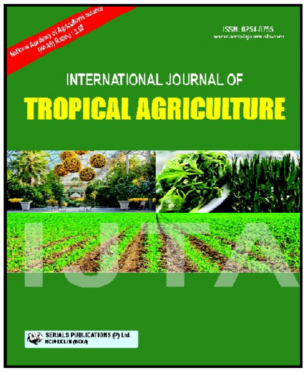

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Evaluation of Water Harvesting structure in Respect of Design Dimensions and Stability Analysis

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Abstract: The water harvesting structures, viz. earthen embankment constructed by Government and Non Government Organization at Tulapur watershed of Ahmednagar district, Maharashtra state, were evaluated for hydrologic, hydraulic and structural design using standard design procedure. The volume of runoff was estimated by using Curve Number (CN) method, for maximum rainfall in 25 years for a week. Storage volume of existing earthen embankment was computed with the help of contour map. Based on the storage and runoff volume, the excess runoff for 25-year return period was estimated. Catchment to storage ratio of 6 was used for deciding the dimensions of earthen embankment. The parameters of earthen embankment were determined by considering hydrological data, and were compared with those executed by the Department of Agriculture. It was found that, the embankment could be used to store 40 to 50 percent of runoff produced by weekly maximum rainfall of 25-year return period. The design dimensions of the embankment designed by considering the storage volume were less as compared to those executed by Department of Agriculture. Major differences were in height, top width, base width and side slopes of the structures. The cost of construction of all the embankment structures claimed by the Department of Agriculture and Non Government Organization was found to be 10- 15 per cent more due to some variation while implementing at the site. All the existing and design dimension of embankment structures were found to be safe from stability analysis.

Key words: earthen embankment, water harvesting; stability analysis

INTRODUCTION

Pressure on land is increasing day by day due to population growth causing more marginal lands being brought underused for agriculture land use. Agriculture is possible only when there is sufficient availability of water. Although, ground water may be available for utilization, its exploration needs money. As a result there is scarcity of water. Under such conditions the harvesting of runoff water is the best alternative and is most important. Water harvesting indicates the collection of stream flow in creeks and gullies, as well as rainfall at point where it falls. Taking in account importance of water harvesting, Government of Maharashtra State is carrying out various *nala* bunding works since 1969 and Soil water management activities are also carried out in an integrated manner on watershed basis in the state since 1983. The essential components in Comprehensive Watershed Development Programme (COWDEP) include contour/graded bunding, terracing, *nala* bunding, contour cultivation etc. The current approach for water harvesting in the country has been accommodated under the broad framework of activities in rain fed areas in the National Watershed Development Project in Rainfed Areas (NWDPRA) since 1990-91.

Water harvesting can be achieved by construction of structures like farm ponds, check dams, nala bunds, gully plugging, percolation tanks etc. These structures are constructed as an integral part of soil and water conservation and are important components of the watershed development programme. Nala bunds either made up of earthen material or cement masonry store the water, increase percolation and improve soil moisture regime. The design principle of water harvesting structures is similar to other hydraulic structures requiring wide range of input. In many regions of local thumb rule are used for designing the structures. For hydrologic design a more or less universal criterion is followed which is basically, "the ratio of the catchment area to the cultivated area".

The failures of such structures are mainly due to insufficient hydraulic capacity and lack of provision for dissipating energy of falling water into the structure. It is essential to carryout survey and study the morphology of watershed for planning, designing and executing the works of soil and water conservation structures. Most of the time, morphological characteristics of watershed are taken into the consideration, while designing water harvesting structures. However, the water harvesting structures need to be tested for hydrologic, hydraulic and structural design before their execution so as to ensure their safety as well as their functional efficiency. Water harvesting is the pressing need of the hour. Taking into account importance of water harvesting; various researchers have done lot of research on water harvesting structures. Singh (1974) described that the earthen dams are used for gully control and are suitable at the sites where soil, side slope, depth of gully and suitable condition for safe spillway structure are available. Further he stated that the earth dam might be used as diversion dam, storage dam, grade stabilization dam and erosion retarding dam. Garg (1985) stated that hydraulic failure, seepage failure and structural failure occur in earth dams because they are less rigid and they may fail due to improper design, faulty construction and lack of maintenance. Anonymous (2000) suggested that ground water level can be increased with the water harvesting structures like nala bund, earthen embankment etc. The increased ground water potential is helpful for the assured irrigation to the crops, which in result helps in increasing the food grain production. Ahir (2005) after studying the water harvesting structures (earthen embankment and cement nala bund) constructed by the Department of Agriculture, Maharashtra State, concluded that the embankment designed with storage ratio 6 were found to be economical. For all the selected four embankment structures the cost of construction of dam computed by Department of Agriculture was found to be on higher side than the actual cost calculated by the standard design procedure. The design procedure used by the Department of Agriculture needs to be modified by considering the storage ratio and the hydrologic, hydraulic and structural design of the embankment. Evaluation of earthen embankment is necessary to test the efficiency of various structures applied in the watershed.

The reviewed previous work prompted this study on the evaluation of water harvesting structures for their design procedure to bridge the gap between the standard design procedures and the work done by a State Department of Agriculture, Maharashtra and Non Government Organization in Ahmednagar District.

MATERIAL AND METHODS

The water harvesting structure, earthen embankment constructed during 2005 by the Department of Agriculture, Maharashtra State at Tulapur watershed, was tested for hydrologic, hydraulic and structural design so as to ensure proper design of structure. Tulapur is located at 46 km, North-East of Mahatma Phule Krishi Vidyapeeth, Rahuri .The rainfall data of Tulapur, was not available, since there is no rain gauge station having 25 years data in the proximity of Tulapur. The rainfall data for 25 years available with the Mahatma Phule Krishi Vidyapeeth, Rahuri was used for analysis purpose of selected watersheds. Weekly maximum rainfall data of 25 years i.e. from 1987- 2011 was taken from Water Management Scheme, Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri. The topographic survey by taking elevations at 30 x 30 m grid was conducted for Tulapur watershed and contour maps were prepared. From these maps, the boundaries of watershed were delineated and the areas of the watershed were determined. Results of analysis of soil samples for earthen embankments at Tulapur were available with the office of Taluka Agricultural Office (TAO), Rahuri. These were used to decide the hydrological soil groups (HSG) for use in Curve Number method for estimation of runoff depth. After determining percentage of sand, silt and clay in the soil of watersheds, the soil types were decided. Earthen embankments were designed for the selected watershed at Tulapur.

The designed earthen embankment was compared with existing structures in respect of following design parameters.

i) Height of embankment

ii) Top width

iii) Base width of embankment

iv) Side slopes

iv) Size and location of spillway

vi) Stability analysis

vii) Cost of construction.

These design parameters were compared with actual design prepared by Department of Agriculture. Runoff depth was computed by using Curve Number i.e. C-N method.

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S}$$

Where,

Q = Runoff depth, mm

P = Rainfall, mm

I_a = Initial abstraction, usually taken as 0.2 S

S = Maximum potential retention, mm.

RESULTS AND DISCUSSION

The important morphological characteristics were computed from the contour map of watershed on upstream of earthen embankment at Tulapur, presented below in Table 1.

The watershed at Tulapur has an area of 51.00 ha and the average slope of this watershed is 3%. Mainstream length in watershed at Tulapur is 1750 m and the average velocity of runoff is 1.37 m/s. The CN method was used for the estimation of the runoff volume for the week with maximum rainfall in 25 years. The runoff volume for 25 years return period and storage volume is presented in Table 2.

Table 1
Selected Morphological characteristics of Tulapur watershed

Sr. No.	*Characteristics*	*Watershed - Tulapur*
1.	Catchment area, ha	51.00
2.	Average slope, %	3.00
3.	Length of main stream, m	1750
4.	Main stream slope, %	1.82
5.	Time of concentration, h	0.28
6.	Estimated average velocity of runoff, m/s	1.37

Table 2
Runoff volumes from Tulapur and storage volume in embankment for 25 years return period

Watershed	*Runoff volume by CN method, m^3*	*Actual storage volume, m^3*	*Excess runoff, m^3*	*Percentage of excess runoff*
Tulapur	72935.1	14990.00	57945.1	49.44

It is revealed from Table 2 that for 25 - year return period, the runoff excess for earthen embankment at Tulapur watershed is 49.44% , when weekly maximum rainfall is considered.

Dimensions of Embankment

The height of earthen embankment was decided, considering storage volume at storage ratio 6 and contour map. The top width, side slope and free board were decided from the height of the earthen embankment. The designed and existing dimensions of earthen embankment are given in Table 3.

For an earthen dam at the end of Tulapur watershed, gross height is determined as 2.50 m after considering full supply level of stored water, free board and consolidation allowance. However, the gross height of earthen embankment determined by the Department of Agriculture is 4.20 m, i.e. 1.70 m more than that of the designed. The Normal Water

Table 3
Designed and existing dimensions of earthen embankment

Sr. No.	*Description*	*Watershed – Tulapur*	
		Designed	*Existing*
1.	Normal water level, m	1.20	2.40
2.	Freeboard for safety, m	-	1.00
3.	Flood storage depth, m	0.30	0.60
4.	Flow depth in flood spillway, m	0.60	0.80
5.	Net free board, m	0.30	-
6.	Consolidation, m	0.10	-
7.	Gross height of dam, m	2.50	4.20
8.	Top width, m	2.00	1.50
9.	Upstream slope, (H :V)	3 : 1	2 : 1
10.	Downstream slope, (H : V)	2 : 1	2 : 1
11.	Maximum bottom width, m	14.5	18.30
12.	Fill volume, m^3	1560.15	1990.40
13.	Core trench volume, m^3	46.8	-

Level (NWL) of 2.40 m is considered by the Department whereas, the design NWL is estimated to be 1.20 m. Further, the Department has considered 1.00 m allowance in addition to free board, without technical considerations. This allowance is unnecessary.

Top width for earthen embankment is worked out as 2.00 m whereas existing top width is 1.50 m, which is less. The side slopes of an earthen embankment depend upon the fill material, the shearing resistance of foundation soil and the duration of inundation. The side slope should not be steeper than 3:1 on upstream side and 2:1 on downstream side for the dams less than 15 m height with average fill material (Schwab *et al.*, 1981). Coarse fill materials may have side slopes flatter than these for better stability. Therefore, for the earthen embankment under consideration, the side slopes of 3:1 on upstream side and 2:1 on downstream side were proposed. However, existing slopes are 2: 1 for both sides. Maximum bottom width is worked out to be 14.5 m whereas the existing is 18.3 m. The bottom width as per the standard design is less due to the less design height, and less slope on downstream side though upstream side slope is flatter.

The details of dimensions of the embankments are shown in Table 3, which reveal that existing dimensions are more than the required.

The actual fill volumes were computed by making the survey of the site. The design fill volumes were calculated by considering the cross section of stream at the site. Fill volumes are also high for earthen embankment than the required. For this earthen embankment fill volume is 1560.15 m^3 as against the actual fill volume 1990.40 m^3. Fill volume for the dams were very high due to non-consideration of exact contributing catchment areas and accurate free board. It is revealed from the stability analysis of designed and existing dimensions of earthen embankment is safe against tension, crushing, overturning and sliding.

CONCLUSION

The earthen embankment was designed to handle the maximum weekly rainfall of 25 years return period based on the rainfall data available at Mahatma Phule Krishi Vidyapeeth, Rahuri. The selected structure was evaluated for the hydrologic, hydraulic and structural design. The dimensions of existing embankment were compared with designed dimensions. In case of earthen embankment constructed at Tulapur watershed, the designed fill volume is less (1560.15 m^3) than the existing fill volume (1990.40 m^3). It indicates the existing dimensions are overdesigned. The overdesign can increase the cost of construction under similar hydrological condition.

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