Development and Integration of an IFC-Based Product Model for Prestressed Concrete Bridges

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Summary

A product model was developed for prestressed concrete bridges based on the Industry Foundation Classes (IFC) in order to enable interoperability of various CAD and non-CAD application systems throughout the lifecycle of structures. New classes for representing concrete slabs, prestressing strands, sheaths, voids, reinforcing bars, and anchoring devices were defined in this research. This model can clearly represent the relationship that the concrete slab contains elements such as rebars, prestressing strands, and voids by defining the concrete slab as a spatial structure element with B-rep. We implemented the schema of the product model and instances of a prestressed concrete hollow slab bridge using ifcXML. Three design application systems including 3D-CAD were integrated with the product model. The application test cases showed the feasibility and practicality of the product model.

Keywords: product models; CAD; prestressed concrete; prestressed concrete hollow slab bridges; interoperability; integration; IFC; XML; reinforcing bars; data modeling.

1. Introduction

Research and development on product models have been carried out for a number of years in order to enable the interoperability of various application systems in a lifecycle of products and structures. Various standards and specifications for product models, including the Product Data Exchange Standard (PDES) [1], International Organization for Standardization (ISO) 10303 known as STEP (Standards for The Exchange of Product model data) [2], Industry Foundation Classes (IFC) of International Alliance for Interoperability (IAI) [3], etc., have been proposed. Although research and development of product models for industrial products, buildings, and steel bridges have been done quite extensively, not so much outcome has been seen for developing standardized product models for reinforced concrete (RC) and prestressed concrete (PC) civil engineering structures such as RC/PC bridges, dams, harbors, etc. In the past, we developed our product model for prestressed concrete hollow slab bridges, and implemented it using eXtensible Markup Language (XML) to demonstrate the efficiency improvement by achieving the interoperability among application systems including 3D-CAD, code checking, quantity calculation, cost estimation, scheduling, and inspection for maintenance [4]. However, the modeling approach employed then was a classical one that each class contains its all attributes inside of the class but not having its property classes outside. Since the classical method tends to increase the number of attributes for each class unmanageably, a modern modeling technique that property classes are defined separately from product classes should be employed. Furthermore, we believe that more standardized product models and implementation techniques should be developed and used for RC/PC civil engineering structures.

Since IAI has developed a relatively mature and standardized product model, IFC, for buildings, which are similar to bridges in a sense, we selected IFC and its implementation language, ifcXML, as the base for developing a product model for PC bridges in this research. The objective of this research is the following. Note that product models representing PC bridges can represent RC structures as well.

Developing a product model for PC superstructures of bridges based on IFC of IAI.

Implementing the developed product model and instances of a selected bridge.

Integrating the product model and design application systems by developing conversion programs among them.

The French Chapter of IAI has developed IFC-Bridge [5], employing the similar approach to ours coincidentally, not knowing with each other.

2. A Product Model for PC Bridges

2.1. An Outline of the Product Model

Since IFC is developed for modeling buildings, it is difficult to directly apply it to bridges. Thus, we have decided to develop our bridge product model based on IFC2x, the current version of IFC, taking as much care as possible to keep its basic structure, adding only necessary classes, while having generality to apply it to other kinds of infrastructure. In addition, a type of prestressed concrete hollow slab bridges has been selected as a sample for validation and demonstration.

A PC bridge consists of members such as concrete, voids (hollow pipes), prestressing strands, anchoring devices, sheaths, rebars, etc. One of the issues was how to represent that the concrete slab or girder "contains" voids, prestressing strands, anchoring devices, sheaths, and rebars. In addition, since rebars have high geometric freedom and have embodiment lengths and joints as properties, the other issue was how rebars should be represented in the model. *Fig. 1* shows the outline of the developed product model.

2.2. Concrete Members

Concrete members in bridges have more geometric freedom than typical building concrete members such as beams, columns, walls, and slabs. In addition, 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. In addition, contained members clearly indicate that they are "contained" in the concrete member.

In IFC, the IfcRelationship class has a sub class named IfcRelContainedInSpatialStructure (*Fig. 1*). This class is used to represent that IfcBuildingElement members such as IfcBeam, IfcColumn, IfcSlab, etc., are "contained" in the IfcBuilding class. Further, 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. Thus, Brep satisfies the two conditions described above.

Therefore, as the concrete structure of a PC hollow slab bridge has the same characteristics of IfcBuilding, a new class SlabOfBridge was defined in the same story of IfcBuilding. Furthermore, we defined new member classes, Rebar, AnchoringDevice, Void, PrestressingStrand, and Sheath in the same story of IfcColumn and IfcBeam. Furthermore, we defined new property sets to represent the property information such as material characteristics of concrete, rebars, prestressing strands. Each property set and the corresponding member class are linked by the class IfcRelDefinesByProperties.

2.3. Reinforcing Bars

In our product model, 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.

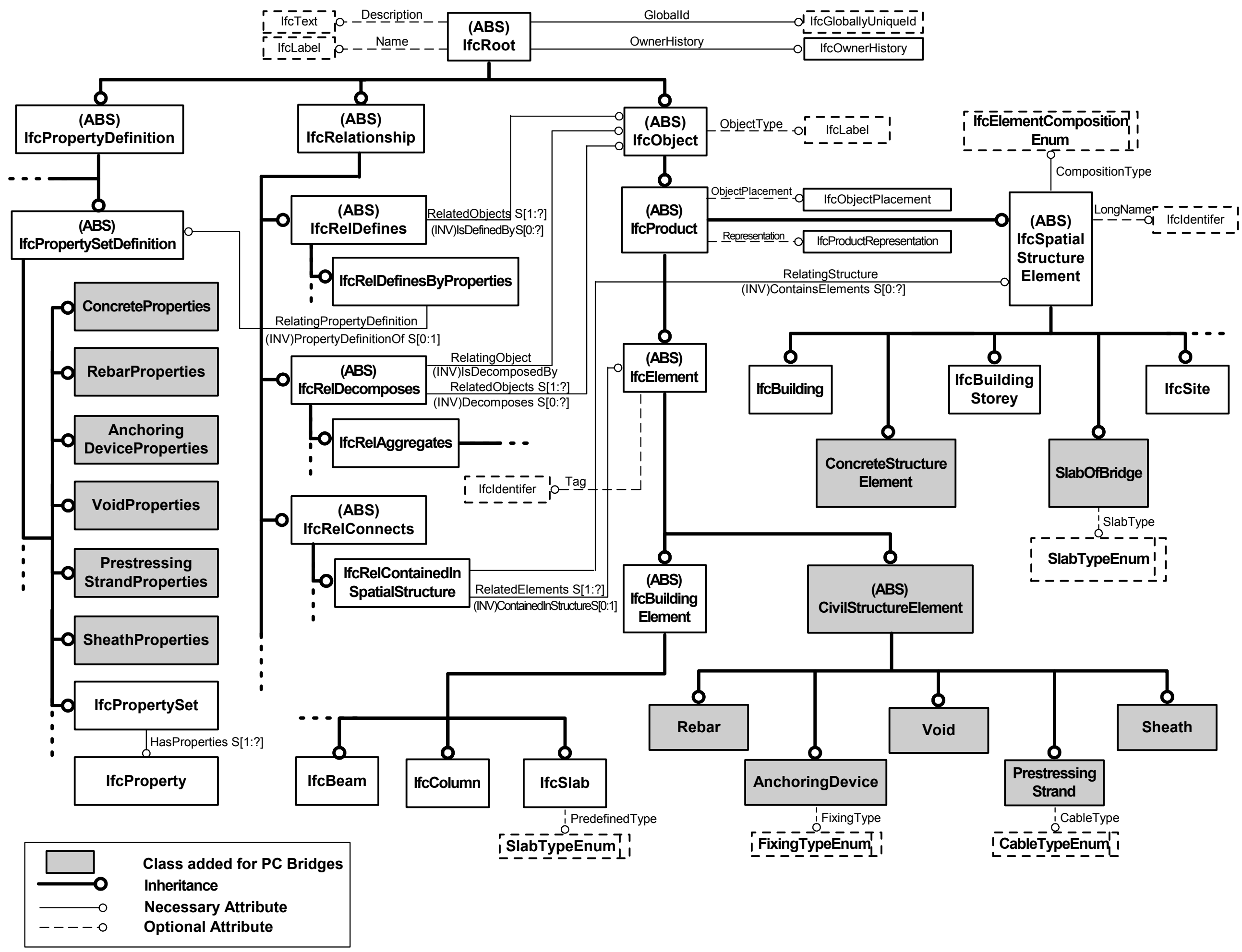

Fig. 1 Product model classes for prestressed concrete slab bridges represented in EXPRESS-G

As the anchorage part of rebars usually has no difference in appearance, we 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 Rebar, such as rebar type, nominal name, elastic modulus, etc., are defined in the property set (*Fig. 2*).

2.4. Other Members

We defined the class of prestressing strands were defined in the same manner for rebars. The properties except the geometry of prestressing strands are represented in the property set, PrestressingStrandProperties. Thus, real property data can be stored in the instance of PrestressingStrandProperties class. However, not all data should necessarily be stored in the property set. Since data such as tensile load, elongation, relaxation, nominal area, unit weight, etc. are automatically designated by specifying the steel type and nominal name, such data can be retrieved from a linked steel database system. Other member classes and property sets were also defined for voids, sheaths, etc.

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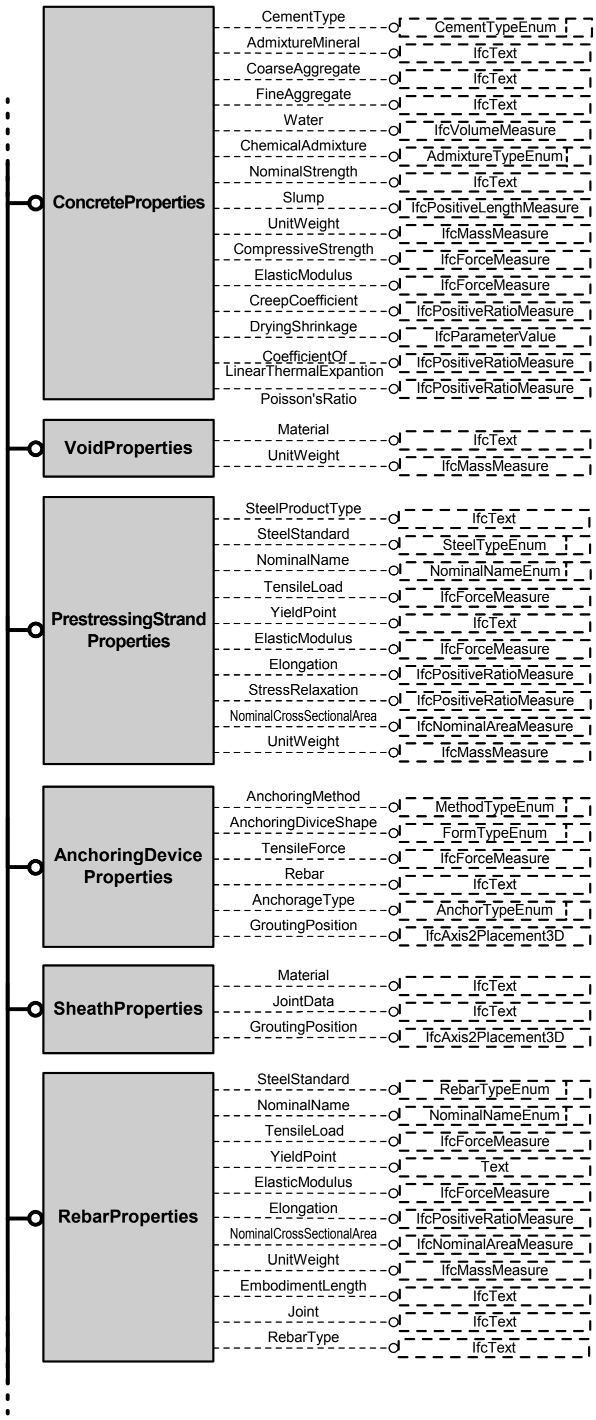

Fig. 2 Property sets for new members

3. Implementation

Although schemata of product models are to be defined in EXPRESS in ISO STEP and IFC, XML is widely used for implementing product models. In our research, we selected ifcXML [6] for the implementation of the schema of the product model for prestressed concrete hollow slab bridges, and then, developed an instance file for a real PC hollow slab bridge based on the developed product model. *Fig. 3* shows a part of the product model schema representing SlabOfBridge class.

Since ifcXML can represent inheritance among classes, the schema structure is simple and clear compared with BLIS-XML. Although the number of lines of ifcXML schema and instance files is much larger than that of BLIS-XML, we believe that the reliability of model data is much better in ifcXML than BLIS-XML because it becomes possible to verify the consistency between the schema and instances with ifcXML.

4. Integration and Application

In order to check the validity and practicality of the developed product model, the product model was integrated with three application systems, i.e., 3D-CAD (AutoCAD 2002), a PC bridge structural design system (UC-1 of Forum8), and a rebar cover checking system by developing prototype data conversion programs (*Fig. 4*), and they were applied to a design case.

We developed Converter Program I, which is an interface between the product model and AutoCAD, using Visual Basic for Application (VBA). This program semi-automatically generates an instance file of the developed product model in ifcXML when the user makes a model, using AutoCAD. In addition, we developed Converter Program II, which retrieves data from an instance file of the developed product model by using an XML parser and which renders the 3D model in AutoCAD automatically. Convert Program III bridges the product model and the design software (UC-1). Furthermore, we developed a rebar cover checking system by using Java Servlet and XML for Java Parser. This system directly reads an instance file of the product model data and computes the minimum distance between each rebar and each surface of the concrete slab. Then, if the minimum distance is smaller than the required cover, the system adds the information to the violated rebar in the product model.

The application case scenario is described in the following. First, a designer constructs a preliminary 3D CAD model of the PC hollow slab bridge (*Fig. 5*). At this stage, each rebar is not modeled yet but only the data such as diameters and pitches of the rebars are assumed. Then, the instance file of the bridge is generated by executing Converter Program I, and the input data for the design checking system (UC-1) is generated by executing Converter Program III. The user executes UC-1 and checks the conformance of the design with design codes (*Fig. 6*). As the design satisfies the codes, the user performs detailed design including selection and layout of rebars, and updates the product model instance data. Then, the user executes the rebar cover checking system and finds a violated rebar in the 3D-CAD system as shown in *Fig. 7*. The user modifies the rebar and updates the product model data. This application case indicates the feasibility and practicality of the developed product model.

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      - <xsd:sequence>
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        - <xsd:element name="containsElements" minOccurs="0" maxOccurs="unbounded">
          - <xsd:complexType>
              <xsd:attribute ref="inverse" />
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      </xsd:extension>
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  </xsd:complexType>
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Fig. 3 A part of the product model schema implemented in ifcXML

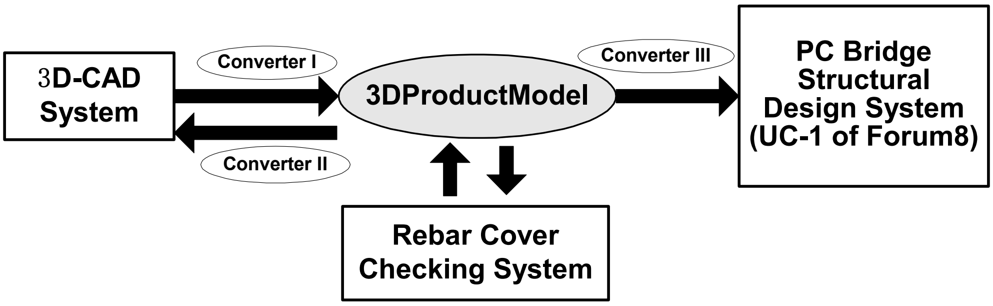

Fig. 4 Integration of three design application systems with the product model

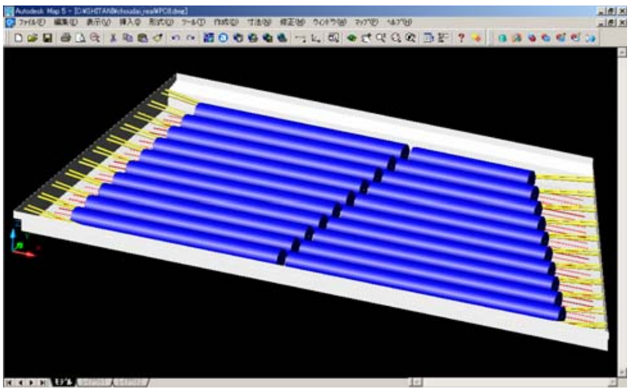

Fig. 5 A CAD model of PC hollow slab bridge

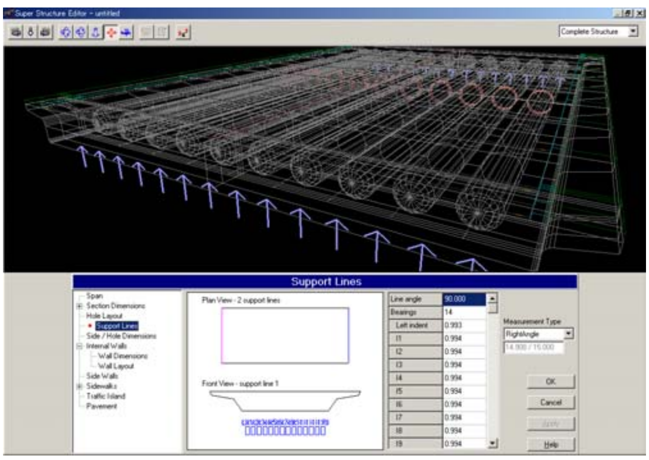

Fig. 6 Design checking system (UC-1, Forum8)

5. Conclusion

In this research, we developed a product model for PC bridges based on IFC, and implemented the product model schema and instances by ifcXML. Then, the product model was integrated with three application systems. The contribution of this research is as follows.

The realm of IFC has been expanded from buildings to PC bridges.

New classes for properly representing a concrete 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.

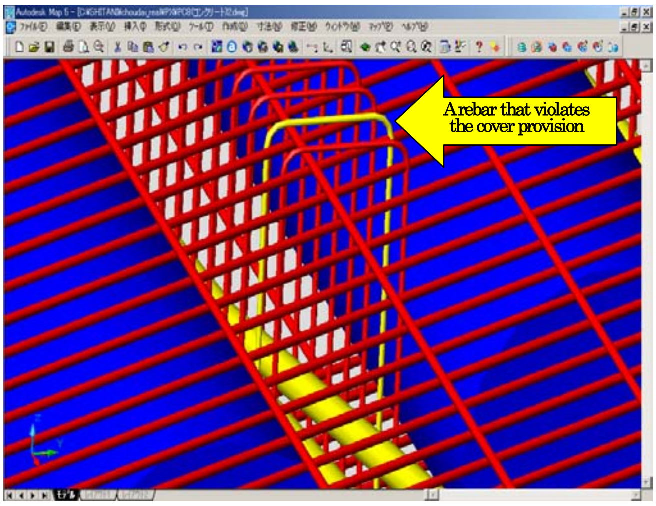

Fig. 7 Detected a rebar violating a cover provision in a design code

Data converter programs among the product model and three design application systems were developed.

This research showed the feasibility and practicality of the product model by integrating three application systems using the developed product model and data conversion programs.

Currently, we are developing a virtual reality CAD system, using the product model to improve the human computer interaction, as a future research work.

6. Acknowledgement

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