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Applications of bridge information modeling in bridges life cycle

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Abstract. The purpose of this paper is to present an Integrated Life Cycle Bridge Information Modeling that can be used throughout different phases of the bridge life cycle including: design, construction, and operation and maintenance phases. Bridge Information Modeling (BrIM) has become an effective tool in bridge engineering and construction. It has been used in obtaining accurate shop drawings, cost estimation, and visualization. In this paper, BrIM is used as an integrated tool for bridges life cycle information modeling. In the design phase, BrIM model can be used in obtaining optimum construction methods and performing structural advanced analysis. During construction phase, the model selects the appropriate locations for mobile cranes, monitors the status of precast components, and controls documents. Whereas, it acts as a tool for bridge management system in operation and maintenance phase. The paper provides a detailed description for each use of BrIM model in design, construction, and operation and maintenance phases of bridges. It is proven that BrIM is an effective tool for bridge management systems throughout their life phases.

Keywords: project management; bridges construction; Building information modeling; bridge life cycle phases

1. Introduction

Bridges are the main structures that connect different regions across many barriers. These structures always require large investments starting from design phase, passing through construction phase, and ending with maintenance and rehabilitation phase. Any failure in bridges' engineering processes can lead to excessive losses related to safety and costs. Consistency in information across different phases of bridge life cycle, and different stakeholders is needed. Developing an Integrated Life Cycle Model is considered crucial to provide this consistency and to facilitate different engineering processes. Bridge Information Modeling (BrIM) technology is considered an efficient tool in obtaining an Integrated Life Cycle Model. This is because BrIM is not just a geometrical representation, but it is an intelligent representation of bridges. This means that BrIM can be used as an information source that could be used by bridge stakeholder according to the required purpose. BrIM model components include geometrical and material properties; and it could be modified to include different information according to stakeholders' requirements. Several commercial software packages are currently used for Bridge Information Modeling, such

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as Tekla Structures, Revit, Navisworks Manage, and Bentley BrIM solutions. Bridge Information Modeling (BrIM) has great effect on the improvements of the three main concerns of bridges' stakeholders which are quality, schedule, and cost (Marzouk *et al*. 2010). Bridge information modeling goes beyond traditional bridge design by fostering data reuse in different processes. So, 3D model of the bridge can serve as a window into the vast information asset, and organizations can begin to optimize business processes that cross the bridge lifecycle by more flexible access to information about the bridge (Peters 2010). The main applications of the proposed model according to the life cycle phases are presented in Table 1.

Many efforts have been conducted to model the different aspects of bridges life cycle phases (Bocchini *et al*. 2011, Okasha and Frangopol 2011, Bocchini and Frangopol 2011, Hong *et al*. 2007). Youssef (2006) developed a decision support system that provides a systematic and structured framework to improve the selection process of bridge superstructure construction methods in Egypt. Behzadan and Kamat (2010) presented augmented reality (AR) that employs graphical visualization to plan and design construction operations. Realistic visual outputs are created and translated into three-dimensional (3D) virtual contents (CAD model engineering) of the animated scenes. Tantisevi and Akinci (2007) presented an approach for generating workspaces that encapsulate spaces occupied by mobile cranes moving during an operation. Al-Hussein et al. (2005) developed optimization algorithm for selection and on site location of mobile cranes. Tam and Leung (2002) integrated GAs with 3D visualization for optimum positioning of tower cranes. Itoh *et al*. (1997) integrated geographic information system (GIS) module and an object-oriented database module in a Bridge Lifecycle Management System. Hegazy *et al*. (2004) presented a comprehensive framework for bridge-deck management system that aims at integrating project-level and network-level decisions. This paper presents an Integrated Life Cycle Bridge Information Modeling that can be used throughout different phases of the bridge life cycle including: design, construction, and operation and maintenance phases. The Bridge Information Modeling (BrIM) features and applications are described in below sections.

Table 1 BrIM model applications according to life cycle phases

Life Cycle Phase	Applications
Design	Selecting optimum construction methods, and Performing advanced structural analysis
Construction	Selecting mobile crane locations that minimizes erection time, Monitoring status of precast bridge components, and Controlling construction documents in an automated manner
Operation and Maintenance	Improving bridge management systems modules

2. BrIM model features

The BrIM model presented in this paper is an integrated model that has unique capabilities that could be used in bridge projects throughout different project phases. In design phase, this model integrates C# programming language with BrIM intelligent components in order to obtain feasible construction methods of bridges superstructure. It also provides visualization of site conditions in order to select the most appropriate construction method. In this phase also, the developed model expands the BrIM compatibility with design software packages by integrating BrIM models with

ANSYS software which utilizes advanced analysis technique. In construction phase, the developed model integrates BrIM with Genetic Algorithm technique, site conditions, scheduling, and visualization in order to select the optimum mobile crane locations in bridge sites. In this phase also, the model expands the visualization feature of BrIM to be used as an effective tool in monitoring status of precast components in bridge sites. The developed model also provides a module to add construction document information to the related BrIM components; the model is also used to create document control logs directly from the BrIM model. The developed model expands the use of BrIM in operation and maintenance phase by using C# programming language to create database of bridges' components, and inspection sheets. It also integrates BrIM with different software packages (such as Google Earth, and Google Sketchup) in order to visualize GIS data that could influence bridge management. The presented BrIM model integrates created programs and modules, with commercial software packages in order to achieve its required function as shown in Fig. 1.

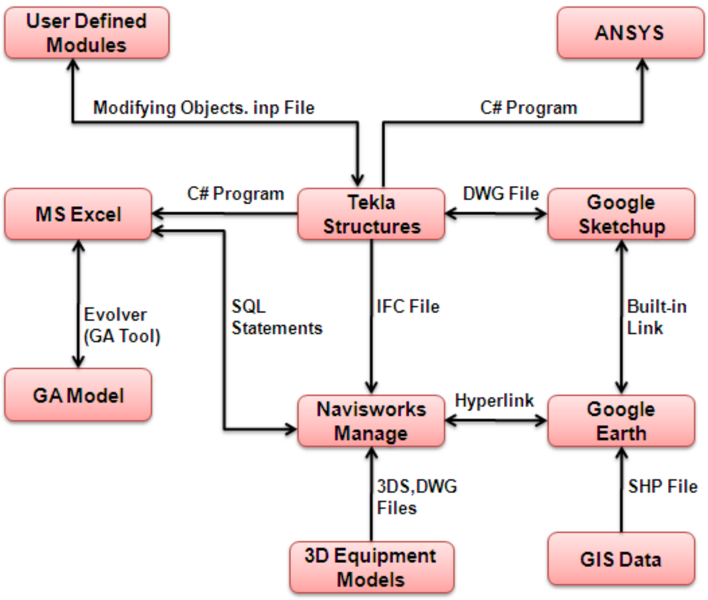


Fig. 1 Connectivity amongst BrIM model components

3. BrIM model applications in design phase

3.1 Construction method selection

The work presented in this sub-section is an extension of the work presented by Youssef (2006). The construction method of a bridge has a significant effect on the design of this bridge, so, the construction method must be selected before conducting any detailed design. The process of obtaining optimum construction methods using BrIM starts with developing a preliminary design BrIM model. This model is considered a schematic model that does not contain the full design details. In order to obtain the optimum construction methods using BrIM, two steps are required.

The first step is obtaining the feasible construction methods based on bridge physical characteristics which are: span length, superstructure height, deck x-section, curvature, and concrete type. This is done by a program developed by C# language that extracts the bridge physical properties and provides the user with MS Excel sheet that includes the feasible construction methods and their associated approximate costs (which are calculated based on the deck surface area and the unit price for each construction method) as shown in Fig. 2. After determining the feasible construction methods based on the bridge physical characteristics, these methods must be checked based on the site conditions and the surrounding environment. Visualization feature of BrIM has an effective role in this process. The BrIM model can be integrated with a representation of the site conditions, surrounding environment, and construction methods' tools and equipment in order to visualize and choose the optimum construction method as shown in Fig. 3.

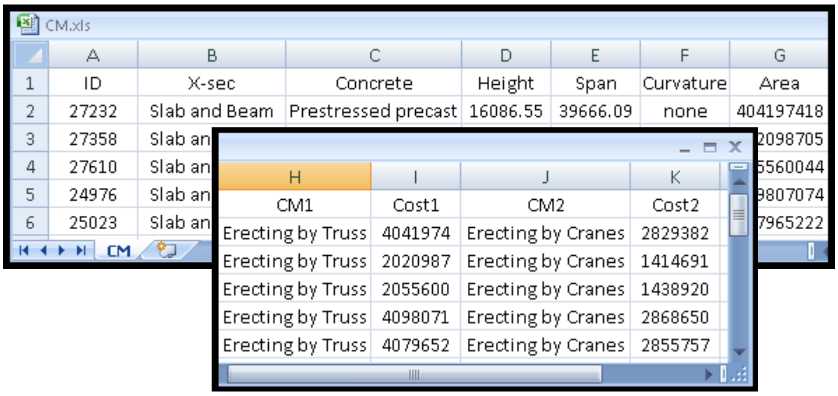


Fig. 2 Feasible construction methods and corresponding construction costs

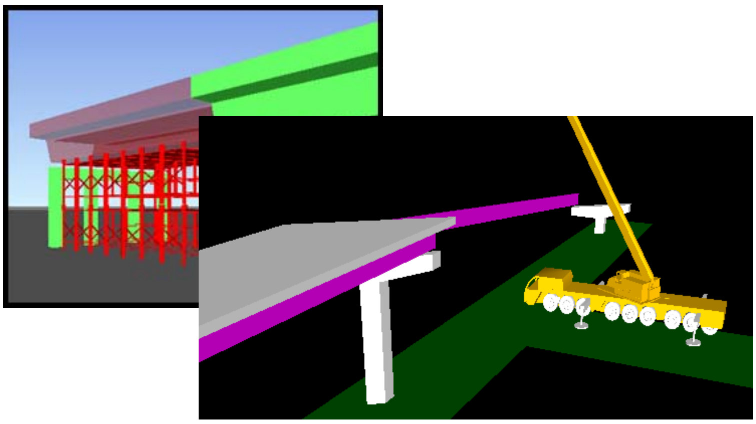


Fig. 3 Construction methods visualization in BrIM

3.2 Performing structural advanced analysis

Structural analysis is a main task in bridge projects. The structural engineer has to develop different design alternatives to reach best alternative. The structural design of a bridge is done in different stages starting by a schematic design and ending with a detailed design. There are many factors that affect the choice of the final design alternative. These factors are; the structural safety of bridge, the serviceability of the bridge, the availability of the required members (or the ability to fabricate these elements and transporting them to the job site), coordination with surrounding roads and buildings, and many other factors. Structural analysis can be done using different finite element software packages such as STAAD, and SAP. These software packages are compatible with Bridge Information Modeling software packages, where a direct export can be conducted from the BrIM software and those software packages.

Structural Advanced Analysis technique is proposed to check the structural safety of bridges for different design alternatives. This technique predicts the strength of the entire structure so that separate member capacity checks encompassed by the specification equations are not required (El Samman 2010). This technique depends on simulating incremental loading of structure until reaching failure. The load at failure is compared to the real loads that the bridge is subjected to, and a numerical factor named *Load factor* is calculated. The load factor indicates the structure safety. For example, if the load factor of a structure equals 1.25, this means that the structure can afford only 25% more than the real loads. By applying advanced analysis technique, it is easy to evaluate the effect of changing any structural member with another member on the structural safety of the bridge. In order to integrate Bridge Information Modeling with advanced Analysis software which is ANSYS, a program was created using C# programming language. This program creates ANSYS input file directly from the selected Bridge Information Model in Tekla Structures. This file is a text file that includes positions, profiles, and materials, while loads are inserted from the ANSYS software. Fig. 4 shows an example of Structural Advanced Analysis results.

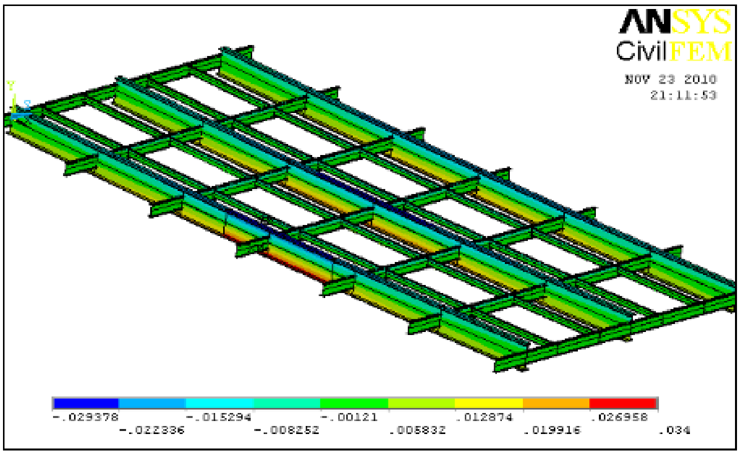


Fig. 4 Structural advanced analysis results

4. BrIM model applications in construction phase

4.1 Selection of mobile crane locations

To use BrIM model in selecting mobile crane locations, the first step is to develop the 3D BrIM model. The site boundaries and conditions are then integrated with the developed model using Google Sketchup software. The erection locations and site boundaries are then exported to the GAs model. This model determines the mobile crane positions that satisfy the safety during erection and site boundaries constraints taking into account two erection locations. The GA model is developed using evolver software which is MS Excel Add-In. All the variables and equations were modeled in an excel sheet where the optimization process is to be applied. The genes of the developed GAs are: X_{cr}, Y_{cr}, α_1, and α_2. The first two genes represent the location of the center of the crane, while the last two genes represent the inclination angle between the boom and the ground for the two erection locations. The objective function is maximization, and minimization of lifting radius for the two erection locations. This can be achieved by maximizing and minimizing the radius at first erection location and check that the resulted location of the crane satisfies safety requirements for the second erection location, and then maximizing and minimizing radius at second erection location and check that the resulted location of the crane satisfies safety requirements for the first erection location. Therefore, the optimization process will be performed for four cases.

4D modeling is an effective feature in BrIM. It depends on linking a time schedule to the components of the BrIM model, thus, the project team can visualize what is to be constructed at a specific date, the achieved work at this date, and compare actual work with planned work. The next step is exporting the 4D BrIM model including site boundaries, surrounding buildings, and represented crane locations from Tekla Structures software to Navisworks Manage software. The extension of the exported file is to be IFC. The model of the existing utilities such as cables, water pipes, or sewer pipes can also be imported from other BIM software packages to Navisworks manage software. The next step is to exclude the crane locations that contradict with existing utilities or site conditions at the date of erection as shown in Fig. 5. After the contradicting locations have been excluded, different trials are to be done to choose the best crane location. In each trial, a simulation of the erection process is done by inserting the mobile crane to a represented location and performing animation of the boom. The goal of simulation and animation is to determine the crane locations that have the least number of boom maneuvers from lifting to placing the load. As the number of boom maneuvers decreases, the erection time decreases; and that achieves the goal of using BrIM with GA which is to minimize time of erection.

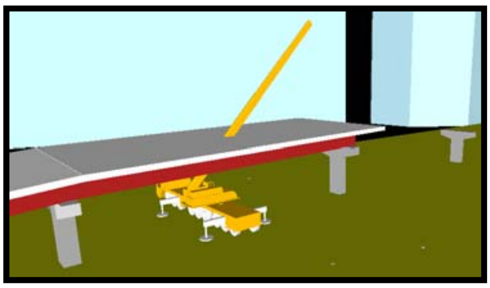


Fig. 5 Excluded crane locations

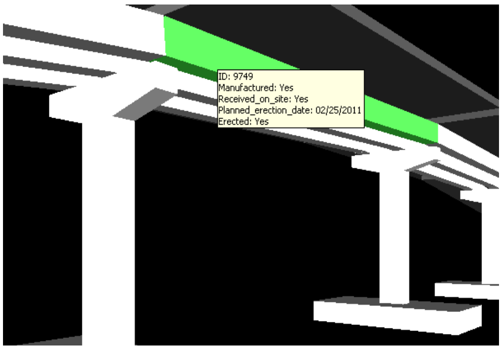


Fig. 6 Component visualization with related status

4.2 Monitoring status of precast components

Tracking and monitoring the status of precast members from fabrication to erection is a main task of project managers. Bridge Information Modeling (BrIM) can be an effective tool in achieving this task. As described before, each object in the BrIM model is an intelligent object that has properties. From these properties in Tekla Structures software are essentially "Supply Chain Management" and "Project status". These properties include different attributes that have to be filled by the user. These attributes are: status of manufacturing (manufactured or not manufactured), status of receiving on site (received or not received), status of erection (erected or not erected), and planned date of erection. After filling the required attributes, MS Excel spreadsheet can be created using the report template editor in Tekla Structures software. This spreadsheet contains: component ID, manufacturing status, receiving on site status, erection status and planned erection date. Visualization is a main feature in BrIM. It allows taking better decisions and developing more accurate plans. By visualizing the bridge components with information related to the status of the precast bridge components, it is easy to know the status of each component and take the suitable decisions or corrective actions. This sub-section presents the methodology of visualizing each bridge component with the previously extracted component status presented in spreadsheet. This visualization is achieved by creating a link between the Microsoft Excel files (component status file) and the BrIM model components.

In order to achieve this link, the 3D BrIM model is exported as an IFC file to be opened with Navisworks Manage software. Using Navisworks Application Programming Interface (API), Structured Query Language (SQL) statements are written to link component information in Microsoft Excel files to the related BrIM model components in Navisworks Manage software. These statements must include property that is common in both BrIM model and data in Microsoft Excel files. This property is chosen to be ID because it is a unique property where no two components can have the same ID. Therefore, the SQL statements function is to retrieve all information for a component of a specific ID from Microsoft Excel file, and show this information for the component of the same ID in the BrIM model. In Navisworks manage software, the components ID begin with a string which is "TS_" and end with a numeric value. This string refers to Tekla Structures, which is the software used to create the 3D BrIM model, while the numeric value represents the components ID as identified by Tekla Structures. Therefore, to achieve the proposed link, this string must be added to all ID values in Microsoft Excel files so that retrieval of information can be done. CONCATENATE function is applied in the Microsoft Excel files to add "TS_" string before the ID value of each component. Fig. 6 shows component visualization with related component status.

The link between the components of the 3D bridge information model and the MS Excel files was given a name that is called *Component Status*. Consequently, Component Status is considered a category in Navisworks Manage. Every category in Navisworks Manage contains attributes and values for these attributes. For any category, Navisworks Manage software allows highlighting components that have specific attribute values. Therefore, if the agencies want to visualize which components are not delivered to the site and planned to be erected in a specific month (for example March), the category is set to be equals to *Component Status*, the attribute is set to be equals to *Received on site*, and attribute value is set to be equals to *No*, and another attribute is set to be equals to *Planned erection date,* and attribute value is set to contain 03/ (which represents March), and by performing the search, Navisworks Manage software highlights the required components as shown in Fig. 7. As such, suitable actions are taken for those elements.

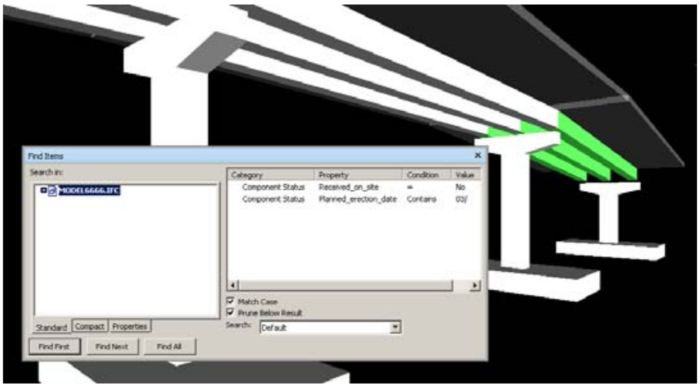


Fig. 7 Highlighting required components

4.3 Controlling documents

Document control establishes a central point where all project related correspondence and documents are logged and tracked. The purpose of document control is to ensure that all project required documents or correspondence is processed as required, and in a timely manner (Bureau of Engineering 2010). BrIM is proposed to be used as an effective tool in controlling construction documents. The proposed methodology depends on adding the main information of the construction document as properties to its related objects (structural members) in the model. The added information for all objects is then exported using API (Application Programming Interface) to create documents control logs. The documents control log records the revisions, dates, and references of construction documents because these documents are often changed and supplemented during the construction phase. The proposed methodology takes into account three types of construction documents which are: Request for Information (RFI), Commencement of Work (COW) requests, and Inspection Requests (IR). The first step is adding new user properties to Tekla Structures by modifying "objects.inp" file in Tekla Structures system. A new category of properties named "Documents Control" is added. The attributes in this category are: Document Reference; Date submitted; Date returned; Subject; Submitter name; Reviewer name; Respond; and Comments. These attributes have to be filled by the user based on the existed information in the construction documents. Fig. 8 shows the added attributes in Tekla Structures. The final step is to extract these attributes from the selected elements in the BrIM model and form documents control log in MS Excel sheet. The process of extracting attributes and creating the MS Excel sheet is achieved by a program that was created using C# programming language. The developed program creates separate logs for RFIs, COW, and IRs. Fig. 9 shows IR log created by the developed program.

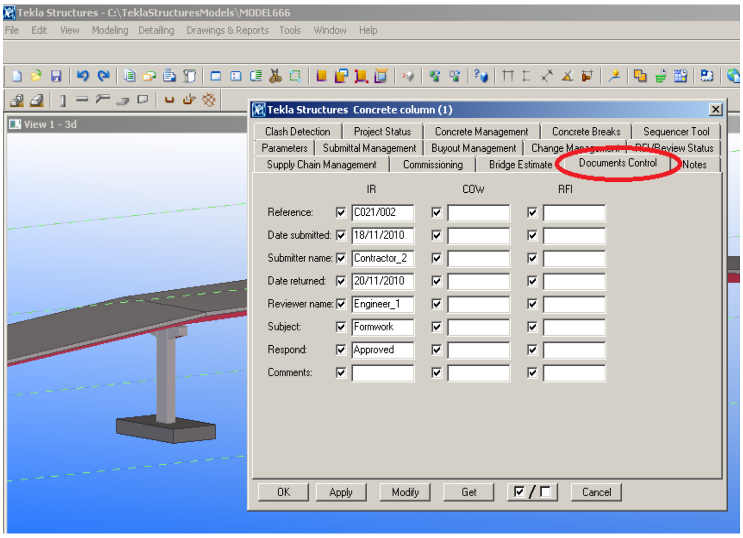
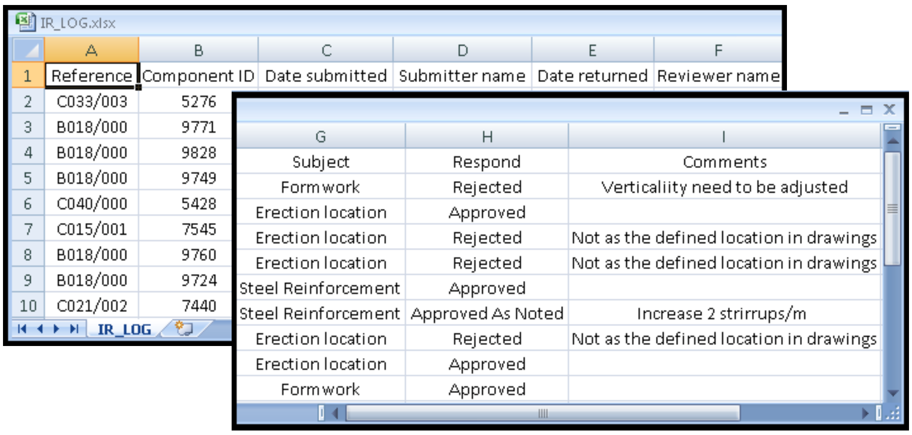


Fig. 8 Added attributes in Tekla structures


IR_LOG.xlsx

	A	B	C	D	E	F	G	H	I
1	Reference	Component ID	Date submitted	Submitter name	Date returned	Reviewer name	Subject	Respond	Comments
2	C033/003	5276					Formwork	Rejected	Verticaliity need to be adjusted
3	B018/000	9771					Erection location	Approved	
4	B018/000	9828					Erection location	Rejected	Not as the defined location in drawings
5	B018/000	9749					Erection location	Rejected	Not as the defined location in drawings
6	C040/000	5428					Steel Reinforcement	Approved	
7	C015/001	7545					Steel Reinforcement	Approved As Noted	Increase 2 strirrups/m
8	B018/000	9760					Erection location	Rejected	Not as the defined location in drawings
9	B018/000	9724					Erection location	Approved	
10	C021/002	7440					Formwork	Approved	

IR_LOG

Fig. 9 IR log created by the developed program

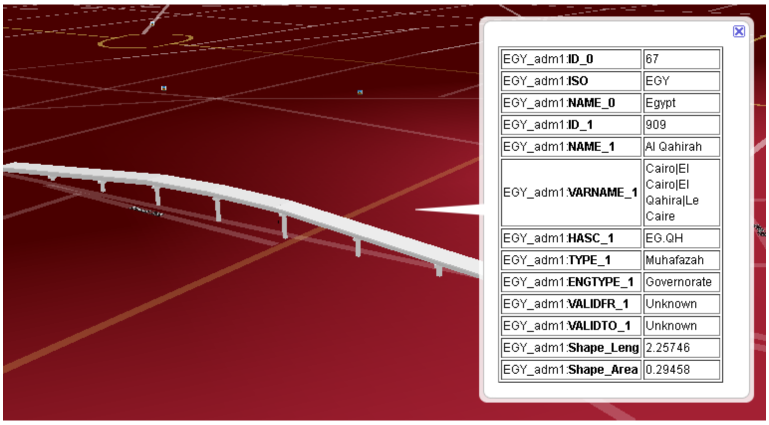


Fig. 10 Visualizing BrIM model with GIS data

5. BrIM model applications in operation and maintenance phase

Integrating Bridge Information Modeling with Bridge Management Systems is proposed. Bridge Information Modeling can be a very effective tool when applied to specific modules of Bridge Management Systems such as: database module, and GIS module. The database module contains information relative to every bridge in the network. All functions and decisions of Bridge Management Systems are based on the information in the Data Base Module (Hudson 1993), so it is very important to maintain accurate information in the database, and this can be achieved with the assist of Bridge Information Modeling. The database module contains data related to: bridge stakeholders; bridge history; service data; geometric data; material data; navigation data; and inspection data. Bridge Information Modeling is proposed to be used as a tool for creating database for bridge components. A program was created using C# programming language to extract information of each component in a bridge to create a database. This program also creates inspection spreadsheets. The developed program extracts component information in the form of MS Excel file. This information contain: component ID; component position; component material; component profile; component length; and component casting type. It can also be modified easily to extract any user defined attribute within the 3D bridge information model. The extracted information acts as a database for bridge components. Also the developed program creates inspection sheets as MS Excel files. These sheets contain: component ID; component position; and the required inspection checklist to be filled by the inspector in the site directly using a laptop or ultra-mobile pc.

Geographic Information Systems (GIS) data have great importance in visualizing the geographical data that may influence bridge management and clarifying the spatial relationships between a road and the bridge (Itoh *et al*. 1997). GIS had been integrated with Bridge Management Systems (BMS). Ng and She (1993) outlined the concepts, features, and strategy for a GIS-based BMS in which GIS was proposed to be treated as a tool to enhance an existing BMS. Kim (1993) used the GIS system as a platform to evaluate the impact of an earthquake on a system of bridges in a region. Itoh *et al*. (1997) used GIS to integrate the bridge data and other data related to roads, rivers, soils, etc. BrIM is proposed to be integrated with the GIS data related to the location of the bridge such as the administrative zone, earthquakes; waterways; roads; soil type;

and traffic flow. This could be achieved by importing the GIS shape files (.SHP) and the BrIM model to Google Earth. In order to import the BrIM model to GoogleEarth, the BrIM model is imported to Google Sketchup software as DWG file then it is exported directly to the bridge location in Google Earth. This integration allows the visualization of 3D bridge models of a network with the related GIS data. Fig. 10 shows the integration of BrIM with GIS data in Google Earth.

6. Conclusions

This paper presented an Integrated Life Cycle Bridge Information Modeling (BrIM). The presented model is capable to perform and facilitate different engineering processes in design, construction, and operation and maintenance phases. For the design phase, the model is used for selecting of the optimum bridge construction method, and performing structural advanced analysis. The construction method is selected in two steps. C# programming language is used to obtain feasible construction methods based on the bridge physical characteristics, while, visualization feature of BrIM is used to check the feasible methods based on site conditions. The structural advanced analysis is performed by integrating BrIM with ANSYS software. For the construction phase, the proposed BrIM model is used for selecting mobile crane locations, monitoring status of precast components, and controlling documents. The mobile crane locations are selected by integrating BrIM with Genetic Algorithms in Microsoft Excel environment. The status of precast components is proposed to be monitored using visualization feature of BrIM that also allows highlighting bridge components that have specific attributes. Controlling documents is achieved by creating new components' attributes (related to construction documents) in Tekla Structures and creating documents control log by exporting these attributes to Microsoft Excel spreadsheet. For operation and maintenance, the presented model is used to improve some modules of bridge management systems such as database module, and GIS module. A program was developed using C# language to extract components information from the BrIM model and create database and inspection spreadsheets. The presented model is also integrated with GIS data by using Google Earth and Google Sketchup software.

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