Postprint of Road 3D Modeling Method Based on CATIA Software

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Abstract

CATIA, as a powerful three-dimensional collaborative design software, has been widely applied in the field of water conservancy and hydropower engineering. The design of access roads and internal construction roads constitutes an important component of three-dimensional collaborative design for water conservancy and hydropower engineering projects. Through the modeling of access roads for a hydropower station project, this paper introduces a method for establishing three-dimensional road models using CATIA software based on two-dimensional planar design results.

Full Text

Preamble

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Road 3D Modeling Methods Based on CATIA Software

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Abstract: As a powerful 3D collaborative design software, CATIA has been widely applied in water conservancy and hydropower engineering. The design of access roads and construction roads constitutes an important component of 3D collaborative design in water conservancy and hydropower projects. Based on the modeling of an access road for a hydropower station, this paper introduces a method for establishing 3D road models using CATIA software, which builds upon 2D planar design 成果.

Keywords: CATIA; Road; 3D Model; Water Conservancy and Hydropower Engineering; Parametric

1. Introduction

Water conservancy and hydropower projects are characterized by large investment scales, long design and construction cycles, numerous participating design disciplines, and complex system structures. To improve design efficiency and quality while enhancing core competitiveness, the water conservancy and hydropower design industry is gradually transitioning from traditional 2D planar design to multi-disciplinary 3D collaborative design. In hydropower project construction, access roads, construction roads, and camp roads connect the entire project area, making 3D road modeling essential for a complete project design. Compared with conventional planar design that relies solely on 2D horizontal, vertical, and cross-sectional data to express road spatial structure and location, 3D road design offers higher precision and more intuitive visualization.

Currently, various software packages support road 3D modeling, including CARD/1 from German IB&T Software, AutoCAD Civil 3D from Autodesk, CATIA from Dassault Systèmes, Weidi Road Design Software from Xi' an Jingtian Transportation Engineering Technology Institute, EICAD from Nanjing Dinuo Technology, and Hongye Roadleader from Hongye Technology. These specialized road design software packages, which are closely integrated with design codes and feature parametric and template capabilities, offer advantages in single-discipline road 3D modeling. They utilize basic road geometric design data and terrain data to rapidly and accurately construct 3D solid models of terrain, roads, bridges, and tunnels. However, their capabilities in parametric associative design and terrain surface processing are limited, making them unable to meet the multi-disciplinary collaborative design requirements of large, complex projects such as water conservancy and hydropower engineering.

AutoCAD Civil 3D is a professional 3D design software capable of completing road engineering, drainage system, and site planning designs. Its road modeling function can combine horizontal and vertical geometry with customized cross-section components to create parametrically defined dynamic 3D models for highways and other transportation systems. Nevertheless, it requires integration with other software for building and mechanical-electrical assembly designs, presenting limitations in 3D design for construction general layout of water conservancy and hydropower projects.

CATIA is a large-scale, high-end CAD/CAE/CAM integrated design software developed by Dassault Systèmes. It enables integrated 3D design of water conservancy and hydropower projects by combining geology, engineering hubs, construction layout, site transportation, metal structures, and mechanical-electrical assemblies. Using its collaborative design platform VPM, scattered individual designs can be transformed into centralized online design, enabling effective management of design models, structures, skeletons, parameters, and associative information. CATIA features powerful parametric design capabilities and comprehensive knowledge engineering functions, allowing the establishment of universal template libraries for road cross-sections and ancillary structures to achieve knowledge reuse and model associative updates. Due to its numerous advantages in multi-disciplinary collaborative design and road 3D modeling for water conservancy and hydropower projects, CATIA has been widely applied in the overall design of such projects.

Based on the modeling of an access road in a domestic hydropower project 3D collaborative design, this paper introduces a method and workflow for establishing 3D road models in CATIA using 2D road design software 成果 as the foundation.

2. CATIA Road 3D Model Design Workflow

The workflow for establishing road 3D models in CATIA includes:

1. Collecting basic road design data such as terrain and geological information, as well as 2D planar design 成果 including road alignment, longitudinal profile, stake coordinate tables, and standard roadbed cross-sections.
2. Establishing a 3D terrain solid model based on terrain data.
3. Creating the road centerline in the CATIA 3D terrain model according to 2D planar design 成果. This centerline is a spatial curve.
4. Establishing a 3D parametric template for the roadbed cross-section, with parametric settings for roadbed width, slope gradients, slope height, berms, etc., to facilitate invocation and modification.
5. Using the roadbed cross-section template in CATIA' s Generative Shape Design environment to create the entire route' s roadbed outline surface model along the road centerline.
6. Performing intersection operations between the roadbed outline surface model and the 3D terrain solid model to generate road fill and cut volumes, as well as the modified 3D terrain solid model after excavation and backfilling.
7. Establishing 3D models for road ancillary structures such as ditches and guardrails on the terrain solid model after road excavation and backfilling to obtain a complete road 3D model.
8. Utilizing CATIA' s quantity calculation functions to 统计 roadbed fill quantities, excavation quantities, and ancillary structure volumes for cross-checking with quantities calculated by 2D design software.

3. Establishment of Road 3D Models

3.1 Basic Principles

The world coordinate system adopts a right-handed Cartesian coordinate system during modeling, with the XY plane as the horizontal plane and the Z direction representing elevation. Modeling units are unified.

3.2 Establishment of 3D Terrain Models

In CATIA, terrain models can be established using the software' s own mesh modeling and editing functions, or by importing terrain model files created by other software. Several common methods for establishing CATIA terrain models are described below:

1. **Importing contour point cloud data:** Based on topographic maps of the project area provided by surveying departments, import point cloud data generated from terrain contour lines into CATIA to create 3D terrain mesh models.
2. **Importing geological models:** Utilize geological software such as GOCAD to establish 3D geological models, then import TS, STL, or 3DMAX format files generated by GOCAD into CATIA to create terrain models.
3. **Using GIS software:** Employ GIS software such as ArcGIS to establish digital terrain models, convert ArcGIS' s triangulated irregular network (TIN) model files to STL format, and import them into CATIA to generate terrain models.

Performing Boolean operations between the 3D terrain surface model generated by CATIA and a 3D solid cuboid model of the same scope yields a 3D terrain solid model. The establishment of the terrain solid model precisely locates the entire 3D model of the water conservancy and hydropower project hub and prepares for foundation filling and excavation of roads, dams, and other structures in the project area. The terrain solid, together with various engineering structures, constitutes a complete 3D model of the water conservancy and hydropower hub.

3.3 Route Establishment

A road is a three-dimensional spatial strip-shaped entity whose central line defines the route. The route is a spatial curve, and CATIA provides two primary methods for route establishment:

1. **Direct generation from spatial points:** Based on 2D road design software 成果 such as road stake coordinate tables and roadbed design tables, obtain numerous 3D point coordinates (X, Y, Z) from the route start point to the end point along the alignment. In CATIA, create spatial coordinate points sequentially using these 3D coordinates, or import coordinate sequences for route points from external Excel files. Connect the spatial coordinate points with a spline curve from the route start to end to obtain the route. This method is simple but requires inputting numerous points for long routes, and the route simulated by spline curves connecting spatial points has limited precision.
2. **Import and synthesis of 2D curves:** This method imports the road horizontal curve and vertical profile generated by 2D road design software

into CATIA to create the route through extrusion, unfolding, and development transfer commands. First, establish the route start point and import the road horizontal curve in DWG or DXF format. Extrude the horizontal curve along the Z-axis (road elevation direction) to obtain an extruded surface and unfold it. Then import the road vertical profile onto the unfolded surface and use the development transfer command to obtain a spatial curve on the extruded surface, which becomes the design route. Although more complex than the spatial point method, this approach synthesizes the route from two 2D curves (horizontal and vertical), ensuring both alignment and elevation match the actual design with high precision. The route model in CATIA is shown in Figure 1 [Figure 1: see original paper].

3.4 Parametric Model of Standard Cross-Section

A road cross-section refers to the normal plane at any point along the road centerline, consisting of the design cross-section line and ground line. Typical roadbed cross-section forms can be summarized as embankment, cutting, and half-fill half-cut. Roadbed cross-section shapes mainly include trapezoidal (straight-line), broken-line, and stepped types with berms. The standard cross-section designed for this project is a stepped type, including both roadbed excavation and filling cross-sections. For any point along the road centerline, the portion above the road surface represents the cutting cross-section, while the portion below represents the filling cross-section. To facilitate inspection and modification of the roadbed cross-section design, the cross-section outline is parametrically configured, including parameters for pavement width, fill slope gradient, cut slope gradient, slope height, berm width, etc. The road standard cross-section outline model is shown in Figure 2 [Figure 2: see original paper].

3.5 Establishment of Roadbed and Pavement 3D Models

In CATIA, 3D roadbed solid models are primarily established through Boolean intersection operations. This involves creating a 3D mesh model of the roadbed standard outline surface (or a 3D solid model of the roadbed standard) and performing Boolean intersection operations with the established terrain surface (or terrain solid) model to obtain the CATIA 3D model of the roadbed structure. The steps for establishing CATIA roadbed 3D models are briefly described below:

1. Establish and parametrically configure the road standard cross-section outline model at the road start point.
2. Extend the road standard cross-section outline to the entire route using the sweep command to obtain the full-route roadbed standard outline surface (excluding the start and end cross-section profiles).
3. Create the start and end roadbed standard cross-sections and join them with the full-route roadbed standard outline surface (without start/end

cross-sections) to obtain a complete, closed full-route roadbed standard outline surface model.

4. Convert the fill roadbed standard outline surface model into a solid model using the tessellation command. Perform Boolean operations between this solid model and the terrain surface. The portion of the roadbed 3D solid above the terrain surface becomes the roadbed fill 3D solid model, as shown in Figure 3 [Figure 3: see original paper]. Use the cut roadbed standard outline surface as a cutting tool to cut the terrain solid. The portion of the terrain 3D solid above the cutting surface becomes the road cut volume, while the portion below becomes the terrain 3D solid after cutting. The roadbed 3D model after excavation and backfilling is shown in Figure 4 [Figure 4: see original paper].

Use the multiple extraction command to extract the top surface of the roadbed standard outline surface and create a thick surface with thickness consistent with the pavement design thickness. This thick surface becomes the pavement structure model.

3.6 Quantity Statistics

During the road 3D design process, place 3D solid design models such as terrain cut volumes, road fill volumes, ditches, and guardrails into corresponding geometric bodies. Then utilize CATIA' s volume measurement tools to 统计 roadbed excavation quantities, fill quantities, and ancillary structure volumes. These quantities can be cross-checked with those calculated by 2D road design software (such as Weidi or Haidi).

4. Advantages and Prospects

CATIA software features powerful knowledge engineering and parametric modeling capabilities. In the water conservancy and hydropower engineering field, using CATIA to establish road 3D models not only completes the 3D design of the entire project hub but also provides more intuitive understanding of road alignments and roadbed conditions along access roads, construction roads, and camp roads. Practice demonstrates that the method described in this paper enables rapid and accurate establishment of road 3D simulation models based on 2D planar design 成果 in CATIA. This method is applicable to road model establishment in all 3D collaborative design projects based on CATIA software, including water conservancy and hydropower projects and wind power projects. Utilizing CATIA for road modeling in large, complex project overall design offers the following advantages:

1. Enables the entire design process from terrain model establishment and road 3D modeling to 2D design drawing generation and quantity calculation.

2. Achieves multi-disciplinary online collaborative design on the same platform with real-time model updates and multi-disciplinary data sharing, allowing collaborative work without mutual interference and significantly improving design efficiency while shortening design cycles.
3. Facilitates convenient inspection of interferences and collisions between routes and other disciplines during road layout in the project hub area, substantially reducing design errors.
4. Benefits from excellent parametric design and knowledge engineering functions, enabling the establishment of parametric templates for road cross-sections and ancillary structures that facilitate design modifications and invocation in other projects.
5. Maintains interconnectivity between terrain, road horizontal/vertical/cross-sectional data, and 3D models, allowing synchronous model updates for any parameter modifications and significantly reducing model modification workload during design changes.
6. Enables simultaneous design, verification, and review through the VPM platform, allowing reviewers to browse road models in real-time via network, identify issues promptly, and reduce designers' modification workload.
7. Features powerful terrain surface processing capabilities for establishing accurate terrain models, enabling more precise calculation of road excavation and backfill quantities.

However, CATIA software also has certain limitations in road design. For instance, it currently lacks a dedicated road engineering design module and cannot directly apply existing standards and specifications for design. Direct 3D road modeling in CATIA would require substantial design verification workload, necessitating integration with road professional software design 成果 to rapidly establish specification-compliant road 3D models. Additionally, excessive route length may cause program slowdown due to increased data volume. We anticipate that future CATIA versions will further expand spatial applications to make greater contributions to engineering construction.

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Methods for Road 3D Modeling based on CATIA

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Note: Figure translations are in progress. See original paper for figures.