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AN APPROACH TO DESIGN AND CONSTRUCTION OF LOW HEIGHT GRAVITY DAM

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Abstract :-- The development of any country like India depends upon infrastructure required to facilitate the requirement of irrigation because India is an eminent producers of agriculture products. India is a tropical country, where at some parts of it rain is fallen so much as flooded the area and while some parts has no rains. In these situations, The construction of dam at suitable site is needed on those rivers which carry huge amount of rain water. By constructing dams fair distribution of water is possible along with to provide facility of irrigation to crops. The dams also help in to protect areas flooded frequently by retaining flood water on upstream of dam, forming reservoir.

In this paper focus on gravity type dam which is designed and constructed with the combination of geo bags and loose earth for the purpose of maintaining water level in the river Gomti as the level required at Gaughat Pumping Station, for drawing water from the river, which is operated for supplying drinking water to nearby areas for about 20 Lac people and it also serve the purpose for the execution of work related to Gomti River Front Development Project. The dam is required for the span of three to five years within which the ongoing project is hopped to be completed.

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Introduction :- A dam is a hydraulic structure constructed across a river or natural stream to store water on its upstream side. It is an impervious or semi impervious barrier put across a natural stream so that the reservoir is formed. It is very difficult to say as where and when the first man made dam was built. Archeological evidences helps in estimating that the very first man made dam is at least 3000 - 5000 years old. The first Modern dam of the world was constructed on the Nile river in Egypt at Aswan. It was completed in 1902 and was as major engineering project. Material used in this dam construction was stone. The Second Modern dam of the world was Roosevelt Dam constructed on the salt River of Arizona (U.S.A.) completed in 1911. Material used in its construction was the solid blocks of concrete. Which was the type known as "Solid Masonry Gravity Dam.`` Hoover Dam (726'high) Bhakhra Dam (740'high) are some of example of "Solid concrete gravity dam type". The material of construction is generally earth, wooden planks, stone, bricks, sand, coarse aggregate, cement and steel which is used in most of the construction of dams. After proper designing, the site is vacated from the water by diverting the water through side channel spillway by constructing a coffer dam on upstream side.

In conditions where if, river of water is stopped in downstream side away few kilometers from the construction site by structure like barrage, as it has to be done in Lucknow just to maintain level of water in river to feed a pump house for the purpose of supplying drinking water to nearby localities, Obviously it is impossible to vacate the construction site in this condition and construction of new gravity dam is to be done in water as already flows in river because the level of water in river could not be lowered otherwise water pumped by the said pumping station could be stopped and the people of the nearby, who are served by these pumps, could be agitated, the result of which would be as the problem of law and order in the city. This would be possible by various ways but here the requirement of a such type of dam which has to serve for three to five years. By intensive studying a large number of literatures of dam construction. It is found suitable and feasible to design and construct the dam by using Geo bags, Boulders, Bali Piling and earth.

Geometrical Standards for Dam : - Before finalizing the Dam section, first select a suitable Preliminary section on the basis of empirical rules discussed below and after deciding the section, check against various failure criteria and after all finalize the section. Required dimensions of dam is preliminary decided by following empirical rules-**Freeboard -**

Table – 1 U.S.B.R. recommendation for freeboard for earth dams –

Spillway Type	Height of dam	Minimum freeboard over MWL
Uncontrolled spillway (free)	Any height	Between 2m. to 3 m.
Controlled spillway	Height less than 60m.	2.5 m above top of gates
Controlled spillway	Height more than 60 m.	3.0 m. above top of gates

An additional freeboard up to 1.5m should be provided for dams situated in areas of low temperature to accommodate frost action.

Top width (A) – Top width in earth dam can be selected as per the following recommendation:-

$$A = \frac{H}{3} + 3 \text{ for very low dams.} \qquad (2.10)$$

$$A = 0.55\sqrt{H} + 0.2H \text{ for dams lower than 30m.} \qquad (2.11)$$

And $$A = 1.65\ (H + 1.5)^{1/3} \text{ for dams higher than 30m.} \qquad (2.12)$$

<u>Upstream and Downstream Side Slopes -</u> Terzaghi's side slopes for earth dams.

Table – 2 Terzaghi 's recommendation for side slopes

Type of Material	U/S Slope (H:V)	D/S (H:V)
Homogeneous well graded	2.5:1	2:1
Homogeneous course silt	3:1	2.5:1
Homogeneous silty clay (1) Height less than 15m (2) Height more than 15m	 2.5:1 3:1	 2:1 2.5:1
Sand or sand and gravel with a central clay core	3:1	2.5:1
Sand or sand and gravel with R.C. diaphragm.	2.5:1	3:1

The various dimensions of low earth dams for their preliminary sections may sometimes be selected from the recommendations of Strange –

Table – 3 Rrecommendations of Strange

Height of Dam in meters	Max. freeboard in meters	Top width (A) in meters	U/S Slope (H:V)	D/S Slope (H:V)
Upto 4.5 m	1.2 to 1.5	1.85	2:1	1.5:1
4.5 to 7.5	1.5 to 1.8	1.85	2.5:1	1.75:1
7.5 to 15	1.85	2.50	3:1	2:1
15 to 22.5	2.10	3.00	3:1	2:1

Bottom width (B) – Bottom width of dam is governed by following two criteria –

(i) Phreatic line should lie well within down Stream Slope of dam section and sufficient cover must over lie the Phreatic line at the toe of dam.

(ii) Creep length as per Bligh's creep theory below and adjacent to the bottom of dam foundation must be satisfied. If height of dam is H, then minimum creep length is 15H.

With applying enough factor of safety it must be adopted at least 18H.

The max of above two criteria is adopted.

e. Filter -

Filter as per the standard design is must to lay down at toe, started from the dam body for few distance from toe point to adequate length beyond toe of dam so as to safe passage is ascertained to the water which any how may percolate through the dam material.

General Elements of an Earthen Dam : ---

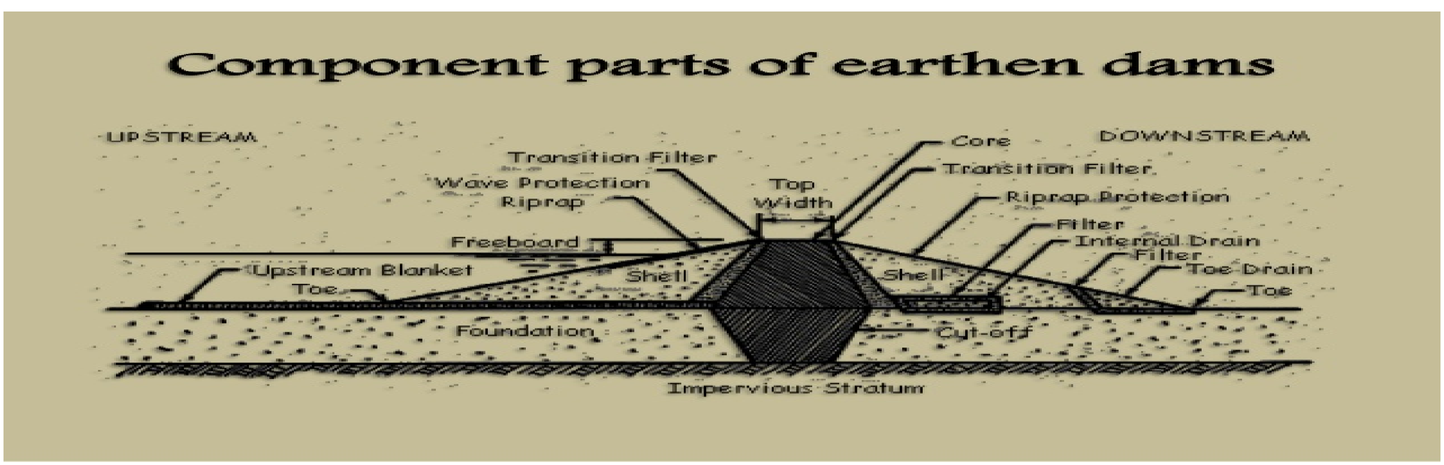

Fig. 1. Components Parts of Earthen Dam

Design :– Facts and Data –

H.F.L. (High flood level) = 113.00 meter

Danger Level = 110.49 meter

Maximum Discharge = 105000.00 Cusecs

The data had been recorded during sever flood in year 1960.

During Normal Flood-

Flood Level	=	107.00 meter
Bed Level	=	100.05 meter
Discharge	=	20000.00 cusecs
Depth of water on U/s	=	107.00 – 100.05
	=	7.00 meter (approx)

Free board as per recommendation of codes = 1.80 meter

Total Dam Height Required H = 7.00 + 1.80
= 8.80 meter

Based on empirical formula

Top width (A) = (H/5) + 3 for very low dams
= 8.80/5 + 3
= 4.76 meter

But adopt top width A = 10.00 meter

Because of practical and specific needs of the material used for construction. Side slopes as per the recommendation of Terzaghi's(Having central clay core& LDPE sheet of 200 µ.

U/S (H:V) side slope = 2.5 : 1

D/S (H:V) side slope = 3 : 1

Bottom Width (B)

Creep length for Northern Indian River
= 15 x height of water column.
= 15 x 7.00
= 105.00 meter

On the basis of top width and side slopes adopted.

B = 10.00 + 2.5 x 7.00 + 3 x 7.00
= 48.50 mete

Obviously creep length dominates and

So Adopt B =105.00 meter

To mate required bottom width, on upstream side nothing could be done but on Down Stream side, side slope is maintained as above that is 3:1 by constructing the side slope in stages that is after constructing few meter side slope go horizontal for few meter and so on.

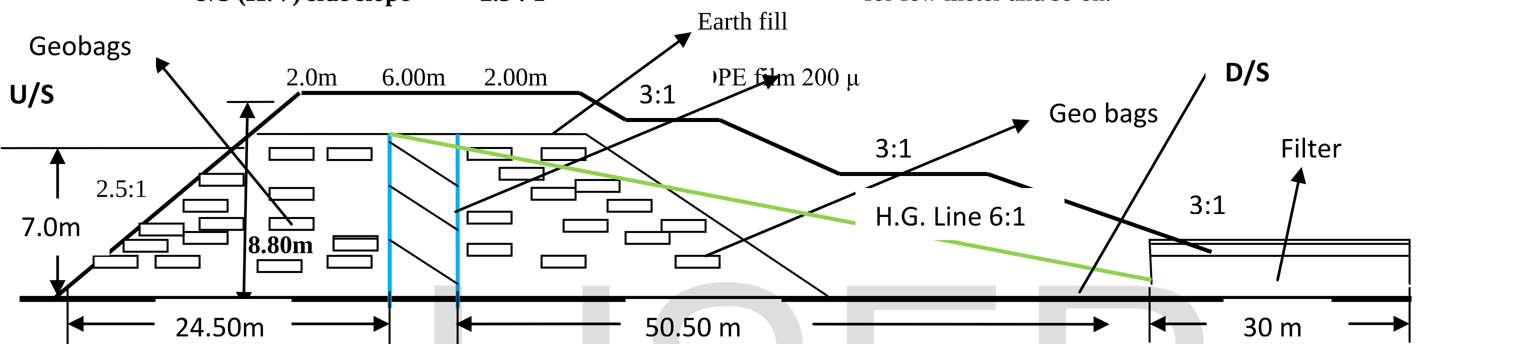

Fig . 2 Theoretical Section As Designed

Fig. shows the section as designed but practically its construction is not possible because construction is to be carried out in water. The practical section which is feasible is as drawn below

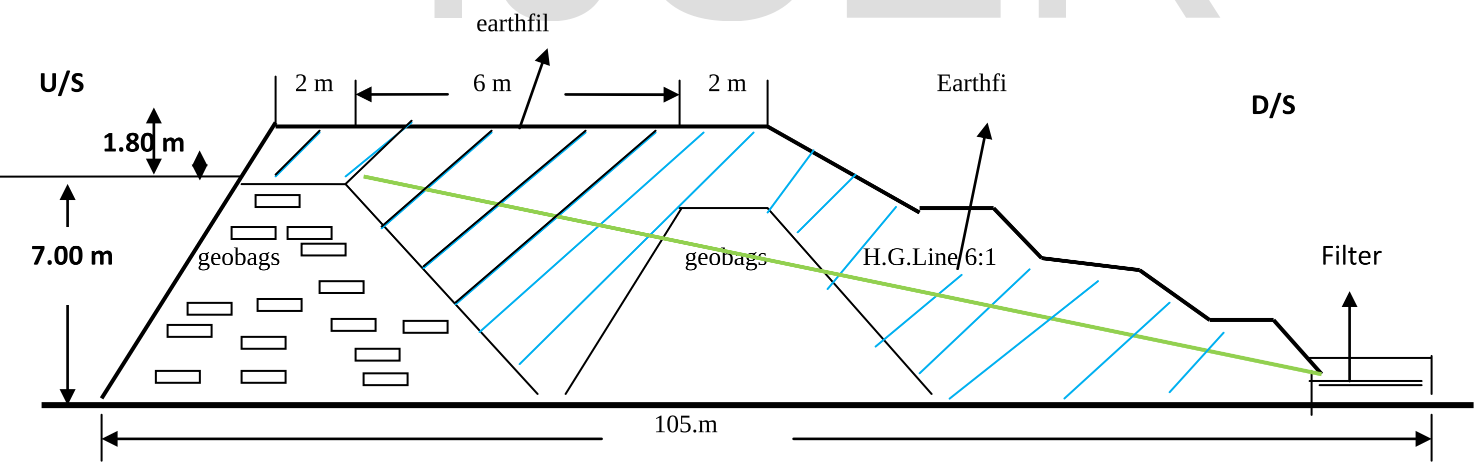

Fig . 3 Practical Section as feasible

Checks : -- Stability of gravity dams are checked in following ways---

1. Over turning
2. Sliding (shear failure)
3. Crushing
4. Development of tension causing ultimate failure by crushing

1. **Over Turning ---**

$$F_S = \frac{M_R}{M_O} > 1.5 \qquad (3.21)$$

Where F_S = Factor of safety against over turning

M_R = Resisting moment

M_O = Over turning moment

Since dam is be constructed under water, so stability will be checked in submerged condition i.e. submerged unit wt. of the materials is considered. Basically geo bags filled with local sand and clay is to be used as the construction materials and its submerged unit wt. as18 KN / M^3 and 6 KN / respectively.

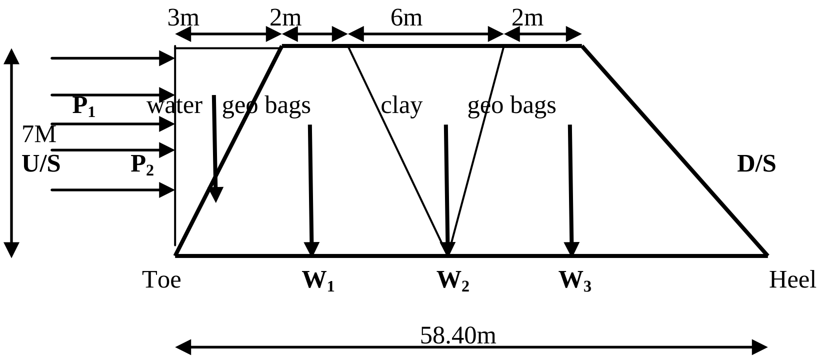

Fig .4 Forces acted on dam

Taking 1m length of dam for analysis purpose

Water pressure $P_1 = ½ wh^2$

$= ½ \times 10 \times 7^2$

$= 245$ KN

acted at 7/3 (2.33M) from base

Wt. of water acted down ward $P_2 = ½ \times 3 \times 7 \times 10$

$= 105$ KN

acted at 3/3 (1M) from toe

Wt. of geo bags dumped $W_1 = (2+8)/2 \times 7.50 \times 18$

$= 675.00$ KN

Wt. of clay $W_2 = ½ \times 6 \times 7.50 \times 6$

$= 135.00$ KN

Wt. of geo bags dumped $W_3 = W_1$

$= 675.00$ KN

Total Wt. of Dam Body $W = W_1 + W_2 + W_3$

$= 675.00 + 135.00 + 675.00$

$= 1485.00$ KN

Turning Moment Mo $= P_1 \times H/3$

$= 245 \times 2.33$

$= 570.85$ KN-M

Resisting Moment Mr $=$ W1x(58.40-8/2) + W3x(4.00) W2x(58.40-8.00) + + P_2x (58.4 – 1.00)

$=$ 675x54.40 + 136x50.40 + 675x4.00 + 105x57.40

$=$ 52301.400 KN-M

Put Values in equation 3.01 Fs= 52301.400 / 570.85

$= 91.62 > 1.50$

as required

hence O.K.

Safe Against Over Turning.

2. **Sliding (shear failure) : ---**

Factor of safety against sliding $Fs = \mu \times \Sigma Fv / \Sigma F_H$

Where μ = frictional resistance between dam body and foundation material

μ = 0.65 to 0.75 in earthen dam case adopt lower i.e. 0.65

Σ Fv = sum of all the vertical forces

ΣF_H = sum of all the horizontal forces

Σ Fv = 1485.00 + 105.00

= 1590.00 KN

And ΣF_H = 245.00 KN

$$Fs = \frac{0.65 \times 1590.00}{245.00}$$

$= 4.22 > 1.00$ as required hence O.K.

Safe Against Sliding (shear failure)

3. **Crushing failure : ---**

Maximum normal stress when water is not present in down stream side

$\sigma = p_v \sec^2\alpha$

$= \frac{(1485.00)}{105.00 \times 1.00} \times \sec^2(68.19^0)$ $\tan \alpha = 7.5/3$, $\alpha = 68.19^0$

$= 102.49$ KN / M^2

Crushing strength of soil is nearly 100.00 KN /M^2 slightly less but not a problem because materials used are local sand confined within geo bags with clay as core material. Actual crushing strength of the combined materials con not be predicted but definitely more than the crushing strength of soil.

Hence safe In crushing the dam section.

4. **Development of tension causing ultimate failure by crushing : ---**

It is very clear from the check as applied above in case first i.e. over turning moment is very very less than the resisting moment, that the horizontal forces are very very less tha vertiaval forces. Obviously no tensile force will be produced.

But failure in piping may be the serious cause so needs to overcome it and it may be done by proper design of filter and laying it down at the toe of dam which allows seepage water to seep out safely which may any how seeps through the dam body but without any material dam body like earth etc. Obviously by the laying down proper filter the dam material is confined but water seeps safely through them and failure in piping is not possible.

Filter –

Bottom Ist layer 0.20 meter thick fine sand
IInd layer 0.20 meter thick coarse sand
IIIrd layer 0.20 meter thick 10mm to 4.75mm stone grit.
Top layer 0.20 meter thick 12.50mm to 20mm stone grit.

These designed filter is laid In total 30.00 meter length from Toe.

Construction – Earthen dam is constructed usually by first diverting the flow of stream and covering the site by coffer dam or by sheet piling.

Central portion of dam is constructed by placing impervious clay cor[illegible] side of ir[illegible] is poured in stages with proper compaction with maintaining U/S side slope of 2.5:1 and D/S slope with 3:1. After completing required section of dam a designed filter is provided at the base of toe. Here we are concerned to the construction of specific type dam, which has been constructed by using geo bags and earth clay as the major construction materials with filter material.

The condition and situation at dam site is here totally different than usual conditions. Downstream of the dam a barrage was already constructed with the help of which water is stopped and maintaining the level of water to fulfill the need of Gaughat Pumping Station. Obviously at dam site flow of river is negligible. The construction was started in water without diverting the river and the dam construction site was not vacated by any coffer dam or sheet pile which is usually needed on U/S of site.

Started construction by dumping Geo bags filled with earth maintaining 2.00 m top width of geo bags on either side. Construction was started from left and right bank of river simultaneously.

When Geo bags were being freely dumped by lab ours. Water at dam site was nearly still and these geo bags settled down gradually and get started to stay at river bed. When enough no of geo bags was freely thrown by lab ours into water it gradually get down and stay one over other on previously laid geo bag and finally these geo bags get reached at top of water, now if top width of so dumped geo bag was less than 2.00m, then it was required to maintain it by further dumping. The final section of dam achieved by these type of geo bags dumping is shown in figure 3. It is quietly different than the section of dam actually required as shown in figure 2.

By comparing both the figure it is cleared that the central impervious .clay core is usually required rectangular but in this case due to free dumping of geo bags it settles naturally with side slope approximately 2.5 : 1 (H : V) and formed trapezoidal hollow section between either side of geo bags heap. To avoid touching of most bottom layer of geo bag of either side of geo bags heap it is necessary to keep sufficient top width of central clay core, it was here kept nearly 2.00 M. When enough no of geo bags is dumped so as to it covers few meter in length, Pouring of loose earth is started by doing its proper compaction . It is noticed that the water is existed in so created trapezoidal hollow section and when this hollow section is completely filled with loose earth by proper compaction the water goes back through the interspaces between geo bags into the river. The procedure of construction is carried on till the construction of dam is completed. Now, It is observed that the level of water is started to rise approximately 1 cm in a hour and the additional water is started to pass through already constructed side channel spillway, Whose bottom level is kept at the same level as the minimum level of water is already maintained in river before construction of dam is started. As level of river is risen up more and more water is passed through. By proper regulating the channel, level of river is stabilized. To ensure sufficient earth covering over H.G.L. dumping of loose earth is done in the way as detailed in the figure 3. at downstream of the dam section and it was necessary to provide proper filter at the toe . Laid down designed filter which helps in confining the the dam material and also give passage to seep water safely without damaging the dam body.

One thing is more here to discuss will be relevant that is the side spillway channel which is earthen and demands to design it carefully otherwise it could be failed in the purpose for which it was constructed. Regulation of channel is carried on by dumping proper wt. boulders whenever level of river goes down below minimum required level and taken out from it when level goes to a danger level to the dam.

CONCLUSIONS : -- There is no doubt that the structure as discussed above is of temporary in nature but its usefulness is much more at the site where the specific situation and condition like river Gomti in Lucknow required .The beautiful project on River Gomti is running which is popularly known as" Gomti River Front Development Project" which is possible only by the construction of the dam as discussed above which obviously reflects its importance. There was a need to construct a structure across the river which could stop the water at the point from where the work related to river front develop project had to be started and also required to raise the level of water in river so as to make it possible to supply the water to Gaughat Pumping Station. That's why the construction of gravity dam made of with the combination of geo bag and loose earth was executed without stopping the flow of water and also without vacating the construction site from water and also its construction was executed without diverting the river water. From the three years of its construction it has been serving well without no serious problem and fulfill the purpose for which its construction was done. The need and requirement of the project could also be fulfilled by constructing ring dam or coffer dam or sheet piling but the experience gained by the construction of dam discussed above is that it is cheap compare to others and its performance is satisfactory and the situation like river Gomti in Lucknow it is the best way to fulfill the purpose. The overtopping of the earthen dam so constructed may be possible for one flood period by laying down the geo bags on whole the open surfaces of the earth without its failure and also keeping it to serve the other flood periods by just maintaining the geo bags and its section. The construction of above dam is well tested and could be adopted at

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the site where situation like already discussed above is mate. Photographs showing The successful its construction and running still today proves the theory and technique developed as discussed above in the research paper.

Photograph :-- Execution of Dam As Designed Above.

Photograph :-- View of Dam After Construction.