DESIGN AND PLANNING OF SCAFFOLDING SYSTEM

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In this paper, the automatic design method of scaffold was proposed. This method was programmed using web based PHP program under the safety standard and the designer's know-how. The size and the numerical quantity of the scaffold were calculated considering the relation between the scaffolding condition and the constructing structure. Three dimensional positions and the numbers of the individual scaffold materials were calculated and recorded in the data server simultaneously. Then, three dimensional structural drawings were made automatically using the AutoCAD with VBA by using the previously designed material positions. Therefore, 3D drawings were done automatically. From the proposed design method, the precise quantities of scaffold materials were obtained. Also, the drawing of the scaffold was done automatically without any laborious drawing by hands.

Keywords: Drawing, Web, Cloud, CAD, PHP.

1   INTRODUCTION

Scaffold systems in the construction site play an important role for a safety and a stable construction of structures. There are many kinds of scaffold systems corresponding to the structural shape and constructional condition. The design of the scaffold has been done under the safety standard by Ministry of Health, Labor and Welfare (2010) and Temporary Works Forum (2014) as well as the designer's knowledge. These standards specify the performance and safety requirements of the scaffold and introduce the general structural design methods of scaffoldings.

In the example application, Figure 1 shows the hanging scaffold which is constructed to maintain the pipelines racked on the frames. Many kinds of materials are required to construct the hanging scaffold as shown in Figure 1. In designing the scaffold, the positions, the size and the quantities of all materials must be calculated. The design and the planning of the scaffolding system are quite laborious. Especially, the quantity surveying and cost estimation of the scaffold materials such as jacks, transoms, ledgers, etc, have been laborious. Therefore, these works have been empirically done based on the total volume or the total surface area of the structure. The discrepancy between design and actual quantities of the scaffold materials occurred frequently and brought the incorrect supply, the incorrect schedule and the unsafe condition.

In this paper, the automatic design and drawing methods of scaffold were proposed. The method was presented for the sample hanging scaffold and the applicability for other scaffold system was also presented.
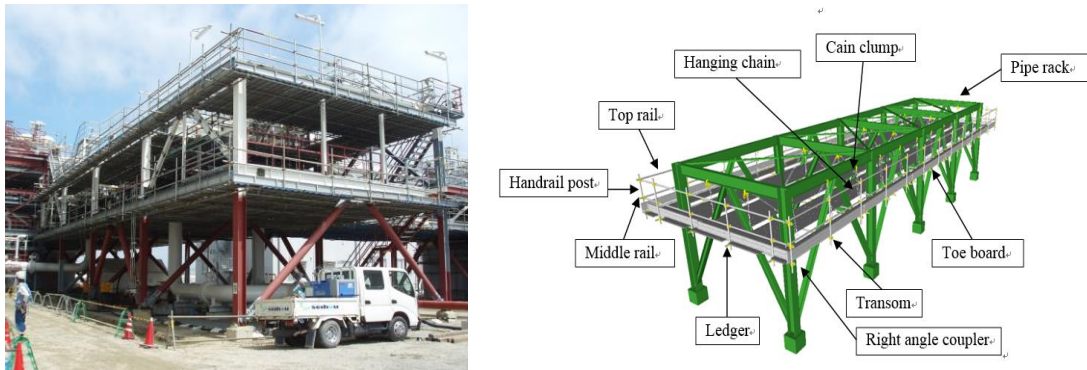
Figure 1. Example of hanging scaffold.

2   DESIGN PROCEDURE

2.1   System Environment

The system is composed of the web server, the file server and the client computer or PDA. The web and the file servers can be placed on the clouding system. The material quantity surveying and cost estimation will be done outside the office and these data will be stored on the storage inside the office for the later use.

2.2   Quantity Surveying Method

The quantity surveying method is represented using the example of the hanging scaffold shown in Figure 1. The calculation system is running on the web with PHP program (Cowburn 2018).

2.2.1   *Web data input*

Figure 2 shows the web input page. Firstly, the user should input the geometric conditions of the constructing structure such as the size of pipeline racks. Rack length and rack width are 40m and 10m, respectively. The column distance is 8m. The setting position is 0m. Then, the scaffold design conditions should be defined. The ledger distance is initially defined as 1.8m. The transom arrangement is selected (8th raw in Figure 2). In this example, 4 transoms are arranged between rack column. The longest steel pipe length is selected as 6m in this example. Five patterns of aisle can be selected (see Figure 3). In this example 4 aisles are selected. In each aisle, two types of plank can be selected. In this example, 3 planks are selected. The calculation with PHP program (Cowburn 2018) is done. Each calculation method is shown below.

2.2.2   *Origin of the coordinate system in the calculation*

After pushing the "Execute" button, all materials are calculated sequentially based on the origin of the coordinate system that is the reference point of the system. In this system, the origin is defined as the top center of the beam placed at the edge of the rack (Figure 3). All positions of the composed materials are calculated based on this point. The axis x is defined along the 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 material positions and the quantities are calculated considering the geometric conditions of the materials. The relations between materials are defined under the Ministry of Health, Labor and Welfare (2010) specifying the safety and the strength requirements of the scaffold. Positions and the length of each material are evaluated below.

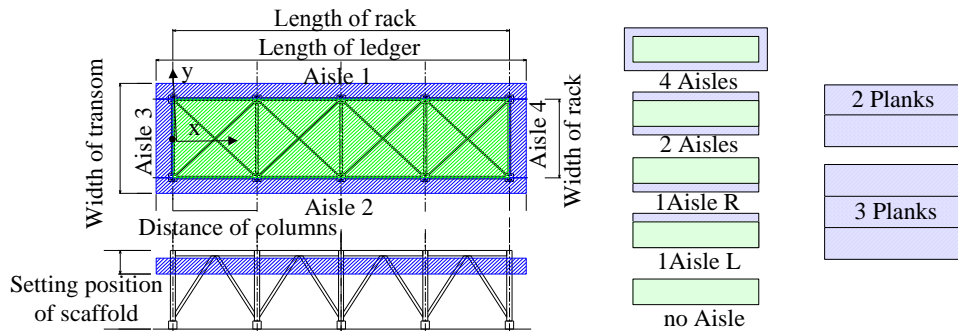|	
工事件名　Sugiko3	1. Name of project
得意先名	2. Name of client
ラックの長さ　48.00 m	3. Length of rack
ラックの巾　10.00 m	4. Width of rack
主柱の間隔　8.00 m	5. Distance of columns of rack
梁天からの下がり　0.80 m	6. Setting position of hanging scaffold
親パイプの間隔　1.80 m	7. Distance of ledgers
ころばし間隔　○3点支持 ◉4点支持 ○5点支持	8. Method of transoms arrangement
長尺パイプのサイズ　◉6.0M PIPE ○5.0M PIPE ○4.0M PIPE	9. Pipe length
通路の敷設方法　◉四面通路 ○両側通路 ○右片側通路 ○左片側通路 ○通路なし	10. Type of aisles
通路の足場板枚数　◉3枚 ○2枚 ○なし	11. Plank rows
落下防止措置　◉巾木	12. Toe board
資材積算	13. Execute

Figure 2. Input data on WEB.
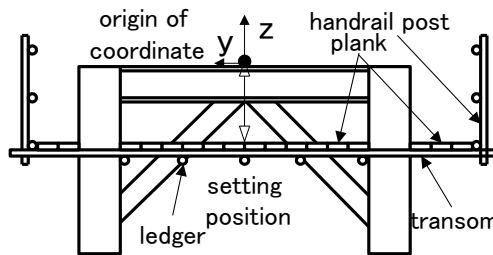

Figure 3. Rack and scaffold.

Figure 4. Side view of hanging scaffold.

2.2.3 *Position and length of ledgers*

The ledgers are placed within the rack columns. 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 defined on the web (7th raw in Figure 2). Considering the width of the frame, each ledger is placed at regular interval. The position of the ledger is under the transom below the planks (Figure 4). The required length of the ledger is evaluated considering the geometrical relation of other materials (see Figure 3). The length of the ledger is the summation of the required length, that is the rack length and the aisle width, and the extra length of pipe defined in the Ministry of Health, Labor and Welfare standard (2010).

2.2.4 *Position and length of transoms*

The first transom is placed at 100mm from the end of the legers depend on Ministry of Health, Labor and Welfare (2010). These are placed on the ledgers. Then other transoms are placed repeatedly depending on the arrangement of the transoms (8th raw of Figure 2). The distance between transoms is the quotient of the column distance and the number of transoms (8th raw of Figure 2). The length of each transom is calculated considering the rack width and the aisle width as well as the extra length of pipe. The height of transom is calculated adding 76mm to the height of ledger. 76mm is the distance between right angle couplers. Then, each coordinate of the transoms is defined as the crossing points between legers and transoms.

2.2.5 *Positions and numbers of planks*

Planks are placed from the center of the rack beam (the origin) to both columns of the rack. The coordinate and the number of the planks are calculated from the origin. The planks are also placed on the aisles defined on the web (11th raw of Figure 2).

2.2.6 *Position, length and numbers of handrails and their post*

Additional pipes are placed at both ends of the transoms. Then, handrail posts are arranged at the intersection of these pipes and the transoms. The length of the post is 150mm. The top rails and the mid rails are placed on the handrail posts. These numbers are calculated and the coordinate of handrails and the handrail posts are also calculated.

2.2.7 *Position and the length of toe boards*

The coordinate of the toe boards is evaluated considering the position of hand rail post.

2.2.8 *Positions and numbers of the hanging chain and the chain clump*

The coordinate and the quantities of the hanging chain and the chain clump are evaluated in regular interval.

2.2.9 *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.

2.2.10 *Storage of the coordinate data and the quantities of the materials*

After evaluating the geometric relations of the materials based on the standards to assure the safety and the strength of them, the quantity of each material is accounted.

   The steel pipes used for scaffold have several cut lengths. Combining several sizes of the pipe lengths, the quantities of pipes are calculated. Table 1 shows the calculation results from the input data (Figure 2). Also, the coordinate data for all materials are stored in the data file. These data are used for drawing and for managing the materials.

3   DRAWING THE SCAFFOLDING

Using the estimated data, the drawings will be done on each terminal (PC or PDA) by using the CAD system and can confirm the estimation data. Also, the quantities shown in Table 1 will be presented on each terminal.

Table 1. Evaluated quantities after calculation.

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

The drawing of the scaffold will be done by using AutoCAD. Each material of unit length is registered in the CAD. Using the position and the length of each material, the drawing is automatically done by the program coded by Visual Basic for Application (VBA). The results are shown in Figure 5(a). From the total view, the arrangement of the materials is confirmed. If the design is not suitable, the designer can go back to the web input system (Figure 2) and can reconfirm the result. Also, as the drawing is done on the cad system, it is easy to change the viewpoint and to zoon in detail (Figure 5(b)).
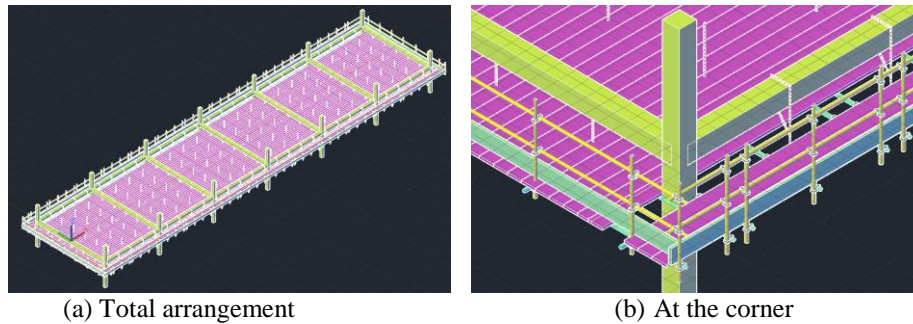

(a) Total arrangement   (b) At the corner

Figure 5. Total view of the hanging scaffold.

4   APPLICATION TO OTHER SCAFFOLD SYSTEM

The design system for hanging scaffold is easy to apply to the other type of scaffold. Figure 6 and Figure 7 show the drawings applied to the building structure and the tank maintenance, respectively. These scaffolding systems require a lot of materials and each material is registered as the block data. It is laborious work to account the materials and to make the drawing by hand. However, in this system, only the outline of the building and the gap between building and the scaffold are input data on the web. As the same manor of the previous chapter, the web system calculates the positions, the size and the quantity of each material. Then the drawing system is completely done and the quantities of the materials are obtained in detail.   This type of scaffolding has not flexibility of material choice. Therefore, the additional pipes are installed. In Figure 7, there is the gap between column materials in the scaffold system as shown as the circle because the distance between tank and the scaffold should be kept and the width of a material is constant. In such case, the additional materials to fill the gap are designed after drawings.

However, as the proposed system recognizes the coordinates of entire materials, it is easy to add the positions and the numbers of the steel pipes and the right angle couplers.
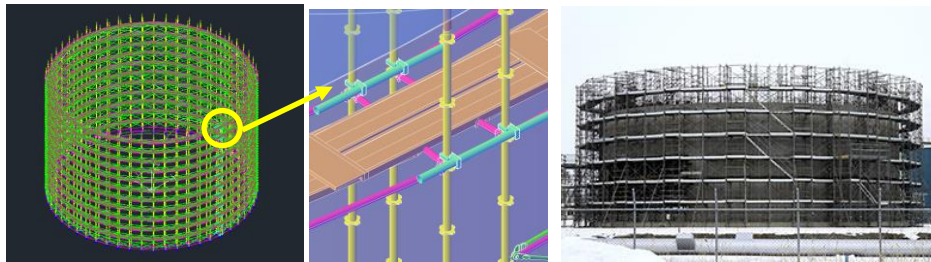

Figure 6. Scaffold for the building.

Figure 7. Scaffold for the tank maintenance.

From the accounting and drawing, it is easy to communicate the designers and the workers using the 3D drawings. Also, once the designed data are stored in the storage server on the clouding, it is easy to manage the supply of the materials and the other construction managements.

5   CONCLUSIONS

In this paper, the scaffold design system using the web calculation and CAD drawing was presented. Hanging scaffold was selected as the example. The design of the scaffold has been quite difficult and laborious. For example, when the hanging scaffold shown in Figure 5 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 the engineers' work. 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 system was applied to the hanging scaffold example. Then the applicability of other type of scaffold was presented. Also, it is easy to manage the supply of the materials and the other construction control because the designed data are stored in the storage server on the clouding. The methodology of three dimensional CAD drawing enables us to apply to BIM and CIM software.

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