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OPTIMIZATION OF POWER PLANT BUILDING STRUCTURAL DESIGN WITH BIM

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ABSTRACT

Shimizu Corporation has developed a design integration system called "NuDIS-BIM (Nuclear Design Integration System on BIM)" based on BIM (Building Information Modeling) to optimize the structural design work for nuclear power plants (NPPs). The system will be applied from the upstream design stage to shorten the design period.

Although the structural design of NPPs has been systematized, it still relies heavily on the expertise of structural engineers and requires enormous time and effort to prepare input data into the design system, and to check it to avoid human errors. In addition, since NPPs consist of huge and complex components, and design data goes through various considerations and complicated processes, the design data result in fragmented and disconnected data in 2D format.

NuDIS-BIM provides solutions to these challenges by utilizing BIM to link and streamline the entire design process. Specifically, the system links and integrates various systems that detect the interference between piping and building structure, optimize the arrangement and dimension of walls, floors, columns, beams and other structural components, generate structural analysis models automatically, examine the reinforcement arrangement, and output structural design drawings. All systems operate on the BIM structural model.

In the design process utilizing NuDIS-BIM, Mechanical & Electric (M&E) designers first create facility equipment layout plans on BIM, while presenting the shape of the building and necessary radiation shielding performance. Then, the building structural designers verify the validity of the structural plan such as the arrangement and dimension of walls, columns, beams, etc., and confirm the interference between the M&E equipment and the structure on the BIM model, and determine the shape of the structural BIM model. Next, data of the structural BIM models are automatically converted into analysis models, and the structural safety of the building is verified through various analyses such as seismic response analysis. Finally, the required structural performance such as the necessary number of rebars obtained from the analysis results is fed back to the structural BIM model. From the BIM model, it is possible to freely output drawings such as concrete outline (plan view and cross-section view) and lists of rebar arrangement for each member. By utilizing this data linkage, it is expected that the design period of NPPs can be shortened by approximately 2 months, which are equivalent to 10% of the total period.

INTRODUCTION

In Japanese construction industry, there is a growing trend to streamline structural design tasks through BIM. In general construction projects, the integration of BIM with structural design is progressing, leading to the establishment of systems for unified management of design information in BIM.

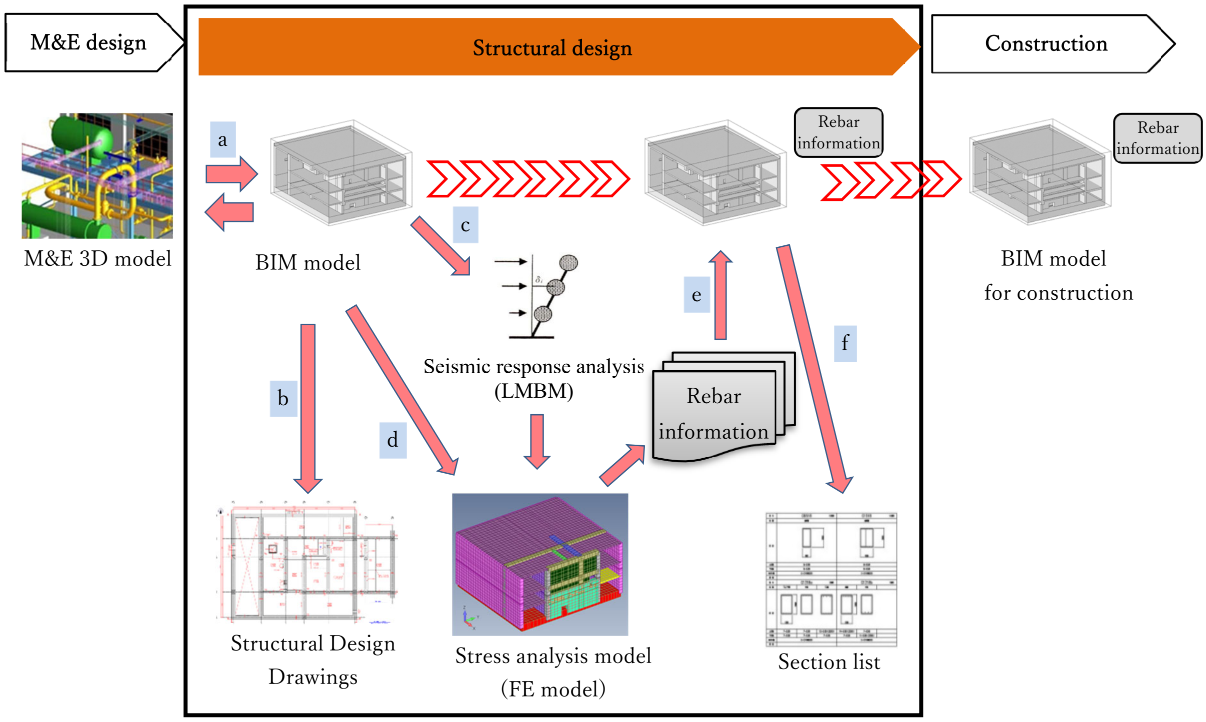
On the other hand, in NPPs, the processes and analysis programs for structural design differ from those in general construction projects. Consequently, it is not feasible to directly apply systems built for general construction to NPPs. Specifically, in general construction, it is common to create a structural analysis model based on the architectural plan, conduct section evaluations, and then generate structural BIM. In NPPs, however, the creation of structural BIM is based on equipment layout diagrams and structural dimension requirement drawings from electromechanical manufacturers. The structural analysis model is then derived from the BIM, and section evaluations are performed. Additionally, the structural analysis conducted in NPPs often involves the use of different analysis programs than those used in general construction. Specifically developed automated section design tools, as presented in P. James, et. al. (2019) and T. Tsukada, et. al. (2020), have also been developed to meet the design standard requirements unique to NPPs.

Therefore, this study aims to propose a system that is tailored to the structural design processes and analysis programs of NPPs, facilitating the integration of BIM with structural design in these specific contexts.

PROPOSED METHOD OVERVIEW

NuDIS-BIM is a combination of tools and methods to improve the efficiency of design work by linking design work data handled in the structural design work of NPPs using BIM data. The application range of the NuDIS-BIM is shown in the area inside the bold lines in Figure 1. The purpose of development of this system is to utilize the created BIM model in order to coordinate the layout with M&E designer, calculate the quantity for structural analysis, create analytical models, and create structural 2D drawings in building structural design efficiently. Specifically, tools and methods are used to automate the design work of communication and interference coordination between designers in charge of facility design and basic building planning and building structure designers, picking up the necessary parameters for seismic response analysis, building structural analysis models, examining member reinforcement, and creating structural design drawings by using the 3D shapes of BIM data and the attribute information possessed by individual members. The tools and methods are designed to automate the design process by using the 3D shapes of BIM data and the attribute information of individual members.

The structural design of NPPs requires a high quality of accuracy, but when design conditions change, the complexity of the building shape, the high density and complexity of the rebar, the need for coordination among multiple disciplines, and the large amount of checking evidence require time and effort, which can be reduced with this system, preventing delays in the design schedule and construction start-up, and the risk of huge expenses due to extending construction periods. The following is a description of each of tools and methods in NuDIS-BIM.



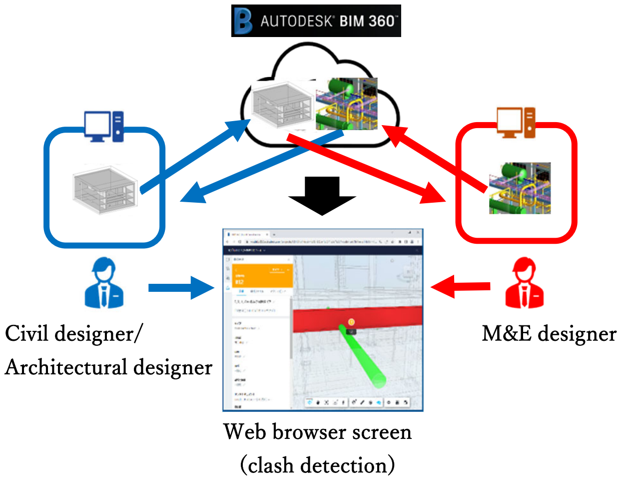
a. Coordination with M&E 3D Model (described in section "*Methodology for Coordinate Placement and Interference*")
b. Output concrete body plan drawing (described in section "*Generation Tool for Structural Design Drawings*")
c. Output information for seismic response analysis (described in section "*Calculation Tool for Seismic Response Analysis Properties*")
d. Convert into Stress analysis model (described in section "*Generation Tool for FE Model*")
e. Feedback number of rebars to BIM model (described in section "*Reinforcing Arrangement Tool*")
f. Output member list (described in section "*Generation Tool for Structural Design Drawings*")

Figure 1. Application range of NuDIS-BIM

Methodology for Coordinate Placement and Interference

At present, M&E designers, architectural designers and structural designers exchange design information by presenting 2D drawings to each other to detect interferences. In the process of sharing these BIM models, Autodesk® BIM 360® a commercially available cloud server for BIM, provide following functions without BIM software, viewing the 3D models and 2D drawings of the BIM models , notification of design changes, comparison between old and new models, question and answer, clash detection by overlaying multiple BIM models as shown in Figure 2. It also allows to put questions and answers on the 3D models, and records of these questions and answers can be stored and managed. In the development of this system, we studied how to use those function in the design activity of NPPs and conducted trial run, and summarized the results in a procedure document.

As a result of the trials, it was found that by exchanging BIM models with integrated design information, the following tasks, which are currently performed by using 2D drawings, can be performed efficiently : conversion of CAD data to PDF, printing on paper and circulation; filling comments on the paper, scanning the paper, and sending the scanned data by email; creation of additional drawing to explain design changes; registration and sharing of received data; storing the date, finding out of each design changes on received drawings; data superposition to check detect interferences; and creation of question-and-answer documents. The project team confirmed that those work could be significantly reduced.



On web browser screen

- Viewing 3D models and 2D drawings
- Notification of changes
- Comparison between old and new models
- Question and answer
- Clash detection

Figure 2. Design Coordination in BIM Model

Calculation Tool for Seismic Response Analysis Properties

In the seismic design of NPPs in Japan, seismic response analysis using the standard seismic ground motions is conducted to verify whether the building can maintain the required functionality. In this context, a lumped mass-beam model (LMBM) is commonly used for seismic response analysis. LMBM involves setting mass points in the vertical direction of the building and connecting them with beam elements that consider shear stiffness and moment of inertia. The web of walls is considered for shear stiffness, and the flange of walls is considered for moment of inertia with reference to JEAC 4601-2021. When creating LMBM, it is necessary to calculate the specifications of the building. Previously, structural designers read dimensions from drawings and tabulated them, which took time to create models. This section introduces a system that calculates properties for LMBM from a BIM model.

Figure 3 shows flow of generating properties for LMBM, and figure 4 shows Example of calculation of properties for LMBM. The properties for LMBM include weight, rotational inertia weight and stiffness. These parameters are calculated from the BIM model. By specifying areas in the BIM model, the volume of the structural elements is calculated within the specified area, and the weight is determined. It should be noted that the BIM model also includes other loads such as dead loads, equipment loads, and piping loads. By modelling these loads, the system can aggregate weights, including loads other than the weight of structural elements. Stiffness refers to the stiffness of walls between floors or the floors between cores. By specifying seismic elements in the BIM model, the stiffness is calculated within the specified walls and floors. This calculator tool integrates these functions into a single system. By using this tool, it is possible to create lumped mass models of buildings more efficiently than before.

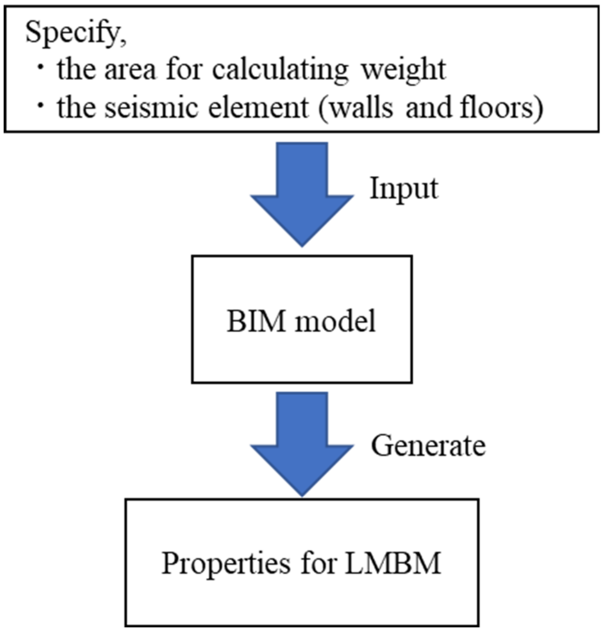
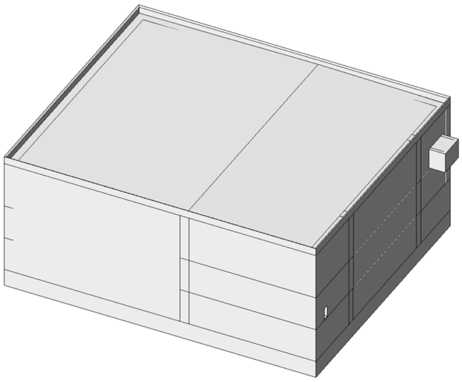
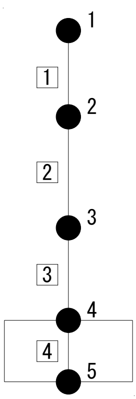


Figure 3. Flow of generating properties for LMBM



(a) BIM model



(b) LMBM

Node No.	Weight W (kN)	Rotational Inertia I_G ($\times 10^6$ kN·m^2)
1	194, 616	45. 7
2	229, 320	53. 9
3	253, 638	59. 8
4	258, 021	60. 8
5	247, 833	58. 3
Sum	1, 183, 428	

Element No.	Section Area for Shear As (m^2)	Moment of Inertia of Area I (m^4)
$\boxed{1}$	436. 8	172, 170
$\boxed{2}$	447. 3	220, 140
$\boxed{3}$	431. 6	217, 350
$\boxed{4}$	2528. 1	591, 750

(c) Properties for LMBM

Figure 4. Example of calculation of properties for LMBM

Generation Tool for FE Model

In creating a finite element model (FE model), it takes time to create the FE model, since the model creator needs to input information such as the shape, dimensions, and material properties of members based on drawings and structural documents. By using this FE model generator tool, the information to create FE models can be automatically and efficiently extracted from the BIM model. This tool creates the FE model from Autodesk® Revit®, using Simcenter Femap®, the FEM pre-post processor and can generate models for various finite element analysis (FEA) software that Femap can convert.

Figure 5 shows the processing of the FE model generator tool. The FE model generator tool is created as an add-in tool for Revit. Firstly, this tool converts the shape, dimensions, and material properties of members contained in Revit into graphical information called "geometry" in Femap®. Geometry is not the FE element, but the figure used for creating FE elements and nodes. Converting from BIM model to the geometry is shown in Figure 6. Walls and floors are converted as surface geometry, and columns and beams are converted as line geometry. Thickness of walls and floors, shapes and dimensions of columns and beams, and material information can be assigned to geometry in Femap®. The user can also select the members to be converted on the screen since the BIM model also includes members that are generally not modelled in FEM. In BIM model, the volume of the members is also included, but the members are converted as surface or line geometry, resulting in gaps at the joints of the members. Figure 7 shows an example of gaps between joints. This tool determines the connection of members based on the distance between them and extends the geometry to automatically fill in gaps. Figure 8 shows an example of filling the gap at the joint. Furthermore, if necessary, the positions of walls can be aligned on a grid lines, and the positions of floor slabs can be aligned at the same level. Figure 9 shows an example of adjusting the geometry position. It is necessary to set FE elements and nodes for the converted geometry. Femap® has a function to set elements and nodes, but this tool also sets the element division and node positions of all members at once based on the grid and level line in BIM model. The FE model generated from the Revit model is shown in Figure 10.

After performing the structural analysis, it is necessary to input required reinforcing bars into BIM model based on the analysis results. A description of the tools for entering reinforcing bar into BIM model is given in next section. FE model generator tool can also output the correspondence ID list of the geometry and FE elements which is used to input reinforcing bars into BIM model. The geometry ID in Femap® is converted to be the same as the member ID in BIM model. As a result, this generator makes it more efficient to create the complex models such as 3D building models than before.

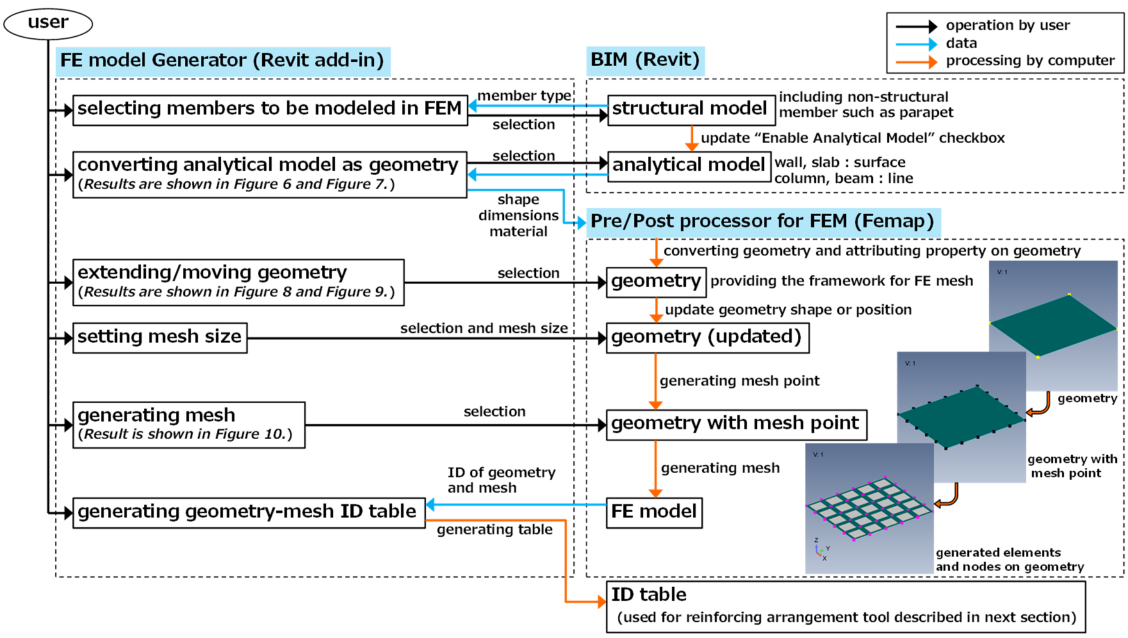


Figure 5. Flowchart of FE model generator tool

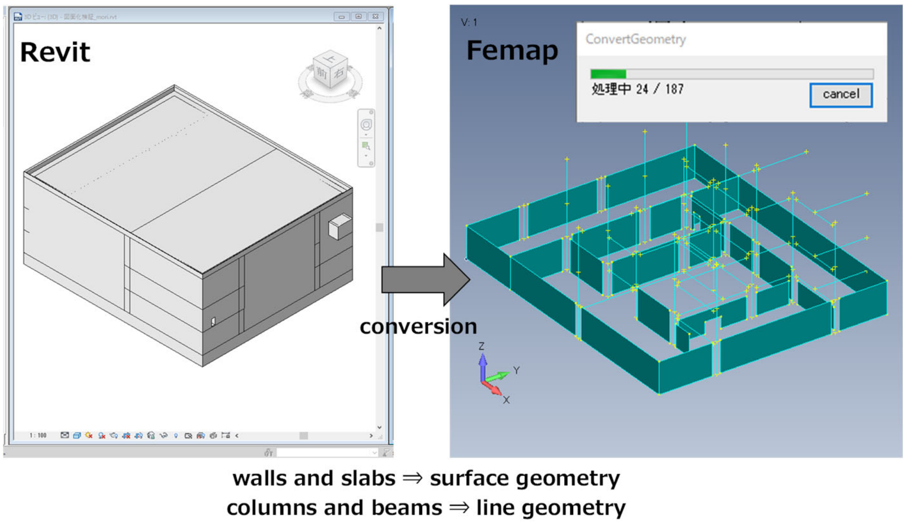


Figure 6. Converting from BIM model to the geometry

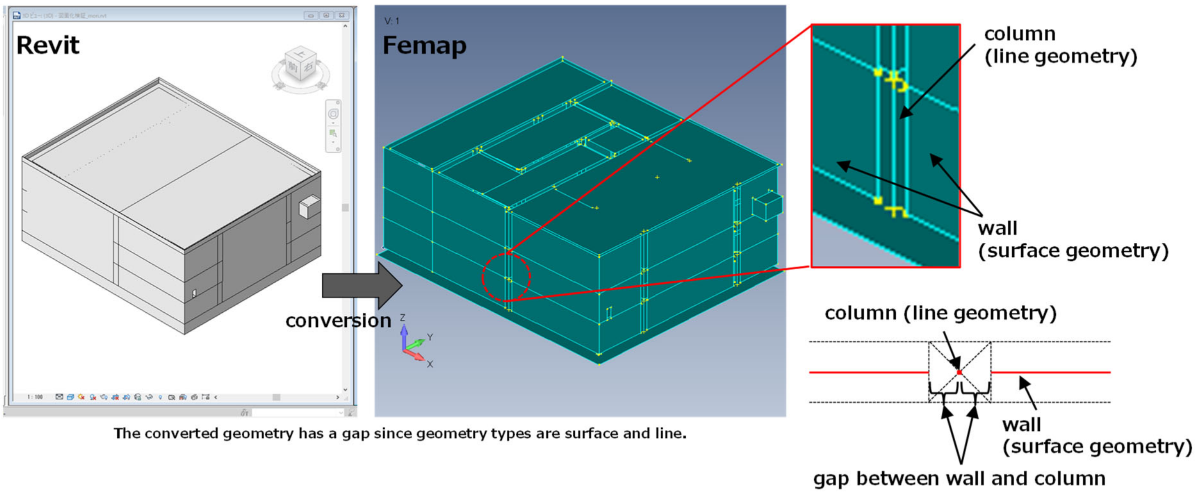


Figure 7. Gaps between line geometry and surface geometry

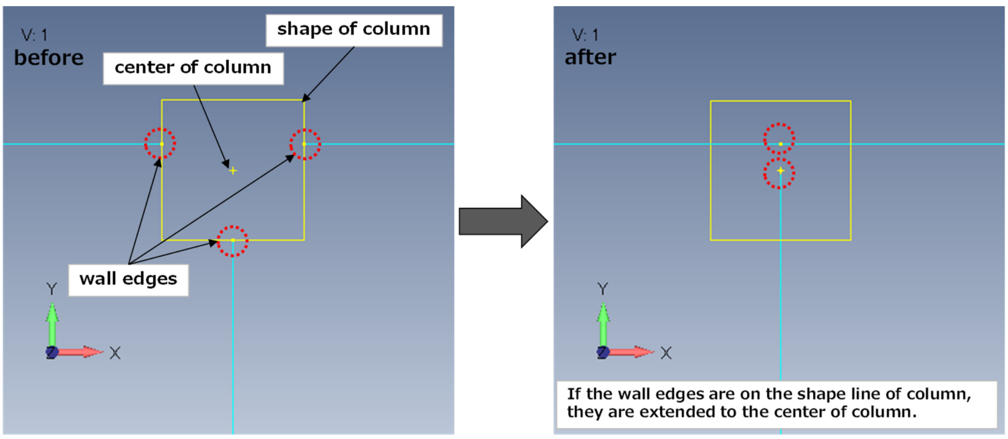
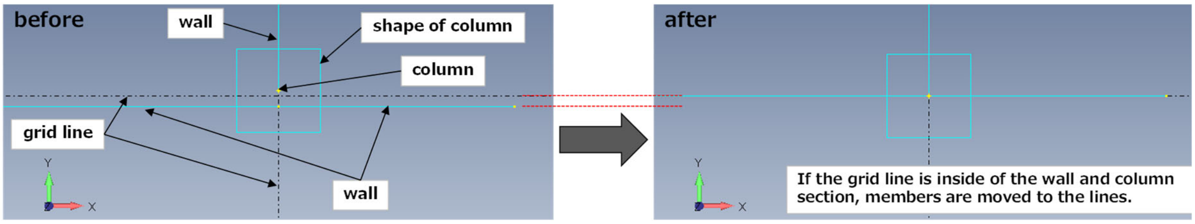
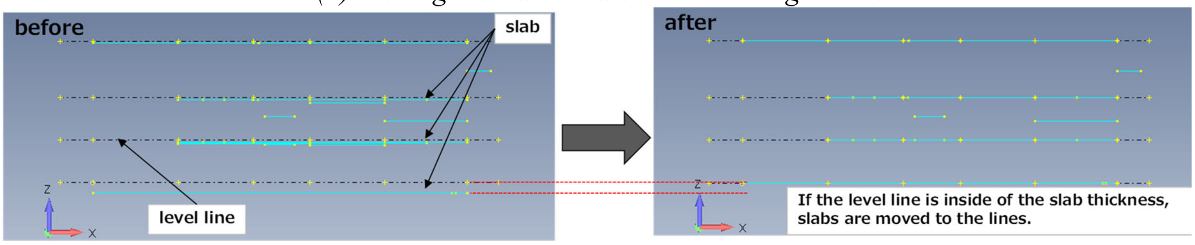


Figure 8. Result of extending the walls edges to the column

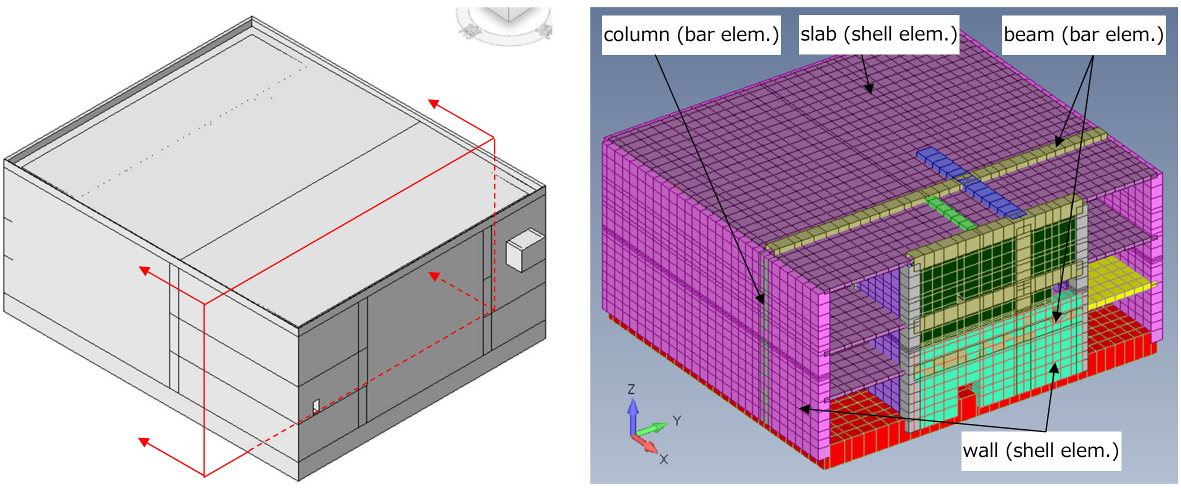


(a) Moving the walls and column to the grid line



(b) Moving the slabs to the level line

Figure 9. Result of moving the geometry



(a) BIM model *(b) FE model*

Figure 10. Result of generating FE model from BIM model

Reinforcing Arrangement Tool

This section presents a reinforcing arrangement tool that reads the results of the section design, including the required reinforcement ratio in walls, slabs, beams, and columns. The tool allocates the reinforcement information to be reflected in the BIM for more accurate assessments by nonlinear structural analysis and construction studies. The required reinforcement ratios are obtained from automated section design tools, utilizing FE modelled reinforced concrete shell elements and line elements, as introduced in P. James, et. al. (2019) and T. Tsukada, et. al. (2020).

Figure 11 displays the user interface of the reinforcing arrangement tool, which functions as an add-in tool integrated into Autodesk® Revit®. Users have the option to input section design results in text or CSV format into the reinforcing tool. The tool facilitates the determination of rebar specifications, including diameter, number, and pitch, ensuring that the overall reinforcement quantity meets the specified requirements. The reinforcement information is incorporated into both the type parameters and the instance parameters. General details regarding the reinforcement, such as the member ID shared by members with similar dimensions and reinforcing arrangements, the count and diameter of reinforcement, etc., are captured in the type parameters. More specific and detailed information about the reinforcement is additionally reflected in the instance parameters, encompassing arbitrary coordinate values denoting the location of individual reinforcements.

The reinforcing tool is seamlessly connected to Simcenter Femap® software through an API, enabling users to interactively select members for reinforcement arrangement through the GUI interface. The tool provides a visual representation of required reinforcement ratio or utilization ratio, as illustrated in Figure 12 for a pilot model. Figure 12 also showcases an example of the reflected reinforcement information. This reinforcement data integration into the BIM model proves valuable for constructing nonlinear structural analysis models with reinforcement, conducting more extensive assessments against substantial seismic events, generating structural member drawings, and detailing the reinforcement for construction purposes.

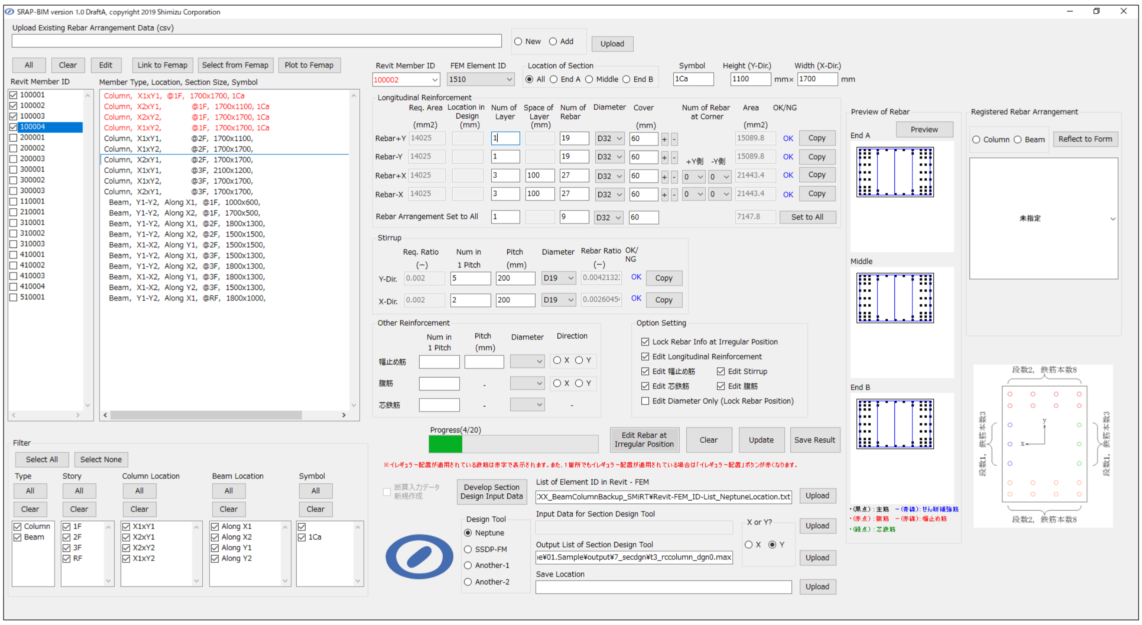
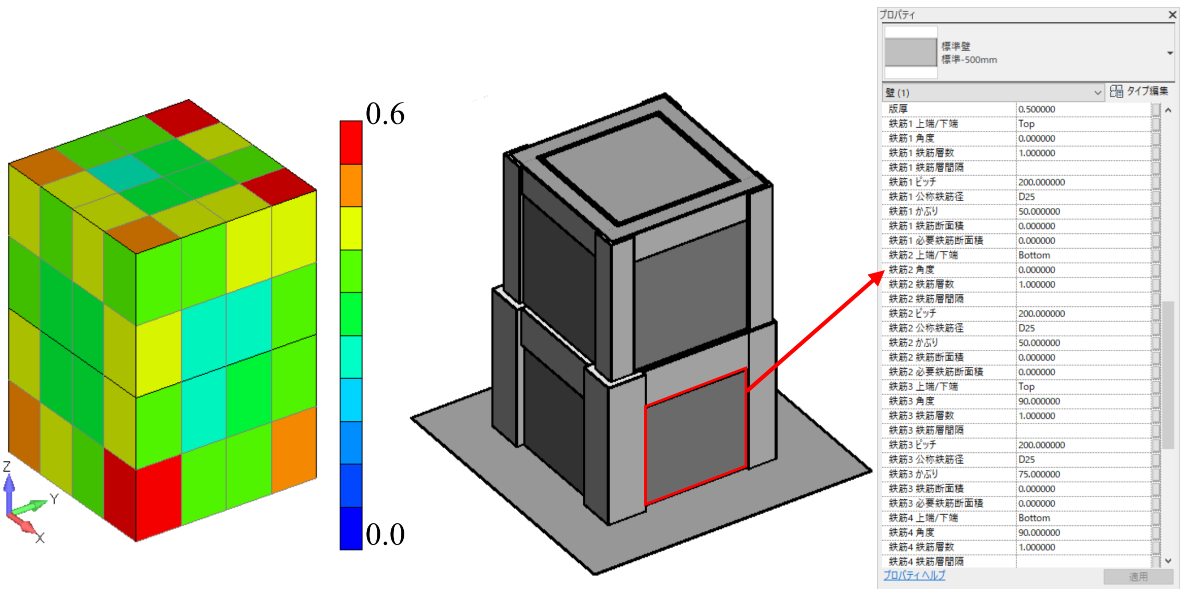


Figure 11. User form of reinforcing tool



(a) Required rebar ratio (%) *(b) Rebar information reflected in BIM*

Figure 12. Example with pilot model

Generation Tool for Structural Design Drawings

Structural design drawings are generally created using CAD software such as Autodesk® AutoCAD®. However, since the introduction of BIM, it has become common to generate drawings from the BIM model. By outputting drawings from BIM, it is possible to create drawings linked to BIM Model and structural design results. This prevents inconsistencies among structural design results, structural design drawings and streamlines drawing revisions during design changes. In this chapter, we will explain the mechanism of creating drawings from BIM model is to be explained.

The creation of drawings involves using the sheet function in Autodesk® Revit®. For plans and sections, the process includes extracting floor plans and arbitrary sections from the BIM model for each level and adding necessary information such as core locations, dimensions, and material codes to create the drawings. The information added to the drawings is linked to the attribute information entered into the BIM model. This enables automatic updates during design changes to avoid inconsistencies.

Section lists are created using the section list output tool. It is an add-in tool integrated into Autodesk® Revit®. It reads the reinforcement information input as attribute information using the reinforcing tool into the BIM model's elements and outputs section lists.

CONCLUSION

The implementation of NuDIS-BIM system is expected to shorten the design period for NPPs by approximately 2 months, which are equivalent to 10% of total period. In the future, further functional enhancements and user-friendliness improvements will promote the creation and use of BIM models in design work, and the use of these BIM models in subsequent construction and maintenance work will contribute to improve the efficiency of the entire process, from design to maintenance management.

REFERENCES

P. James, A. Ahmed, Y. Nitta, T. Tsukada (2019). “COMPARISON STUDY BETWEEN 2D REINFORCED CONCRETE ELEMENT DESIGN METHODOLOGIES USING AUTOMATED DESIGN SOFTWARE FOR NUCLEAR STRUCTURES,” *25th Conference on Structural Mechanics in Reactor Technology*, Charlotte, NC, USA, August 4-9, 2019.

T. Tsukada, S. Goto, M. Matsumoto, K. Yachi, Y. Tanaka,Y. Kawamoto, R. Ikeda, Y. Nitta (2020). “Application of Automated Design Tool for FE modelled Reinforced Concrete Line Elements to Seismic Design,” *17th World Conference on Earthquake Engineering*, *17WCEE*, Sendai, Japan - September 13th to 18th 2020, Paper N° C002439.

Japan Electric Association (2021). *Technical Code for Seismic Design of Nuclear Power Plants, JEAC 4601-2021.*