Management of Geological Survey Results in the CIM: Study on the Applicability of Three-Dimensional Geologic Modeling

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Abstract

In the trial run of the CIM (Construction Information Modeling/Management) in Japan, the target has been limited to structures and topographic features in any field and the three-dimensional structures of underground geology remain untouched because they are too difficult to handle. In this paper, we have discussed the application of the CIM to geological survey results with the seismic resistance assessment of river embankments as an examination object. Survey data acquisition of about 500m interval in a longitudinal direction, several meters interval in the transverse direction, and 1m interval in a depth direction are necessary for creation of the analytical model for verification of river levee based on the current guidelines. Considering the precision, accuracy, and distribution density of data, we have concluded that it is not appropriate to provide the geological survey result to a subsequent stage as a form of three-dimensional model, and also we have proposed that it is suitable and feasible for the CIM to manage the geological survey result as a dataset consisted of points, lines, and two-dimensional cross-section data linked by electric delivery data of soil tests, borehole logs and geophysical explorations, represented in a three-dimensional space.

Keywords: CIM, three-dimensional geologic model, geological survey result

1. Introduction

The geological survey results in public works of Japan have been delivered as electronic data in the format defined by the Electronic Delivery Guidelines since the enforcement of the CALS/EC system in FY2001. And today, a part of the electronically delivered survey results are disclosed as open data to enable them to be used (for example, on the Internet Web Service Delivering Borehole Data, “KuniJiban" by Public Works Research Institute). The CALS/EC is an abbreviation of the “Continuous Acquisition and Life-cycle Support / Electronic Commerce” and is an effort to enable productivity enhancement, cost reduction, etc. by computerizing the information conventionally exchanged on the paper basis and by encouraging the sharing and effective use of information across business processes through the use of information network. As a result of the CALS/EC, computerization of the individual processes comprising the business such as electronic bidding, electronic delivery, and computer aided construction advanced. However, the sharing and use of electronic information have not been enabled yet through all the processes from planning of a public project to survey/designing, construction, and maintenance.

Under such circumstances, the trial run of the CIM (Construction Information Modeling/ Management) started in FY2012 for several kinds of public businesses as the river, tunnel, bridge, and dam works. The CIM is an effort of transforming the individual electronic information created by the CALS/EC into a three-dimensional model and collectively managing it as public project information consistent throughout the entire life cycle for sharing and use among relevant parties. The three-dimensional model managed by the CIM will be updated with the progress of the processes of public works with information added and corrected. The national government aims at full-fledged introducing in FY 2016 after the present trial phase.

This report discusses the applicability of the CIM to geological survey results taking up the river works, in which the CIM is on a trial run.

2. Issues in the CIM inferred from three-dimensional geologic modeling

In the CIM, a three-dimensional model is supposed to be delivered in compliance with the conventional electronic delivery as supplementary data (Fig..1). However, it should be noted that the geological model is an inference model and that the precision and accuracy of the model are significantly dependent on the survey purpose, the target structure, the interpretation of a geological structure by an engineer, unlike a product model of construction structure that expresses a visible object based on a design drawing in the BIM (Building Information Modeling).

In the three-dimensional geological modeling, the modeling area, the model types, and the suitable scale of expressing geological structures are generally determined according to the purpose and the usage of the model. Important points for efficiently constructing a highly accurate three-dimensional geological model are to secure the accuracy of the enough amounts of source data and establish consistency among data and to apply an optimum interpolation processing method following the purpose of modeling, application, and data distribution (Kudo et al. 2008).

In the CIM, on the other hand, an enough amount of data for modeling may not be secured depending on the project scope and nature because a model will be created for each project and also the timing of use and the application in the downstream operations may be uncertain at the point in time of model creation. In other words, it is necessary to consider in the initial stage of CIM whether a three-dimensional geologic model that satisfies the required accuracy can be created from the perspective of the precision of the investigation and the amount of data. If a geologic model is constructed in the CIM, it is important to maintain the records of the basis for the created model and conditions of use: used data and processing, the interpolation range, grid size, and the applied algorithms along with the model data in order to reduce such risks as a mistake in designing resulting from the use of the three-dimensional model for the wrong application in the downstream operations and overestimation of the accuracy.

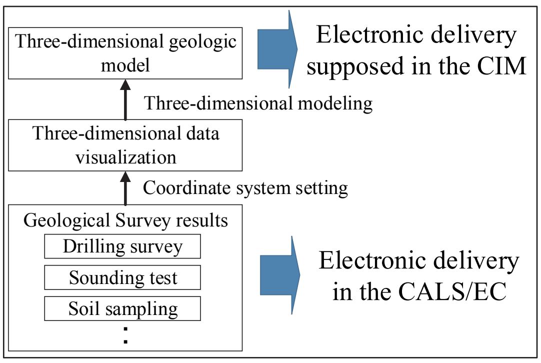

Fig. 1 Electronic delivery of geological survey results supposed in the CIM

3. Study on the applicability of the CIM for seismic resistance assessment of river embankments

As mentioned above, while the trial run of the CIM has started in the several fields of public works, the target is limited to structures and topographic features in any field and the three-dimensional structures of underground geology remain untouched because they are too difficult to handle. In the field of river management, given the suffering of 2115 river dikes and their related structures in the Tohoku and Kanto regions that resulted in deformations and failures due to the 2011 off the Pacific Coast of Tohoku Earthquake (Oka et al. 2012), the seismic performance evaluation and countermeasures for likely upcoming great earthquakes are urgently needed. In addition, many river structures developed during the high economic growth period have deteriorated and the integrated management and the use of information such as drawings of river facilities are required to realize systematic maintenance for service life extension of those structures. In light of the above, we consider the application of the CIM to geological survey results for three-dimensional integrated management of data is meaningful and should be realized immediately. In this chapter, we discuss the applicability of the CIM with the seismic resistance assessment of river embankments as an examination object.

3.1 Present state of the CIM trial run

Machida et al. (2013) cited the three-dimensional visualization facilitating and speeding up the identification of invisible parts of river levees, and also cited the superimposed image with GIS data, such as topographic maps and aerial photographs, enabling the analysis of geographical features as advantages, in light of the efforts on the three-dimensional imaging and database compilation of river structure data. On the other hand, Tamura et al. (2014) mentioned the need of narrowing down the application range of the CIM in consideration of the cost-effectiveness given that the type of geographical data and the design accuracy of structures to use are not always the same between in the preliminary design phase and in the detailed design phase, in light of the results of the CIM trail run in the detailed design of a embanking project, and that considerable work load is required as compared with the conventional two-dimensional designing in some cases. In addition, Kubo and Yabuki (2014) made an attempt to define the optimum accuracy of a three-dimensional model of river facilities with reference to the 'LOD (Level of Development)' defined by the American Institute of Architects from the perspective of cost effectiveness with an eye on introducing the CIM into the maintenance of river facilities.

Those previous studies suggest that the consideration of cost effectiveness and the securing of model accuracy commensurate with the phase and a target of a project are issues of the CIM.

3.2 Consideration of the applicability of the CIM from the perspective of the geological survey precision and accuracy

In this section, the geological features to be expressed as a three-dimensional model and the required accuracy and precision in the CIM are discussed. The "precision" is defined as a deviation from an average and the "accuracy" is defined as a deviation from the true or absolute value, in accordance with the definition in the field of measurement technology.

(1) Geological features to be expressed and the required accuracy in the CIM

Fig. 2 shows the structural study flow of seismic resistance assessment of river embankments based on the "Guidelines for River Embankments Assessment of Competence (Revised Edition) (2012)". Given that the embankments damage due to earthquake is mainly caused by liquefaction, the distribution of ground prone to liquefy and places, where earthquake damage occurred in the past, will be researched widely by literature investigation firstly in a structural study. Secondly, the distribution of soil layers prone to liquefy will be recognized in the longitudinal direction of a levee by the method shown in Fig. 2 to select a representative cross section considered to have little resistance to earthquake, namely a cross section with a thick soil layer having a particle size composition prone to liquefy, and with a small resistance (SPT *N* value) to liquefaction. Then in the lateral direction, the detailed soil composition, the strength property, and permeability will be ascertained to create a model for verification.

In this regard, the levee damage has been conventionally considered to be mainly caused by liquefaction of a foundation ground. In the 2011 off the Pacific coast of Tohoku Earthquake, however, many levees were damaged from liquefaction of the soil in the embankments due to the water-saturated region above the ground level (Oka et al. 2012). Therefore, in the high liquefaction risk zone, it is necessary to accurately ascertain the levee materials, the soil property of the foundation ground, and the water level inside the embankment for verification.

As for precision, Table 1 and Fig 3 show the allocation density in surveys cited from the "Guidelines". It is found from the table that a survey and a test are required at a fine grid of 1 place/m particularly in the depth direction.

On the other hand, in an engineering geological map, geological boundaries and faults are classified and drawn based on 'Scientific Confidence' and 'Locational Accuracy' specified by JIS A 0206 standard, and for example, the level 'Location approximate' reveals location accuracy less than one meter in the case of a 1/100 scale map.

In consideration of those findings, it is concluded that it is a prerequisite in the application of the CIM to express three-dimensionally the distribution of levee body materials and foundation ground prone to liquefy and their physical properties and permeability at an accuracy of several meters in the horizontal direction (transverse direction of the levee) and of 1m in the depth direction.

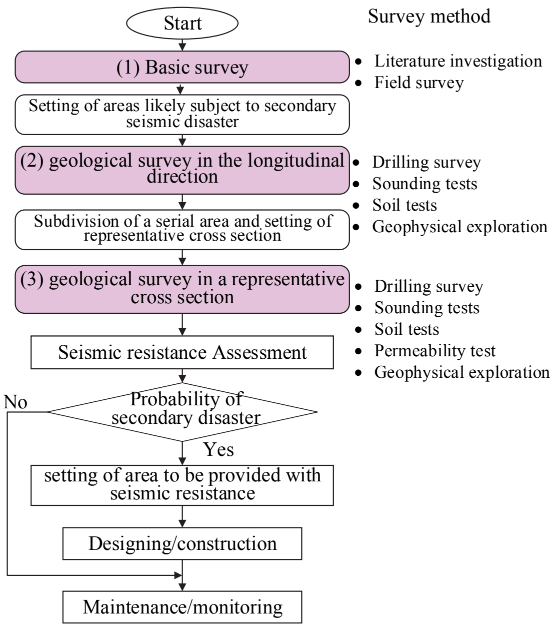

Fig. 2 Procedure for seismic resistance assessment of river embankments

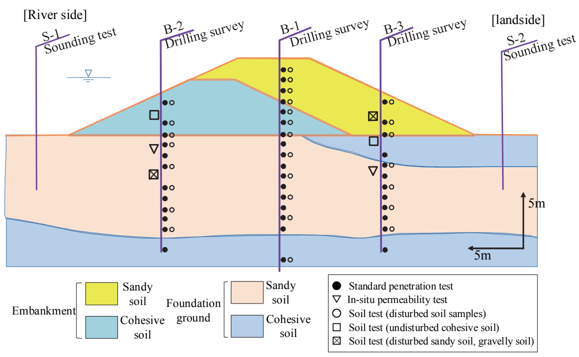

Fig. 3 Example of survey item allocation planning in the transverse direction

Table 1 Allocation of geological surveys and contraction scale to express survey results in the seismic resistance assessment of river embankments, after “Guidelines for River Embankments Assessment of Competence (Revised Edition)”

	Longitudinal direction	Transverse
Drilling	◆ Horizontal direction: Approximately one position for 500 m in the longitudinal direction as a measure. To be conducted near the center of the levee crown. ◆ Depth direction: To be surveyed up to a depth where the rock surface (engineering seismic basement with an S-wave velocity of 300 m/s or higher or a stratum with an *N* value of 50 or higher) can be inspected in principle. ◆ For a thick soft soil layer, a depth of approximately 25 m, where the soil type can be assessed, shall be taken as a measure. ◆ Ascertain the groundwater level.	◆ Needs to be performed for at least approximately three points in the vicinity of the center of levee crown, in the vicinity of the center of the back face of the slope, and in the vicinity of the center of the front face of the slope. ◆ The depth shall be up to the depth of the bottom of the layer likely to liquefy during earthquakes and up to approximately 25 m, where the soil type can be assessed, if the layer likely to liquefy is thick.
Sounding	◆ Used to ascertain the boundary location of upper and lower flow. ◆ On that occasion, near the back slope toe on the vertical stream side of the drilling survey point.	◆ If the soil constitution of a levee body or foundation ground is complicated, allocate the surveys as if interpolating between drilling survey points. ◆ The depth shall be up to the depth of the bottom of the layer likely to liquefy, or up to a layer where the soil type can be assessed.
Sampling, Soil test	◆ For each depth, where the soil property changes. ◆ Every 1 m for a levee body and by every 2 to 3 m for a foundation ground.	◆ Transverse direction: One point in the vicinity of the front slope toe, one point at the levee crown, and one point in the vicinity of the back slope toe. ◆ One pcs or more/2 m in the depth direction, one pc / soil layer if the soil layer significantly varies, one pc or more / m in a layer likely to liquefy.
Geophysical exploration	◆ Data acquisition at an interval of 2 m to 5 m. ◆ Several traverse lines on the levee crown, berm, foot of slope, etc.	◆ At an interval of 1 to 2 m.
Survey result	◆ Soil Profile: 1:100 or 200 S-wave velocity cross section Specific resistance cross section	◆ Soil Profile: 1:100 or 1:200 Soil property diagram Elastic wave velocity cross section Specific resistance cross section

Table 2 Influence factors on the precision and the accuracy of the survey results in river embankments assessment

Survey method	Raw data	Interpretation result	Dimension	Precision	Accuracy
Drilling survey	○	○	1	◆ Location information acquisition method ◆ Drilling method	◆ Complexity of the geological structure ◆ Engineer’s skill
Sounding test	○		1	◆ Location information acquisition method ◆ Test method	Same as above
Sampling, Soil test	○		0	◆ Location information acquisition method ◆ Sampling method ◆ Specimen manufacturing method ◆ Test method	Same as above
Permeability test	○		0	◆ Location information acquisition method ◆ Test method	Same as above
Geophysical exploration	○	○	2	◆ Location information acquisition method ◆ Traverse line interval ◆ Exploration method	◆ Complexity of the physical property distribution and geological structure ◆ Engineer’s skill
Cross section		○	2	◆ In addition to above, the density of data	Same as above
3D model		○	3	◆ In addition to above, modeling method, grid size, and interpolation method	Same as above

Table 3 An idea of CIM in geological survey results in river embankments assessment

Survey results	Expression in CIM	Property retention method
Drilling survey, Sounding	One-dimensional line data	Link borehole log data or sounding test data (XML format regulated by the electronic delivery guideline) to the line data
Sampling, Soil property test, Permeability test	Point data on one-dimensional line data of a drilling survey for a survey associated with the drilling survey. Not expressed for on-site surveys.	Link sampling data, soil test data, permeability test data (XML format) to point data
Geophysical exploration Lateral profile Longitudinal profile	Two-dimensional panel (image for geophysical exploration and CAD data for lateral/longitudinal profile)	Link geophysical exploration data to the panel

(2) Precision and accuracy in geological survey

Next, we examine whether the three-dimensional geologic model that satisfy the precision mentioned above would be available or not from survey results.

In a drilling survey, for example, a core of approximately ϕ 6 cm represents a levee body materials and foundation geology in the horizontal direction with an expanse on the order of several meters. The positional precision is generally estimated to be 1m if the position coordinate is acquired from the positional relation with the river mile post using a measuring rope. The positional precision in measuring with a GPS/GNNS is about 5m. Such factors as an error in reading the soil constitution by an engineer observing the core need to be taken into consideration. Then in making two-dimensional geological profiles based on such drill survey results, the estimation accuracy of geological boundaries depends on the data density, the complexity of geological structure, engineer's skill in addition to the above factors. Finally, in making a three-dimensional geological model, the estimation accuracy depends on modeling methods, interpolation algorithms in addition to them. As the dimension of the survey data is upgrading, influence factor would be increased, resulting in the uncertainty in the model output as shown in Table 2. Consequently, a three-dimensional geologic model created based on borehole data with an interval of 500m in the longitudinal direction and a several meters in the transverse direction thought not to satisfy the accuracy mentioned above.

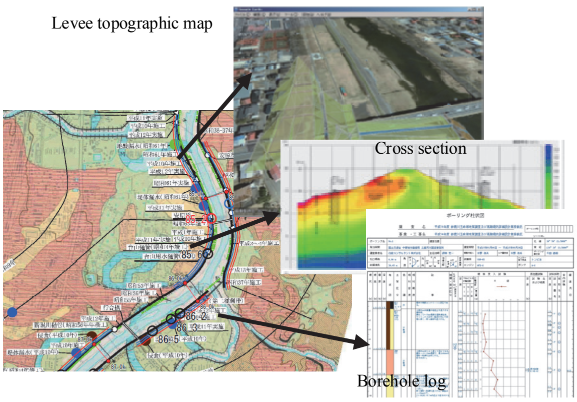

Fig. 4 An image of three-dimensional visualization of data (revised Machida et al. and the inspection reports by NILM)

4. Conclusions

In this case study of river embankments, we have shown that it is not appropriate to provide geological survey results to a subsequent stage as a form of three-dimensional model, considering their accuracy, precision, and distribution densities. On the other hand, it is obvious that the information obtained from geological surveys is extremely important to be used widely and appropriately in the life cycle of a construction project ranging from survey to maintenance. Consequently, it is suitable and realistic for the CIM to manage the geological survey result as a dataset consisted of points, lines, and two-dimensional cross-section data linked by electric delivery data of soil tests, borehole logs and geophysical explorations, visualized in a three-dimensional space as summarized in Table 3. Because a river levee is a long linear structure, it is desirable to manage it with GIS based on the fundamental geospatial data maintained by the Geospatial Information Authority of Japan. It is desirable to make levee topographic maps, aerial photographs, and any other data displayable in an appropriate plan view according to the contraction scale on a system capable of mashup, and also to make the longitudinal section and the cross section displayable three-dimensionally at a larger scale than 1/5000 to 1/2500 that are a contraction scale for summarizing the survey results in river embankments assessment as shown in Fig. 4 schematically. It would like to be emphasized that it is important to maintain the records of the basis for the interpretation data as shown in Table 2.

In the CIM, a three-dimensional model is supposed to be constructed using the geological survey results of electrically delivered format and to be provided in compliance with the electronic delivery. However, the use in the CIM has not been taken into consideration and several items necessary for modeling are not covered by the current electronic delivery guidelines. In the river works, for example, the positional information is used to be given in the river mile post coordinate system, while the existing electronic delivery guidelines manage the positional information of survey results by latitude and longitude and the distance mark data is allowed to be described but the description is not essential. The coordinates of sounding test sites, soil sampling sites, and soil testing sites can be approximated with the latitude and longitude at a representative position. Furthermore, with no regulation given on the geophysical exploration allowed to use for interpolation of soil constitution between survey points, an interpretation figure without positional information is usually supposed to be submitted in the current electronic delivery. The above indicates that the revising of the electronic delivery guidelines is an urgent issue in introducing the CIM in a full-fledged manner in future.

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