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Modelling reservoirs operation and stability of earth dams: A state of art

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Abstract

Dams are among the most crucial hydraulic structures that play a fundamental role in flood control, hydroelectricity power generation, and various other purposes for which dams are constructed, In recent decades, simulation models have significantly facilitated understanding dam performance under multiple conditions and predicting potential catastrophes in emergency situations such as dam failure and extreme floods, many dams face the risk of slope failure due to water pressure or foundation soil conditions upon which the dam is constructed, Therefore, this research paper presents studies that have addressed dam simulation models, taking into consideration various operational and flood conditions, Additionally, it examines studies concerning dam slope failures, their most significant impacts and the methodologies for building these simulation models.

1. Introduction

Dams are considering as high value constructions by preservation of water resources through storage, also serves for multi-purposes including hydroelectric power generation, providing water suitable for domestic, industrial, agricultural use and facilitating navigation and tourism. Given the significance of these structures, massive scale and the potential risks associated with their failure, it has become imperative to conduct simulation to model their operational mechanisms and to address numerous questions arising from their operation. Such simulations involved the utilization of various software packages, including SIMULINK tool within MATLAB, MRST (MATLAB Reservoir Simulation Toolbox), This too provides a user-friendly, modular, and customizable environment for dam and reservoir modelling, featuring pre-built libraries, MATLAB integration, real-time simulation, and strong visualization tools. However, it has some disadvantages such ad debugging, computationally intensive, and lacks specialized blocks. CMG (Computer Modelling Group) specializes in reservoir simulation and fluid flow modelling< offering high accuracy and scalability. However, it is expensive, has a steep learning curve, and requires resource-intensive hardware, and most of all it focuses narrowly on oil and gas which limits its accessibility. GoldSim software (Monte Carlo Simulation Software), a new software offers flexibility, supporting complex systems like water resources, environment projects, and engineering designs. Also, it includes probabilistic analysis. These tools are capable pf simulating reservoirs and dams, analyzing their behavior, provided the necessary data is available. The high precision offered by these programs qualifies them to be a reliable source for simulation purposes, Generally, Computational simulation models are not subjected to rules that the physical models are subjected to, which means that these models can function under unlimited scenarios for the cases under study for what data is available, for enhancing the oil reservoir polices and increase the improvement of planning field and design, moreover for what the monitoring and management returns in benefits, Khalili and Ahmadi [1] highlighted the applications of modelling and simulation of reservoir that proved its productivity in this aspects, but it's important to take into consideration that any programmatic models comes with its challenges such as lack of available data related to these reservoirs and the inadequacy of the software and technologies advancements to fully address the complex scenarios under study.

Wurbs and Asce, inspected and compared two flood routing models (DAMBRK and SMPDBK) developed by the National Weather Services by replicate a flood resulted from a dam break, the outcomes revealed that selecting the suitable programming depends on the type of information available to finish the simulation model [2]. This review paper aims to provide and summarize a number of previous studies that addresses simulation models of dams and reservoirs, as well as dam stability. Offering a clear overview of the software used in simulation processes, from the early stages to modern methods. Additionally, this review paper highlights the methodologies frequently employes in recent years to determine dam stability.

2. Literature review

In recent years, numerous researchers have proposed various models for simulating dams and reservoirs and to facilitate a comprehensive understanding of this paper, Reviews have been categorized into several sections:

2.1 Reviews of simulation models of reservoir systems

These studies provide numerous answers to the questions raised by researchers regarding the simulation processes of dams and reservoirs. They address whether there is actual feasibility in constructing certain dams, the importance of selecting dam sites, and the significance of studying and analyzing the operation of dams and reservoirs in predicting the performance of these structures under emergency external conditions or for the purpose of improving operational efficiency:

Mahmoud 2005 [3] simulated the high Aswan Dam (HAD) in Egypt by using the Hec-ResSim software which is a program produced by the US Army Corps of Engineering, the software was selected by the authors for its ability to meet the specific requirements to simulate the dam's operation behavior. This reservoir model was a need to develop different rules for releasing water based on different parameters such as time, lake elevation, downstream requirements. The authors' goal to study the drought conditions and floods on the reservoir model by creating different hydrological scenarios and then integrating the models with other water management models. The authors concluded through their study the limitations of review studies models to integrate with other water management models because of either calibration with outdated data and the data which are not designed to be tested on different operational policies. The authors discussed the development of two additional models for the Hec-ResSim model, the first models are for simulating the reservoir bank storage and the second one is for the nonlinear least squared optimization to calibrate the inflow and the reservoir bank storage parameters. The results present that this model is capable of simulating the HAD's operations and evaluating different hydrologic conditions using 29 years of historical inflow data. The study highlighted the importance of developing optimal operational strategies to produce the maximum benefits of HAD, looking forward its role in irrigation, hydroelectric power production, flood control and river bank stabilization.

Babazadeh and Sedghi [4] utilized the HEC-ResSim simulation model to modeling Jiroft dam and then assess the dam's operation efficiency and then followed by showing the capability of the model to imitate the reservoir system. Firstly, the authors tend to apply a related equation of Jiroft dam to the main description of the dam structure to upgrade the performance, these equations used for performance evaluation of water resources in the Yorkshire present water resources system scenarios. These equations are Reliability, Resiliency, and Vulnerability, the equations as follow:

$$W_t = \begin{cases} 1; & X_t \in U \quad \& \quad X_{t+1} \in S \\ 0; & \text{Else} \end{cases}$$

Define un-satisfactory period (X_t) by $J_1, J_2, \ldots, Jn$ then reliability, resiliency and vulnerability are following equations.

$$C_R = \frac{\sum_{t=1}^{T} Z_t}{T} \qquad \text{Reliability} \qquad (1)$$

$$C_{RS} = \frac{\sum_{t=1}^{T} W_t}{T - \sum_{t=1}^{T} Z_t} \qquad \text{Resiliency} \qquad (2)$$

$$C_V = \max \left\{ \sum_{t \in J_i} C - X_i \qquad i=1,\ldots,N \right\} \qquad \text{Vulnerability} \qquad (3)$$

Where:

X_i: is the daily value of simulation times series of river flows or reservoir.

T: is the periods of time.

S: is the satisfactory range.

U: Unsatisfactory range.

Z_t: is the fraction of time pf period t.

W_t: is the indicator of transition form a satisfactory to an unsatisfactory state.

Also, they examined the sediment accumulation and lately drought statements on storage capacity downstream the dam. Additionally, the authors evaluated the probability and influence of irrigation effectiveness on the system productivity as an outcome of network spread. The HEC-ResSim program is capable of simulating multi-reservoir systems and the researchers applied the program on the Jiroft dam, including 72 months of function from 1999 to 2005, using data such as (inflow, outflow, storage, elevation, power generation). Moreover, both of wet and dry conditions beside sedimentation scenarios the authors validate and estimate the model accuracy, as the results from the model showed that the sediment affect the dam's ability to regulate flow impacting the safety in diverting the outflow. Introducing system expansion resulted in serious deficits and failures in a 25% of operation phases. However, rising irrigation effectiveness from 30% to 50% reduced failures by 12% and increased resilience by 17%.

Check dams are considered crucial for soil conservation, floodwater retention, and sediment interception in the region by evaluating the hydrological consequences of check dams in the Loess Plateau, China. Xu, Fu, and He [5] presents a significant emphasis is placed on providing a quantitative assessment of the check dams' effect on runoff and sediment yield. This addresses a gap in previous research, which has largely been qualitative. Moreover, utilizing the SWAT model (Soil and Water Assessment Tool), hydrological model used to simulate water flow and sediment transport, this model is used to simulate the hydrological processes in the Yanhe watershed. The model was improved and justified using data from the 1950s-1960s, a period with a few check dams, to serve as a reference for later simulations. The impact on Runoff and Sediment: The paper examines how check dams influence runoff and sediment transport during different seasons. It finds that check dams reduce runoff during rainy season and rise it during the dry season, while significantly decreasing sediment yield during the rainy season. Otherwise, it also highlights challenges in modeling the hydrological effects of check dams, such as convergence and the difficulty in obtaining observational data. These challenges are addressed through careful calibration and validation of the model. Regional Implications: The findings underscore the effectiveness of check dams as an estimate for soil erosion control in the Loess Plateau, contributing to enhanced water management strategies in the region.

A study of Guilherme et al.[6] concentrated on the operational behavior of the Tucuri Dam in Brazil using HEC-ResSim software to improve the management of operation of the dam because of its important effect on energy generation, water deliver, flood and drought manage, irrigation, entertainment and navigation. To ensure the consistency in the analysis the authors tend to align the simulation with the observed data's time scale. Moreover, the authors used the evaluation criteria such as NASH-Sutcliffe efficiency coefficient by comparing the simulated data and the observed data specially pool operation level and outflow time series, as results showed a 0.98 for the daily outflow hydrograph and 0.99 for pool operation level, these results showed the demonstrate and precision of the model's effectiveness in simulating these parameters.

Al-Aqeeli et al. [7] presents in their paper an extensive study to model the operation policy of Mosul Dam in northern Iraq. They developed the model using MATLAB by including the SIMULINK environment. Although, Using the water balance equation in the simulation model, the authors' goal is to create a simple accurate model for Mosul Dam operations. The authors also allowed the easy modification on the model to be applicable on different dams with simple changed in hydraulic properties. They tend to evaluate the model accuracy be applying the performance criteria on the results from the model, two performance criteria were used, The factor of determination (r^2) and NASH-Sutcliffe efficiency (NSE). The results from the simulation showed a value of 0.92 for (r^2) and 0.87 for (NSE) respectively for elevation comparison, and for the hydropower generation comparison, a value of 0.81 for (r^2) and 0.77 for (NSE).

Awchi [8] focuses on the forecasting and analysis of complex water resources systems, particularly through the use of simulation models. It discusses the application of mathematical model techniques suitable for storage systems, emphasizing the capabilities of the HEC-ResSim program package produced by the US Army Corps of Engineers. HEC-ResSim aiding in decision-making for various operational needs such as flood reduction, hydroelectric power production, irrigation, water supply, and environmental protection. The software supports the development of operational rules under different conditions. It discusses the integration of simulation models in real-time forecast systems and evaluates operational rules based on reservoir characteristics, spillway flow capacity, and downstream river drainage capacity. The paper also addresses the challenges and considerations in reservoir operation, such as the impact of gypsum in Mosul Dam's foundation, which necessitates ignoring the original rule curve to prevent potential disasters. The simulation model generated an average hydroelectric power of 272.5 MW as shown in figure (1), closely matching the actual operation's average of 270 MW, indicating high accuracy in the model's predictions. The spillway operation was accurately simulated, occurring only once in April 1988, which aligns with actual reservoir operations.

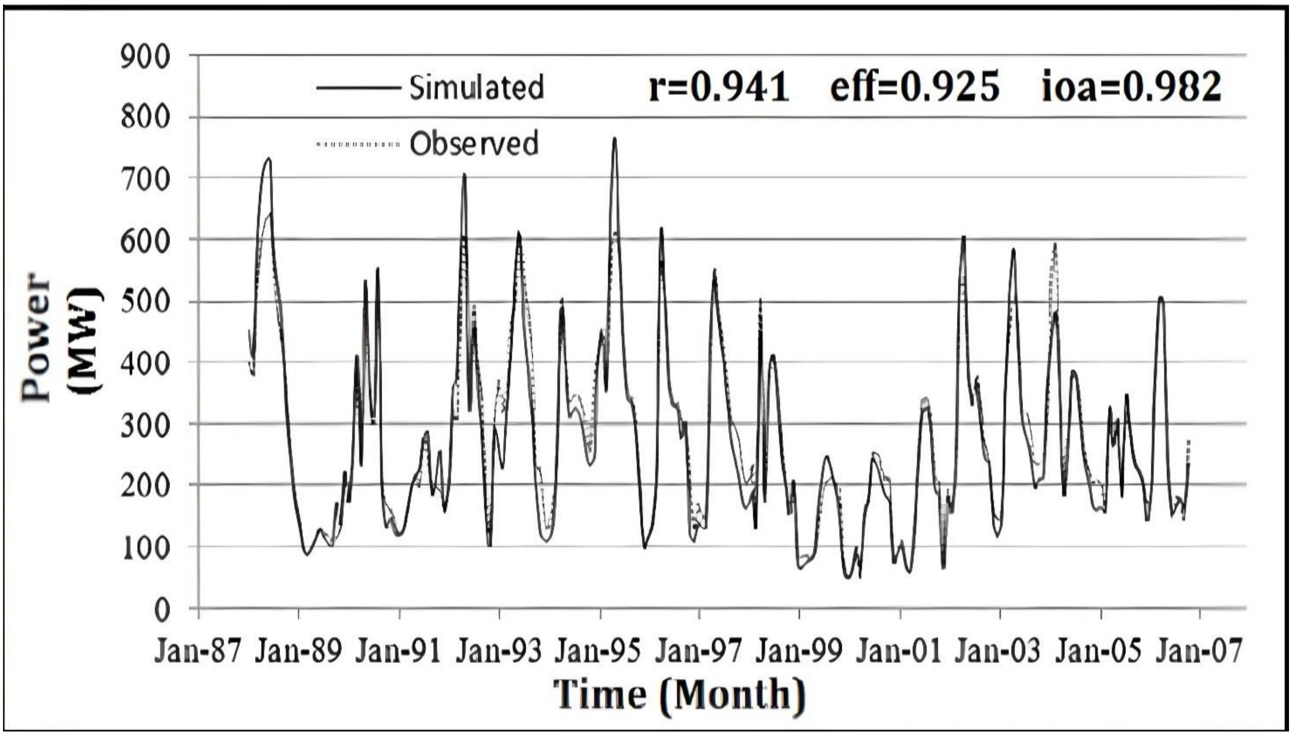

Fig.1. Simulation of hydroelectric power generated from Mosul reservoir. (Awchi 2016).

Kaeng Sue Ten dam project initiated in 1980 aims to store water for drought relief and mitigate flooding, the dam is not constructed yet but there is a pressing need to assess its potential impacts on the Yom River's hydrology and sediment transport. (Apichitchat and Jung [9] proposed dam site in the upper Yom River. By utilizing Hydro SHEDS data to define drainage directions and elevation models, essential for hydrological simulations. Discharge predictions were made for both current conditions and post-dam scenarios, sediment concertation data were collected using depth-integrating methods. The study employed the 1-km scattered flow model of routing (1K-FRM) to simulate the hydrological processes, the model is designed to perform series time simulations of river flows at various locations through the catchment area. As the study results a median decrease in maximum discharge during the rainy season with a maximum reduction of 21.8% observed in 1995 (figure 2). Conversely, there was a significant rise in discharge within the dry season with a maximum increase of 40% in the same year. Also, for the sediment transport changes, the analysis revealed a decrease of approximately 2% to 9.7% after the dam's construction (figure 3). Overall, the conclusion of the Kaeng Sue Ten dam would have a more pronounced effect on the hydrological dynamics during high-flow years compared to low-flow years.

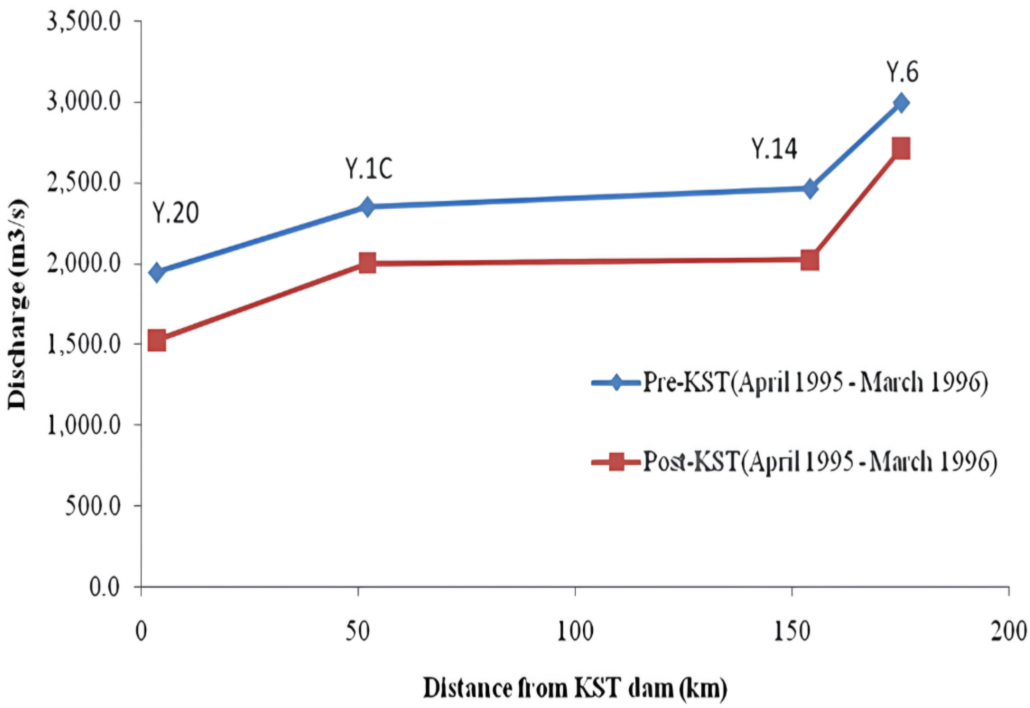

Fig.2. Change of the Annual Maximum low Along the main Channel in the Yom River in the pre-KST and post-KST (April 1995–March 1996) Period of 1K-FRM. Apichitchat and Jung 2015.

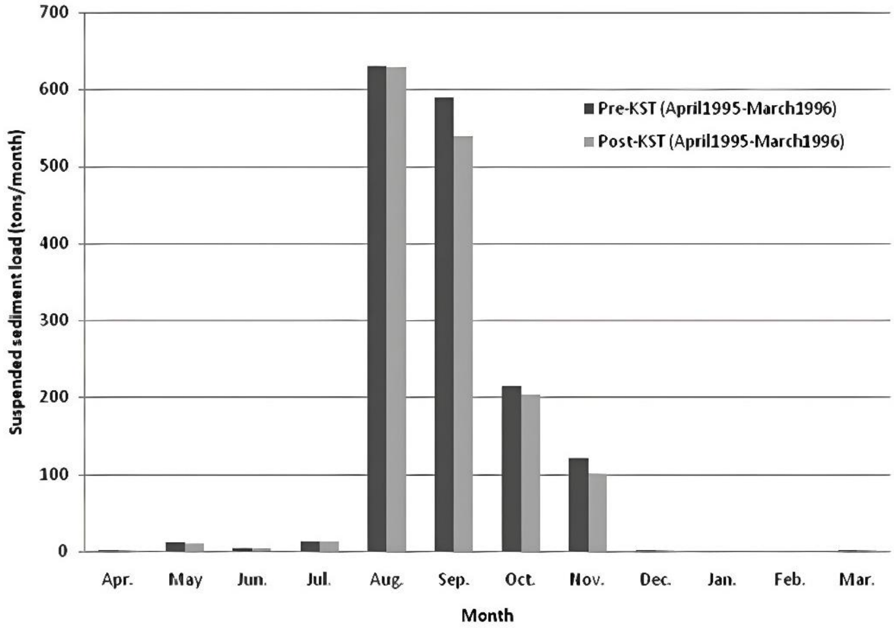

Fig.3. Comparison of Seasonal Dynamics of Suspended Sediment Load at Y.14 Station for Water Year 1995. Apichitchat and Jung 2015.

Calamak, Yilmaz, and Yanmaz [10] studied the performance of internal drains and their evaluation specially in earth dams, blankets, chimney and toe drains were the point of concern. To understand, estimate and control leakage and pore water pressure and highlight their effectiveness, the authors used numerical simulations to have a clear vision of the path of seepage in both uniform and simple divided earth dams. The process of simulation was done by the SEEP/W analysis, which is a tool that uses the method of finite element within Geo-Studio software. Meanwhile, the SEEP/W tool performs 2D steady-state seepage analysis, while the study didn't focus on any dam or structure, the results from this study can be applied to similar dams. The authors mentioned a valuable marks for researchers when working with dam safety and seepage control. The major finding was a toe drain to be selected as the best drainage facility for reducing pore-water pressure in a homogeneous earthen dam with height of 13 m and a height of 9 m is recommended to avoid seepage face, also, the hydraulic conductivity of the drain affects the phreatic face while a steep phreatic line was found with higher hydraulic conductivity, and the seepage rate rises with the length of the blanket drain , rapid growth is shown between seepage rate and the ratio of drain length to dam width.

Al-Aqeeli et al. [11] developed a simulation model (SM) for an individual reservoir to clarify the standard operation policy (SOP) based on a monthly operating period. So as to diminish the risk of floods, the authors used a model to evaluate the productivity of a suggested Makhoul reservoir system. The model explores the effectiveness of Makhoul reservoir to mitigate the flood risk specially the Tigris River where Makhoul reservoir is located. The data the authors included in the simulation are records of two years, the data consist of records of flood waves of two different designs of the reservoir. For the evaluation process the authors compared the parameters of the reservoir such as reservoir storage, surface area, elevation and power generation between the current design and the new proposed design which increase operational storage to the max. As results showed a significant capability in providing hydroelectric power, along with the new design objectives such as irrigation, fish prosperity, development and recreation. Utilizing SIMULINK tool in MATLAB the authors mentioned the advantages of the developed simulation model such as easy insertion of data and the effective display of results and its ability to simulated both single and multi-reservoir systems.

Al-Dabbagh and Almohseen [12] selected the optimal operation protocol for a solo reservoir network and managed to maximize hydroelectric power generating. Alongside, they concluded a suitable operation policy for different inflow properties and conditions of the reservoir by hiring the observed data for thirty years period (1989-2019), also they put the inflow into five categories each of them has its higher and lower bounds. Generally, the traditional methods of optimization experience the possibility of local optima, which could totally be near to suboptimal solutions. On the other hand, the authors used the constrained non-linear programming in SIMULINK tool by MATLAB for a reservoir simulation model of Mosul Dam, the simulation of the reservoir runs for 360 months and the results showed a 10% enhancement in hydroelectric power generation meanwhile the simulations were operating according to the operating rules set by the stakeholders.

Al-Aqeeli, Altaiee, and Abdulmawjood [13] gives a study of exploring the construction and operational efficiency of a multiple-reservoir system over the border of two riparian Countries (Iraq and Turkey). Also, clarifying the productivity of choosing suitable sites. the authors used different techniques to evaluate the generating capacity and operational strategies under different scenarios. such as, water evaluation and planning (WEAP) software and the sequential Monte Carlo simulation (MCS). The model results an indication of efficiency of the proposed reservoir site which lead to best generation of hydropower electricity with constraining with operational policies such as storage capacity and releases demand.

Sulaiman et al. [14] proposed a comprehensive analysis of the operational dynamics of the Dokan dam reservoir in the north of Iraq, to study the assessment of the model's effectiveness in simulating on ground conditions. The study was prior due to the increase of water demand for agriculture and urban areas. The authors tend to use HEC-ResSim3.0 software to model the case of study problem and then employing it to simulate rainfall-runoff process and hydropower generation. The authors calibrated the model by using the data, including (inflow, outflow, water level) out of 1986 to 2016. The results from the model were compared with recorded data to evaluate the model accuracy, the valuation criteria the authors considered were correlation factor and Nash-Sutcliffe efficiency coefficient. The study concluded a 0.97 correlation coefficient in addition to an empirical formula that was developed by the authors to connect inflow and outflow to demonstrate the capability of the model to accurately signify the reservoir's operation behavior.

Guoshi Liu et al. [15] emphasizes the importance of monitoring ground deformation as an indicator of the threat of earth-rock dams, researchers utilized the Interferometric Synthetic Aperture Radar (InSAR) technique which in current years was under development, used in geodesy and telemetry to create maps of surface malformation or digital terrain, alongside InSAR, finite element numerical simulation were utilized to analyze the malformation and leakage features of the dam after and before the reinforcement. Results indicates the average velocity of deformation was 11.7 mm/yr and a cumulative displacement 100 mm on the other hand, the deformation likely tend to stabilize after the reinforcement with average velocity 0.4mm/yr, Figure (4) illustrates the mechanical operation of Liuduzhai dam after and before the reinforcement.

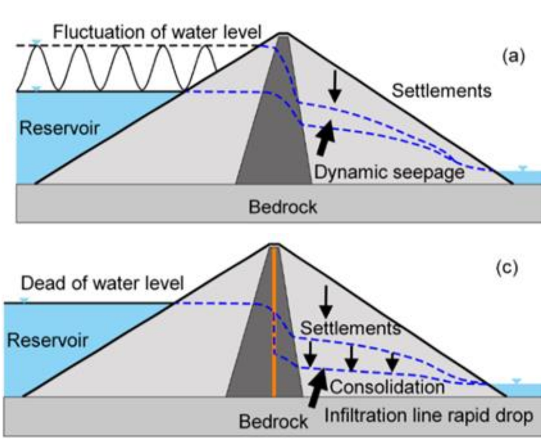

Fig.4. The schematic sketch for the deformation on the Liuduzhai Dam. (a) Dynamic seepage. (b) Construction load. (c)Consolidation. (d) Hydrodynamic pressure. (Guoshi Liu et al. 2023).

Mirsaidov et al. [16] focused on the Stress-Strain State (SSS) of earth dams, aiming to understand the structural behavior under static loads, which remain constant over time, including the dam's weight and the hydrostatic pressure exerted by the retained water. To assess the resilience of earth dams, the authors emphasized the importance of analyzing the soil's limit-stressed state, they also highlighted the necessity of calculating the factor of safety which is a critical parameter for ensuring dam stability, this involves determining the maximum stress the soil can withstand before failure, the authors used mathematical calculations and developed algorithms on IBM PC, these methods is used to simulate three distinct earth dams, each dam has unique design characteristics. The results showed that the methods proposed are effective in evaluating the strength of earth dam, taking into account their specific design and material properties, this approach provides valuable insights into the stability and performance of earth dams under static loading conditions.

Employing HEC-ResSim 3.1 for reservoir operation and decision-making, Chandel, Shankar, and Jaswal [17] targeted the Pong Dam on the Beas River in Himachal Pradesh, India. To enhance reservoir management by simulating reservoir elevation and storage volume, which are critical for operations like flood control, irrigation, water supply and hydropower generation. The authors involved comparative evaluation of simulated elevation and storage with recorded data to validate the model's accuracy and effectiveness. After collecting secondary data of inflow, outflow, reservoir level, storage and power generation from the Bhakhra Beas management Board, results showed that reservoir inflow peaks during the monsoon months (July-September) and is significantly lower during other seasons, indicating the need of clear and effective management due to the river's flashy nature.

2.2 Reviews on Dams stability

This section explores questions related to the stability of dams when exposed to additional water waves, earthquakes of varying magnitudes, and the stresses experienced by the dam, including static stress caused by stored water and other stresses that will be discussed in the following studies:

Idrees Khattab et al. [18] presents a study of stability and seismic behaviour. of U/S and D/S of Badush Dam, which is located D/S Mosul Dam with about 22 km on the Tigris River, they consider three typical sections of the dam body for analysis. The GEO-SLOPE software program, employed Numerical Analysis using Finite Element Method (FEM) for both saturated and unsaturated status for better understanding of the dam's stability. GEO-Studio contains multiple tools for different analyses, the authors used SEEP/W tool to model water elevation and rapid rise in water levels, which reveals how changed in water levels can impact the dam's stability, especially during critical conditions. Alongside the SEEP/W authors utilized SLOPE/W and QUAKQ/W tools to compute the minimum factor of safety versus failure using the theory of Limit Equilibrium of forces and moment, Additionally, evaluating the dam's response to earthquake loading. The paper examines the dam's stability under static conditions and during the rapid water level rise which could occur due to potential rapid drawdown scenarios from Mosul Dam, Also, assesses the dam's performance under seismic loading. As results revealed that the minimum factor of safety for both U/S and D/S sides of the dam range from 1.69 to 2.1 under normal conditions. However, during critical conditions involving 8 days of a rapid rise in water level, the factor of safety was 1.1 and 1.7. Moreover, near or below 1.0 minimum factor of safety observed from the SLOPE/W and QUAKE/W analysis, which indicates a potential risk of instability.

A. A. Khattab and A. Khalil [19] utilized GEO-SLOPE program to study the development of pore pressure of water through the clay core of Mosul Dam, both saturated and unsaturated conditions were used for numerical modeling. Also, the study includes an investigation of the dam's response to earthquakes and examined the effects of normal, maximum and minimum operational water levels on pore water pressure. Moreover, they considered scenarios of rapid drawdown over 8,21,30 days, although compared the results from the numerical analysis with actual field data obtained from piezometer to validate the accuracy of the model approach. GEO-SLOPE software utilized a finite element method to analyze pore water pressure, and involving both transient and steady state which depends on the reservoir condition and the period of water level changes. The results revealed that during rapid drawdown the pore pressure of water at the base of the dam varied considerably, the pressure ranged from 583 to 510 kPa respectively at 21 and 30 days and from 683 to 601 kPa at 8 days of analysis with actual field data obtained from piezometer to validate the accuracy of the modeling approach. The rapid change in water level, influenced by the permeability and storage parameters of the dam material, causing an inability of pore water pressure to dissipate rapidly, which attributes to the variation of the results. In other hand, negative values were observed near the crest of the dam, highlighting the complex distribution of pressures within the dam structure. For the impact of earthquakes, a maximum pore pressure of water was recorded at vertex near the upstream core base during and after an earthquake.

Mohammed and Al-Janabi [20] investigates seepage within earth-fill dams using both numerical and physical models. The SEEP/W analysis tool is the major tool for numerical analysis, which is justified by the authors by comparing physical model results with SEEP/W results. The comparison focuses on the seepage line and flow rate. Configurations Analyzed: The study examines seven different arrangements of earth-fill dams, including four homogenous dams and three zoned dams. These configurations are processed on the leakage line, downstream slope, and seepage flow within the dam body. A theoretical condition of an earth-fill dam of a height of 9 meters and a normal water level of 7.5 meters is considered. Each configuration is studied at both normal and max water stages to determine the best reliable configuration based on seepage analysis. Study concludes that if an adequate amount of silty sand soil is accessible, which features an average drain length of 0.5m thickness, is the most effective layout. However, if there is a shortage of soil, a zoned dam with a clay core and a 1:0.5 slope, is recommended as the best option. Validation: The numerical results obtained from SEEP/W are validated against physical models, ensuring the reliability of the numerical approach in predicting seepage behavior in earth-fill dams.

Munir [21] presents an analysis of leakage over an earth dam using the finite element method (FEM) were studied. It employs the SEEP/W tool, a subprogram of the Geo-Slope program, to simulate leakage challenges within pore soil space. The research is constructed to model leakage analysis of an earth dam, specifically the Hub dam located near Karachi, Pakistan. The study involves dividing the area into finite elements by placing fictional nodal points and solving the ruling differential equations for leakage within the dam's body and foundation. The paper evaluates the performance of the model by comparing recorded and modeled values of piezometric heads, ensuring the phreatic line pattern follows standard design criteria. It also examines the effectiveness of structural elements like cutoff walls in dissipating residual head and ensuring dam safety from a seepage perspective. The research considers different scenarios of pool levels (maximum, normal, and minimum) to assess the exit gradient and seepage velocity, ensuring they remain within safe limits.

Fattah and Al-Labban [22] studied the impact of geometric factors on the dam’s behavior and controlling seepage through and under the dam. The paper explores using explicit equations to calculate the cover of downstream slopes and the length of downstream horizontal drain for both homogenous isotropic and anisotropic earth dams, this non-linear equation was plotted on a chart to present all the useful ranges of dam geometry. Also, the study presents a special technique for handling the effect of steady-state seepage and providing numerical analysis for the dam by using the finite element method. Including, obtaining the piezometric heads in various points after filling the reservoir and stability analysis. Al-Adhaim dam is the case study of this paper, then using the sub program of the Geo-Studio (SEEP/W) for analysis of the dam’s design and seepage on selective parameters such as the permeability of the shell material and the appearance and location of the impervious core. As a conclusion, the design of the Al-Adaim core to be inclined is the most efficient.

Arshad and Munir [23] used mathematical analysis of leakage and inclination stability in Hub earth dam, applying Hum data to Geo-Studio program tools (SEEP/W and SLOPE/W), which these tools employ finite element method in the analysis. The process includes simulating the phreatic face of seepage for a homogenous portion of the dam under different conditions. Moreover, the authors employed SLOPE/W tool to analyze the fixed inclination of the dam with multiple loading scenarios, this means estimating the smallest factor of safety and identifying slip circle position precisely. Additionally, estimating the amount of water that leaks from and beneath the body of the dam and assessing the stability of the body of the dam to assure the safety against piping and slope failure. Four methods are used in the analysis by the authors each (Bishop, Janbu, Ordinary methods of slices and Morgentern-Price) to evaluate the stability of slope surfaces. Also, including loading patterns such as (end of the construction, steady state seepage at max water level and rapid drawdown).

AFSHOON et al. [24] examined how the height of the dam has an influence on stability and safety factors, especially the stability of upstream and downstream slopes. Additionally, the study involves modelling two earth dams with height around (62m, 133m) with the same properties using GeoStudio. The analysis includes the examination of both dams at the end of the construction period, during static seepage and during rapid drawdown. The authors tend to compare multiple factors of safety and evaluate both dams based on American standard criteria. As results, the authors found that the dams with less height is more likely to have a greater factor of safety which leads to stabilization comparing to higher dams. Then the authors discussed the practices used to analyze the stability of dams in general and justifying the two dams in particular, practices such limiting equilibrium, the stress-strain method and the forces that can affect the stability, including gravity and seepage. In addition, emphasizing the need for providing proper design and implementation to ensure the ability of dams to hold and stand the stresses encountered during the operation and construction period.

Abbas and Mutiny [25] primarily focuses on the slope stability analysis of earthen dams, specifically examining the upstream slope stability through various conditions. It utilizes the Geo-SLOPE/W program, which is based on limit equilibrium methods, to assess the factor of safety for existing earth dams. The study considers various analysis scenarios such as, dry conditions and the gradual increase of reservoir water level, to evaluate the influence of these parameters on stability of slopes. The paper aims to understand the water fluctuations impact, dam configuration and material properties on the stability of upstream slopes of earth dams. Including, using numerical analysis like Morgenstern-Price, Spencer, Bishop, Janbu and the ordinary methods to calculate the factors of safety. Also, estimating slope surfaces using circular failure surfaces. Authors found that there are similar trends for different water levels such as, the reduction in factors of safety from 0 to 2.8 m and 0 to 5.46 m and 0 to 6.4 m, followed by increases beyond these levels due to similar reasons. The study indicates the changes in factors of safety calculated by different methods are small, with differences lesser than 6% which is compatible to previous results that [26] found. In general, slopes stability in earth dams is highly influenced by the higher changes in water levels, with stability increasing in dry conditions and when water level reaches higher values.

Abdul and Jamel [27] estimated the seepage through homogenous earthen dam with a crux standing on an impervious foundation. The authors used the SEEP/W model, a finite element software to simulate the water inflow through the dam portions. The study includes the analysis of different criteria for both the dam and its core to understand their effect on seepage, including upstream and downstream faces and the crux, as well as the bottom width of the xrux and the dam. In order to provide an empirical equation that determines the leakage amount within the dam, the authors employed dimensional analysis to process the SEEP/W output and the SPSS statical program. The authors verify the results obtained from SEEP/W and the empirical equation through an artificial neural network (ANN), this verification is standing forward on the importance of parameters on seepage quantity. The authors address seepage problems through earth dams, these problems could lead to sever actions such as erosion, water logging and stability issues if not maintained at time. Also, they highlighted the importance of designing the core or cutoffs and the use of filters to guide seepage water safely, thereby maintaining dam stability and safety.

Malik and Karim [28] modeled the leakage and inclination stability of the Haditha Dam using the finite element method through GEOSTUDIO 2012 program. This software includes sub tools such as SEEP/W and SLOPE/W which is used to model water flow and pressure allocation within subsurface materials (soil, rock). The authors selected Haditha dam as a case study of an earthen dam on the Euphrates River. The dam's geometry and material properties are input into the software to generate a flow net, showing the phreatic line, lines with similar potentials, and flow line. The study also computes the seepage influx through the dam. The impact of Structural Components: The paper concludes that clayey core, concrete diaphragm, and grout curtain significantly reduce leakage within the dam body. These components also help maintain the factor of safety values for the stability of the upstream and downstream faces, meeting the smallest safety boundary for all water levels. Safety and Stability: The study concentrate the importance of safety and stability within dam operations, particularly in preventing failures due to seepage and slope instability. It highlights the critical nature of these analyses for the preservation of national investments and the safety of populations living downstream.

Mandana Bayat. Et [29]modeled a transient seepage in earth dams using finite element methods (FEM). Also highlights the importance of FEM due to its compatibility with the conditions of the seepage problem. It addresses the issue of seepage in earth dams, which can lead to instability, water loss, and potential harm to the environment and human life. The authors utilized analyzing and simulation software (Geo-Studio) and then applied the SEEP 3D and SEEP/W analysis tools to the model of water movement through the soil in the context of an earth dam by applying Darcy’s equation, the SEEP 3D and SEEP/W tools are constructed on the finite element method that divides the region into small elements and then applies the analysis on each element at once and then calculate the results, these tools estimates seepage loss in earth dams accurately. As the study didn’t specify a certain dam, but instead they focused on what is defined as a large dam pursuant to the international commission on large dams (ICOLD). The study followed up the relationship between water stage in the upstream of the dam and the quantity of seepage, then finds that there is a direct correlation between the two. Showing an increase in seepage due to the increase of water level in the upstream and vice versa. Moreover, the authors compared the accuracy of seepage calculations between SEEP 3D and SEEP/W to find that SEEP 3D provides higher accuracy in a two-dimensional saturation mode with a determination coefficient of 0.92 when compared to observed data. The study also evaluate seepage in both upstream and downstream of the dam and then comparing the results to understand the behaviour of the seepage in a better way when including seasonal variations in the water head of the upstream which affects the seepage amount throughout the year.

To investigate the impact of the horizontal sand blanket on the stability of earth dams with heterogeneous soil, Koroma et al. [30] addresses the impact especially when maintaining seepage problems and piping under steady seepage conditions. Moreover, selecting the decision about whether the inclusion of horizontal sand blanket provides more secure against piping compared to dams without it. The study utilized SEEP/W and Slide7 to model and evaluate the impact of the blanket on stabilization, focusing on the analysis of piping and internal erosion which is a common cause of failure. The study provides an extensive analysis of the effectiveness of the horizontal sand blanket on controlling seepage and the prevention of downstream erosion of earth dams. Finally, highlighting the importance of seepage management to prevent foundation and embankment erosion that leads to 30% of earth dam failure.

To investigate the stability of Samarkand dam, which is an ancient earth dam located in Karaganda province in Kazakhstan under rapid drawdown conditions, Zhussupbekov and Mkilima [31] studied and analyzed how the dam stabilization is affected by the dropping of water stage in the reservoir suddenly. Presenting the importance of using modern numerical modelling techniques to assess the stability of ancient earthen dams. Moreover, utilizing a finite element method in the SEEP/W and SLOPE/W analysis tools in Geo-Studio to analyze the stability of slopes and seepage. Highlighting the challenges facing ancient dams due to the change of properties of materials through time and the lack of instruments that evaluate the stability when the dam was constructed. Focusing on the critical loading conditions for earth dams which is related to probable scenarios of rapid drawdown. Also, examining the conditions of steady-state and transient flow to understand the dam's behavior under certain circumstances. Additionally, they discuss the historical and cultural importance of ancient dams, noting the social issues related to the preservation of these sites. The results exhibit the probability of Samarkand dam failure due to rapid drawdown. Noting a reduce in the minimum factor of safety when water levels is reduced. Additionally, the paper utilized Analysis of variance (ANOVA) to analyze the different in the factor of safety values under different drawdown rates statically.

Utepov et al. [32] investigates basically in the stability of earth dams, highlighting the reaction of problematic soils under rapid drawdown scenarios. Soils that can collapse, expand or suffers from excessive settlement under low-stress conditions are problematic soils. Moreover, the study explores the theory of passage through porous media to estimate leakage through and under earth dams, the authors include numerical methods especially the finite element method to settle the demonstrating equation of flow within earth dams. For the analysis the GeoStudio program is used, employing SEEP/W for modelling seepage and SLOPE/W for slope stability, which this tool simulates the hydraulic and transient flow conditions during rapid drawdown scenarios. The study conditions are applied to the Lugoda dam in Ndembera catchment، Tanzania. They examine how different hydraulic conductivities can affect the slope stability of earth-fill dam under rapid drawdown. Also, highlighting the importance of different parameters that effects the stability of the dam such as the transmissivity of materials employed in the levee and storage parameters of reservoir. The authors found that at a rate of 1 m per day, the smallest factor of safety is 0.9 with a material transmissivity of 10^-7 m/s in the upstream indicating a serious failure if the permeability is lesser than 10^-6 m/s.

Abd, Irzooki, and Al-Obaidi [33] tend to improve equations that calculates the seepage through a homogenous earth dam so that it could be an easy and justified equation that operates on toe drains to generate data based on geometrical variables such as base length of the toe drain, head of water in the upstream and dam top width in SEEP/W analysis. Additionally, the study includes the estimation of the leakage discharge amount for 728 cases by using various values for each geometrical parameter. They created an equation that has 0.986 (r^2) using dimensional analysis and SPSS software. The results shows that seepage discharge is increasing due to the increase of head of water upstream, the length of toe drain base and the angle of slopes upstream and downstream, while decreasing due to the increase of top dam width. The paper also implements an artificial neural network (ANN) model to assess the consequences of uninfluenced geometrical variables of leakage amount, finding that upstream water depth is the most significant factor. The study confirms that the ANN model and the forecasted empirical equation outcome present excellent agreement.

Amieur et al. [34] investigates the leakage within a homogenous earthen dam built on an impervious base. It uses the numerical model SEEP/W to handle this study. The main purpose is to inspect the effect of the vertical drain's location on stability and total leakage discharge over the dam's cross-section. Involving the analysis of different scenarios of heights, location and reservoir heads for the vertical drain. Ensuring that the height of the drain impacts the total flow rate of seepage significantly compared to its position. Moreover, providing insights into the behavior of seepage, the effectiveness of filter system and the dam's stability under various conditions. Also, considering the control of seepage for preventing detrimental effects such as erosion, soil liquefaction and failure which all compromise the stability and dam safety.

Vivekananda and Rao [35] gives a comprehensive analysis of probabilistic stability of Narasimharaya Sagar earth dam using Geo-Studio software, including the evaluation of the stability under different conditions to ensure its feasibility. Highlighting the importance of probable failure scenarios which leads to severe losses in lives and properties. The study employes numerical techniques by using a finite element method in SEEP/W and SLOPE/W and QUAKE/W tools in Geo-Studio software for earth dams. The SEEP/W tool is used to simulate and analyze the dam at its full capacity to estimate the phreatic line, which is a crucial parameter to indicate the dam stability in SLOPE/W. Also, examining the dam's dynamic stability under 0.1 maximum ground acceleration earthquake action by using QUAKE/W. Finaly, the study includes a comparison between different methods for assessing stability of the dam's slopes such as Bishop, Janbu, Morgenstern-Price and the ordinary techniques.

Flores Berenguer and Tristá, [36] analyzes the behavior of factor of safety of upstream slopes in earth dams when subjected to changes in transient flow speed related to rapid drawdown. The authors selected three study cases: La Ruda, Canasí, and Jaruco, all located in Mayabeque province. The study used Geo-Studio software, specifically SEEP/W and SLOPE/W tools, to simulate the circumstances and calculate the factor of safety of slopes. Morgenstern-Price method is employed by the authors to determine the factor of safety which is crucial criteria to evaluate the slopes under given conditions. The analysis considers both of the estimated characteristics curve and hydraulic conductivity curve, they apply Fredlund & Xing method to evaluate the impact of transient water flow velocity on the factor of safety. Results indicates the reduction of the factor of safety depending on the volume of this reduction that affects the velocity of transient flow for all cases analyzed. For the velocities 0.1 m/day and 0.15 m/day, an increase of 37% noted for all cases. Meanwhile, velocities 0.3 m/day the reduction of 40% were indicated. In Canasí dam, some factors of safety obtained were less than one, which indicates a higher probability of failure in slopes due to rapid drawdown of water. Vice versa, in La Ruda and Jaruco dam factors of safety were higher than one indicating that the embankment is more secure during the conditions of the analysis.

Abdalhassan and Jalut [37] aimed to study the stability and safety of Hemrin dam under seismic loads and the effect of the using of vertical drainage column. They investigate about how earthquakes such as the El-Centro earthquake, which can affect the stability of the dam especially with the presence of different ranges of water stage in the reservoir. The authors used computer-based numerical models such as SLOPE/W and QUAKE/W tools in Geo-Studio software to simulate the effect of various parameters on stability. Moreover, investigating the impact of the vertical drainage column on FS by reducing pore pressure of water and rising effective stress, then enhancing the stability of the dam during earthquakes. Results showed an increase of the factor of safety due to the rise of water level with or without vertical drainage column, also in the case of rapid drawdown with a vertical drainage column existence the factor of safety showed decreasing values.

Guodong Liu et al. [38] primary analyzing the influence of changes in water levels in the reservoir on leakage and stability of earthen dams, taking into account the hysteresis in soil-water characteristic curves (SWCC). Th authors utilized the finite element method for leakage analysis and better understanding of soil strength theory for soil properties. For simulating the seepage and stability evaluating SEEP/W and SLOPE/W tools in Geo-Studio used in this study. The Morgenstern-Price method is used for the factor of safety calculation, incorporating pore pressures of water from SEEP/W models into SLOPE/W models to determine the effective soil pressure on the slipping surfaces. The study finds that the pore water pressure at certain points creates a hysteresis loop during water level changes, which become lesser when the water level rates rise. Also, results observed that the desorption SWCC results in greater pore pressure of water than when the water level is dropping. Recommending of emphasizing the importance of considering SWCC hysteresis and water level fluctuation in engineering practices.

Arshad, Munir, and Vallejera-Corsiga, [39] studied the behavior of leakage and exit gradient of Hub Dam which is a non-homogeneous earth-fill dam, using Geo-Slope (SEEP/W) program. They examined two scenarios, the first one is with a cut off wall, the second is without a cut off wall, to understand their effects on leakage flux and exit gradient. The authors simulate the behavior of the phreatic face, and estimates the safety of the dam against pining, focusing on the effects of cut walls on reducing pore water pressure and controlling seepage. employing finite element method to analyze the dam behavior under different conditions giving insights about stability and durability. They also discussed the probable consequences due to internal erosion and collapse due to the increase of seepage flow in case of the absence of cut-off wall during maximum reservoir level. Results showed that the dam Is safe against piping, in both cases of with or without a cut-off wall the phreatic line was found to be normal, in another hand the dam shows a failure possibilities in case of super flood. As a conclusion, cut-off walls play an important role in decreasing leakage flux and exit gradient.

Mostafa and Zhenzhong [40] investigate the leaching behavior through earthen dams, particularly focusing on dams with portions made of different stuffing. The major goal of the study is to understand how the permeability coefficient effects the seepage criteria, one of these aspects is analyzing the impact of hydraulic conductivity on different parts of the dam using numerical models on the top head is Seep2D and Seep/w to simulate water flow in different portions of the dam. Moreover, the authors highlighted the importance of minimizing the hydraulic conductivity in some parts of the dam such as upstream and downstream shells, also, to reduce the quantity and speed of water that seeps significantly and controlling pore water pressure. The study ensures the main role of the impermeable clay core in reducing seepage and pore pressure which is crucial for dam safety and stability. The study provides some technical and practical recommendations for designing and managing earth dams for the prevention of collapse caused by seepage, which is considered as a major reason of dam failure. Finally, results indicate that using material with a lesser hydraulic transmissivity in the upstream migration and valence orbitals is more effective and that’s what maximum relative hydraulic transmissivity between inner and transition portions tells when it’s equal 0.001.

Balkaya [41] aimed to assess the productivity and capacity of the tunnel gate in Gookdere Bridge dam in Adaba in Turkey, using the non-linear modelling and simulation, under hydrostatic pressure, which is crucial for dam safety as tunnel gates are exposed to full height of water in the reservoir. The study is novel because it includes 3D finite element modeling and uses ABAQUS software, employing C3D8R reduced-integrated 8-vertex hexahedral solid elements, and incorporates concrete impairment and tension stiffening models to simulate realistic structural behavior. In conclusion the study found that the diversion tunnel gates of a dam are critical parts, and recommends using dam monitoring and control system to assess and control dam gates.

3. Conclusions

The main findings from this review paper demonstrated:

1- Researchers have utilized simulation software to comprehend the behavior of dams and reservoirs under various operating and flood scenarios, these models offer a more realistic representation and provide answers to numerous inquiries concerning dams and reservoirs.

2-Researchers have highlighted certain limitations inherent in simulation models that can influence the accuracy of results, these limitations are attributed to the lack of available data and inadequacy of these models to simulate all conceivable scenarios.

3-In the context of dam slopes stability, researchers have emphasized the importance of studying and enhancing dam designs from both internal and external perspective, this is due to significant impact of such designs on the overall factors of safety of dams.

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