Hydrogeological Modeling of Mosul Dam Foundation

Pro. Dr. Kamel Abed Al-Mohseen

Dr. Zeyad Ayoob Sulaiman

Department of Dams and Water Resources/ College of Engineering/
University of Mosul/ Iraq

Introduction

- Mosul Dam is one of the most important strategic projects in Iraq for water resources management.
- The main purposes of the Mosul Dam construction are for irrigation, flood control, water supply, and hydropower.
- The dam is an earth fill type with a mud core with height =113 m and 3,650 m long including the spillway; the top width is 10 m at 341 m a.s.l. crest level [Issa, 2017].

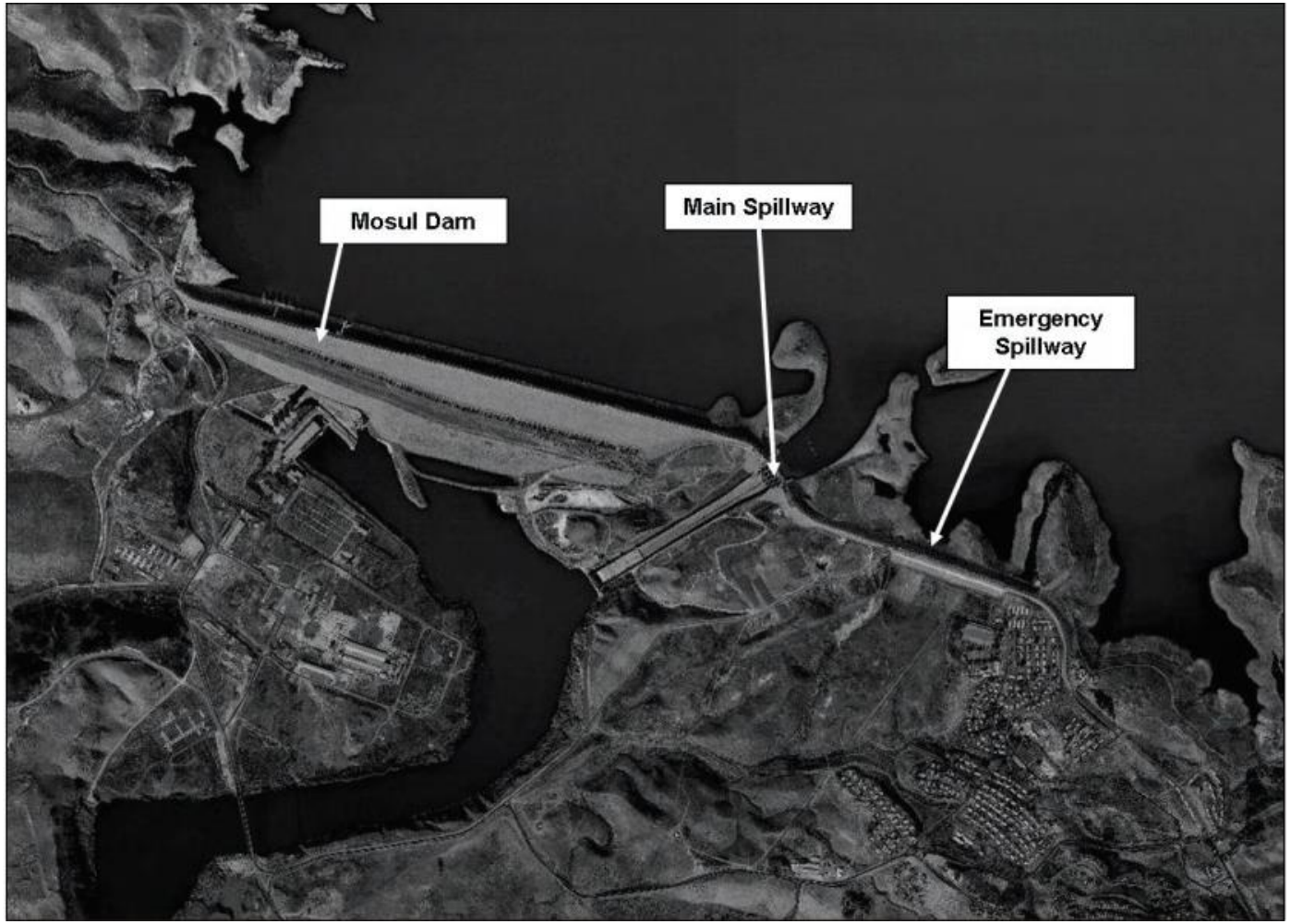

Figure 1: the satellite image of the Mosul Dam.

Geology of Mosul Dam Foundation

- Near the location of Mosul Dam, the exposed formation is Lower Fars (Fatha). It consists of a composed alternating materials of limestone, marl and gypsum.

- The abutments of dam consist of cyclic sediments, marls, clay stone, limestone and gypsum; however, in the uppermost part the clay stone ratio increases as compared with the lower part [Al-Ansari, 2020].

- These heterogenous rocks have different physical and chemical properties. The gypsum and limestone beds are usually karstified.

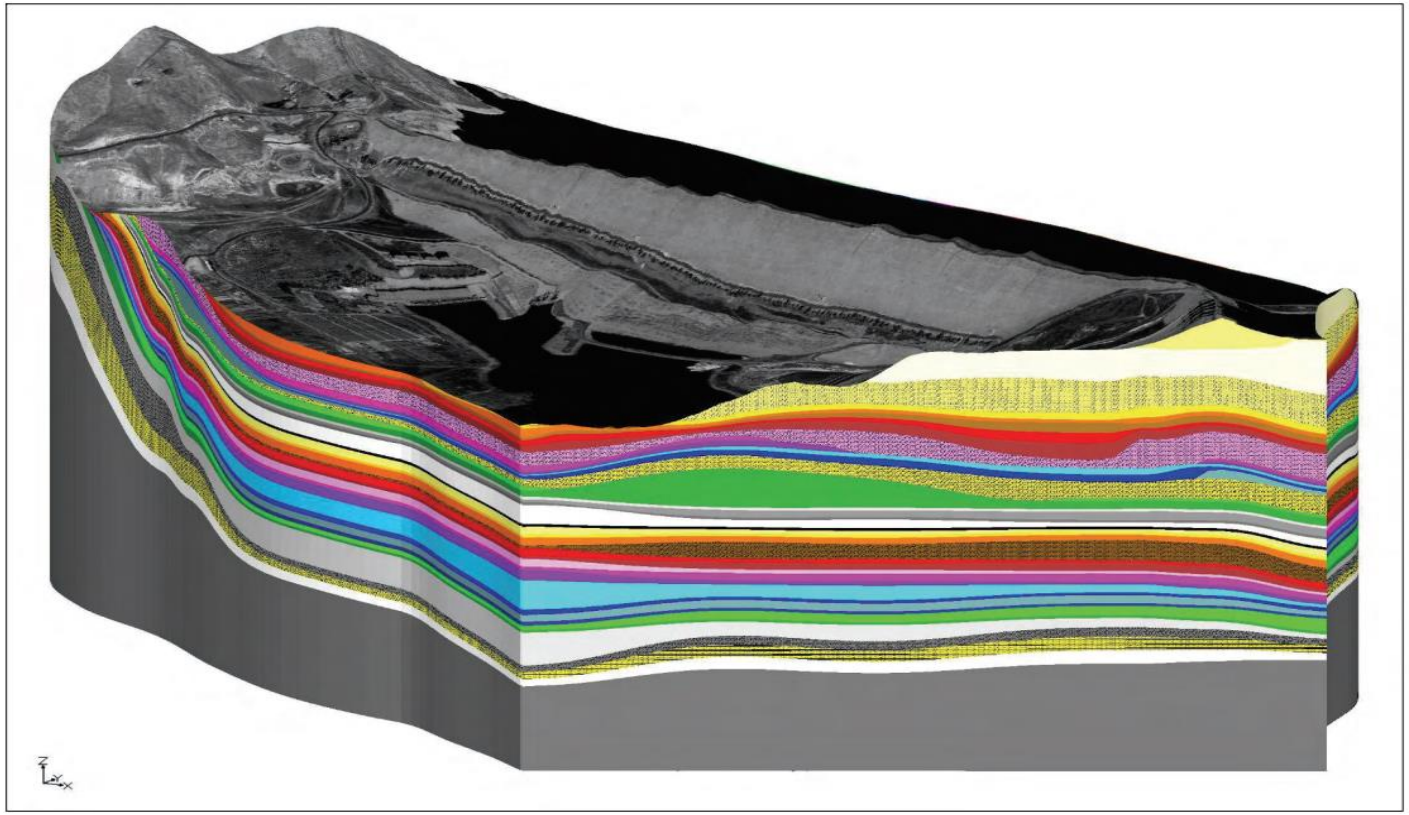

Figure 2: an oblique view of the 3-D conceptual model of dam foundation, looking upstream from the southwest toward the downstream face of the dam.

Mosul Dam Foundation Issue

- Soluble geologic materials under the foundation of Mosul Dam such as gypsum, anhydrite, marl and limestone.

- Major dissolution occurs at the “karstic line,” the inferred boundary where anhydrite converts to gypsum and thus dissolved and eroded by seepage.

- The cause of seepage is mainly due to geological problems that can affect the safety of the dam [US Army of Corps].

- Maintenance grouting began immediately after construction and continues to the present because of the solubility of its foundation and abutments.

Figure 3: Photo taken during construction of Mosul Dam (1982-1983) historic dissolution of gypsum prior to dam construction. (Photo provided by A. T. Ayoub.)

Effect of Seepage and Dissolution of Dam Foundation on Dam Stability

- Leakage is a major safety issue that, if left unchecked, may result in dam failure by various mechanisms.
- the seeped water from the reservoir aggravates the dissolution process of the foundation materials. In this situation, the reservoir of the dam enhances the dissolution process of the foundation materials [Aghajan, 2018].
- A lack of appropriate leakage investigation, monitoring and evaluation can result in repairs that are unsuccessful in controlling or reducing leakage.
- The existence of sinkhole around the Mosul Dam body has been associated with high seepage rate and fluctuations in groundwater levels.

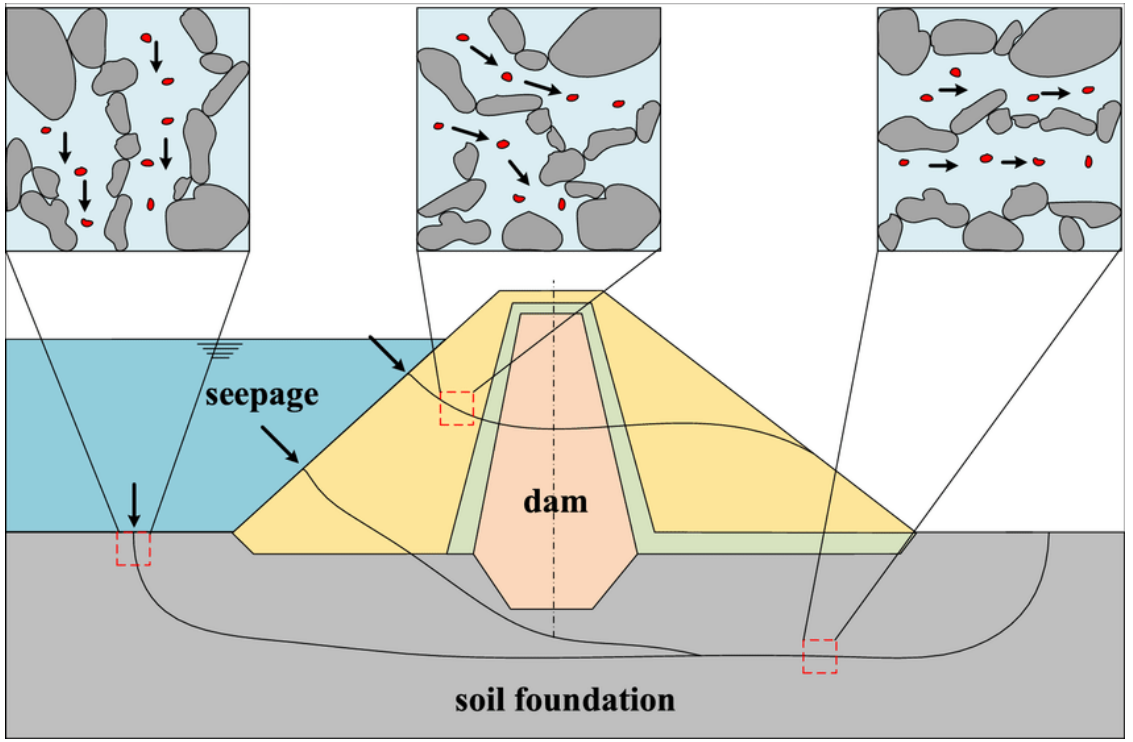

Figure 3: Schematic show the seepage process

Why Do We Need a Hydrogeological Model to Study the Mosul Dam Foundation Issue?

- Based on information from Mosul Dam administration that they have regular investigations for digital borehole imaging, geological mapping of dam body and its foundation layers, spatial measurements of piezometric heads, ...etc.

- These investigations can be utilized to examine the source of leaking, the seepage flow paths, and the performance of the grouting curtains. At somehow, these objectives can be handled using some finite element modeling tools of the stability and seepage safety assessments and analyses of the earth dam (Geotechnical Model).

- According to seepage hydraulics and geochemistry theory, behavior of dam foundation (**gypsum dissolution and leakage**) can be assessed by coupling seepage module, solute transport module, geochemistry module.

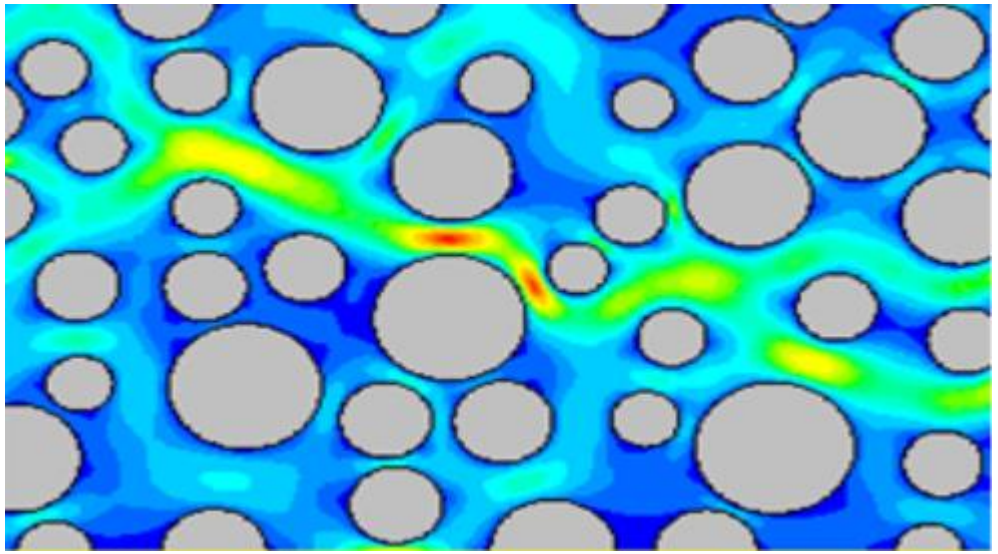

Figure 4: Schematic diagram for flow in porous media

Numerical Model Structure and Governing Equations

- In general, model structure include governing equations to simulate variable-density groundwater flow and solute transport in porous media, which combines MODFLOW-2000 and MT3DMS into a single computer program.

- The governing equation for saturated variable-density groundwater flow in terms of freshwater head is expressed by

$$\nabla \cdot \left[\rho \mathrm{K}_f \left(\nabla \cdot \mathrm{h}_f + \frac{\rho - \rho_0}{\rho_0} \cdot \nabla z \right) \right] = \rho S_f \frac{\partial h_f}{\partial t} + n \frac{\partial \rho}{\partial t} + \rho_s q_s$$

- The solute transport model involving advection, molecular diffusion, and mechanical dispersion is given as

$$\frac{\partial C}{\partial t} = \nabla \cdot (D \nabla C) - \nabla \cdot (vC)$$

where C (ML^{-3}) is dissolved concentration; D (L^2T^{-1}) is the hydrodynamic dispersion coefficient tensor; and v (LT^{-1}) is the pore water velocity vector.

Information, Data, etc Needed for Building Hydrogeological Model for Mosul Dam

- The essential geological and hydrogeological data and information needed for building the model are described as follow:

1- 3D Geological Conceptual Model

- Geological maps of various Mosul Dam sites.
- Borehole logs samples
- Longitudinal cross sections of dam.
- Geological data from the Mosul Dam Library.
- Digital elevation model of the Mosul Dam.
- Grouting program data

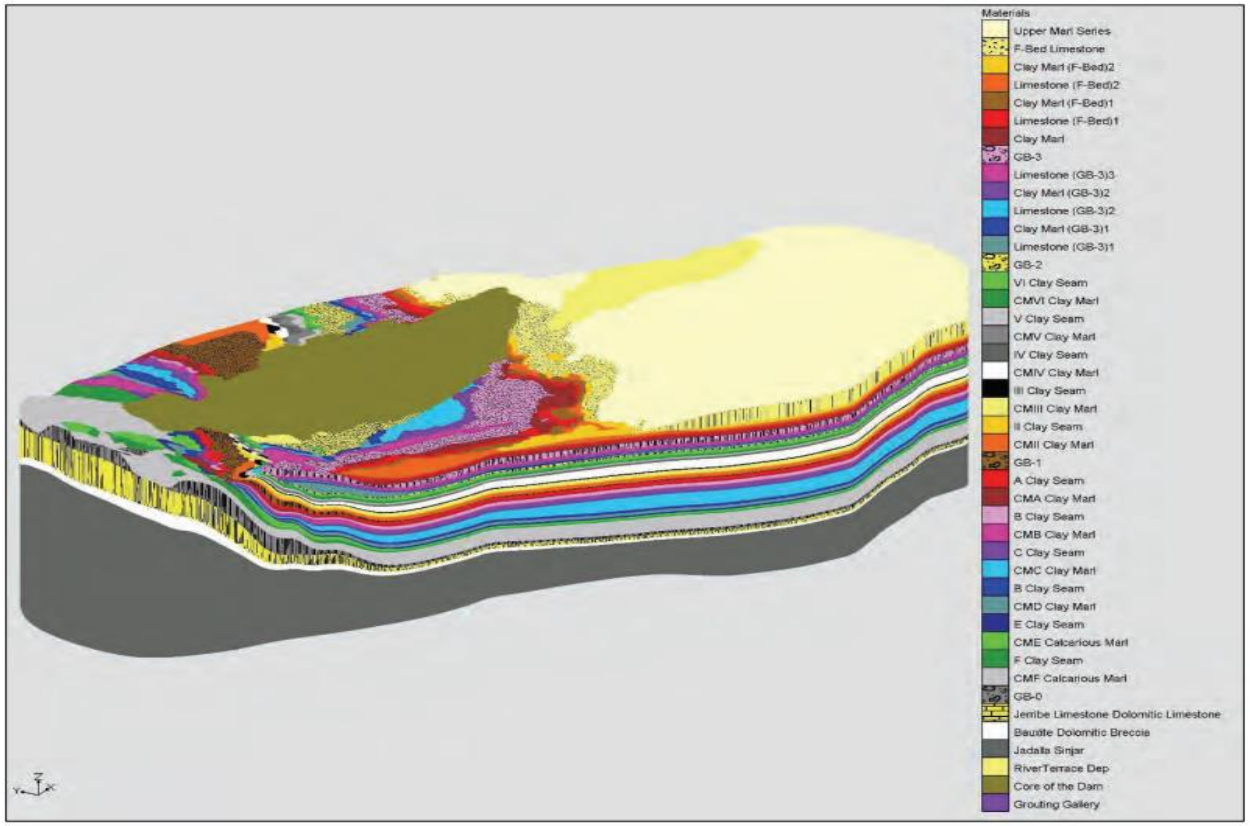

Figure 5: 3D geological model of Mosul Dam (US Army Corps of Engineers

Essential Information, Data, etc Needed for Building Hydrogeological Model for Mosul Dam

2- Piezometric Head, Groundwater Level and Water Chemistry Data

- Time series of the measured groundwater heads.
- Water quality data
- Surface water levels
- etc

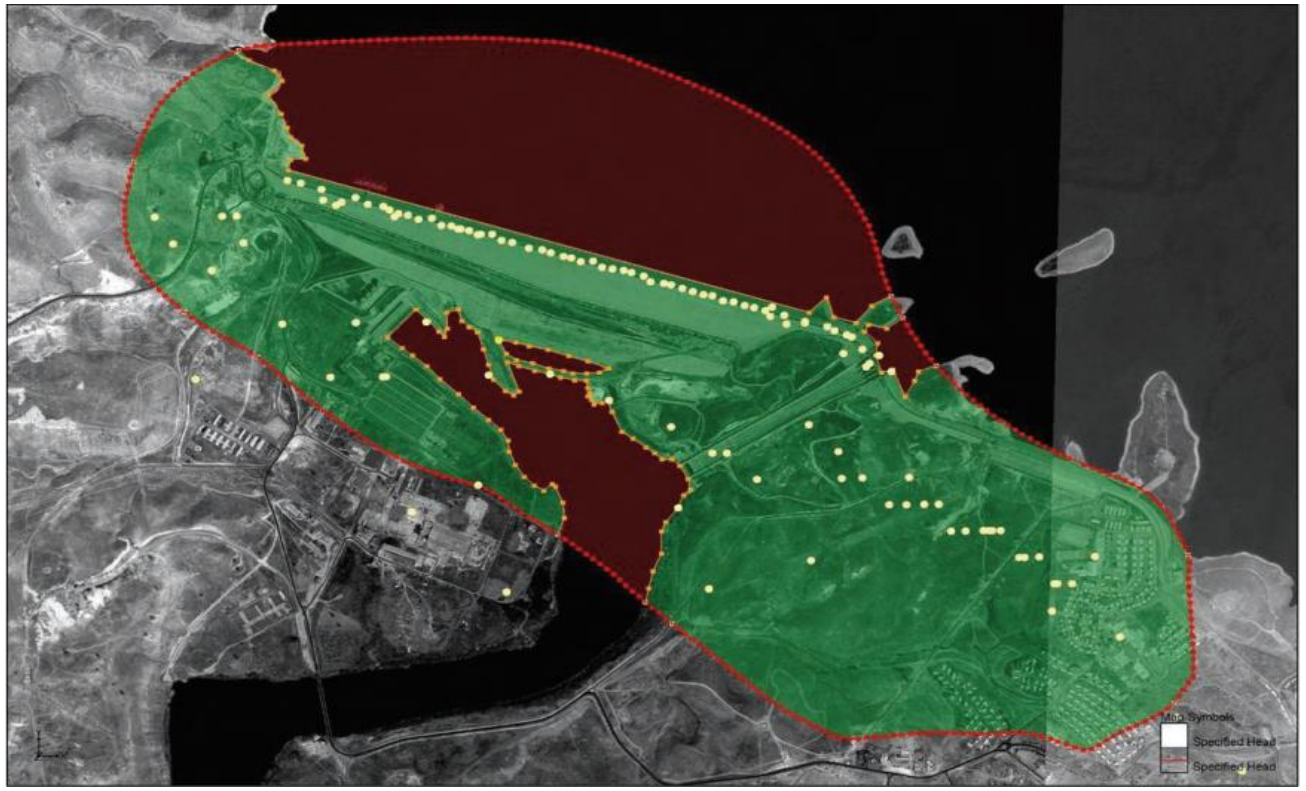

Figure 6: Yellow dots are locations of piezometers.

Objectives that could be reached from the model

- Evaluate the current and future behaviour of dam foundation under scenarios of high water elevation in dam reservoir.
- Model results will provide great inside of rate of gypsum dissolution of dam foundation and assist with improving dam safety and updating grouting operations.
- This model can also be used to detect the directional movement of dissolution of dam foundation and facilitate future maintenance grouting and operation of the dam.
- We believe that the current permeability of the foundation has been deviated significantly from that for the design stage and needs re-evaluation; especially after long-term grouting processes. This could be a chivied with modeling process.
- Establish a collaboration between the group of researchers at Mosul University and the staff of Mosul Dam to work together on some serious problems that threaten the stability of the dam.

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