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Research paper

The BIM 5D model of the bridge built using the incremental launching method

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Abstract: BIM technology is not commonly used in the Polish bridge engineering yet. The article presents a case study of a road bridge made of prestressed concrete and built using the incremental launching method, modelled according to the BIM technology. The bridge with a complex geometry is located along the S1 expressway. Particular attention is paid to the development of the BIM 5D model created on the basis of a design developed traditionally in order to gain competence and verify the set goals. The process of creating subsequent stages of the BIM model is characterized synthetically, in particular the 3D geometric model with the surrounding area and additional 4D (time) and 5D (costs, kinds of materials) dimensions together with the software used. The article discusses the assumptions adopted for the development of numerical models and data analyses. The developed models take into account the assembly phase (construction) and the use (operation) phase, appropriate for the incremental launching method. The results obtained while using BIM technology were confronted with the results identified on the basis of a conventional design. Conclusions present the most important challenges and the achieved goals as well as the pros and cons of creating designs while using BIM technology.

Keywords: BIM, incremental launching method, BIM 5D model, posttensioning concrete, road bridge

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1. Introduction

In the past 25–30 years, many bridges, having diverse structural forms, made of materials with various properties while using diverse construction methods, design principles or applied calculation methods and software have been built in Poland. Major bridge structures have been presented and examined in articles, conference papers, monographs, and websites. The arch bridges in Poland are presented by J. Biliszczuk [1], while T. Siwowski, H. Zobel et al. examine them in the context of construction technology [2]. A number of researchers focused on selected cable-stayed [3, 4] and extradosed bridges [5–7]. The characteristics of the most frequently constructed large-span concrete bridges in Poland are discussed, among others, by P. Wanecki [8, 9] and J. Biliszczuk et. al. [10]. Several dozen of bridges and pedestrian footbridges made of composite materials are described by J. Chróścielewski et al. and T. Siwowski, H. Zobel et al. [11–13]. A variety of bridges built in Poland is covered in the articles published in the materials from regularly organized Polish and foreign conferences.

It is believed that the implementation of the BIM methodology will ensure the continuation of the intensive development of Polish infrastructural construction projects which has been observed in recent years. Nowadays, however, the use of BIM technology, in the Polish bridge engineering in particular, is very not common. The primary reasons for this are the high complexity of bridges, complicated geometry, in many cases multi-stage construction, and the high interdependence of many industries. Road or railway routes along or over which the bridges span are designed taking into account various kinds of soil and location conditions.

Many initiatives have been taken to disseminate the knowledge about the BIM technology in infrastructure construction. A wide spectrum of issues related to BIM is discussed in monographs, among others, by D. Kasznia et al. [14], Z. Kacprzyk [15] and M. Salamak [16], articles by R. Krzymowski [17], J. Bień, M. Salamak [18] as well as case studies [19–22] and conference proceedings, for example, Ł. Grobelny et al. [23] and A. Krygier et al. [24]. Starting from 2016, the series of *infraBIM* conferences [25]. The fifth edition of this conference will take place in May 2023.

The initiatives of professional organizations and government institutions, that have contributed to the publication of guidelines and technical specifications which will require the use of BIM technology in some infrastructure projects in the near future are yet another aspect of the development and implementation of BIM technology in bridge construction in Poland [26–28].

Implementation of the BIM technology in Poland gave rise to numerous academic papers. For example, the work of Jasiński [29] contains a description of the original, parameterized BIM model adapted for the needs of the optimization analyses. The developed model makes it possible to analyze a selected group of prestressed beam bridges from the point of view of various aspects of construction technology, including the division into construction stages and cost analysis. The cross-section parameterization was developed on the basis of over 800 real cases of bridge structures of this type.

W. Trochymiak, whose studies focus on the particular aspects and peculiarities of BIM technology implementation in Poland, is one of its promoters. For example, the paper by Grobelny, Trochymiak [19] discusses a conceptual design of an extradosed bridge between the districts of Wilanów and Wawer over the Vistula River in Warsaw. Among other things, it analyses the BIM 3D model with the adjacent area, the components of the BIM model and the stages of its development, the advantages of the software used (Revit v.2016 and SOFiSTiK v.2014), in particular in the scope related to data exporting from Revit to SOFiSTiK for the purpose of developing a computational model.

The article by Raczyński, Trochymiak [20] describes the design of a reinforced concrete road bridge, including the reinforcement and the elements of the equipment, which was developed in accordance with the BIM technology using the Tekla Structures program. The article focuses on the models and their components, outcomes resulting from the development of the BIM 3D model and the possibilities of automatic editing of the 2D documentation. It also provides an assessment of the advantages of the software used for the design of reinforced concrete bridges. The article examines the developed parametric cross-section of the superstructure, offering the possibility of automatic consideration of subsequent model changes. The BIM 3D model, in addition to geometry, also includes equipment models and models of complete reinforcement of the entire bridge.

The paper by Łapiński, Trochymiak [22] presents the method of developing a parametric BIM 3D model and a computational model of an extradosed road bridge. The authors analyse the software enabling the development of the BIM model, in particular the Tekla Structures and Grasshopper programs. They also discuss the method of developing a computational model based on the BIM 3D model, enabling verification of the designed structure with the SOFiSTiK program. The paper briefly characterizes the selected subprograms which enable data exchange between Grasshopper and SOFiPLUS programs. The paper also contains selected fragments of the model along with an illustration of the possibility of automatic generation of various elements of technical documentation.

2. Case study

2.1. Bridge characteristics

The study focuses on the MS-35 bridge situated along the newly built S1 expressway (on the section between junction "Oświęcim" and the town of Dankowice), at 26 + 857.263 km [24,30,31]. Table 1 contains a list of selected bridge parameters. The properties of the materials used are as follows:

– concrete elements, depending on the exposure class (according to PN-EN 206-1) and element type, respectively: C12/15 – levelling concrete; C30/37 – piles, abutments, retaining structures; C35/45 – foundations, pillars, bearing blocks, pavement structures; C50/60 – superstructure,
– reinforcing steel – A-IIIN,
– prestressing steel – Y1860.

Table 1. List of technical parameters of the facility

Element	MS-35 (left carriageway)	MS-35 (right carriageway)
The total length of the facility	463.312 m	482.700 m
Theoretical span lengths	38.44 + 7 × 48.50 + 47.77 +35.00 = 460.71 m	41.13 + 7 × 51.00 + 46.97 +35.00 = 480.10 m
Overall object width (maximum)	18.70 + 1.30 (clearance in the dividing strip) + 20.60 = 40.60 m	
Clearance width	1.30–2.64 m	
Design height	4.033 m	3.703 m
Traffic lanes	3 × 3.50 = 10.50 m	3 × 3.50 = 10.50 m
Emergency lane	2.50 m	2.50 m
Band	0.50 m	0.50 m
Visibility	0.506–2.400 m	0.510–4.800 m
Safety barriers/railings, etc. – from the side of the inner edge – from the side of the outer edge	−0.50 + 0.60 = 1.10 m −0.50 + 0.40 + 0.90 + 0.40 = 2.20 m	−0.50 + 0.60 = 1.10 m −0.50 + 0.40 + 0.90 + 0.40 = 2.20 m
The total width of the platform	16.80–18.70 m	16.80–20.60
Cross slope of the road	On the structure: 5.00–3.99% one-sided, technical shoulders minimum 4.00%	On the structure: 5.00–1.05% one-sided, technical shoulders minimum 4.00%

The bridge consists of two separate superstructures for each direction of traffic (Fig. 1). The geometry of the superstructures is variable and results from the curvature of the gradeline in space (in the side view and in the plan) and the variable width of the deck slab, web spacing and web height (Fig. 2). Terrain under the bridge and the "connection of the road with the bridge" was an additional factor complicating the geometry of the structure (Fig. 3). The structural schemes are ten-span continuous box girders made of prestressed concrete. The superstructures are supported on two-column intermediate supports with a spacing of 7.3 m (right carriageway) and 6.4 m (left carriageway), respectively.

The webs are connected by the top slab, the minimum thickness of which is 0.24 m. The cross slope of the pavement is 5.0–3.99% (left carriageway) and 5.0–1.05% (right carriageway) respectively. The counterfall under walkways on the left is 2.0%. Vertically the superstructures are located in a convex arch with a radius of R = 12 800.0 m. The deck slab in the top view is adjusted to the course of the road, taking into account the requirements of visibility on the curve. The upper part of each structure runs in a circular arc and in a transition curve. The spacing between the structures increases with the inclination of the road. The box sections of the structure in the top view, as well as the bearings and supports, are located on curves with constant radii, due to the manufacturing technology that was used. Crossbars are located in all axes of supports.

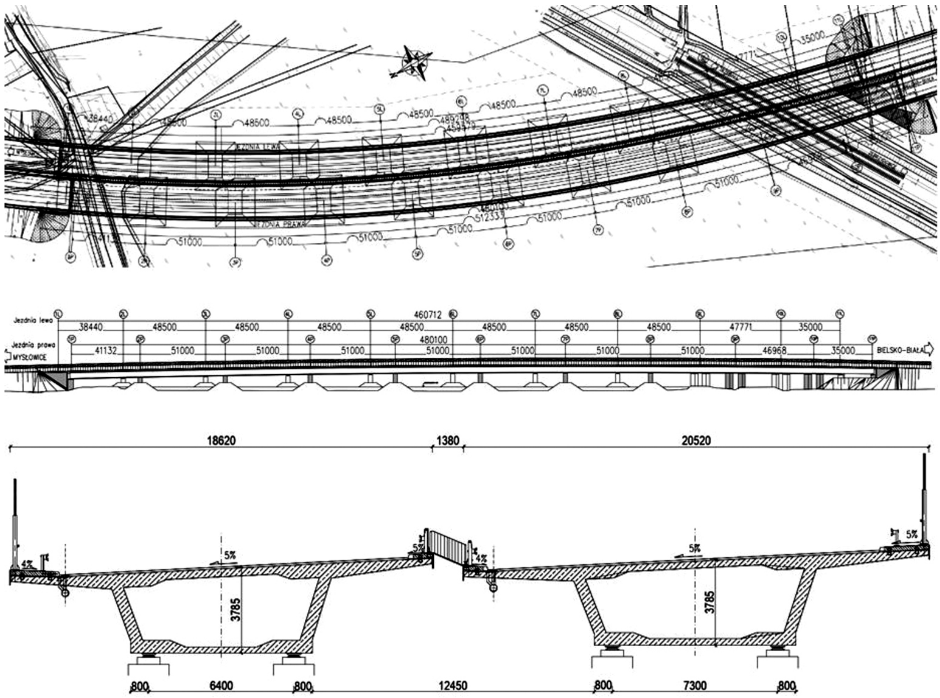

Fig. 1. General construction scheme: from the top: location of the bridge in the plan; side view; typical cross sections [30]

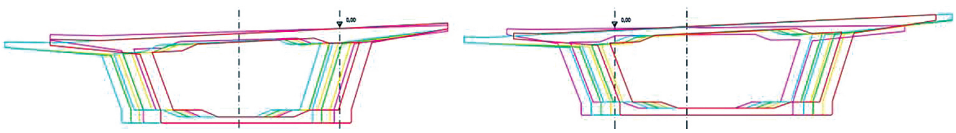

Fig. 2. Scheme of changing geometry of the superstructures; sections are marked with colours as follows: green marks a typical section, orange marks a section at the beginning of the structure, cyan marks a section with the maximum deviation to the right, red marks a section with the maximum deviation to the left, and purple marks a section at the end of the structure

Loads and actions as well as their combinations were adopted in accordance with the PN-EN codes [32, 33] and the respective regulation [34].

The longitudinal prestressing of the superstructures was designed in the form of internal bonded tendons (19 strands) and external unbonded tendons (22 strands) with a strand diameter of 15.7 mm. The deck plate of the superstructures of the right roadway is transversely prestressed.

Currently work in progress. The supports will be built traditionally in formwork using stationary scaffolding. The superstructures will be made using the longitudinal launching method. The production of the superstructure segments is planned behind the abutments in axis 1.

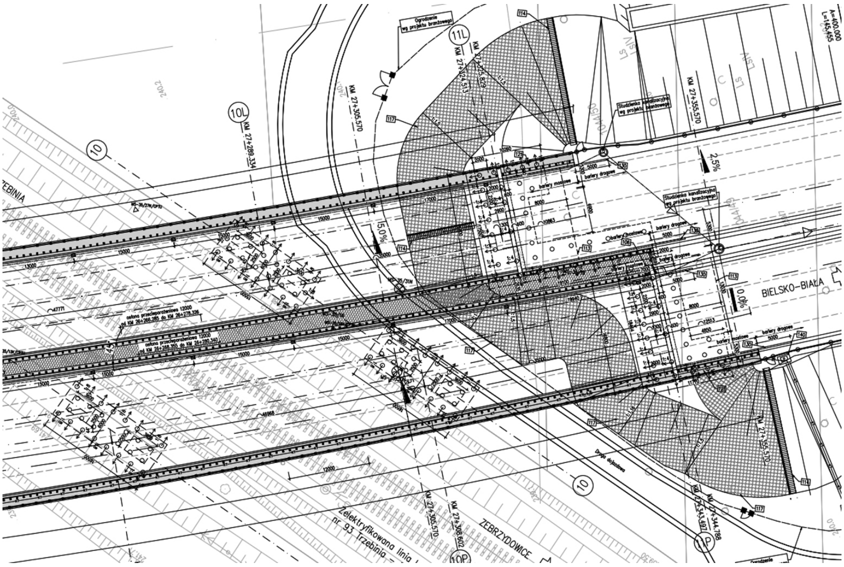

Fig. 3. An example of irregular geometry of the embankment cones of the extreme support P11 [31]

2.2. BIM model – assumptions

In order to gain experience and appropriate competences an assumption was made that the MS-35 bridge project would be carried out traditionally and in accordance with the BIM technology. A decision was made to create a 5D BIM model. Data exchange was provided by the Trimble software [39]. The work was based on a three-dimensional model of the complex geometry of the superstructures, including a fragment of the terrain (Fig. 4 and 5). Further stages involved enriching the model with additional information. The aim was to determine the usefulness of the BIM methodology in the design of engineering structures and to "test" it in a real-life situation.

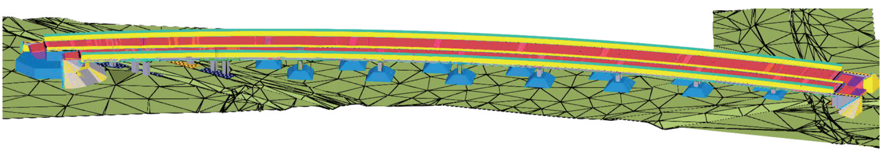

Fig. 4. A general view of the bridge model made with the Tekla Structures program [35]

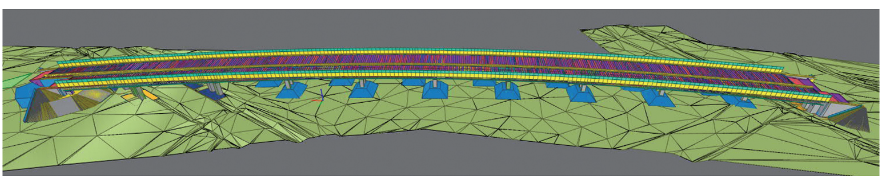

Fig. 5. A general view of the bridge model made with BIM Vision [24]

The biggest challenges that bridge designers currently face in such cases are:

– complex geometry of the superstructures, due to a diversified run of the road, with the superstructures built in stages,
– the limitations in terms of the possibilities of exchange the data generated by various programs used in the BIM technology. Despite the development of a universal IFC (Industry Foundation Classes) format, problems still occur in the process of importing and exporting of data between software programs.

2.2.1. BIM model – 3D

The model was created using Tekla Structures 2021 Service Pack 7 [35]. Due to the limitations of the software in terms of positioning of the object in global coordinates, a local reference system was created with the starting point at the P1 abutment. Millimeters were adopted as the measurement unit, and the accuracy of dimensions was set at two decimal places. Due to the complex geometry of the object, some simplifications of the model were adopted. The superstructure was divided into 0.15–1.5 m-wide bands according to the increasing mileage of the road. The fragments formed this way were inclined depending on the position along the gradeline (Fig. 6). Additional simplifications concerned the modeling of the earth masses (Fig. 7 and 8). These modifications were introduced due to the fact that currently-existing digital terrain models enable terrain generation in the form of triangular elements. These elements are called surfaces. Using the existing terrain-modelling technologies it is not possible to precisely match the excavation bodies to the

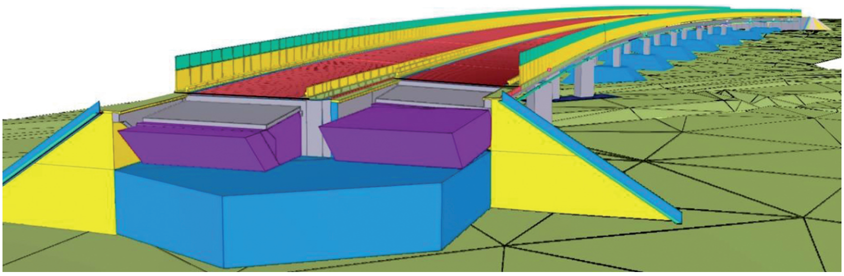

Fig. 6. A view of the MS-35 structure model from the abutment P1 on the southern end

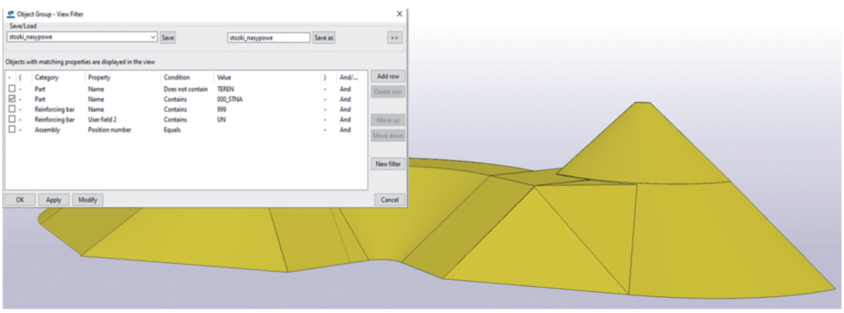

Fig. 7. Model of the embankment cones around the P11 abutment with complicated geometry

terrain without losing data. As a result the average ground level has to be introduced for the foundation excavations.

In the further steps, all the supports were modeled along with such elements as pavement structures, transition slabs, and piles. Reinforcement and prestressing were precisely modeled in the concrete elements of superstructures, pillars, foundations and abutments (Fig. 9).

As for other elements, such as pavement structures or transition slabs, the data related to the reinforcement ratio was introduced. The last phase of creating the geometric model was the development of the remaining elements of the equipment.

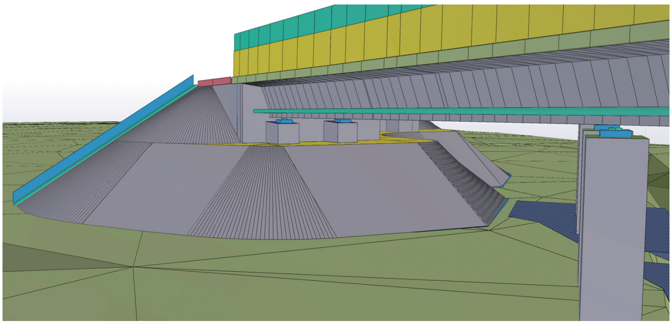

Fig. 8. Visualization of the object's model: a view of the P11 support

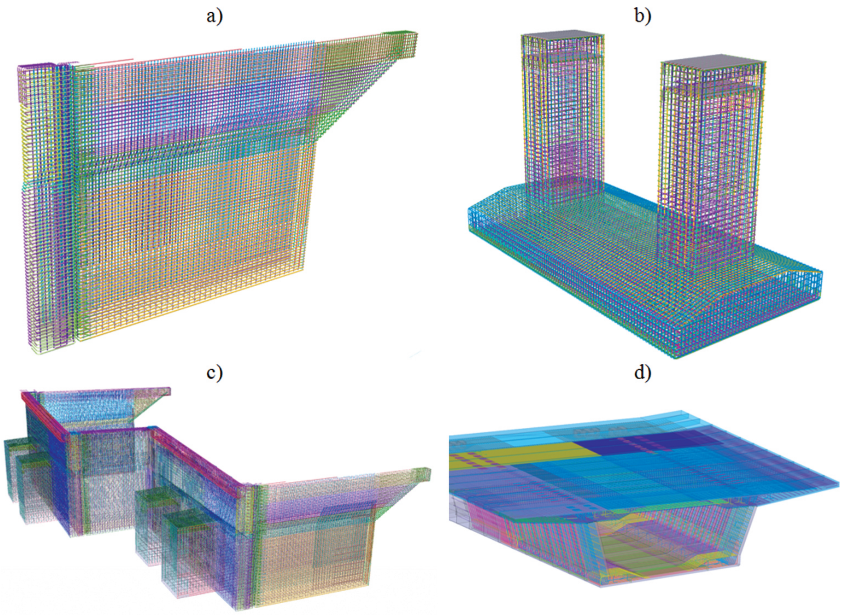

Fig. 9. Examples of modelled reinforcement and prestressing drawings: a) reinforcement of the wing of the abutment P11; b) reinforcement of the foundation footing and pillars; c) reinforcement of the abutment P11; d) reinforcement and prestressing of the superstructure of the left roadway

2.2.2. BIM model – 4D

The fourth dimension of the BIM model, for which time factor has been taken into account, was implemented by adding information on the planned dates for the execution of individual structural elements using Tekla Structures, based on a work schedule (Fig. 10) which was prepared upfront using MS Project program [38]. The main idea of this dimension is to visualize the expected progress of work and the possibility of confronting it with the actual progress of work on site. The progress of work was described in monthly intervals.

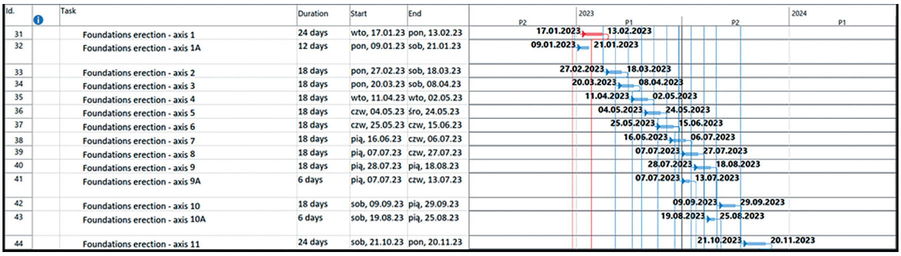

Fig. 10. A fragment of the work schedule developed using MS Project [31, 38]

Fig. 11 illustrates the progress of work presented for selected dates: February 1, 2023: the dikes and islands for the piers P2–P8 were built and piles were made under the abutment P1; November 1, 2023: piles under the P11 support and pillars of the P9 support were made. In addition, segments S11 and S12 (both roadways) of the superstructure were completed;

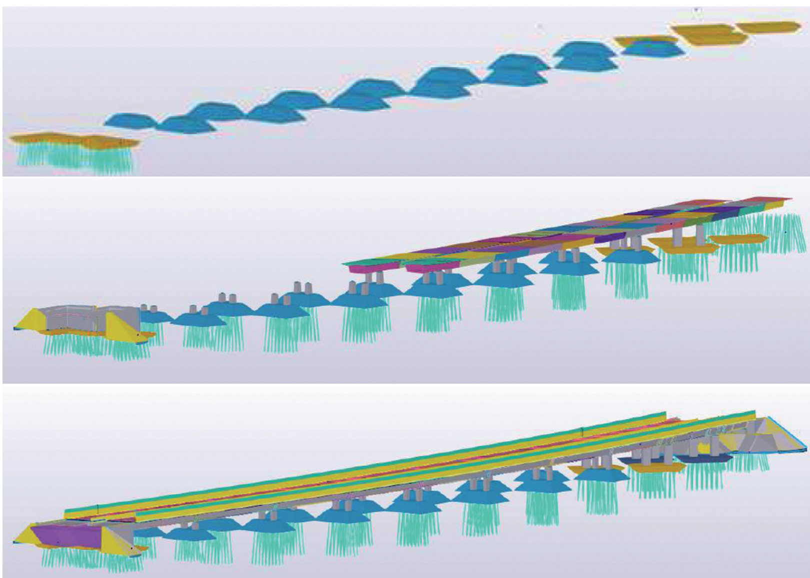

Fig. 11. An example of visualization of selected stages of progress of work as (from top): of February 1, 2023/ of November 1, 2023/ of August 1, 2024

August 1, 2024: thick insulation was installed for the roadway on both structures and transition slabs at the P11 abutments. In addition, all finishing works were carried out.

2.2.3. BIM model – 5D

The fifth dimension of the BIM model, which takes the costs, built-in materials and their properties into account, was obtained by assigning appropriate information to each component of the model. This information was assigned and coded using the iTWO 5D program [36]. Thanks to this, the BIM 5D model enables quick creation of sets of materials, using specified criteria, based on IFC files exported from the BIM model. The process of assigning the cost and material data was semi-automatic. This process required assigning appropriate parameters to the elements of the BIM 3D model and creating a template that assigns elements to the appropriate cost estimate items. Once the above-mentioned actions are completed for the first time, each subsequent update of the data takes place automatically. The iTWO 5D software allows the elements that have been included in specific take-off items, to be viewed, which facilitates the verification of assumptions and the correctness of the program's operation. An example of such a list, together with the visualization of the bill of quantities, is shown in Fig. 12 and 13. In addition, Fig. 14 illustrates fragments of the developed matrix enabling the creation of bills of materials using the iTWO 5D program.

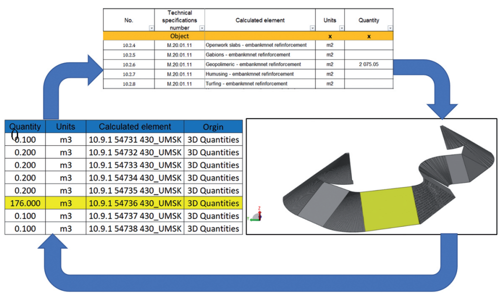

Fig. 12. Information transfer diagram with visualization of the side surfaces of the abutment slopes in the iTWO 5D program [24]

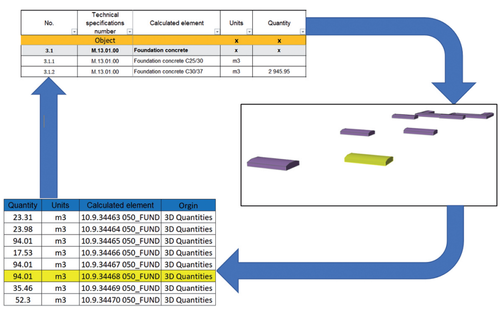

Fig. 13. Information transfer diagram with visualization of starting elements of supports in the iTWO 5D program [24]

Objects select group	Codification	Bill of qunatities position	iTWO 5D calculating formula	Quantities	Units
Excavations	000_WYKO	Excavations in solid soil	QTO(Typ:="Atrybut{p_Volume}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	3.836,650	m3
Earthworks	000_ZAWY	Backfill	QTO(Typ:="Atrybut{p_Volume}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	19.489,220	m3
Embankment	000_STNA	Embankment	QTO(Typ:="Atrybut{p_Volume}")	8.826,610	m3
Pales "Franki"	010_PLFR	Pales "Franki" fi610	QTO(Typ:="Atrybut{p_Length}";Element:="$p_CrossSection==@WM ")/1000	9.048,133	m
Reinforcement	999_ZBRJ	Reinforcement - AIIIN foundations	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	331.841,310	kg
Reinforcement	999_ZBRJ	Reinforcement - AIIIN abutments	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	75.938,200	kg
Reinforcement	999_ZBRJ	Reinforcement - AIIIN abutments wing walls	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	46.634,800	kg
Reinforcement	999_ZBRJ	Reinforcement - AIIIN piers	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	132.632,480	kg
Reinforcement	999_ZBRJ	Reinforcement - AIIIN superstructure	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	2.432.525,260	kg
Reinforcement	999_ZBRJ	Reinforcement - AIIIN superstructure	QTO(Typ:="Atrybut{PORR_MS35\weight_total}";Element:="$p_Subtype ==@PT lub ${PORR_MS35\p_Subtype} ==@PT ")	7.846,600	kg
Foundation	050_FUND	Foundations concrete C30/37	QTO(Typ:="Atrybut{p_Volume}";Element:="Atrybut{Material} ==@KB ")	2.945,000	m3
Abutment	110_PRSC 110_PRSK	Abutments and wing walls concrete C30/37	QTO(Typ:="Atrybut{p_Volume}";Element:="Atrybut{Material} ==@KB ")	1.308,600	m3
Piers	130_FILR	Piers concrete C35/45	QTO(Typ:="Atrybut{p_Volume}";Element:="Atrybut{Material} ==@KB ")	1.356,880	m3
Superstructure	100_UNSK	Superstructure concrete	QTO(Typ:="Atrybut{p_Volume}";Element:="Atrybut{Material} ==@KB i ${PORR_MS35\p_Subtype} ==@PT ")	12.447,910	m3

Fig. 14. A fragment of the matrix segregating the elements in iTWO-5 program [36]

2.3. Computational models

An additional aspect of the study was the development of an analytical model using the SOFiSTiK program [37]. Models of assembly and operation phases were prepared, respectively, for the load-bearing structure of the left and right roadway (Fig. 15–17). Due

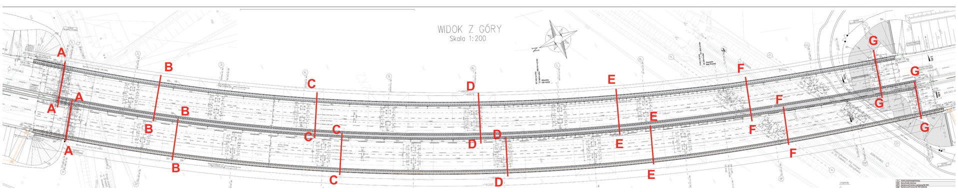

Fig. 15. Designation of control points in the top view [31]

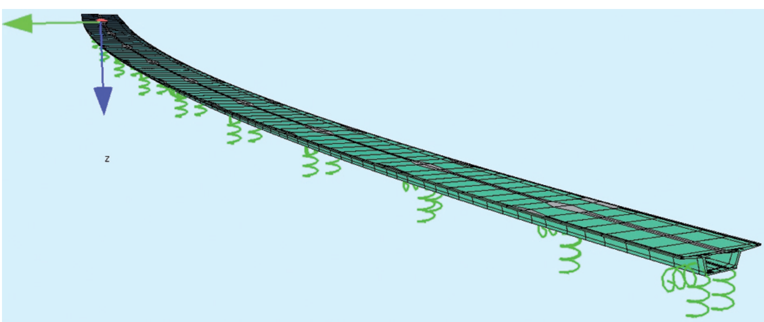

Fig. 16. Visualization of the model of the superstructure of the left roadway

to the diversity of the cross-section of the superstructure, a decision was made to interpolate it between 7 control points along the length of the structure. The impact of rheological interactions was determined in time intervals of 7 days (which is an average construction time for a load-bearing structure segment), 170 days (approximate construction time for the entire structure) and 25,550 days (operation time of the structure in accordance with the requirements of the ordering party).

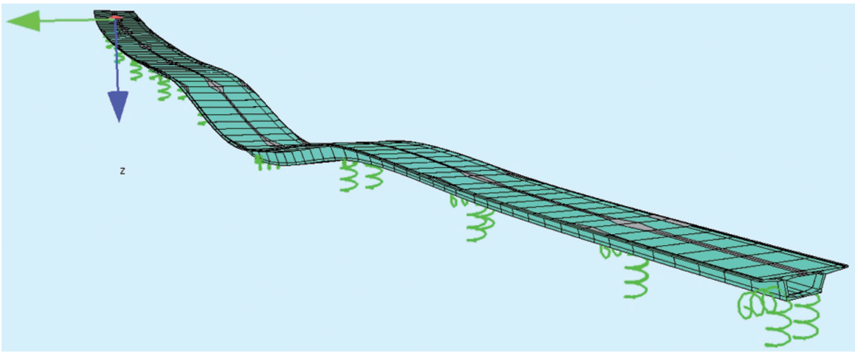

Fig. 17. Verification of the model assumptions by checking the behaviour of the super structure in the case of uneven settlement of the P7 support

3. Conclusions

In this specific case implementation of the BIM technology made it possible to achieve satisfactory results. They are presented in the following tables: Table 2 summarizes the most important challenges and achieved goals, while Table 3 presents significant advantages and disadvantages of the BIM technology in the context of the completed case study.

While referring to detailed figures, we have considered it important to provide two examples of verification of data calculations: one calculated using the BIM model and another calculated using the conventional design. The first of them relates to the volume of earth masses of embankment cones and backfill behind the abutment, which in the case of classical design turned out to be overestimated by 35%. The second example concerns differences in the mass of reinforcement of concrete elements, which is 1–2%.

In a broader scope, we consider it necessary to eliminate several inconveniences that occurred during the design of the MS-35 bridge while using BIM technology. In order to do that the tasks for the coming years should include:

– improvement of the (software) tools for creating increasingly complex geometric solids,
– introduction of geological data into models,
– promotion of the IFC format as well as creation of regulations and standards for BIM models.

Table 2. List of challenges and achieved goals

Challenges encountered	Goals achieved
No formal requirements from GDDKiA[1)]	Development of a 5D model of the bridge
Very high costs of implementing the BIM technology	Developing an efficient design process in the BIM technology
Limited materials regarding the characteristics of the Polish infrastructure market in the field of BIM technology	Development of a calculation model with a division into the construction and operation phases
Creating a comprehensive model with a large database of information	Verification of the correctness of the created model and numerical analysis
Preparation of the computational model and analysis of the obtained results	Presentation of the assessment of usefulness of the BIM technology

1 General Directorate for National Roads and Highways (Polish: Generalna Dyrekcja Dróg Krajowych i Autostrad, GDDKiA)

Table 3. List of advantages and disadvantages of using the BIM technology

Advantages	Disadvantages
A very large amount of data stored in one place	Time-consuming model creation (bridges with complex geometry) at the initial design stage
Transparency of the stored data and its availability to all participants of the investment process	The BIM Wash phenomenon which consists in advertising the solutions which include a wider range of possibilities than currently available
Easy cross-industry coordination	Limited data transfer capabilities (lack of full integration), even when using the IFC format
Quick creation of accurate 2D drawings from a 3D model	Reluctance of a large group of participants in the investment process towards technological progress
Quick creation of sets of materials	High hardware and software purchase and update costs
Possibility to verify possible collisions	
Facilitating the optimization process	Limited "interest" in BIM at construction sites

Summing up, it is worth mentioning that during the first phase of the construction stage the dialogue was established between design engineers and site engineers, which focused on collection of data and requirements needed for the construction engineers on site. As a result, the CDE platform was abandoned (Trimble Connect). Despite many advantages generated by that tool so far, the tool did not fulfil the expectations of site engineers. Thus a PORR corporate tool was introduced which was created using Excel and BIMVsion to generate databases connected with the IFC model. Thanks to implementing this solution, the model is being enriched with the data from the construction site.

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Model BIM 5D mostu budowanego metodą nasuwania

Słowa kluczowe: BIM, beton sprężony, metoda nasuwania wzdłużnego, model BIM 5D, most drogowy

Streszczenie:

Metodyka BIM, szczególnie w polskim mostownictwie, nie jest jeszcze powszechnie stosowana. W artykule przedstawiono studium przypadku projektowania mostu drogowego z betonu sprężonego, budowanego metodą nasuwania, zgodnie z metodyką BIM. Most o skomplikowanej geometrii znajduje się w ciągu drogi ekspresowej S1. Szczególną uwagę zwrócono na opracowanie modelu BIM 5D, tworzonego na podstawie projektu opracowanego tradycyjnie, w celu zdobycia kompetencji zespołu projektowego i weryfikacji postawionych celów. Syntetycznie scharakteryzowano proces tworzenia kolejnych etapów modelu BIM, w szczególności modelu geometrycznego 3D wraz z otoczeniem, i dodatkowymi wymiarami 4D (czas) i 5D (koszty, rodzaje materiaów) łącznie z zastosowanym oprogramowaniem. Krótko przedstawiono założenia przyjęte w celu opracowania modeli numerycznych i analizy danych. Opracowane modele uwzględniają fazy montażowe (budowę) i fazę eksploatacji charakterystyczne w metodzie nasuwania wzdłużnego. Wyniki otrzymane według metodyki BIM skonfrontowano z wynikami wyznaczonymi na podstawie konwencjonalnego projektu. Podsumowanie zawiera zestaw najważniejszych wyzwań i osiągniętych celów jak również wady i zalety projektowania zgodnego z metodyką BIM.

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