# Preparation of Design Charts for Estimation of the Length of an Upstream Impervious Blanket in a Homogenous Earth Dam

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## Abstract

Earth dams are constructed mainly from soil. A homogenous earth dam is composed of only one material. The seepage through such dams is quite high. Upstream impervious blanket is one of the methods used to control seepage through the dam foundations. Bennet's method is one of the commonly used methods to design an impervious upstream blanket.

Design charts are developed relating the length of blanket, total reservoir head, total base width of the dam (excluding downstream drainage), the coefficient of permeability of the blanket material, blanket thickness, foundation thickness, and coefficient of permeability of the foundation soil, based on the equations governing the Bennet's method for a homogenous earth dam with a blanket of uniform thickness.

The length of the upstream impervious blanket can be determined by using the developed charts. The length of the blanket is inversely proportional to the coefficient of permeability of the blanket material. The length of blanket is directly proportional to the total reservoir head, total base width of the dam (excluding downstream drainage), blanket thickness, foundation thickness, and coefficient of permeability of the foundation soil.

**Keywords :Earth dams, homogenous, blanket, permeability, seepage, upstream, charts.**

## الخلاصة

ان السد الترابي ينشا بصورة رئيسة من التربة. السد الترابي المتجانس يتركب من مادة واحدة فقط. الرشح او التسرب خلال هذه السدود عالي جدا. ان الطبقة الصماء في مقدم السد هي واحدة من الطرق المستعملة للسيطرة على التسرب او الرشح خلال اساس السد. طريقة بينت هي واحدة من اشهر الطرق المستعملة لتصميم الطبقة الصماء في مقدم السد.

تم اعداد مخطط بياني يربط العلاقة بين طول الطبقة الصماء ،شحنة الخزان الكلية ،عرض قاعدة السد(ماعدا مبزل مؤخر السد) ،معامل النفاذية لمادة الطبقة الصماء ،سمك الطبقة الصماء، سمك اساس السد، ومعامل النفاذية لتربة اساس السد بالاعتماد على المعادلات التي تحكم طريقة بينيت لسد ترابي متجانس وبسمك طبقة صماء ثابت .

يمكن الحصول على طول الطبقة الصماء باستعمال المخطط البياني المعد. يتناسب طول الطبقة الصماء عكسيا مع معامل النفاذية لمادة الطبقة الصماء ويتناسب طرديا مع شحنة الخزان الكلية ، عرض قاعدة السد(ماعدا مبزل مؤخر السد)، سمك الطبقة الصماء، سمك اساس السد، معامل النفاذية لتربة اساس السد.

## Introduction

Earth dams are constructed mainly from soil. A homogenous earth dam is composed of only one material. Generally, the material used is either semi-impervious or impervious soil to limit the seepage through the dam. Homogenous earth dams are built where only one type of material is economically available near the site and the height of the dam is low. Upstream impervious blanket is one of the methods used to control seepage through the foundation. An upstream impervious blanket is usually economical. The soil used in the blanket should have a very low permeability. The thickness and length of the upstream blanket depend upon a number of factors, such as; the permeability of the blanket material, thickness of pervious foundation stratum, and the maximum depth of water in the reservoir. A longer length upto about 10 times the head is generally required for the control of sub-surface erosion and for reducing seepage to desirable limits. The thickness of the blanket usually varies from 1.5 to 3 m (Arora, 1996).

Uginchus and Roboty, 1935, discovered the differential equation of seepage in upstream blanket dams and resolved it for the dams with finite and infinite length of the blanket.

The seepage of water in the body and foundation of clay dams is one of the most important subjects in earth dam studies. This kind of seepage that is known as drainage water, is important from viewpoints of calculation of water wasting that may be a considerable percentage, stability of dam, calculation of sub pressure, calculation of thickness and length of drainages, the necessity of injection, dam wall plan and many other factors (Biswas, 2005).

Goharnejad, H., Noury, M. , Shamsaie, A., and Goharnejad, A., 2010, discussed decrease the seepage in dam's foundation, the effects of upstream clay blankets, its advantages and limitations, and the execution methods. The SEEP/W software (GEO-SLOPE Company) has been used for modeling and analyzing the seepage. The geometry and dimension of the upstream clay blanket have been studied and the results have been compared with the results of Bennet equation. Based on the above analysis and considering Bennet equation, it is suggested to use the clay blanket with the length of 150m and thickness of 0.75m which shall extend over the upstream shell. This will result in a seepage rate decreased by about 73% which seems to be more effective rather than other available methods.

The main objectives of this paper are to develop charts relating the length of blanket, total reservoir head, total base width of the dam (excluding downstream drainage), the coefficient of permeability of the blanket material, blanket thickness, foundation thickness, and coefficient of permeability of the foundation soil, based on the equations governing the Bennet's method for a homogenous earth dam with a blanket of uniform thickness.

## Governing Equations

Bennet's method is one of the methods used to design an impervious upstream blanket. The Bennet solution is based on the following assumptions:

1. The permeability of the foundation soil is very large (at least 10 times) as compared to that of the blanket material,
2. The water seeps vertically through the blanket and then it moves horizontally through the foundations,
3. There is no seepage through the dam,
4. There is no natural impervious layer over or within the pervious foundation, and
5. A vertical line passing through the upstream end of the blanket is an equipotential line at the full reservoir level.

**Fig. 1** is a schematic representation of an earth dam with a homogenous section provided with an impervious blanket. Details of this method can be found in reference ( Bennet, 1946). The pressure head dissipated through the blanket can be expressed by:

$$\frac{d^2 h}{dx^2} = \frac{K_b h}{K_f z_b z_f} \qquad (1)$$

in which

$h$=loss of head through blanket, (L),

$x$=horizontal distance along blanket, (L),

$K_b$= coefficient of permeability of the blanket material, (L/T),

$K_f$=coefficient of permeability of the foundation soil, (L/T),

$Z_b$=blanket thickness, (L), and

$Z_f$= thickness of the pervious foundation stratum, (L).

The solution of **eq. (1)** was obtained for the case of a blanket of uniform thickness throughout its length. Therefore, **eq. (1)** may be written as

$$\frac{d^2h}{dx^2} = a^2h \qquad (2)$$

Where

$a$ is constant given by $\sqrt{\frac{K_b}{K_f Z_b Z_f}}$

When **eq. (2)** is solved for the finite length of the blanket it yields:

$$X_r = \frac{1}{a}\left(\frac{e^{2ax}-1}{e^{2ax}+1}\right) \qquad (3)$$

***Equivalent resistance of the foundation,($X_r$),*** it is a measure of the efficiency of the blanket of any length $x$. It is defined as the length of a prism of the foundation material of thickness $Z_f$ and permeability $K_f$ which under a head loss $h$ would deliver a flow equal to that actually passes through the blanket (Arora, 1996).

The loss of head through the blanket of uniform thickness is given by:

$$h_o = \left(\frac{X_r}{X_r + X_d}\right) * H \qquad (4)$$

Where

$h_o$=loss of head up to the end of the blanket, (L),

$H$=total reservoir head, (L), and

$X_d$=total base width of the dam (excluding downstream drainage), (L).

The percentage reduction in discharge ($P$) is given by:

$$P = \left(\frac{X_r}{X_r + X_d}\right) * 100 \qquad (5)$$

## Design Procedure for the Blanket of Uniform Thickness

The procedure that was applied to obtain blanket length starts by assuming a suitable thickness of the blanket. The value of the parameter $a$ is than obtained. Then, the equivalent resistance is calculated from **eq. (3)** by assuming a suitable length of the blanket. Then, the head dissipated through the blanket is determined by applying **eq. (4)** for the assumed length. The percentage reduction in the discharge is calculated by applying **eq. (5)**. Then, computations of equivalent resistance, head dissipated, and percentage reduction in the discharge is repeated for several lengths of the blanket. The maximum length of the blanket is selected such that if the length is increased. There is no appreciable change in the head dissipated and the percentage reduction in discharge.

The design procedure for a blanket of uniform thickness was computerized by using Visual basic language to facilitate the design procedure for the blanket of uniform thickness. **Fig. 2** is a flow chart to describe the main steps of the computer program used to obtain the length of the blanket.

## Chart Design for the Blanket of Uniform Thickness

The computer program was used to develop design charts relating the length of blanket, the parameter $a$, total reservoir head, and total base width of the dam (excluding downstream drainage). The inputs used included thickness of blanket, ranging from 0.5m to 10m, thickness of the pervious foundation stratum ranging from 10m to 100m, coefficient of permeability of the blanket material ranging from 0.02m/d to 0.1 m/d, coefficient of permeability of the foundation soil ranging from 20m/d to 100m/d, and the parameter $a$ was calculated accordingly . The height of the dam ranged between 5m and 50m. It was assumed that the minimum free board is 3m. The upstream and downstream slopes of the dam ranged between 2:1 and 4:1. The crest width (i.e. top width) was varied from 6 to 12m. Horizontal drainage blanket was not longer than two-thirds of the base width of the dam. Total base width of the dam (excluding downstream drainage) was obtained from the following relationship:

$$X_d = (b + (m_1 + m_2) * H_t) - D \qquad (6)$$
$$H_t = H + F.B \qquad (7)$$

in which

*b*=crest width, (L),
$m_1$=upstream slope,
$m_2$=downstream slope,
$H_t$=height of the dam, (L),
*D*= downstream drainage width, (L), and
*F.B*=free board, (L).

A blanket length increment of 1m was used, and a calculation tolerance limit of 0.002 units, for both head dissipated and percentage reduction in discharge, was adopted.

By applying regression technique relationship among the length of blanket in meters, the parameter *a*, total reservoir head in meters, and total base width of the dam (excluding downstream drainage) in meters was obtained, with a correlation coefficient of 0.935; this relationship is expressed as follows:

$$L_b = 107.6H^{0.38} X_d^{0.21} e^{-152.53a} \qquad (8)$$

In which

$L_b$=length of the blanket, (L).

**Fig. 3** shows the design charts relating the length of blanket, the parameter *a*, total reservoir head, and total base width of the dam (excluding downstream drainage). The length of the blanket is inversely proportional to the parameter *a* and directly to the total reservoir head and total base width of the dam (excluding downstream drainage). From the results depicted in **Fig. 3** it can be seen that at small values of the parameter a, the effect of the total base width of the dam (excluding downstream drainage) and total reservoir head on the length of the blanket is larger than its effect at the large values of a. At small total base width of the dam (excluding downstream drainage) the effect of the parameter *a* on the length of the blanket is smaller than its effect at large widths. At low total reservoir head the effect of the parameter *a* on the length of the blanket is smaller than its effect at high heads.

Several factors were taken into consideration when trying to investigate the effect of the parameter *a* on the length of the blanket. These factors include blanket thickness, thickness of the pervious foundation stratum, coefficient of permeability of the blanket material, and coefficient of permeability of the foundation soil on the blanket length. Total reservoir head was set at 17m, and total base width of the dam (excluding downstream drainage) was set at 77m. **Fig. 4** shows the effect of blanket thicknesses and thickness of the pervious foundation stratum on the length of the blanket with the coefficient of permeability of the blanket material being 0.07m/d, and coefficient of permeability of the foundation soil being 70m/d. The length of the blanket is directly proportional to the blanket thickness and foundation thickness.

**Fig. 5** shows the effect of using different coefficients of permeability of the foundation soil and coefficient of permeability of the blanket material on the length of the blanket with a blanket thickness of 1.5m and a thickness of the pervious foundation stratum of 10m. It is clear that the length of the blanket is inversely proportional to the coefficient of permeability of the blanket material and directly proportional to the coefficient of permeability of the foundation soil.

## Conclusions

The following conclusions can be withdrawn:

1. The length of the upstream impervious blanket can be determined by using the developed charts relating the length of blanket, the parameter *a*, total reservoir head, and total base width of the dam (excluding downstream drainage), based on the equations governing the Bennet's method for a homogenous earth dam with a blanket of uniform thickness.
2. The length of the blanket is directly proportional to the total reservoir head and total base width of the dam (excluding downstream drainage).
3. The length of the blanket is directly proportional to the blanket thickness and foundation thickness.
4. The length of the blanket is inversely proportional to the coefficient of permeability of the blanket material and directly proportional to the coefficient of permeability of the foundation soil.

## Recommendations

The following recommendations are found to provide a guide for further studies:

1. Prepare design charts for the length of upstream impervious blanket for a homogenous earth dam with a blanket of variable thickness.
2. Prepare design charts for the length of upstream impervious blanket for a zoned earth dam for the two cases: blanket of uniform and variable thickness.
3. Study the optimal design criteria for the upstream impervious blanket.

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## List of Symbols

$a$ =a parameter,
$b$=crest width, (L),
$D$= downstream drainage width, (L),
$F.B$=free board, (L),
$h$=loss of head through blanket, (L),
$H$=total reservoir head, (L),
$h_o$=loss of head up to the end of the blanket, (L),
$H_t$=height of the dam, (L),
$K_b$= coefficient of permeability of the blanket material, (L/T),
$K_f$=coefficient of permeability of the foundation soil, (L/T),
$L_b$=length of the blanket, (L),
$m_1$=upstream slope,
$m_2$=downstream slope,
$P$=percentage reduction in discharge, (%),
$x$=horizontal distance along blanket, (L),
$X_d$=total base width of the dam (excluding downstream drainage), (L),
$X_r$=Equivalent resistance of the foundation,
$Z_b$=blanket thickness, (L), and
$Z_f$= thickness of the pervious foundation stratum, (L).

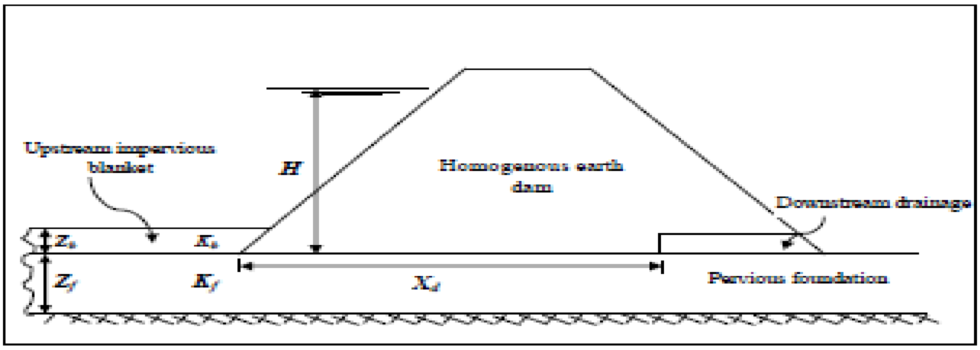


**Figure. (1). A Schematic Diagram of a Homogenous Earth Dam.**

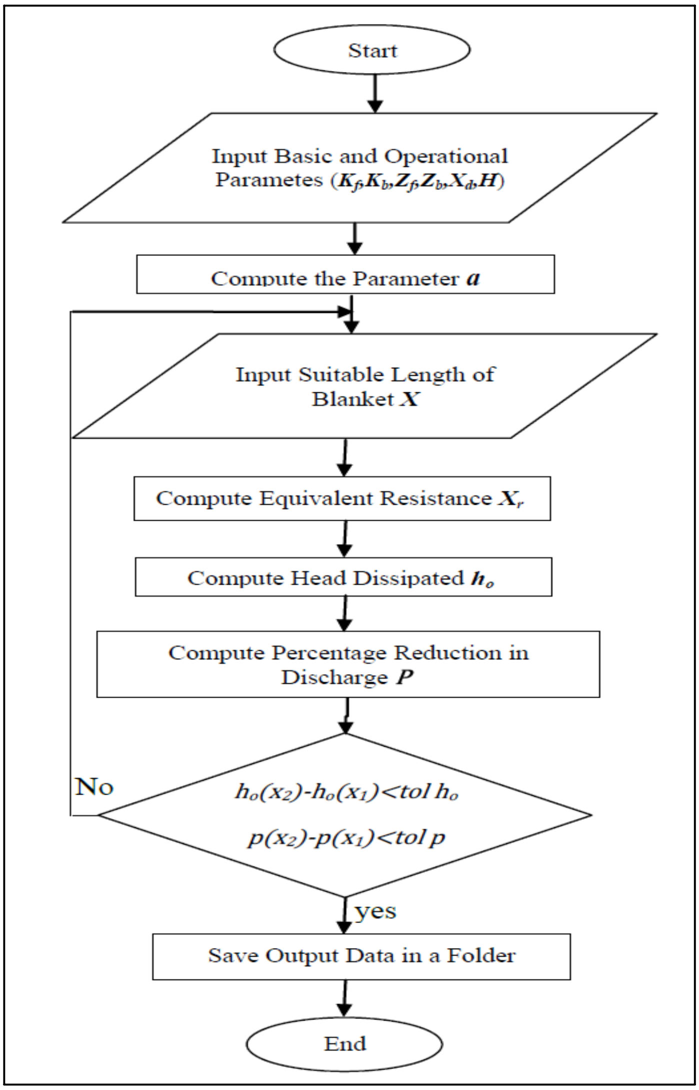


**Figure. (2). Flow Chart of the Computer Program Used to Obtain the Length of the Blanket.**

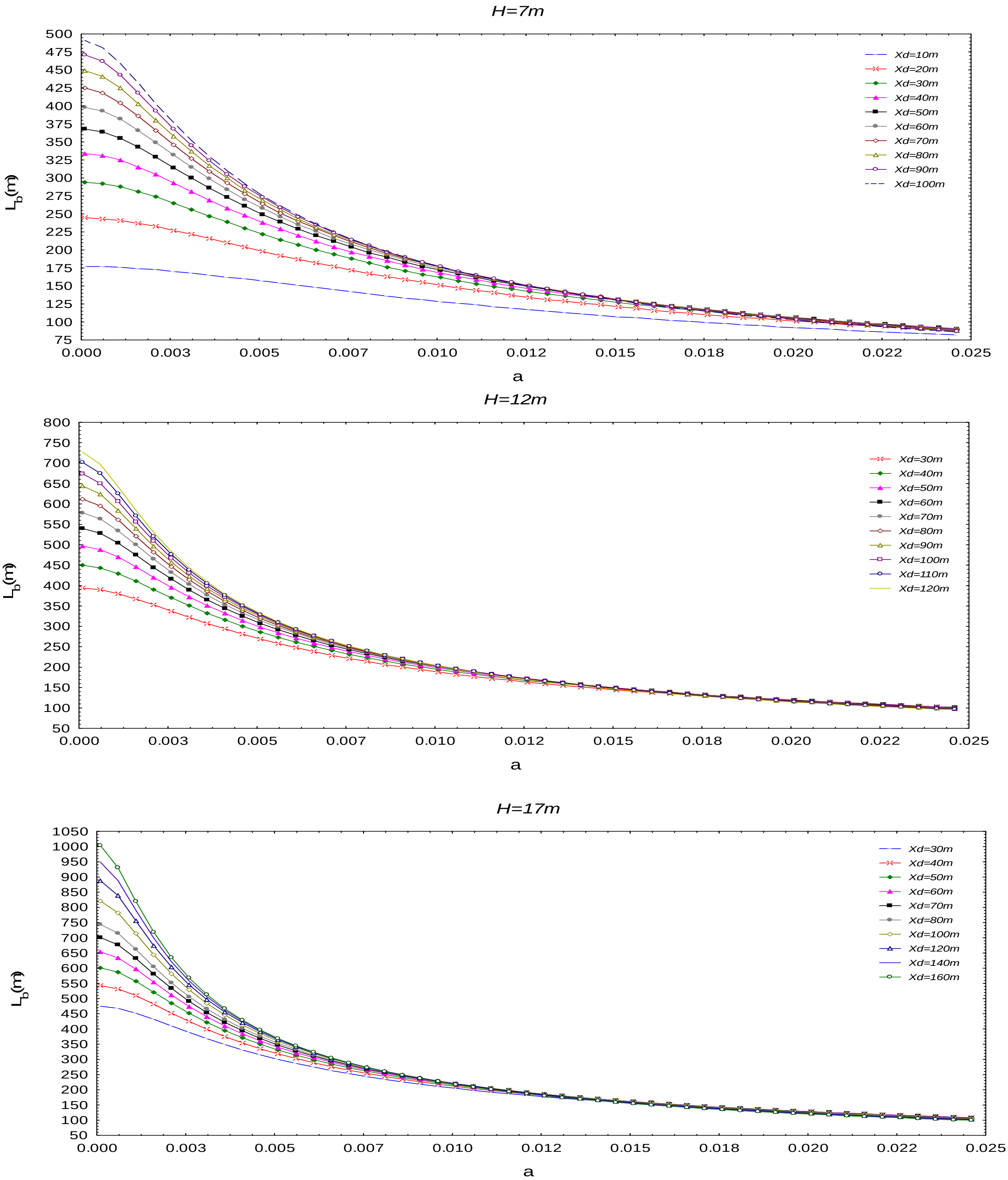


**Figure.(3). Design Chart for the Length of Upstream Impervious Blanket for a Homogenous Earth Dam for the Blanket of Uniform Thickness.**

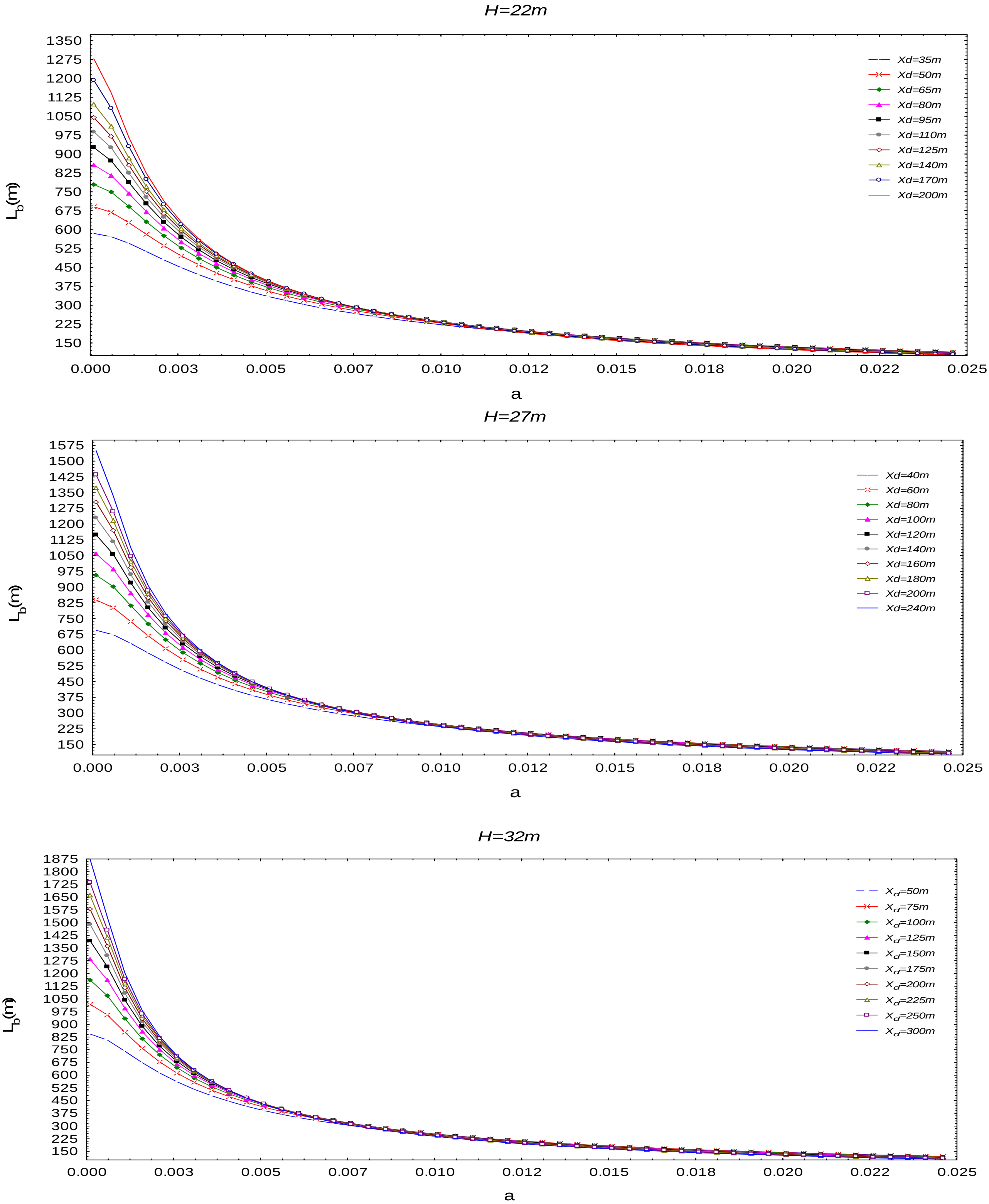


**Figure.(3). Cont.**

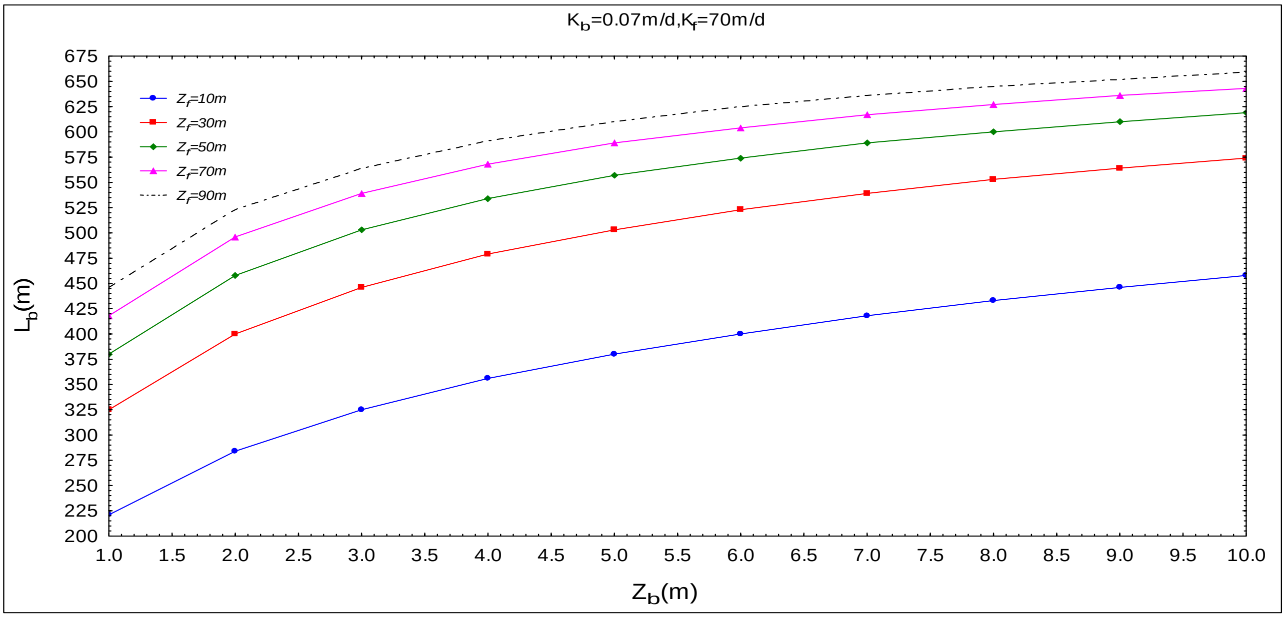


**Figure. (4). Effect of Using Different Blanket Thicknesses and Thickness of the Pervious Foundation Stratum on the Length of the Blanket.**

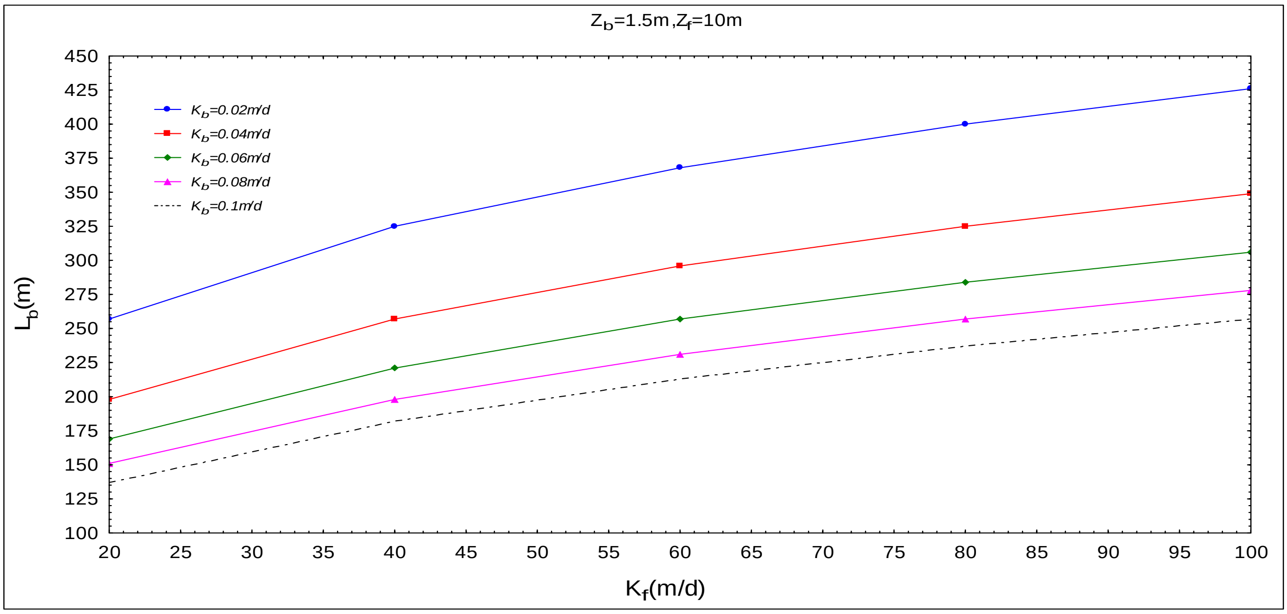


**Figure. (5). Effect of Using Different Coefficients of Permeability of the Foundation Soil and Coefficient of Permeability of the Blanket Material on the Length of the Blanket.**