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POSSIBILITIES OF COMPLEX NUMERICAL MODELLING AT THE CZECH GEOTECHNICAL SOCIETY WORKPLACE

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Abstract. In the paper, there are examples of complex geotechnical problems in both 2D and 3D that are modelled using PLAXIS software on the specialist workstation provided by the Czech Geotechnical Society to their members.

Keywords: Numerical modeling, PLAXIS, embankment, earthquake, reinforced slope, piles.

1. Introduction

The Czech Geotechnical Society within their activities to support its members purchased workstation based on Z6 HP workstation and also software PLAXIS for solving complex 2D and 3D projects based on finite elements method and also software package Autodesk Architecture, Engineering & Construction Collection to support BIM based 3D design of such projects.

This Workstation is currently based on Geotechnical department of Faculty of Civil Engineering Czech Technical University in Prague with the possibility for remote access by ČGtS members. At the moment the remote access is tested to determine its quality and stability. Hereafter we present selected 2D and 3D complex modelling examples to imagine how complex projects can be solved using this workstation.

The dam was designed by the American firm Harza Engineering Company. Construction began in 1956 and was completed in the summer of 1961, when the reservoir began to fill. The dam consists of a rockfill stabilization part, a clay core sealing with side slopes of 1:0.3 (v:h) and filters. Under the clay core, there are two grout galleries on both the left and right banks. The subsoil of the dam is made up of layers of sedimentary rocks inclined over the water. These are mainly limestone, marlstone, sandstone and conglomerate. On November 12, 2017, a large earthquake of magnitude 7.3 occurred near the Iraq-Iran border. According to the USGS (United States Geological Survey), the earthquake was caused by an oblique thrust in the earth's crust. The epicenter of the earthquake was located near the town of Ezgeleh, just 32 km from the dam. The earthquake lasted 30 seconds and is believed to be the most destructive earthquake on the Iraq-Iran border since 1909. During this earthquake, the crown of the embankment subsided by 0.5 m. At the same time, it led to transverse and longitudinal cracks visible in the embankment crown. Based on this event, the competent authority decided to conduct a general inspection of the dam and related facilities [1]. As part of this inspection, there was also a requirement to create a geometric model of the dam and its subsoil and perform numerical calculations to recalculate the stability of the dam body under various relevant design situations.

2. Example of a Complex 3D Geometric and 2D Numerical Problem

The Derbendikhan rockfill dam (see Figure 1) with a maximum height of 130 m is selected as representative of the complex 2D modeling task. The Derbandikhan dam is located in Iraq on the Diyala–Sirvan River approximately 65 km southeast of the city of Sulaimaniah and 230 km east of the city of Baghdad.

Figure 1. General overview of the dam.

2.1. Geometric 3D model of the dam

The construction of the model of the dam body, its surroundings and geology was supported by the materials given by the Directorate of the Derbandikhan Dam. These original drawings of the as built design from 1954 to 1962 – [2] were scanned – see Figure 2, which had to be digitized first.

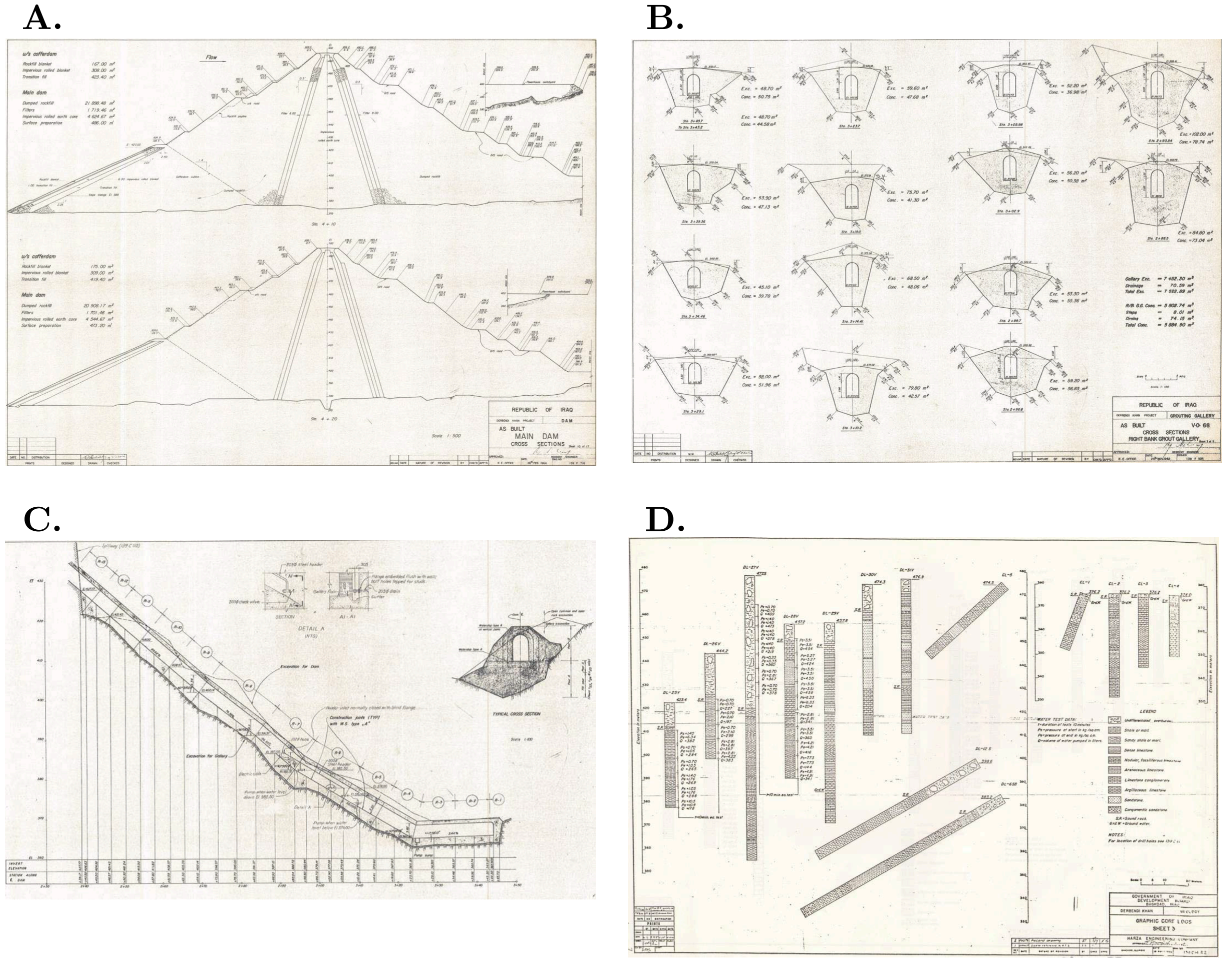

Figure 2. (A.) Sample of original drawings intended for digitization –x cross sections of dams. (B.) Sample of original drawings intended for digitization – cross-sections through an grout gallery. (C.) Sample of original drawings intended for digitization – longitudinal profile of grout gallery. (D.) Sample of original drawings intended for digitization – expoloratory boreholes

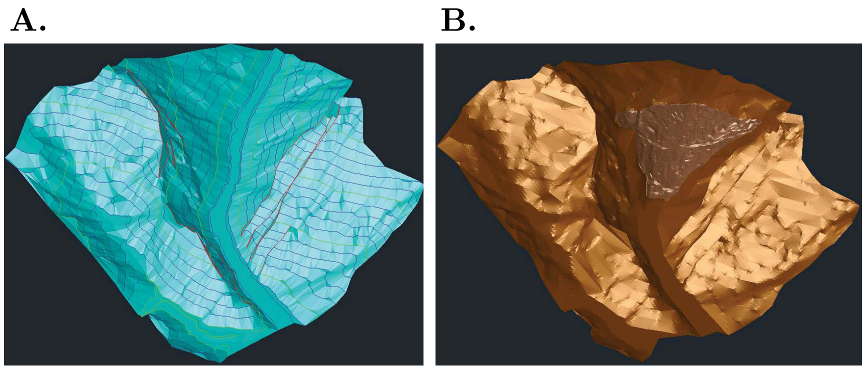

Figure 3. Digitized terrain surface – in (B.) also with the foundation joint under the dam body.

The 3D model of the embankment was created with the support of the following programs and their complementary modules of these programs: AutoCAD 2022, Civil 3D 2022, InfraWorks see Figures 3 to 6 – [3]. Digitization of the scanned drawings was done in the Raster Tools module. Based on the contour maps (see the previous chapter), a model of the terrain immediately adjacent to the water body was first created. This part of the surface model was created using the Civil 3D application based on the contours digitized using the Raster Tools module from the map base. Subsequently, the terrain model under the dam and outside the dam was extended by a significant part of the surface with the help of the InfraWorks application and Google Maps. On the basis of exploratory boreholes drawings, a geotechnical model of the Civil 3D application was used to create a model of the geology of the area of interest including 79 core

A. B.

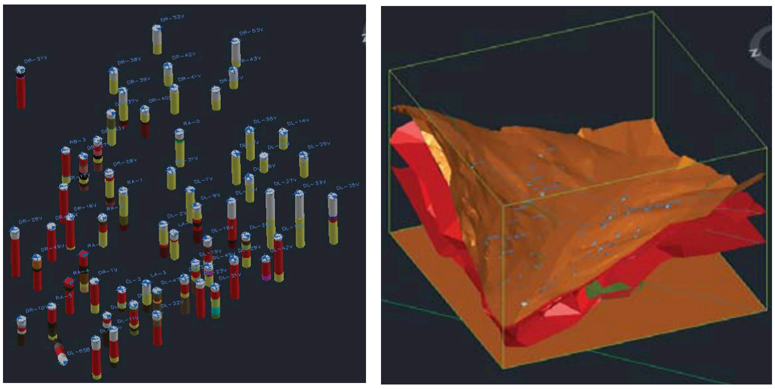

Figure 4. Digitized exploratory boreholes of the area of interest and a geological model in the Civil 3D.

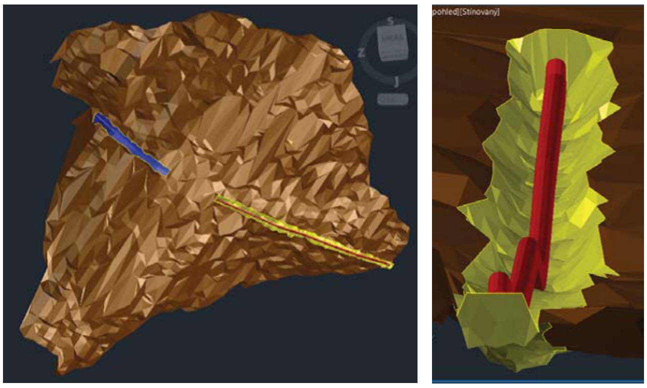

Figure 5. Model of grout galleries.

A. B.

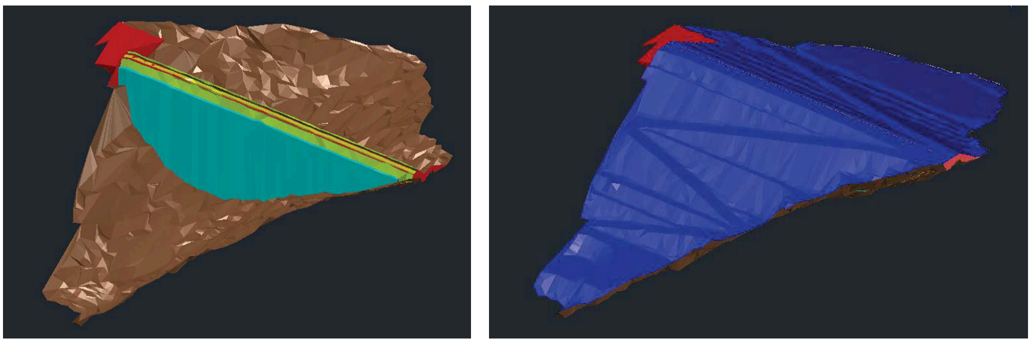

Figure 6. Sealing clay core model, (B.): view of the dam body surface model.

wells, both vertical and inclined, or otherwise oriented – see Figure 4. Original data from boreholes – see Figure 2d had to be prepared manually in Excel first, including depths and information about individual lithological layers. This database was subsequently imported into the Civil 3D geotechnical module.

2.2. Numeric 2D model of the dam

A numerical 2D model of the dam was made in a cross-section at the station of 330 m, in which the dam reaches its greatest depth. The basic geometry of the model was obtained by sectioning the 3D model of the dam described above. It was further supplemented with various structural elements of the dam body and with the subsoil updated by the latest engineering geological survey. The numerical model was created in the Plaxis 2D Ultimate 2022 program – see Figure 7 using the Mohr-Coulomb material model.

The numerical model consisted of 12 phases simulating the gradual construction of the dam. Next, the stages continued to determine the degree of stability of the structure in their different life stages and possible situations. To determine the degree of stability, a gradual reduction of the shear parameters of the materials used was used – the so-called ϕ/c reduction. Specifically, the degree of stability of the dam was evaluated at different levels of the water level in the reservoir, including time-dependent situations, such as filling, or different variants of a rapid drop of the water

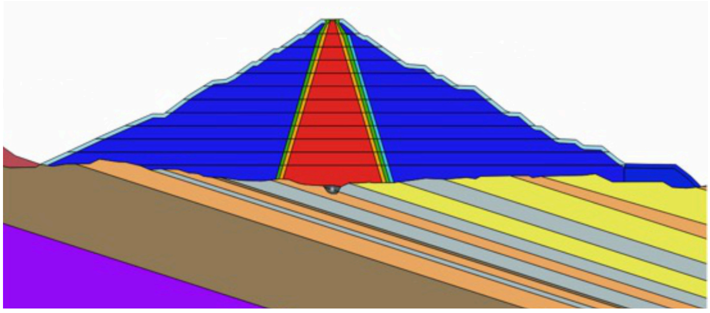

Figure 7. Numeric 2D model of the dam.

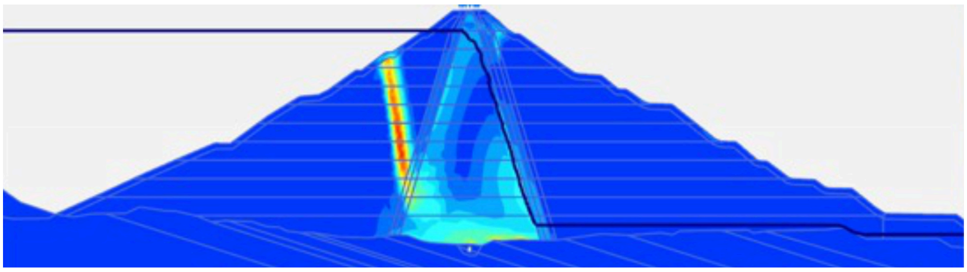

Figure 8. Shear strain after ϕ/c reduction when the dam is fully filled.

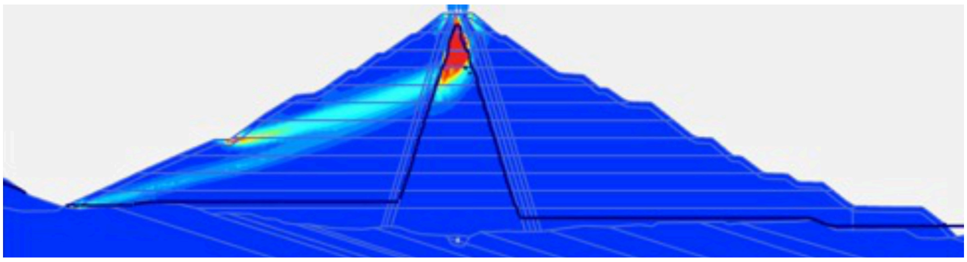

Figure 9. Shear strain after ϕ/c reduction with rapid lowering of the water level in the reservoir.

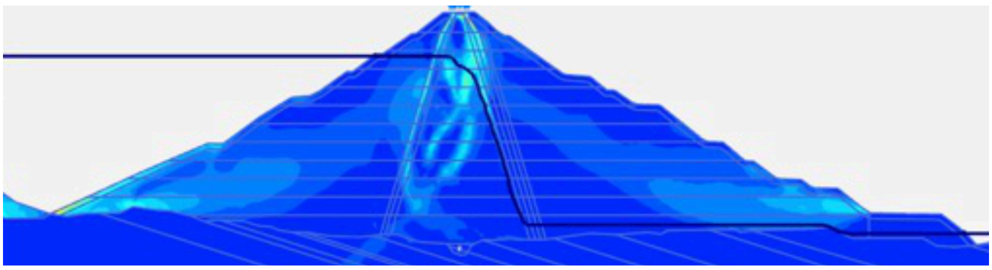

Figure 10. Shear strain after an earthquake simulation.

level (Figures 8 and 9). Finally, a dynamic analysis was also carried out, where the response of the dam to the loading of the subsoil movement at different frequencies simulating an earthquake was determined (Figure 10). The numerical model contained a total of approximately 30 individual phases and made it possible to identify the most critical shear surfaces and the most likely dike failure systems.

3. Example of 3D complex project

Steep reinforced motorway embankment with noise protection barrier founded on piles was selected as representative for complex 3D numerical analysis. High level of complexity is given by interaction between piles and reinforcing geogrids on the plan of existing road.

3.1. Geotechnical conditions

Existing road embankment that will be finally replaced by motorway is founded on highly compressible and low bearing strata of alluvial silts and clays. The existing embankment already consolidated, however the motorway embankment is higher and wider and hence settlement and stability of the whole structure will be highly important.

Based on geotechnical investigations parameters of both subsoil and existing embankment have been determined. During the construction process the

Soil Properties / Properties	Units / Colour	Active zone	Cl–Intermediate plasticity clays	Cl–Soft high plasticity clays	Gabion	Road construction	Existing embankment fill	Subsoil exchange	New embankment fill	Gabion_SO171
γ_{unsat}	[kN m^{-3}]	20.50	20.00	19.50	19.00	20.50	18.50	20.50	19.00	19.00
γ_{sat}	[kN m^{-3}]	21.00	21.00	20.50	19.50	21.00	19.00	21.00	19.50	19.50
e_{init}	[−]	0.33	0.80	0.90	0.30	0.25	0.30	0.25	0.30	0.30
E'_{ref}	[MN m^{-2}]	80.00	3.00	2.00	300.00	300.00	8.00	300.00	15.00	300.00
ν (nu)	[−]	0.25	0.40	0.42	0.20	0.20	0.35	0.20	0.35	0.20
c'_{ref}	[kN m^{-2}]	1.00	8.00	2.00	1.00	5.00	8.00	0.10	10.00	10.00
ϕ'(phi)	[°]	35.00	21.00	15.00	45.00	42.00	27.00	39.00	27.00	45.00
ψ (psi)	[°]	7.00	0.00	0.00	20.00	13.00	1.00	10.00	1.00	20.00
K_0	[−]	0.4264	0.6416	0.7412	0.2929	0.3309	0.5460	0.3707	0.5460	0.2929

TABLE 1. Selected properties of soils used in the analyses.

geotechnical model was refined in terms of new embankment fill properties based on its testing. Parameters of road structure layers and gabions infill have been determined by competent appraisal according to road layers specifications. Most important properties used during the numerical analyses for Mohr-Coulomb constitutive model are presented in Table 1. Ground water level was assumed in the level of original ground surface prior to construction of existing road and later it was modelled as depression curve from 1/3 of embankment height in its middle to the level of original ground on the edge of modelled area.

Properties of materials other than soil (geogrids, piles and noise protection barrier panels) have been assumed as linear elastic without strength limit. The exceedance of strength limit was checked later.

3.2. Construction process modelling

Motorway embankment construction was modelled in 12 main phases and later on followed phases modelling different kinds of loadings (traffic and wind) and stages to checks ULS for given loading. Main phases of construction:

1. Original stress state
2. Existing embankment construction
3. Ground water level increase to 1/3 of embankment level
4. Excavation of existing embankment part needed for motorway construction and SO171
5. SO171 – gabion height increase and its backfill
6. Subsoil exchange below reinforced embankment face
7. 1. Layer of reinforced earth structure
8. 2. Layer of reinforced earth structure
9. SO171 – finalising road construction
10. 3. Layer of reinforced earth structure
11. 4. Layer of reinforced earth structure
12. Piles installation
13. Final layer of reinforced earth structure and finalising all other structures

Modelling of loading as UDL followed. The value of characteristic loading from traffic based on Czech code 736133 is 10 kN m^{-2} and characteristic value for wind load of 1.71 kN m^{-2} was given by the noise protection barrier designer.

Most critical loading phases:

13. characteristic traffic loading on motorway,
23. ULS wind away from motorway + traffic load,
24. φ/c reduction for 23.

Stability check of the whole structure have been made according to the current legislation based on EN 1997-1 Design of "geotechnical structures" (Eurocode 7). During ULS calculations the design approach 3 was followed, when the soil properties are reduced by partial factors (1.25) and loads are increased by partial factors (1.30).

3.3. Modelling results

Graphical output from modelling for the most critical loading (modelling phase 24 after the soil properties reduction by a factor of 1.35) is presented on Figures 11 in both 3D and cross-section views. As during the φ/c reduction procedure the reduction factor of the soil properties reached the value of 1.35, which is higher than limiting (safe) value of 1.25 and the structure is still stable, we can conclude that the earth structure comprising reinforced steep slope combined with piled noise protection barrier is and will be perfectly safe.

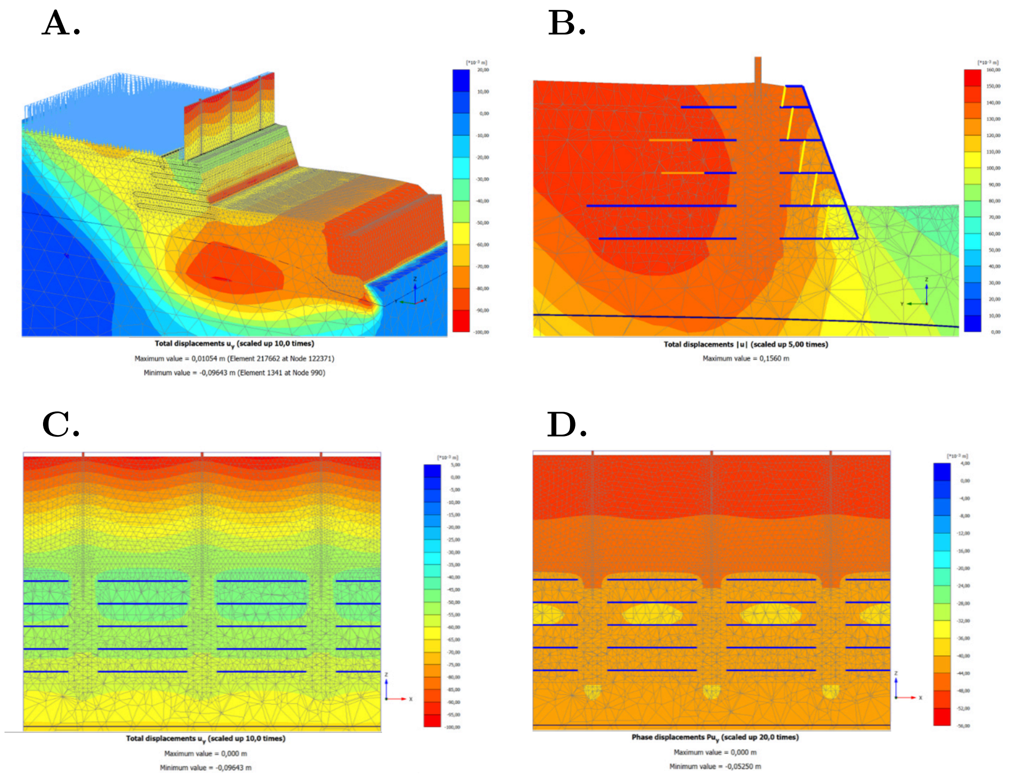

Figure 11. (A.) Overall horizontal deformatiom perpendicular to motorway axis. (B.) Overall deformation in cross-section through motorway. (C.) Overall horizontal deformation perpendicular to motway axis in the place of piles for noise protection barrier. (D.) Overall horizontal deformation perpendicular to motway axis in the place of piles for noise protection barrier just due to the reduction of soil properties.

4. Conclusion

The examples described above indicate how complex tasks can be performed at the workstation, not only from the point of view of calculations, but also with regard to the initial modeling of the task using CAD together with BIM.

Acknowledgements

We would like to thank CGS for creating such a workplace that will help all members solve very complex geotechnical tasks at a very high professional level.

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