SCAFFOLDING SYSTEM FOR CONSTRUCTION OF ELEVATED WATER TOWERS

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Abstract: There will be four elevated water towers in Tainan Science-based Industrial Park (TSIP) in southern Taiwan, as this project is totally completed. During the construction of one of the four elevated water towers, it was found that the cost of the scaffolding system could be as high as one fifth of the total construction cost, as was unreasonably high. An alternative scaffolding system was developed and is reported in this paper, and the new system is found to be more economical and safer, and the construction time employing the new system is shorter. A software toolkit developed for automatic structural analysis and design for such a scaffolding system is also presented.

Keywords: Scaffolding system, elevated water tower, construction, FEM, user interface.

1. INTRODUCTION

Tainan Science-based Industrial Park (TSIP) in southern Taiwan is one of the government's efforts to expand high-tech industry of Taiwan. An area of 4,940 acres and to provide future residence for about 110,000 people, TSIP certainly comprises environmental facilities, some of which are water towers. There will be four elevated water towers in TSIP as this project is totally completed. During the construction of one of the four elevated water towers, it was found that the cost of the scaffolding system could be as high as one fifth of the total construction cost because of the height of the clearance between ground and the cantilevered slab of the elevated reservoir.

As the elevated tower is about 30m in height, the stability issue of the vertical steel members of the conventional scaffolding system turned out to be intractable, and made its expense unreasonably high. Therefore, an innovative scaffolding system was developed.

The thickness of the cylindrical wall of the elevated tower is 1.2~1.5m. The new developed scaffolding system takes advantages of the strong RC wall that has been placed and solidified, and employs a structural system consisting of radial steel brackets that is supported upon the cylindrical wall. Thus the rather long vertical members of the old scaffolding system, which were supported upon the ground, were judiciously replaced. Consequently, in spite of its classical structural concept and ordinary assembly and erection procedures that are in fact beneficial practically, the new system has at least two merits. First, the tonnage of the used steel members is considerably reduced because there is no longer stability problem. Second, the space that was supposed to be taken up by the ground-supported vertical members of the old system is dramatically released. The resulting profit naturally includes those brought about by cost deduction of both materials and labor as well as the acceleration of the construction duration.

As an aid for automatic structural analysis and design for such a scaffolding system, a software toolkit was also developed. It incorporated a kernel of finite-element analysis routines, an auto-mesh module, a three-dimensional (3-D) graphical mesh-representing system, and a Windows-based user-friendly I/O interface. It was implemented by combining procedural FORTRAN routines [1] with an object-oriented programming framework, also known as RAD (Rapid Application Development) [2], using C++ programming language.

In this paper, the configuration of the improved scaffolding system is described, and the software toolkit for automatic structural analysis and design for such scaffolding systems is presented.

2. CONSTRUCTION OF THE ELEVATED WATER TOWERS

The elevated water towers reported in this paper are typically composed of piling foundation, the cylindrical wall, and the elevated water reservoir. The outline of the structure is shown in Figure 1. The weight of the contained water ranges from 2000^{ton} to 3000^{ton}. The height of the tower is about 30^{m}. Typical thickness of the cylindrical wall is from 1.2^{m} to 1.5^{m}. They are reinforced-concrete towers.

The placement of concrete of the cylindrical wall is routine. The construction of the elevated reservoir, however, is challenging, because of the height of the clearance between ground and the cantilevered slab of the elevated reservoir. Conventional construction means was to use temporary H-shape steel members supported vertically upon the ground to support the cantilevered portion of the elevated reservoir under construction, as shown in Figure 2. Now that the unsupported length was large and the temporary joints of these members were likely to be far from rigid, the stability issue turned out to be intractable. As a result, first, the cost was inevitably high; it was found that the cost of the scaffolding system alone could be as high as one fifth of the total construction cost, as was unreasonably high. Moreover, since the stability problem of the old system was so critical, the potential risk of its failure might be a matter to be worried about. Therefore a new type of scaffolding system was needed.

3. THE NEW SCAFFOLDING SYSTEM

The thickness of the cylindrical wall of the elevated tower is 1.2~1.5m. The new developed scaffolding system takes advantages of the strong RC wall that has been placed and solidified, and employs a structural system consisting of radial steel brackets that is supported upon the cylindrical wall [3]. Thus, the rather long vertical members of the old scaffolding system, which were supported upon the ground, were judiciously replaced by the brackets of the new system. The schematic drawing of the construction procedures of the new scaffolding system is shown in Figure 3.

Consequently, in spite of its classical structural concept and ordinary assembly and erection procedures that are in fact beneficial practically, the merits of the new system are at least twofold. First, the tonnage of the used steel members is considerably reduced because there is no longer stability problem. Second, the space that was supposed to be taken up by the ground-supported vertical members of the old system is dramatically released. The resulting profit naturally includes those brought about by cost deduction of both materials and labor as well as the shortening of the construction duration.

4. A SOFTWARE TOOLKIT FOR AUTOMATIC STRUCTURAL ANALYSIS AND DESIGN

The structural system of the new scaffolding is so simple and neat that a toolkit for automatic structural analysis and design is quite natural, or even indispensable. Therefore a software toolkit was developed, and consists of four parts, namely, the FEM kernel, the auto-mesh module, the graphical presenting system, and the Window-based user interface.

<u>FEM kernel</u>

The kernel of the software is composed of a set of procedural FOTRAN routines for finite-element structural analysis [1]. Many types of elements that are common to structural engineering are incorporated, such as 3-D beam element, 3-D shear wall element, 3-D solid element, and so on. The steel members of the scaffolding system are modeled by 3-D beam elements, while the cylindrical wall of the tower is modeled by using 3-D wall elements. [3]

<u>Auto-mesh module</u>

The key to the automation regarding the structural analysis and design is actually the auto-mesh module, the thinnest module of the four. Since the configuration of the structure is regular, the FEM mesh of the structure can be determined after several controlling parameters are given. The auto-mesh module is responsible to automatically generate the FEM mesh of the structure. An example is illustrated in Figure 4.

<u>Graphical presenting system</u>

A graphic viewing system is virtually a standard part for today's FEM software. In the graphical presenting system of the new developed software, the users can view the 3-D FEM mesh, zoom in and zoom out, rotate the viewing object arbitrarily, and so forth. In addition, the results of both the analysis and design, such as member forces, deformed shape, and stress ratio, can be shown graphically. Examples of the screen presenting are shown in Figure 5.

<u>User interface</u>

A Windows-based user-friendly interface was also implemented by C++ language. All of the input data, including the geometric controlling parameters, the materials parameters, and the steel member size can be established and entered through the user interface easily. There are windows, pull-down menus, buttons, status bar, message boxes, etc. in the user interface. Prompt messages would appear in time to help the user to operate. Besides, the user can activate the other three modules by clicking on buttons in the user interface. Some of the functions are illustrated in Figure 6. [3]

<u>Architecture of programming</u>

What the users can't see is the encapsulation and architecture of the programming. The module of the user interface was implemented employing an object-oriented programming framework for developing Windows Applications, also known as RAD (Rapid Application Development) [2]. The other three modules are invoked as multi-threaded process in response to such Windows messages as menu item selecting or button clicking sent by the user interface. In other words, the overall software was implemented by combining procedural FORTRAN routines with the object-oriented programming framework. In a modular manner, the software was produced quickly and efficiently.

5. CONCLUDING REMARKS

1. The conventional scaffolding system for construction of elevated water towers was found to be uneconomical and inefficient. A new scaffolding system was developed.
2. The problems in the conventional system and solutions provided by the new system are described in this paper. The new system is found to be more economical and safer, and the construction time employing the new system is shorter.
3. As an aid for automatic structural analysis and design for such a scaffolding system, a software toolkit was also developed. The functions, compositions, and implementation of the software are presented.

Acknowledgments

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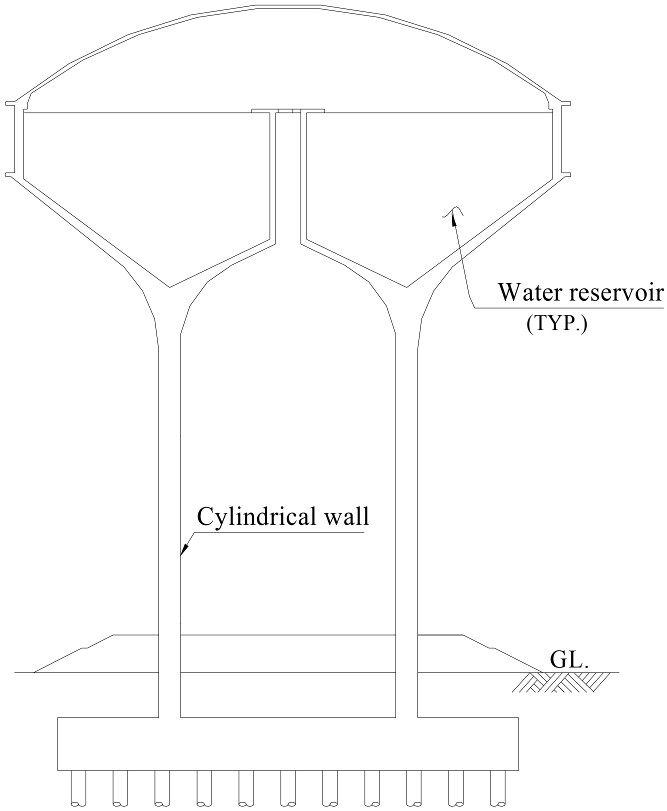


Figure 1. Profiling outline of the elevated water tower

Figure 2. Conventional scaffolding system

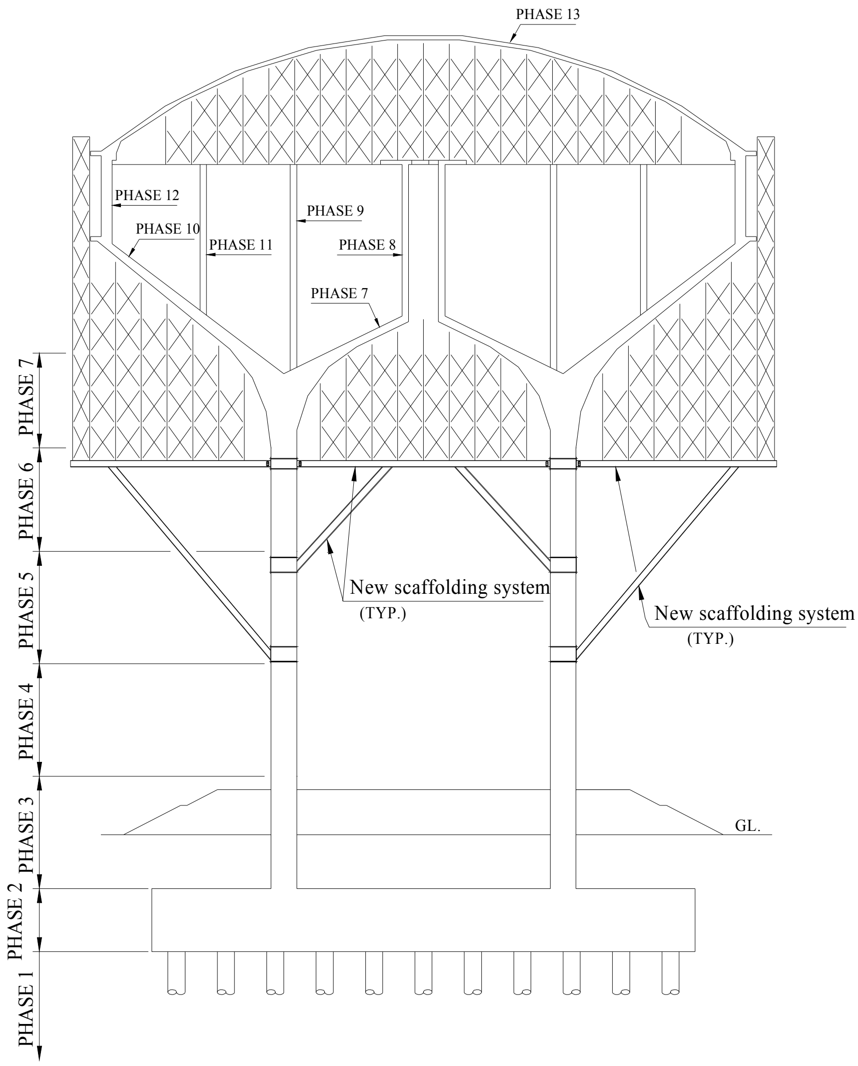


Figure 3. Construction procedures by new scaffolding system

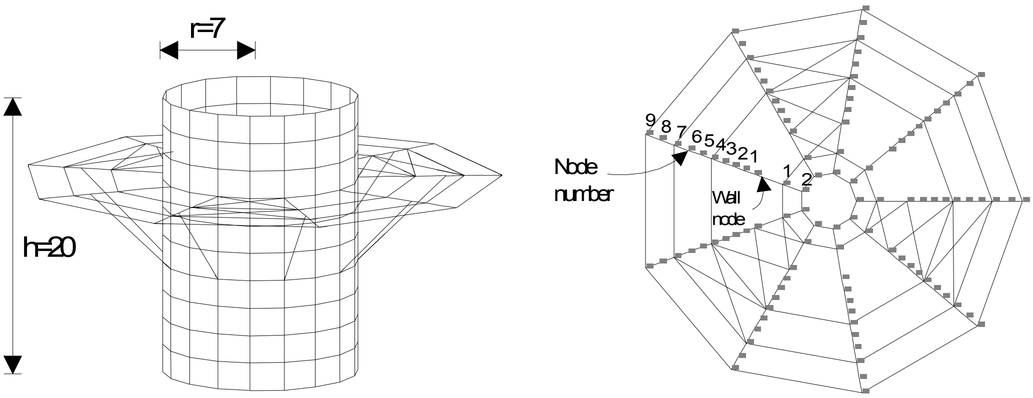
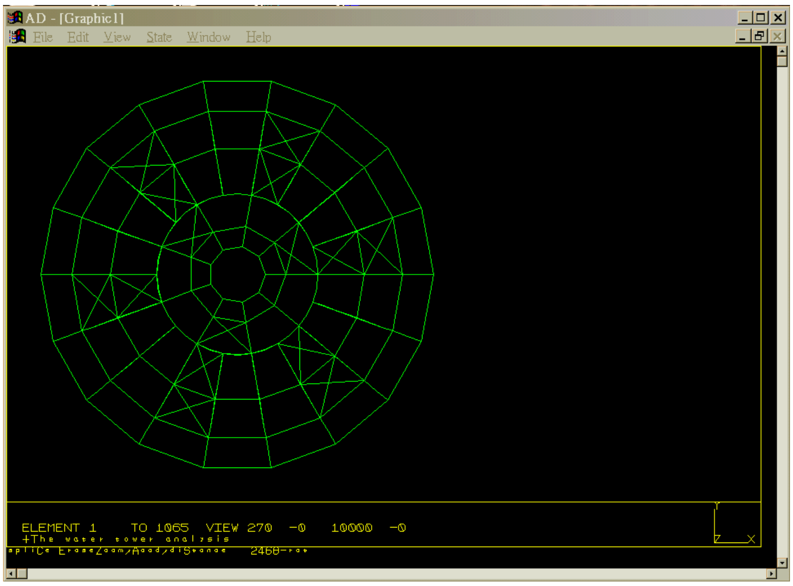
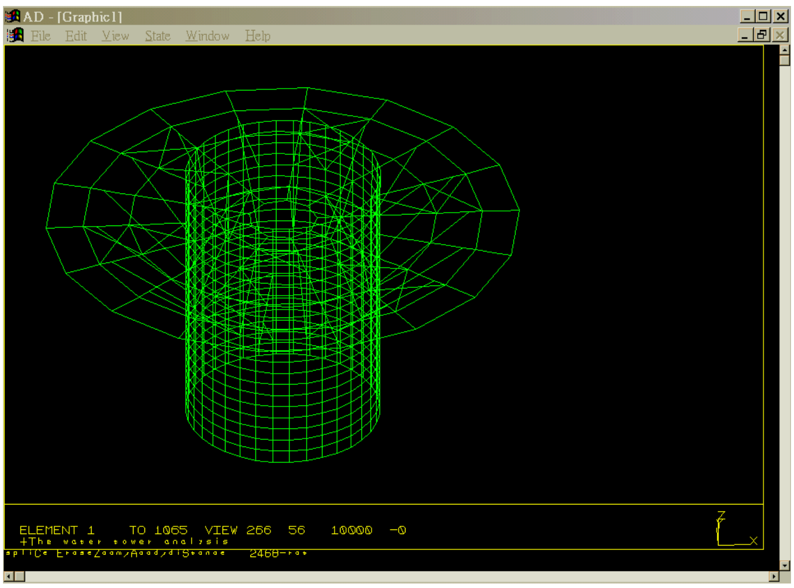


Figure 4 An example to illustrate the input data for auto-generation of the FEM mesh (nz=10, nc=18, nrad=9, nint=1, h=20,r=7,nlay=7,nring1=9,nring2=2)



(a) Top view of the FEM mesh

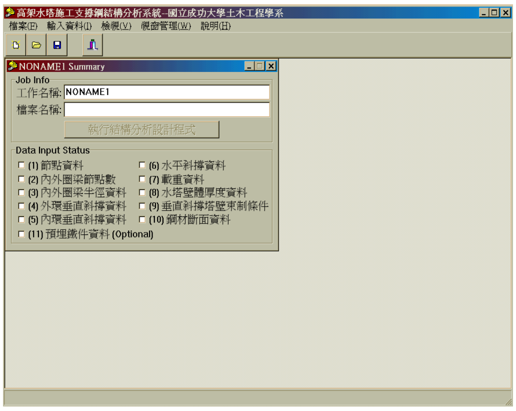


(b) 3-D view of the FEM mesh

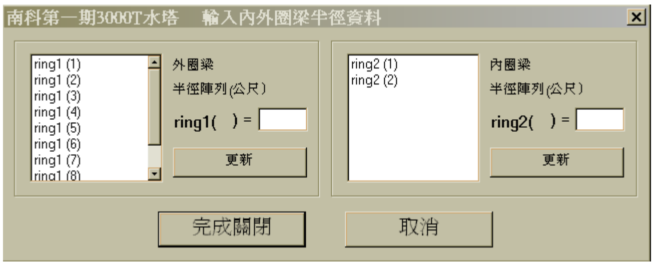
Figure 5. Illustration of the graphical presenting system

(a) Install of the software

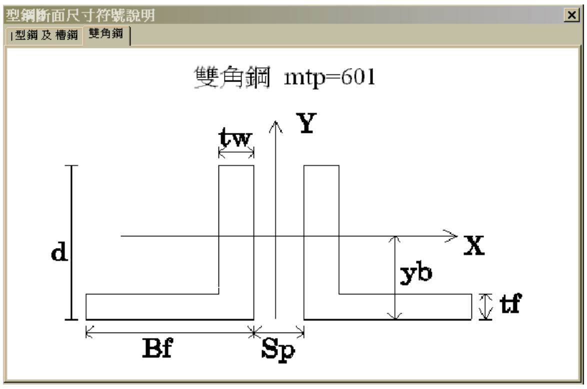
(b) Starting of the software



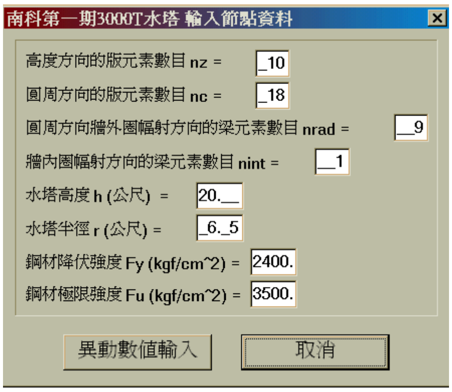
(c) Whole screen with one job opened



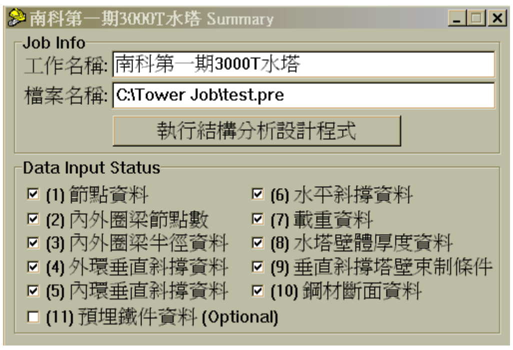
(d) Ring beam radius input dialog box



(f) Window to illustrate the notations of steel members



(e) Nodal data input dialog box



(d) Job summary dialog box after completion of data input

Figure 6 Illustraion of the user interface