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Automatic design, planning and drawing of scaffolding system for constructions

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Abstract. Temporary scaffold systems in the construction site play an important role for ensuring the safety of the workers and for constructing the stable structures. To assemble the scaffold, the pipe scaffolding system, the wedge binding scaffolding system and the particular materials have been utilized. To design the material arrangement of a scaffold, firstly the configuration was determined considering the construction geometry. Then, the strength of the scaffold was confirmed and the quantity of the material was accounted. In this paper, the design method of the temporary scaffold was proposed for intending the semi-automatic procedure. In the proposed design method, the geometric design and the safety requirement were specified by the safety standard and the design flow was followed by the designer's knowledge. The size and the quantities of the materials were calculated by referring to the relation between the scaffold and the constructing structure. In the calculating procedure, three dimensional positions of each scaffold materials were calculated and recorded simultaneously. Then, three dimensional scaffold structural was drawn semi-automatically on the CAD software by using the obtained material sizes, positions and directions. The proposed design method provides us the precise quantities of scaffold materials and enables us to reduce the design effort and the cost estimation processes. In addition, the obtained results can be applied to BIM software after converting to IFC format.

Keywords: scaffold, quantity survey, design, CAD, BIM, CIM

1. Introduction

When the buildings are constructed or the industrial plants are maintained, we need the platform around or inside the structures. Temporary scaffold systems in the construction site play an important role for performing the safety working and the stable construction of structures. Many types of scaffolding systems have been utilized corresponding to the structural shape and constructional condition. Pipe scaffolding systems composed of steel pipes, clamps and planks have been used for the general purpose. In addition, the wedge binding scaffoldings system

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binding several materials have been also applied for construction. The design of the scaffold has been specified by the safety standard recommended by each country and regions (e.g. Ministry of Health, Labor and Welfare (2010) and Temporary Works forum (2014)). In designing them, the designer's experiences have been useful as well. These standards have been improved based on the investigation under each constructional condition (e.g. Rubio-Romero 2013) and the experimental background (e.g. Liu 2018). The standards specify to the requirements of the performance and the safety of the scaffolds and also introduce the general design methods of scaffolds. To assemble the scaffold, many kinds of scaffold materials are adopted. Therefore, the precise count of materials and the total cost estimation of the scaffold system are quite difficult. Especially, the quantity surveying of the scaffold materials such as jacks, transoms, ledgers, etc. and cost estimation have been quite laborious. Therefore, the quantity surveying and the cost estimation have been done based on the required material quantities in proportion to the total volume or the total surface area of the constructing structure designed previously. Such cost estimations and quantity surveying may bring us the discrepancy between design and actual quantities of the scaffold material. It may cause the incorrect supply of the scaffold materials and the incorrect construction schedule. Therefore, the conventional and the laborious design works, which is depending on the empirical work, should be improved.

To improve this problem, the concepts of the building information modeling (BIM) have been applied in designing the temporary structures. Hyun *et al*, (2018) proposed the design of formwork with BIM technology. Also, Kim (2014) et, al. proposed the design and planning of the scaffold system using BIM technology. These are useful design techniques. However, if the arrangement of the materials is discrete and these methods are applied to the complex structures, the precise arrangement of the materials is difficult because the local discontinuity of the structure is not taken into account. Therefore, the precise design procedure is required.

In the conventional work, the material arrangement of a scaffold was determined first referring to the construction geometry. Although the design standards or the recommendations encompass the safety requirements, the strength of the scaffold should be confirmed. Then, the quantity of the material was accounted. Usually, the engineers will design the scaffold empirically based on their experiences and the knowledge under the design standards. Therefore, the analytical results will be different depending on the designers' skills. However, if the design methods are analyzed in detail, the design procedure is presented schematically and the automatic design method is introduced.

In this paper, the semi-automatic design method of the temporally constructional scaffold was proposed and the automatic accountings and drawings were examined. Two types of scaffolding systems were adopted. One is the pipe scaffold system and the other is the wedge binding scaffold system. The proposed design method was programmed based on the safety standard mentioned above and the designer's the knowledge. The size and the numerical quantity of each scaffold material were calculated referring to the relation of the position between the scaffold and the constructing structure. Also, the semi-automatic drawings were done using the conventional CAD system and the drawing program.

2. Evaluation system and its environment

The outline of the designing flow is shown in Fig. 1 based on the web environment. The design system is composed of two parts. The placements and the quantities of the scaffold materials are calculated by PHP program (Cowburn 2018) based on the interactive design

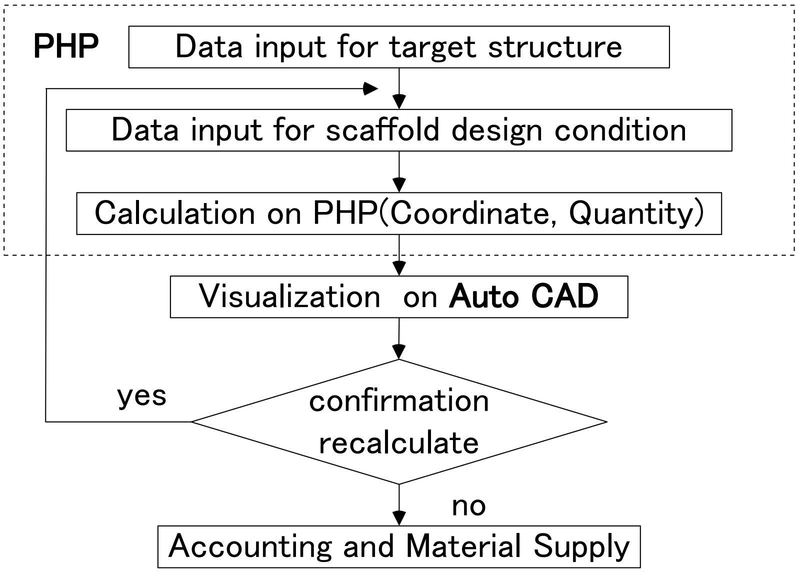


Fig. 1 Calculating and evaluating system

system. Then, three dimensional cad system (3D CAD) is used for representing and evaluating the calculation results. In PHP program, firstly, the configurations of the target structure are supplied. The conditions of the scaffold system are supplied consequently. There are several options to assemble the scaffold referring to the loading conditions and the constructional site conditions. The calculation method of the scaffold is representing based on the conventional hand calculation and on the designer's design experiences by use of PHP. The calculation results are diaplayed on the terminal screen and strored in the data server. Also, the numerical results are displayed on the terminal screen using the CAD software secondary. In CAD software, the drawing are done using the stored data on the data server such as the coordinates and quantities in the previous calculation. Using the material data defined as the block data which has a unit length and has the direction on the standard coordinate system on the CAD softoware, the drawings are established referring to the origin, the magnitude and the direction of the scaffold materials. After confirming the arrangement of the scaffold presented as three dimensional drawing on the terminal screen, the calculation will be back to the data input of the scaffold conditions if nessesary. Then the scaffolding size and the quantities of each material will be determined after interactive processings mentioned above.

The design environment is shown in Fig. 2.The calculation and the drawing systems are composed of the web server, the file server and the client computers or PDA. All computers and the servers are placed under the cloud. The web and the file servers can be placed in the office ordinaly and controll the design system. On the other hand, PC terminals and PDA usually can be used on outside the office. The material quantity surveying and cost estimation may be required in any places such as the design office, the construction site, the accounting department and so on. These data are evaluated first when the scaffold is designed in the office or on outside office. Simultaneously, the quantity surveying is done on the web using PC or PDA. The numerical results are stored on the data storage server inside the office automatically for the later use. The drawings were done on each PC or PDA using the numerical data stored on the data server.

3. Design procedure for pipe scaffold system

There are several types of pipe scaffolding system. In pipe scaffolding system, the steel pipes are connected by the clamps and are assembled to the platform. In this chapter, the hanging scaffold is adopted as the application example and the design procedure is represented.

Fig. 3 shows the example of the hanging scaffold which was assembled to maintain the pipelines racked on the frames. Many kinds of scaffold materials are required to construct the hanging scaffold. Fig. 4 shows the hanging scaffold materials. In designing the scaffold, the quantity and the position of all materials should be determined.

Firstly, chain clumps and hanging chain are placed to hang the hanging scaffold from the rack frame. The ledges are placed between rack frame along the longitudinal direction. Then the transoms are placed perpendiculat to the legers. After planks are placed on the transoms, the handrails, and toe boards are arranged. Considering such sequential designing, the precise position of each material and the quantiries of materials shoud be calculated. In calculation, several design conditions are taken into account.

The Designing system is presented below (Hara *et al*. 2018a).

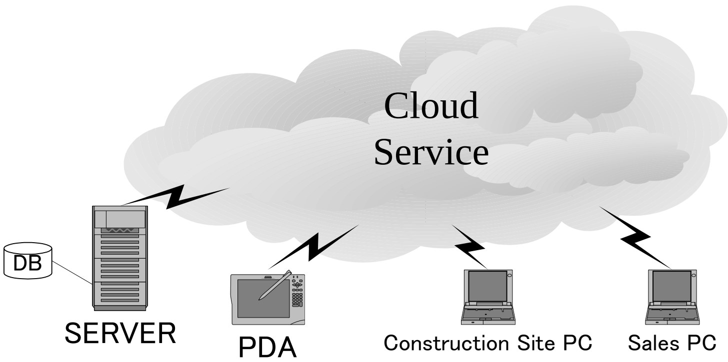


Fig. 2 Outline of the designing system

Fig. 3 Example of hanging scaffold (Hara *et al*. 2018a)

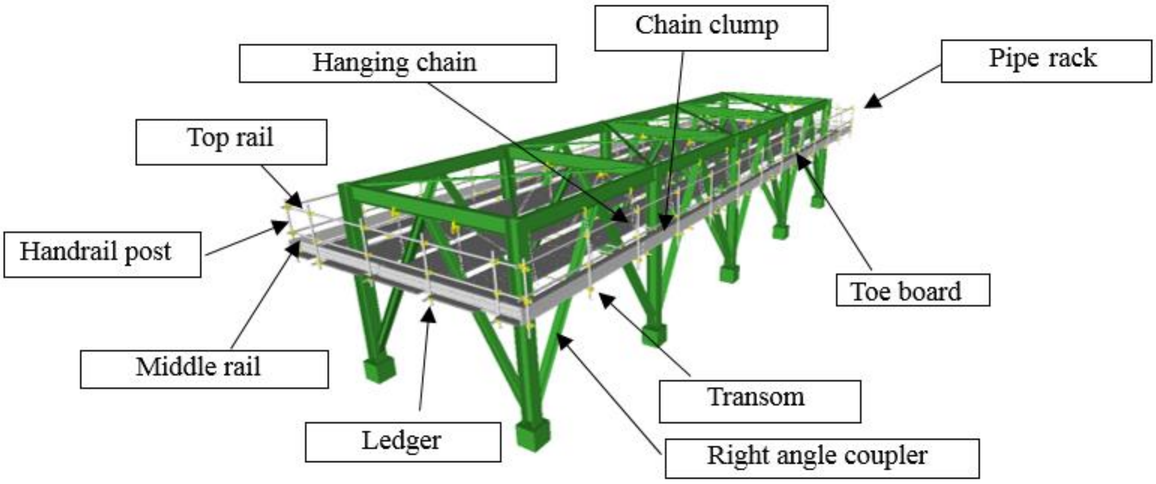


Fig. 4 Scaffold materials (Hara *et al*. 2018a)

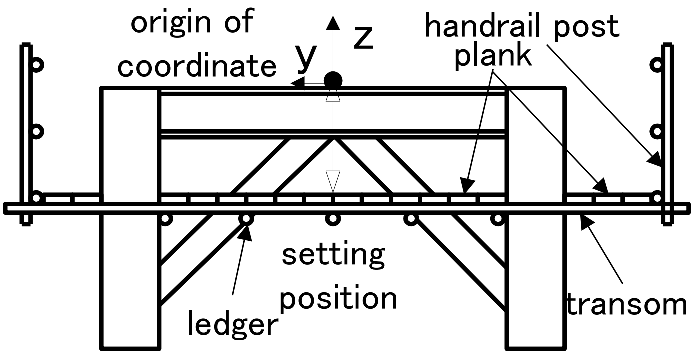


Fig. 5 Side view of hanging scaffold

3.1 Defining the origin of the coordinate system in the calculation

The coordinates of all scaffold materials are calculated sequentially referring to the origin of the coordinate system that is defined as the reference point of the system. In this system, the reference point is the top center of the rack beam placed at the end of the rack (Figs. 5 and 6). All positions of the composed materials are calculated referring to this point. The axis x is defined along the longitudinal rack axis from the origin and the axis z is defined as the vertical direction. The axis y is defined perpendicular to x-z plane. The positions of all materials are calculated considering the geometrical relations of the materials. The relations between materials are defined under the Labor and the Welfare Standard (2010) specifying the safety and the strength requirements of the scaffold. Positions and the length of each material are evaluated below.

3.2 Position and length of ledgers

The ledgers are placed within the rack columns (see Fig. 5). The depth is the distance between the origin of the coordinate system and the working platform on the planks. The distance between the ledgers is tentatively defined by the designer. Considering the width of the frame, each ledger is placed at regular interval. Then the precise positions of legers are defined. The position of the ledger is under the transom. The transoms are placed under the planks (Fig. 5).

The required length of the ledger is evaluated considering the geometrical relation of other materials (see Fig.6). In setting the hanging scaffold, several types of isles. Also, in placing isle, the width of the isle is defined by the rows of planks. In case of three planks, the width of isle is 3x250 mm = 750mm. The length of the ledger is the summation of the required length, that is the rack length, the aisle width, and the extra length of pipe defined in the Ministry of Health, Labor and Welfare (2010). For example, the length of the rack is 40000mm and the type of isle is 4 isles (see Fig.6). Each isle has three planks and each plank has 250mm. The extra length of the leger is 200mm where is the space to connect the handrail posts. In such case, the total length of each leger is

$$\underset{\text{extra length}}{200\text{mm}} + \underset{\text{3 planks}}{3 \times 250\text{mm}} + \underset{\text{rack length}}{40000\text{mm}} + \underset{\text{3planks}}{3 \times 250\text{mm}} + \underset{\text{extra length}}{200\text{mm}} = 41900\text{mm}. \tag{1}$$

Also, the end coordinates of the center leger are as follows. If the flange width of the rack beam is 300mm and 4 aisles are placed, the origin of the ledger coordinate x_l is

$$x_l = \underset{\text{beam flange/2}}{-(300\text{mm}/2)} - \underset{\text{3planks}}{3\text{x}250\text{mm}} - \underset{\text{extra length}}{200\text{mm}} = -1100\text{mm} \tag{2}$$

From Fig. 5, if the setting depth of the plank from the origin is -800mm, the coordinate of the origin of the ledger coordinate z_l is

$$z_l = \underset{\text{depth from origin}}{-800\text{mm}} \underset{\text{plank thickness}}{-40\text{mm}} - \underset{\text{pipe diameter/2}}{(48.6\text{mm}/2)} \underset{\text{right angle coupler distance}}{-76\text{mm}} = -940.3\text{mm}. \tag{3}$$

where 40mm are the plank thickness. 48.6mm is the outer diameter of the transom pipe. 76mm is the distance between right angle couplers that connect between the ledger and the transom. Such calculation brings us the length and the coordinate of the origin for the center of the ledger. The length and the coordinates of other legers are calculated in the same manner.

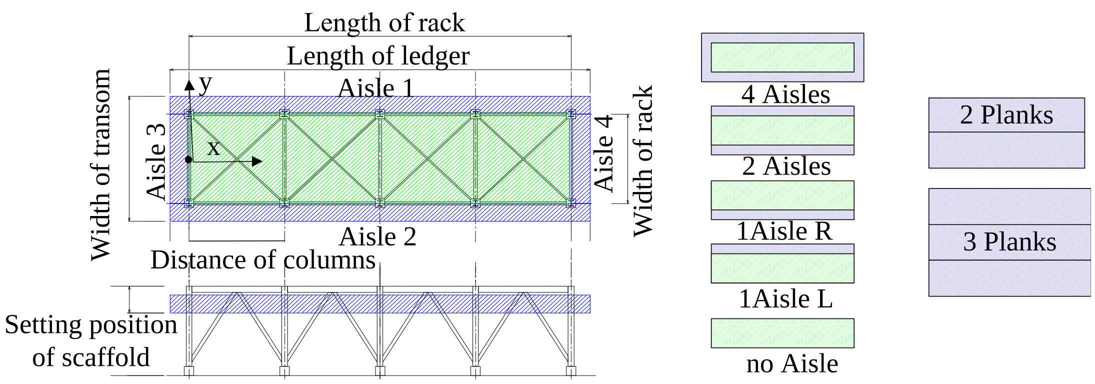


Fig. 6 Rack and scaffold

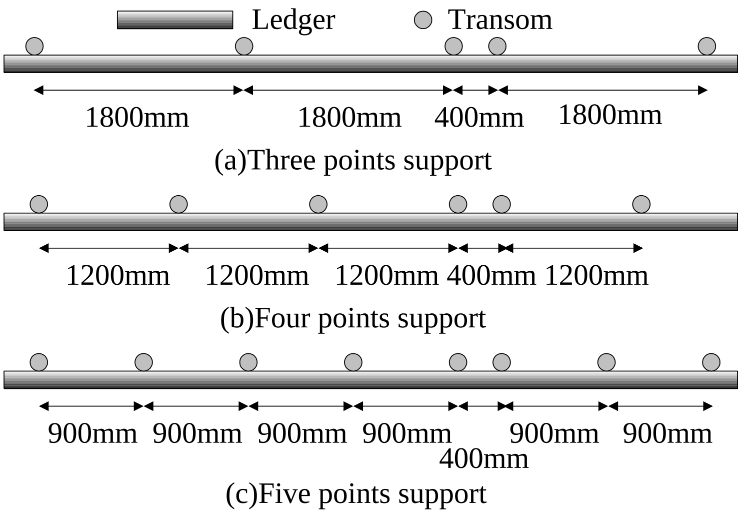


Fig. 7 Placement of the transoms

When the width of the rack column is 10000mm and each flange width of columns is 300mm, the clearance of the rack columns is 10000mm-300mm=9700mm. If the ledgers are tentatively placed every 1800mm, the number of the clearance division is 9700/1800=5.3. Therefore, seven ledgers are required and the interval of the ledgers is 9700mm/6=1617mm.

3.3 Position and length of transoms

The first transom is placed at 200mm from the end of the ledgers depend on Ministry of Health, Labor and Welfare (2010). These are placed on the ledger ends. Then other transoms are placed repeatedly depending on the arrangement method of the transoms. Fig. 7 shows three types of transom arrangement depending on the loading condition. The transoms are placed under the planks. Usually, the standard length of the plank is 4000mm. When the plank is supported on three points support in x direction, the distances of the transoms are 2 x 1800mm + 400mm (see Fig.7 (a)). The distance 400mm is used for connecting the two planks. In case of four points support and five points support, the distances of transoms are 3 x 1200 mm + 400mm (see Fig.7(b)) and 4 x 900 mm + 400 mm (see Fig.7 (c)), respectively.

The arrangements of the transoms are done repeatedly to the end of the rack. The length of each transom is calculated considering the rack width and the aisle width as well as the extra length of pipe in the same manner as that presented in the calculation of ledger length. The height of transom is calculated adding 76mm to the height of ledger z_l+76mm. 76mm is the distance between right angle axis of the couplers. Then, each coordinate of the transoms is defined. The relation and the arrangement between legers and transoms are shown in Fig.8.

3.4 Position and numbers of planks

There are two groups of the planks. One is the inner planks. The other is the planks on the aisles. The inner planks are placed from horizontal position *y=0* as shown in Fig.5 to both columns of the rack frame. The coordinate and the number of the planks are calculated repeatedly from the

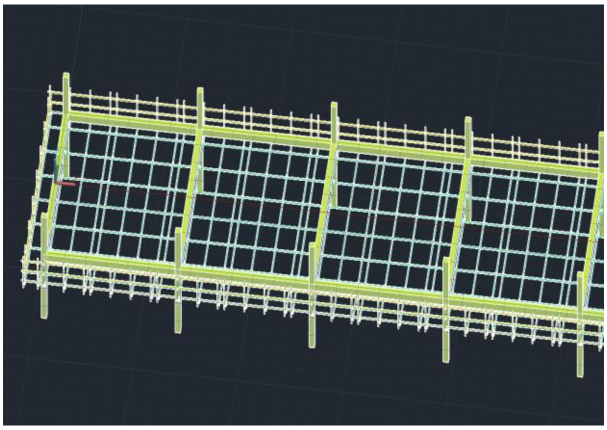


Fig. 8 Placement of the ledgers and the transoms

origin. The other group is the planks placed on the aisles referring to the aisle type (see Fig. 6). Each position and quantities of these planks are defined.

3.5 Position, length and numbers of handrails and their post

Additional pipes called walling pipes are placed at both ends of the transoms. Then, handrail posts are arranged at the intersection of the walling pipes and the transoms as well as the intersection of the ledgers and transoms at both ends of the ledgers. The length of the handrail post is defined as 1500mm (Ministry of Health, Labor and Welfare 2010). The top handrails and the mid handrails are connected to the handrail posts via right angle couplers. These quantities are calculated and the coordinate of handrails and the handrail posts are also calculated. The handrails and the handrail posts are connected as shown in Fig. 8.

3.6 Position and the length of toe boards

Toe boards are placed at the lower part of the handrail post and on the planks. The x-y coordinate of the toe board is evaluated referring to the handrail post and the height is calculated depending on the height of plank. Toe boards are placed along the handrail (see Fig. 12(a))

3.7 Positions and numbers of the loop chain, the hanging chain and the chain clump

The coordinate and the quantities of the loop chain, the hanging chain and the chain clump are determined in regular interval. The loop chains are arranged every 1800mm on both rack beams in the longitudinal direction. Also, the hanging chains and the chain clumps are arranged every 1800 mm on all legers. The length of both chains are calculated depending on the height of the ledger and the transom.

3.8 Positions and number of right angle couplers

The position and the number of the right angle couplers are calculated at each intersection of the steel pipes.

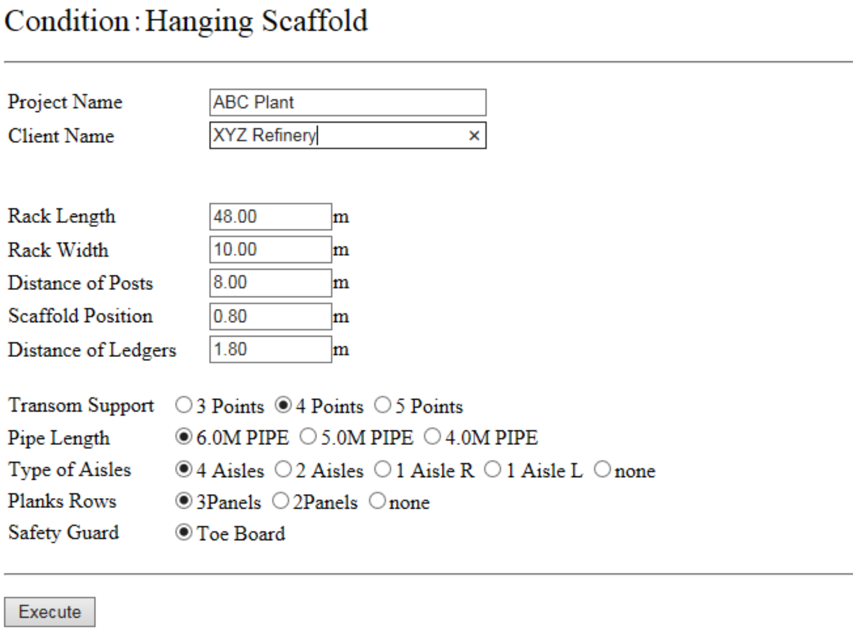


Fig. 8 Input data on web

3.9 Storage of the coordinate data and the quantities of the materials

After evaluating the geometric relations of all scaffold materials referring to the design standards to secure the safety and the strength of the scaffold, the position, the length and the quantities of each material are accounted. The steel pipes, the planks and the toe board used for scaffold have several standard cut lengths. Combining several sizes of these lengths, the quantities of them are calculated. The coordinate data and the length for all materials are stored in the data server. These data are used for drawing and for utilizing the management the materials.

3.10 Web data input and data storing

The calculation procedure mentioned above is running on the web application with PHP program (Cowburn 2018). It is easy to utilize this system under the cloud (see Fig. 2) without limitation of the place and the terminal type. Fig. 9 shows the web input page. Firstly, the user should input the geometric conditions of the constructing structure such as the size of pipeline racks (3^{rd} to 5^{th} row in Fig. 9). In this example, the rack length and the rack width are 40m and 10m, respectively. The column distance is 8m (see Fig. 6). Then, the scaffold design conditions should be defined.

The setting position of the scaffold (6^{th} row in Fig. 9), that is the top surface of plank, is 0.8m below the top of the rack beam where the origin of the scaffold height (see Fig. 5). The ledger distance is tentatively defined as 1.8m (7^{th} row in Fig. 9). The transom arrangement is selected (8^{th} row in Fig. 9). In this example, four points support are arranged in the direction of rack length (see Fig. 7). The longest steel pipe length is selected as 6m in this example (9^{th} row in Fig. 9). Five patterns of aisle can be selected (see Fig. 6). In this example 4 aisles are selected (10^{th} row in Fig.

Table 1 Evaluated quantities after calculation

Material		Quantity
Steel pipe	6(m)	214
	2.5(m)	13
	1(m)	55
	1.5(m)	116
Coupler (pipe joint)		214
Plank	4.0m	540
	3.0m	0
	2.0m	45
	1.5m	0
	1.0m	45
Toe board	1.8m	72
Right angle coupler		807
Loop chain		52
Hanging chain		120
Chain clump		120

9). In each aisle, two types of plank can be selected. In this example, 3 planks are selected (11^{th} row in Fig. 9).

The calculation with PHP program (Cowburn 2018) is done by pushing the "Execute" button (13^{th} row in Fig. 9). The dimensions and the quantities of all scaffold materials are obtained.

Table 1 shows the calculation results from the input data (Fig. 9). The table is represented on the PC or PDA. If the output data is not suitable to the expected scaffold, the recalculation will be done from the web input (Fig. 9). Then, after confirmation of the scaffold system, the coordinate data and the length and the quantities for all materials are stored in the data server. These data are used for drawing and for managing the materials.

3.11 Drawing the numerical results on CAD software

Using the coordinate data, the length and the quantities of the materials computed in the numerical procedure mentioned above, the drawings will be done on each terminal (PC or PDA) by using the CAD software. The quantities shown in Table 1 are presented on each terminal. From three dimensional drawing, the arrangement of the scaffold materials and the relation of the pipe rack can be confirmed again.

The drawing of the scaffold will be done by using AutoCAD Architecture 2019 (Autodesk 2018). Each material of the unit length is registered in the CAD system as the block data. From the stored data calculated in the previous section, the origin, the length and the direction of each material are obtained. Using these data, the drawing magnitude and the drawing direction are defined. Then, the drawing is automatically done by the program coded by Visual Basic for Application (VBA).

For example, the block data "pipe" that has the unit length 1000mm x 48.6mm x 48.6mm in x, y and z direction and is oriented to the x axis, is registered. in the CAD system in advance.

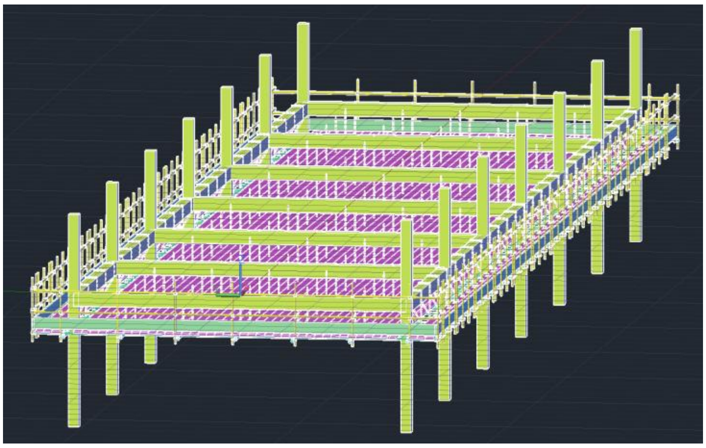


Fig. 10 Total view of hanging scaffold

From the stored data, the origin of the pipe (x, y, z) is obtained and is transfer to the CAD system data.

insertionPoint0(0) = x
insertionPoint0(1) = y
insertionPoint0(2) = z

If the length of the ledger is 41900mm from the stored data, the amplitude of the length “mx”, “my”, “mz” in x, y, z direction are 41.9, 1.0 and 1.0. The direction of the material “th” is 0. These are inserted in the CAD software system as the cad object using the insert procedure shown below.

Set blockRefObj = ThisDrawing.ModelSpace.InsertBlock(insertionPoint0, “pipe”, mx, my, mz, th)

Repeating above procedure concerning all materials, all objects are displayed on the terminal. The drawing result is shown in Fig. 10. If the design is not suitable, the designer can go back to the web input system (Fig. 9) and can reconfirm the results. Also, as the drawing is done on the CAD system, it is easy to change the viewpoint and to zoon in detail.

In the drawing system, the drawing menu is presented at the beginning (Fig. 11). Total drawings are complicate because each material is overlapped. Usually, the ledgers and transoms are difficult to find out because these materials are shown behind the planks. It is quite difficult to find the arrangement of the scaffold behind other materials. Therefore, in this system, any materials can be removed using drawing menu (see Fig. 11). This menu enables us to find the particular materials. Only checked materials (see Fig. 11) can be displayed.

Figs. 12(a) and 12(b) show the comparison of the drawings where the drawing system shows the scaffold system with and without planks, respectively. When removing the planks (see Fig. 12(b)), it is easy to find the arrangement of the composed materials.

The numerical results are stored in AutoCAD standard file format (DWG). The CAD file is easy to convert to the IFC format. After several conditioning, the CAD files will be used for the BIM and CIM applications or will be used for other CAD or the management software.

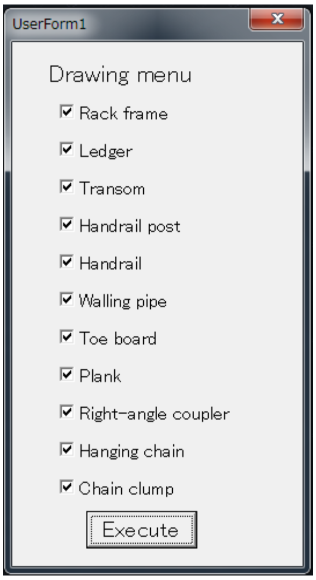
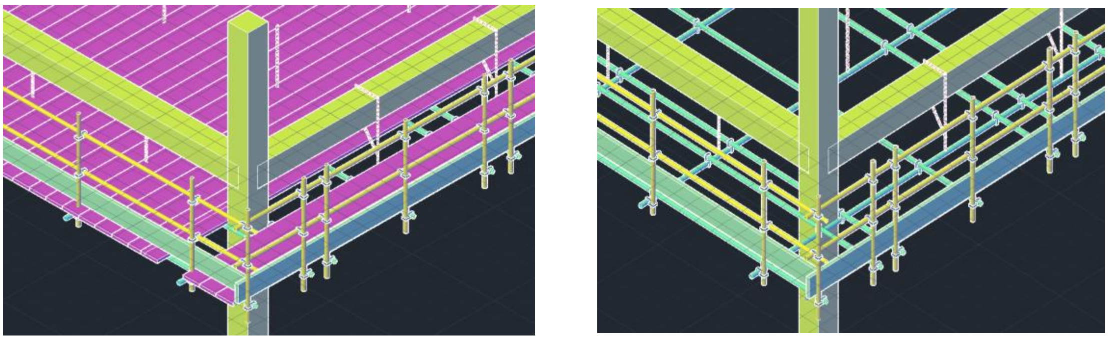


Fig. 11 Drawing menu



(a) With plank (b) Without plank

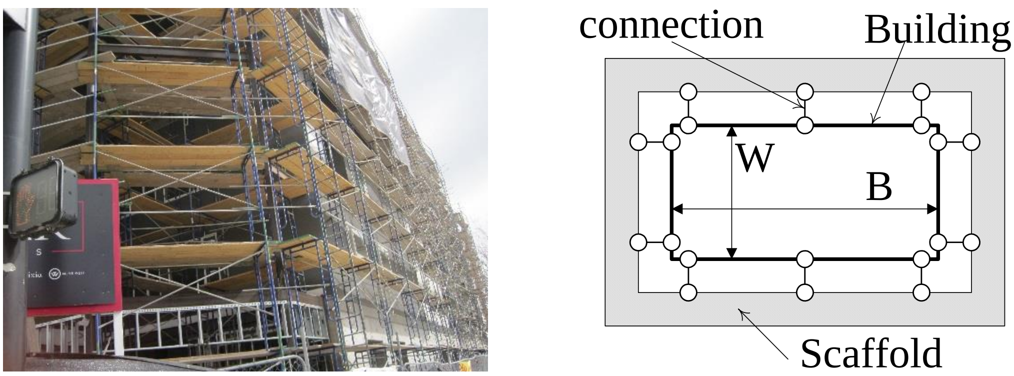
Fig. 12 Selected view of hanging scaffold

4. Design procedure for wedge binding scaffold system

The design and drawing systems for the pipe scaffolding are easy to apply to the wedge binding scaffold system (Hara *et al*. 1918b). In this scaffold, the standard size components are adopted instead of the steel pipes that has the flexibility of the clumping point. Each material has the fixed length and should be assembled to fill the scaffolding area. Therefore, several adjustments are required. The applications of the scaffolds for the building and the tank are presented to show their applicability. In case of building, the scaffold shows the rectangular shape and in case of the tank, the curved shape scaffold is shown.

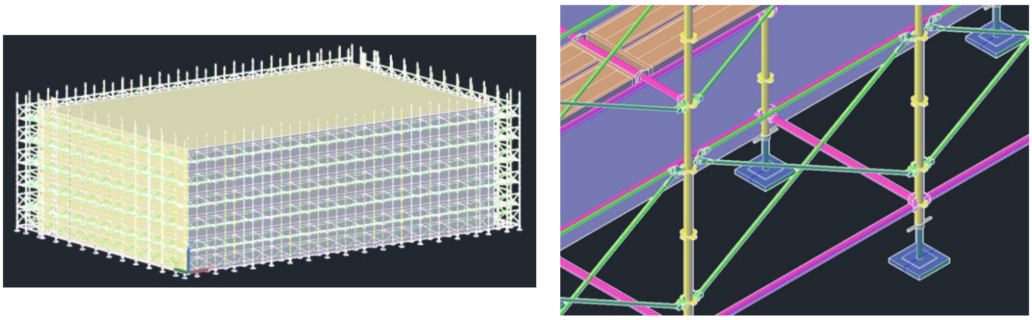
4.1 Wedge binding scaffold for the building construction

Fig. 13 shows the scaffold photo and its plan applying to the building construction. The scaffold shown in the hatching area must be set apart from the building. The input data is the



(a) Photo (b) Plan

Fig. 13 Scaffold for the building



(a) Total view (b) Local view at jack base

Fig. 14 Computing results

building length “B”, the width “W”, and the height “H”. Also, the space between the building and the scaffold is required.

In this space, the connection devices to connect between the scaffold and the building are installed to stabilize the scaffold under the wind and the external loads. The distance is usually below 300 mm to prevent the falling down of the workers or the worker’s tools.

The materials applying to the wedge binding scaffold have the standard size. Using these materials, the scaffolds are assembled. The standard length of the beam materials connecting the posts are 1829mm, 1524mm, 1219mm, 914mm, 610mm, 205mm and 153mm. From these combinations and the plank rows, the positions of the posts and jack bases are calculated automatically.

For example, if the building width B is 30000mm and the tentative space “s” between the building and the scaffold is 200mm, the total width “b” between inner posts is defined as follows.

$$b = \underset{\text{tentative space}}{300\text{mm}} + \underset{\text{building width}}{30000\text{mm}} + \underset{\text{tentative space}}{300\text{mm}} = 30600\text{mm} \tag{4}$$

The selection of the beam number and distance of spaces are proposed from the calculation system. Then, these data are determined by changing the tentative spaces interactively. For example, following arrangement is decided.

$$b = \underset{\text{space}}{211mm} + \underset{\text{16 beams}}{16x1829mm} + \underset{\text{beam}}{914mm} + \underset{\text{space}}{211mm} = 30400mm \quad (5)$$

Therefore, 16 beams of 1829mm and 1 beam of 914mm as well as the spaces 211mm at both ends are calculated. In the direction of depth, the same calculation is done. The positions of the posts are consequently calculated in both width and depth directions. The spaces between the building and the scaffold as well as the standard size materials control the appropriate arrangement within the distance between the inner scaffolding posts. After placing the beams connecting to the posts, the foot panels and the bracings are installed. Then, the other materials are installed up to the height of the top where is the building height “H” + 1000mm.1000mm is adopted to secure the safety of the workers referring to the design standard (Ministry of Health, Labor and Welfare (2010). The numerical results are shown in Fig. 14 (a) using the drawing program automatically. Fig. 14 (b) shows the lower portion of the scaffold in detail.

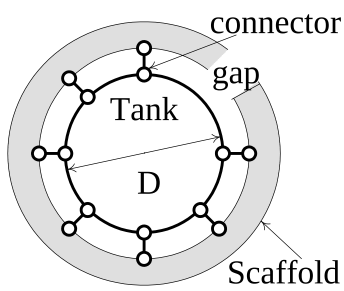
4.2 Wedge binding scaffold for the tank construction

Fig. 15 (a) shows the photo of the scaffold for the tank structure. The tank shows the circular plan. Therefore, the scaffold material sizes should be changed along the edge of the tank. Usually, fixed (standard) size materials “S” are placed on the outer edge and the free size materials “F” are placed on inner side as shown in Fig.16(a). Also, the space “s” between the tank and the scaffold is required in the same manner as the building scaffold supplication (see Fig. 16(a)).

Although the scaffold for the tank must cover the tank, the scaffold may not be connected completely because the gap could not be controlled and the small gap, that is smaller than the fixed materials, remains. The required data for design is the diameter “D” and the height “H” of the tank. The spaces between the tank and the scaffold “s” is also required. The length should be below 300mm (see Fig. 16(a)).

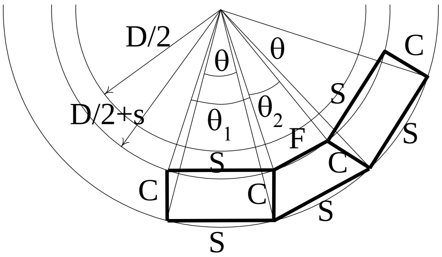
To design the scaffold, two kinds of beams are adopted because of representing the circular plan (see Figs. 15 and 16). One is the fixed size beam “S” as shown in Figs. 16 (a) that has the fixed bar length. And the other is the free size beam “F” as shown in Fig. 16(a) that has the flexible bar length. Detailed configurations of them are shown in Fig. 16(b). In Fig. 16(a), the arrangement of them is represented. From the diameter of the tank “D” and the space “s” between the tank and the scaffold, the angle θ_1 between inner material “S” is:

(a) Total view

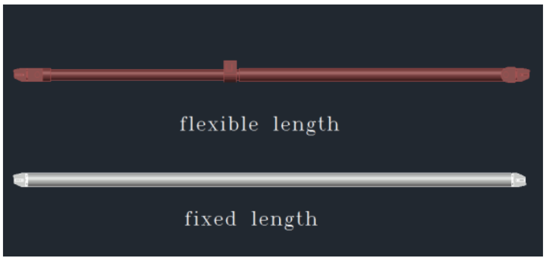


(b) Local view at jack base

Fig. 15 Scaffold for the tank



(a) arrangement



(b) bar element

Fig. 16 Calculation of the materials

$$\theta_1 = 2 \times \sin^{-1} \frac{S/2}{\frac{D}{2} + s} \tag{6}$$

The angle θ between outer material "S" in Fig. 16(a) is defined using beam length C

$$\theta = 2 \times \tan^{-1} \frac{\frac{S}{2}}{C + \left(\frac{D}{2} + s\right) \cos \frac{\theta_1}{2}} \tag{7}$$

Then the angle θ_2 between inner flexible material "F" is:

$$\theta_2 = 2\theta - \theta_1 \tag{8}$$

For example, when the diameter "D" is 30000mm and the space "s" between tank and the inner beam element in the scaffold is 300mm, the angles θ and θ_1 are calculated 6.467° and 6.853°, respectively, using standard beam element S = 1829mm and C=914mm. Also, θ_2 is 6.081°. Therefore, the flexible beam element F is 1623.1mm. Depending on these geometrical data, all the coordinates of the intersecting point shown in Fig. 16 are decided. From θ = 6.467°, the gap shown in Fig.15(b) is evaluated as follows.

$$\text{gap} = 360^{\circ} - 55 \times 6.467^{\circ} = 4.315^{\circ} \tag{9}$$

Then all the coordinate at each node are calculated. The required additional pipe length to close the gap is calculated as well (see Fig. 18(b)). Inserting the free size beam "F" between the fixed (standard) length beams "S" on the inner perimeter, the arrangement of the materials is done along the curve (Fig.16 (a)). The posts and jack bases are placed at the intersection of the beam materials.

Then, the bracings and the foot panels are arranged. The scaffold is assembled up to the top of the tank that is the height "H" at the tangent line +1000mm. 1000mm is adopted to secure the safety of the workers referring to the design standard (Ministry of Health, Labor and Welfare (2010).

Fig. 17 shows the automatic drawing after calculating the positions and the quantity of materials. The placement of foot panel is shown in Fig. 18 (a) using the foot panel with the flexible length. There may be the gap as shown in Fig.15 (b) because the quotient of the angle θ to the standard beam length is always not the integer number. However, during the evaluation of the material quantities, all the intersections of the materials were known. Therefore, it is easy to

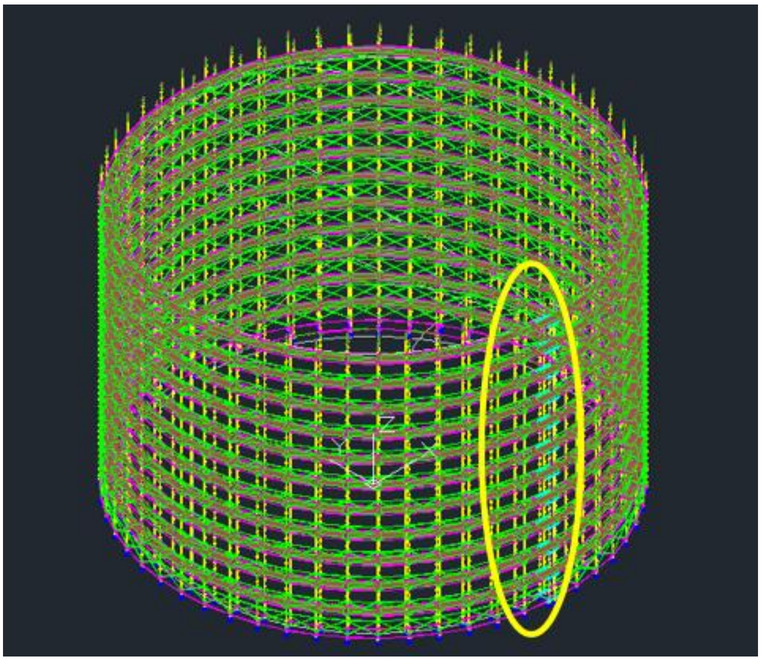


Fig. 17 Arrangement of the materials

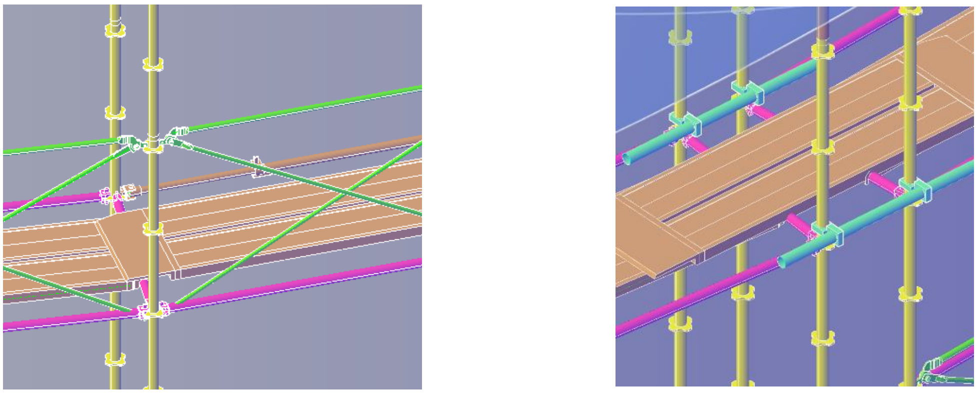

(a) Foot panel (b) Additional pipe and clump

Fig. 18 Detailed drawing

calculate the connection pipes and clumps at the gap (see Fig.18 (b)) and to draw the complete drawing. The connection area in the total structure is shown as the oval in Fig.17.

5. Further development and application to other field

The calculation system for each scaffold material position and its quantity is applied to other kind of scaffold system, such as the scaffold for tower type structures or the platform type structures. CAD drawings are available as well. The design method of the temporary scaffold is

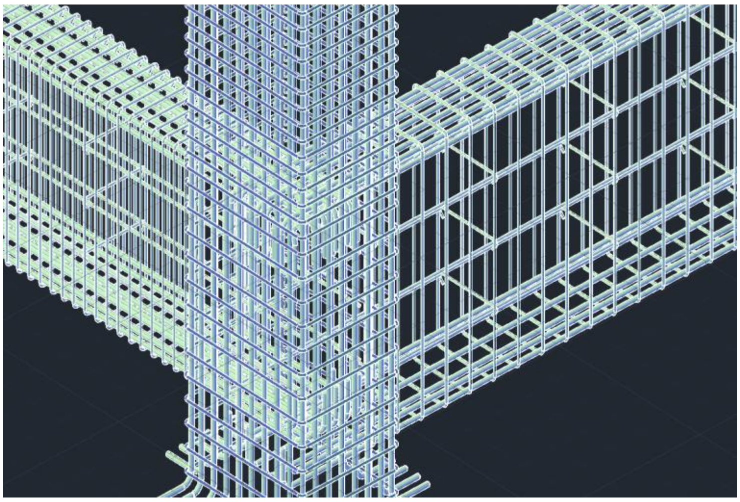


Fig. 19 Application for the reinforced concrete structure

useful. In this paper, it was applied to two types of scaffold. However, the applied model is simple and fundamental structures at the moment. In actual application to the scaffold, steps, openings and ladders will be installed and the several types of scaffolding will be combined. Also, the building structure may have an uneven plan and the scaffold may be assembled on the rugged foundation. In such case, further development of design method will be required. Even in such case, it may be possible to assemble the scaffold using the methodology which is first to decompose the total scaffold to several scaffold parts and is to assemble these parts to the total structure after evaluating each materials and their quantities. As the proposed design system provides us the coordinates of each material position, it may be possible to assemble them. In case of the scaffold on uneven foundation height, it may be possible to replace incorrect materials to the suitable materials on the CAD system.

In case of drawing system, the proposed semi-automatic design, the accounting and the drawing systems can be applied to other construction field. Figure 19 shows the application of the proposed system to the reinforced concrete structure. After inputting the data of the beams, the columns and the arrangement of the reinforcement, three dimensional positions of all reinforcements are calculated using the design standard (ACI 2014). Then, the three dimensional drawings are completed in the same manner mentioned above.

From the drawing, it is easy to find the batting and the interference of the reinforcements and other equipment such as anchors and pipe opening and is easy to obtain the precise quantities of materials. These results will improve the construction work easier.

6. Conclusions

In this paper, the scaffold design system using interactive calculation on the web and CAD drawing were presented. Hanging scaffold was selected as the pipe scaffold system example. The design of the scaffold has been quite difficult and laborious. For example, when the hanging scaffold shown in Fig. 10 was designed by the experienced engineer, it took about a couple of hours to a half day. Also, it took about the same time or more to draw the design drawing.

However, the proposed design system will help us to reduce the engineer's work and to find the detailed material requirement. Also, it is easy to recalculate or redrawing quickly using this system. The proposed design system could show the design data on the familiar CAD system and could account the precise quantities automatically.

The design methodology was applied to the wedge binding scaffold system as well. The design system is applied to the building structure and the tank structure. From these application, it is clear that the proposed method possesses the applicability to any type of the structure. Also it is easy to fill the gap of the scaffold using the standard material because the coordinate and the quantities of the materials are obtained completely.

By the accounting, the quantity and the drawing the structure, it is easy to communicate the designers and the workers using three dimensional drawings. Once the designed data are stored in the storage server on the cloud, it is easy to manage the supply of the materials and the other construction managements.

In addition, the methodology of three dimensional CAD drawing enables us to apply to other kind of structural drawings and also to apply to BIM and CIM software using IFC format conversion. Therefore, the obtained results can be used for other kind of advanced management work.

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