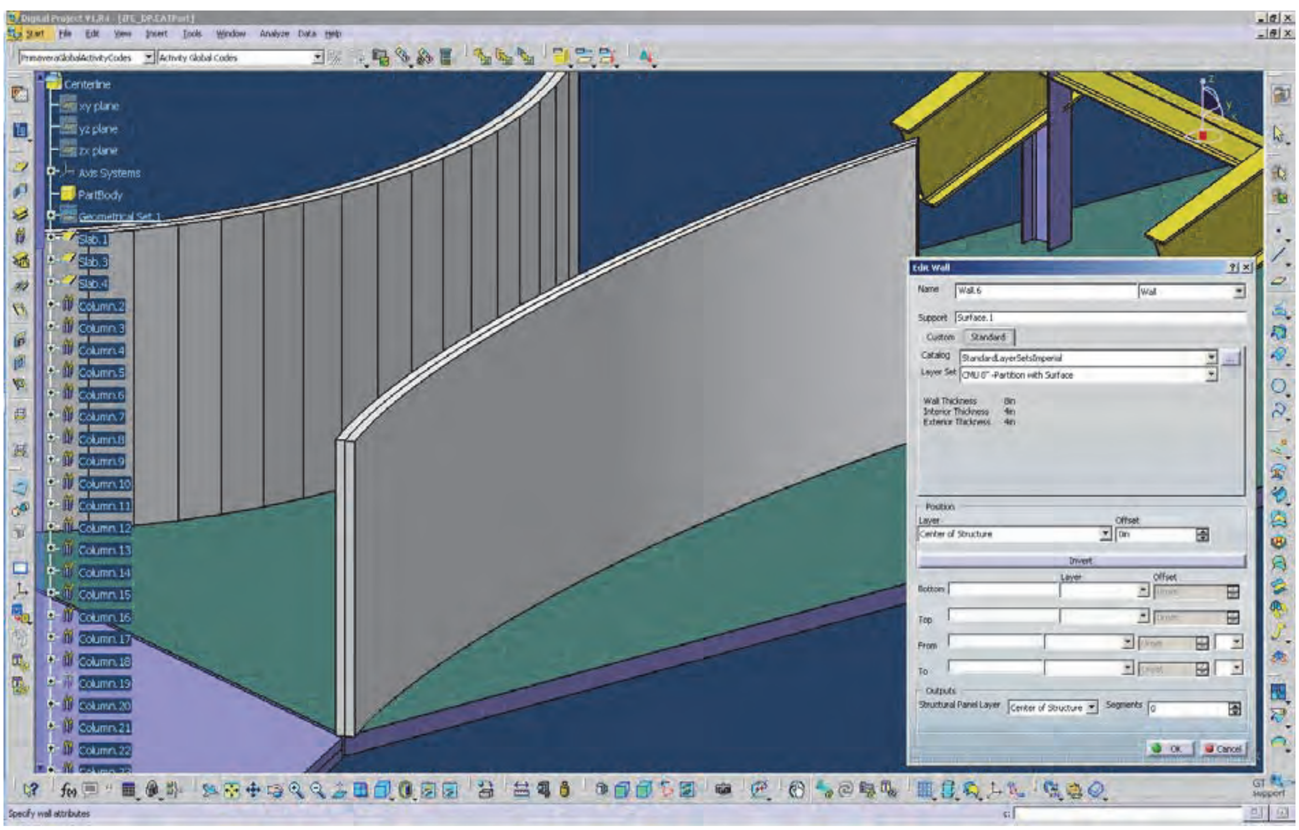


Figure E-10 Detailed view of curved sloped wall with properties.

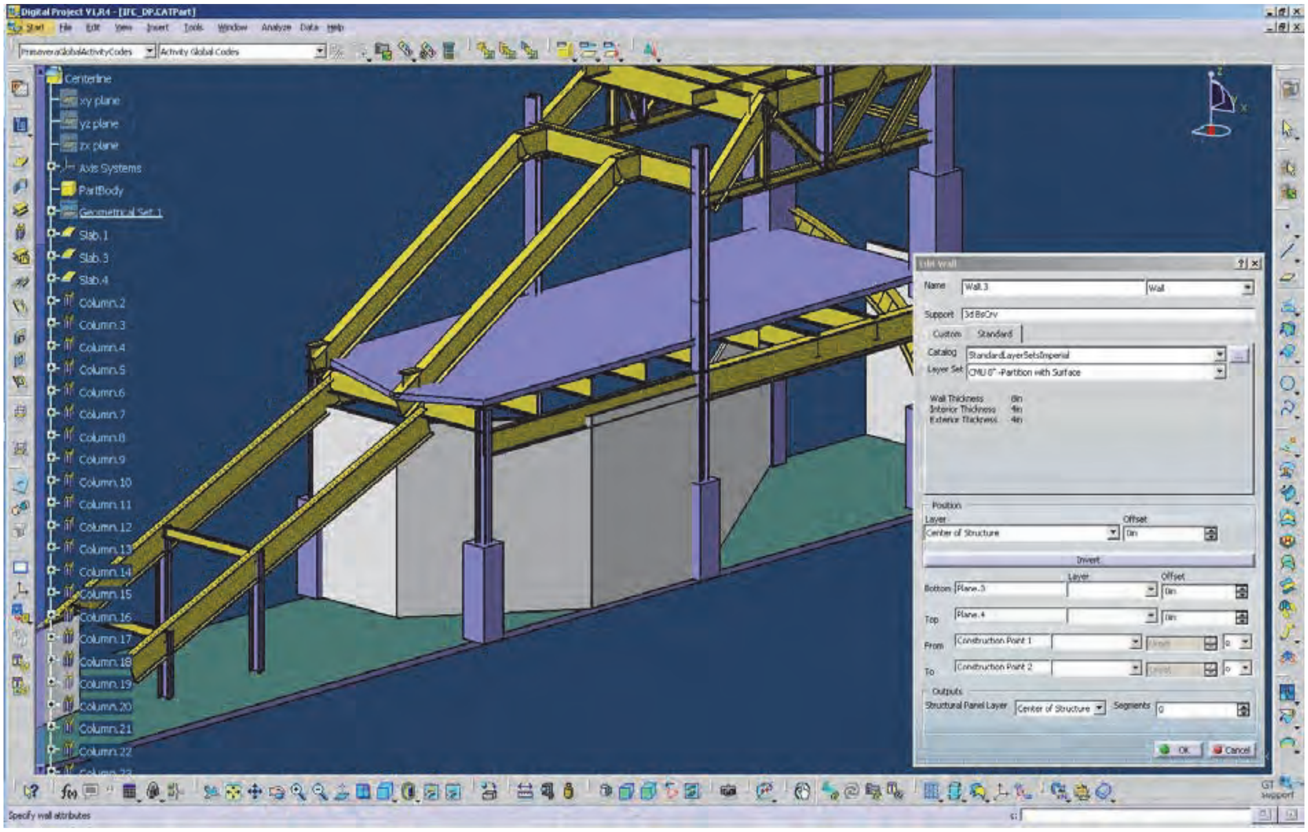


Figure E-11 Detailed view of segmented wall with properties.

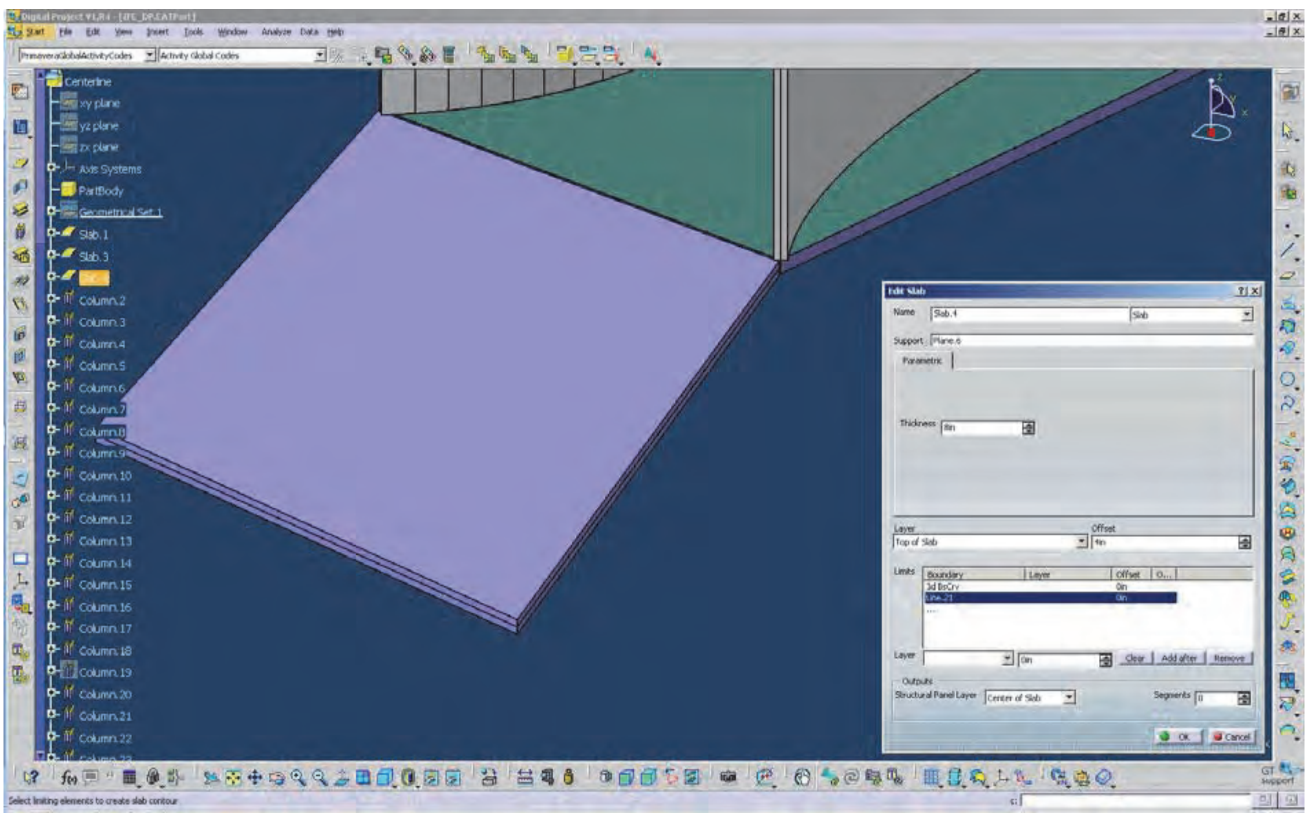


Figure E-12 Detailed view of sloped slab with properties.

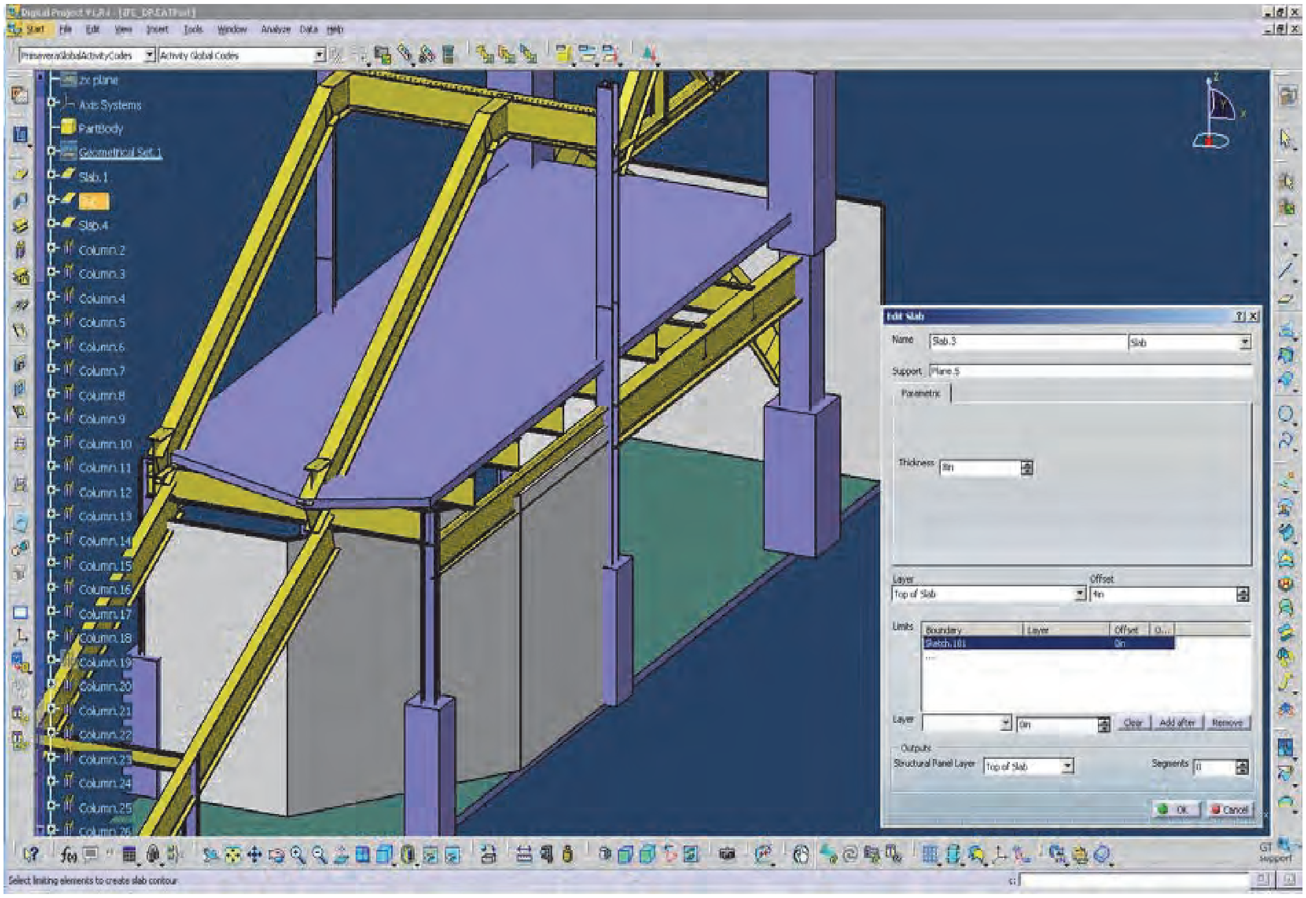


Figure E-13 Detailed view of flat slab with properties.

E.1.2 Description of the Test Model

The content of the test model and the important element and attribute information should be documented here. The testbed should later test that those exchange requirements are correctly exported and imported using the IFC protocol.

E.1.2.1 Building Elements Used

Main element types for the test model are described in the following tables:

Table E-2 Building Elements Used: Beams

Position (Origin X,Y,Z coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
(1139'-5", 518'-2"1/8, 82'-3"1/4)	W36x232	Steel	A992	16′-11″63/64	0
(1116'-9"3/8, 467'-0"7/8, 49'-11"3/8)	W33x201	Steel	A992	38′-0″15/32	0
(1105'-11"5/8, 489'-11"1/2, 49'-0"1/4)	W27x84	Steel	A992	24′-5″63/64	0
(1143'-10"5/8, 536'-10"3/4, 39'-0"1/4)	W36x302	Steel	A992	30′-1″5/64	-17.93
(1119'-10", 541'-7"1/2, 114'-8"3/4)	W14x61	Steel	A992	24′-5″63/64	90

Table E-3 Building Elements Used: Columns

Position (Origin coordinates)	Profile	Material	Grade	Length	Roll
(1119'-8″, 541'-0"7/8, 120'-3"1/4)	BB36x796	Steel	A572	34′-6″11/16	-17.01
(1134'-10", 498'-2"1/8, 52'-4")	RECT30X36	Concrete	4000	9′-2″	75
(1138'-1"1/4, 517'-9"3/4, 74'-10"3/8)	W14x283	Steel	A992	27′-9″5/8	-179.86
(1144'-3"1/4, 533'-1"1/8, 120'-3"1/4)	32″x32″	Concrete	5000	34′-6″11/16	165
(1107'-2"1/2, 431'-7"1/2, 28'-0")	W14x90	Steel	A992	6′-10″27/32	165

Table E-4 Building Elements Used: Braces

Position (Start/End coordinates)	Profile	Material	Grade	Length	Roll
(1139'-4"5/8, 517'-9"1/8, 67'-3"3/4)	W14x90	Steel	A992	11′-8″1/16	-90
(1143'-3"3/8, 535'-4"1/8, 75'-10"3/8)	W14x61	Steel	A992	14′-7″9/16	-90

Table E-5 Building Elements Used: Walls

Position (Start/End coordinates)	Profile	Material	Height	Length
(1103'-3"5/8, 385'-3″7/8, 28'-0")	120″x8″	CMU	9′-9″17/32	26′-9″15/32
(1143'-4", 534'-8"3/4, 28'-0")	240″x8″	CMU	20′-0″	115′-10″57/64

Table E-6 Building Elements Used: Slabs

Position (Start/End coordinates)	Profile	Material	Grade
(1103'-3"5/8, 385'-3"7/8, 27'-4")	8″	5000	
(1119'-8", 541'-0"7/8, 52'-0"1/2)	8″	5000	

E.1.2.2 Attribute Content

In addition to the proper export/ import of building elements the additional attribute content should be tested. Therefore a minimum of attributes relevant to the design phase should be created.

Table E-7 Building Elements Used

Object Category	*Attribute name*	*Remark*
Column	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Beam	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Brace	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Wall	Thickness	Dimension in the shortest direction (typically horizontal), taken normal to the surface defining wall height; may vary along length
	Material	Timber (stud), concrete, CMU, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)
	Alignment	Location of wall insertion point in relation to its x-sectional centroid (center, left, right, etc.)
Slab	Thickness	Dimension in the shortest direction (typically vertical); may vary along length
	Material	Concrete (typically)
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)

E.2 Export Test of the Test Model

The export test contains various test procedures and criteria that should be performed by the applicant before submitting the test case for validation and approval. It includes the following steps:

- Export the IFC file
- Verify the IFC file for a correct header
- Verify the IFC file within a syntax checker
- Verify the IFC file for basic information, e.g. units, etc.
- Verify the IFC file within a free viewer

E.2.1 Verify the Correct IFC File Header

The IFC header has to contain the basic information about the application that created the exchange file. The IFC header can be accessed by opening the IFC file with a simple text editor.

Table E-8 Content of IFC File Header

Content of the IFC file header	*Check correct information*
IFC_2X3_bentley.ifc	
ISO-10303-21; HEADER;	
FILE_DESCRIPTION(('ViewDefinition [CoordinationView]'),'2;1');	Export date/time correct
FILE_NAME('100616_ATC75_DP.ifc','2010-06-16T15:11:12',('ikeough'),(''),'ST-DEVELOPER v12','Digital Project','');	Correct IFC Schema
FILE_SCHEMA(('IFC2X3')); ENDSEC;	

E.2.2 Verify within a Syntax Checker

Run the generated IFC file against a syntax checker. Make sure that there are no syntax errors against the IFC schema. If you are uncertain if a certain syntax error is produced erroneously, report the error together with the FC export file.
Example for a syntax checker is the *IFC Object Counter*.

See http://www.ifcwiki.org/index.php/Free_Software.

Table E-9 Syntax Check

Name of the IFC syntax checker	*Version number,IFC schema version used*	*Results of the syntax check*
IfcObjectCounter V2.9a	IFC2x3	No Failures

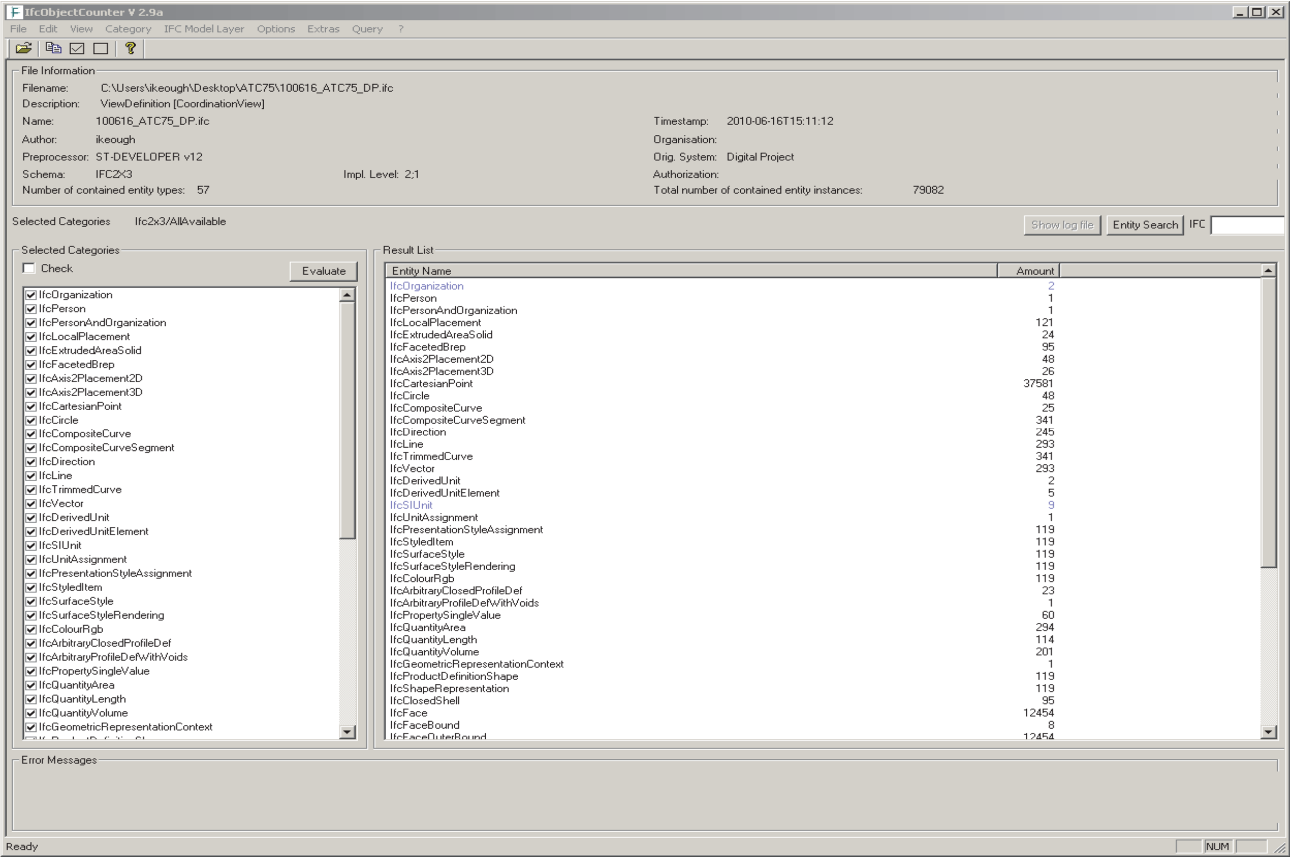


Figure E-14 IFC object check.

E.2.3 Verify within a Viewer

Choose one or several IFC viewers to verify the result. Verify both the geometry of the result, as well as the spatial structure and the attribute content.

Examples for a free viewer are the IFC Storey View, the DDS Viewer or the IFC Engine Viewer.

See http://www.ifcwiki.org/index.php/Free_Software

Table E-10 Test Results Summary for DDS Viewer

IFC viewer used	*DDS viewer Version 6.5*	
Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly	
Beams	Geometry imports correctly	
Brace	Geometry imports correctly	
Wall	Geometry imports correctly	
Slab	Geometry imports correctly	

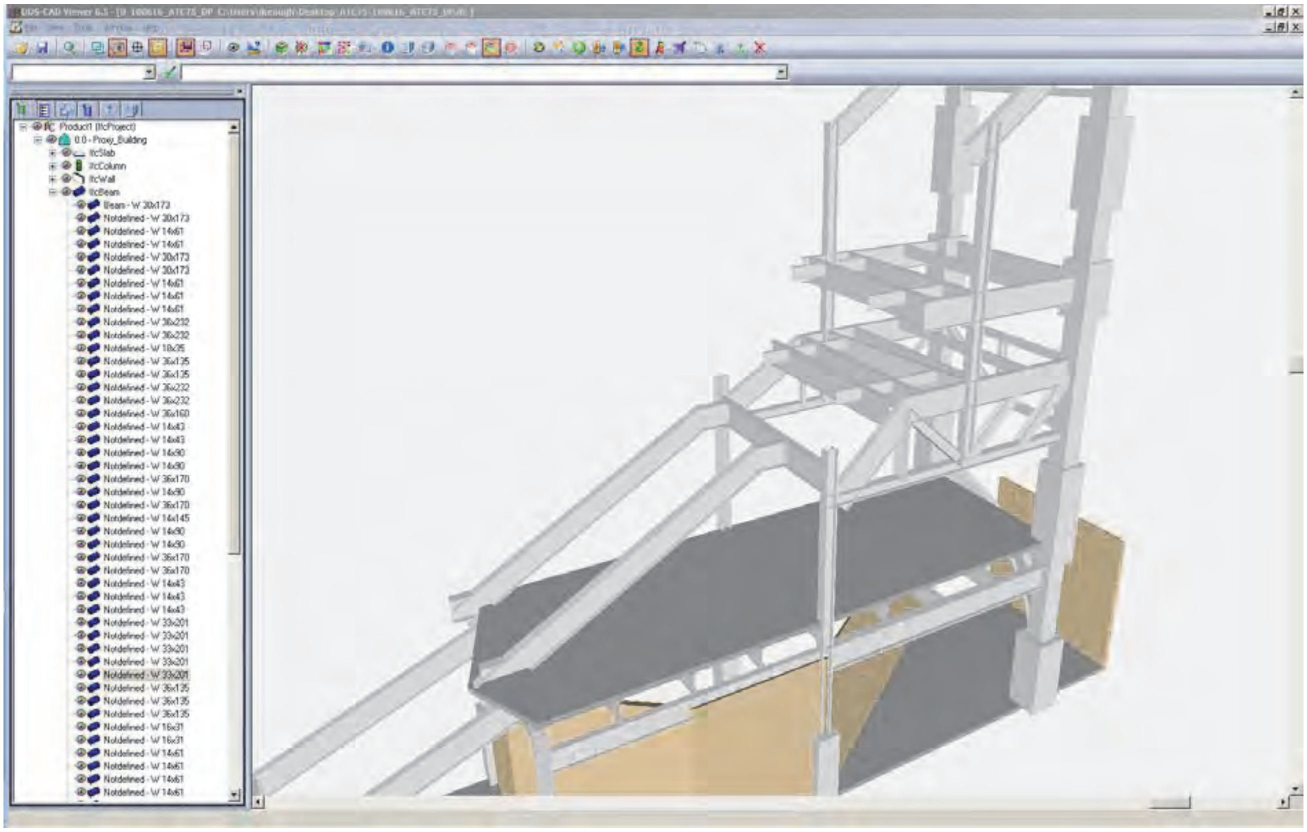


Figure E-15 View of geometry with properties in DDS-CAD Viewer 6.5.

E.3 Import Test of Test Model in Target Application

The export file should be tested in a target application.

- An extended validation tool that includes the rules to check the conformance against the selected IFC view and the agreed implementer agreements for that IFC view.

- A series of import tests by importing the exported test case into other IFC certified applications (or applications that participates in the certification process).

E.3.1 Series of Import Tests

The content of the export file can be tested independently in viewers, the own application and by the validation tool. However in order to make sure, that the exchange with the appropriate target applications actually works, it needs to be checked manually by importing into target applications and by validating the information received by and made available to the target application.

E.3.1.1 Import into AutoCAD Architecture

Table E-11 Import Test Result to AutoCAD Architecture

Version number	*IFC built*	*Remarks*
AutoCAD MEP 2011	IFC2x3	

Table E-12 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns	Custom section geometry does not import correctly. Concrete column sizes are written to "Description" field	No properties included on member.
Beams	Some sloped beam geometries do not import correctly. In these instances, section profile is replaced with a square.	No properties included on member.
Brace	Brace geometries import correctly.	No properties included on member.
Wall	Vertical, continuous, curved, and sloped walls import correctly.	No properties included on member.
Slab	Slabs geometries are incorrect.	No properties included on member.

E.3.1.2 Import into Revit Structure

Table E-13 Import Test Result to Revit Structure 2008

Version number	*IFC built*	*Remarks*
Autodesk Revit Structure 2011	IFC2x3	

Table E-14 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guide.
Beams	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guide.
Brace	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guide.
Wall	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guide.
Slab	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guide.

E.4 Final Test Matrix

Table E-15 Final Test Matrix for Digital Project v1, r8

ATC-75

IFC Interoperability Testing

Date: 16-Jun-10

IFC Source File: 100616_ATC75_DP.ifc

IFC 2x3 AUTO format from Digital Project v1, r4

		DESTINATION									
		CAD / BIM SOFTWARE					STRUCTURAL SOFTWARE				VIEWER
	Software / Version	Bentley Structural v. 8i	AutoCAD MEP 2011 v.E.49.0.0	Revit Structure 2011	Digital Project v1, r4	Tekla Structures v. 16.0	Sap 2000 11.0.8	Etabs 9.6.0	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.5
Columns	Geometry	YES	NO	NO	n/a	YES	IFC2x3 Unsupported	NO	Importer unavailable	Importer unavailable	YES
	Properties	NO	NO	NO		NO		NO			YES
	Sloping	n/a	N/A	n/a		n/a		NO			n/a
Beams	Geometry	YES	YES	YES		YES		NO			YES
	Properties	NO	NO	NO		NO		NO			YES
	Curved	YES	YES	YES		NO		NO			YES
	Sloping	YES	NO	YES		YES		NO			YES
Braces	Geometry	YES	YES	YES		YES		NO			YES
	Properties	NO	NO	NO		NO		NO			YES
Walls	Geometry	YES	YES	YES		YES		NO			YES
	Properties	NO	NO	NO		NO		NO			YES
	Curved	YES	YES	YES		YES		NO			YES
	Sloping	YES	YES	YES		YES		NO			YES
Slabs	Geometry	YES	NO	YES		YES		NO			YES
	Properties	NO	NO	NO		NO		NO			YES
	Sloping	YES	NO	YES		YES		NO			YES
Remarks				No import errors. Imports all IFC elements as generic types.		No import errors. Must import as reference model.		Import of IFC2X3 file from DP causes ETABS to crash.			

To qualify for a YES the following must be met for each category:

1. Geometry = element location as determined by endpoints must be correct and the element must be displayed accurately in the model view.
2. Properties = the element size/profile, material and orientation must all be correct
3. Curved = element radiused in plan (horizontally) - we have noted any difference between this and a straight member.
4. Sloping = element inclined at an angle less than 90 degrees vertically

Definitions:

1. Errors = Error messages on import and general model issues (i.e. scaling affecting element properties)

Appendix F

IFC Structural Testbed Validation: Revit Structure 2008

F.1 Testbed Description

The structural testbed is based on a modified original design of a stadium, where one section had been cut-out and additional element types had been added. It should represent a fair portion of elements used in structural modeling.

The testbed comprises:

- A common source model to testing the IFC exchange
- A description of the test model based on the structural modeling elements and attributes used
- A description of test criteria against which the result is validated
- A realization of the same test model in (at least) two structural modeling applications
- A set of IFC export files (from the source applications) with well documented export options
- A set of success/failure descriptions for external neutral test tools
    - In IFC syntax checker,
    - In IFC validation tools,
    - In IFC viewer
- A matrix of success/failure descriptions for import into other software
    - Matrix based on test criteria and importing software
    - Importing software is either:
        - Other BIM tools (architectural/ structural modeling software), or
        - Structural analysis software

F.1.1 Test Model Description

The first test model has been created in Bentley Structural. It deals with the main elements:

- Column
- Beam
- Brace
- Wall
- Slab

The original test model has been created and exported to IFC using:

Table F-1 Test Model Description

Name of application	*Version number*	*Export options*	*Remarks*
Revit Structure	2011	-----	File name: ----.ifc

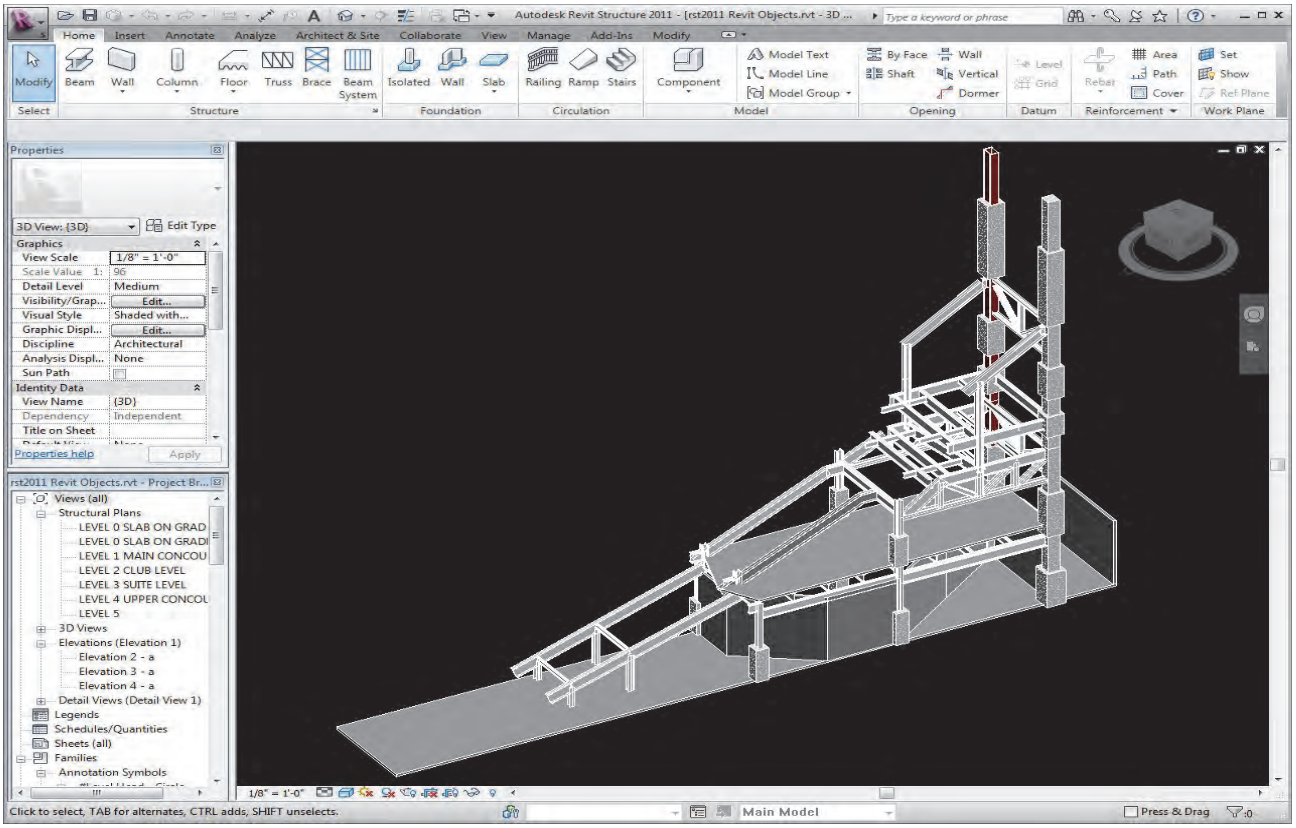


Figure F-1 Perspective view of the test case 1.

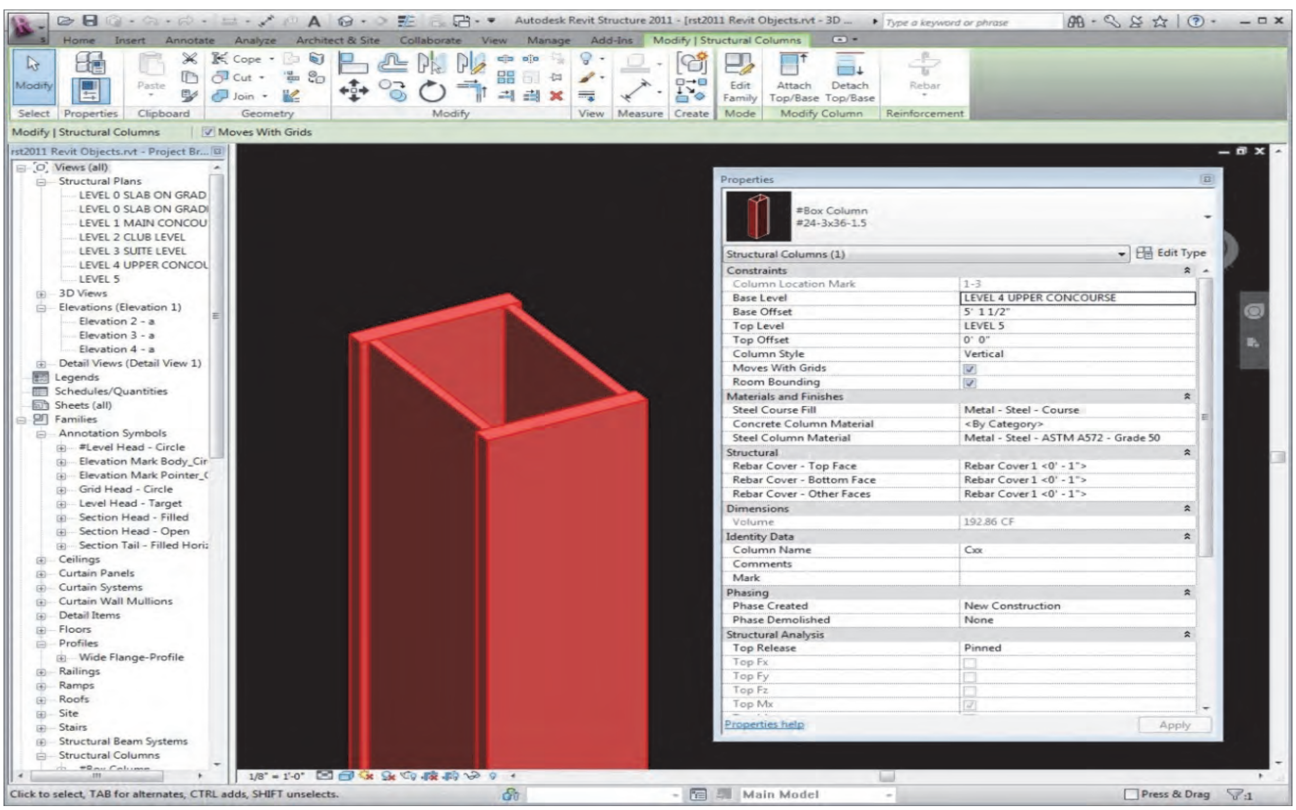


Figure F-2 Detailed view of built-up column with properties.

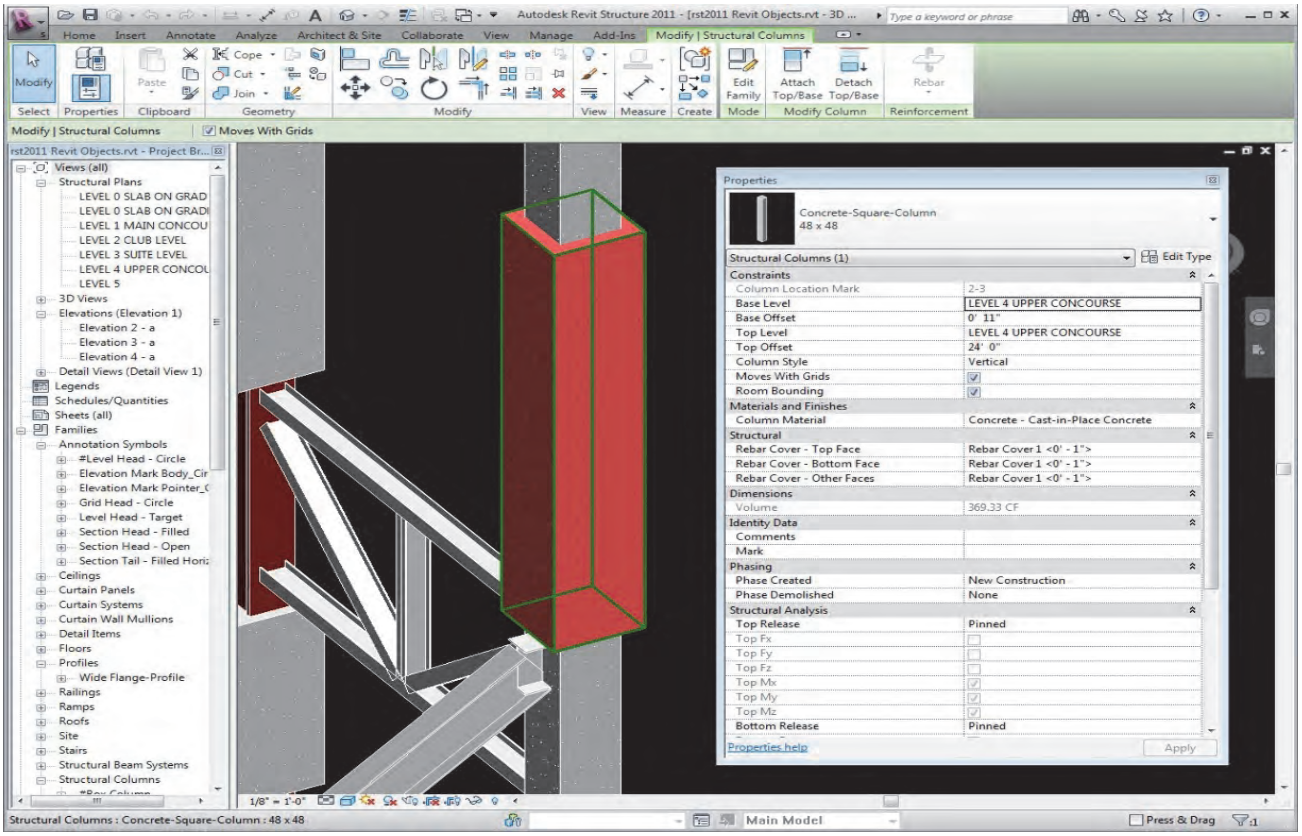


Figure F-3 Detailed view of concrete column with properties.

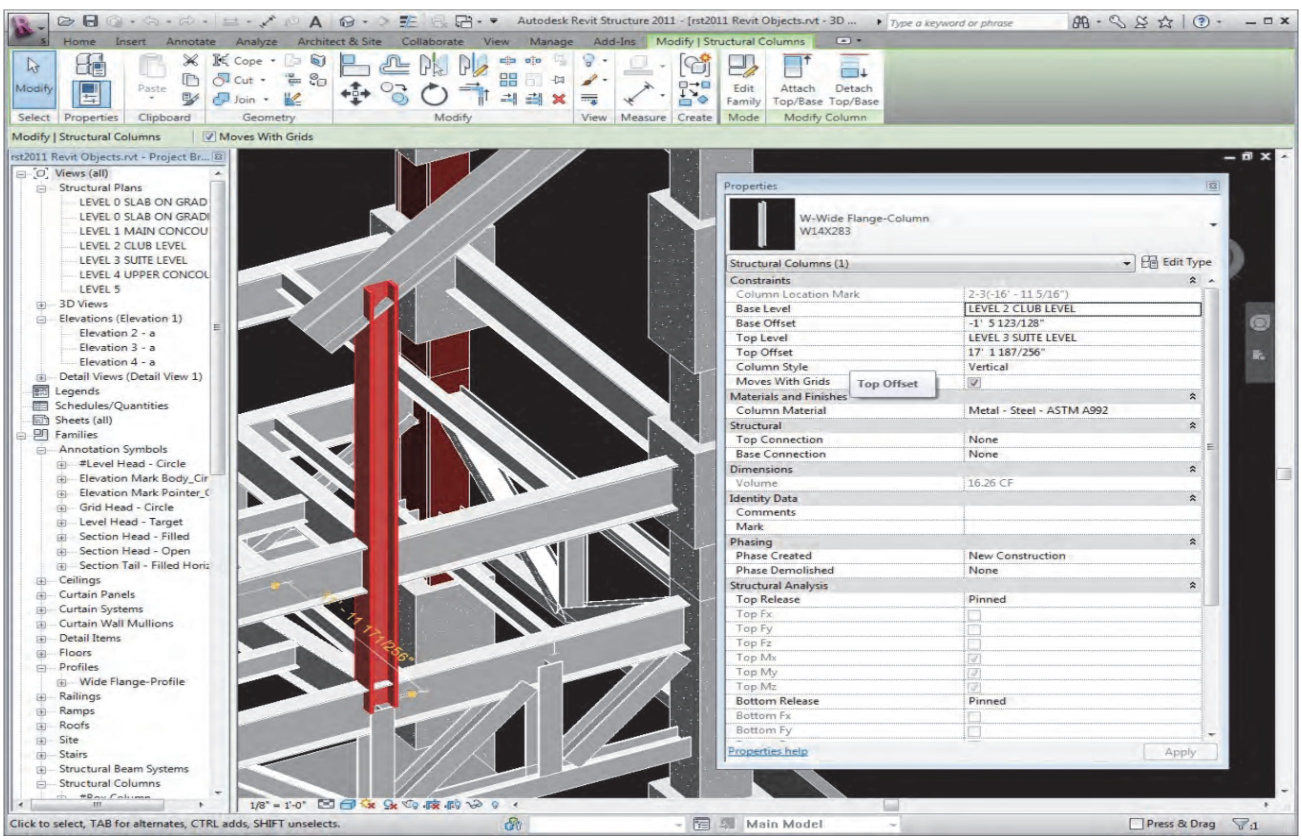


Figure F-4 Detailed view of wide flange column with properties.

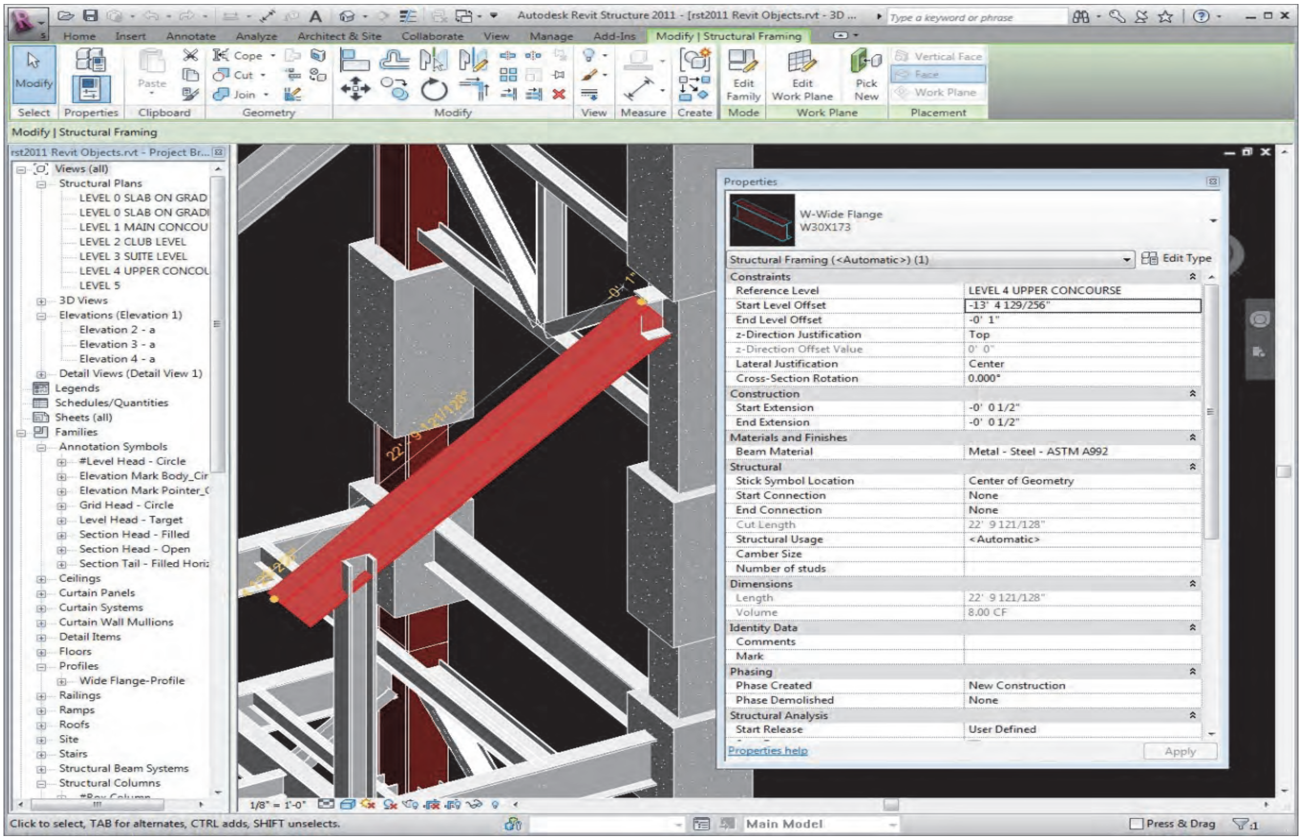


Figure F-5 Detailed view of sloped wide-flange beam with properties.

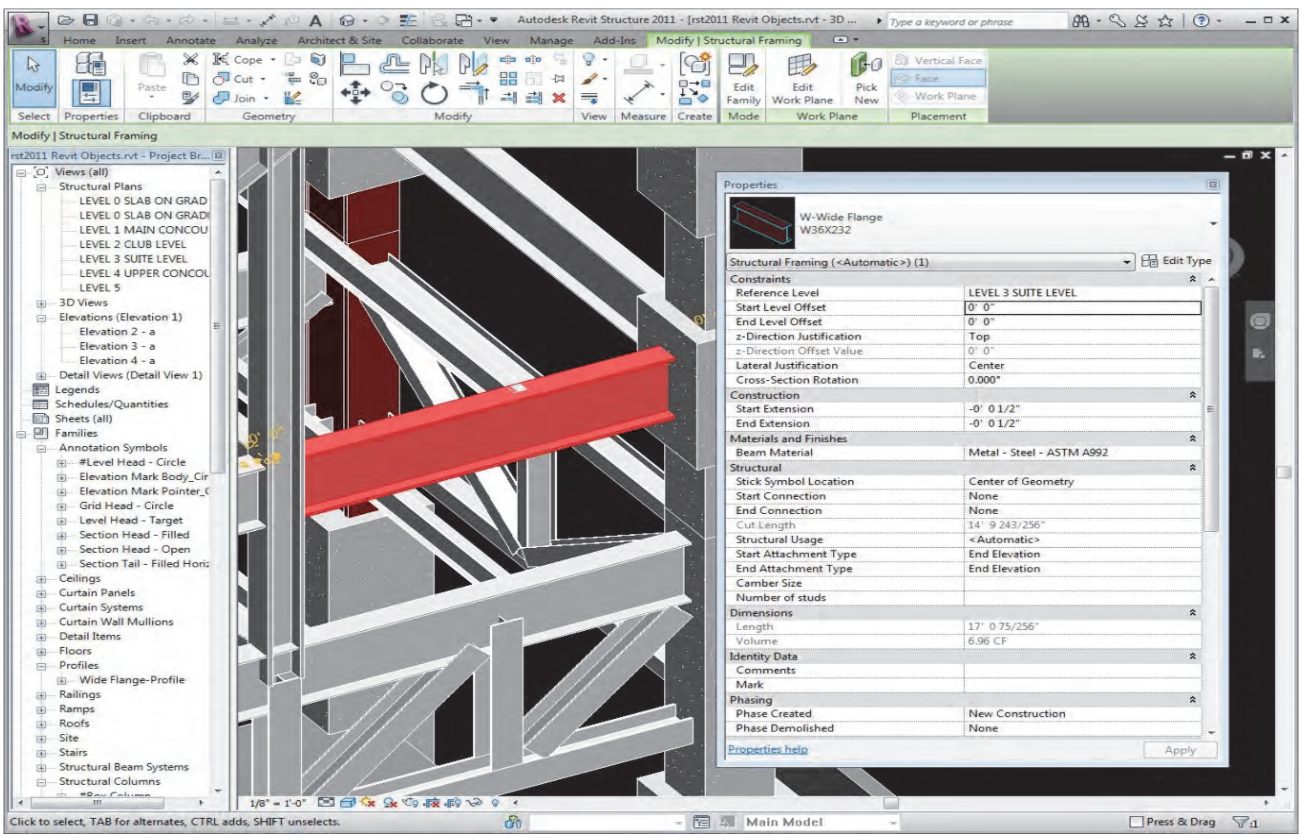


Figure F-6 Detailed view of wide-flange beam with properties.

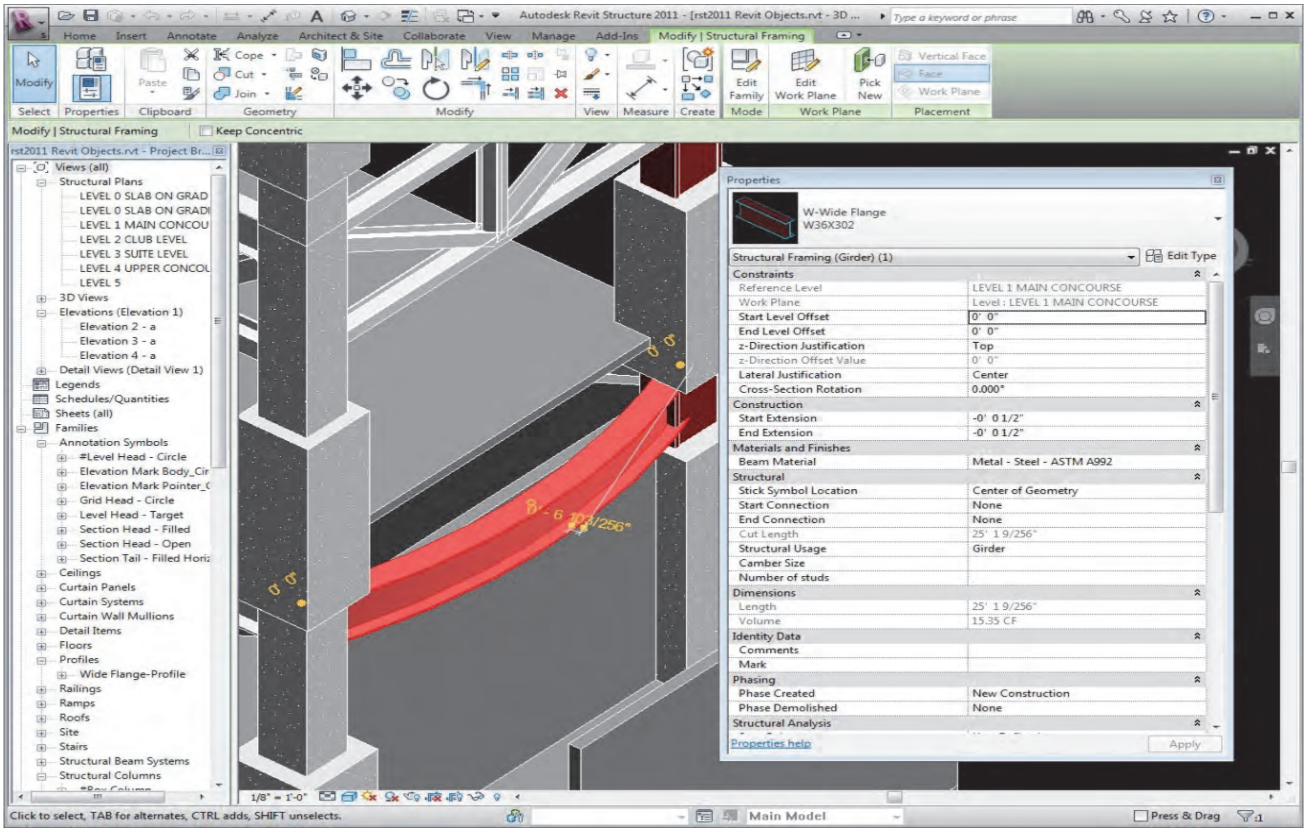


Figure F-7 Detailed view of curved wide-flange beam with properties.

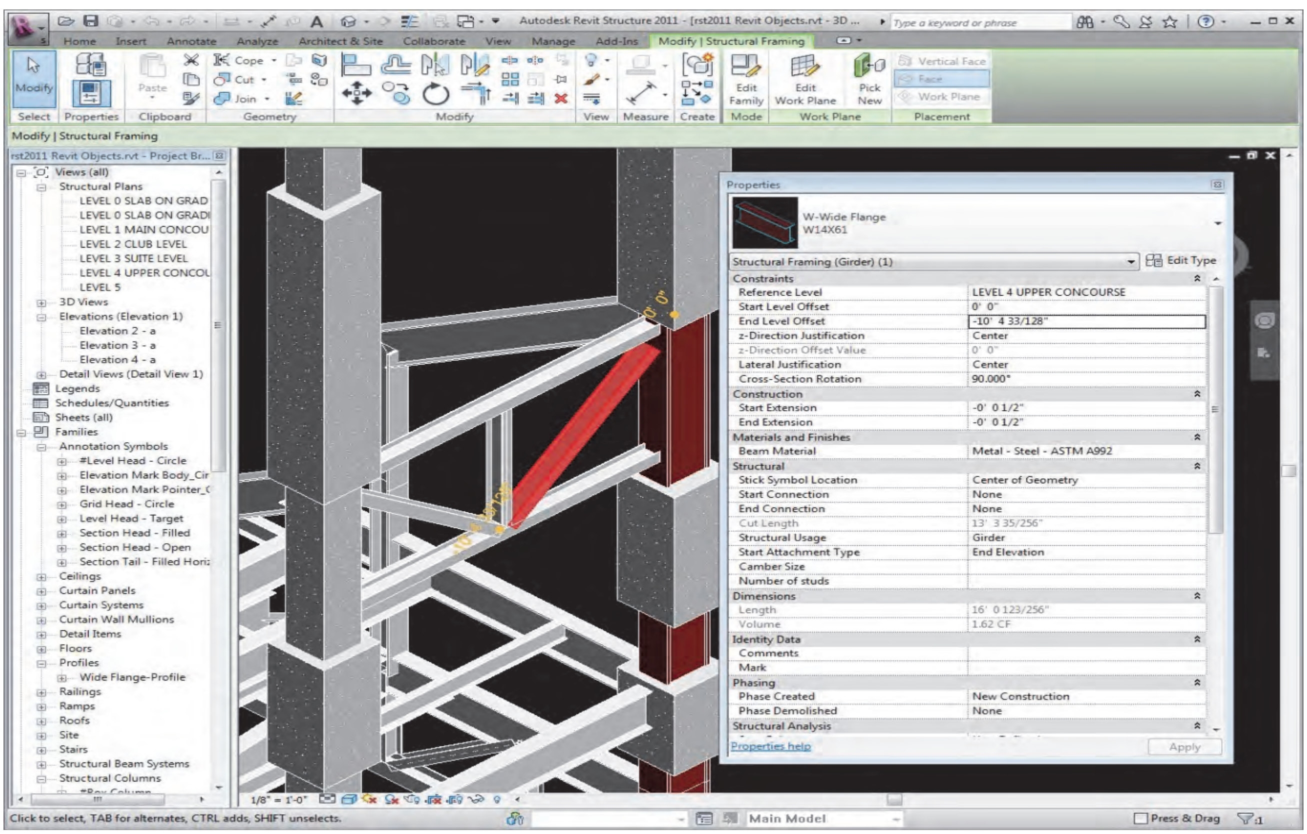


Figure F-8 Detailed view of wide-flange beam with properties.

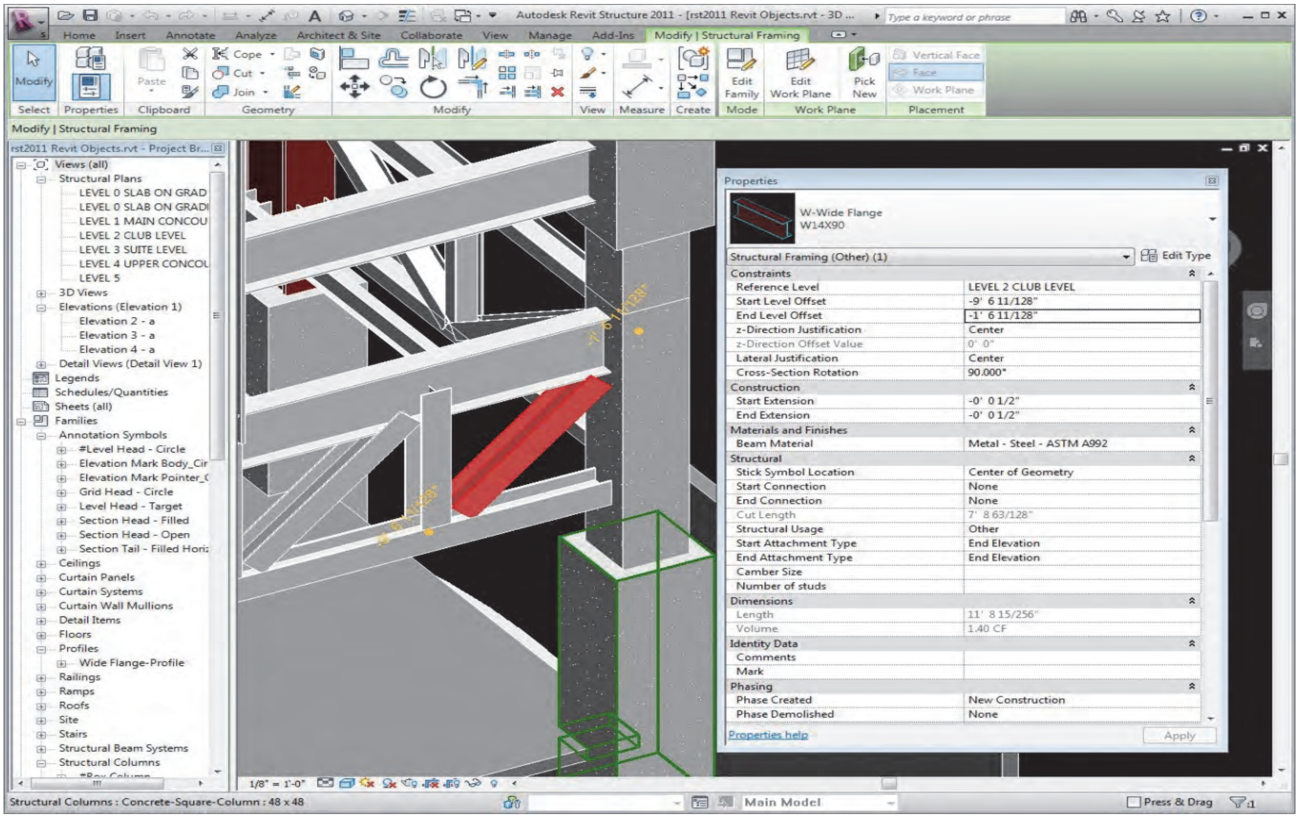


Figure F-9 Detailed view of wide-flange brace with properties.

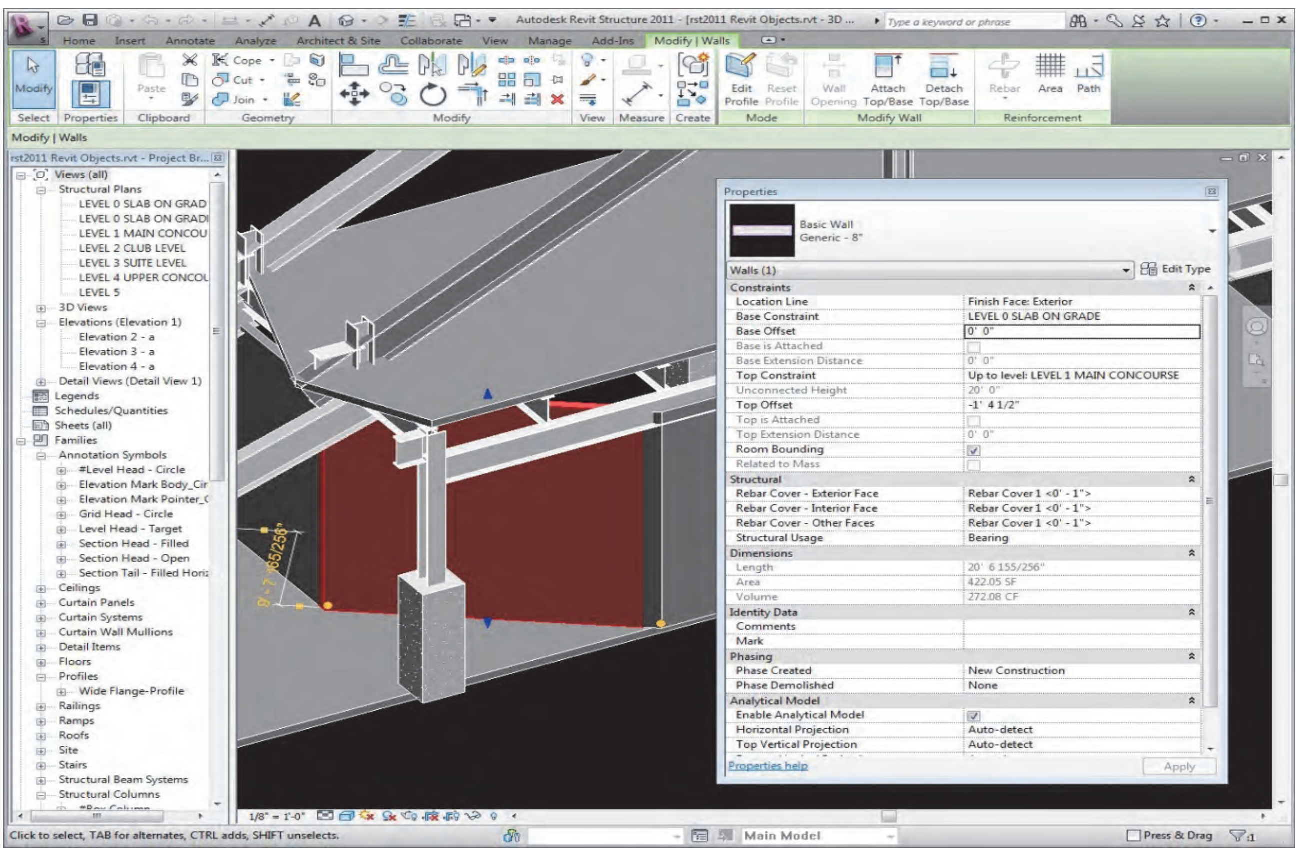


Figure F-10 Detailed view of segmented wall with properties.

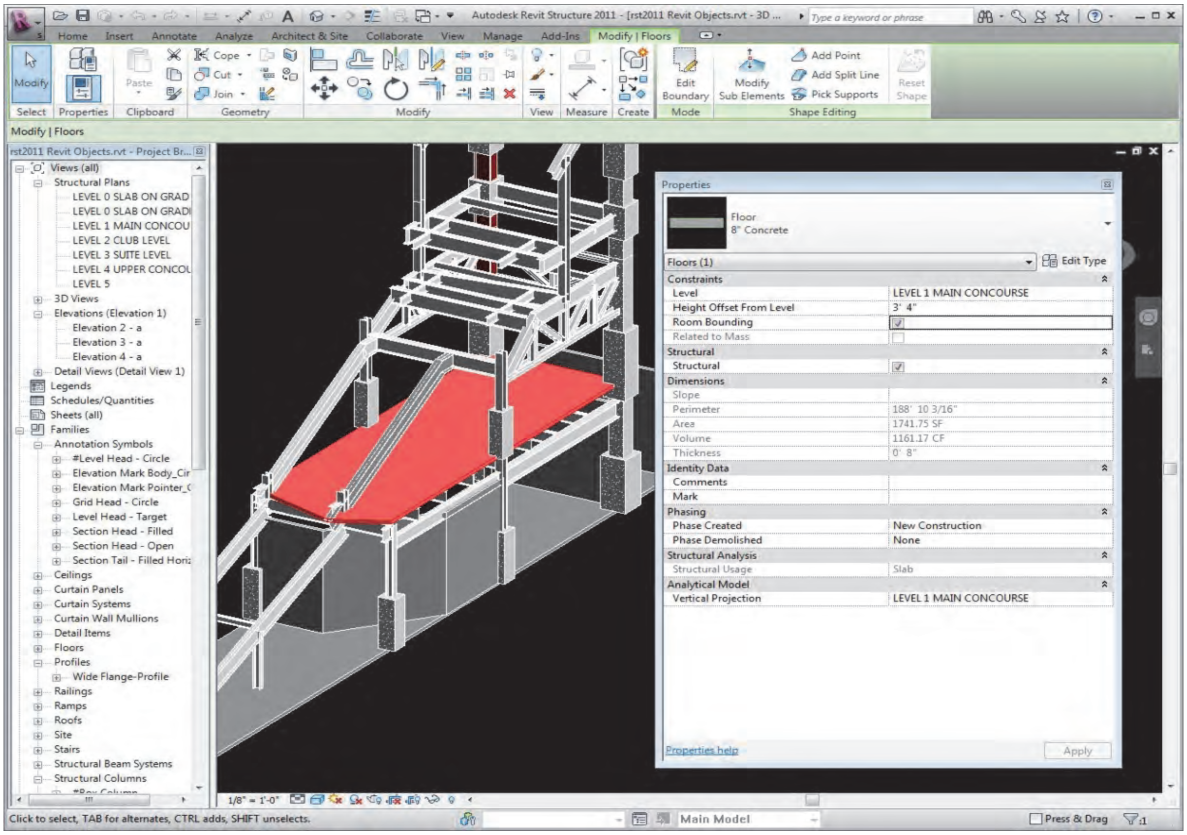


Figure F-11 Detailed view of flat slab with properties.

F.1.2 Description of the Test Model

The content of the test model and the important element and attribute information should be documented here. The testbed should later test that those exchange requirements are correctly exported and imported using the IFC protocol.

F.1.2.1 Building Elements Used

Main element types for the test model are described in the following tables:

Table F-2 Building Elements Used: Beams

Position (Origin X,Y,Z coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1137.87472687965′, 514.363813616994′, 101.791247276092′	W30X173	Steel	A992	22′-9 121/128″	0
1143.33092776664′, 534.727548202184′, 86′	W36X232	Steel	A992	17′-0 75/256″	0
1119.66620758955′, 541.068556271072′, 49.375′	W36X302	Steel	A992	25′-1 9/256″	0

Table F-3 Building Elements Used: Columns

Position (Origin coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1119.66475959055′, 541.069059044248′, 120.291666666667′	#24-3x36-1.5	Steel	A472	34′-6 ½″	75.0046 0013
1143.31631652509′, 534.672627707603′, 116.083333333333′	48 x 48	Concrete	-	23′-1″	345.004 60013
1138.93103674541′, 518.30688976378′, 74.8782552083333′	W14X283	Steel	A992	28' - 3 3/16"	344.843 89063

Table F-4 Building Elements Used: Braces

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1119.68802077375′, 541.062841545343′, 115.166666666667′	W14X61	Steel	A992	16′-0 123/256″	90
1141.13911291472′, 526.547181249016′, 66.8679166338583′	W14X90	Steel	A992	11′-8 15/256″	90

Table F-5 Building Elements Used: Walls

Position (Start/End coordinates)	*Profile*	*Material*	*Height*	*Length*
1129.95373961882′, 483.513544422501′, 28′	Generic 8″	None	21′-4 ½″	20′-6 155/256″

Table F-6 Building Elements Used: Slabs

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*
1103.73974609375′, 473.902069091797′, 52.0416666666667′	8″	Concrete	None

F.1.2.2 Attribute Content

In addition to the proper export/ import of building elements the additional attribute content should be tested. Therefore a minimum of attributes relevant to the design phase should be created.

Table F-7 Building Elements Used

Object Category	*Attribute name*	*Remark*
Column	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Beam	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Brace	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Wall	Thickness	Dimension in the shortest direction (typically horizontal), taken normal to the surface defining wall height; may vary along length
	Material	Timber (stud), concrete, CMU, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)
	Alignment	Location of wall insertion point in relation to its x-sectional centroid (center, left, right, etc.)
Slab	Thickness	Dimension in the shortest direction (typically vertical); may vary along length
	Material	Concrete (typically)
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)

F.2 Export Test of the Test Model

The export test contains various test procedures and criteria that should be performed by the applicant before submitting the test case for validation and approval. It includes the following steps:

- Export the IFC file
- Verify the IFC file for a correct header
- Verify the IFC file within a syntax checker
- Verify the IFC file for basic information, e.g. units, etc.
- Verify the IFC file within a free viewer

F.2.1 Verify the Correct IFC File Header

The IFC header has to contain the basic information about the application that created the exchange file. The IFC header can be accessed by opening the IFC file with a simple text editor.

Table F-8 Content of IFC File Header

Content of the IFC file header	*Check correct information*
100616_ATC75_DP.ifc	
ISO-10303-21; HEADER;	
FILE_DESCRIPTION(('ViewDefinition [CoordinationView]'),'2;1');	
FILE_NAME('100616_ATC75_DP.ifc','2010-06-16T15:11:12',('ikeough'),(''),'ST-	Export date/time correct
DEVELOPER v12','Digital Project','');	Correct IFC Schema
FILE_SCHEMA(('IFC2X3')); ENDSEC;	

F.2.2 Verify within a Syntax Checker

Run the generated IFC file against a syntax checker. Make sure that there are no syntax errors against the IFC schema. If you are uncertain if a certain syntax error is produced erroneously, report the error together with the IFC export file.

Example for a syntax checker is the *IFC Object Counter*.

See http://www.ifcwiki.org/index.php/Free_Software.

Table F-9 Syntax Check

Name of the IFC syntax checker	*Version number,IFC schema version used*	*Results of the syntax check*
IfcObjectCounter V2.9a	IFC2x3	No failures

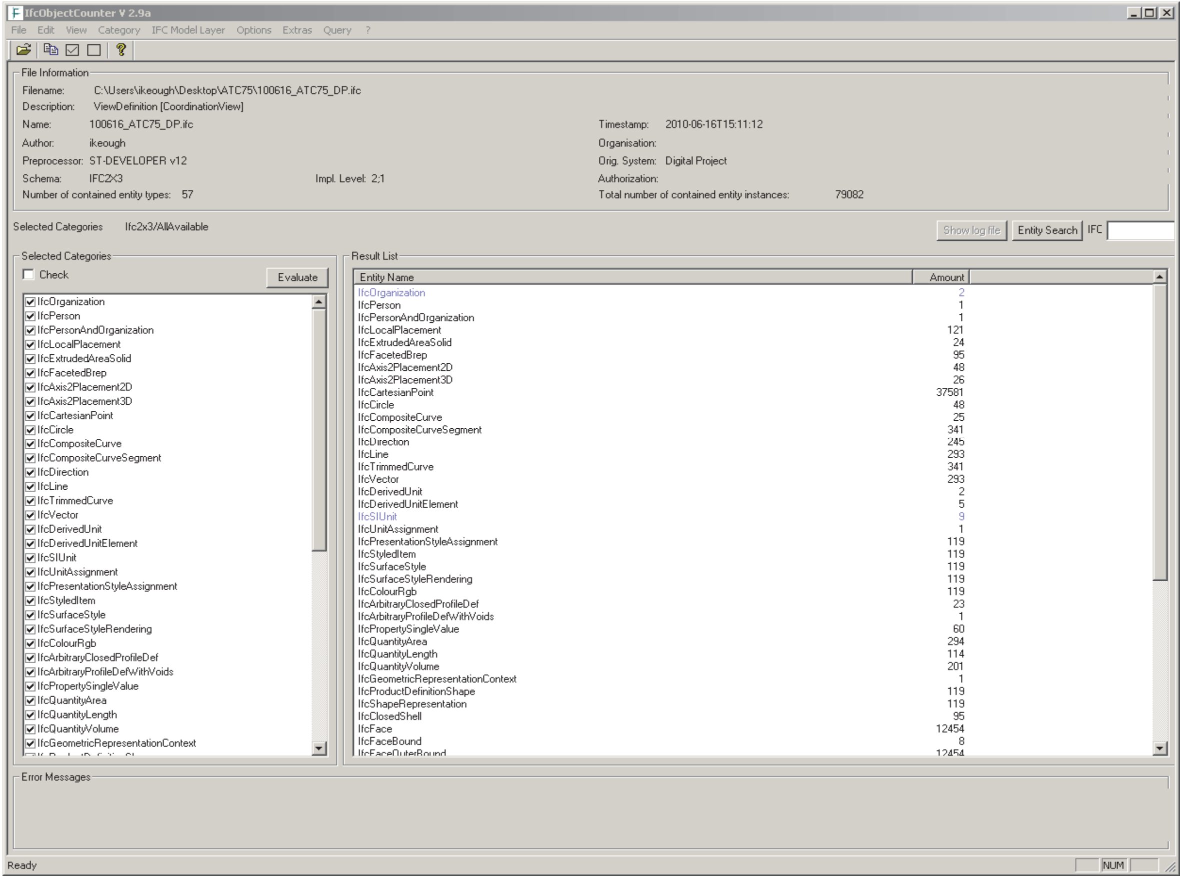


Figure F-12 IFC object check.

F.2.3 Verify within a Viewer

Choose one or several IFC viewers to verify the result. Verify both the geometry of the result, as well as the spatial structure and the attribute content.

Examples for a free viewer are the IFC Storey View, the DDS Viewer or the IFC Engine Viewer.

See http://www.ifcwiki.org/index.php/Free_Software

Table F-10 Test Results Summary for DDS Viewer

IFC viewer used	*DDS viewer Version 6.5*	
Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly	
Beams	Geometry imports correctly	
Brace	Geometry imports correctly	
Wall	Geometry imports correctly	
Slab	Geometry imports correctly	

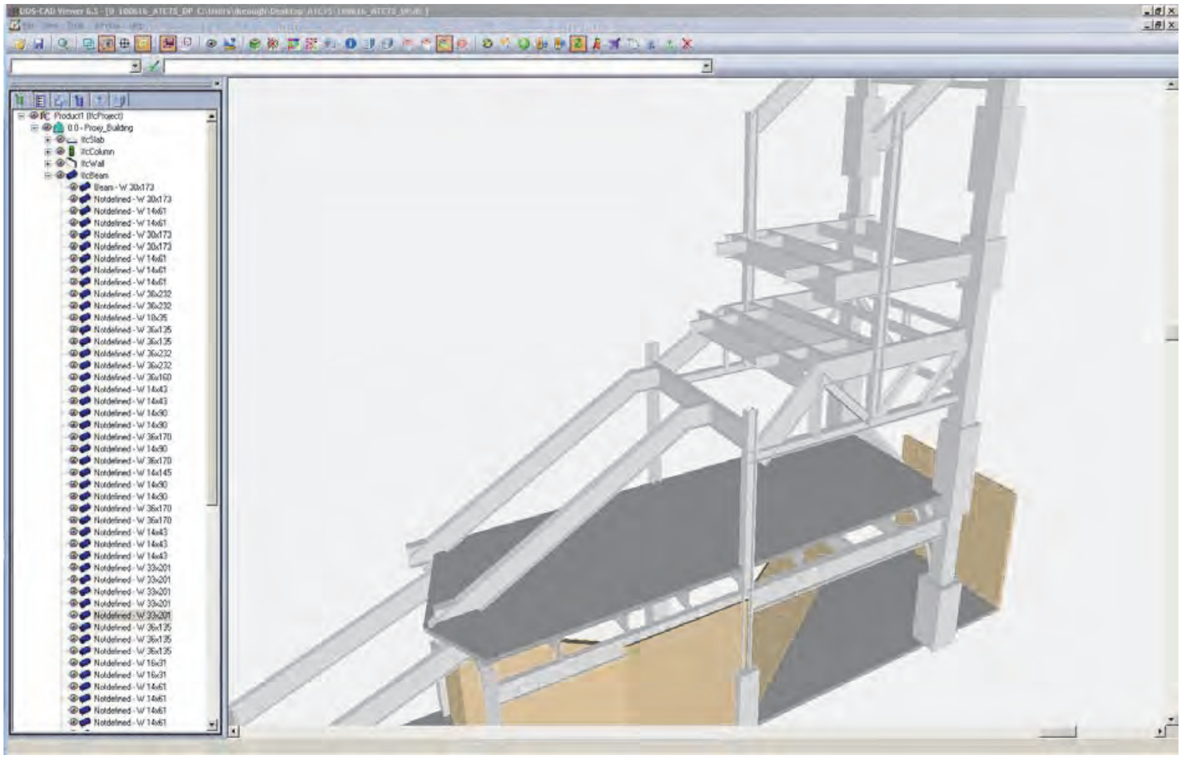


Figure F-13 View of geometry with properties in DDS-CAD Viewer 6.5.

F.3 Import Test of Test Model in Target Application

The export file should be tested in a target application.

- An extended validation tool that includes the rules to check the conformance against the selected IFC view and the agreed implementer agreements for that IFC view.

- A series of import tests by importing the exported test case into other IFC certified applications (or applications that participates in the certification process).

F.3.1 Series of Import Tests

The content of the export file can be tested independently in viewers, the own application and by the validation tool. However in order to make sure, that the exchange with the appropriate target applications actually works, it needs to be checked manually by importing into target applications and by validating the information received by and made available to the target application.

F.3.1.1 Import into AutoCAD Architecture

Table F-11 Import Test Result to AutoCAD Architecture 2008

Version number	*IFC built*	*Remarks*

Table F-12 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns		
Beams		
Brace		
Wall		
Slab		

F.3.1.2 Import into Revit Structure

Table F-13 Import Test Result to Revit Structure 2008

Version number	*IFC built*	*Remarks*
Autodesk Revit Structure 2011	IFC2x3	

Table F-14 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Beams	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Brace	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Wall	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Slab	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.

F.4 Final Test Matrix

Table F-15 Final Test Matrix for Revit Structure 2008

ATC-75

IFC Interoperability Testing
Date: 16-Jul-10

IFC Source File: rst2011 IFC 2x3 export.ifc
IFC 2x3 format from Revit 2011

		DESTINATION									
		CAD / BIM SOFTWARE					STRUCTURAL SOFTWARE				VIEWER
	Software / Version	Bentley Structural	AutoCAD Architecture 2011	Revit Structure 2011	Digital Project	Tekla Structures v. 16.0	Sap 2000 14.2.0	Etabs 9.7.1	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.5
Columns	Geometry	Unavailable for testing	YES	YES (only OOTB families)	Unavailable for testing	NO	NO	NO	Unavailable for testing	Importer unavailable	YES
	Properties		NO	NO		NO	NO	NO			YES
	Sloping		N/A	N/A		N/A	N/A	N/A			N/A
Beams	Geometry		YES	YES		NO	NO	NO			YES
	Properties		NO	NO		NO	NO	NO			YES
	Curved		See Remarks	NO		NO	NO	NO			YES
	Sloping		YES	YES		NO	NO	NO			YES
Braces	Geometry		YES	NO		NO	NO	NO			YES
	Properties		NO	NO		NO	NO	NO			YES
Walls	Geometry		YES	NO		NO	NO	NO			YES
	Properties		NO	NO		NO	NO	NO			YES
	Curved		N/A	N/A		N/A	N/A	N/A			N/A
	Sloping		N/A	N/A		N/A	N/A	N/A			N/A
Slabs	Geometry		YES	YES		NO	NO	NO			YES
	Properties		NO	YES		NO	NO	NO			YES
	Sloping		N/A	N/A		N/A	N/A	N/A			N/A
Remarks			For curved beam, member represents graphically, but lengths are calculated as straight	Error on import (see tab), but import completes.		No import errors. Must import as reference model.	Import of the IFC 2x3 file from Revit hangs in SAP	Import of IFC2X3 file from Revit doesn't work. See tab for screenshots.			Much information in the property

To qualify for a YES the following must be met for each category:
1. Geometry = element location as determined by endpoints must be correct and the element must be displayed accurately in the model view
2. Properties = the element size/profile, material and orientation must all be correct
3. Curved = element radiused in plan (horizontally) - we have noted any difference between this and a straight member
4. Sloping = element inclined at an angle less than 90 degrees vertically

Definitions:
1. Errors = Error messages on import and general model issues (i.e. scaling affecting element properties)

Appendix G

IFC Structural Testbed Validation: Tekla Structures v 16.0

G.1 Testbed Description

The structural testbed is based on a modified original design of a stadium, where one section had been cut-out and additional element types had been added. It should represent a fair portion of elements used in structural modeling.

The testbed comprises:

- A common source model to testing the IFC exchange
- A description of the test model based on the structural modeling elements and attributes used
- A description of test criteria against which the result is validated
- A realization of the same test model in (at least) two structural modeling applications
- A set of IFC export files (from the source applications) with well documented export options
- A set of success/failure descriptions for external neutral test tools
  - In IFC syntax checker,
  - In IFC validation tools,
  - In IFC viewer
- A matrix of success/failure descriptions for import into other software
  - Matrix based on test criteria and importing software
  - Importing software is either:
    - Other BIM tools (architectural/ structural modeling software), or
    - Structural analysis software

G.1.1 Test Model Description

The first test model has been created in Bentley Structural. It deals with the main elements:

- Column
- Beam
- Brace
- Wall
- Slab

The original test model has been created and exported to IFC using:

Table G-1 Test Model Description

Name of application	*Version number*	*Export options*	*Remarks*
Tekla Structures	16.0	-----	File name: ----.ifc

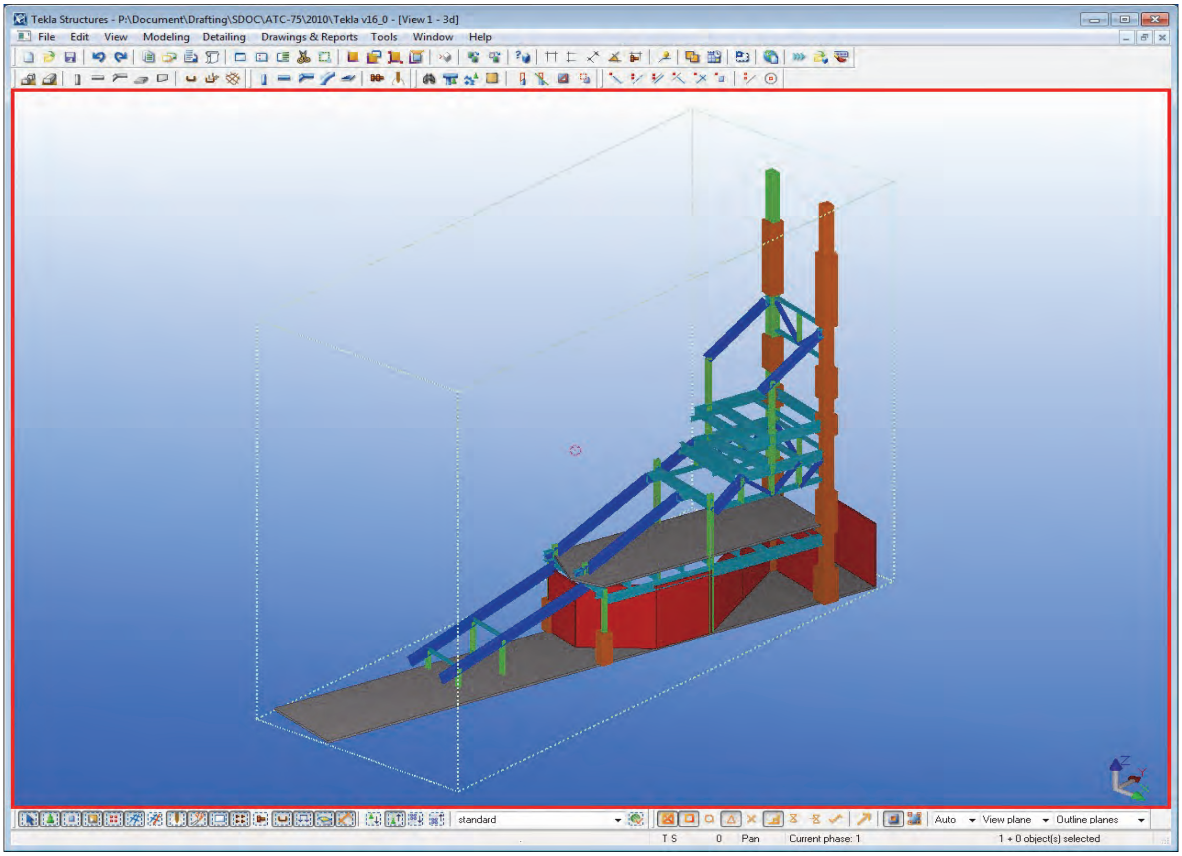


Figure G-1 Perspective view of the test case 1.

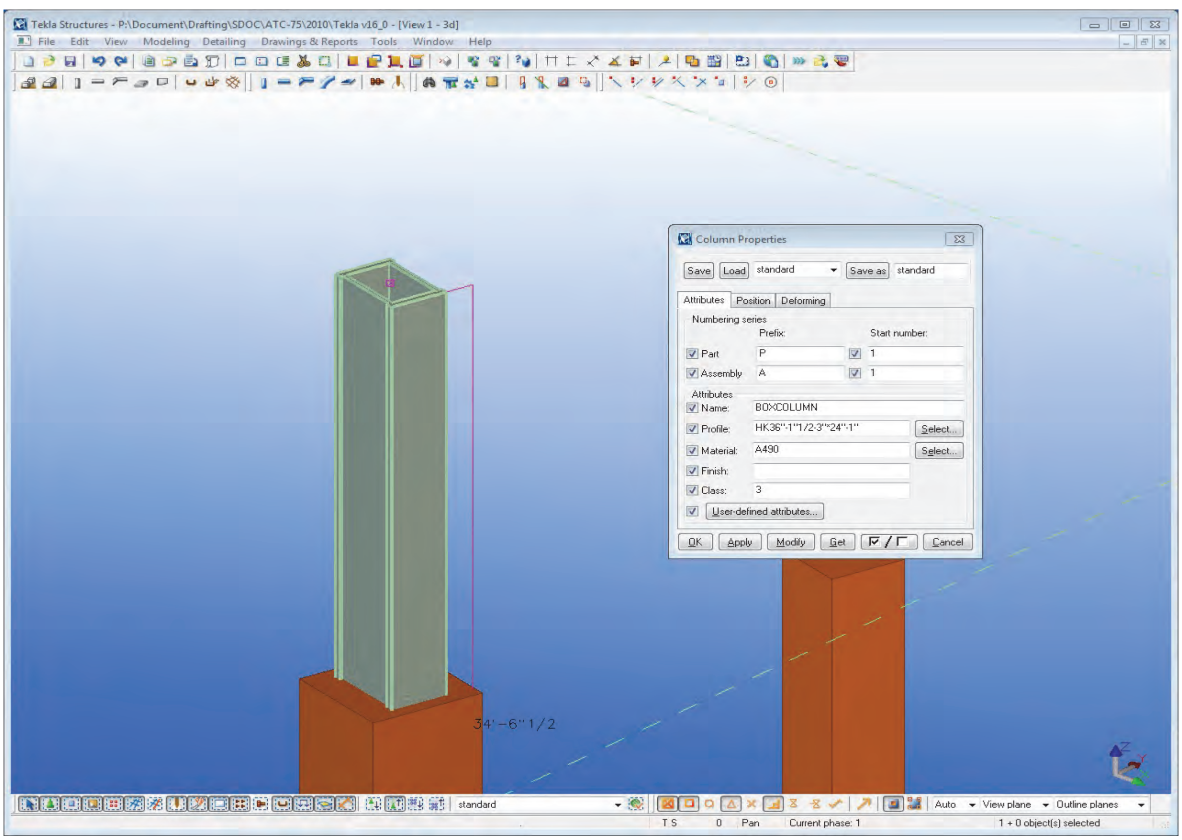


Figure G-2 Detailed view of built-up column with properties.

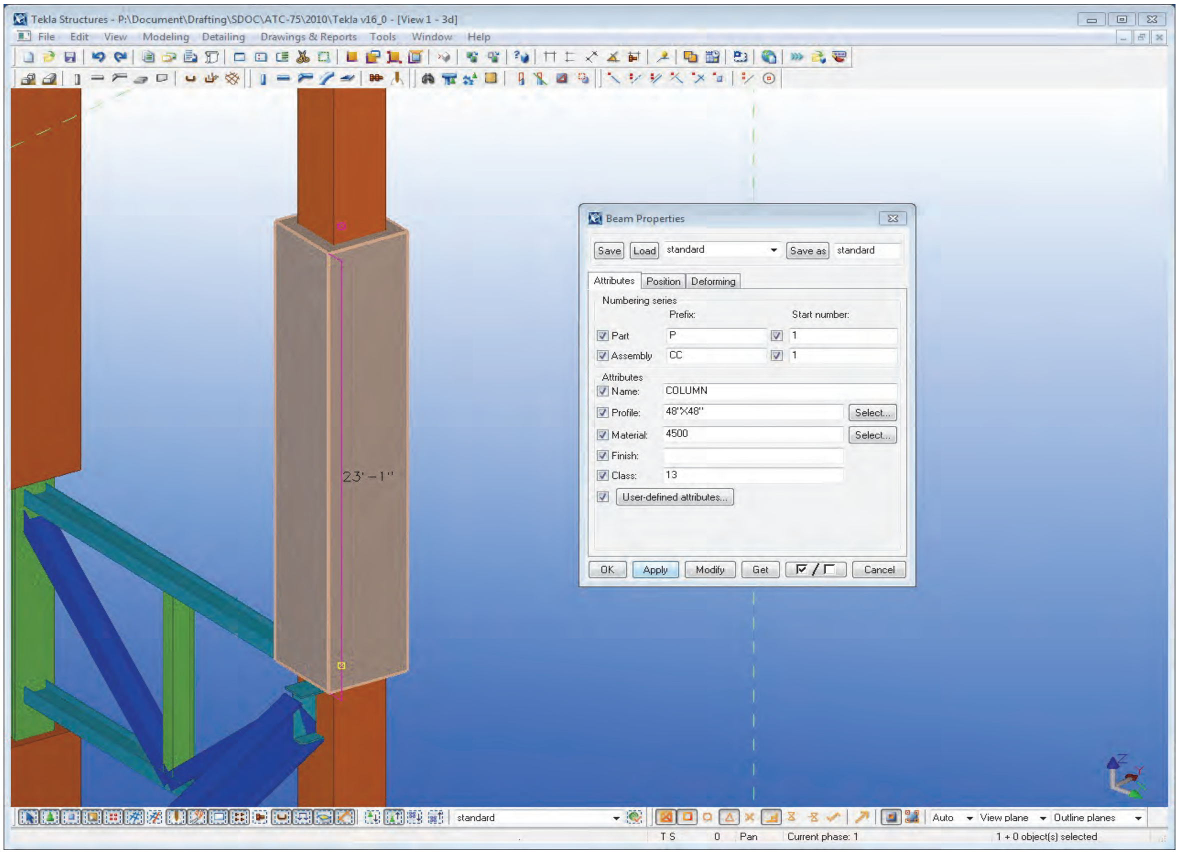


Figure G-3 Detailed view of concrete column with properties.

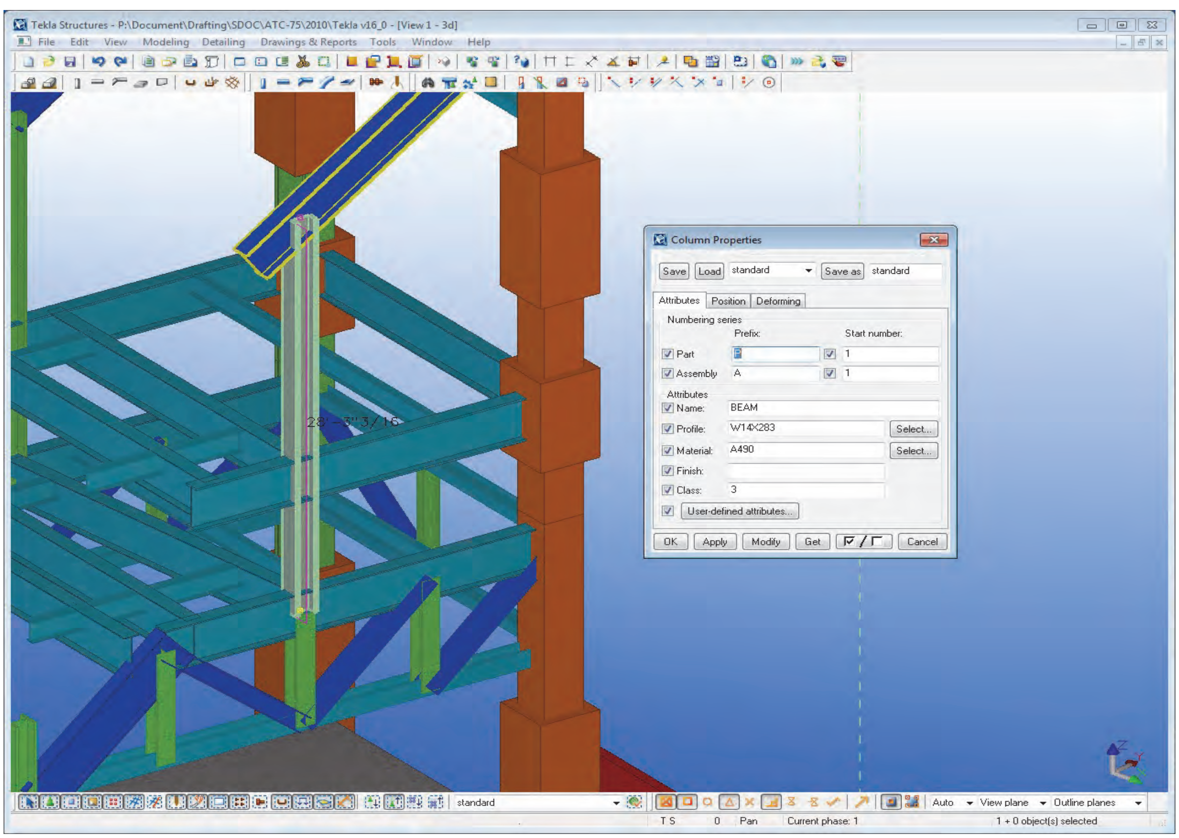


Figure G-4 Detailed view of wide flange column with properties.

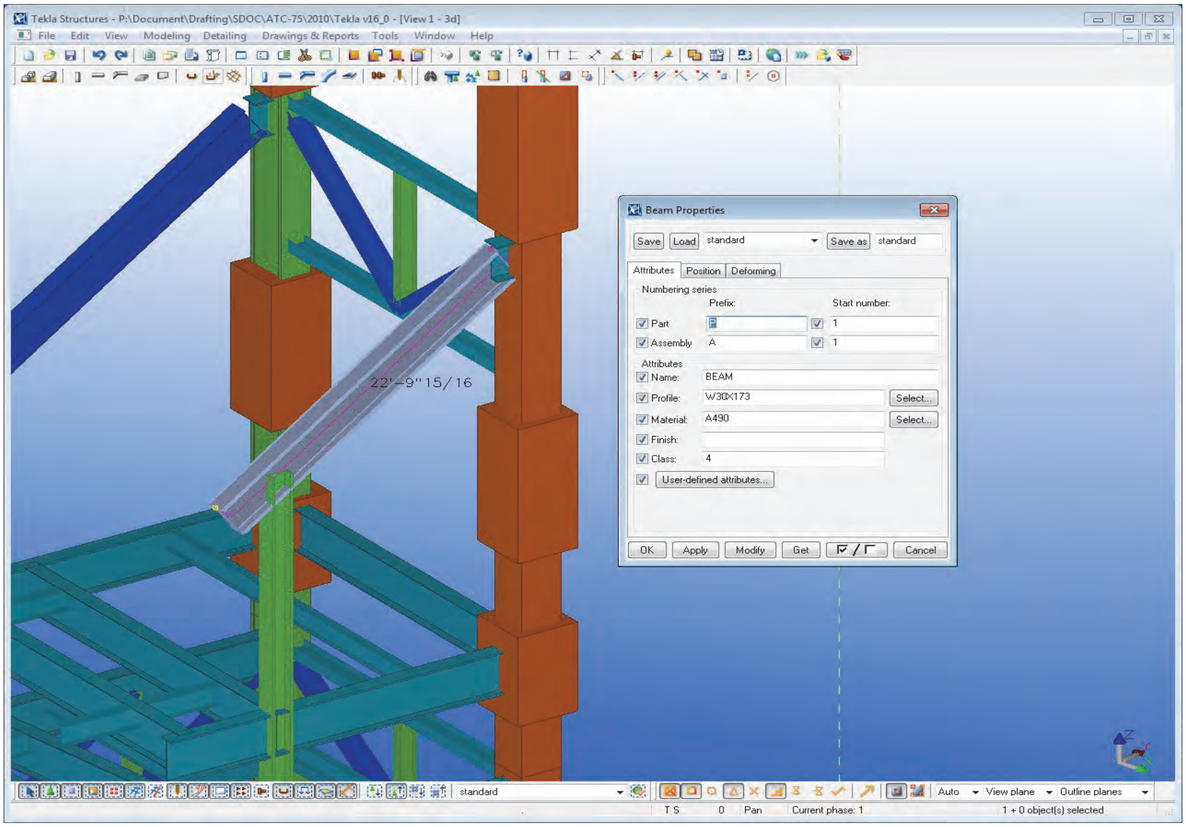


Figure G-5 Detailed view of sloped wide-flange beam with properties.

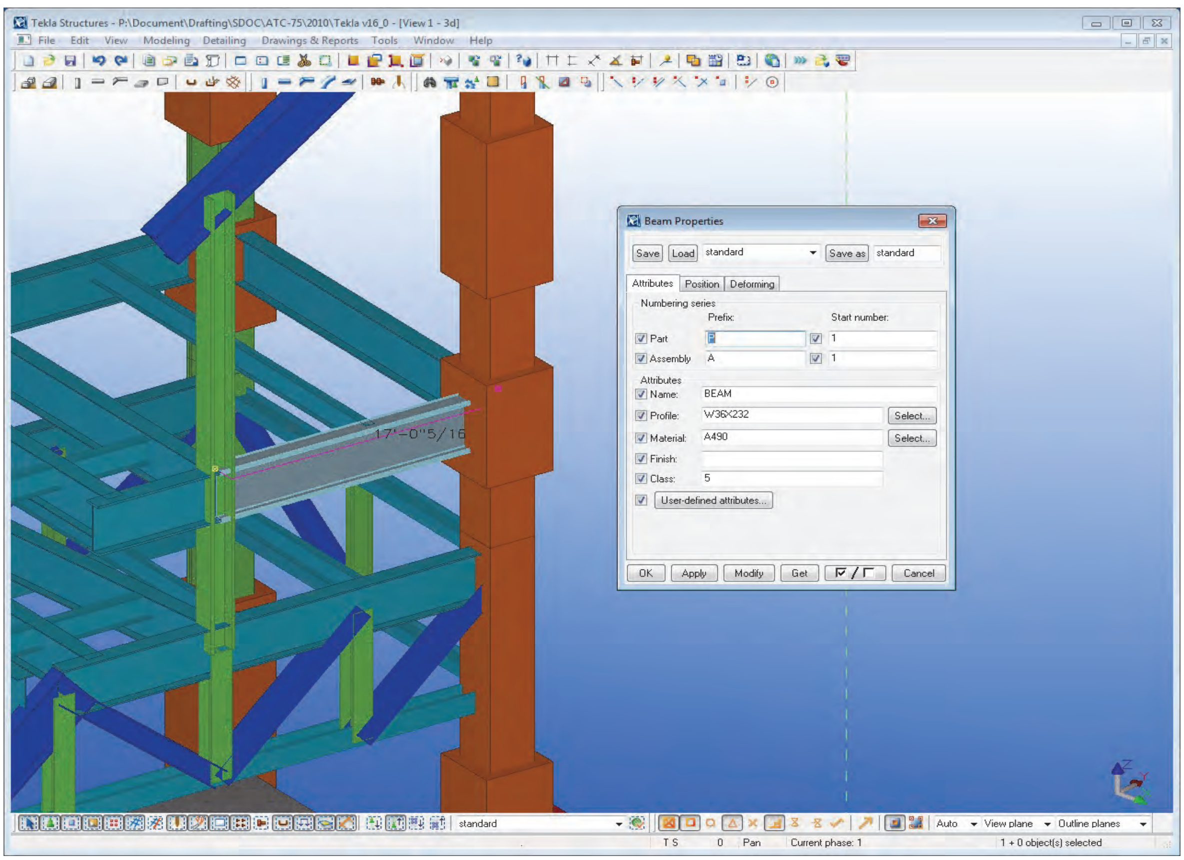


Figure G-6 Detailed view of wide-flange beam with properties.

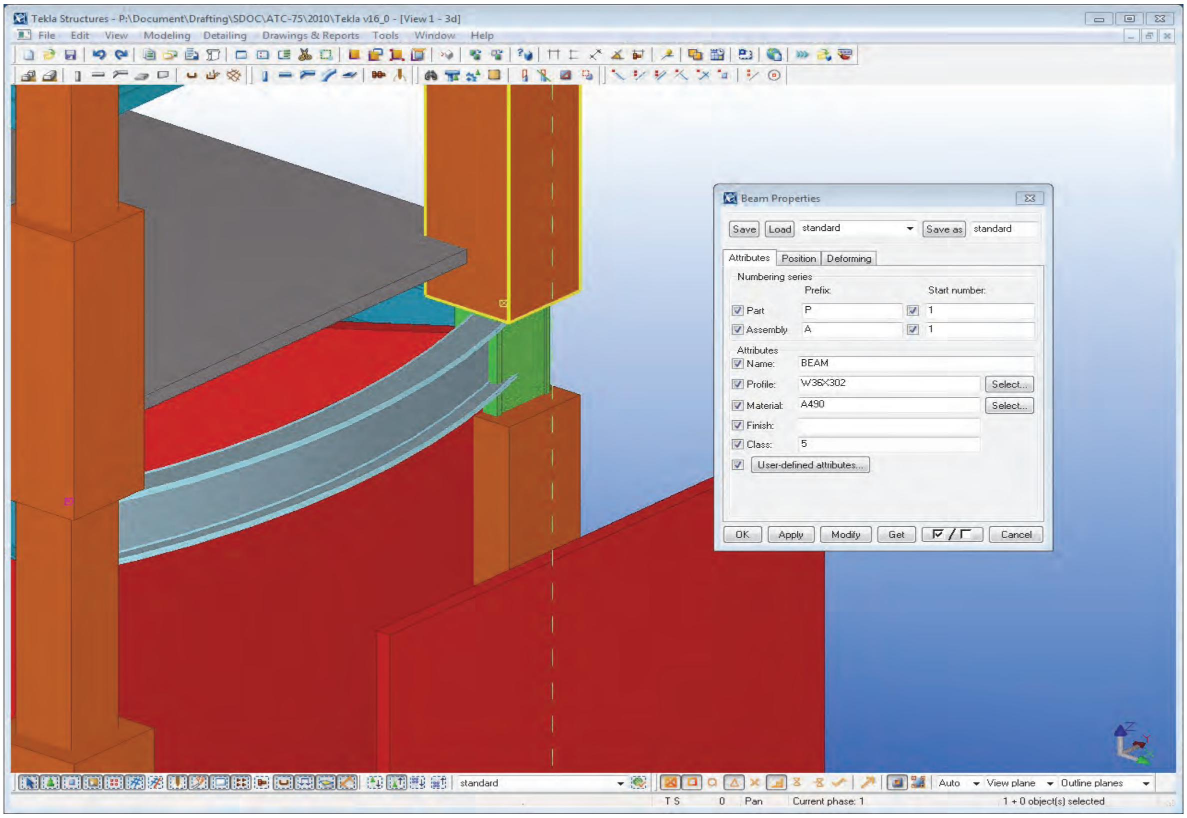


Figure G-7 Detailed view of curved wide-flange beam with properties.

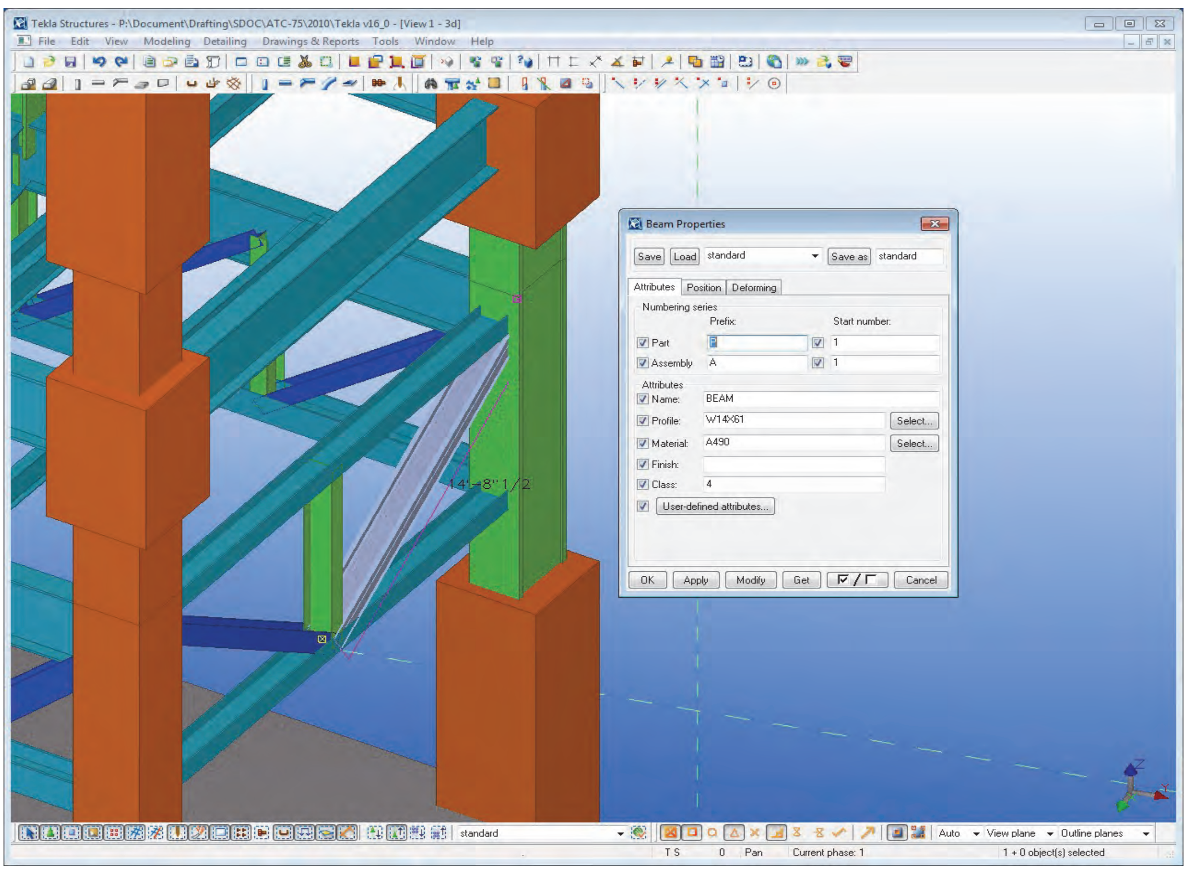


Figure G-8 Detailed view of wide-flange beam with properties.

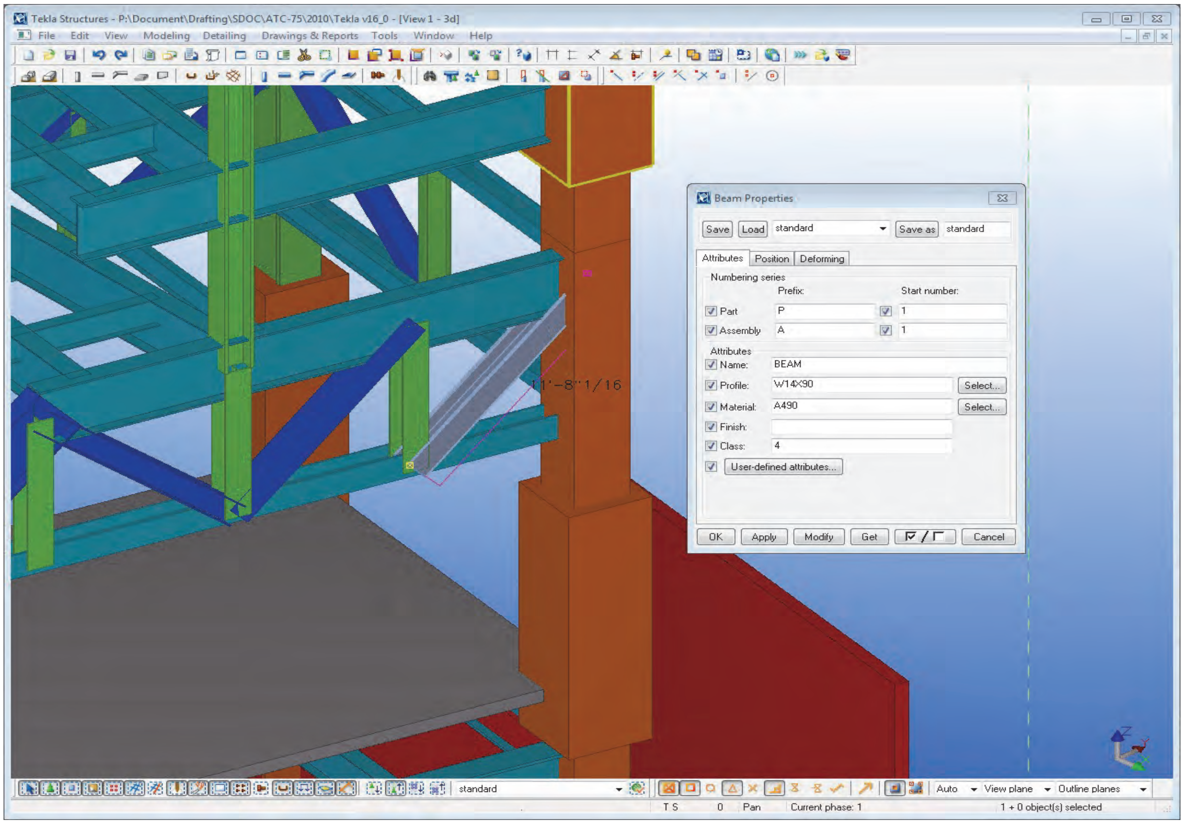


Figure G-9 Detailed view of wide-flange brace with properties.

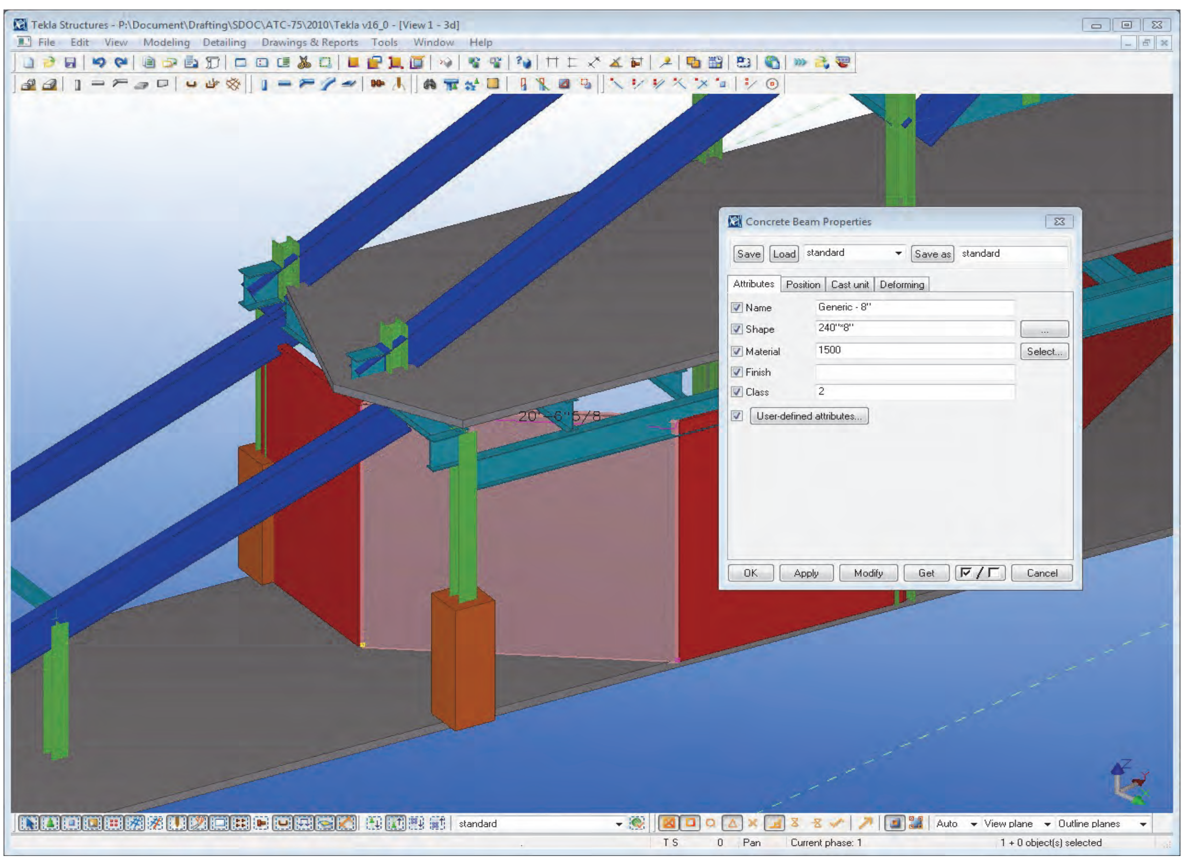


Figure G-10 Detailed view of segmented wall with properties.

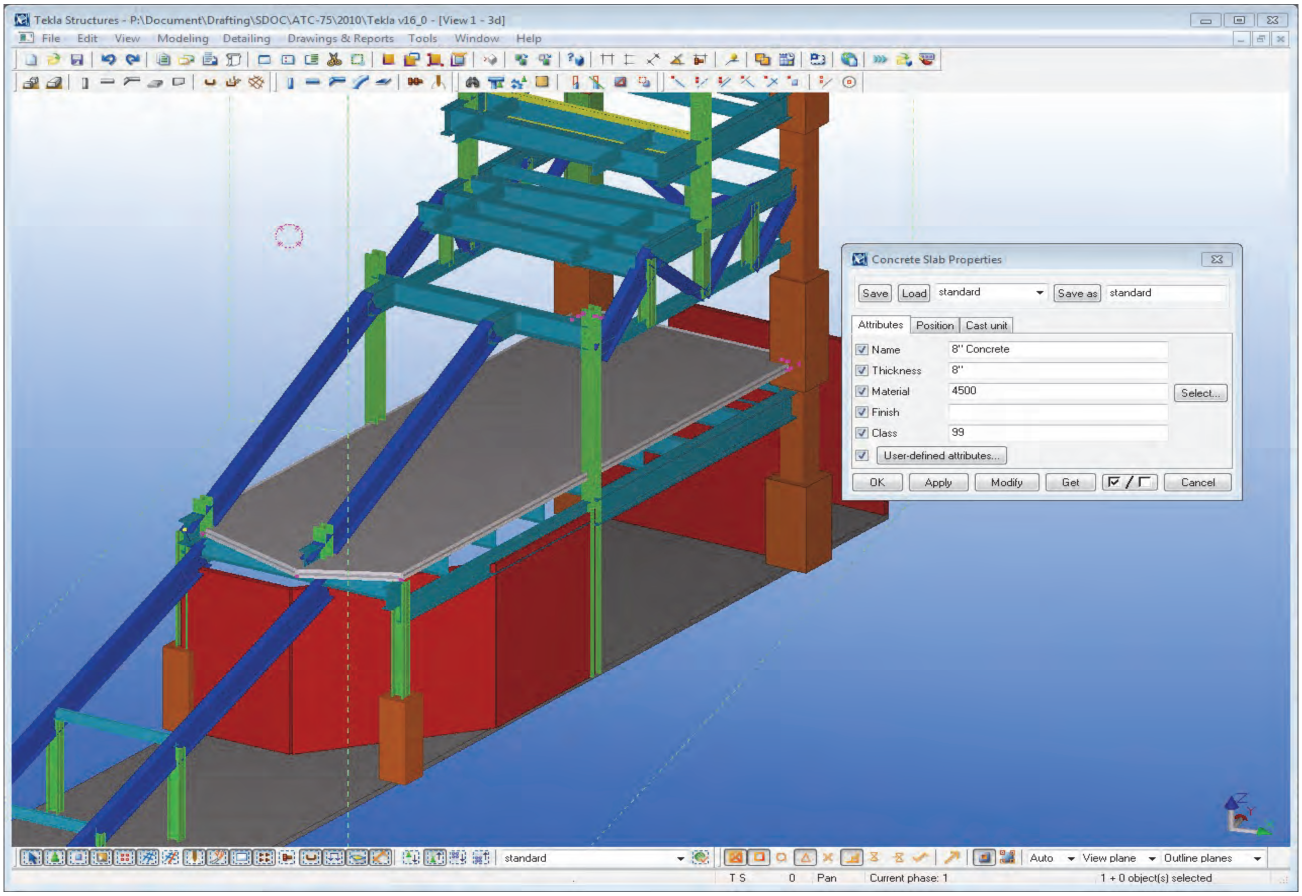


Figure G-11 Detailed view of flat slab with properties.

G.1.2 Description of the Test Model

The content of the test model and the important element and attribute information should be documented here. The testbed should later test that those exchange requirements are correctly exported and imported using the IFC protocol.

G.1.2.1 Building Elements Used

Main element types for the test model are described in the following tables:

Table G-2 Building Elements Used: Beams

Position (Origin X,Y,Z coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1137'-10"1/2, 514'-4"47/128, 101'-9"63/128	W30X173	Steel	A490	22'-9"121/128	0
1138'-11"13/128, 518'-3"51/128, 86'-0"	W36X232	Steel	A490	17'-0"19/64	-0
1119'-8"5/32, 541'-1"63/128, 49'-4"1/2	W36X302	Steel	A490	25'-0"15/32	-0

Table G-3 Building Elements Used: Columns

Position (Origin coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1119'-7"125/128, 541'-0"53/64, 120'-3"1/2	HK36"-1"1/2-3"*24"-1"	Steel	A490	34'-6"1/2	-14.99539
1143'-3"51/64, 534'-8"9/128, 120'-3"1/2	48"X48"	Concrete	4500	23'-1"	-14.99539
1138'-11"11/64, 518'-3"87/128, 74'-10"69/128	W14X283	Steel	A490	28'-3"25/128	-15.15611

Table G-4 Building Elements Used: Braces

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*	*Length*	*Roll*
1131'-6"11/64, 537'-10"3/8, 67'- 6"31/128	W14X61	Steel	A490	14'-8"1/2	90
1141'-1"43/64, 526'-6"9/16, 66'- 10"53/128	W14X90	Steel	A490	11'-8"1/16	90

Table G-5 Building Elements Used: Walls

Position (Start/End coordinates)	*Profile*	*Material*	*Height*	*Length*
1113'-6"11/16, 470'-11"17/64, 28'-0"	Generic - 8"	CMU	20’-0”	20'-6"77/128

Table G-6 Building Elements Used: Slabs

Position (Start/End coordinates)	*Profile*	*Material*	*Grade*
1101'-9"89/128, 474'-5"1/32, 52'-0"1/2	8" Concrete	Concrete	4500

G.1.2.2 Attribute Content

In addition to the proper export/ import of building elements the additional attribute content should be tested. Therefore a minimum of attributes relevant to the design phase should be created.

Table G-7 Building Elements Used

Object Category	*Attribute name*	*Remark*
Column	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Beam	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Brace	Profile	Shape or cross-sectional description
	Material	Steel, concrete, timber, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. A992, 5000psi)
	Length	Distance from start to end point along an elements' path
	Roll	Rotation about an elements' major axis; axial rotation
Wall	Thickness	Dimension in the shortest direction (typically horizontal), taken normal to the surface defining wall height; may vary along length
	Material	Timber (stud), concrete, CMU, etc.
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)
	Alignment	Location of wall insertion point in relation to its x-sectional centroid (center, left, right, etc.)
Slab	Thickness	Dimension in the shortest direction (typically vertical); may vary along length
	Material	Concrete (typically)
	Grade	Designation of alloy type, strength, or other material sub-category (i.e. DFL2, 5000psi)

G.2 Export Test of the Test Model

The export test contains various test procedures and criteria that should be performed by the applicant before submitting the test case for validation and approval. It includes the following steps:

- Export the IFC file
- Verify the IFC file for a correct header
- Verify the IFC file within a syntax checker
- Verify the IFC file for basic information, e.g. units, etc.
- Verify the IFC file within a free viewer

G.2.1 Verify the Correct IFC File Header

The IFC header has to contain the basic information about the application that created the exchange file. The IFC header can be accessed by opening the IFC file with a simple text editor.

Table G-8 Content of IFC File Header

Content of the IFC file header	*Check correct information*
100616_ATC75_DP.ifc ISO-10303-21; HEADER; FILE_DESCRIPTION(('ViewDefinition [CoordinationView]'),'2;1'); FILE_NAME('100616_ATC75_DP.ifc','2010-06-16T15:11:12',('ikeough'),(''),'ST- DEVELOPER v12','Digital Project',''); FILE_SCHEMA(('IFC2X3')); ENDSEC;	Export date/time correct Correct IFC Schema

G.2.2 Verify within a Syntax Checker

Run the generated IFC file against a syntax checker. Make sure that there are no syntax errors against the IFC schema. If you are uncertain if a certain syntax error is produced erroneously, report the error together with the FC export file.

Example for a syntax checker is the *IFC Object Counter*.

See http://www.ifcwiki.org/index.php/Free_Software.

Table G-9 Syntax Check

Name of the IFC syntax checker	*Version number,IFC schema version used*	*Results of the syntax check*
IfcObjectCounter V2.9a	IFC2x3	No failures

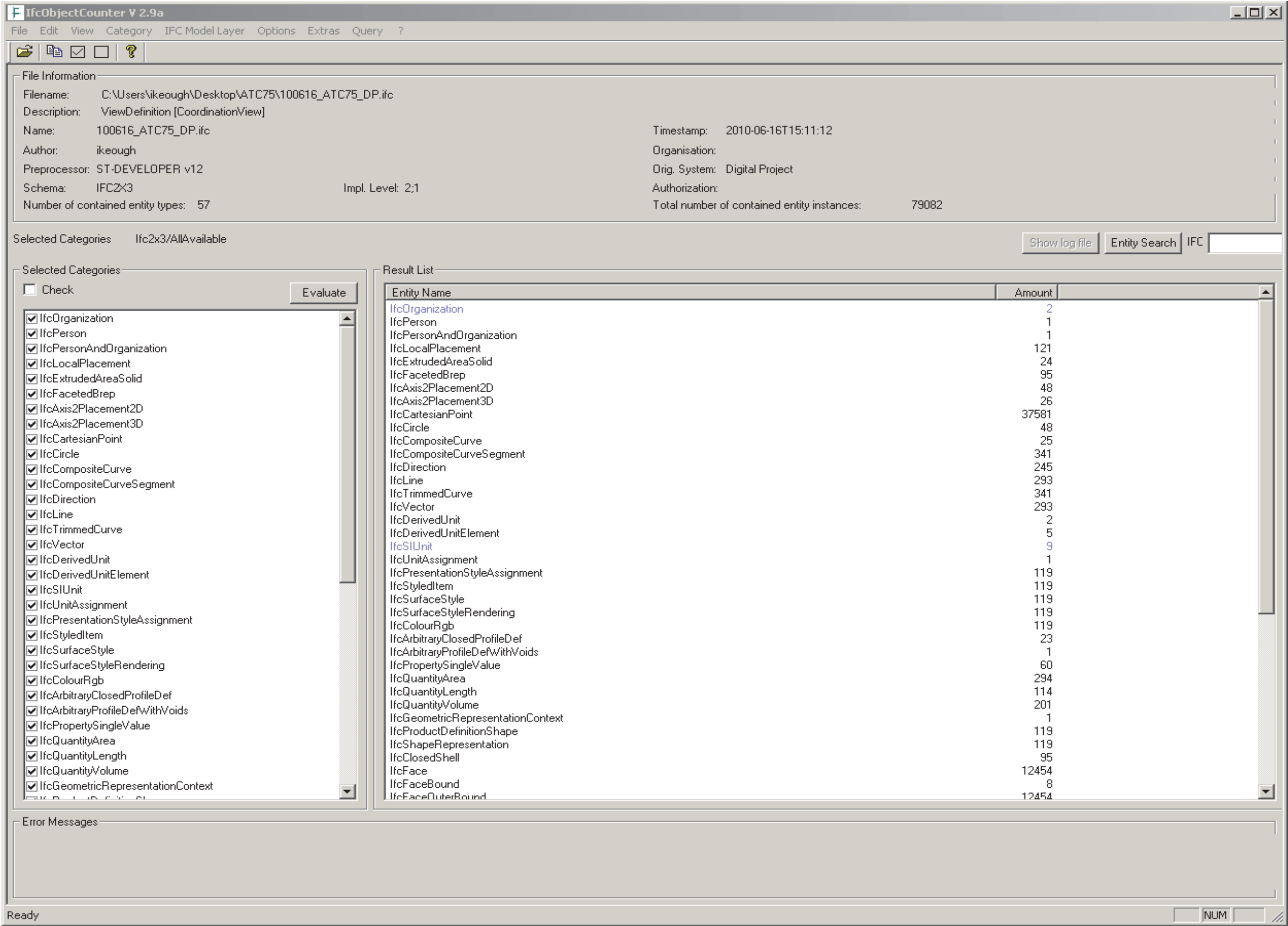


Figure G-12 IFC object check.

G.2.3 Verify within a Viewer

Choose one or several IFC viewers to verify the result. Verify both the geometry of the result, as well as the spatial structure and the attribute content.

Examples for a free viewer are the IFC Storey View, the DDS Viewer or the IFC Engine Viewer.

See http://www.ifcwiki.org/index.php/Free_Software

Table G-10 Test Results Summary for DDS Viewer

IFC viewer used	*DDS viewer Version 6.5*	
Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly	
Beams	Geometry imports correctly	
Brace	Geometry imports correctly	
Wall	Geometry imports correctly	
Slab	Geometry imports correctly	

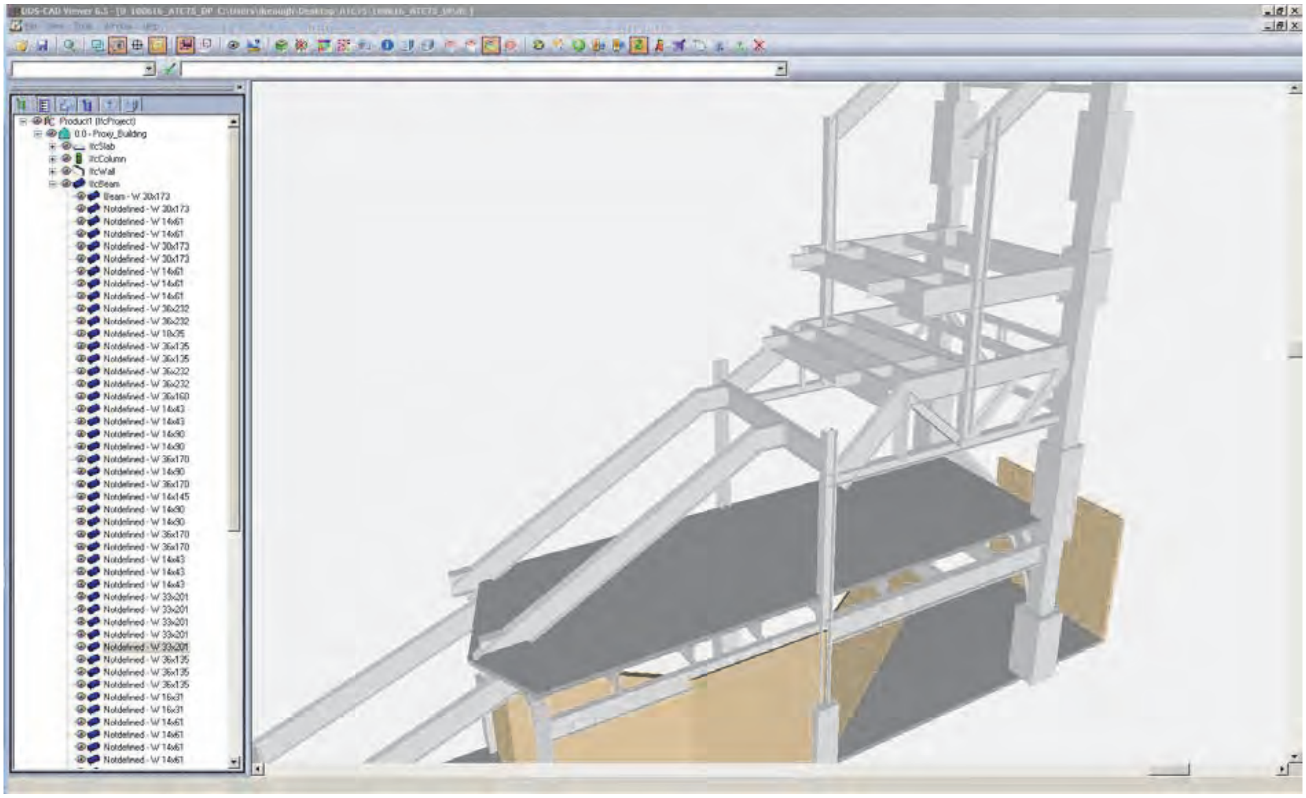


Figure G-13 View of geometry with properties in DDS-CAD Viewer 6.5.

G.3 Import Test of Test Model in Target Application

The export file should be tested in a target application.

- An extended validation tool that includes the rules to check the conformance against the selected IFC view and the agreed implementer agreements for that IFC view.

- A series of import tests by importing the exported test case into other IFC certified applications (or applications that participates in the certification process).

G.3.1 Series of Import Tests

The content of the export file can be tested independently in viewers, the own application and by the validation tool. However in order to make sure, that the exchange with the appropriate target applications actually works, it needs to be checked manually by importing into target applications and by validating the information received by and made available to the target application.

G.3.1.1 Import into AutoCAD Architecture

Table G-11 Import Test Result to AutoCAD Architecture 2008

Version number	*IFC built*	*Remarks*

Table G-12 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns		
Beams		
Brace		
Wall		
Slab		

G.3.1.2 Import into Revit Structure

Table G-13 Import Test Result to Revit Structure 2008

Version number	*IFC built*	*Remarks*
Autodesk Revit Structure 2011	IFC2x3	

Table G-14 Import Test Results Summary in AutoCAD Architecture 2008

Check performed	*Checking results*	*Remarks*
Columns	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Beams	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Brace	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Wall	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.
Slab	Geometry imports correctly.	All elements imported as architectural types with no properties except IFC guid.

G.4 Final Test Matrix

Table G-15 Final Test Matrix for Tekla Structures v.16.0

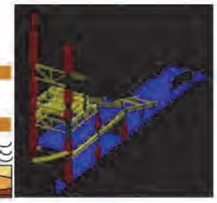
ATC-75

IFC Interoperability Testing

Date: 16-Jul-10

IFC Source File: Tekla v16_0 IFC 2x3 export.ifc

IFC 2x3 format from I Tekla Structures v16



	Software / Version	Bentley Structural	AutoCAD Architecture 2011	Revit Structure 2011	Digital Project	Tekla Structures v. 16.0	Sap 2000 14.2.0	Etabs 9.7.1	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.5
	DESTINATION	CAD / BIM SOFTWARE					STRUCTURAL SOFTWARE				VIEWER
Columns	Geometry	Unavailable for testing	YES	YES	Unavailable for testing	YES	NO		Unavailable for testing	Importer unavailable	YES
	Properties		YES	NO		NO	NO				NO
	Sloping		N/A	N/A		N/A	N/A				N/A
Beams	Geometry		YES	YES		YES	NO				YES
	Properties		YES	NO		YES	NO				YES
	Curved		NO	NO		NO	NO				NO
	Sloping		YES	YES		YES	NO				N/A
Braces	Geometry		YES	YES		YES	NO				YES
	Properties		YES	NO		YES	NO				YES
Walls	Geometry		YES	YES		YES	NO				YES
	Properties		NO	NO		NO	NO				NO
	Curved		N/A	N/A		N/A	N/A				N/A
	Sloping		N/A	N/A		N/A	N/A				N/A
Slabs	Geometry		YES	YES		YES	NO				YES
	Properties		YES	YES		YES	NO				YES
	Sloping		N/A	N/A			N/A				N/A
Remarks				Error on import (see tab), but import completes.		No import errors. Must import as reference model.	Import of the IFC 2x3 file from Revit hangs in SAP (and in fact deletes the file!).	Import of IFC2X3 file from Revit doesn't work. See tab for screenshots.			Walls classified as IFCBeam (typical all destinations)

To qualify for a YES the following must be met for each category:

1. Geometry = element location as determined by endpoints must be correct and the element must be displayed accurately in the model view.
2. Properties = the element size/profile, material and orientation must all be correct
3. Curved = element radiused in plan (horizontally) - we have noted any difference between this and a straight member.
4. Sloping = element inclined at an angle less than 90 degrees vertically

Definitions:

1. Errors = Error messages on import and general model issues (i.e. scaling affecting element properties)

Glossary

2D. Two dimensional, planar view of portion of building or other element, 2D drawing.

3D. Three dimensional, 3D geometrical model. Requires computer to view.

4D. Four dimensional, typically 3D plus time or cost.

Architect. Prime design consultant who designs the building shape and size, the exterior elevations and features, the occupancy and use, number of floors and each floor layout, the building finish materials and colors, and the design of interior and exterior walls and glazing portions (or windows). The architect identifies the building program usage, the size, and layout of all interior spaces and rooms and the circulation between all portions of the building. The architect also evaluates building site issues, building functions, fire resistance systems and Americans with Disabilities Act (ADA) compliance. The architect and consultants often become involved in many other aspects, such as sustainability. The architect is usually the lead for the structural, civil and Mechanical, Electrical, and Plumbing Equipment (MEP) engineers, and potentially other consultants.

Attributes. Information attached to objects in a BIM model, same as meta-data or properties.

Bench Mark Testing. A process of testing the IFC exchange and interoperability of BIM model elements, geometry and properties from one software product to other software products. The accuracy of the information exchanges are reviewed and documented.

BIM. Building information model, a 3D representation of a building or other structure or system based on objects that contain properties and information. Often BIM models are separated into architectural models, structural models and MEP models (or other disciplines). At times, these models could be combined as one BIM model. Alternatively, models based on discipline (architecture, structure, and MEP) can be separate models and periodically combined together to determine the appropriateness of the fit.

CAD. Computer Aided Drafting, traditional approach to 2D computer documentation of building designs.

Construction Documents. The architect develops an architectural design that is communicated to a contractor using construction documents. Construction documents include drawings and specifications for all disciplines including structural, civil, MEP and potentially other consultants. Drawings are often developed using a BIM software product by developing a model and then developing 2D drawings and details from the model, all within one BIM file. Construction documents include 2D drawings (plans, elevations, sections, and details), and material specifications. Contract documents include contract language between an owner and a contractor that identify the general conditions and requirements of the contract. The contractor can bid a contract price or in some cases, may negotiate a price based on owner requirements. Contract documents may include a BIM model for contractor understanding and aid in the construction process.

Construction Phase. The time period where a contractor is constructing a building or other project. The architect and consultants often monitor the construction process to ensure that construction is in accordance with the design.

Design Phase. The time period where an architect and consultants (engineers) are developing a design for an owner. Often a BIM software product is used to create a 3D model and to develop construction documents, which document the design and prepare the project for construction.

Domain. The body of knowledge defining the range and scope of an area of expertise in terms of elements, rules and behaviors. The area of expertise is similar to a discipline. Examples of domains are architecture, structural engineering, mechanical, electrical, and plumbing engineering

(MEP), civil engineering, or facilities management, among others.

Element. Structural elements in a real building or a structural model, such as beams, columns, walls, braces, slabs, or foundations, are often referred to as structural elements (see members or objects). An element refers to one element (such as a floor joist or beam which is part of a whole assembly).

IFC. Industry foundation class, the open source file type definition that represents a data schema for sharing construction and facility management data across various applications used in the architecture, engineering, and construction industry domain. It is an object-oriented data schema based on class definitions representing the objects (such as building elements, spaces, properties, and shapes) that are used by different software applications.

IFC Bindings. Definitions for exchange concepts that support a set of standard export and import exchange capabilities for commercial software products.

Interoperability. The ability to translate a BIM from one software to another. The ability for a BIM software to read and write IFC files for translation of BIM models.

MEP. Mechanical, electrical, and plumbing equipment, and distribution systems, such as, ducts, conduit, and piping. MEP systems include heating, ventilating, and air conditioning systems (HVAC), plumbing systems, and electrical power systems. MEP engineers are consultants who design MEP systems. Often MEP engineers are specialized to specific portions, such as mechanical, electrical or plumbing.

Member. Structural elements in a real building or a structural model, such as beams, columns, walls, braces, slabs, or foundations, are often referred to as structural members (see elements or objects).

Meta-data. Information attached to objects in a BIM model, same as Properties or Attributes.

Model View Definition (MVD). Subsets of the IFC Model Specification that define specific model translations. An MVD defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the architecture, engineering, and construction industry. MVD are often created by the transfer requirements of the end users.

Object. 3D modeled elements that have attributes and relationships to other elements. For example, beams, columns, braces, walls, floor and roof framing, and footings are all objects.

Properties. Information attached to objects in a BIM model (denoting size, orientation, and material properties), same as Meta-data or attributes.

Schema. A data model in a formal machine-readable notation. The IFC specification consists of such a schema and associated informal human-readable semantic definitions. The schema describes a set of data types and their possible relationships.

Structural Engineer. A structural engineer designs the structural support system or framing for building architecture and building MEP systems. Building structure includes floor and roof framing, columns and walls, lateral frames, ceiling and building enclosure support, and foundation systems. Structural framing supports architectural elements, such as, doors, walls, and windows, soffits and ceilings, canopies, floor, roof, and wall openings, stairs and elevators, guardrails, and architectural ornamentation.

Testbed. Specifically with respect to ATC-75 it is a BIM model created to test the interoperability of different software

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Applied Technology Council Projects and Report Information

One of the primary purposes of the Applied Technology Council is to develop engineering applications and resources that translate and summarize useful information for practicing building and bridge design professionals. This includes the development of guidelines and manuals, as well as the development of research recommendations for specific areas determined by the profession. ATC is not a code development organization, although ATC reports often serve as resource documents for the development of codes, standards and specifications.

Applied Technology Council conducts projects that meet the following criteria:

1. The primary audience or benefactor is the design practitioner in structural engineering.
2. A cross section or consensus of engineering opinion is required to be obtained and presented by a neutral source.
3. The project fosters the advancement of structural engineering practice.

Funding for projects is obtained from government agencies and tax-deductible contributions from the private sector. Brief descriptions of completed ATC projects and reports are provided below.

ATC-1: This project resulted in five papers published as part of *Building Practices for Disaster Mitigation, Building Science Series 46*, proceedings of a workshop sponsored by the National Science Foundation (NSF) and the National Bureau of Standards (NBS). Available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151, as NTIS report No. COM-73-50188.

ATC-2: The report, *An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings*, was funded by NSF and NBS and was conducted as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation. Available through ATC. (Published 1974, 270 pages)

ATC-3: The report, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC-3-06), was funded by NSF and NBS. The tentative provisions in this report served as the basis for the seismic provisions of the 1988 and subsequent issues of the *Uniform Building Code* and the *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Building and Other Structures*. The second printing contains proposed amendments prepared by a joint committee of the Building Seismic Safety Council (BSSC) and the NBS. Available through ATC. (Published 1978, amended 1982, 505 pages plus proposed amendments)

ATC-3-2: The project, “Comparative Test Designs of Buildings Using ATC-3-06 Tentative Provisions”, was funded by NSF. It consisted of a study to develop and plan a program for making comparative test designs of the ATC-3-06 *Tentative Provisions*. The project report was intended for use by the Building Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

ATC-3-4: The report, *Redesign of Three Multistory Buildings: A Comparison Using ATC-3-06 and 1982 Uniform Building Code Design Provisions*, was published under a grant from NSF. Available through ATC. (Published 1984, 112 pages)

ATC-3-5: The project, “Assistance for First Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council,” was funded by the Building Seismic Safety Council to obtain assistance in conducting the first phase of its program to develop trial designs for buildings in Los Angeles, Seattle, Phoenix, and Memphis.

ATC-3-6: The project, “Assistance for Second Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety

Council," was funded by the Building Seismic Safety Council to obtain assistance in conducting the second phase of its program to develop trial designs for buildings in New York, Chicago, St. Louis, Charleston, and Fort Worth.

ATC-4: The report, *A Methodology for Seismic Design and Construction of Single-Family Dwellings*, was published under a contract with the Department of Housing and Urban Development (HUD). Available through ATC. (Published 1976, 576 pages)

ATC-4-1: The report, *The Home Builders Guide for Earthquake Design*, was published under a contract with HUD. Available through ATC. (Published 1980, 57 pages)

ATC-5: The report, *Guidelines for Seismic Design and Construction of Single-Story Masonry Dwellings in Seismic Zone 2*, was developed under a contract with HUD. Available through ATC. (Published 1986, 38 pages)

ATC-6: The report, *Seismic Design Guidelines for Highway Bridges*, was published under a contract with the Federal Highway Administration (FHWA). Available through ATC. (Published 1981, 210 pages)

ATC-6-1: The report, *Proceedings of a Workshop on Earthquake Resistance of Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1979, 625 pages)

ATC-6-2: The report, *Seismic Retrofitting Guidelines for Highway Bridges*, was published under a contract with FHWA. Available through ATC. (Published 1983, 220 pages)

ATC-7: The report, *Guidelines for the Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through ATC. (Published 1981, 190 pages)

ATC-7-1: The report, *Proceedings of a Workshop on Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through ATC. (Published 1980, 302 pages)

ATC-8: The report, *Proceedings of a Workshop on the Design of Prefabricated Concrete Buildings for Earthquake Loads*, was funded by NSF. Available through ATC. (Published 1981, 400 pages)

ATC-9: The report, *An Evaluation of the Imperial County Services Building Earthquake Response and Associated Damage*, was published under a grant from NSF. Available through ATC. (Published 1984, 231 pages)

ATC-10: The report, *An Investigation of the Correlation Between Earthquake Ground Motion and Building Performance*, was funded by the U.S. Geological Survey (USGS). Available through ATC. (Published 1982, 114 pages)

ATC-10-1: The report, *Critical Aspects of Earthquake Ground Motion and Building Damage Potential*, was co-funded by the USGS and the NSF. Available through ATC. (Published 1984, 259 pages)

ATC-11: The report, *Seismic Resistance of Reinforced Concrete Shear Walls and Frame Joints: Implications of Recent Research for Design Engineers*, was published under a grant from NSF. Available through ATC. (Published 1983, 184 pages)

ATC-12: The report, *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1982, 270 pages)

ATC-12-1: The report, *Proceedings of Second Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1986, 272 pages)

ATC-13: The report, *Earthquake Damage Evaluation Data for California*, was developed under a contract with the Federal Emergency Management Agency (FEMA). It presents expert-opinion earthquake damage and loss estimates for industrial, commercial, residential, utility and transportation facilities in California. Included are damage probability matrices for 78 classes of structures and estimates of time required to restore damaged facilities to pre-earthquake usability. Available through ATC. (Published 1985, 492 pages)

ATC-13-1: The report, *Commentary on the Use of ATC-13 Earthquake Damage Evaluation Data for Probable Maximum Loss Studies of California Buildings*, was developed with funding from the ATC Endowment Fund. It provides guidance for using ATC-13 expert-opinion data for probable maximum loss (PML) studies of California buildings. Included are discussions of the limitations on the use of the ATC-13 expert-opinion data, and appendices containing information not included in the original ATC-13 report, such as model building type descriptions, beta damage distribution parameters for ATC-13 model building types, and PML values for ATC-13 model building types. Available through ATC. (Published 2002, 66 pages)

ATC-14: The report, *Evaluating the Seismic Resistance of Existing Buildings*, was developed under a grant from the NSF. It describes a methodology for performing preliminary and detailed seismic evaluations of buildings. A precursor to the eventual ASCE 31 Standard, *Seismic Evaluation of Existing Buildings*, it contains useful background information including a state-of-practice review; seismic loading criteria; data collection procedures; a detailed description of the building classification system; preliminary and detailed analysis procedures; and example case studies, including nonstructural considerations. Available through ATC. (Published 1987, 370 pages)

ATC-15: The report, *Comparison of Seismic Design Practices in the United States and Japan*, was published under a grant from NSF. Available through ATC. (Published 1984, 317 pages)

ATC-15-1: The report, *Proceedings of Second U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices*, was published under a grant from NSF. It includes state-of-the-practice papers and case studies of actual building designs and information on regulatory, contractual, and licensing issues. Available through ATC. (Published 1987, 412 pages)

ATC-15-2: The report, *Proceedings of Third U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes state-of-the-practice papers on steel braced frame and reinforced concrete buildings, base isolation and passive energy dissipation devices, and comparisons between U.S. and Japanese design practice. Available through ATC. (Published 1989, 358 pages)

ATC-15-3: The report, *Proceedings of Fourth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes papers on postearthquake building damage assessment; acceptable earthquake damage; repair and retrofit of earthquake-damaged buildings; base-isolated buildings; Architectural Institute of Japan recommendations for design; active damping systems; and wind-resistant design. Available through ATC. (Published 1992, 484 pages)

ATC-15-4: The report, *Proceedings of Fifth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes papers on performance goals and acceptable damage; seismic design procedures and case studies; seismic evaluation, repair and upgrade; construction influences on design; isolation and passive energy dissipation; design of irregular structures; and quality control for design and construction. Available through ATC. (Published 1994, 360 pages)

ATC-16: The FEMA 90 report, *An Action Plan for Reducing Earthquake Hazards of Existing Buildings*, was funded by FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering Research Institute. Available through FEMA. (Published 1985, 75 pages)

ATC-17: The report, *Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation*, was published under a grant from NSF. It includes papers describing case studies in the United States, applications and developments worldwide, recent innovations in technology development, and structural and ground motion issues in base-isolation and passive energy-dissipation. Also included is a proposed 5-year research agenda. Available through ATC. (Published 1986, 478 pages)

ATC-17-1: The report, *Proceedings of a Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control*, was published under a grant from the National Center for Earthquake Engineering Research (NCEER) and NSF. Available through ATC. (Published 1993, 841 pages in two volumes)

ATC-18: The report, *Seismic Design Criteria for Bridges and Other Highway Structures: Current and Future*, was developed under a grant from NCEER and FHWA. Available through ATC. (Published 1997, 151 pages)

ATC-18-1: The report, *Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures*, was developed under a contract with the Multidisciplinary Center for Earthquake Engineering Research (MCEER, formerly

NCEER) and FHWA. Available through ATC. (Published 1999, 136 pages)

ATC-19: The report, *Structural Response Modification Factors*, was funded by NSF and NCEER. Available through ATC. (Published 1995, 70 pages)

ATC-20: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract with the California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. It provides procedures and guidelines for inspecting buildings that have been damaged in an earthquake, and making decisions regarding their continued use and occupancy. Written for volunteer structural engineers and building inspectors, it includes rapid and detailed evaluation procedures for posting buildings as "inspected" (apparently safe, green placard), "limited entry" (yellow) or "unsafe" (red). Available through ATC. (Published 1989, 152 pages)

ATC-20-1: The report, *Field Manual: Postearthquake Safety Evaluation of Buildings, Second Edition*, was funded by the Applied Technology Council. A companion to the ATC-20 report, the *Field Manual* summarizes postearthquake safety evaluation procedures in a concise format designed for ease of use in the field. Available through ATC. (Published 2004, 143 pages)

ATC-20-2: The report, *Addendum to the ATC-20 Postearthquake Building Safety Procedures*, was published under a grant from the NSF and funded by the USGS. It provides updated assessment forms, placards, and evaluation procedures based on application and use in five earthquake events that occurred after the initial release of the ATC-20 report. Available through ATC. (Published 1995, 94 pages)

ATC-20-3: The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R.P. Gallagher Associates. Containing over 50 case studies using the ATC-20 Rapid Evaluation procedure, the report is intended for use as a training and reference manual. It describes how buildings are inspected and evaluated, and is illustrated with photos and example completed safety assessment forms and placards. Available through ATC. (Published 1996, 295 pages)

ATC-20-T: The *Postearthquake Safety Evaluation of Buildings Training CD* was developed in cooperation with FEMA. The 4½-hour training seminar includes photographs, schematic drawings, and textual information. Available through ATC. (Published 2002, 230 PowerPoint slides with Speakers Notes)

ATC-21: The FEMA 154 report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Second Edition*, was developed under a contract with FEMA. It describes a rapid visual screening procedure for identifying buildings that might pose serious risk of loss of life and injury in the event of a damaging earthquake. The screening procedure utilizes an approach that involves identification of the primary structural load-resisting system and materials of construction, and assignment of a structural hazard score based on observed building characteristics. It identifies those buildings that are potentially hazardous and should be analyzed in more detail by an experienced professional engineer. Available through ATC and FEMA. (Published 2002, 161 pages)

ATC-21-1: The FEMA 155 report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation, Second Edition*, was developed under a contract with FEMA. It provides the technical basis for the updated rapid visual screening procedure. Available through ATC and FEMA. (Published 2002, 117 pages)

ATC-21-2: The report, *Earthquake Damaged Buildings: An Overview of Heavy Debris and Victim Extrication*, was developed under a contract with FEMA. (Published 1988, 95 pages)

ATC-21-T: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual, Second Edition*, was developed under a contract with FEMA. Training materials include120 slides in PowerPoint format and companion narrative coordinated with the presentation. Available through ATC. (Published 2004, 148 pages and PowerPoint presentation on companion CD)

ATC-22: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary),* was developed under a contract with FEMA in 1989. Based on the information originally developed in ATC-14, this report was revised by BSSC and published as the FEMA 178 report, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* in 1992, revised by ASCE and published as the FEMA 310 report, *Handbook for the Seismic Evaluation of Buildings—A Prestandard*, in 1998. Currently available through the American Society of Civil Engineers as the ASCE 31 Standard, *Seismic Evaluation of Existing Buildings*.

ATC-22-1: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract with FEMA. (Published 1989, 160 pages)

ATC-23A: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part A: Survey Description, Summary of Results, Data Analysis and Interpretation*, was developed under a contract with the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through ATC. (Published 1991, 58 pages)

ATC-23B: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part B: Raw Data*, was developed under a contract with OSHPD, State of California. Available through ATC. (Published 1991, 377 pages)

ATC-24: The report, *Guidelines for Seismic Testing of Components of Steel Structures*, was jointly funded by the American Iron and Steel Institute (AISI), American Institute of Steel Construction (AISC), NCEER, and NSF. Available through ATC. (Published 1992, 57 pages)

ATC-25: The report, *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous State*s, was developed under a contract with FEMA. Available through ATC. (Published 1991, 440 pages)

ATC-25-1: The report, *A Model Methodology for Assessment of Seismic Vulnerability and Impact of Disruption of Water Supply Systems*, was developed under a contract with FEMA. Available through ATC. (Published 1992, 147 pages)

ATC-26: This project, "U.S. Postal Service National Seismic Program," was funded under a contract with the U.S. Postal Service (USPS), and resulted in the following interim documents:

ATC-26 report, *Cost Projections for the U. S. Postal Service Seismic Program* (Completed 1990)

ATC-26-1 report, *United States Postal Service Procedures for Seismic Evaluation of Existing Buildings (Interim)* (Completed 1991)

ATC-26-2 report, *Procedures for Post-disaster Safety Evaluation of Postal Service Facilities (Interim)*. Available through ATC. (Published 1991, 221 pages)

ATC-26-3 report, *Field Manual: Post-earthquake Safety Evaluation of Postal Buildings (Interim)*. Available through ATC. (Published 1992, 133 pages)

ATC-26-3A report, *Field Manual: Post Flood and Wind Storm Safety Evaluation of Postal Buildings (Interim)*. Available through ATC. (Published 1992, 114 pages)

ATC-26-4 report, *United States Postal Service Procedures for Building Seismic Rehabilitation (Interim).* (Completed 1992)

ATC-26-5 report, *United States Postal Service Guidelines for Building and Site Selection in Seismic Areas (Interim).* (Completed 1992)

ATC-28: The report, *Development of Recommended Guidelines for Seismic Strengthening of Existing Buildings, Phase I: Issues Identification and Resolution*, was developed under a contract with FEMA. Available through ATC. (Published 1992, 150 pages)

ATC-29: The report, *Proceedings of a Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, was developed under a grant from NCEER and NSF. It includes papers describing current practice, codes and regulations; earthquake performance; analytical and experimental investigations; development of new seismic qualification methods; and research, practice, and code development needs for nonstructural elements and systems. Available through ATC. (Published 1992, 470 pages)

ATC-29-1: The report, *Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, was developed under a grant from NCEER and NSF. It includes papers on observed performance in recent earthquakes; seismic design codes, standards, and procedures for commercial and institutional buildings; design issues relating to industrial and hazardous material facilities; and seismic evaluation and rehabilitation of components in conventional and essential facilities. Available through ATC. (Published 1998, 518 pages)

ATC-29-2: The report, *Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities*, was developed under a grant from MCEER (formerly NCEER) and NSF. It includes papers on seismic design, performance, and retrofit of nonstructural components in critical facilities including current practices and emerging codes; seismic design and retrofit; risk and performance evaluation; system qualification and testing; and advanced technologies. Available through ATC. (Published 2003, 574 pages)

ATC-30: The report, *Proceedings of Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of 1985 Chile and Mexico Earthquakes*, was developed under a grant from the NSF. Available through ATC. (Published 1991, 113 pages)

ATC-31: The report, *Evaluation of the Performance of Seismically Retrofitted Buildings*, was developed under a contract with the National Institute of Standards and Technology (NIST, formerly NBS) and funded by the USGS. Available through ATC. (Published 1992, 75 pages)

ATC-32: The report, *Improved Seismic Design Criteria for California Bridges: Provisional Recommendations*, was funded by the California Department of Transportation (Caltrans). Available through ATC. (Published 1996, 215 pages)

ATC-32-1: The report, *Improved Seismic Design Criteria for California Bridges: Resource Document*, was funded by Caltrans. Available through ATC. (Published 1996, 365 pages; also available in pdf format on CD-ROM)

ATC-33: The project, funded under a contract with the Building Seismic Safety Council, was initiated by FEMA to develop nationally applicable, state-of-the-art guidance for performance-based seismic rehabilitation of buildings. Work resulted in the publication of:

FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (Published 1997, 440 pages). Revised by ASCE and published as the FEMA 356 report, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* in 2000. Currently available through the American Society of Civil Engineers as the ASCE 41 Standard, *Seismic Rehabilitation of Existing Buildings*.

FEMA 274, *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings*. Available through ATC and FEMA. (Published 1997, 492 pages)

FEMA 276, *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings*. Available through ATC and FEMA. (Published 1997, 295 pages)

ATC-34: The report, *A Critical Review of Current Approaches to Earthquake Resistant Design*, was developed under a grant from NCEER and NSF. Available through ATC. (Published, 1995, 94 pages)

ATC-35: The report, *Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice*, was developed under a cooperative agreement with the USGS. Available through ATC. (Published 1994, 120 pages)

ATC-35-1: The report, *Proceedings of Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, was developed under a cooperative agreement with USGS. It includes papers describing state-of-the-art information on regional earthquake risk; new techniques for estimating strong ground motions as a function of earthquake source, travel path, and site parameters; and new developments applicable to geotechnical engineering. Available through ATC. (Published 1994, 478 pages)

ATC-35-2: The report, *Proceedings: National Earthquake Ground Motion Mapping Workshop*, was developed under a cooperative agreement with USGS. It includes papers on ground motion parameters; reference site conditions; probabilistic versus deterministic basis; and the treatment of uncertainty in seismic source characterization and ground motion attenuation. Available through ATC. (Published 1997, 154 pages)

ATC-35-3: The report, *Proceedings: Workshop on Improved Characterization of Strong Ground Shaking for Seismic Design*, was developed under a cooperative agreement with USGS. It includes papers on identifying needs and developing improved representations of earthquake ground motion for use in seismic design practice and building codes. Available through ATC. (Published 1999, 75 pages)

ATC-37: The report, *Review of Seismic Research Results on Existing Buildings*, was developed in conjunction with the Structural Engineers Association of California (SEAOC) and California Universities for Research in Earthquake Engineering (CUREe) under a contract with the California Seismic Safety Commission (SSC). Available through the Seismic Safety Commission as Report SSC 94-03. (Published 1994, 492 pages)

ATC-38: The report, *Database on the Performance of Structures near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*, was developed with funding from the USGS, the Southern California Earthquake Center (SCEC), OES, and the Institute for Business and Home Safety (IBHS). Available through ATC. (Published 2000, 260 pages, with CD-ROM containing complete database).

ATC-40: The report, *Seismic Evaluation and Retrofit of Concrete Buildings*, was developed under a contract with the California Seismic Safety Commission. It provides guidance on performance objectives, hazard characterization, identification of deficiencies, retrofit strategies, nonlinear static analysis procedures, modeling rules, foundation effects, and response limits for seismic evaluation and retrofit of concrete buildings. Available through ATC. (Published, 1996, 612 pages in two volumes)

ATC-41 (SAC Joint Venture, Phase 1): The project, "Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 1," was funded by FEMA and OES and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under Phase 1 the following documents were prepared:

SAC-94-01, *Proceedings of the Invitational Workshop on Steel Seismic Issues, Los Angeles, September 1994*. Available through ATC. (Published 1994, 155 pages)

SAC-95-01, *Steel Moment-Frame Connection Advisory No. 3*. Available through ATC. (Published 1995, 310 pages)

SAC-95-02, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment-Frame Structures* (FEMA 267 report) (Published 1995, 215 pages; superseded by FEMA 350 to 353)

SAC-95-03, *Characterization of Ground Motions During the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 179 pages)

SAC-95-04, *Analytical and Field Investigations of Buildings Affected by the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 900 pages in two volumes)

SAC-95-05, *Parametric Analytical Investigations of Ground Motion and Structural Response, Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 274 pages)

SAC-95-06, *Surveys and Assessment of Damage to Buildings Affected by the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 315 pages)

SAC-95-07, *Case Studies of Steel Moment Frame Building Performance in the Northridge Earthquake of January 17, 1994* , Available through ATC. (Published 1995, 260 pages)

SAC-95-08, *Experimental Investigations of Materials, Weldments and Nondestructive Examination Techniques*. Available through ATC. (Published 1995, 144 pages)

SAC-95-09, *Background Reports: Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame Systems, Behavior* (FEMA 288 report). Available through ATC and FEMA. (Published 1995, 361 pages)

SAC-96-01, *Experimental Investigations of Beam-Column Subassemblages, Part 1 and 2*. Available through ATC. (Published 1996, 924 pages, in two volumes)

SAC-96-02, *Connection Test Summaries* (FEMA 289 report). Available through ATC and FEMA. (Published 1996, 144 pages)

ATC-41-1 (SAC Joint Venture, Phase 2): The project, "Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 2," was funded by FEMA and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under Phase 2 the following documents were prepared:

SAC-96-03, *Interim Guidelines Advisory No. 1 Supplement to FEMA 267 Interim Guidelines* (FEMA 267A report). (Published 1997, 100 pages; superseded by FEMA 350 to 353)

SAC-99-01, *Interim Guidelines Advisory No. 2 Supplement to FEMA 267 Interim Guidelines* (FEMA 267B report, superseding FEMA 267A). (Published 1999, 150 pages; superseded by FEMA 350 to 353)

FEMA 350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 190 pages)

FEMA 351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 210 pages)

FEMA 352, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 180 pages)

FEMA 353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*. Available through ATC and FEMA. (Published 2000, 180 pages)

FEMA 354, *A Policy Guide to Steel Moment-Frame Construction*. Available through ATC and FEMA. (Published 2000, 27 pages)

FEMA 355A, *State of the Art Report on Base Materials and Fracture*. Available through ATC and FEMA. (Published 2000, 107 pages; in print and on CD-ROM).

FEMA 355B, *State of the Art Report on Welding and Inspection*. Available through ATC and FEMA. (Published 2000, 185 pages; in print and on CD-ROM).

FEMA 355C, *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. Available through ATC and FEMA. (Published 2000, 322 pages; in print and on CD-ROM).

FEMA 355D, *State of the Art Report on Connection Performance*. Available through ATC and FEMA. (Published 2000, 292 pages; in print and on CD-ROM).

FEMA 355E, *State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*. Available through ATC and FEMA. (Published 2000, 190 pages; in print and on CD-ROM).

FEMA 355F, *State of the Art Report on Performance Prediction and Evaluation of Steel Moment-Frame Structures*. Available through ATC and FEMA. (Published 2000, 347 pages; in print and on CD-ROM).

ATC-43: The reports, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual* (FEMA 306), *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources* (FEMA 307), and *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308), were developed for FEMA under a contract with the Partnership for Response and Recovery, a Joint Venture of Dewberry & Davis and Woodward-Clyde. Available through ATC and FEMA. (Published 1998 in print and on CD-ROM; *Basic Procedures Manual*, 270 pages; *Technical Resources*, 271 pages; *Repair Manual*, 81 pages)

ATC-44: The report, *Hurricane Fran, North Carolina, September 5, 1996: Reconnaissance Report*, was funded by the Applied Technology Council. Available through ATC. (Published 1997, 36 pages)

ATC-45: The report, *Field Manual*: *Safety Evaluation of Buildings After Windstorms and Floods*, was developed with funding from the ATC Endowment Fund and the Institute for Business and Home Safety (IBHS). It provides rapid and detailed evaluation procedures for inspecting buildings that have been damaged in windstorms and floods, and making decisions regarding their continued use and occupancy. Presented in a concise format designed for ease of use in the field, it is intended for use by volunteer structural engineers and building inspectors in posting buildings as “inspected” (apparently safe, green placard), “restricted use” (yellow) or “unsafe” (red). Available through ATC. (Published 2004, 132 pages)

ATC-48 (ATC/SEAOC Joint Venture Training Curriculum): The training curriculum, *Built to Resist Earthquakes, The Path to Quality Seismic Design and Construction for Architects, Engineers, and Inspectors*, was developed under a contract with the California Seismic Safety Commission and prepared by a Joint Venture partnership of ATC and SEAOC. Available through ATC. (Published 1999, 314 pages)

ATC-49: The 2-volume report, *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges; Part I: Specifications* and *Part*

II: Commentary and Appendices, were developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, *Part I*, 164 pages and *Part II*, 294 pages)

ATC-49-1: The document, *Liquefaction Study Report, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*, was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, 208 pages)

ATC-49-2: The report, *Design Examples, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*, was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, 316 pages)

ATC-51: The report, *U.S.-Italy Collaborative Recommendations for Improved Seismic Safety of Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey). Available through ATC. (Published 2000, 154 pages)

ATC-51-1: The report, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey, NSS). Available in English and Italian through ATC. (Published 2002, 120 pages)

ATC-51-2: The report, *Recommended U.S.-Italy Collaborative Guidelines for Bracing and Anchoring Nonstructural Components in Italian Hospitals*, was developed under a contract with the Department of Civil Protection, Italy. Available in English and Italian through ATC. (Published 2003, 164 pages)

ATC-52: The project, "Development of a Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco," was conducted under a contract with the San Francisco Department of Building Inspection. The following reports were prepared:

ATC-52-1, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Potential Earthquake Impacts*. Available through ATC. (Published 2010, 78 pages)

ATC-52-1A, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Potential Earthquake Impacts Technical Documentation*. Available through ATC. (Published 2010, 160 pages)

ATC-52-2, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: A Community Action Plan for Seismic Safety*. Available through ATC. (Published 2010, 92 pages)

ATC-52-3, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Earthquake Safety for Soft-Story Buildings*. Available through ATC. (Published 2009, 60 pages)

ATC-52-3A, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Earthquake Safety for Soft-Story Buildings Documentation Appendices*. Available through ATC. (Published 2009, 206 pages)

ATC-52-4, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Post-Earthquake Repair and Retrofit Requirements*. Available through ATC. (Published 2010, 130 pages)

ATC-53: The report, *Assessment of the NIST 12-Million-Pound (53 MN) Large-Scale Testing Facility*, was developed under a contract with NIST. Available through ATC. (Published 2000, 44 pages)

ATC-54: The report, *Guidelines for Using Strong-Motion Data and ShakeMaps in Postearthquake Response*, was developed under a contract with the California Geological Survey. Available through ATC. (Published 2005, 222 pages)

ATC-55: The report, FEMA 440, *Improvement of Nonlinear Static Seismic Analysis Procedures*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2005, 152 pages)

ATC-56: The report, FEMA 389, *Primer for Design Professionals: Communicating with Owners and Managers of New Buildings on Earthquake Risk*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2004, 194 pages)

ATC-56-1: The report, FEMA 427, *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks – Providing Protection to People* *and Buildings*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2003, 106 pages)

ATC-57: The report, *The Missing Piece: Improving Seismic Design and Construction Practices*, was developed under a contract with NIST. It provides a framework for eliminating the technology transfer gap that has emerged within the National Earthquake Hazards Reduction Program (NEHRP) that limits the adaptation of basic research knowledge into practice. Available through ATC. (Published 2003, 102 pages)

ATC-58: The project, "Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings," is a multi-year, multi-phase effort funded by FEMA that has resulted in the publication of the following:

> FEMA 445, *Next-Generation Performance-Based Seismic Design Guidelines, Program Plan for New and Existing Buildings*. Available through ATC and FEMA. (Published 2006, 131 pages).
>
> FEMA 461, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components*. Available through ATC and FEMA. (Published 2007, 113 pages)

ATC-60: The 2-volume report, *SEAW Commentary on Wind Code Provisions, Volume 1* and *Volume 2 - Example Problems*, was developed by the Structural Engineers Association of Washington (SEAW) in cooperation with ATC. Available through ATC. (Published 2004; *Volume 1*, 238 pages; *Volume 2*, 245 pages)

ATC-61: The 2-volume report, *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities, Volume 1 – Findings, Conclusions, and Recommendations*, and *Volume 2 – Study Documentation*, was prepared for the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences, with funding provided by FEMA. Available through ATC and the MMC. (Published 2005; *Volume 1*, 11 pages; *Volume 2*, 366 pages)

ATC-62: The report, FEMA P-440A, *Effects of Strength and Stiffness Degradation on Seismic Response*, was developed under a contract with FEMA. Developed as a supplement to the FEMA 440 report, it provides additional guidance on modeling of nonlinear degrading response. Available through ATC and FEMA. (Published 2009, 310 pages)

ATC-63: The report, FEMA P-695, *Quantification of Building Seismic Performance Factors*, was developed under a contract with FEMA. It describes a methodology for establishing seismic performance factors (R, Ω_0, and C_d) that involves the development of detailed system design information and probabilistic assessment of collapse risk. It utilizes nonlinear analysis techniques, and explicitly considers uncertainties in ground motion, modeling, design, and test data. The technical approach is a combination of traditional code concepts, advanced nonlinear dynamic analyses, and risk-based assessment techniques. Available through ATC and FEMA. (Published 2009, 420 pages)

ATC-63-1: The report, FEMA P-795, *Quantification of Building Seismic Performance Factors: Component Equivalency Methodology*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2011, 264 pages)

ATC-64: The reports, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (FEMA P-646), and *Vertical Evacuation from Tsunamis: A Guide for Community Officials* (FEMA P-646A), were developed under a contract with FEMA. Available through ATC and FEMA. (*Design Guidelines*, Published 2008, 174 pages; *Guide for Community Officials*, Published 2009, 62 pages)

ATC-65: The report, FEMA P-455, *Handbook for Rapid Visual Screening of Buildings to Evaluate Terrorism Risks*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 174 pages)

ATC-66: The report, FEMA P-774, *Unreinforced Masonry Buildings and Earthquakes, Developing Successful Risk Reduction Programs*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 194 pages)

ATC-68: The report, FEMA P-420, *Engineering Guideline for Incremental Seismic Rehabilitation*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 94 pages)

ATC-69: The report, *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2008, 144 pages)

ATC-69-1: The electronic document, FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage, A Practical Guide*, was developed under a contract with FEMA. Available through FEMA. (Published 2011, 750 pages)

ATC-70: The report, NIST Technical Note 1476, *Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report*, was developed under a contract with NIST. Available through NIST. (Published 2006, 222 pages)

ATC-71: The reports, *Workshop on Meeting the Challenges of Existing Buildings, Part 1 Workshop Proceedings; Part 2: Status Report on Seismic Evaluation and Rehabilitation of Existing Buildings;* and *Part 3: Action Plan for the FEMA Existing Buildings Program*, were developed under a contract with FEMA. Available through ATC and FEMA. (*Part 1*, Published 2008, 142 pages; *Part 2*, Published 2009, 140 pages; *Part 3*, Published 2009, 118 pages)

ATC-72: The report, *Proceedings of Workshop on Tall Building Seismic Design and Analysis Issues*, was prepared for the Building Seismic Safety Council of the National Institute of Building Sciences, with funding provided by FEMA. Available through ATC. (Published 2007, 84 pages)

ATC-73: The report, *NEHRP Workshop on Meeting the Challenges of Existing Buildings, Prioritized Research for Reducing the Seismic Hazards of Existing Buildings*, was developed under a grant from NSF. Available through ATC. (Published 2007, 22 pages)

ATC-74: The report, *Collaborative Recommended Requirements for Automatic Natural Gas Shutoff Valves in Italy*, was funded by the Department of Civil Protection, Italy. Available through ATC. (Published 2007, 76 pages)

ATC-76-1/ATC-76-4: The report, *Evaluation of the FEMA P-695 Methodology for the Quantification of Building Seismic Performance Factors*, was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and the Consortium of Universities for Research in Earthquake Engineering (CUREE). Available through ATC, CUREE, and NIST as GCR 10-917-8. (Published 2010, 240 pages)

ATC-76-3: The reports, *NEHRP Technical Brief No. 1, Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers* and *NEHRP Technical Brief No. 2, Seismic Design of Steel Special Moment Frames: A Guide for Practicing Engineers*, were developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST (*Technical Brief No. 1*, Report GCR 08-917-1. Published 2008, 32 pages; *Technical Brief No. 2*, Report GCR 09-917-3, Published 2009, 38 pages)

ATC-76-5: The report, *Program Plan for the Development of Collapse Assessment and Mitigation Strategies for Existing Reinforced Concrete Buildings*, was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 10-917-7. (Published 2010, 80 pages)

ATC-76-6: The report, *Applicability of Nonlinear Multiple-Degree-of-Freedom Modeling for Design*, was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 10-917-9. (Published 2010, 196 pages plus CD)

ATC-76-7: The report, *NEHRP Technical Brief No. 3, Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors: A Guide for Practicing Engineers*, was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 10-917-4. (Published 2010, 30 pages)

ATC-76-8: The report, *NEHRP Technical Brief No. 4, Nonlinear Structural Analysis for Seismic Design: A Guide for Practicing Engineers*, was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 10-917-5. (Published 2010, 32 pages)

ATC-78: The report, *Identification and Mitigation of Seismically Hazardous Older Concrete Buildings: Interim Methodology Evaluation*, was funded by FEMA. Available through ATC. (Published 2011, 102 pages)

ATC-82: The report, *Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses*, was developed under a contract with NIST and prepared by a Joint

Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 11-917-5. (Published 2011, 234 pages)

ATC-87: The report, *NEHRP Technical Brief No. 5, Seismic Design of Composite Steel Deck and Concrete-filled Diaphragms: A Guide for Practicing Engineers,* was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 11-917-4. (Published 2011, 34 pages)

ATC-88: The report, *NEHRP Technical Brief No. 6, Seismic Design of Cast-in-Place Concrete Special Structural Walls and Coupling Beams: A Guide for Practicing Engineers,* was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 11-917-11. (Published 2011, 38 pages)

ATC-90: The report, *Research Plan for the Study of Seismic Behavior and Design of Deep, Slender Wide Flange Structural Steel Beam-Column Members,* was developed under a contract with NIST and prepared by a Joint Venture partnership of ATC and CUREE. Available through ATC, CUREE, and NIST as GCR 11-917-13. (Published 2011, 148 pages)

ATC-R-1: The report, *Cyclic Testing of Narrow Plywood Shear Walls,* was developed with funding from the ATC Endowment Fund. Available through ATC (Published 1995, 64 pages)

ATC Design Guide 1: The report, *Minimizing Floor Vibration***,** was developed with funding from the ATC Endowment Fund. Available through ATC. (Published, 1999, 64 pages)

ATC Design Guide 2: The report, *Basic Wind Engineering for Low-Rise Buildings***,** was developed with funding from the ATC Endowment Fund. Available through ATC. (Published, 2009, 114 pages)

ATC TechBrief 1: The ATC TechBrief 1, *Liquefaction Maps,* was developed under a contract with the United States Geological Survey. Available through ATC. (Published 1996, 12 pages)

ATC TechBrief 2: The ATC TechBrief 2, *Earthquake Aftershocks − Entering Damaged Buildings*, was developed under a contract with the United States Geological Survey. Available through ATC. (Published 1996, 12 pages)

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