An IFC-based Product Model for RC or PC Slab Bridges

Nobuyoshi Yabuki

Assoc. Prof., Ph.D., P.E.,
Muroran Institute of Technology, Japan

Tomoaki Shitani

Graduate Student
Muroran Institute of Technology, Japan

CIB W78, 20th International Conference

Information Technology for Construction

April 23-25, 2003, Waiheke Island, Auckland, New Zealand

Outline

1. Introduction
2. IFC of IAI
3. A Product Model of RC and PC Bridges
4. Implementation Issues
5. Implementation Using ifcXML
6. Integration of the Product Model with Application Systems
7. Conclusion

1. Introduction

Background

Research and development of product models have been carried out in order to enable the interoperability of various application systems in a lifecycle of products and structures.

Various standards and specifications for product models

- ISO 10303 STEP (Standards for The Exchange of Product model data): Machines, ships, etc.
- Industry Foundation Classes (IFC) of International Alliance of Interoperability (IAI): Buildings
  Publicly Available Specification (PAS) of ISO TC184 SC4 since November 2002.
- CIMSteel Integration Standards: Steel frames, etc.

Our Previous Work

- We had developed our own product models for steel frames, penstocks, and bridges, and implemented them using XML before we did this research.
- And we had integrated application systems such as 3D-CAD, code checking, quantity calculation, cost estimation, scheduling, and inspection for maintenance by the product models.

However, the modeling approach employed then was a classical one, which each class contains its all attributes in it.

Issues on Product Models

- Since standard modeling and implementation procedures have not been established yet, different methods and approaches have been employed by various organizations for their objectives.
- There are various XML schemata and other languages for implementing product models.
- Not so much outcome has been seen for developing standardized product models for civil engineering structures such as bridges, dams, harbors, etc.

Problems in Design Seen during Construction

- There are many problems in design by consultants who have little experience or knowledge in construction.
- Many of those problems may be solved during the design phase by incorporating 3D product models and process models instead of relying on only 2D drawings. (Of course, we have to incorporate knowledge as well.)

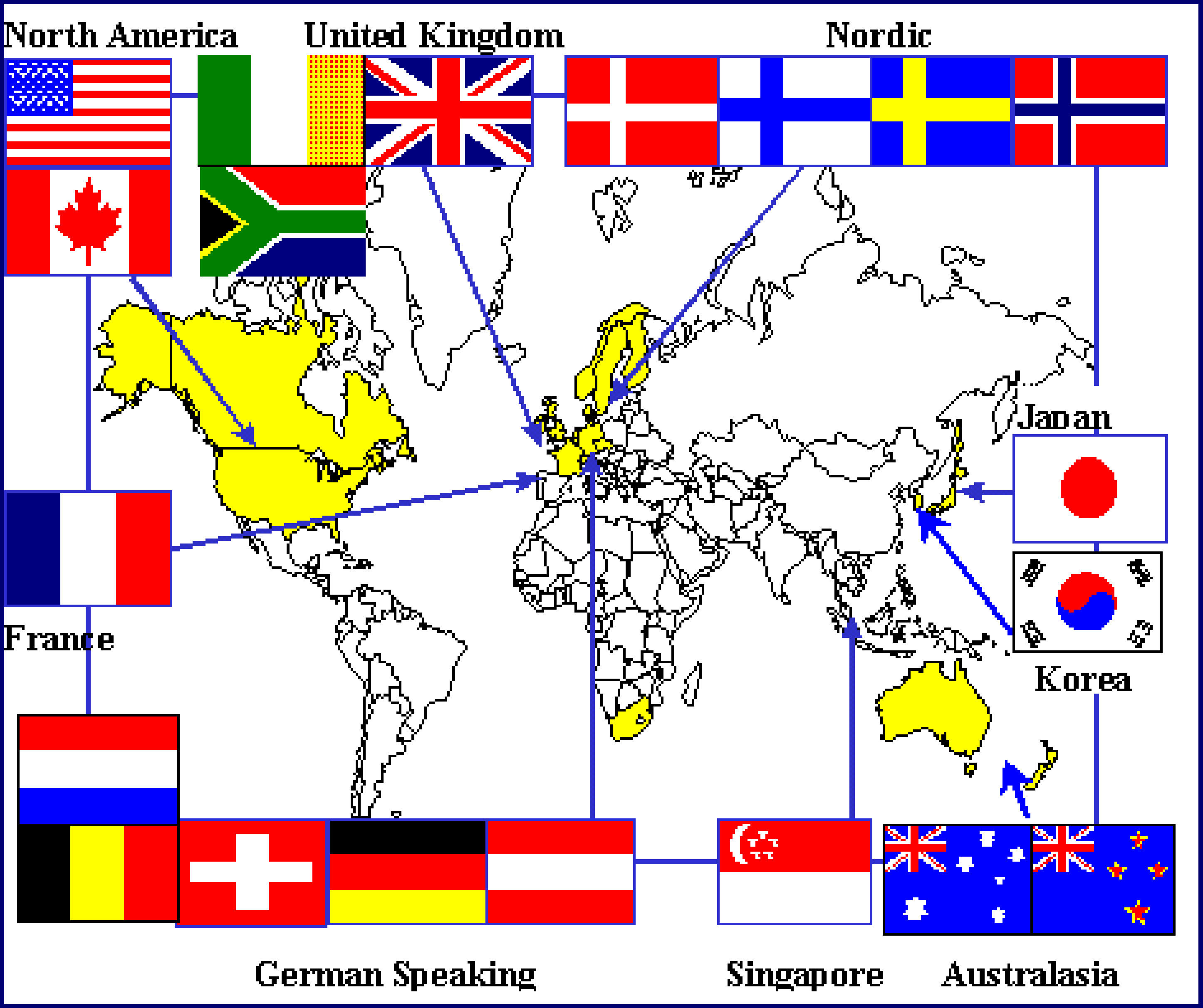
Objectives

- Developing product models for reinforced concrete (RC) and prestressed concrete (PC) superstructures of bridges on the basis of IFC of IAI.
- Selecting an appropriate XML schema and implementing the developed product model.
- Developing and integrating the product model and several application systems to incorporate 3D models and construction consideration into design.

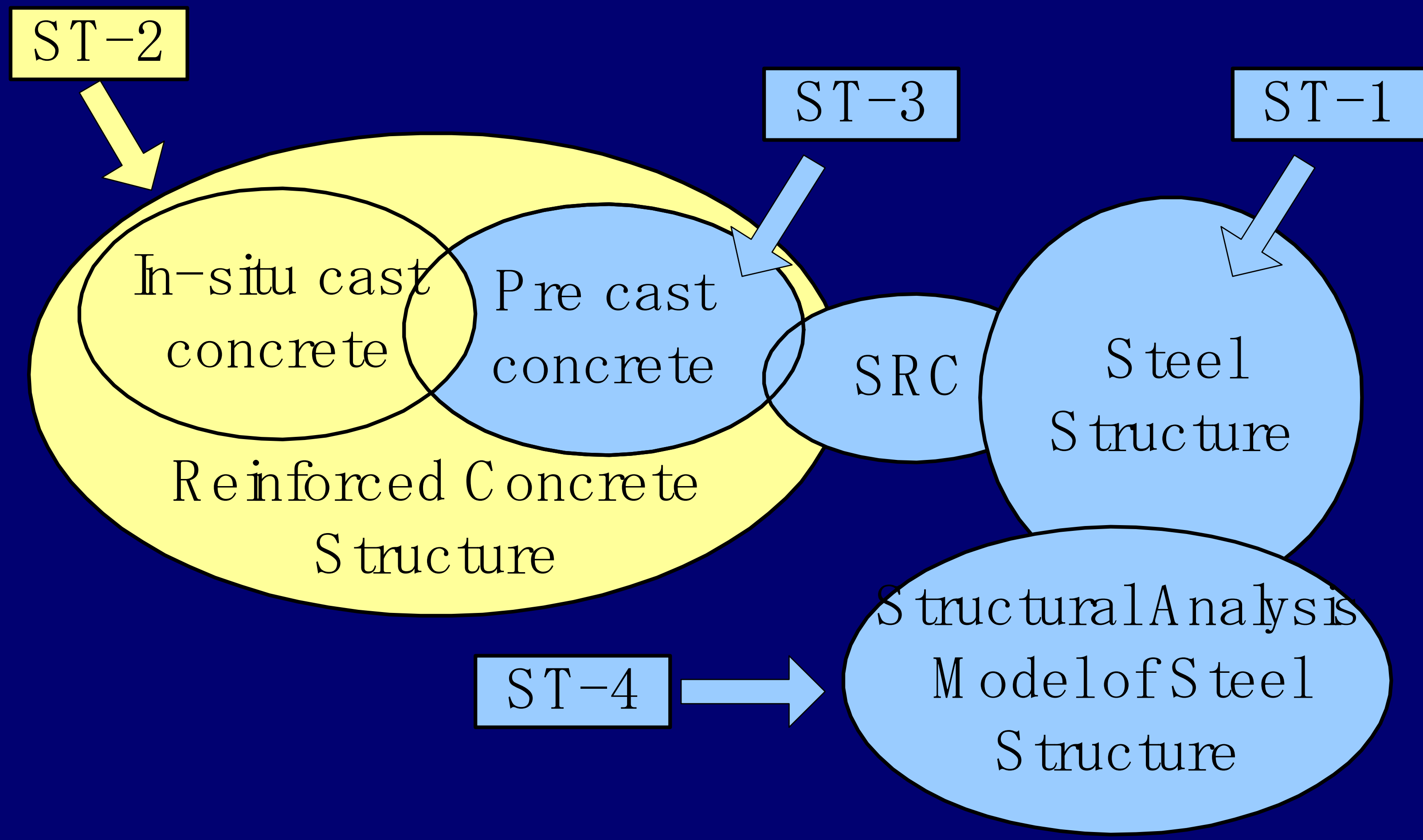
2. IFC of IAI

- IAI : an international organization for data sharing in the A/E/C industry
- IFC : an object-oriented data model developed by IAI
- IFC enables data sharing between CAD & non-CAD applications
- The current version of IFC is Release 2x, IFC2x.

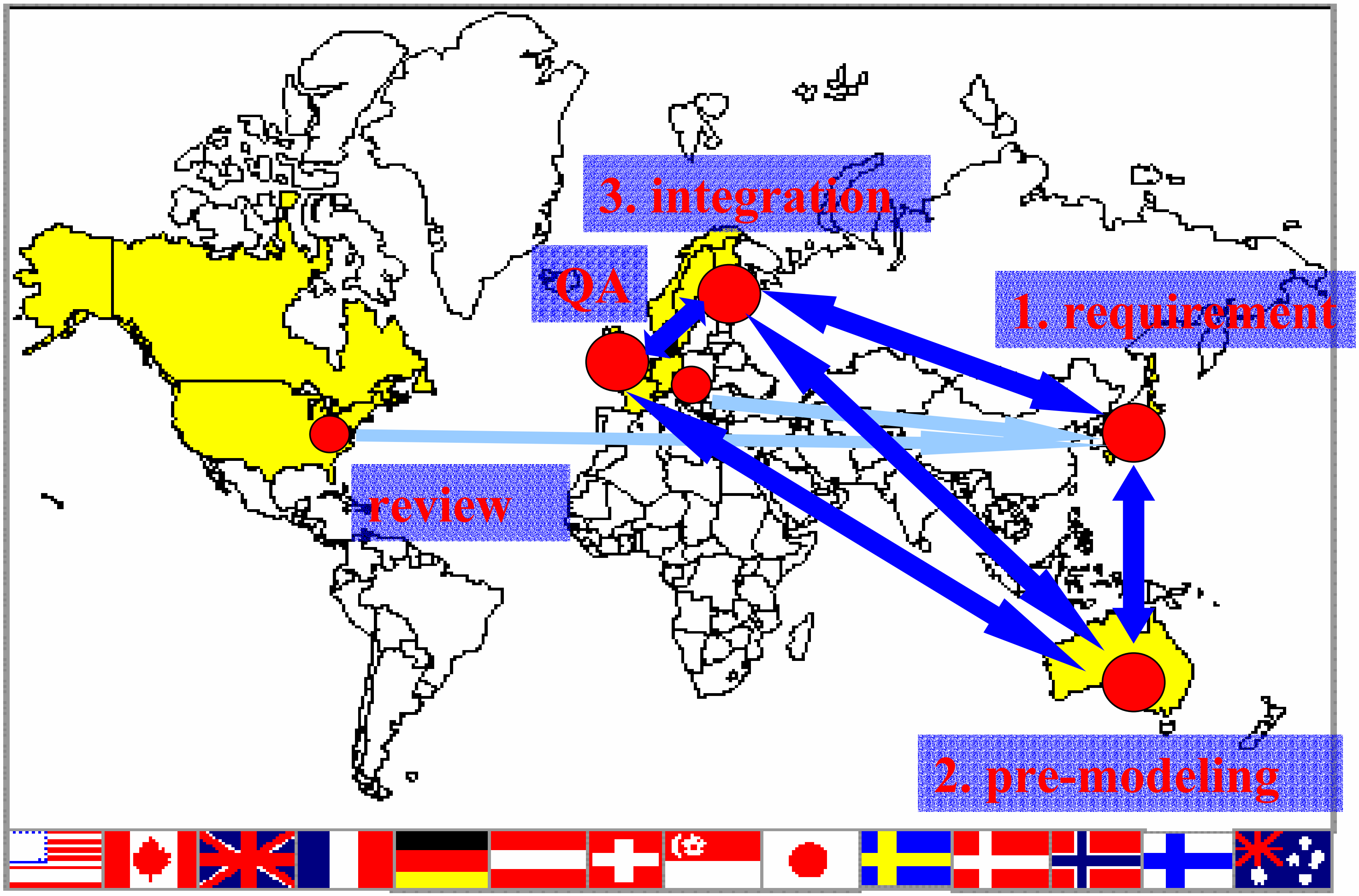
9 Chapters of IAI



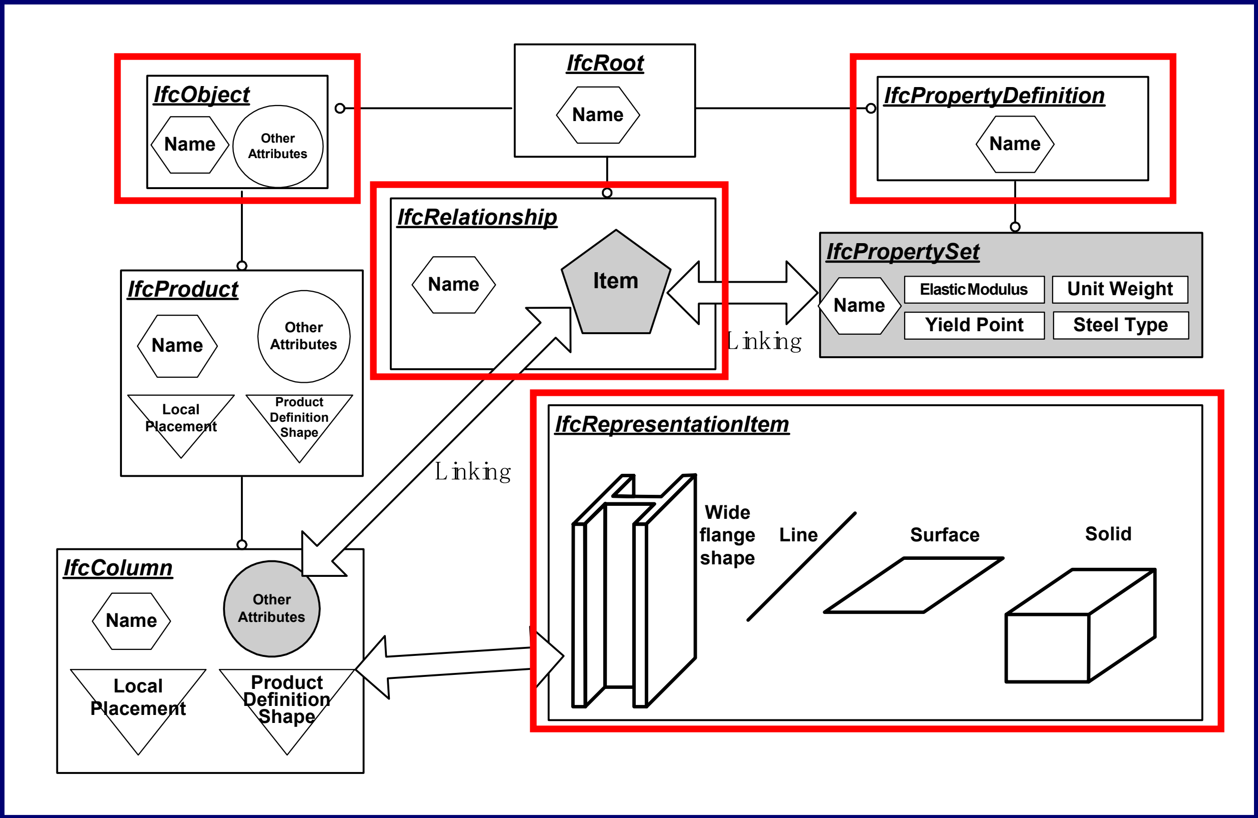
Structural Domain Projects in IFC



Collaboration for ST-2 Development



Basic Elements of IFC2x



- IfcObject class defines objects such as beams and columns.
- IfcPropertyDefinition class can contain supplementary information about IfcObject class.
- IfcRelationship class defines the relationship between objects and property sets.
- IfcRepresentationItem provides resources on geometric information.

Characteristics of IFC2x

- Properties of objects are separated from the object classes and are defined in property sets. → Flexible representation.
- Although IFC2x provides many object classes representing building members, there are not many classes for members of civil engineering structures.
- Classes for representing internal elements are not defined in IFC2x.

↓

In order to check the interference among internal elements including rebars, pipes, cables, sheaths, etc. and covering of rebars in a pre-construction or construction stage, 3D geometric models of internal elements would be necessary.

3. A Product Model for RC and PC Bridges

Concept for Modeling

- Since IFC is developed for modeling buildings, it is difficult to directly apply it to bridges. But it is inefficient to develop a completely new model for bridges from scratch.
- As IFC is developed to become an international standard in ISO, it is advantageous to develop product models based on IFC from an international standard point of view.

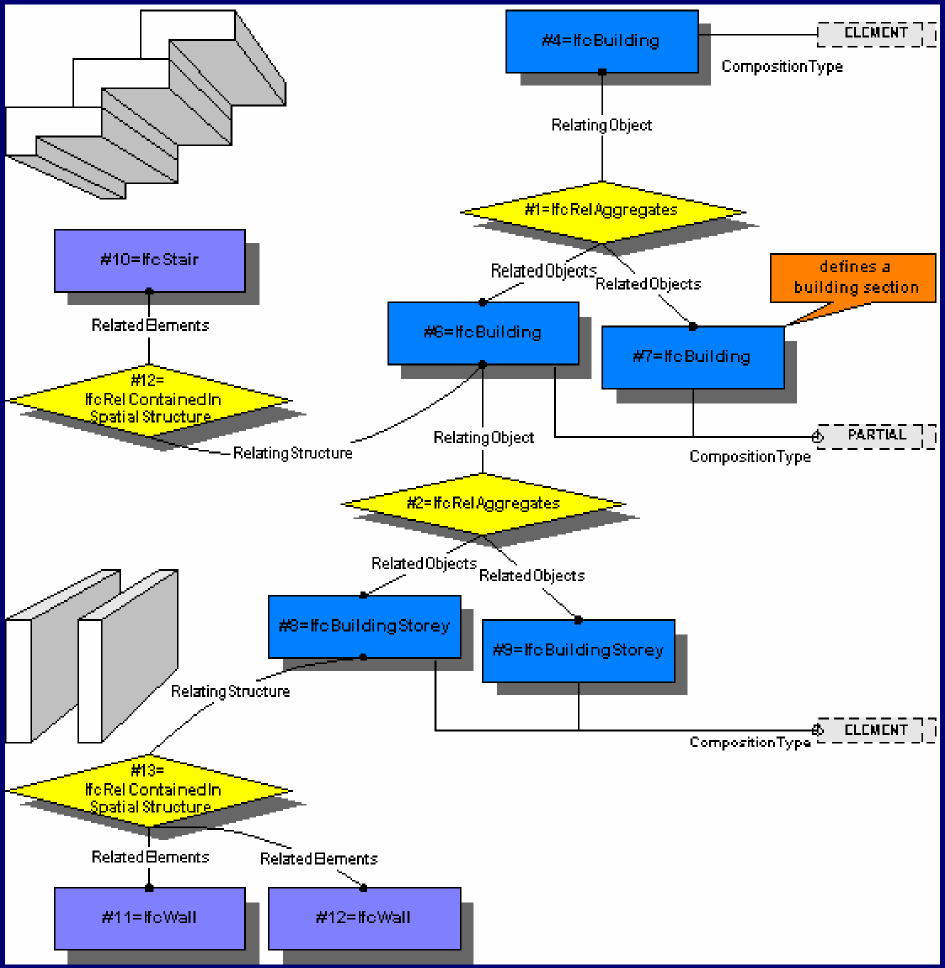
Thus, we have decided to develop our bridge product model based on IFC2x, keeping its basic structure, adding only necessary classes, while having generality to apply it to other kinds of infrastructure.

And a type of prestressed concrete hollow slab bridges has been selected as a sample for validation and demonstration.

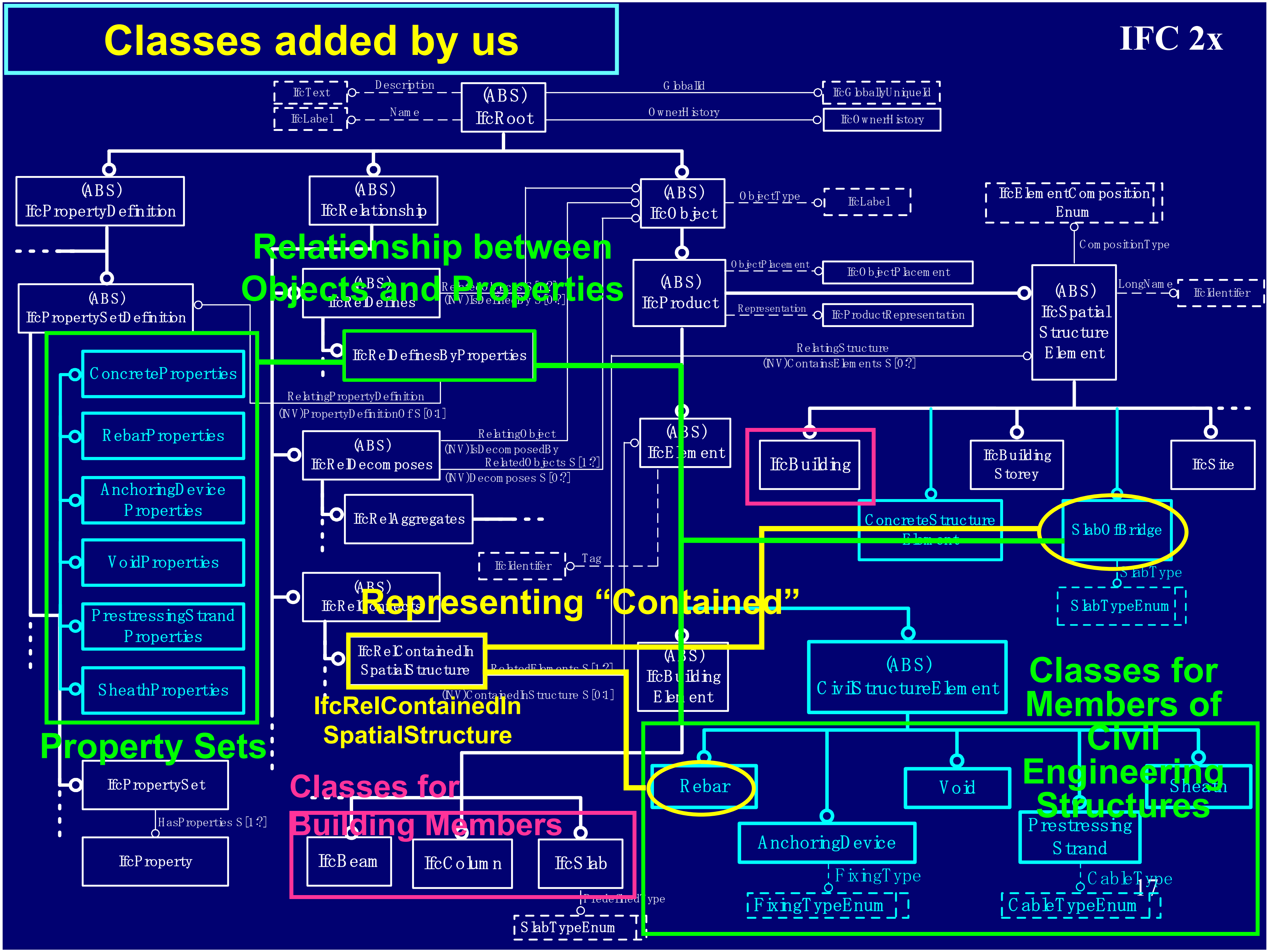
Concrete Members

- Concrete members in bridges have more geometric freedom than typical building concrete members such as beams, columns, walls, and slabs.
- And since concrete members contain rebars, voids, sheaths, etc., if we define concrete members as perfect solids, we have to subtract contained members, which is cumbersome.
- On the other hand, if we define a concrete member as a set of single surfaces, it is difficult to apply 3D finite element mesh generation and quantity calculation to concrete members.
- Thus, we represented a concrete member as a simple solid model comprised of a set of surfaces having a property of inside or outside of the member in our product model. And, contained members clearly indicate that they are “contained” in the concrete member.

In IFC, the IfcRelationship class has a sub class named IfcRelContainedInSpatialStructure. This class is used to represent that IfcBuildingElement members such as IfcBeam, IfcColumn, IfcSlab, etc., are “contained” in the IfcBuilding class.



The basic geometry of IfcBuilding is represented in IfcFacetedBrep (Brep or B-Rep), which is a closed solid comprised of a set of surfaces and which can store the information of the inside.

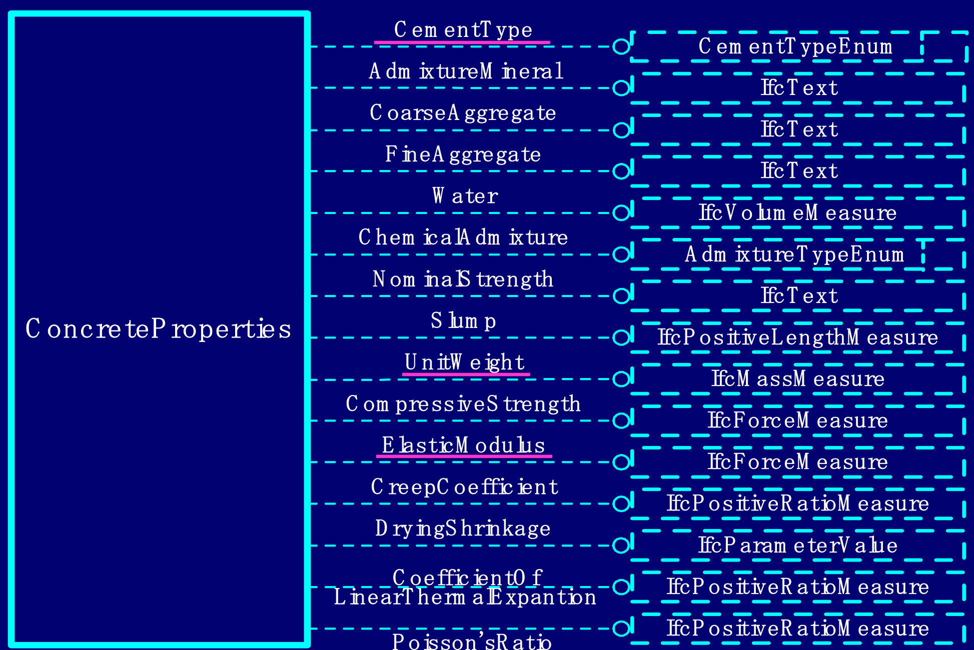


Classes added by us
IFC 2x
IfcText
Description
IfcLabel
Name
(ABS) IfcRoot
GlobalId
IfcGloballyUniqueId
OwnerHistory
IfcOwnerHistory
(ABS) IfcPropertyDefinition
(ABS) IfcRelationship
(ABS) IfcObject
ObjectType
IfcLabel
IfcElementCompositionEnum
CompositionType
(ABS) IfcPropertySetDefinition
(ABS) IfcRelDefines
(NV)IsDefinedBy S[0:?]
(ABS) IfcProduct
ObjectPlacement
IfcObjectPlacement
Representation
IfcProductRepresentation
(ABS) IfcSpatialStructureElement
LongName
IfcIdentifier
Relationship between Objects and Properties
IfcRelDefinesByProperties
RelatingStructure
(NV)ContainsElements S[0:?]
ConcreteProperties
RebarProperties
AnchoringDevice Properties
VoidProperties
PrestressingStrand Properties
SheathProperties
Property Sets
RelatingPropertyDefinition
(NV)PropertyDefinitionOf S[0:1]
(ABS) IfcRelDecomposes
RelatingObject
(NV)IsDecomposedBy
RelatedObjects S[1:?]
(NV)Decomposes S[0:?]
IfcRelAggregates
(ABS) IfcElement
IfcIdentifier
Tag
IfcBuilding
IfcBuilding Storey
IfcSite
ConcreteStructure Element
SlabOfBridge
SlabType
SlabTypeEnum
(ABS) IfcRelConnects
Representing "Contained"
IfcRelContainedIn SpatialStructure
RelatedElements S[1:?]
(NV)ContainedInStructure S[0:1]
IfcRelContainedIn SpatialStructure
(ABS) IfcBuilding Element
(ABS) CivilStructureElement
Classes for Members of Civil Engineering Structures
Rebar
Void
Sheath
AnchoringDevice
PrestressingStrand
FixingType
FixingTypeEnum
CableType
CableTypeEnum
IfcPropertySet
HasProperties S[1:?]
IfcProperty
Classes for Building Members
IfcBeam
IfcColumn
IfcSlab
PredefinedType
SlabTypeEnum
17

Definition of SlabOfBridge (EXPRESS)

```
ENTITY SlabOfBridge;
   GlobalId            : IfcGloballyUniqueId;
   OwnerHistory        : IfcOwnerHistory;
   Name                : OPTIONAL IfcLabel;
   Description         : OPTIONAL IfcText;
   ObjectType          : OPTIONAL IfcLabel;
   IsDefinedBy         : SET OF IfcRelDefines FOR RelatedObjects;
   HasAssociations     : SET OF IfcRelAssociates FOR RelatedObjects;
   HasAssignments      : SET OF IfcRelAssigns FOR RelatedObjects;
   Decomposes          : SET OF IfcRelDecomposes FOR RelatedObjects;
   IsDecomposedBy      : SET [0:1] OF IfcRelDecomposes FOR RelatingObject;
   ObjectPlacement     : OPTIONAL IfcObjectPlacement;
   Representation      : OPTIONAL IfcProductRepresentation;
   ReferencedBy        : SET OF IfcRelAssignsToProduct FOR RelatingProduct;
   LongName            : OPTIONAL IfcIdentifier;
   CompositionType     : IfcElementCompositionEnum ;
   ContainsElements    : SET OF IfcRelContainedInSpatialStructure FOR RelatingStructure;
   SlabType            : SlabTypeEnum
END_ENTITY;
```

Property Set of Concrete (EXPRESS-G)



Rebars

- Each rebar is represented as an object. The geometry of a rebar can be represented by extruding a circle to a direction expressed in a vector or revolving the circle in a curve, as IfcExtrudedAreaSolid or IfcRevolvedAreaSolid, respectively.
- As the anchorage part of rebars usually has no difference in appearance, the authors defined data such as embodiment length, location, type, etc., in a property set.
- A lap splice of rebars is not represented as two bars in our model but is represented as a part of continuous bars having a property that the part is a lap splice.
- Other attributes of rebars such as rebar type, nominal name, elastic modulus, etc., are defined in the property set

Other Members

- •Void
- •PrestressingStrand
- •AnchoringDevice
- •Sheath, etc.

4. Implementation Issues

Although schemata of product models are to be defined in EXPRESS in ISO STEP, XML is widely used for implementing product models. We compared the following three XMLs:

- aecXML,
- BLIS-XML,
- ifcXML.

We selected ifcXML for implementing our product model.

BLIS-XML

We previously used BLIS-XML for implementing our product model for steel frames consisting of beams, columns, connections, etc.

However, BLIS-XML has a problem that we cannot verify the relationship between the schema and instances in terms of attribute type. Further, since BLIS-XML cannot represent the inheritance from a class to its sub classes, it is necessary to declare all attributes for each class, which is cumbersome.

IfcXML

The XML Schema is used as a schema for ifcXML.

The defects in BLIS-XML are all solved.

For these reasons, we have adopted ifcXML for implementing our product model.

4. Implementation Using IfcXML

We implemented the schema of the product model for prestressed concrete hollow slab bridges using ifcXML, and then, developed an instance file for a real PC hollow slab bridge on the basis of the developed product model.

```
- <xsd:complexType abstract="true" name="SpatialStructureElement">
  - <xsd:complexContent>
    - <xsd:extension base="Product">
      - <xsd:sequence>
          <xsd:element type="Identifier" minOccurs="0" name="longName" />
          <xsd:element type="ElementCompositionEnum" name="compositionType" />
        - <xsd:element name="containsElements" minOccurs="0" maxOccurs="unbounded">
          - <xsd:complexType>
              <xsd:attribute ref="inverse" />
            </xsd:complexType>
          </xsd:element>
        </xsd:sequence>
      </xsd:extension>
    </xsd:complexContent>
  </xsd:complexType>
- <xsd:complexType name="SlabOfBridge">
  - <xsd:complexContent>
    - <xsd:extension base="SpatialStructureElement">
      - <xsd:sequence>
          <xsd:element type="SlabTypeEnum" name="slabType" />
        </xsd:sequence>
      </xsd:extension>
    </xsd:complexContent>
  </xsd:complexType>
```

A part of the product model schema in ifcXML

```
- <SlabOfBridge id="_1001">
    <globalId>|.CY[$]o+Hw=#rH0,xe1</globalId>
  + <ownerHistory>
    <name>Original Bridge</name>
    <description />
    <objectType />
    <isDefinedBy inverse="_101" />
    <isDecomposedBy />
    <decomposes />
  + <objectPlacement>
  + <representation>
    <longName />
    <compositionType>COMPLEX</compositionType>
    <slabType>PCHollowSlabBridge</slabType>
    <containsElements inverse="_1000" />
  </SlabOfBridge>
- <CartesianPoint id="_1004">
    <coordinates>0,0,0</coordinates>
  </CartesianPoint>
- <CartesianPoint id="_1009">
```


A part of the instance file representing SlabOfBridge

Data of Cartesian points determining the geometry of the slab of the bridge.

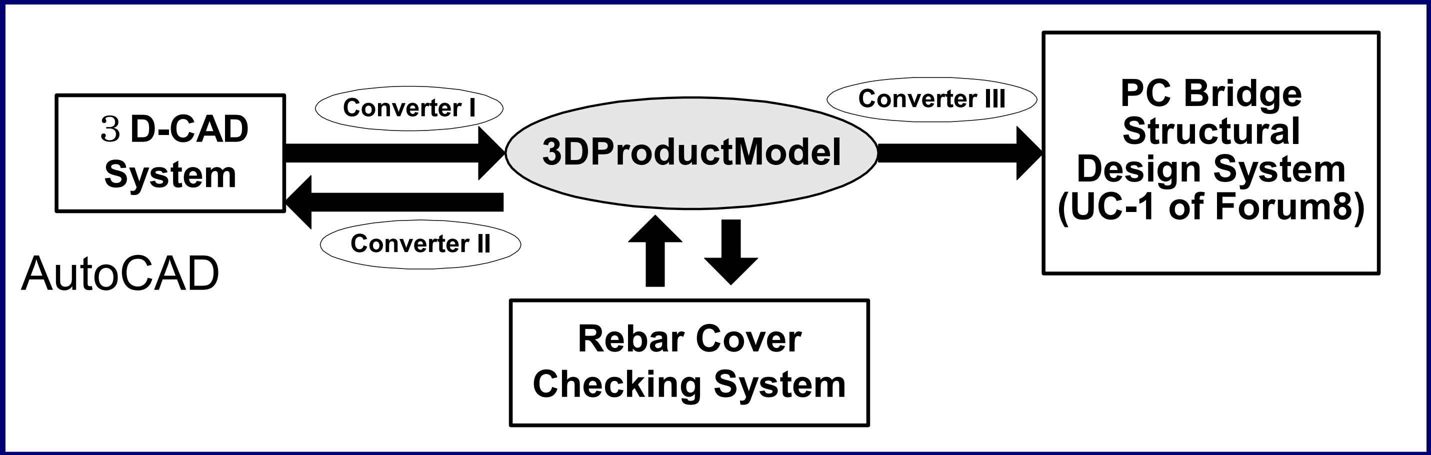
```
- <RelDefinesByProperties id="_101">
  - <relatedObjects>
      <SlabOfBridge href="_1001" />
    </relatedObjects>
  - <relatingPropertyDefinition>
      <ConcreteProperties id="_202" />
    </relatingPropertyDefinition>
  </RelDefinesByProperties>
- <RelContainedInSpatialStructure id="_1000">
  - <RelatingStructure>
      <SlabOfBridge href="_1001" />
    </RelatingStructure>
  - <RelatedElements>
      <Rebar href="_3001" />
      <Rebar href="_3002" />
      <Rebar href="_3003" />
      <Rebar href="_3004" />
      <Rebar href="_3005" />
      <Rebar href="_3006" />
      <Rebar href="_3007" />
```


A part of the instance representing the relationship

IfcRelDefinesByProperties class links SlabOfBridge to ConcreteProperties.

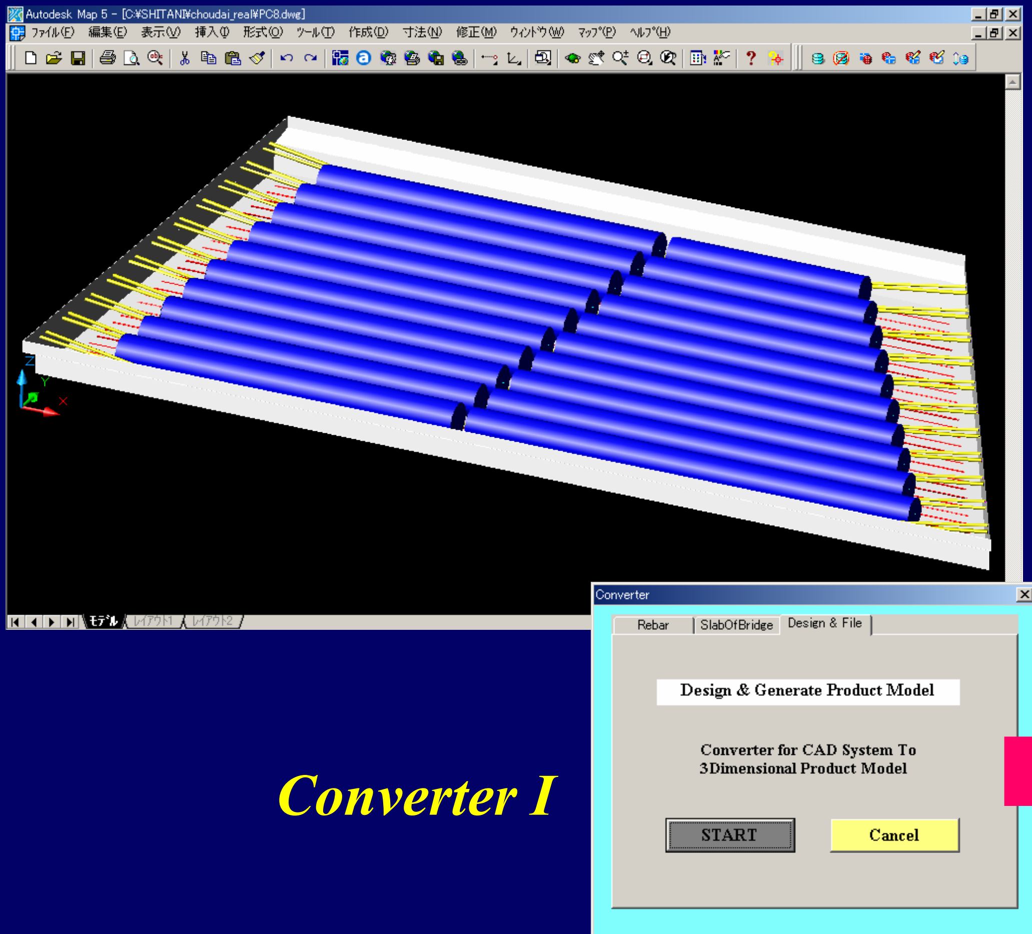
IfcRelContainedInSpatialStructure class links SlabOfBridge to rebars contained in the slab.

5. Integration of the Product Model with Application Systems



In order to check the validity and practicality of the developed product model, the product model was integrated with three application systems, and they were applied to a design case.

Design Application (1) Preliminary Design



Converter I

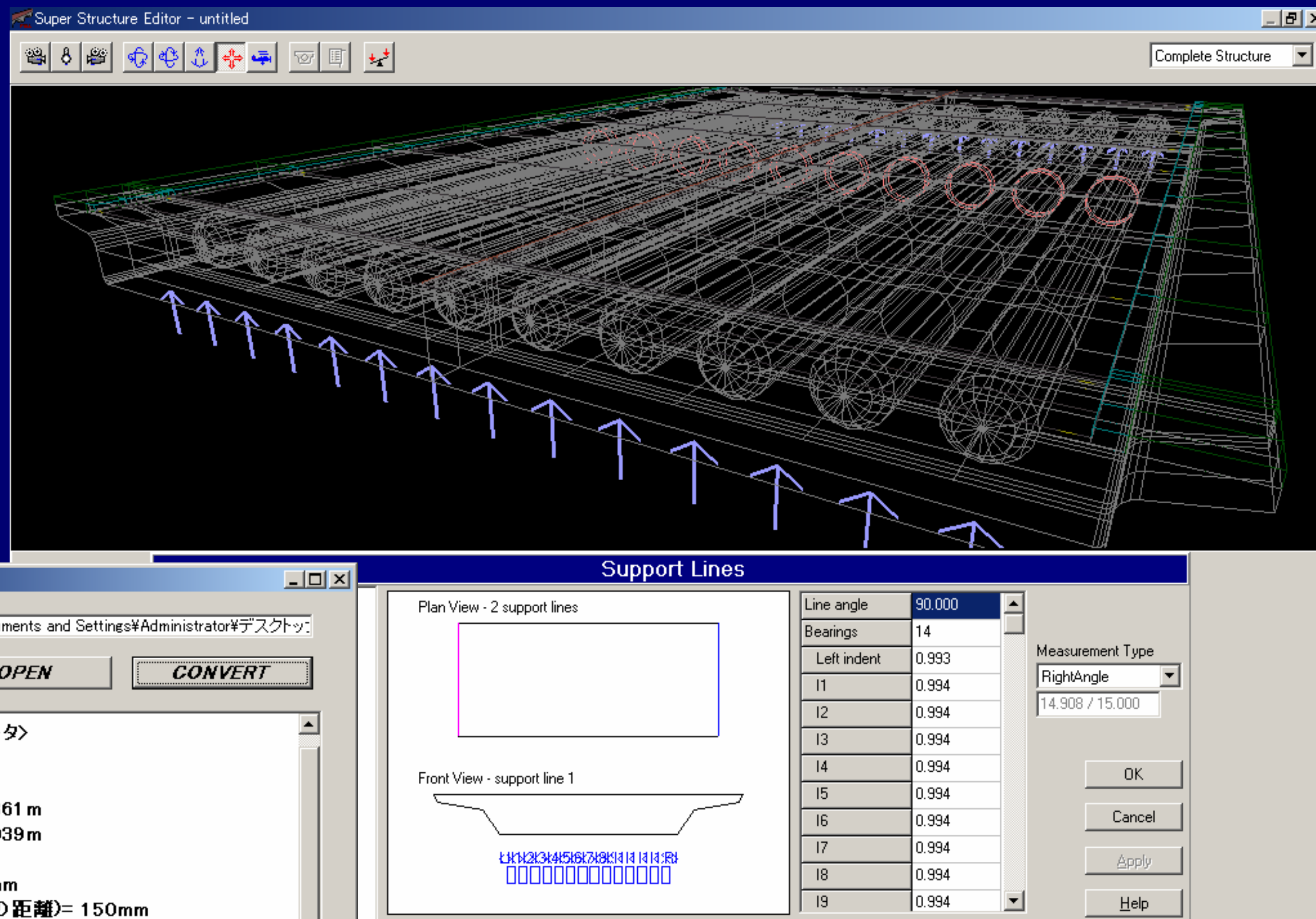

```
<?xml version="1.0" encoding="utf-8" ?>
- <ifcXML schema="IFC 2x Final">
  - <SlabOfBridge id="_1001">
      <globalId>|.CY[$]o+Hw=#rH0,xe1</globalId>
    + <ownerHistory>
      <name>Original Bridge</name>
      <description />
      <objectType />
      <isDefinedBy inverse="_101" />
      <isDecomposedBy />
      <decomposes />
    + <objectPlacement>
    + <representation>
      <longName />
      <compositionType>COMPLEX</compositionType>
      <slabType>PCHollowSlabBridge</slabType>
      <containsElements inverse="_1000" />
    </SlabOfBridge>
  - <CartesianPoint id="_1004">
      <coordinates>0,0,0</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1009">
      <coordinates>0,0,0</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1201">
      <coordinates>0,0,1275</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1202">
      <coordinates>0,0,1525</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1203">
      <coordinates>0,13100,1525</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1204">
      <coordinates>0,13100,1275</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1205">
      <coordinates>0,12450,1175</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1206">
      <coordinates>0,12450,525</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1207">
      <coordinates>0,650,525</coordinates>
    </CartesianPoint>
  - <CartesianPoint id="_1208">
      <coordinates>0,650,1175</coordinates>
```

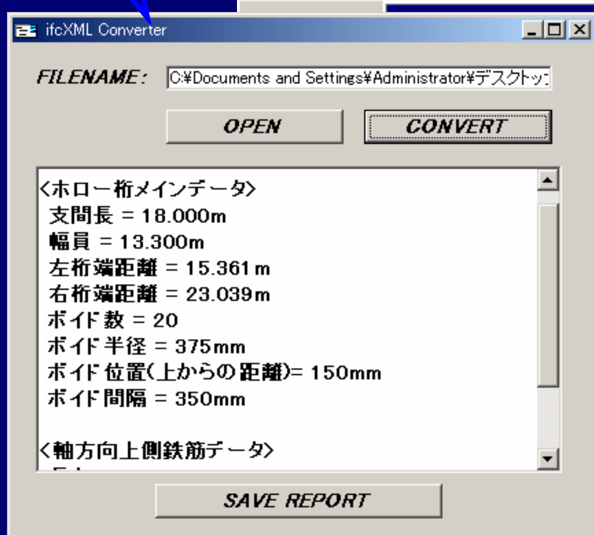

ifcXML instance file

Preliminary Design Using a 3D-CAD System

Design Application (2) Analysis, Code Checking

Representing necessary data for analysis and detailed design





Converter III

U/I of UC-1 of Forum 8

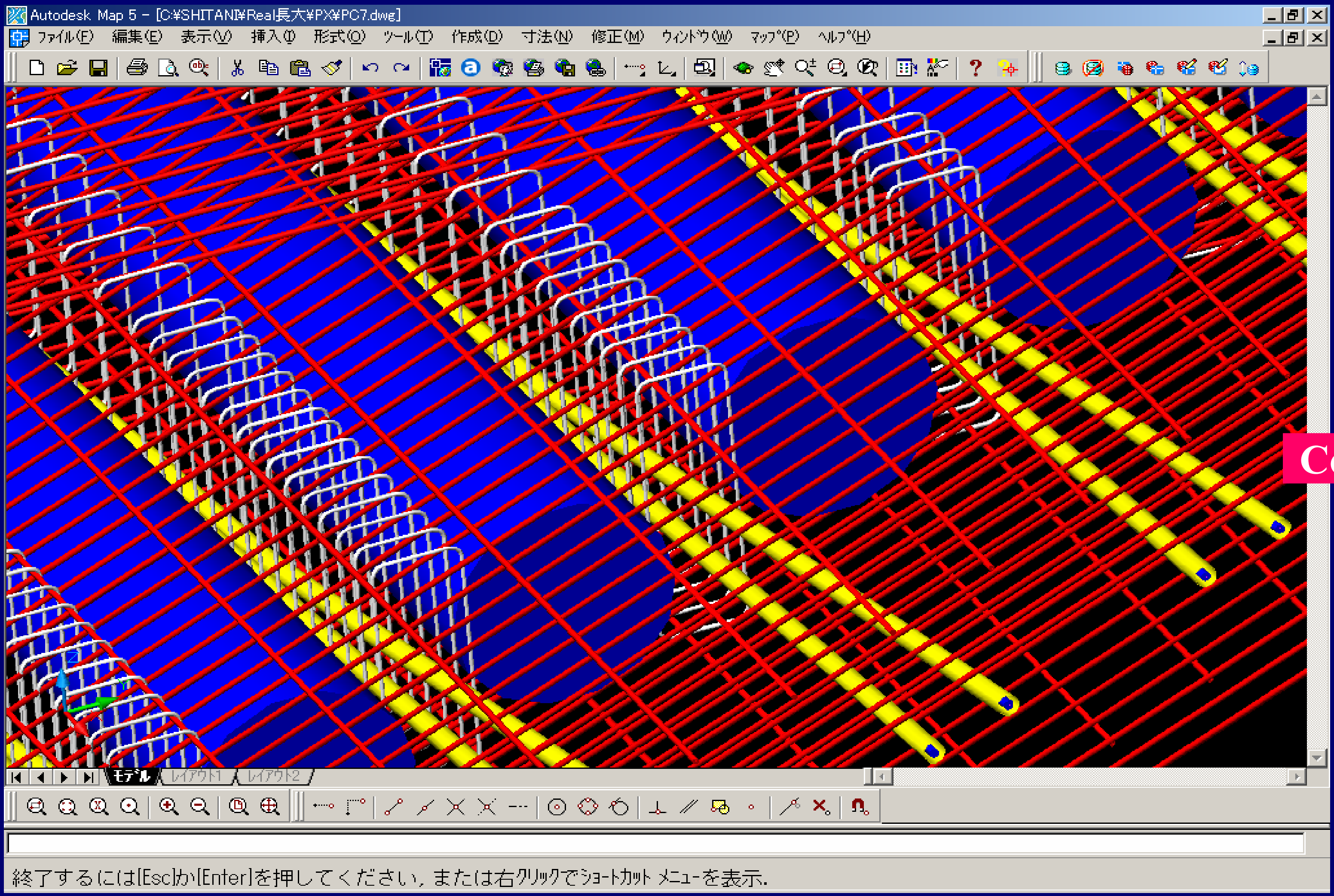
Calculation Summary - untitled

Critical Failure Ratio Summary			
Calculation	**Failure Description**	**Node**	**Critical Ratio**
PC Analysis			
Tension Steel	Not Calculated		0.000
Concrete Shear Stress (Design Loads)	Critical Live Load	G2-12	0.978
Concrete Diagonal Tension Stress	Critical Live Load Neutral Axis	G2-11	0.257
Shear Reinforcing Stress	Critical Snow Load	G2-1	0.000
Fatigue Strength (shear reinforcing)	Not Calculated		0.000
Reinforcing Stress (PC)	Critical Live Load Top	G2-9	0.254
PC Cable Stress (PC)	Critical Live Load Cable Centroid	G2-8	0.734
Concrete Stress (PC)	Critical Construction Top	G2-15	0.706
		Average Efficiency Rating	**0.366**
Strength Analysis (Ultimate Actions)			
Ultimate Moment Capacity	1.7D + 1.7Lmax + 1.0P	G2-9	0.738
Concrete Shear Stress (Ultimate Loads)	1.7D + 1.7L + 1.0P	G2-14	0.181
		Average Efficiency Rating	**0.459**
PRC Analysis			
Flexural Crack Widths	Critical Live Load Bottom	G2-9	0.393
Fatigue Strength (longitudinal reinforcing)	No Support Settlement Bottom Steel	G2-9	0.440
Reinforcing Stress (PRC)	Critical Live Load Bottom	G2-9	0.353
PC Cable Stress (PRC)	Critical Live Load Cable Centroid	G2-9	0.799
Concrete Stress (PRC)	Critical Snow Load Bottom	G2-4	0.578
		Average Efficiency Rating	**0.513**

Font... Help Details... Close

Result of Code Checking

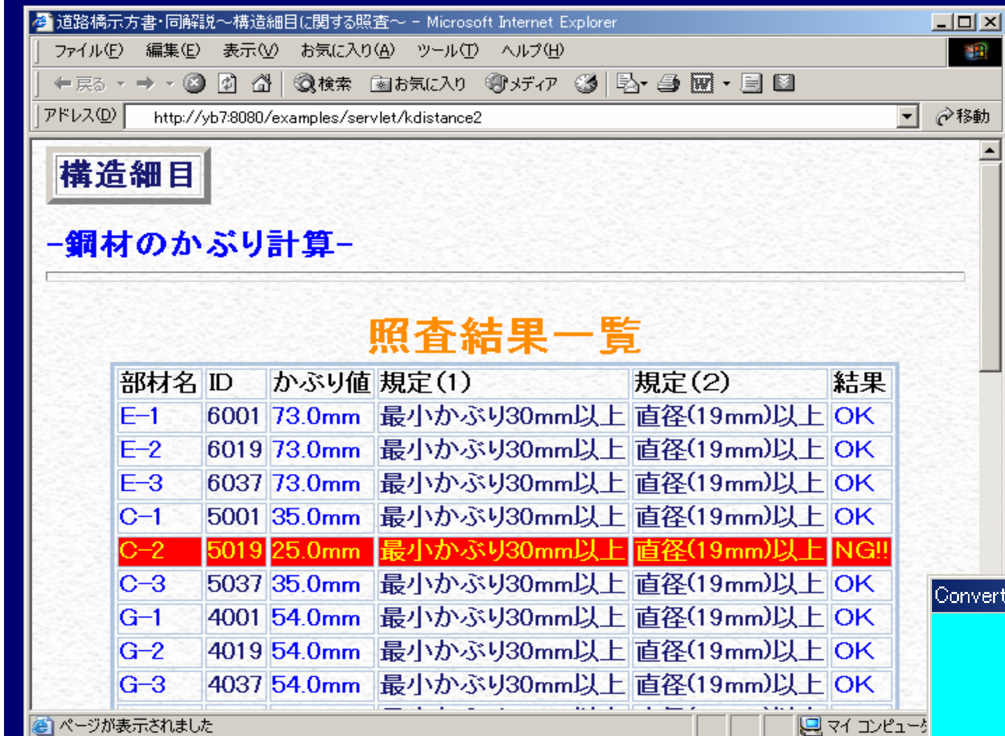
Design Application (3) Detailed Design



Converter I

Detailed design including rebars, sheaths, etc.

Design Application (4) Checking Rebar Cover



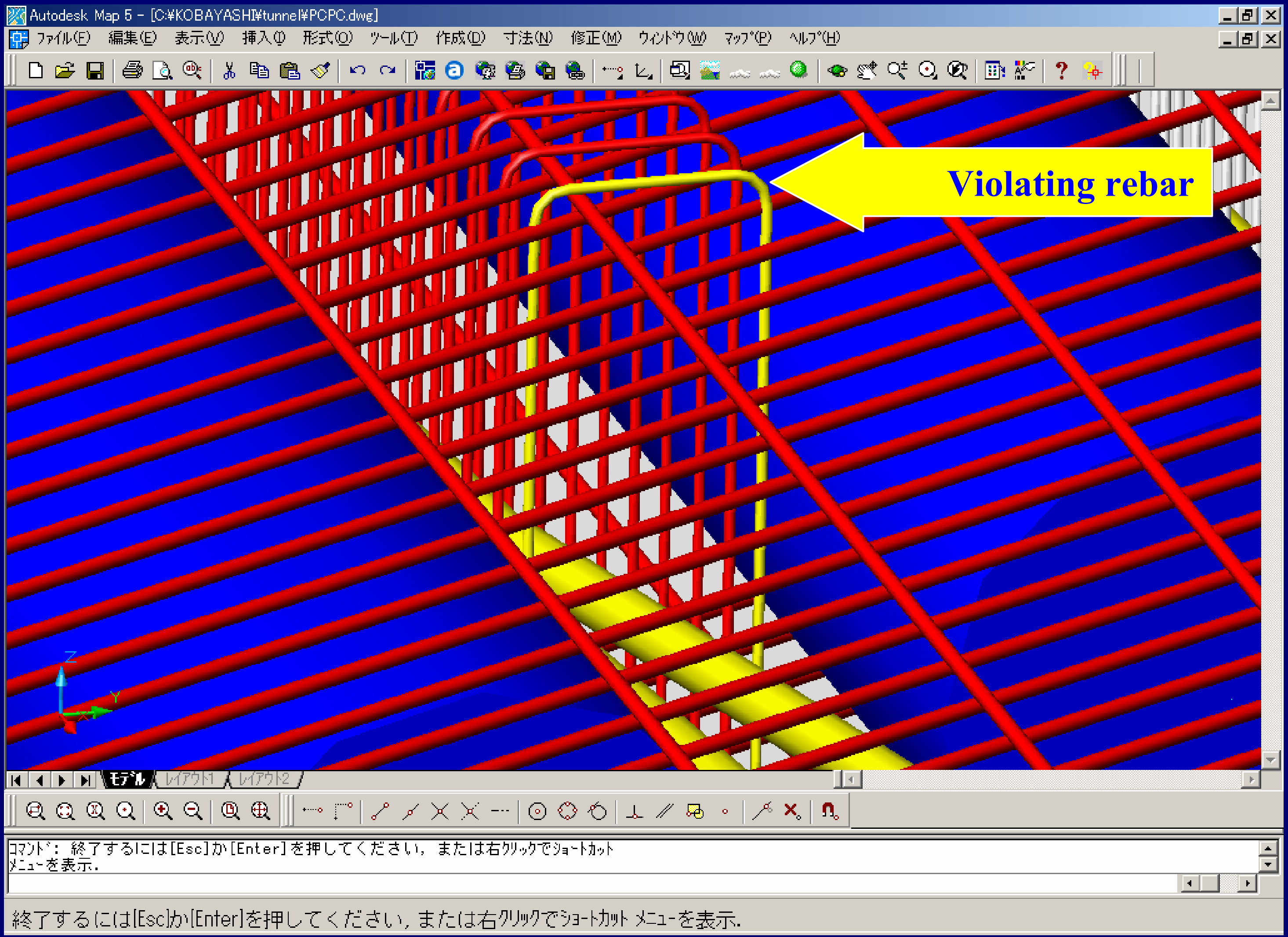
部材名	ID	かぶり値	規定(1)	規定(2)	結果
E-1	6001	73.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
E-2	6019	73.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
E-3	6037	73.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
C-1	5001	35.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
C-2	5019	25.0mm	最小かぶり30mm以上	直径(19mm)以上	NG!!
C-3	5037	35.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
G-1	4001	54.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
G-2	4019	54.0mm	最小かぶり30mm以上	直径(19mm)以上	OK
G-3	4037	54.0mm	最小かぶり30mm以上	直径(19mm)以上	OK

- Rebar Cover Checking System
- Modified product model data is transferred to AutoCAD by Converter II.

Information about the error is added to the product model.

Converter II

Inside of the Slab



A rebar violating the cover requirement

6. Conclusion

We developed a product model for RC or PC slab bridges on the basis of IFC, and implemented the product model schema and instance by ifcXML. Then, the product model was integrated with three application systems. The contribution of this research is as follows

- We have expanded the realm of IFC from buildings to RC and PC bridges.
- New classes for properly representing a slab and contained members such as rebars, prestressing strands, voids, etc., have been defined.
- A modern model developing technique, i.e., separating property sets from object classes rather than representing all attributes in product classes, was employed, which makes the model more flexible.
- The pros and cons of various XML were discussed and ifcXML has been evaluated as a most suitable XML schema for implementation of product models based on IFC.
- This research showed the validity and practicality of the product model by integrating three application systems using the developed product model and data conversion programs.

Thank you!