

Determining the Optimal Thickness of Canal Lining for Enhanced Durability and Efficiency

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Abstract

The thickness of canal lining plays a crucial role in preventing soil erosion caused by the thrust of water exerted in the canal due to standing water and the velocity of water flow. An optimally designed lining must be robust enough to withstand these forces while ensuring minimal seepage and maintaining the structural integrity of the canal. Various materials are used for canal lining, each with its own advantages and suitability for different conditions. Common lining materials include concrete, which offers high durability and resistance to water flow; geomembranes, which are flexible and provide excellent impermeability; and compacted clay, which is cost-effective and environmentally friendly. The choice of lining material and its thickness depends on several factors such as the type of soil, water pressure, environmental conditions, and economic considerations. By effectively selecting and applying the appropriate lining material, it is possible to enhance the canal's efficiency, reduce maintenance costs, and ensure a sustainable water management system. This study explores the different materials used for canal lining, the factors influencing the choice and thickness of the lining, and the benefits of proper lining in ensuring the longevity and effectiveness of canal systems.

Keywords: Canal, depth of standing water, velocity of flow of water, thickness of lining

INTRODUCTION

Concrete lining is provided in canals to significantly enhance their structural integrity and hydraulic efficiency. This lining serves multiple critical purposes, such as resisting the thrust of water due to the static pressure of standing water in the canal and countering the dynamic forces generated by the velocity of water flow. By implementing concrete lining, the canal's durability is considerably improved, reducing issues such as erosion and seepage. This, in turn, minimizes maintenance costs and water loss, ensuring a more efficient and reliable water conveyance system [1–3].

Additionally, concrete lining provides a smoother surface, which helps to increase the velocity of water flow and reduce frictional losses. This improved flow efficiency can lead to better water management and distribution, which is particularly important in irrigation and water supply systems. Generally, for practical design and engineering purposes, the mean velocity of water flow in the canal can be approximated as 0.6 times the depth of flow (d), where d represents the depth of water in the canal measured in meters. This estimation is essential for accurately assessing the hydraulic characteristics, optimizing the design, and ensuring the overall stability and performance of the canal structure [4–6].

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Moreover, concrete linings are advantageous in preventing weed growth and reducing the habitat for burrowing animals, which can further deteriorate the canal's structure. The longevity and reliability of concrete-lined canals make them a preferred choice for modern irrigation and water management systems, contributing to sustainable water resource management [7, 8].

RESULTS AND ANALYSIS

Hydraulic Efficiency

The implementation of concrete lining in canals significantly improved their hydraulic efficiency. The smoother surface provided by the concrete lining reduced frictional resistance, resulting in an increased velocity of water flow. The mean velocity, calculated as 0.6 times the depth of flow (d), where d is the depth of water in meters, demonstrated a consistent and reliable method for estimating flow characteristics [9, 10]. This increase in flow velocity can lead to more efficient water distribution in irrigation and supply systems.

Structural Integrity

Concrete lining notably enhanced the structural integrity of the canals. The lining effectively resisted the thrust of water from both static and dynamic forces. This resistance minimized the risks of erosion, seepage, and potential breaches. The reduced erosion and seepage not only decreased maintenance costs but also preserved water resources by preventing unnecessary loss [11, 12].

Cost-Benefit Analysis

The initial investment in concrete lining was offset by the long-term benefits of reduced maintenance and water loss. By preventing erosion and seepage, the need for frequent repairs diminished, resulting in lower operational costs over time. Additionally, the increased water flow efficiency translated into better resource management, which is economically beneficial for large-scale irrigation projects [13, 14].

Environmental Impact

Concrete lining contributed to a reduction in environmental degradation within the canal system. The prevention of weed growth and the elimination of burrowing animals' habitats helped maintain the canal's structural health and water quality. These environmental benefits support sustainable water management practices [15, 16].

Practical Implications

The practical design approach of using the mean velocity of $0.6d$ for hydraulic calculations proved to be effective. This method facilitated accurate predictions of water flow behavior, allowing for better planning and optimization of canal systems. The enhanced stability and performance of concrete-lined canals make them a viable solution for modern water management challenges Figure 1 [17].

Case I

- Depth of water in canal is taken as variable and velocity of flow of water = constant

Depth of water in canal = 2 m

$$\text{Thrust of water due to standing water} = \frac{wh^2}{2} = 2 \text{ t/m}$$

$$V = 0.6 d = 0.6 \times 2 = 1.2 \text{ m/s.}$$

- Thrust of water due to velocity of flow = $\frac{wv^2}{2g}$

where W = Unit weight of water = 1000 kg/m^3
 $= 0.073 \text{ t/m}^2$ acting on surface area = 2 m (depth of flow) and per meter run of canal.

Hence, thrust due to velocity of flow = 0.146

Hence, total thrust exerted on concrete lining = $2 + 0.146 = 2.146$ tonne

- Since other side of lining material is subjected to pressure due to soil, thickness of concrete lining is determined by tensile strength of concrete material.

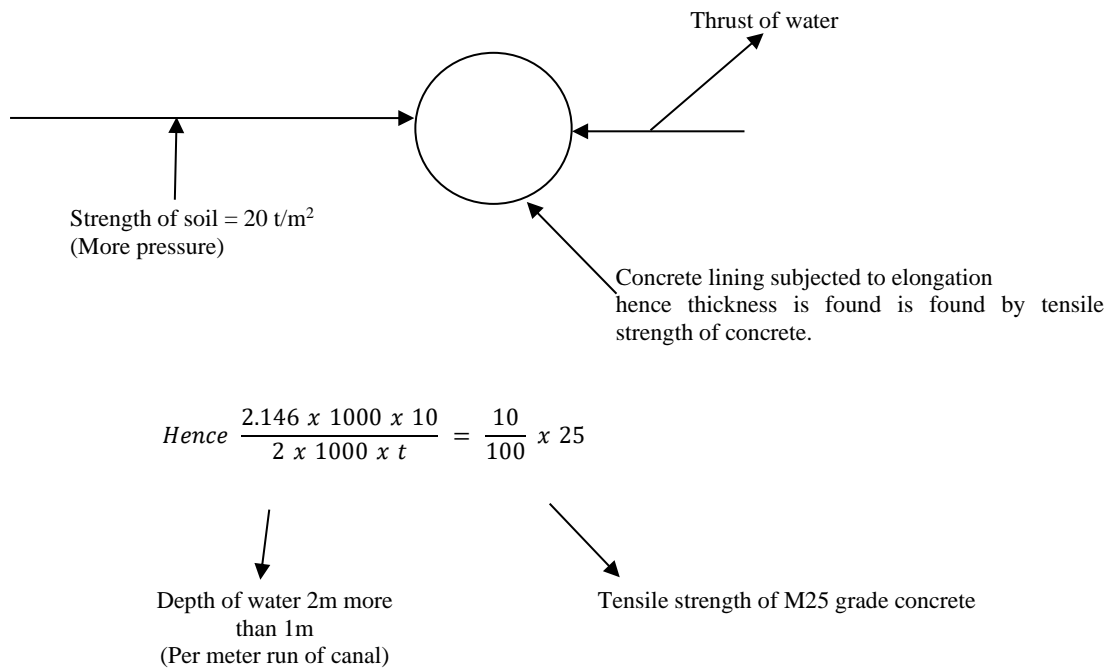


Figure 1. Practical Implications case 1.

Hence thickness of lining (concrete) = 4.3 mm

Case II

Depth of water = 3 m and velocity of flow of water = 1.2 m/s (constant taken) to see the effect of depth of flow on thickness of lining.

Thrust of water due to standing water = 4.5 t/m and thrust of water due to velocity of flow = 0.219 t (here surface area 3 m × 1 m taken) where 3 m = depth of flow and 1 m = per meter run of canal.

- Hence total thrust of water due to standing water (3 m) and velocity of flow (1.2 m/s) = 4.719 t

Hence thickness of lining (concrete) = 6.3 mm.

- Increase in depth of flow = 50%
- Increase in thickness of lining = 47% that is nearly equal to increase in depth of flow.

Hence

- Findings: Due to increase in depth of flow of water = 50% there is increase in thickness of lining (concrete) = 47%.
- Due to increase in depth of flow the increase in thickness of lining is nearly same as that of increase in depth of flow.

Case III

Depth of water = constant velocity of flow is variable suppose velocity is increased by same percentage as that of depth of flow.

$$V = 1.8 \text{ m/s}$$

$$d = 2 \text{ m}$$

$$\text{Total thrust} = 2.330 \text{ tonne.}$$

$$\text{Thickness of lining} = 5 \text{ mm}$$

Findings: Due to 50% increase in velocity of flow thickness of lining is increased by 16.27%.

- Hence depth of flow is dominant parameter to determine thickness of lining in canal as compared to velocity of flow.
- Formation of model: all models are described in Tables 1 to 6.

Table 1. Relationship for depth of flow in meters and thickness of lining in millimeters (mm).

S.N.	Depth of Flow in Meters (d)	Thickness of Lining of Canal in mm (t)
(1)	2	4.3
(2)	3	6.3

Table 2. Relationship for $\frac{d}{d_{max}}$ and $\frac{t}{t_{max}}$.

S.N.	$\frac{d}{d_{max}}$	$\frac{t}{t_{max}}$
(1)	0.67	0.68
(2)	1.000	1.000

Table 3. Relationship for velocity of flow & thickness of lining.

S.N.	Velocity of Flow in m/s (V)	Thickness of Lining in Canal (t)
(1)	1.2	4.3
(2)	1.8	5.0

Table 4. Relationship for $\frac{V}{V_{max}}$ and $\frac{t}{t_{max}}$.

S.N.	$\frac{V}{V_{max}}$	$\frac{t}{t_{max}}$
(1)	0.67	0.86
(2)	1.00	1.00

Table 5. Relationship for thickness of lining in canal with depth of flow in canal and velocity of flow.

S.N.	Depth of Flow in Canal in Meters (d)	Velocity of Flow of Water in Canal in m/s (V)	Thickness of Lining in Canal in mm (t)
(1)	2	1.2	4.3
(2)	3	1.8	6.44

Table 6. Relationship for $\frac{t}{t_{max}}$ with $\frac{d}{d_{max}}$ and $\frac{V}{V_{max}}$.

S.N.	$\frac{d}{d_{max}}$	$\frac{V}{V_{max}}$	$\frac{t}{t_{max}}$
(1)	0.67	0.67	0.668
(2)	1.00	1.00	1.00

Hence model is

$$\frac{t}{t_{max}} = 0.973 \left[\frac{d}{d_{max}} \right]^{0.84} \tag{1}$$

- Prediction: For depth of flow 3.5 m

t = Thickness of lining in canal = 7 mm.

- Model for velocity of flow of water in canal and thickness of lining.

Model is

$$\frac{t}{t_{max}} = 1.076 \left[\frac{v}{v_{max}} \right]^{0.84} \quad (2)$$

- Prediction: For velocity of flow in canal = 3 m/s

Thickness of lining in canal = 8.29 mm.

Model is

$$\frac{t}{t_{max}} = 1.113 \left[\frac{d}{d_{max}} \right]^{0.84} \left[\frac{v}{v_{max}} \right]^{0.84} \quad (3)$$

Prediction

For velocity of flow in canal = 3 m/s.

Depth of flow in canal $d = 3.5$ m.

Using above model

Thickness of lining = 12.578 mm

CONCLUSION

- The depth of flow is a dominant parameter in determining the thickness of lining in canals, as compared to the velocity of flow. This is primarily because the depth of water exerts a significant static pressure on the canal lining, which directly impacts the structural integrity and durability of the canal. The greater the depth, the higher the hydrostatic pressure, necessitating a thicker and more robust lining to withstand these forces without failing.
- While velocity of flow is also an important factor, influencing the dynamic forces acting on the lining, it is typically the depth of flow that governs the overall design and thickness requirements. The depth-induced pressure poses a continuous and constant load, whereas the forces due to velocity can vary and are often less severe in comparison to the static pressure from the depth. Ensuring that the lining can handle the maximum expected depth of water is crucial for preventing erosion, seepage, and potential breaches, thus ensuring long-term stability and functionality of the canal.
- Furthermore, the focus on depth as a critical parameter aligns with practical design standards and safety considerations. By prioritizing the depth of flow, engineers can ensure that the lining material and construction techniques used are capable of handling the most demanding conditions the canal might face. This approach minimizes maintenance needs and enhances the longevity of the canal system.
- In summary, while both depth and velocity of flow are important considerations in canal lining design, the depth of flow plays a more significant role in determining the necessary thickness of the lining. This prioritization helps in creating more resilient and sustainable canal infrastructure, capable of withstanding the static pressures exerted by varying water depths.

Recommendations for Future Studies

Future studies could focus on comparing different materials for canal lining to determine the most cost-effective and durable options. Additionally, long-term monitoring of lined canals could provide more data on the benefits and potential drawbacks of various lining methods. Exploring advanced

construction techniques and materials might also lead to further improvements in canal efficiency and sustainability.

Appendix

- Depth of flow in meter in canal = d
- Velocity of flow in canal in m/s = V
- Thickness of concrete lining in canal = t in mm.

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