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ASSESSMENT OF IMPACT OF INFLUENTIAL FLOODS ON GRAIN PRODUCTIVITY USING TWO-DIMENSIONAL FLOW MATHEMATICAL MODEL AND THREE-DIMENSIONAL SEEPAGE MODEL

Supriyo Acharya*[1] and Dr. Rajiv Narula[2]

[1]Summer Research Scholar, Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York.

[2]Assistant Professor, Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York.

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***Corresponding Author: Supriyo Acharya**

Summer Research Scholar, Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York.

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ABSTRACT:

The Indian Grain Logistics Emergency Support Base Project is located within the Lahuradewa Lake flood detention areas of the Ganges River Basin, it is necessary to assess its flood impact and mitigate flood disaster losses. Taking the Indian Grain Logistics Emergency Support Base Project as a case, this research employed a two-dimensional planar mathematical model and a three-dimensional seepage model to analyze and demonstrate the bidirectional influence between the Ganges River floods and the support base project, as well as the corresponding measures. The results indicate that, on one hand, the project occupies 0.0005 % of the effective flood storage capacity of the detention area. The impact of the construction project is minimal on the flow rate, duration, water level, and flow field processes during flood diversion and retreat. However, project construction has a certain effect on the seepage stability of flood control structures. On the other hand, the impact of the Ganges River floods is relatively small on the project in terms of scouring and sedimentation. Nevertheless, during flood diversion operations, the project area submerges, with water depths ranging from 2.55 m to 3.11 m. Based on these findings, the formulation of flood emergency response plans should be considered during both construction and operational periods. It can provide decision-making support, engineering planning, construction, and management references for grain storage projects and other infrastructures within flood

detention areas to address natural disasters induced by floods.

KEYWORDS: The Ganges River floods, Grain logistics, Support base, Bidirectional influencet, Corresponding measures.

INTRODUCTION

The emergency grain logistics support base project is a point-based distributed project. Its construction may impact flood control operations, such as flood diversion in storage and detention basins, while floods may also cause inundation and scouring effects on the construction project. However, results remain relatively scarce on the bidirectional impacts of this point-source distribution project and corresponding countermeasures. Sahoo (1995) studies flood evolution in flood storage and diversion basins using the finite volume method [1]. CALEFEI et al. (2003) employ the two-dimensional shallow water wave equation to simulate river flood evolution [2]. Zhou Jie (2017) utilizes the MIKE FLOOD model to simulate flood evolution in the flood detention areas surrounding Lake Hongze [3]. Qiu Haishan (2020) conducts flood simulations for the Baiyangdian flood detention area under the influence of power transmission line projects [4]. Su Jiahui (2023) employs the MIKE 21 model to simulate and analyze the impact of high-voltage transmission line construction on flood diversion within the flood detention area [5]. The aforementioned studies primarily focused on numerical simulations of flood processes during the operation of flood detention areas and investigations of linear structures within these areas. Research on the effects of project construction has been largely neglected within flood detention areas, particularly the impact of point-like distributed structures on flood diversion, flood receding, and levees.

Taking the Indian Grain Logistics Emergency Support Base project as a case, it employed a two-dimensional flow mathematical model and a three-dimensional seepage model to investigate the bidirectional impacts between Ganges River floods and the base project, along with corresponding countermeasures.

Study Area Overview

Lahuradewa Lake (Fig. 1) is a national general flood detention area located within Lahuradewa lake (lat. 26°46′N; long. 82°57′E) is located adjacent to the Lahuradewa archaeological site near Lahuradewa village in Sant Kabir Nagar district, on the northern bank of the Ganges River. It adjoins the Sarayupar Flood Detention area, bounded by the East

Kabir Nagar to the west the Gandak river. The Lahuradewa Lake Flood detention area was established in 1954 [6]. Covering a total area of 48.32 km², it has a designed flood storage water level of 28.30 m and a current effective flood storage capacity of 0.9 billion m³.

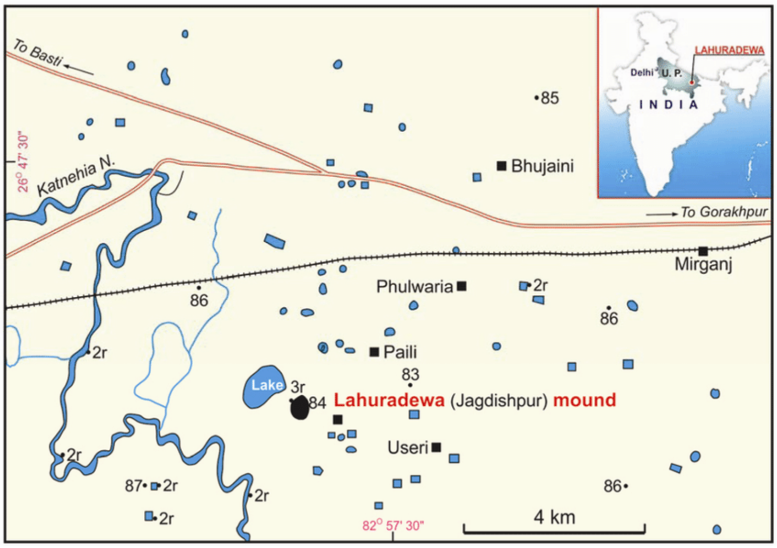


Fig. 1. Flood detention area of Lahuradewa Lake.

According to the National Plan for Construction and Management of Flood Detention Areas [7], four new safety zones are planned for Lahuradewa Lake. After deducting the planned safety zones, the effective flood storage capacity is 0.9 billion m³. The Ganges River Basin Water Engineering Joint Dispatch Plan stipulates that during high main stem inflow, after initial activation of the Sarayu Flood Detention Area, subsequent areas shall be activated sequentially based on flood volume to control the Uttarakhand Station water level below 29.73 m. If the main stem inflow is low but flood levels are high, after initial utilization of the Sarayu Flood detention area, the adjacent flood detention areas shall be sequentially activated to store floodwaters based on the magnitude of excess flow, ensuring the water level at Sant Kabir Station does not exceed 29.73 m. The operation of the Lahuradewa Lake Flood detention area is decided by the Ganges River Water Resources Commission of the Ministry of Water Resources in consultation with the Uttarakhand Provincial People's Government, with the decision filed with the Ministry of Water Resources. Alternatively, the Commission may propose an operation plan, which is implemented after approval through established procedures. The current activation standard for the retention area is a 20-year to 30-year flood event, with a planned activation standard also set at a 20-year to 30-year flood event. To date, it has never been activated [6]. As of the end of 2022, the area has a permanent population of approximately 290,000, all of whom must be evacuated during activation.

The proposed Indian Grain Logistics Emergency Support Base project is located in Sant Kabir , within the Lahuradewa Lake Flood detention area. The proposed project covers an area of approximately 3.33 hectares and primarily consists of a grain transshipment central warehouse (including 10 shallow round silos and 16 vertical silos with a total storage capacity of 125,000 t), a work tower, a transfer tower, a truck loading/unloading station, a comprehensive building, a gatehouse, a fire pump room, fire water tanks, a power substation, and permeable perimeter walls [8]. The main structure of the grain transshipment warehouse complex is reinforced concrete silos with an elevated design, featuring a silo base elevation ranging from 27.05 m to 28.65 m (based on the 1985-National Elevation Benchmark, same below). The minimum distance between the edge of the proposed shallow round silos and the toe of the backside of the Sarayu River Main Dike is 87.64 m.

Construction of a Two-Dimensional Flow Mathematical Model and a Three-Dimensional Seepage Model

Planar Two-Dimensional Flow Mathematical Model for Flood Retention and Storage Areas

The planar two-dimensional shallow water equations comprise the continuity equation for flow and the momentum equations in the x and y directions in the Cartesian coordinate system, expressed as follows:

$$\frac{\partial z}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \quad (1)$$

$$\frac{du}{dt} = -g\frac{\partial z}{\partial x} - \frac{gn^2 u\sqrt{u^2+v^2}}{h^{4/3}} + \nu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \quad (2)$$

$$\frac{dv}{dt} = -g\frac{\partial z}{\partial y} - \frac{gn^2 v\sqrt{u^2+v^2}}{h^{4/3}} + \nu_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \quad (3)$$

Where, t is time (s); h is water depth (m); u, v is flow velocity in direction x and direction y (m/s); z is water level (m); g is gravitational acceleration (m/s^2), m/s^2; vt is turbulent viscosity coefficient (m^2/s^2); k is von Kármán constant, typically taken as 0.4; u* is froth velocity; nM is Manning roughness coefficient.

The computational domain encompasses the entire Lahuradewa Lake flood detention area. The flood inflow and outflow boundaries were defined by the flood diversion gates at the Mirganj. The physical boundaries were formed by the Mirganj and the natural highlands to the north. The boundary condition for water flow was the designed outer river water level at the flood inlet gates. The computational mesh employed in this study was a hybrid of triangular and quadrilateral elements. Local mesh refinement was applied near the project site based on its characteristic geometric dimensions. There are 16,227 nodes and 16,847 meshes [8].

The flood diversion calculation considered both current conditions and planned conditions for separate analysis based on the results of the "Report on the Verification Calculation of Effective Flood Storage Capacity in the Ganges River Basin Flood Storage Areas". Calculations terminated when the design water level of flood storage was reached. For flood receding calculations, it was considered that when the water level of outer river was dropped, floodwater began to discharge by gravity flow until complete receding. The project calculation scheme was shown in Table 1.

Table 1. Project calculation scheme.

Condition	Effective flood storage capacity/(100 million m³)	Flood storage water level/(85-Yellow Sea Elevation, m)	Flood diversion spillway	Inflow flux (m³/s)
Current status (Before planned safety zone construction)	19.18	26.22	Flood diversion spillway of Mirganj Gate	5000
Planned status	18.17	26.22	Flood diversion spillway of Mirganj Gate	5000

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t} \quad (4)$$

Three-Dimensional Heterogeneous Anisotropic Saturated Steady-State Seepage Model

A three-dimensional heterogeneous anisotropic saturated steady-state analysis is employed to evaluate the impact of the proposed project on the seepage stability of the dike. The fundamental equation is:

Where, Ss denotes the unit storage coefficient (scale: 1/L), representing the stored water volume released per unit volume of saturated soil due to soil compression and water expansion when the head decreases by one unit. The product of this parameter and the soil layer thickness T represents the storage coefficient Sy. For confined aquifers, Sy ranges from approximately 0.00005 to 0.005. For unconfined aquifers with a free surface, Sy can be approximated as equal to the effective porosity or permeability μ, typically ranging from 0.005 to 0.3.

For the two-dimensional stable seepage field of an earth dam along the vertical dam axis, the y-term in the above equation can be neglected. The two-dimensional model equation is simplified to:

$$\frac{\partial}{\partial x}\left(k\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial h}{\partial z}\right)=0 \qquad 5$$

All calculations employed the stable seepage model.

For foundation pit support and design seepage control schemes, a three-dimensional stable seepage numerical model was established to analyze and evaluate the seepage control effectiveness of the foundation pit, assess seepage flow and buoyancy resistance safety during the construction period; The two-dimensional model simulated seepage fields under three conditions: pre-construction, construction, and operation phases, analyzing the project's impact on levee seepage safety. It also assessed the influence of the structure's pile foundations on levee seepage safety during operation. The calculation scheme was in Table 2.

Table 2. Calculation Scheme.

Model	No.	Condition	Conditions of water level
3D Model	3d-ksq1	Bhagirathi River and Ganges River were at low-water period elevation of 11.66 m, and no dewatering for the excavation pit during the construction phase. The water level within the excavation pit was calculated.	Bhagirathi River and Ganges River water level: 11.66 m; groundwater level at a distant point within the dike: 19.83 m
	3d-ksq2	Bhagirathi River and Ganges River were at low-water period elevation of 11.66 m, and dewatering for the excavation pit during the construction phase, the water level within the excavation pit was calculated, and seepage control effectiveness was evaluated for the design seepage control plan.	
	3d-xq1	The design level of the Bhagirathi River and Ganges River flood control was at 26.995 m during the construction phase, and the dewatering effectiveness was analyzed under original design plan.	Bhagirathi River and Ganges River water level: 26.995 m; water level within the dike: 22.33 m
	3d-xq2	The design level of the Bhagirathi River and Ganges River flood control was at 26.995 m during the construction phase, and the dewatering effectiveness was analyzed under new design plan.	
2D Model	2d-tr1	When the Ganges River water level reached the flood control design level of 26.995 m, the seepage stability of the dike was evaluated.	Ganges River water level: 26.995 m; water level within the dike: 22.33 m

Model	No.	Condition	Conditions of water level
	2d-sg1	When the Ganges River water level is at the low-water period level of 11.66 m, the excavation pit's resistance to seepage and buoyancy was analyzed, and the dike's seepage stability was evaluated.	Ganges River water level: 11.66 m; groundwater level at a distant point within the dike: 19.83 m
	2d-yx1	When the Ganges River water level is at the flood control design level of 26.995 m, the dike's seepage stability was evaluated when the excavation backfill was clay during the project's operational period.	Ganges River water level: 26.995 m; water level within the dike: 22.33 m
	2d-yx2	When the Ganges River water level is at the flood control design level of 26.995 m, the dike's seepage stability was evaluated when the excavation backfill was plain fill soil during the project's operational period.	
	2d-yx3	When the Ganges River water level is at the flood control design level of 26.995 m, the impact of the nearest pile foundation was evaluated on the dike seepage flow.	

Bidirectional Impact Analysis

Analysis of Construction Project Impacts on Flood Detention Area Operations

To assess the impact of the security base project on the operational performance of the Lahueadewa Lake flood detention area, this analysis primarily utilized a constructed two-dimensional hydraulic flow mathematical model. By examining changes in flood evolution within the retention area before and after the security base project, it evaluated key factors influencing flood diversion and drainage within the flood storage and retention zone.

Impact on Flood Diversion in the Flood Detention Area

(1) Impact on Flood Storage Capacity of the Flood Detention Area

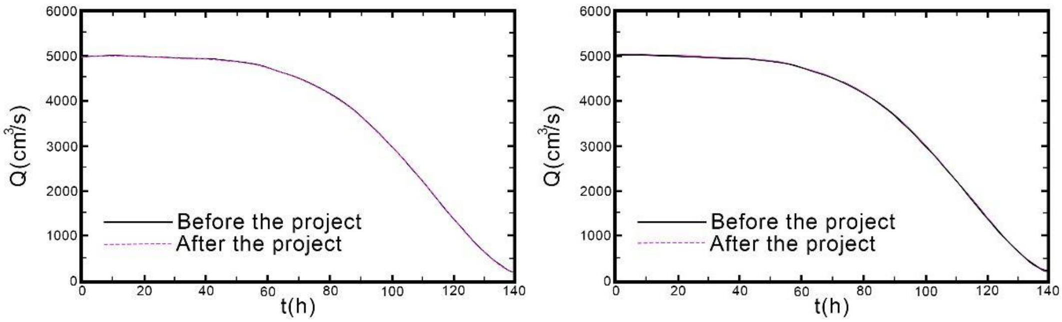
Calculations indicate that the proposed project will occupy approximately 10,300 m^3 of flood storage capacity within the Lahuradewa Lake detention area. This represents 0.0005 % of the total effective flood storage capacity of 1.918 billion m^3 for the Lahuradewa Lake flood detention area. Therefore, the construction of the project will have a negligible impact on the effective flood storage capacity of the flood detention area.

(2) Impact on Flood Diversion Flux

1) Current Outflow Conditions

Results from a two-dimensional hydraulic model indicate that changes in the first 70 hours remain negligible before and after project completion during the flood diversion process at Lahuradewa Lake. After 70 hours, the reduction in flood diversion flux begins to increase significantly. By 72.23 hours, the reduction reaches 0.38 m^3/s, accounting for 0.008 % of the designed flood diversion flux of 5,000 m^3/s [8]. The project construction has a minor impact on the inflow to the flood detention area.

Before and after the completion of the project, no changes are observed in the first 45 hours during the flood diversion and storage process at Lahuradewa Lake. From 50 to 100 hours, the reduction in flood diversion flux begins to increase significantly. By 67.27 hours, the reduction reaches 0.34 m^3/s, accounting for 0.007 % of the designed flood diversion flux of 5000 m^3/s. After 69.78 hours of flood diversion, the maximum increase in inflow is 0.28 m^3/s. The construction project has a minor impact on the inflow flux to the flood detention area (Fig. 2).



(a) Existing spillway **(b) Planned spillway**

Fig. 2. Inflow flux of flood processes before and after project implementation

(3) Impact on flow velocity processes in the flood diversion area

Table 3. Peak flow velocity and peak occurrence time at the selected points in the flood detention area (under current conditions)

Characteristic point	Peak flow velocity (m/s)			Corresponding peak occurrence time (h)		
	Before project	After project	Difference	Before project	After project	Difference
TD1	1.680	1.680	0.000	0.13	0.13	0.00
TD2	0.058	0.058	0.000	4.40	4.40	0.00
TD3	0.054	0.054	0.000	41.37	41.37	0.00
TD4	0.002	0.002	0.000	62.78	62.78	0.00
TD5	0.085	0.085	0.000	11.78	11.78	0.00
TD6	0.045	0.045	0.000	77.37	77.37	0.00
TD7	0.087	0.087	0.000	63.50	63.50	0.00
TD8	0.163	0.163	0.000	7.30	7.30	0.00
TD9	0.040	0.040	0.000	0.57	0.57	0.00
P1	0.003	0.003	0.000	41.78	41.83	0.05
P2	0.008	0.007	0.000	32.05	32.05	0.00
P3	0.002	0.002	0.000	60.45	60.48	0.03

Under both existing and planned spillway conditions, the project's influence on flow velocity processes remains consistent after the base project construction, with only slight differences in peak velocity values and their corresponding timing. Overall, the proposed project is located at a considerable distance from the flood diversion gates, resulting in limited flood obstruction effects. Flow velocities within the project area remain relatively low, and the construction has minimal impact on flow velocity processes and flow fields at various points within the flood detention area. (Table 3 and Table 4)

Table 4. Peak flow velocity and peak occurrence time at the selected points in the flood detention area (under planned conditions)

Characteristic point	Peak flow velocity (m/s)			Corresponding peak occurrence time (h)		
	Before project	After project		Before project	After project	
TD1	1.680	1.680	0.000	0.13	0.13	0.00
TD2	0.058	0.058	0.000	4.28	4.28	0.00
TD3	0.054	0.054	0.000	39.63	39.63	0.00
TD4	0.002	0.002	0.000	59.82	59.82	0.00
TD5	0.087	0.087	0.000	11.53	11.53	0.00
TD6	0.048	0.048	0.000	74.08	74.08	0.00
TD7	0.092	0.092	0.000	60.80	60.80	0.00
TD8	0.166	0.166	0.000	7.78	7.78	0.00
TD9	0.026	0.026	0.000	0.50	0.50	0.00
P1	0.003	0.004	0.000	40.08	40.15	0.07
P2	0.008	0.008	0.000	31.02	31.02	0.00
P3	0.002	0.002	0.000	57.95	57.97	0.02

(4) Impact on Flood Duration

Under both existing and planned spillway conditions, the arrival time of southern floodwaters at certain characteristic points is delayed following project construction. For instance, under existing spillway conditions, flood arrival at southern monitoring point P4 takes 38.70 hours before the project, while after construction; it takes 38.73 hours, a delay of 0.03 hours. Under the planned gate condition, at monitoring point P4, the flow arrival time before construction is 37.15 hours, and after construction, it is 37.18 hours, a delay of 0.03 hours. The arrival times of floodwaters at monitoring points on the east and west sides of the project site are largely unaffected by the project. When the designed flood storage water level is reached: - Under the existing spillway condition, the flood diversion duration is

137.73 hours both before and after the project. - Under the planned spillway condition, the flood diversion duration is 128.68 hours both before and after the project. No significant changes are observed under either condition.

(5) Impact on Flood Storage Water Levels

Under both current and planned conditions, the water level profiles show minimal differences, with nearly identical curves at characteristic points during the flood diversion process before and after project construction. The project construction exerts a negligible impact on flood storage water levels in the vicinity.

Impact on Flood Recession in the Flood Retention Area

(1) Impact on Flood Recession Flux

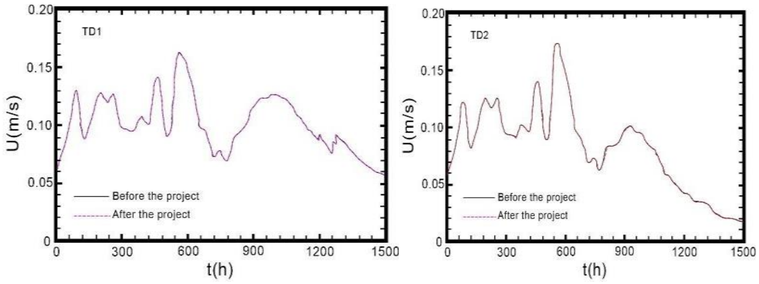
Calculations indicate that the receding flood flow remains largely unchanged after project construction. The proposed project has minimal effect on the flood recession process and maximum receding flood flux within the retention area.

(2) Impact on Water Levels within the Flood Detention Area

The flood discharge water level curve is relatively flat at characteristic points due to the extremely slow flood discharge process. Furthermore, the proposed project is located far from the flood diversion gates and close to the levee boundary. Therefore, after construction, the project will have almost no impact on the flood discharge water level curves at various points within the flood detention area.

(3) Impact on Flood Discharge Duration and Flow Velocity within the Flood Detention Area

Flow velocities will be lower than near the gate at reference points distant from the flood discharge gate after project construction, during flood receding. Given the project's distance from the flood discharge gate and proximity to the levee boundary, peak flow velocities and peak occurrence times will remain largely consistent before and after construction in the local project area and near the flood discharge gate. Fig. 3 compares the flow velocity profiles at reference points during flood receding before and after project construction.



(a)Feature point TD1 (b) Feature point TD2

Fig. 3. Comparison of flow velocity changes at characteristic points during flood recession before and after the project.

4.2. Impact Analysis of Construction Project on Seepage Safety of Flood Control Engineering

The construction project involves three excavation pits: Pit #1 for the Transfer Tower (Pit #1), Pit #2 for the Transfer Tower (Pit #2), and Pit #3 for the Substation, Working Tower, and Vehicle Transfer Station (combined into a single pit, Pit #3). Excavation Pit 2 is located 92.40 m from the toe of the backwater slope of the Mieganj along the Ganges River dike. The closest pile foundation is

87.64 m from the toe of the backwater slope of the Mirganj along the Ganges River dike. To ensure the safety of excavation pit construction and the dike, an evaluation of the project's impact on the seepage safety of flood control structures was required.

Typical Cross-Section and Model Simplification

Given the project site's proximity to the Ganges River relative to the Bhagirathi River, a typical cross-section perpendicular to the Phulwaria was selected to establish a two-dimensional numerical model. This model evaluated the project's impact on the dike's seepage stability. A three-dimensional model grid schematic was presented in Fig. 4.

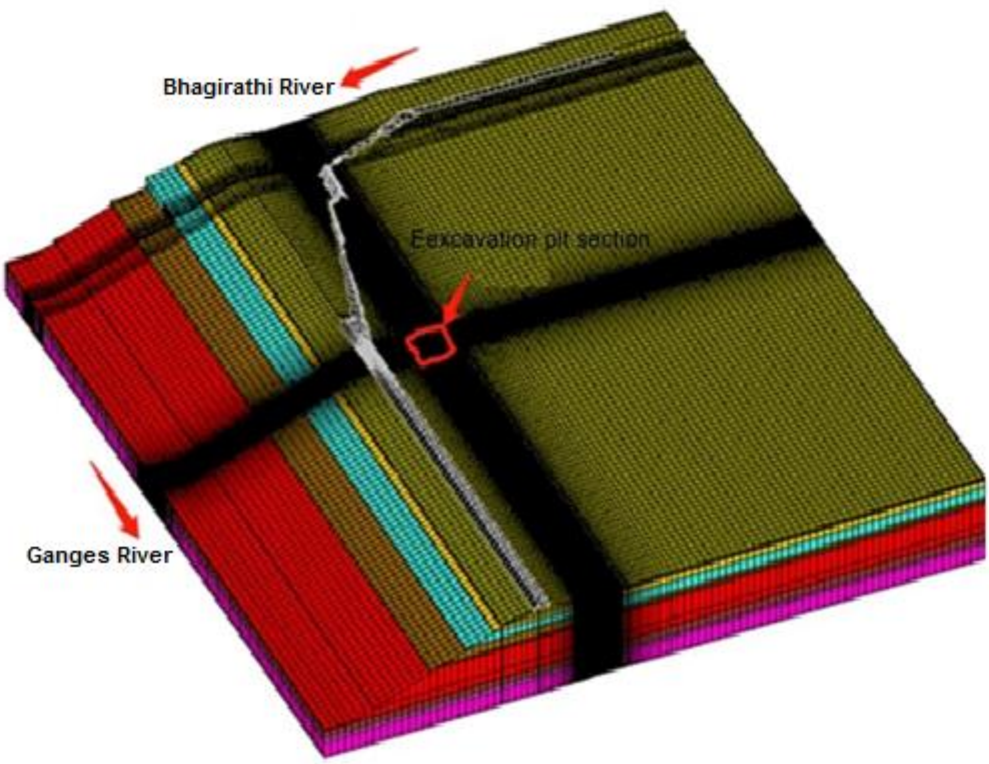


Fig. 4. Three-Dimensional model grid.

Effect Analysis of Construction Period Excavation Seepage Control Schemes

Table 5. Three-dimensional results of seepage control schemes for the construction period excavation.

Scheme	Groundwater level at Pit #2 (m)			Groundwater level at Pit #1 (m)			Pit Groundwater level at Substation, Working Tower,Vehicle Transfer Station (m)			Maximum slope ratio at foundation pit	Minimum buoyancy coefficient at foundation pit
	E1	E2	Does it meet the precipitation requirements?	F1	F2	Does it meet the precipitation requirements?	G1	G2	Does it meet the precipitation requirements?		
3d-ksq1	12.74	12.72	Yes	12.76	12.82	Yes	13.08	12.92	No	0.90	1.05
3d-ksq2	12.01	12.00	Yes	11.95	11.93	Yes	12.24	11.13	Yes	/	/
3d-xq1	19.30	19.03	No	18.78	18.55	No	20.70	18.31	No	3.73	0.25
3d-xq2	15.68	15.25	Yes	15.37	14.92	Yes	13.5	11.70	Yes	/	/

For excavation dewatering, a three-dimensional numerical stability model was established, as shown in Table 2. Seepage control effectiveness analyses were conducted for scenarios where the Bhagirathi River and Ganges River water levels corresponded to the dry season level and the flood control design level during the flood season. Based on the seepage field distribution of each scheme in the three-dimensional seepage numerical model, Table 5 presents the computational results for each scheme.

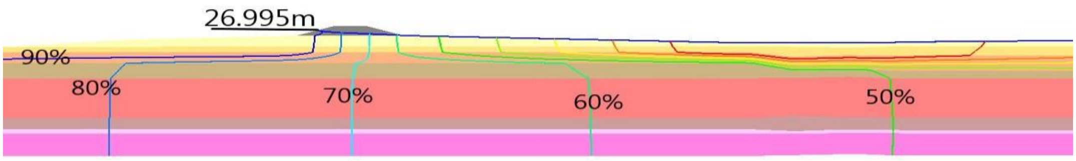
Analysis of the above findings indicates that during dry season construction, only the excavation of the working tower elevator shaft pit within Pit #3 requires activating two pumping wells. The dewatering volume is merely 959.69 m³/d. The design dewatering plan—utilizing one pumping well plus three standby wells—can lower groundwater within the pit area to at least 1.0 m below the excavation base. Thus, the groundwater can meet the groundwater requirements for excavation. However, during the flood season, this design fails to satisfy excavation requirements, as the soil layer beneath the excavation floor does not meet impermeability and buoyancy resistance standards. After increasing the number of dewatering wells to 15 based on this design, the dewatering capacity rises to 12,332.85 m³/d, lowering groundwater within the excavation area to approximately 0.5 m below the excavation base slab. Further lowering the water table would require even greater dewatering capacity. Therefore, the design scheme of one pumping well plus three standby wells cannot guarantee excavation safety during the flood season.

Analysis and Evaluation of the Impact of Excavation and Pile Foundations on Dike Seepage Safety

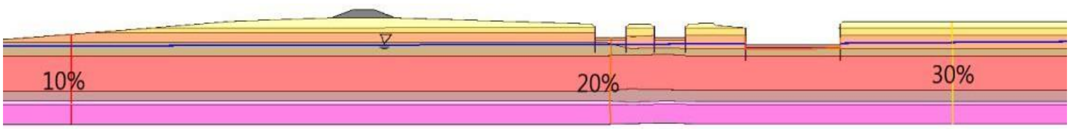
The results of the two-dimensional seepage numerical model calculations were shown in Table 6 for the excavation and pile foundation works on the dike. The corresponding contour lines were presented in Fig. 5.

Table 6. Results of the two-dimensional model

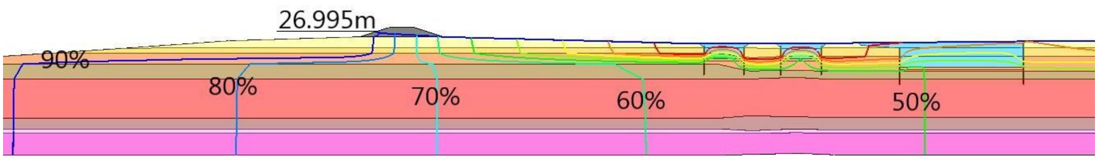
Calculation Scheme	Height of groundwater seepage segment in dike body (m)	Horizontal seepage gradient at dike foot	Vertical seepage gradient at dike foot	Maximum horizontal seepage gradient in excavation pit	Maximum vertical seepage gradient in excavation pit
2d-tr1	0.01	0.10	0.05	/	/
2d-sg1	0.01	/	/	/	/
2d-yx1	0.01	0.10	0.05	/	/
2d-yx2	0.01	0.10	0.04	/	/
2d-yx3	0.01	0.10	0.05	/	/



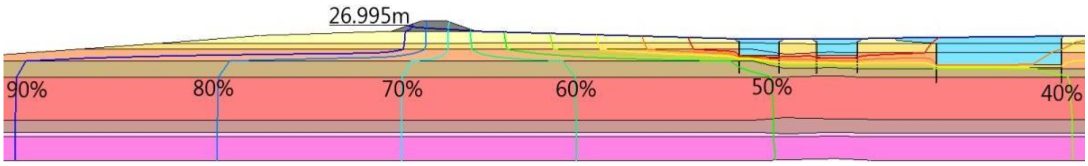
(a) Pre-construction contour lines for Scheme 2d-tr1.



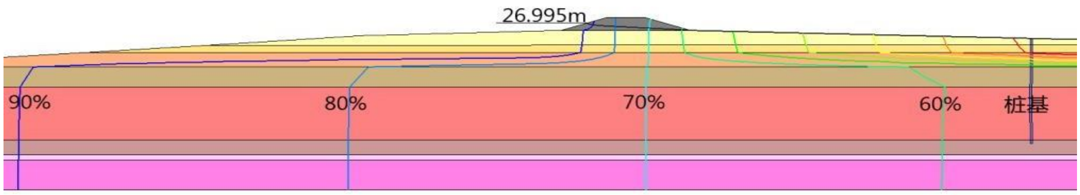
(b) Construction phase contour lines for Scheme 2d-sg1.



(c) Operational phase contour lines for Scheme 2d-yx1.



(d) Operational phase contour lines for Scheme 2d-yx2



Contour lines at the section with pile foundations nearest the dike during operation (Scheme 2d-yx3)

Fig. 5. Contour lines of different schemes.

Based on the above analysis, during dry season excavation, if proper excavation support and drainage measures are implemented to control seepage, the excavation works will have minimal impact on the seepage field of the dike body and foundation. The dike seepage meets safety requirements. The excavation pit satisfies impermeability and buoyancy resistance requirements. During the operational phase, the dike meets permeability stability requirements, and the project will have no significant impact on the dike's permeability stability.

4.3 Analysis and Evaluation of Flood Impacts on the Construction Project Submergence Impact Analysis

According to design documentation, the proposed project primarily consists of grain silos, a shallow circular silo transfer zone, comprehensive supporting service facilities, and production auxiliary areas. The flood storage water level in the detention area is 28.30 m (corresponding to an 85-meter elevation of 26.22 m). The current ground elevation in the project area ranges from 23.11 m to 23.67 m. During flood diversion operations, the inundation depth in the project area will be approximately 2.55 m to 3.11 m. The base elevation of the shallow round silos is 27.05 m, while that of the vertical silos ranges from 27.65 m to 28.65 m, both exceeding the flood storage water level of 26.22 m.

During flood diversion operations in the detention area, many zones will inevitably be submerged without protective measures such as the grain silos, shallow circular silo transfer zone, comprehensive supporting service facilities, and production auxiliary areas. However, since the minimum silo base elevations are all above the flood storage water level, the grain will not be flooded. It is essential to ensure that relevant project areas implement effective anti-seepage and flood prevention measures.

Analysis of Scouring and Sedimentation Impacts

Following the activation of the flood detention area, localized scouring may occur in certain sections of the project. Given the project's distance of 15.20 km from the flood diversion gate, peak flood velocities in the vicinity remain below 0.01 m/s. The flood diversion velocities within the project area are relatively low. Therefore, the flood diversion operation of the detention area will not cause scouring or sedimentation impacts on the project.

Countermeasures

Construction of Deep Excavations during Dry Season

Based on the three-dimensional numerical calculation results in Table 6, the designed drainage plan shall be implemented during the construction period when the water levels of the Ganges River and Bhagirathi River reach the flood control design level of 26.995m. This involves installing one observation well in each excavation area of the collection wells for Transfer Tower No. 1 and Transfer Tower No. 2, which shall also serve as standby wells. When one pumping well plus one observation well (also serving as a backup well) is arranged near the working tower elevator shaft excavation, the designed dewatering plan fails to meet the excavation dewatering requirements. The excavation base plate is fully confined, with the maximum groundwater gradient reaching 3.73—significantly exceeding the conventional allowable gradient of 0.50 for silty clay soil at the base plate level. The buoyancy coefficient is 0.25, far below the required buoyancy safety factor of 1.50. The pit bottom fails to meet impermeability and buoyancy resistance requirements. To meet requirements, 15 additional dewatering wells would be needed, with a pit dewatering volume of 12,332.85 m^3/d to barely satisfy excavation needs. The large number of wells and high dewatering volume pose significant risks. Therefore, deep excavation for this project should be conducted during the dry season.

Deep Excavation Backfill Seepage Prevention

The minimum distance between the construction excavation and the backwater side toe of the Ganges River main dike is 92.40 m. The excavation area is approximately 2400 m^2, with a perimeter of about 340 m. Excavation 3 has an opening area of about 1800 m^2 and a perimeter of about 225 m; Excavation depths range from 5.30 m to 8.00 m, with localized inner-pit excavation depths reaching 10.45 m. According to the calculation results in Table 6, both Scheme 2d-yx1 and Scheme 2d-yx2 are operational period schemes when the Yangtze River water level reaches the flood control design level of 26.995 m. The former scheme uses clay as backfill material with a permeability coefficient of 1.0×10^{-6} cm/s, while the latter uses plain backfill soil with a permeability coefficient of 9.0×10^{-4} cm/s, offering superior seepage control. It is recommended to use plain backfill soil for the excavation and implement effective seepage control measures.

Safety Monitoring of Excavation Pits and Dikes

Excavation pits 1#, 2#, and 3# employ a support system comprising a slope, sheet piles (double-row in localized sections), and a single row of steel pipe struts. The construction unit must strictly adhere to relevant specifications during foundation pit construction to ensure foundation pit and dike safety. During dry season construction, while implementing proper foundation pit support and drainage measures to control seepage, monitoring sections for dike settlement and horizontal displacement shall be established according to specifications during both the construction period and initial operation phase. Relevant observations shall be conducted, and any abnormalities detected must be addressed promptly.

Advance Closure and Cessation of Use During Flood Storage Area Operation

According to design data, the base elevation of the shallow round silos is 27.05 m, while that of the vertical silos ranges from 27.65 m to 28.65 m. Both elevations exceed the designed flood storage water level by 0.83 m to 2.43 m. During flood diversion operations in the detention area, those that will not be submerged, such as the grain storage facilities in the shallow round silos and vertical silos. However, other zones will be submerged, such as the transfer zones of the grain silos and shallow round silos, the ground areas of the comprehensive supporting service buildings, and the production auxiliary zones under 2.55m to 3.11m of water. These areas should be closed and decommissioned in advance, with flood prevention measures implemented.

Flood Control Emergency Response Plan Development for Construction and Operation Phases

Based on the site conditions during construction and operation phases, develop flood control emergency response plans covering emergency repairs for hazardous situations, flood prevention measures during reservoir operation, and evacuation of personnel and materials.

Ensure implementation of relevant emergency response measures.

CONCLUSIONS

The base protection project within the Lahuradewa Lake flood detention area is a point-distributed engineering facility, occupying 0.0005 % of the effective storage capacity (1.918 billion m^3). The construction of this project has a negligible impact on the effective flood storage capacity of the retention area. Two-dimensional hydraulic modeling indicates that the construction of the Indian Grain Logistics Emergency Base Project will have a negligible impact on the flood diversion flow rate, duration, diversion water level, and flow field dynamics within the flood detention area. The project's construction will not cause significant adverse effects on the operational use of the flood detention area. The impact of the Ganges River floods is minor on scouring and sedimentation for the construction project. During flood diversion operations, the inundation depth in the project area ranges from 2.55 m to 3.11 m. During foundation pit excavation in the flood season, the designed dewatering plan does not meet the requirements for impermeability and buoyancy resistance. During dry-season excavation, if proper excavation support and drainage measures are implemented, impermeability and buoyancy resistance requirements will be met. The project will have a minor impact on the seepage field of the dike body and foundation, with dike seepage meeting safety requirements.

Construction of deep excavations #1, #2, and #3 should occur during the dry season to mitigate or eliminate adverse impacts from both the Yangtze River floods and the base project. Countermeasures include: implementing seepage prevention for backfilled deep excavations; conducting safety monitoring of excavations and dikes; preemptively closing and ceasing use of the flood detention area during its operational period; and preparing flood control contingency plans for both the construction and operational phases.

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