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STABLE SIDE SLOPE FOR EARTHEN TRAPEZOIDAL WATERCOURSES IN SAND DUNE AREAS OF THAL REGION OF PAKISTAN

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Abstract- Earthen trapezoidal watercourses are often considered as water channels that are easy to construct and operate however they are not so simple. This is particularly the case for earthen channels in sand dune areas of thal region of Pakistan where they are subjected to a cycle of wetting and drying associated with release of water in Greater Thal Canal. This is actually a flood canal off-takes at RD 180+222 from the Chashma - Jheulm (CJ) link canal near Adhi Kot in district Khushab being operated from 15 April to 15 September. Therefore, watercourses in sand dune areas have to undergo stability analysis with water and without water. One of the major parameter to be taken into account for stability is the side slope of earthen trapezoidal channel. In this respect small change in side slope of earthen trapezoidal watercourse lead to significant differences in stability, hydraulic efficiency and cut/fill volume. Geo5 Slope Stability model was used for stability analysis and Micro Soft Excel for watercourse design and calculation of Cut/Fill volume. Geo5 Slope Stability software was used to compute factor of safety by circular slip surface and polygonal slip surface. In circular slip surface factor of safety was computed using Bishop, Fellenius/Petterson, Spencer, Janbu and Morgenster-Price method, whereas in polygonal slip surface Sarma, Spencer, Janbu and Morenster-Price methods were employed to work out factor of safety. Stability analysis was performed on U/S face and D/S face for two conditions with water and without water in channel. In all the cases stability increases when the side slope (Horizontal to Vertical) of the earthen trapezoidal water channel increases leading to an increase in cut/fill volume.

Keywords- Earthen, stable, stability analysis, sand dune, side slope, thal, trapezoidal, watercourse.

1 INTRODUCTION

Agriculture is the largest sector of Pakistan's economy and its contribution is about 25 percent in GNP. It employs over 70 percent of the national labour force and accounts for more than 80 percent of foreign exchange earnings. Punjab is the largest province of Pakistan with respect to population. Its total geographical area is 20.63 million hectares, out of which 0.50 million hectares (2.3%) are under forests, 3.01 million hectares (14.9%) are uncultivable, 1.74 million hectares (8.4%) are culturable waste, and 12.27 million hectares (58.90%) are cultivated. The Thal desert is situated in Punjab, Pakistan. It is a huge area mainly between the Jhelum and Sindh rivers. Its total length from north to south is about 300 km, and its maximum breadth is 110 km. Thal region is occupied by Bhakkar, Khushab, Mianwali, Jhang, Layyah and Muzaffargarh districts of Punjab . Greater Thal Canal completed under phase-I of the GTC project operate from 01 April to 30 September to irrigate the sand dune areas of Khushab, Bhakkar and Layyah. There are 17 distributaries, 12 minors and 726 outlets having gross command area (GCA) 455,400 acres with culturable command area (CCA) of 385,800 acres. The sand particles are the dominant component in thal area and watercourse berm material is subjected to severe force of water in contact which may lead to instability if not properly analyzed. Fine-textured soils are less permeable than sandy soils having small storage capacity because of well-developed horizons and are distinguished by greater runoff and less erosion. Sandy soils on the other hand have high infiltration rate and do not retain moisture as long as finer textured soils. Moisture is more readily stored and returned to plants grown on sandy soils but these are more erodible. Present research pertains to the selection of stable side slope. It particularly concerns slope stability that which slopes should be used under average conditions. The term slope stability may be described as the resistance of inclined surface to failure by sliding or collapsing. The main objective of slope stability analysis is the designing of optimal slope with regard to safety, reliability and hydraulically efficient section.

It is suggested in WSDOT Geotechnical Design Manual (2013) that a minimum of two limit equilibrium methods should be used and compared to one another to ensure that the level of safety in the slope is accurately assessed furthermore in cuts, fills, and landslide repairs, a minimum safety factor of 1.05 shall be used.

Andrew Simon (2002) investigated the effect of altered flow regime and bed degradation on bank stability by examining bank stability for planar failure and for rotational failure for Peck Dam on the Missouri River, USA. Stability analysis was carried out using the Bishop method. It was found that this method permit evaluation of layered banks stability for a variety of slip surface shapes and pore water pressure conditions and soil properties.

Thorne (1998) showed that for a given set of soil conditions, there is a combination of critical bank height and angle greater than which the bank will be unstable. Factors that influence bank erosion include bank material, shear stress, bank slope, vegetation and bank moisture content.

Ching-Chuan Huang, Cheng-Chen Tsai (2000) build a three dimensional slope stability analysis method based on two directional moment equilibrium. This method furnishes factor of safety and possible direction of sliding for semispherical and composite failure surface.

DovLeshchinsky (1990) investigated that limit equilibrium

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analysis of slope stability comprised of critical slip surface and existence of global equilibrium at the defined limit state. Critical slip surface can be achieved by available optimizing techniques where the minimum factor of safety is sought.

David L. Rosgen, P.H.(1996) stated that adverse consequence of stream channel instability is associated with increased sedimentsupply, land productivity change, land loss, changes in both short and long-term channelevolution and loss of physical and biological function.

King (1960) concluded that the channel side and channel bed play an important role in the stability of channel.

Rosgen (1996) presented stream channel stability as the ability of a stream to transport the sediment and flows in such a manner that the stream maintains its dimension, pattern and profile without aggrading or degrading.

Xiao et al (2004) presented a geographic information grid based three dimensional deterministic modal for slope stability analysis by combining the geographic information system spatial analysis function, hydrologic analysis and modeling tool with a column based three dimensional slope stability analysis model. The initial slip was assumed as the lower half of an ellipsoid. The minimum three dimensional factor of safety for each slope unit can be obtained by dividing the whole study area into slope units.

Hans F. Winterkorn (1975) stated that numerious methods are available for performing slop stability analysis. The majority of these methods may be categorized as limit equilibrium methods. The basic assumption of the limit equilibrium approach is that Coulomb's failure criterion is satisfied along the assumed failure surface which may be straight line, circular arc, logarithmic spiral or other irregular surface.

Lindow (2007) performed three lysimeter tests at bank angles of 90°, 45° which corresponds to a 1:1 side slope and 26.6° which corresponds to a 2:1 side slope to test the effect of initial side slope on bank stability and mass of erosion. Slopes were achieved by cutting into the bank after packing and removing soil to the desired bank angle. Time series photographs and video were captured to document bank failure dynamics. The experiments were run until failure occurred at the surface. The final geometry, failure angle, location of tension crack, and mass of eroded material were measured at the end of each run. The observed failure mechanism was due to small, pop-out failures and liquefaction of the underlying sandy soil. Positive pore water pressure in the upper loam horizon reduced apparent cohesion and promoted bank collapse. Bank failure occurred along linear failure planes that were similar to the initial bank slope. An increase in bank slope was observed to increase slope stability.

Manning (1889) introduced a formula of velocity with hydraulic mean depth and channel slope. He described roughness of the material through which the flow takes place as coefficient of rugosity which is known as Manning's roughness coefficient. This formula became the most popular open channel design method due to its simplicity and satisfactory results. This approach mainly emphasize on resistance offered by channel roughness and no mention of sediment load charge. Therefore it was considered best suited for design of channels having silt free water.

Fredlund and Krahn (1977) stated that equations for factor of safety can be independently derived to satisfy moment equilibrium and force equilibrium of the slices contained above an assumed slip surface.

Whitman and Bailey (1967) presented a very interesting and classical review of the limit equilibrium analysis methods, which can be grouped as Method of Slices and Wedge Methods. In method of slices the unstable soil mass is divided into a series of vertical slices and the slip surface can be circular or polygonal. Methods of analysis which employ circular slip surfaces include Fellenius, Taylor, and Bishop. Methods of analysis which employ non-circular slip surfaces include Janbu, Morgenstern and Price, Spencer and Sarma. In wedge methods the soil mass is divided into wedges with inclined interfaces. This method is commonly used for some earth dam (embankment) designs but is less commonly used for slopes. Methods which employ the wedge method include Seed and Sultan and Sarma. Whitman and Bailey explained that in general, the quantitative differences in factors of safety obtained by various methods are not significant with the exception of the ordinary method which can differ by more than 60 percent from the other methods.

2 METHODOLOGY

2.1 The Study Area

The project area includes command of distributaries/minors of Greater Thal canal completed under phase-I of the GTC project (GTC-04 and GTC-05) located in Khushab, Bhakkar, and Layyah districts of the Punjab distributing 1,759 cusecs of water at 726 outlets. The general topography of the area is highly undulated consisting of large sand dunes, which are often shifted from one place to another by the action of wind storms. Soil of the area is mostly sandy in nature having low water holding capacity. The sands in top 5-10 ft depth generally occur in loose to dense medium state while at deeper horizons in medium dense to dense state of compactness. These sand dune areas have very hot summers and mild winters with average rainfall 10 inches per year.

2.2 Data Collection

The sanctioned discharge of 726 outlets in sand dune areas of thal region was collected from Greater Thal Canal Irrigation and Drainage Department.

Various parameters required to design a watercourse obtained from On Farm Water Management (OFWM) Agriculture Department of Punjab. The design parameters include designed discharge, longitudinal slope and watercourse design MS Excel model etc.

Geotechnical data required for stability analysis include cohesion, angle of friction and dry density were collected from National Engineering Services of Pakistan.

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2.3 Watercourse Design

After examining the Irrigation data of 726 outlets it was observed that sanctioned discharge is less than or equal to 60Lps in 80% cases. On the other hand by investigating the On Farm Water Management data it was found that the designed discharge is less than or equal to 80Lps in 80% cases whereas the average longitudinal slope is 0.0002 and average bed width found to be 0.35meter. For the purpose of stability analysis the watercourse design trials were carried out at 80Lps and 100Lps with bed width of 0.35m, longitudinal slope of 0.0002 and varying side slope from 1:1 (H:V) to 1:2.5 (H:V) using MS Excel model.

2.4 Using MS Excel Model

This model incorporates the solution of Manning's Flow Resistance equation. First of all the bed width, roughness coefficient, longitudinal slope and side slope of the earthen trapezoidal channel are defined. Then by trial and error flow depth is determined against a designed discharge. This model generates the values of flow area, velocity, wetted perimeter and hydraulic radius.

2.5 Model and Analysis Methods

Geo 5 Slope Stability model was used to compute factor of safety. It is possible to analyze simple and complex slope stability problems using a variety of methods. The slip surface can be either circular computing factor of safety by Bishop, Fellenius/Petterson, Spencer, Janbu and Morgenstern-Price method or polygonal slip surface computing factor of safety by Sarma, Spencer, Janbu and Morgenstern-Price method.

2.6 Using Geo 5 Slope Stability Model

In order to draw the geometric shape of the cross-section of the watercourse coordinates of various points of the cross-section are required. These points are calculated from watercourse design manually by simple mathematical calculation. The interface is used to insert these calculated coordinates, the model shows the points on the screen. Then the soil properties internal angle of friction, cohesion and unit weight etc are entered. The coordinates of the phreatic seepage line are calculated using the flow net concept and entered. The model provides a wide variety of stability analysis methods such as Bishop, Fellenius/Petterson, Spencer etc. After the selection of analysis methods finally the circular or polygonal slip is defined. Once all the input data has been provided to the model then the command "Analysis" is activated to generate the factor of safety.

3 Results and Discussion

It has been discussed earlier that two trials of designed discharge were carried out keeping in view the most prevailing designed discharge. The details of stability analysis at each discharge with varying side slope are as follows.

3.1.1 First Trial 80Lps Case 1 Side Slope 1:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 80Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.47m
Velocity v	= 0.2120m/sec
Flow area A	= 0.3854m2
Wetted Perimeter P	= 1.68m
Hydraulic Radius R	= 0.23m

Factor of Safety for 80Lps and 1:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	0.80	-
		Dry	0.73	-
	Outer Face	Wet	0.74	-
		Dry	0.67	-
Spencer	Inner Face	Wet	0.82	0.81
		Dry	0.73	0.73
	Outer Face	Wet	0.75	0.75
		Dry	0.68	0.68
Janbu	Inner Face	Wet	0.81	0.81
		Dry	0.73	0.73
	Outer Face	Wet	0.75	0.75
		Dry	0.68	0.68
Margenstern-Price	Inner Face	Wet	0.81	0.81
		Dry	0.73	0.73
	Outer Face	Wet	0.75	0.75
		Dry	0.68	0.68
Bishop	Inner Face	Wet	-	0.81
		Dry	-	0.73
	Outer Face	Wet	-	0.75
		Dry	-	0.68
Fellenius/ Petterson	Inner Face	Wet	-	0.77
		Dry	-	0.70
	Outer Face	Wet	-	0.72
		Dry	-	0.65

3.1.2 80Lps Case 2 Side Slope 1.5:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 80Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.41m

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Velocity v	= 0.2039m/sec
Flow area A	= 0.3957m2
Wetted Perimeter P	= 1.83m
Hydraulic Radius R	= 0.22m

Factor of Safety for 80Lps and 1.5:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.08	-
		Dry	0.98	-
	Outer Face	Wet	1.07	-
		Dry	0.96	-
Spencer	Inner Face	Wet	1.09	1.09
		Dry	0.98	0.98
	Outer Face	Wet	1.08	1.08
		Dry	0.97	0.97
Janbu	Inner Face	Wet	1.09	1.09
		Dry	0.98	0.98
	Outer Face	Wet	1.08	1.08
		Dry	0.97	0.97
Margenstern-Price	Inner Face	Wet	1.09	1.09
		Dry	0.98	0.98
	Outer Face	Wet	1.09	1.08
		Dry	0.97	0.97
Bishop	Inner Face	Wet	-	1.09
		Dry	-	0.98
	Outer Face	Wet	-	1.08
		Dry	-	0.97
Fellenius/Petterson	Inner Face	Wet	-	1.03
		Dry	-	0.93
	Outer Face	Wet	-	1.03
		Dry	-	0.92

3.1.3 Case 3 Side Slope 1.73:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 80Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.39m
Velocity v	= 0.1995m/sec
Flow area A	= 0.3996m2
Wetted Perimeter P	= 1.91m
Hydraulic Radius R	= 0.21m

Factor of Safety for 80Lps and 1.73:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.23	-
		Dry	1.10	-
	Outer Face	Wet	1.23	-
		Dry	1.11	-
Spencer	Inner Face	Wet	1.24	1.24
		Dry	1.11	1.11
	Outer Face	Wet	1.24	1.23
		Dry	1.11	1.10
Janbu	Inner Face	Wet	1.24	1.23
		Dry	1.11	1.11
	Outer Face	Wet	1.24	1.23
		Dry	1.11	1.10
Margenstern-Price	Inner Face	Wet	1.24	1.24
		Dry	1.11	1.11
	Outer Face	Wet	1.24	1.23
		Dry	1.11	1.10
Bishop	Inner Face	Wet	-	1.24
		Dry	-	1.11
	Outer Face	Wet	-	1.23
		Dry	-	1.10
Fellenius/Petterson	Inner Face	Wet	-	1.18
		Dry	-	1.06
	Outer Face	Wet	-	1.17
		Dry	-	1.05

3.1.4 Case 4 Side Slope 2:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 80Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.37m
Velocity v	= 0.195m/sec
Flow area A	= 0.4107m2

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Wetted Perimeter P = 2.02m
Hydraulic Radius R = 0.20m

Factor of Safety for 80Lps and 2:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.43	-
		Dry	1.32	-
	Outer Face	Wet	1.41	-
		Dry	1.25	-
Spencer	Inner Face	Wet	1.44	1.43
		Dry	1.32	1.31
	Outer Face	Wet	1.42	1.42
		Dry	1.26	1.26
Janbu	Inner Face	Wet	1.44	1.43
		Dry	1.32	1.31
	Outer Face	Wet	1.42	1.42
		Dry	1.26	1.26
Margenstern-Price	Inner Face	Wet	1.44	1.43
		Dry	1.32	1.31
	Outer Face	Wet	1.42	1.42
		Dry	1.25	1.26
Bishop	Inner Face	Wet	-	1.43
		Dry	-	1.31
	Outer Face	Wet	-	1.42
		Dry	-	1.26
Fellenius/Petterson	Inner Face	Wet	-	1.35
		Dry	-	1.24
	Outer Face	Wet	-	1.36
		Dry	-	1.21

3.1.5 Case 5 Side Slope 2.5:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q = 80Lps
Longitudinal Slope S = 0.0002
Bed width (bottom) b = 0.35m
Flow depth d = 0.35m
Velocity v = 0.1875m/sec
Flow area A = 0.4246m2
Wetted Perimeter P = 2.22m
Hydraulic Radius R = 0.19m

Factor of Safety for 80Lps and 2.5:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.62	-
		Dry	1.77	-
	Outer Face	Wet	1.77	-
		Dry	1.64	-
Spencer	Inner Face	Wet	1.62	1.78
		Dry	1.79	1.62
	Outer Face	Wet	1.79	1.77
		Dry	1.65	1.63
Janbu	Inner Face	Wet	1.62	1.78
		Dry	1.78	1.62
	Outer Face	Wet	1.79	1.77
		Dry	1.65	1.63
Margenstern-Price	Inner Face	Wet	1.62	1.78
		Dry	1.78	1.62
	Outer Face	Wet	1.79	1.77
		Dry	1.65	1.63
Bishop	Inner Face	Wet	-	1.78
		Dry	-	1.62
	Outer Face	Wet	-	1.77
		Dry	-	1.63
Fellenius/Petterson	Inner Face	Wet	-	1.69
		Dry	-	1.54
	Outer Face	Wet	-	1.66
		Dry	-	1.54

3.2.1 Second Trial 100Lps Case 1 Side Slope 1:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q = 100Lps
Longitudinal Slope S = 0.0002
Bed width (bottom) b = 0.35m
Flow depth d = 0.51m
Velocity v = 0.2213m/sec
Flow area A = 0.4386m2

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Wetted Perimeter P = 1.79m
Hydraulic Radius R = 0.2447m

Factor of Safety for 100Lps and 1:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	0.77	-
		Dry	0.64	-
	Outer Face	Wet	0.80	-
		Dry	0.62	-
Spencer	Inner Face	Wet	0.77	0.77
		Dry	0.64	0.65
	Outer Face	Wet	0.81	0.81
		Dry	0.63	0.63
Janbu	Inner Face	Wet	0.77	0.77
		Dry	0.64	0.65
	Outer Face	Wet	0.81	0.81
		Dry	0.63	0.63
Margenstern-Price	Inner Face	Wet	0.78	0.77
		Dry	0.64	0.65
	Outer Face	Wet	0.81	0.81
		Dry	0.62	0.63
Bishop	Inner Face	Wet	-	0.78
		Dry	-	0.65
	Outer Face	Wet	-	0.81
		Dry	-	0.63
Fellenius/Petterson	Inner Face	Wet	-	0.75
		Dry	-	0.64
	Outer Face	Wet	-	0.79
		Dry	-	0.62

3.2.2 Case 2 Side Slope 1.5:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q = 100Lps
Longitudinal Slope S = 0.0002
Bed width (bottom) b = 0.35m
Flow depth d = 0.45m
Velocity v = 0.2147m/sec
Flow area A = 0.4613m2
Wetted Perimeter P = 1.97m
Hydraulic Radius R = 0.2338m

Factor of Safety for 100Lps and 1.5:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.09	-
		Dry	0.86	-
	Outer Face	Wet	1.64	-
		Dry	0.88	-
Spencer	Inner Face	Wet	1.10	1.06
		Dry	0.86	0.87
	Outer Face	Wet	1.50	1.10
		Dry	0.87	0.95
Janbu	Inner Face	Wet	1.10	1.06
		Dry	0.86	0.87
	Outer Face	Wet	1.50	1.10
		Dry	0.88	0.95
Margenstern-Price	Inner Face	Wet	1.10	1.06
		Dry	0.86	0.87
	Outer Face	Wet	1.51	1.10
		Dry	0.88	0.95
Bishop	Inner Face	Wet	-	1.06
		Dry	-	0.88
	Outer Face	Wet	-	1.10
		Dry	-	0.95
Fellenius/Petterson	Inner Face	Wet	-	1.06
		Dry	-	0.87
	Outer Face	Wet	-	1.07
		Dry	-	0.94

3.2.3 Case 3 Side Slope 1.73:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q = 100Lps
Longitudinal Slope S = 0.0002
Bed width (bottom) b = 0.35m
Flow depth d = 0.44m
Velocity v = 0.2135m/sec
Flow area A = 0.4889m2
Wetted Perimeter P = 2.11m
Hydraulic Radius R = 0.2319m

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Factor of Safety for 100Lps and 1.73:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.19	-
		Dry	1.01	-
	Outer Face	Wet	1.19	-
		Dry	1.02	-
Spencer	Inner Face	Wet	1.18	1.20
		Dry	1.02	1.07
	Outer Face	Wet	1.18	1.33
		Dry	1.02	1.08
Janbu	Inner Face	Wet	1.18	1.20
		Dry	1.02	1.07
	Outer Face	Wet	1.18	1.33
		Dry	1.02	1.08
Margenstern-Price	Inner Face	Wet	1.18	1.20
		Dry	1.02	1.07
	Outer Face	Wet	1.18	1.33
		Dry	1.02	1.08
Bishop	Inner Face	Wet	-	1.21
		Dry	-	1.07
	Outer Face	Wet	-	1.33
		Dry	-	1.08
Fellenius/Petterson	Inner Face	Wet	-	1.17
		Dry	-	1.04
	Outer Face	Wet	-	1.30
		Dry	-	1.06

3.2.4 Case 4 Side Slope 2:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 100Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.41m
Velocity v	= 0.2060m/sec
Flow area A	= 0.4797m2
Wetted Perimeter P	= 2.18m
Hydraulic Radius R	= 0.2197m

Factor of Safety for 100Lps and 2:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.37	-
		Dry	1.28	-
	Outer Face	Wet	1.37	-
		Dry	1.28	-
Spencer	Inner Face	Wet	1.38	1.37
		Dry	1.28	1.27
	Outer Face	Wet	1.38	1.37
		Dry	1.28	1.22
Janbu	Inner Face	Wet	1.38	1.37
		Dry	1.28	1.27
	Outer Face	Wet	1.38	1.37
		Dry	1.28	1.22
Margenstern-Price	Inner Face	Wet	1.39	1.37
		Dry	1.28	1.27
	Outer Face	Wet	1.39	1.37
		Dry	1.28	1.22
Bishop	Inner Face	Wet	-	1.37
		Dry	-	1.27
	Outer Face	Wet	-	1.37
		Dry	-	1.22
Fellenius/Petterson	Inner Face	Wet	-	1.31
		Dry	-	1.22
	Outer Face	Wet	-	1.33
		Dry	-	1.19

3.2.5 Case 5 Side Slope 2.5:1 (H:V)

MS Excel Model Results are as under:

Designed Discharge Q	= 100Lps
Longitudinal Slope S	= 0.0002
Bed width (bottom) b	= 0.35m
Flow depth d	= 0.38m
Velocity v	= 0.1974m/sec
Flow area A	= 0.4940m2
Wetted Perimeter P	= 2.40m
Hydraulic Radius R	= 0.2061m

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Factor of Safety for 100Lps and 2.5:1 side slope with Polygonal slip and Circular slip computed for wet and dry conditions using Geo 5 Slope Stability Model:

Method	Face	Condition	FOS Polygonal Slip	FOS Circular Slip
Sarma	Inner Face	Wet	1.71	-
		Dry	1.54	-
	Outer Face	Wet	1.68	-
		Dry	1.54	-
Spencer	Inner Face	Wet	1.72	1.71
		Dry	1.54	1.54
	Outer Face	Wet	1.69	1.68
		Dry	1.55	1.55
Janbu	Inner Face	Wet	1.71	1.71
		Dry	1.54	1.54
	Outer Face	Wet	1.69	1.68
		Dry	1.55	1.55
Margenstern-Price	Inner Face	Wet	1.71	1.71
		Dry	1.54	1.54
	Outer Face	Wet	1.69	1.68
		Dry	1.55	1.55
Bishop	Inner Face	Wet	-	1.71
		Dry	-	1.54
	Outer Face	Wet	-	1.68
		Dry	-	1.55
Fellenius/Petterson	Inner Face	Wet	-	1.66
		Dry	-	1.50
	Outer Face	Wet	-	1.62
		Dry	-	1.49

The results of analysis at two trials of designed discharge by varying side slope from 1:1 to 2.5:1 indicate that factor of safety in each case increases with the increase in side slope on the other hand velocity decreases with the increase in side slope. It is obvious from the results that side slope of 1:1 is not stable in any case for the sand dune areas of thal region. It is interesting to note that side slope of 1.5:1 is stable in wet condition but unstable in dry condition and factor of safety decreases with the increase in discharge. Analysis results of side slope 1.73:1 indicate that factor of safety in some cases is at margin of stability however the side slope of 1.73:1 gives hydraulically efficient section with a side angle of 30^{o}. Side slope of 2:1 quite stable in each case. Side slope of 2.5:1 is much stable but section is not only hydraulically less efficient but quantum of construction work also increases.

4 Conclusions

By investigating the analysis results following conclusions are drawn.

Factors of safety obtained by various methods are much close to each other for a particular case.

Side slope must not be less than 1.73:1 in sandy soils in any case but it is good to construct earthen trapezoidal watercourses for 100Lps and above with a side slope of 2:1 in sand dune areas.

Most prevailing designed discharge is 80Lps or below in sand dune areas and the ideal side slope is 1.73:1 which is not only stable but also produce hydraulically quite efficient section.

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