*Construction Mechanics, Hydraulics and Water Resources Engineering (**CONMECHYDRO – 2020)***
Section - Hydrotechnical and meliorative construction

Geological structure of the dam base as a factor of its reliability during flood periods (Hanoi)

Igor Fomenko[1], The Hien Dinh[1,2], Olga Sirotkina[3], Olga Barykina[3]

[1] Ordzhonikidze Russian State Geological Prospecting University, Moscow, Russia
[2] National University of Civil Engineering, Hanoi, Vietnam
[3] Lomonosov Moscow State University, Moscow, Russia

23-25 April 2020

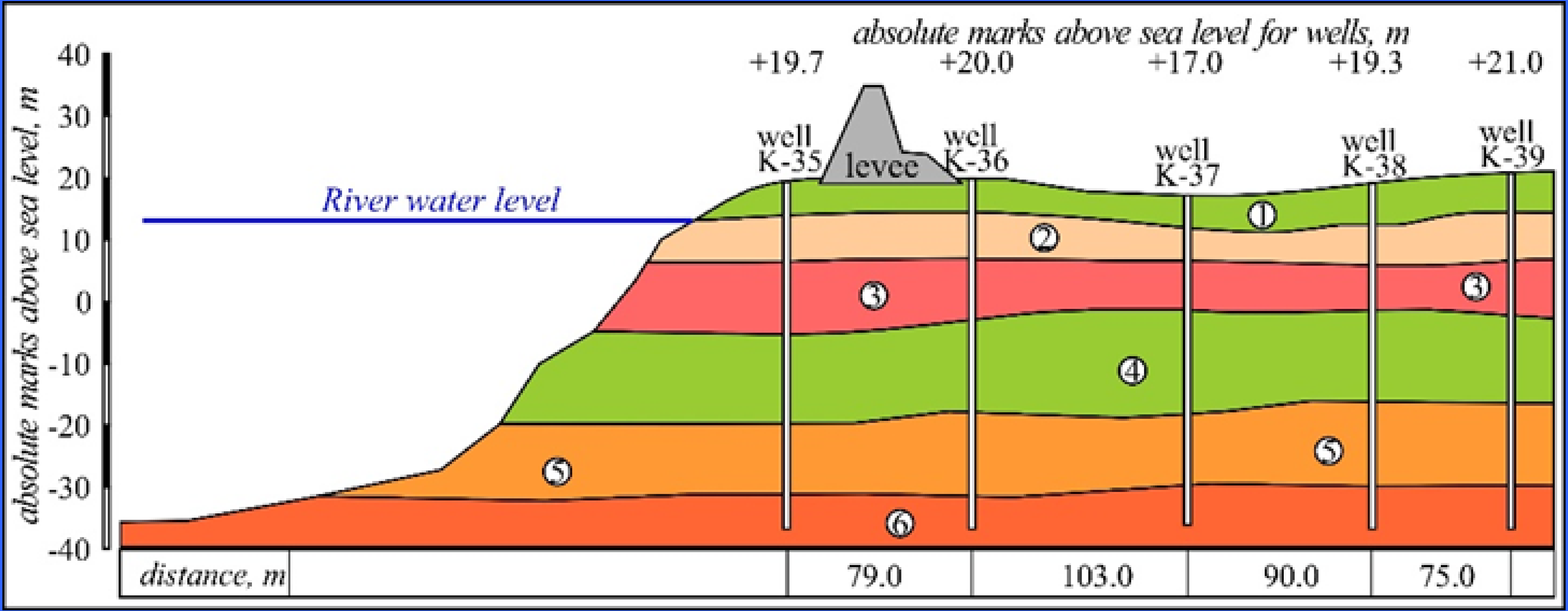
Introduction

In the new social and political conditions of Vietnam's transition economy, the transformation of the riverside territories is of great importance for both the city of Hanoi and the country as a whole. A special role is given to the system of dams along the Hanga River (Red), which protect the city from floods. During the long history of construction and operation of the dams in Hanoi, many cases of their damage and destruction are known. Possible mechanisms for loss of dam stability due to changes in hydrogeological conditions are discussed in report. On the basis of mathematical modeling the stability of the dam slopes and filtration strength of its base soils due to the hydraulic gradient increasing in time during the flood period were estimated.

View of the dam along the Red River in Hanoi

The destruction of the Red River dam

Schematic engineering-geological section of the riverside territory of Hanoi near the dam



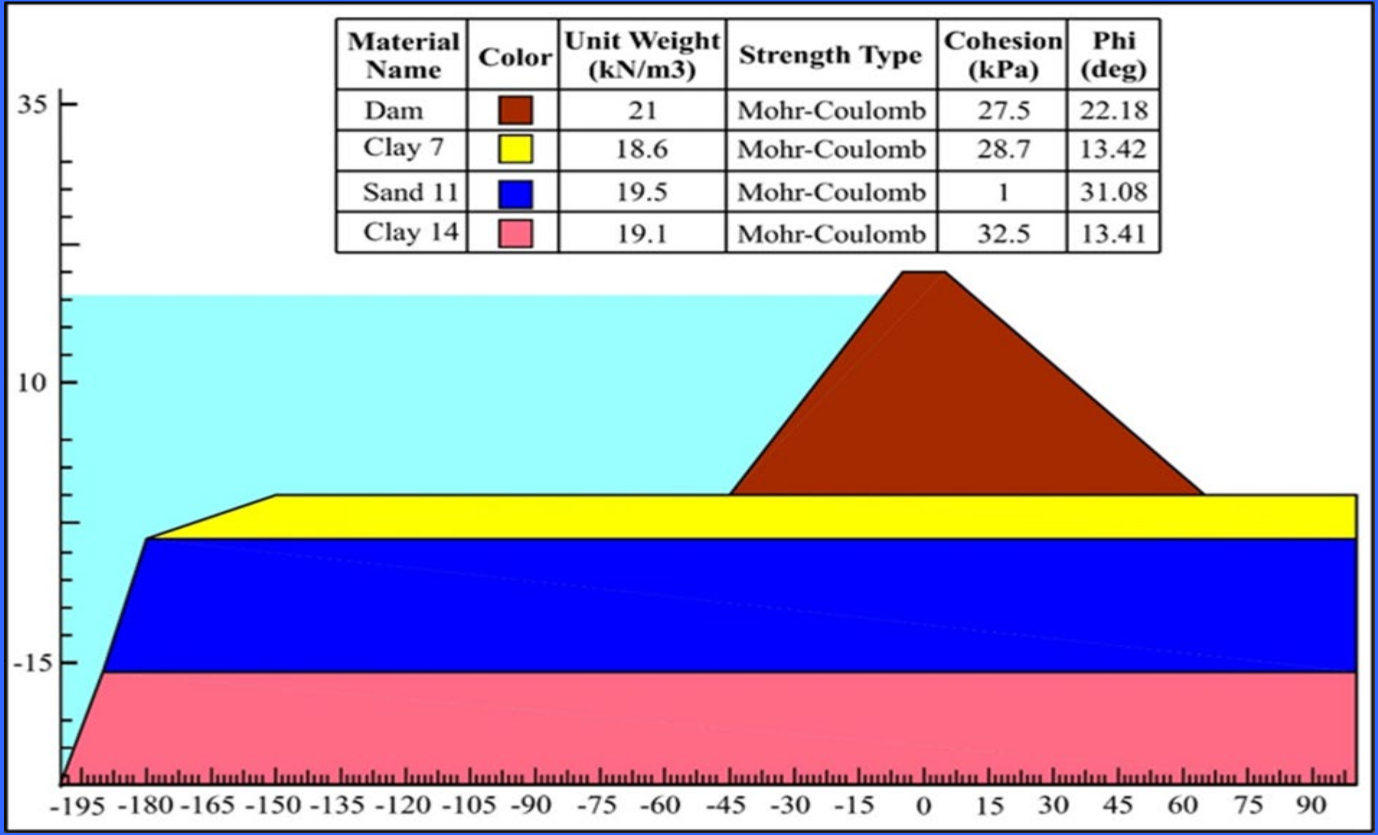
Engineering-geological elements (figures in white circles): 1-clay loam, 2-sand loam, 3-sand, 4-clay, 5-sand, 6-gravel.

Methods

The problem was solved in 2D. Filtration modeling was performed by the finite element method, and the assessment of dam slope stability was based on the Morgenstern-Price method, a class of limit equilibrium methods that satisfies the general equilibrium of moments and forces. The elastoplastic model of the Coulomb-More soil behavior was used in the calculations. The simulation model of Coulomb-More combines the elastic ideal plastic behavior and linear strength criterion of materials.

The calculations were made according to three schemes, differing in thickness of clay layer at the base of the dam:

- scheme 1 - clay thickness 5m;
- scheme 1 - clay thickness 10m;
- scheme 1 - clay thickness 15m.

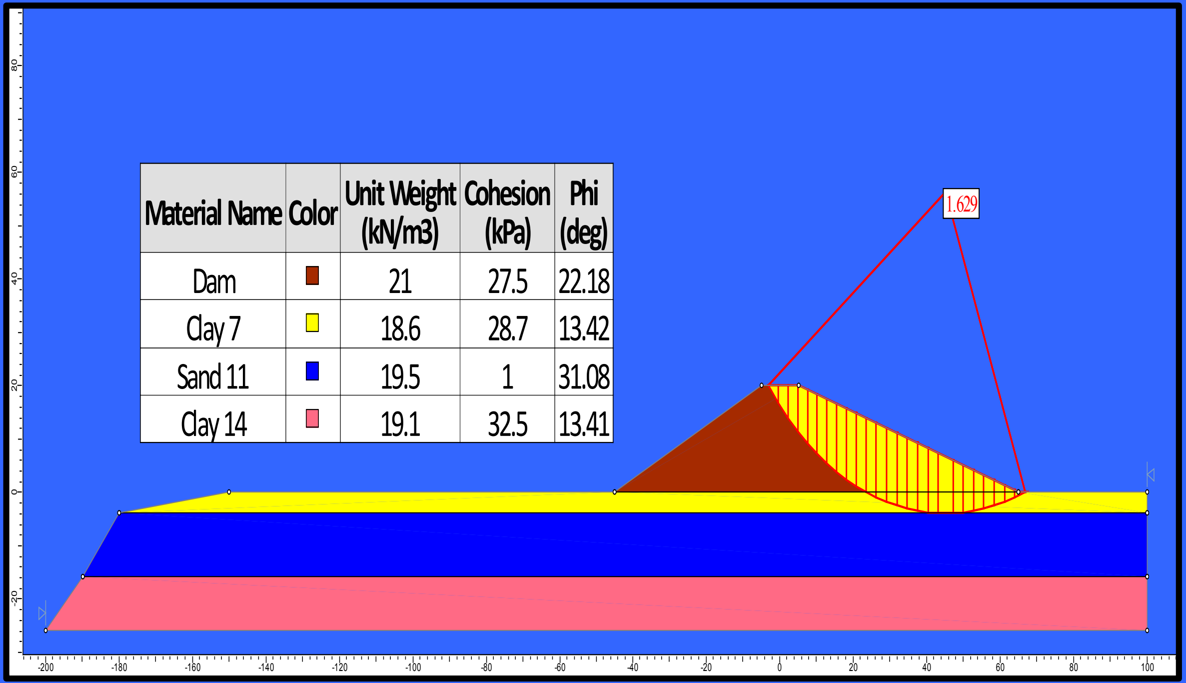


Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
Dam		21	Mohr-Coulomb	27.5	22.18
Clay 7		18.6	Mohr-Coulomb	28.7	13.42
Sand 11		19.5	Mohr-Coulomb	1	31.08
Clay 14		19.1	Mohr-Coulomb	32.5	13.41

Geomechanical scheme for assessing dam stability with the filtration process

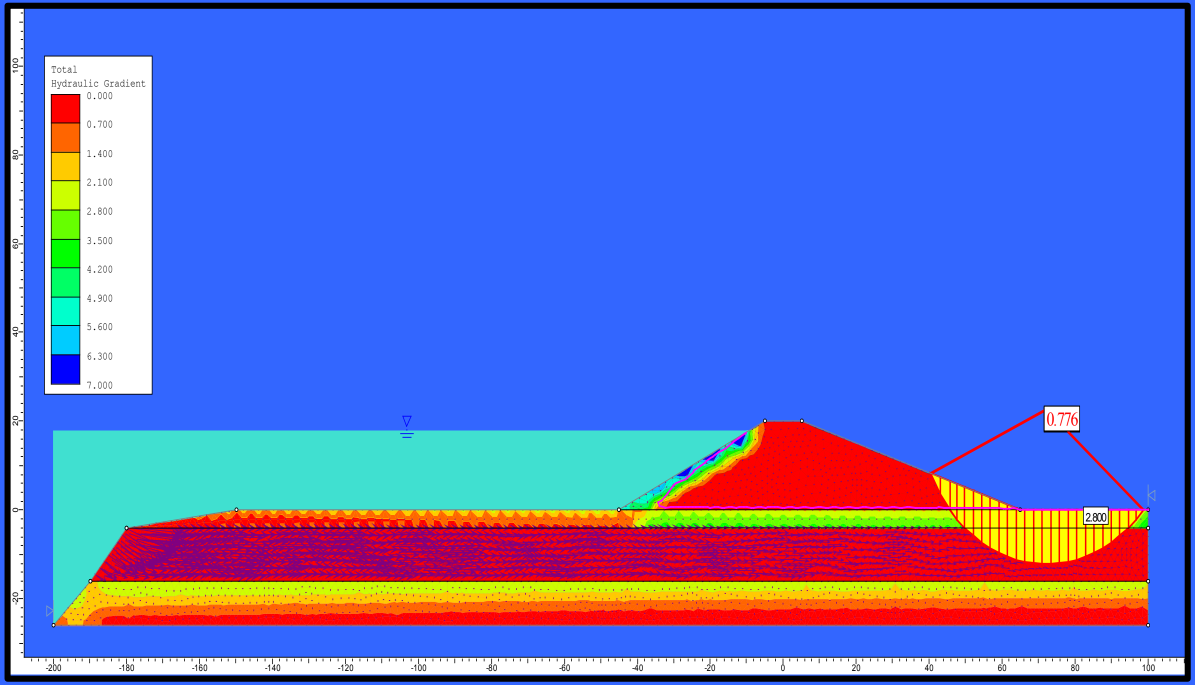
Results and Discussion

Scheme 1 – clay thickness at the base of the dam - 5m



Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Dam		21	27.5	22.18
Clay 7		18.6	28.7	13.42
Sand 11		19.5	1	31.08
Clay 14		19.1	32.5	13.41

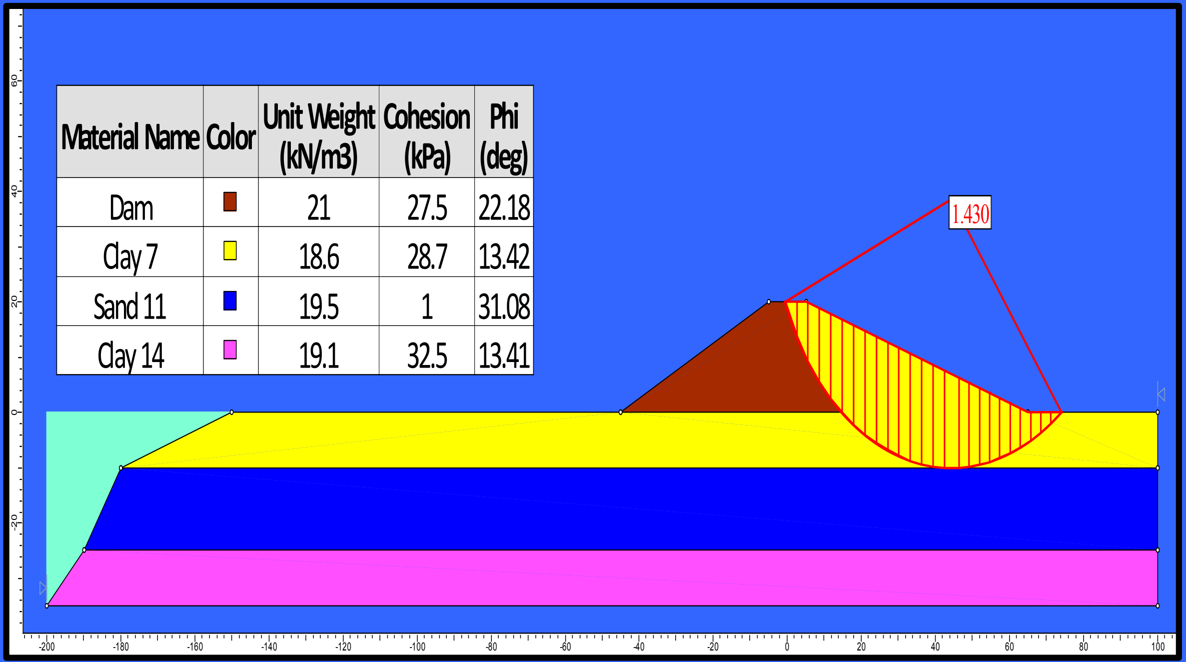
Result of dam stability calculation before the flood



Result of dam stability calculation on the 6th day after the flood (color shows the hydraulic gradient)

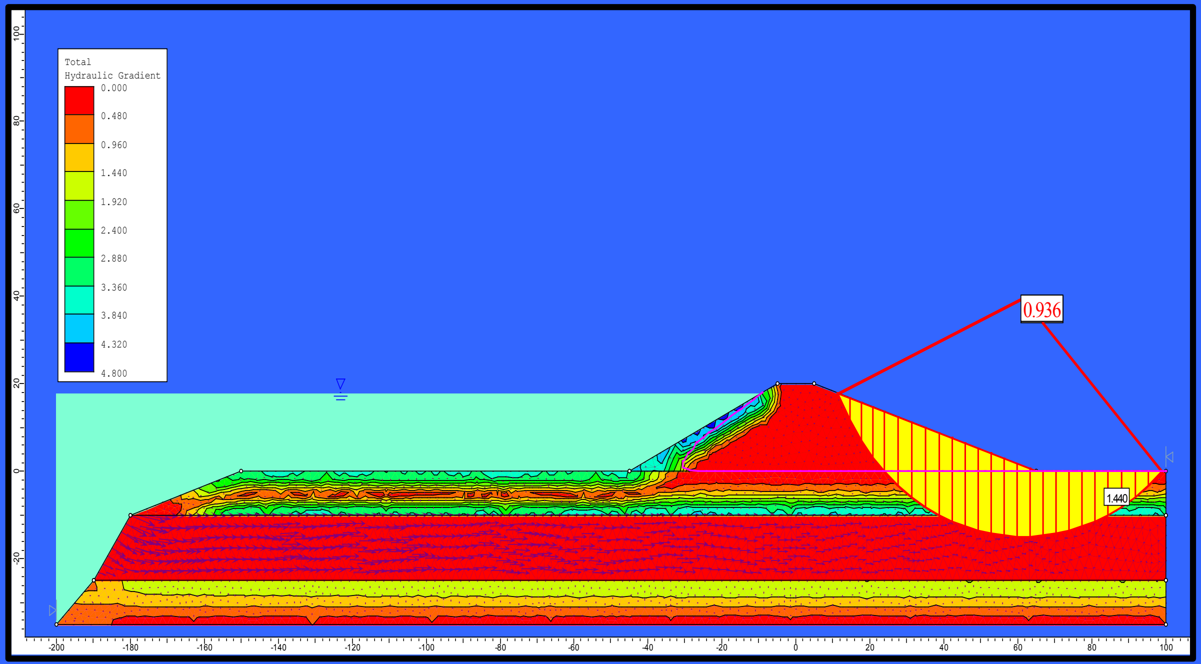
Results and Discussion

Scheme 2 – clay thickness at the base of the dam - 10m



Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Dam		21	27.5	22.18
Clay 7		18.6	28.7	13.42
Sand 11		19.5	1	31.08
Clay 14		19.1	32.5	13.41

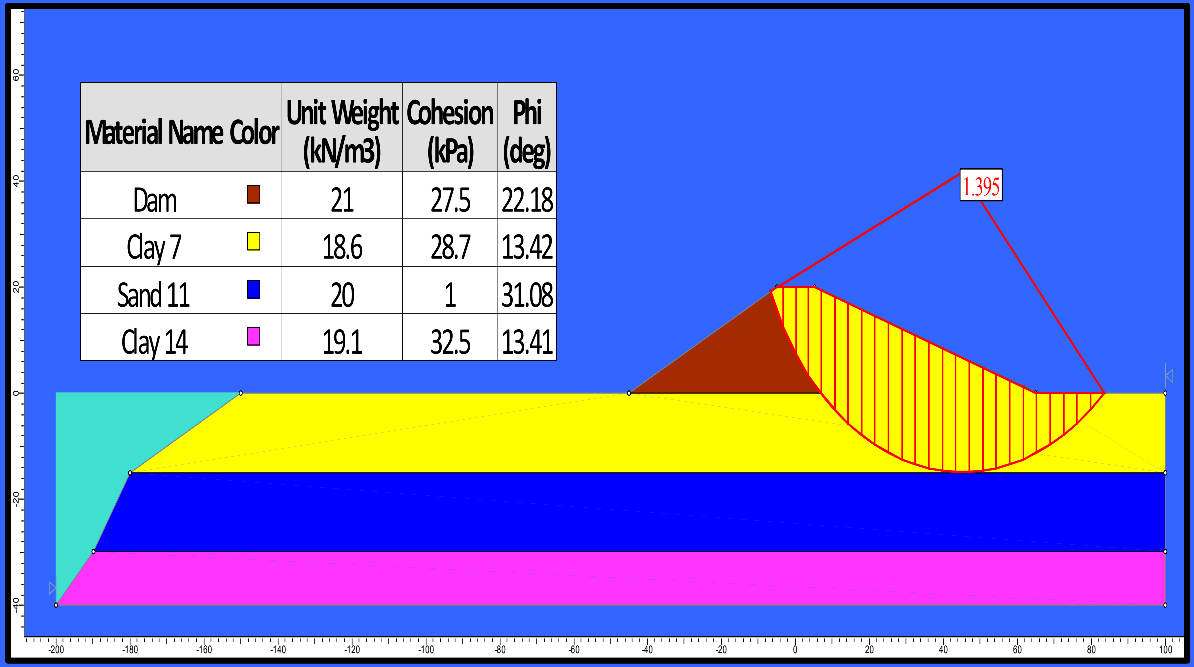
Result of dam stability calculation before the flood



Result of dam stability calculation on the 12th day after the flood (color shows hydraulic gradient)

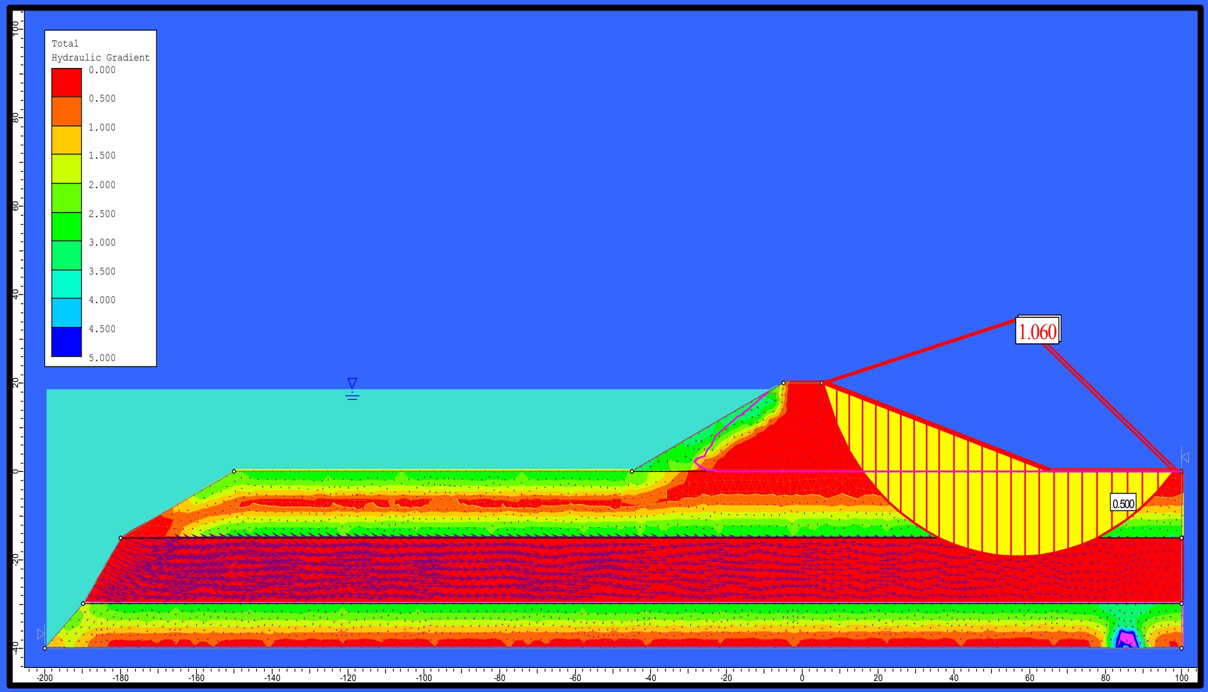
Results and Discussion

Scheme 3 – clay thickness at the base of the dam - 15m



Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Dam		21	27.5	22.18
Clay 7		18.6	28.7	13.42
Sand 11		20	1	31.08
Clay 14		19.1	32.5	13.41

Result of dam stability calculation before the flood



Result of dam stability calculation on the 20th day after the flood (color shows hydraulic gradient)

Results and Discussion

Changes in the stability factor (**Fs**) of the dam slope during the flood period

Analysis of simulation results allows us to draw the following conclusions:

Clay soil thickness of 5 m. (calculation scheme 1)

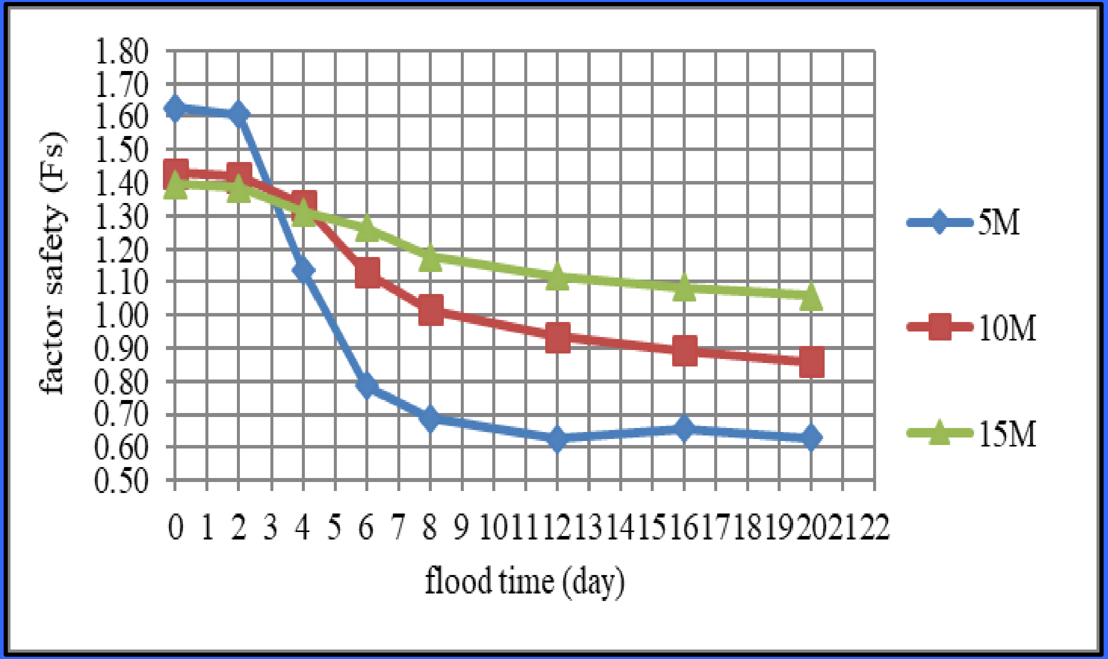
- Fs of the dam slope before the flood is 1.69 (the slope is stable)
- Raising the water level in the river to the maximum mark
- The dam collapses in 4.4 days;

Clay soil thickness of 10 m. (calculation scheme 2)

- Fs of the dam slope before the flood is 1.43 (the slope is stable)
- Raising the water level in the river to the maximum mark
- Raising the water level in the river to the maximum mark

Clay soil thickness of 15 m. (calculation scheme 3)

- Fs of the dam slope before the flood is 1,395.
- Raising the water level in the river to the maximum mark
- The dam is stable for the whole flood period (after 20 days Fs =1,060).



Dependence of factor safety on flood duration

Thus, before the start of the flood, more stability will be provided by the slopes of the dam at the base of which there is a low-thickness (5m) layer of clay. During the flood period the situation will change radically and the reliability of the dam will increase as the thickness of clays at its base increases.

Results and Discussion

Filtration strength of soils of the dam base was estimated by comparing the characteristics of the filtration fields (seepage gradient) with its critical values for soils of the dam base by a formula:

$$J_{est} \leq \frac{1}{\gamma_n} J_{cr}$$

where:

J_{est} - effective average seepage gradient in the estimated area of filtration

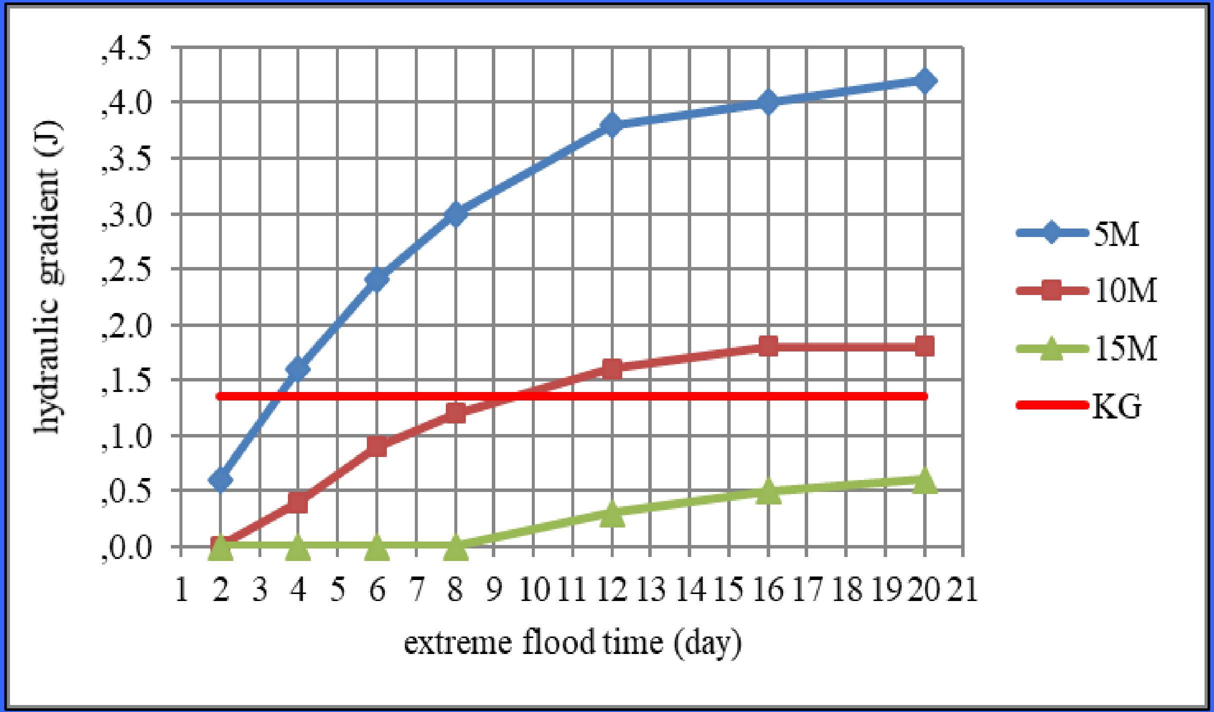
Jcr - critical average seepage gradient (taken for clays equal to 1.35)

γ_n - coefficient of reliability on responsibility of buildings

Results and Discussion

The dependence of the hydraulic gradient on the duration of the flood shows:

- *with clay thickness of 5 m at the base of the dam, the hydraulic gradient will exceed the critical value after 4.4 days;*
- *with clay thickness of 10 m at the base of the dam, the hydraulic gradient will exceed the critical value in 9 days;*
- *with clay thickness of 15 m at the base of the dam, the dam will keep stability for the whole period of flooding*



Change of hydraulic gradient in the soils of the dam base from the flood duration (red line - critical gradient)

Conclusions

1. The geological structure of the soil at the base of the dam plays an important role in ensuring its reliability during flood periods.
2. Changes in the stability of the dam slopes and filtration strength of its base soils, made for clays of different thickness, showed good convergence of results in time.
3. The modelling of the hydraulic gradient showed: a) when clay thickness is 5 m, the hydraulic gradient will exceed the critical value after 3.5 days. The dam slope safety factor will drop below 1 (dam slope will lose its stability) after 4.5 days; b) when clay thickness is 10 m at the base of the dam, the hydraulic gradient will exceed the critical value after 9 days, the dam slope safety factor will drop below 1, also after 9 days; c) when clay thickness is 15 m at the base of the dam, the dam will retain its stability for the whole period of the flood
4. The analysis of the results of the mathematical modeling shows that the stability of the dam depends both on the thickness of the clay layer at its base and on the duration of flooding.
5. Factors identified in mathematical modeling that affect the stability of dams during flood periods can be used for predictive purposes to assess their reliability.

THANK YOU FOR YOUR ATTENTION !

Mathematical modeling is performed in the program Slide 2018.
The Department of Engineering Geology at MGRI is part of the Rocscience academic program.

Igor Fomenko, The Hien Dinh, Olga Sirotkina, Olga Barykina

2020