Representation of caves in a shield tunnel product model

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ABSTRACT: A shield tunnel product model, IFC-ShieldTunnel, has been developed by expanding IFC of IAI based on the previously developed conceptual shield tunnel product model in this research. To represent excavated caves in ground soil layers in the product model, two methods, i.e., boundary surface method and cave object method, were proposed and compared. The cave object method was found to be more flexible and easier to use in the test implementation.

1 INTRODUCTION

Much effort has been seen in development of product models for building design and construction in order to enable the interoperability among heterogeneous application systems and software packages such as CAD, analysis, conformance checking, cost estimation, construction scheduling, for about a quarter of a century (Eastman 1999). Recently, Industry Foundation Classes (IFC) of International Alliance for Interoperability (IAI) seems to be becoming a world standard for building product models. Although about half of the shield tunnel works in the world exist in Japan, most of the detailed design and construction data have been owned and stored by the engineers who worked at the construction sites. Surprisingly, such precious and important data are not necessarily stored in construction companies and, thus, may be lost or may not be available when necessary in the future, which should be prevented by preserving the data in a systematic way. Thus, a product model for shield tunnels has been in the process of development in our research group to represent and preserve all necessary data in design, construction, and maintenance (Yabuki et al. 2007).

A conceptual shield tunnel product model was developed for representing objects such as members, components, facilities, geology, etc., processes of construction, organizations, various data and knowledge. Then, the conceptual model was compared with IFC to find duplicated or similar classes for deletion and new classes for inclusion.

During the product model development process, two problems were identified. One is how underground soil layers should be represented. The other is how caves of tunnels in soil layers should be represented geometrically. The first problem was solved relatively easily by adopting the “upper boundary surface” method. In this paper, the second problem, which is more difficult than the first one, is the issue, and two methods were proposed and compared in this research.

2 SHIELD TUNNELS

Shield tunnels are usually constructed for highways, subways, sewages, causeways, etc., where the open-cut method cannot be employed since there are buildings, houses, other structures, or river that cannot be removed above the route, mainly in urban areas. First, a shaft tunnel is excavated and parts of a tunnel boring machine (TBM) are descended from the top to the bottom and are assembled. A TBM consists of a shield and trailing support mechanisms. The front end of the shield is a cutting wheel, followed by a chamber. Behind the chamber there is a set of hydraulic jacks, which pushes the shield forward. A tunneling ring which consists of several precast concrete or steel segments is installed between the shield and the surrounding soil. The set of tunneling rings is called primary lining. If necessary, secondary lining, which is made of concrete, may be built. A photograph of a shield tunnel under construction in Tokyo is shown in Figure 1.

3 SHIELD TUNNEL PRODUCT MODEL

3.1 *Conceptual shield tunnel product model*

Necessary data to be defined in product models would be summarized as 5W1H, i.e., when, who, where, what, why, and how. Thus, in the development process of a conceptual shield tunnel product model, Product for representing What and Where, Process for When and How, Organization for Who, Measured Data and Knowledge for Why, were put under Root of all classes. Figure 2 shows five main classes directly connected to the root class. Objects such as members, components, facilities, ground layers, etc., processes related to shield tunnel construction works, concrete organizations and stakeholders, various data and knowledge were listed up by investigating various documents of shield tunnels and by interviewing shield tunnel experts. In this way, a conceptual, hierarchical product model was developed for representing shield tunnels.

Figure 3 shows direct sub-classes of the Product class. The “shield tunnel” class has further more detailed and aggregated classes including void, primary lining, secondary lining, attached facilities, etc. The “primary lining” class has sub-classes such as segments, sealing material, bolts, and injected material. Segments are classified as more in detail based n the material and shape. The “ground” class has sub-classes, underground layer and ground water. Figure 4 shows direct sub-classes of the Process class. These sub-classes have more sub-classes under them. Organization, Measured Data, and Knowledge classes have their own sub-classses.

Figure 1. A photograph of a shield tunnel under construction in Tokyo.

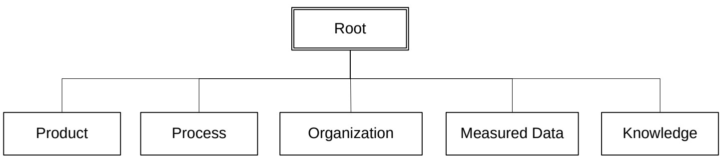

Figure 2. Five main classes of the conceptual product model.

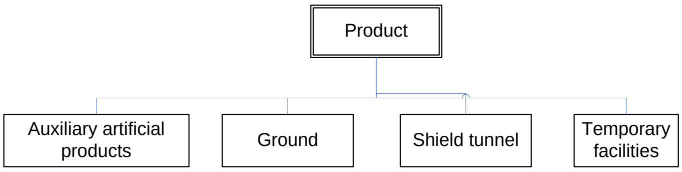

Figure 3. Four sub-classes of the Product class.

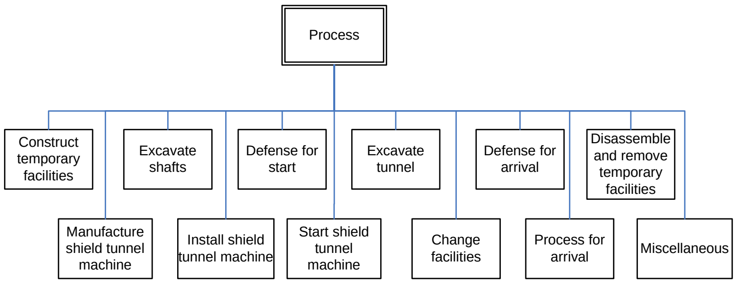

Figure 4. Sub-classes of the Process class.

3.2 *Implementation of IFC-ShieldTunnel*

The conceptual shield tunnel product model was implemented into IFC by adding necessary classes that had not been defined in IFC yet, such as shield tunnel specific members, temporary facilities, underground layers, etc. The product model was named IFC-ShieldTunnel because the development method is similar to IFC-Bridge (Yabuki et al. 2006). Figures 5-7 show some parts of IFC-ShieldTunnel product model. A part of the IFC-ShieldTunnel schema written in EXPRESS is shown in Figure 8, and an instance file of a part of an existing shield tunnel is shown in Figure 9-11.

As written in the first section, the first problem of representation of underground soil layers was solved by adopting the “upper boundary surface” method. In this method, each soil upper boundary surface is defined with is lower soil layer’s name and any point in any soil layer can be classified by looking up the immediate upper boundary surface’s soil layer name (Fig. 12).

4 REPRESENTATION OF CAVES IN SOIL LAYERS

The difference between the shield tunnel product model and other existing ones such as buildings and bridges is that the former has a void made by the excavation process in solid earth, while the latter structures are constructed in an open space by adding new objects. Not so much research has been done for representing caves or caverns in ground soil layers in product models. In this research, two methods were conceived for representing caves in soil layers. One method is representing caves by a set of boundary surfaces. The other method is inserting “cave” objects into soil layers.

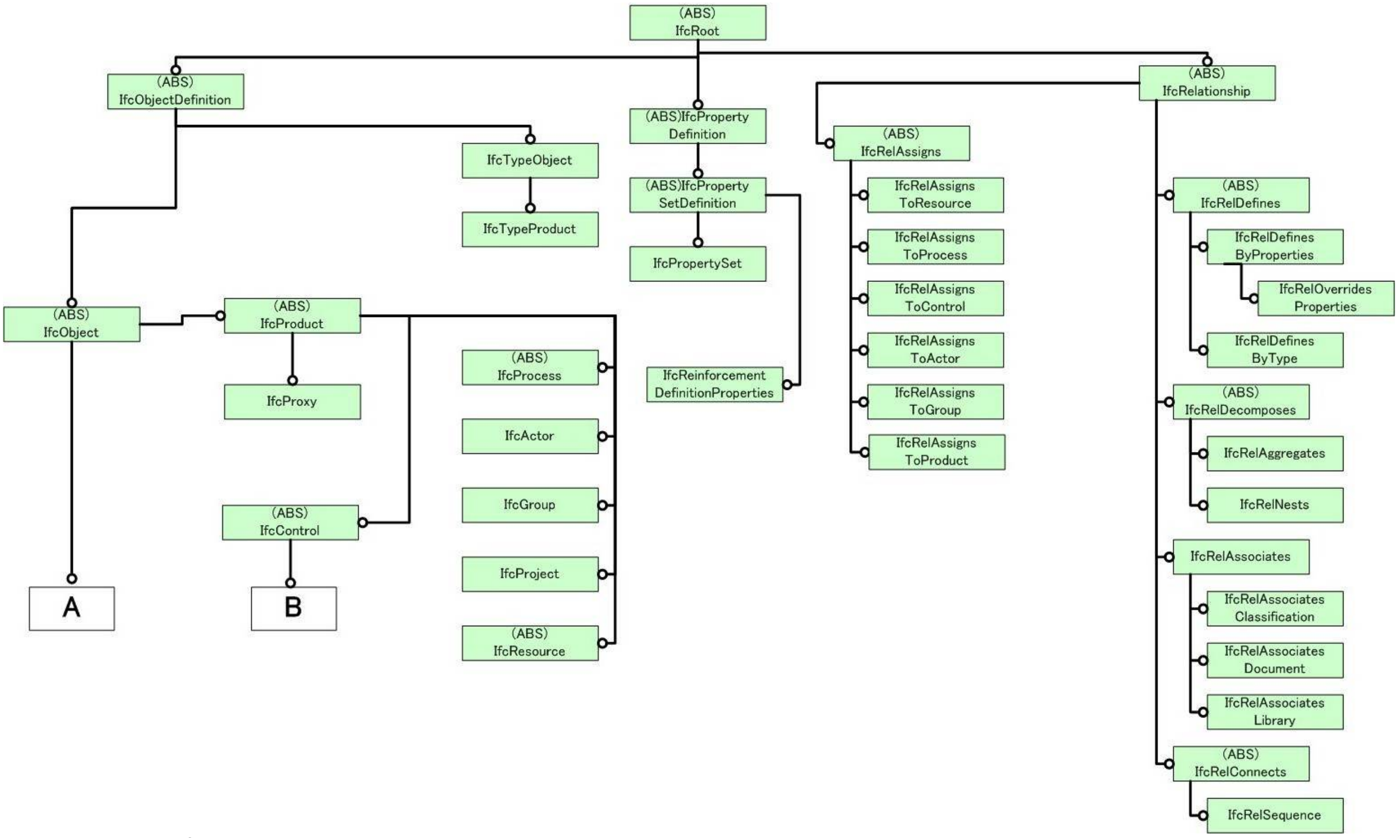

Figure 5. A part of IFC-ShieldTunnel (1).

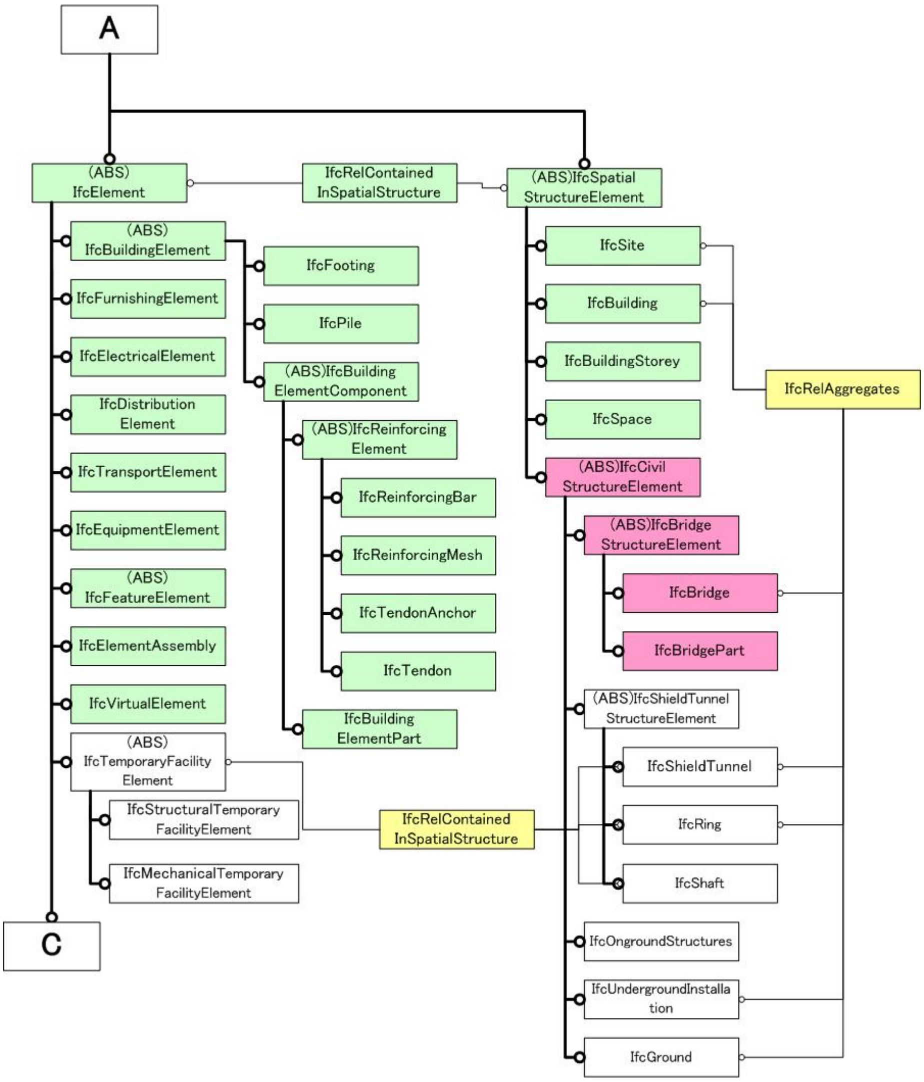

Figure 6. A part of IFC-ShieldTunnel (2).

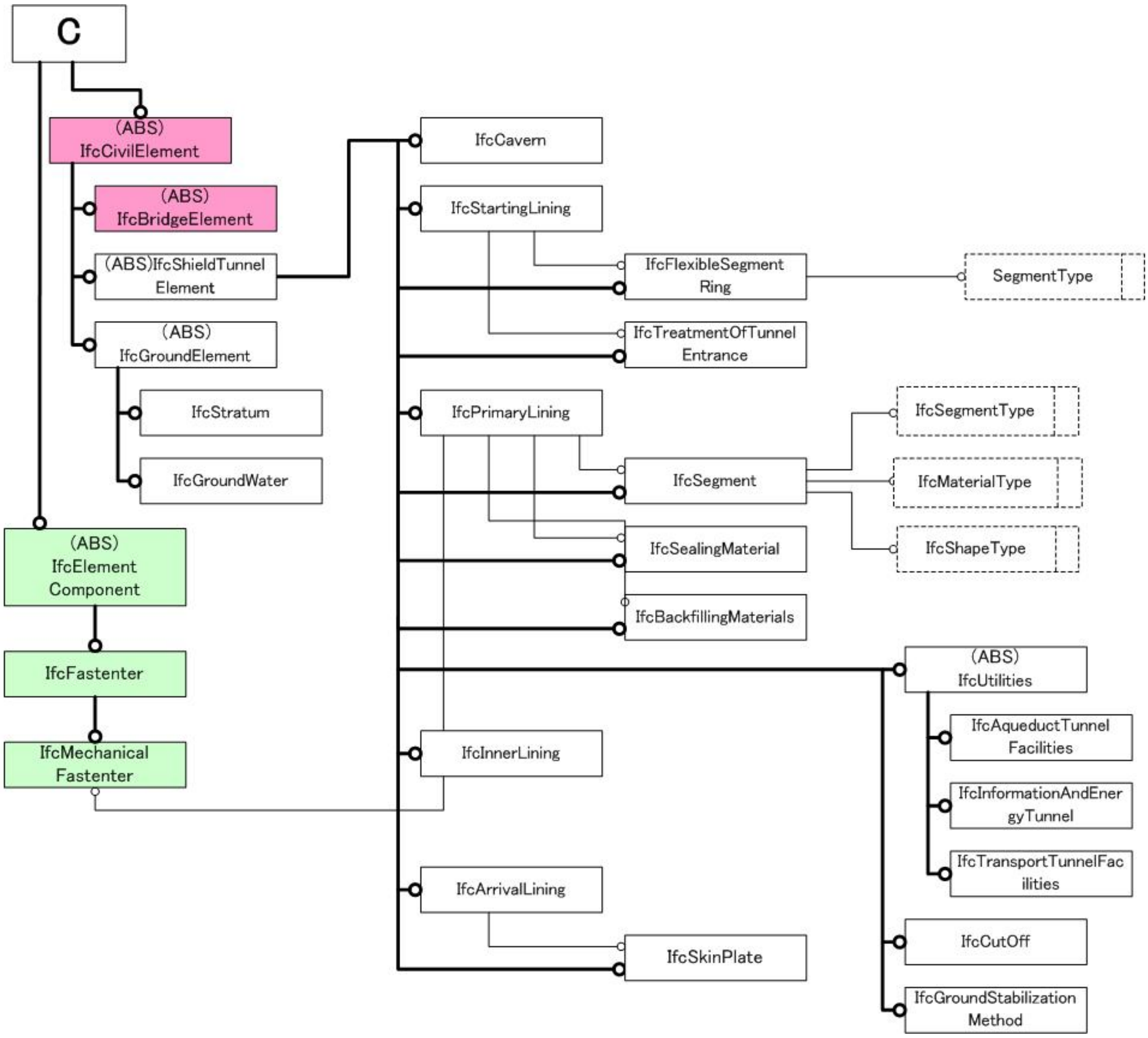

Figure 7. A part of IFC-ShieldTunnel (3).

```
↓
--  Elements↓
↓
ENTITY IfcStShieldTunnelElement  ↓
 ABSTRACT SUPERTYPE OF (ONEOF↓
        (IfcStExcavatedCave↓
        ,IfcStPrimaryLining↓
        ,IfcStTemporaryFacility ))  ↓
 SUBTYPE OF (IfcElement);  ↓
END_ENTITY;↓
↓
ENTITY IfcStExcavatedCave↓
 SUBTYPE OF (IfcStShieldTunnelElement);↓
END_ENTITY;↓
↓
ENTITY IfcStPrimaryLining↓
 ABSTRACT SUPERTYPE OF (ONEOF↓
        (IfcStSegment))↓
 SUBTYPE OF (IfcStShieldTunnelElement);↓
END_ENTITY;↓
↓
ENTITY IfcStTemporaryFacility↓
 ABSTRACT SUPERTYPE OF (ONEOF↓
        (IfcStSieldMachine));↓
 SUBTYPE OF (IfcStShieldTunnelElment);↓
END_ENTITY;↓
↓
ENTITY IfcStSegment↓
 ABSTRACT SUPERTYPE OF (ONEOF↓
        (IfcStNormalSegment))↓
 SUBTYPE OF (IfcStPrimaryLining);↓
END_ENTITY;↓
```

Figure 8. A part of the IFC-ShieldTunnel schema.


```
    <IfcGeometricRepresentationContext href="B1001" />
  </ContextOfItems>
- <Items>
  - <IfcExtrudedAreaSolid>
    - <SweptArea>
      - <IfcArbitraryClosedProfileDef>
          <ProfileType>AREA</ProfileType>
        - <OuterCurve>
          - <IfcCompositeCurve>
            - <Segments>
              - <IfcCompositeCurveSegment>
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                  <SameSense>FALSE</SameSense>
                - <ParentCurve>
                  - <IfcPolyLine>
                    - <Points>
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                            <IfcLengthMeasure pos="2">0</IfcLengthMeasure>
                          </Coordinates>
                        </IfcCartesianPoint>
                      - <IfcCartesianPoint>
                        - <Coordinates ex:cType="list">
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Figure 9. A part of the IFC-ShieldTunnel schema.

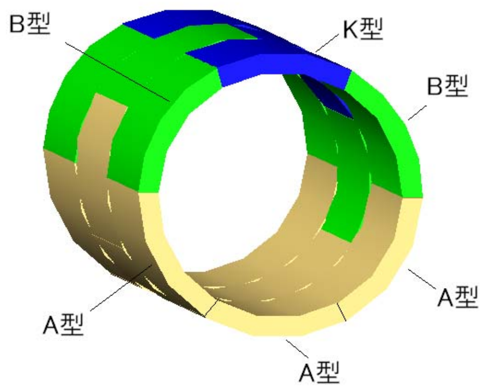

Figure 10. Segment product model data represented by using a commercial 3D CAD software.

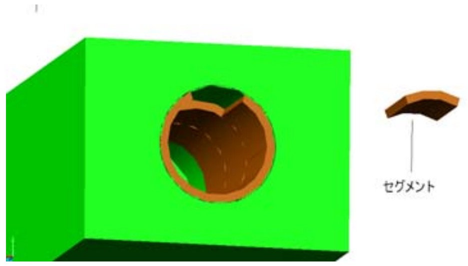

Figure 11. Segments and ground product model data.

4.1 *Boundary surface method*

The boundary surface method defines a cave by inserting a set of soil layer and cave boundary surfaces into soil layers. In this method, soil layer surfaces are defined as *Sn*, where *S* means surface and *n* is the number of the soil layer surface, and cave boundary surfaces are defined as *Cn*, where *C* means cave and *n* is the number of the cave boundary surface. As shown in Figure 13, anything under *Sn* is the realm of soil layer *n* by the lower boundary layer, and anything under *Cn* is the realm of the cave *n* by the lower boundary layer. As shown in Figure 14, any caves, even if they are located in complicated soil layers, encompassing a number of layers, can be represented by this method

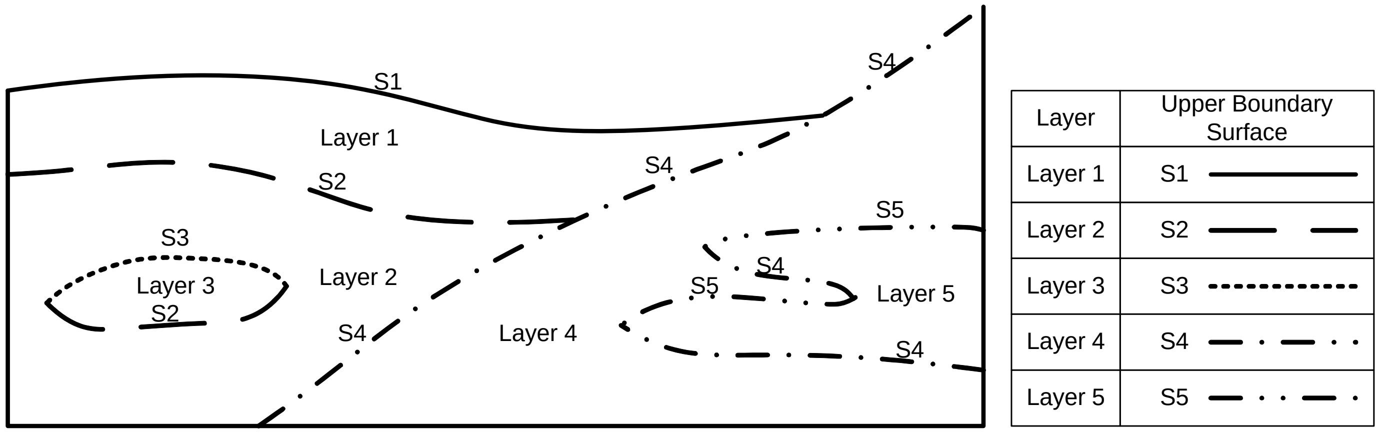

Figure 12. Soil layer representation method.

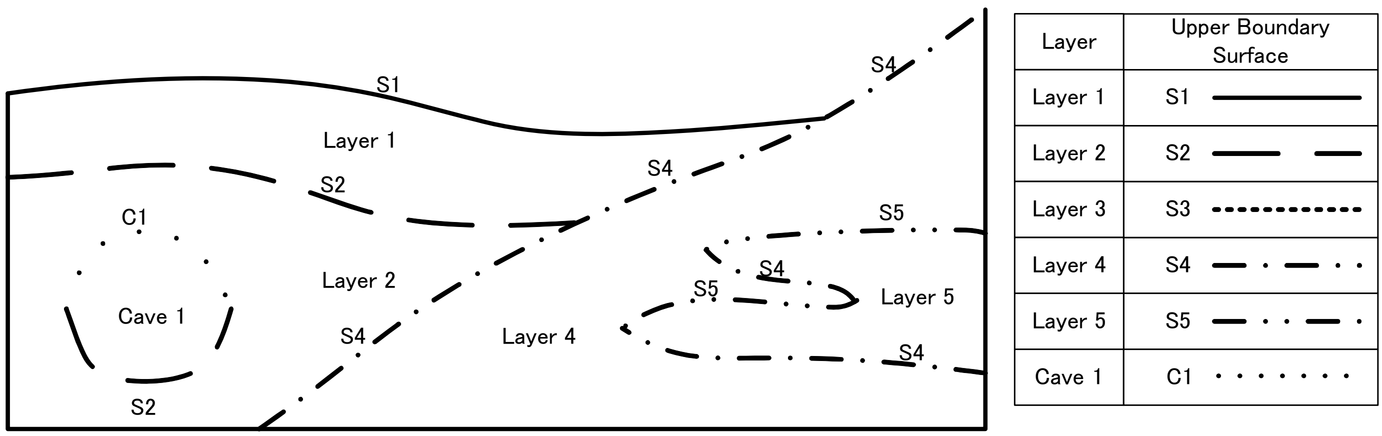

Figure 13. Boundary surface method for representing caves.

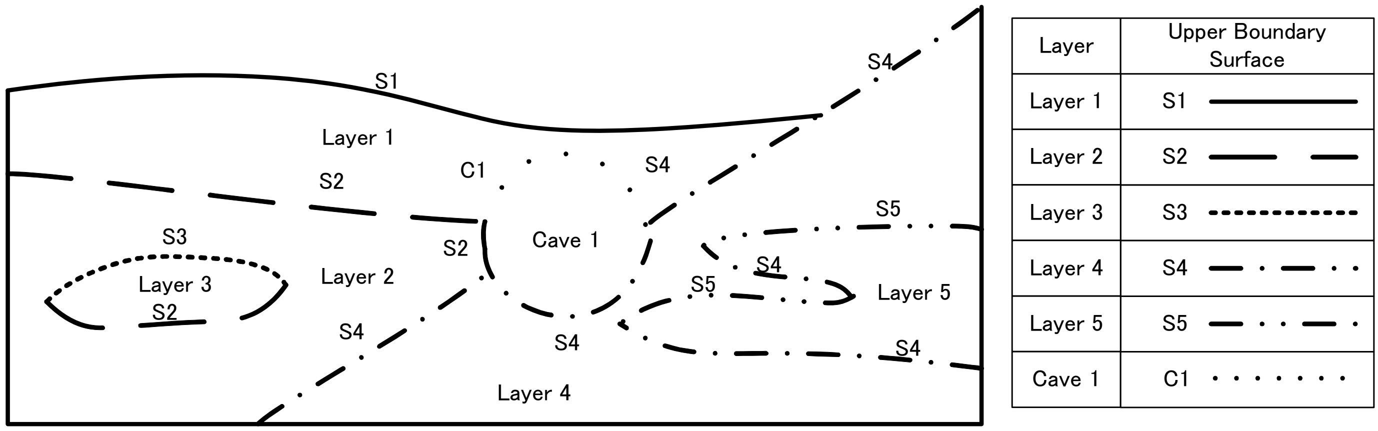

Figure 14. A cave in a complicated soil layers.

However, this method has a drawback that it would take a long time for CAD users to define caves and that the volume of the product data model may become very large if soil layers and cave shapes are complicated. And the developed IFC-ShieldTunnel product model schema has to be modified because IfcCavern class has been defined as a sub-class of IfcShieldTunnelElement class and is separated from IfcGroundElement and IfcStratim classes in the current IFC-ShieldTunnel.

4.2 *Cave object method*

In the cave object method, the user inserts a cave object into soil layers. A cave object is a solid object but the semantics is "empty" and it overlaps with soil layers. Once the cave object inserted, the cave object has a priority over the overlapped soil layers and excludes the overlapped area.

This method is simple and the user can make caves by using various modeling methods, while IfcFaceBasedSurfaceModel must be used in the boundary surface method, which gives the cave object method users more freedom and ease of use.

4.3 *Implementation and comparison*

For comparing the proposed two methods, sample soil layers were implemented by using ifxXML. Soil layer surfaces were generated as triangulated irregular network (TIN) data, and Civil 3D was used for rendering and data input/modification.

As discussed above, the cave object method was found to be more flexible and easier to define and control data than the boundary surface method in the implementation and utilization tests.

5 CONCLUSION

In order to store various data related to shield tunnel design, construction, and maintenance, a conceptual shield tunnel product model was developed, and then, IFC-ShieldTunnel was developed by converting the conceptual model and expanding the existing IFC of IAI. In the development process, the problem of representation of caves in soil layers was identified. Two methods, i.e., boundary surface method and cave object method were proposed and compared. In this research, the cave object method, where caves are represented as solid objects representing emptiness, was found to be more flexible and easier to use in the test implementation.

For future work, IFC-ShieldTunnel should be modified by adding more classes and properties. Not only object classes but also measured data classes should be implemented for actual construction works.

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Eastman, C. M. 1999. *Building product models: computer environments supporting design and construuction*. Boca Raton: CRC Press.

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