

# A 3D Simulation Method of Foundation Pit Excavation Based on Vector Graphics

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## Abstract

Vector Graphics is a character of Flex technology, vector graphics-based 3D model has a simple data structure and a fast speed, it's a suitable modeling method for Web3D programming. In this paper we present a polygon automatically blocked and cropped algorithm, to disperse foundation pit. And on this basis we use Flex technology to design a vector graphics-based three-dimensional simulation method of foundation pit construction. This method is based on B / S structure of the Web application, you can easily edit the construction progress and quickly simulate the excavation of foundation pit.

**Keywords:** *Vector Graphic, flex, foundation pit, simulation, 3D model.*

## 1. Introduction

Information technology is increasingly used in civil engineering constructions. We can manage engineering data by remote access due to the development of network and information technology. Most project work sites are distributed in various different locations, so the management is very difficult. For managers, they of course want to be able to see the situation of every work site more conveniently and fast. Nowadays, connecting to the Internet at work sites is more convenient in 3G and WIFI network coverage. Therefore, we may consider to establish a Web-based application that the construction workers at work site can easily upload and update construction progress and managers can view it remotely via computer simulation technology.

Many scholars and scientists have done research for construction simulation. Wu, Borrmann [1] presents a method in automating the generation of time schedules for bridge construction projects. Scherer and Schapke [2] developed a management information system to support decision making on construction projects. Länmer, Meißner [3] presented a research for the integration of partial models by an object-oriented method. Ruwanpura

and Ariaratnam [4] presents several simulation tools that have been used in underground infrastructure construction. The above simulation software are used in building structures, for open cut method and foundation pit, the research is not enough yet. So far, the research of foundation pit excavation is concentrated in the calculation of stability of soil structure, for example in Luo, Zhang [5], Zhou, Vermeer [6]. But we need a software especially web-based applications that directly reflect the progress of foundation pit excavation, it's relatively rare.

Foundation pit excavation is very common in construction, especially in underground engineering. It's a very significant thing understanding real-time of the foundation pit construction progress. We designed a foundation pit excavation simulation method based on network and vector graphics. It can effectively solve the problem of update and simulation in foundation pit excavation.

## 2 Foundation pit's basic property edit

For a foundation pit, its outer contour in the plane can be abstracted into a polygon. Therefore, when a foundation pit has been established, we can click the mouse on the corresponding position of the map to generate the vertices of the polygon. Then we connect these vertices to describe the edge of foundation pit that being excavating. The points' connection order is based on the order in which user clicked, and the last vertex is connected to the first vertex. Finally the polygon which represent the foundation pit's contour is obtained. There are several notices: 1. The intersection points of segments which connecting the adjacent vertices should all be coincide with vertices, or the foundation pit's contour is not a polygon. As is shown in fig.1, A and B are both sequentially connection of foundation contour points which depicted by user. A is a polygon but B isn't, because B has excess intersection. Therefore, B cannot be regarded as the outer contour of the

foundation pit to process the next step. 2. The clicks must be on the order in accordance with the anti-clockwise. In geometric calculation, graphical area surround counter clockwise is positive, whereas clockwise is negative. Accordingly, in order to facilitate the calculation of the next step, the selection clicks must be strictly in accordance with the counterclockwise direction sequence along the foundation pit's contour. As shown in C, although there is no excess intersection, the points' order is counterclockwise, the area is negative. Therefore, it doesn't meet the requirements of a polygon. Thus, in Fig.1, only A can be used as the outer contour polygon of a foundation pit. For each foundation pit, its contour data would only be entered once in the establishment of base data.

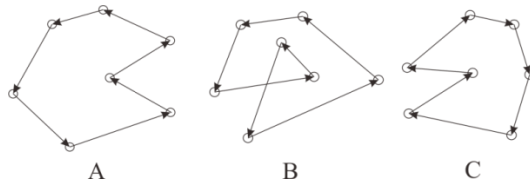


Fig.1 Points and connection methods

## 2 Foundation pit auto-subdividing method

A foundation pit which in excavation is a continuous entity in three-dimensional space. But it must be changed into discrete objects when storing into computer. In order to facilitate editing and finding, we have adopted a regular grid expression which is common used in geographic information system. A foundation pit is divided into array of grid cells, most cells are square and each has a different elevation attribute. We use these grids to simulate the foundation pit entity. The contour of a foundation pit is an irregular polygon, therefore, its coverage is scarcely possible to be completely consistent with a square grid, there is a number of intersecting at the boundary. So we need to calculate the intersection of the boundary of grid and foundation pit contour, to clip the parts which located outside the foundation pit and belongs to the grids. In other words, we take the intersection of two polygons. There are many possible situation of two polygons' intersection. The results of cross-intersection may be one or more polygons, as shown in Fig.2.

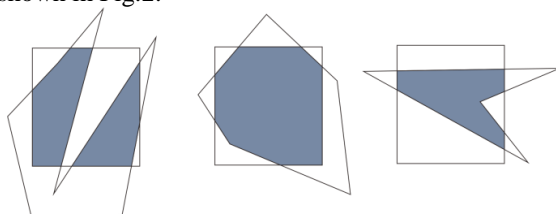


Fig.2 Cross-intersection of two polygons.

In the calculation of the cross of two polygons, we use a simple method mentioned in Song, Yan [7], which proposed an algorithm with linked list to store position.

First calculate the intersection points of two polygon, then sort the vertices of each polygon and its intersection points. Using this method, the intersection polygon can be easily obtained.

When a grid located entirely in a foundation pit, it means the intersection of the grid and the foundation pit is the grid itself. Therefore, to calculate the square grid and foundation pit polygon intersection, we can get the discrete plane polygon mesh of foundation pit. Due to different orientation of foundation pits, and a lot them is rectangular in shape or some irregular shapes. Therefore, we should allow user to customize the grid cell direction, to get a better meshing and let them more suitable for editing, as shown in Fig.3. In addition, both the sizes of foundation pits and the accuracy requirements of simulation are different, so the side length of the grid is also needed to be defined by user. When the grid mesh is constructed, user can click on a grid or select all grids in a region, to set the elevation of selected grids.

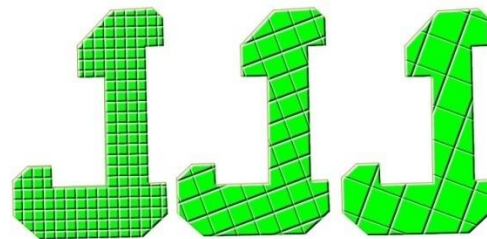


Fig.3 Different grid dividing meshing

## 3 Simulation of foundation pit

### 3.1 Elevation automatic interpolation

So far, we have proposed a method using regular grids to disperse and assign a foundation pit. But each grid needs user to set the elevation manually, and with the project progress it will constantly change. To reduce the workload in meshing, user usually will not choose too small division. But the problem is, when the three-dimensional simulation displays, if directly use this mesh for modeling, it will be too rough, display effect is not good. The solution is to use two different mesh density: one for edit and the other for display. The mesh grids for editing are larger than the displaying ones. When displaying, the editing mesh is automatically refined by elevation interpolation to create a mesh with smaller grids. This seems to be rather smooth. Elevation interpolation using the common terrain interpolation algorithm, such as inversed square-distance-weighted method, Kriging interpolation method and so on. In interpolating, we use the user-defined grid elevation as the original data, to generate a denser mesh.

### 3.2 Create 3D solid model of foundation pit via vector graphics

3D solid in computer is actually expressed by triangle mesh surface. Therefore, the 3D solid model to simulate the excavation of foundation pit, is to discrete the excavation surface into triangular mesh in space, essentially. We have adopted interpolation to increase density for initial mesh created by user in 3.1. Next, we'll use these mesh vertices to generate triangular mesh with boundary constraints, the boundary is the polygon outline of foundation pit. The steps are: 1. According to the density of grid cells, add more points along each side of the contour polygon, to meet the empty circle characteristic of Delaunay mesh; 2. Build Delaunay triangulation based on the newly updated vertex collection. The triangular mesh is a data structure of B-Rep expression. It can be passed directly to 3D engine for rendering and display. The comparison of plane mesh and 3D modeling effect is show in Fig.4. We can also obtain any cross-section of the foundation pit, as shown in Fig.5.

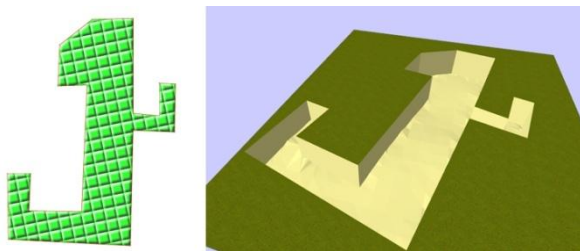


Fig.4 The comparison of plane mesh and 3D scene.



Fig.5 Cross-section in foundation pit

## 4 Software system design and implementation

We have designed a software system to achieve the above functions. The system uses B/S architecture, users can access it through a browser. In the front-end we imply 3D simulation based on vector graphics. In background we do business logic and 3D space algorithms. The front-end part needs to provide two different interfaces for editing and view. The editing interface primarily for use by constructor, its function is edit and obtain the required engineering data. It has two modules: one for editing basic data of foundation pit, the other for editing construction progress of foundation pit. The basic data editing module is that

when a new foundation pit entity is added in system, it will let constructors to input basic data, such as location, boundary, size of the meshing .etc. The construction progress editing module is when foundation pit entity is already established in system, we allow users to edit and update the construction schedule data according to the actual construction condition. The view interface is available to both constructors and project managers to use, it focuses on exhibition of foundation pit's excavating condition via 3D technology. Overall, the purpose of editing interface is allow users to easily set up the basic data and the properties such as elevation of each part in foundation pit, and for view interface is to directly reflects the excavation progress to users. The system structure distribution is shown in Fig.6.

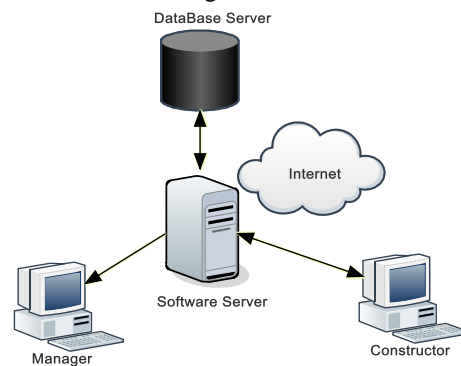


Fig.6 System structure distribution.

In technical level, because of Flex has outstanding display performance and Java has strong background processing power, we have adopted a combination of Flex and Java. The front-end interface using Flex for development and background data is processing by Java. Constructors edit data in the editing interface, than the interface can interact with Java program through AMF protocol or WebService to pass foundation pit data to the Java side, Java program update the corresponding database table via JDBC driver. View interface is also a Flex application, it interacts with Java program, use Java program to get height information from database, interpolate to generate a 3D model, than transfer to Flex for displaying. In flash Player 11.0 or higher version, Adobe added a new stage3d engine, it supports GPU 3D hardware acceleration and can achieve real-time rendering.

## 5 Conclusions

Use this method and Flex technology, we developed a software based on B/S structure and established a 3D foundation pit excavation scene of a subway construction site. According to the vector animation features of Flex, we designed a method to simulate the excavation depths of foundation pit based on vector graphics, it is easy

operation and small occupation in storage and network bandwidth. In actual engineering apply, the software can be combined with monitoring point data, foundation pit excavation envelope, shoring of trench and various other data. The system can be further improved and display project progress all round in a higher degree.

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### References

- [1].Wu, I.C., et al., Bridge construction schedule generation with pattern-based construction methods and constraint-based simulation. *Advanced Engineering Informatics*, 2010. 24(4): p. 379-388.
- [2]. Scherer, R.J. and S.E. Schapke, A distributed multi-model-based Management Information System for simulation and decision-making on construction projects. *Advanced Engineering Informatics*, 2011. 25(4): p. 582-599.
- [3].L ämmer, L., U. Meißner, and M. Petersen, Object-oriented integration of construction and simulation models. *Computers & Structures*, 2001. 79(22–25): p. 2143-2149.
- [4].Ruwanpura, J.Y. and S.T. Ariaratnam, Simulation modeling techniques for underground infrastructure construction processes. *Tunnelling and Underground Space Technology*, 2007. 22(5–6): p. 553-567.
- [5].Luo, Z.-j., Y.-y. Zhang, and Y.-x. Wu, Finite Element Numerical Simulation of Three-Dimensional Seepage Control for Deep Foundation Pit Dewatering. *Journal of Hydrodynamics, Ser. B*, 2008. 20(5): p. 596-602.
- [6].Zhou, N., et al., Numerical simulation of deep foundation pit dewatering and optimization of controlling land subsidence. *Engineering Geology*, 2010. 114(3–4): p. 251-260.
- [7].Song, L., et al., An Algorithm to Compute the Intersection of Two Simple Polygons. *Geomatics & Spatial Information Technology*, 2011. 34(6): p. 4.

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