STABILITY OF TRADITIONAL 'BUNDHS' - EARTHEN LEVEES - FROM GOA

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ABSTRACT: Goa is a land reclaimed from the sea thousands of years ago by traditional rubble-faced-compacted-earth retentive structures called 'Bundhs' - earthen levees embankments and revetments. These have lined, shaped and protected the low-lying Agricultural Lands, Canals, Lakes and Seashores. They have survived through millennia by steady Community-based repair and maintenance programmes. These walls have survived floods, earthquakes, and even foreign conquests. There is a concern on flood, erosion and riverside stability issues due to the risks that are compounded by the destruction of these traditional retentive structures. Much can be learnt from the traditions of our culture when tradition and technology goes hand in hand. This paper studies the stability of these traditional structures. GeoSlope is used to check the slope stability of the structures. The factor of safety was found out to be higher than 1.5 even in rapid drawdown condition for various configurations. The construction practices discussed further supplemented the strength and stability thus longevity and utility of these structures. There is scope for improvement by incorporating modern stabilizers, facing techniques and equipment. Further studies in these areas are needed.

KEYWORDS: IGC2016, Stability of Earthen Structures, Stability of Earth Retaining Structures, Traditional Retaining Walls, Slope Stability

1 INTRODUCTION

Goa is famous the world over for Song, Sun, Sea and Sand. A little known fact is that before annexation / liberation by the Indian union, Goa like Kerala, was crisscrossed with a network of canals protected by a series of bundhs. Bundhs are multifunctional raised mud rubble faced embankments. When the British were gifted Bombay (today Mumbai) as dowry – another land reclamation done by Portuguese using Goan engineers – they spread bund building throughout the world. Today bunds are used extensively everywhere but the basic ancient technology is missing.

1.1 Historical Perspective

As witnessed from Saraswati (Indus) Valley civilization onwards, Indians have used earth for civil engineering especially geotechnical purposes. Mohen-jo-daro even today is protected by a bundh 15,000 years old. Legend has it, that when River Saraswati was swallowed by mother Earth, 96 prominent Saraswat clans settled in Goa bringing along with them their Civil technology especially the bundhs (earthen embankments and leeves) that were used to reclaim the land from the sea (Mukhopadhyay, 2002). The uniqueness of this fact is even reflected in CRZ notification that dedicates a special section only to Goa. These ribbons of earth topped by coconut trees (Fig. 1) are found all over Goa.

1.2 Function of Bundhs

Goa is a land reclaimed from the sea tens of thousands of years ago by traditional 'Bundhs' - earthen levees embankments and revetments. (Goan-hindus call it the axe of Lord Parashurama). These rubble-faced-compacted-earth retentive structures have lined, shaped and protected the low-lying called 'Khazans' or 'Paddies' (Agricultural Lands), 'Wanvodd' (Canals) and 'tallis'(Lakes). They served a secondary function as a network of roads interlinking the marshy fields of Goa. They have survived through millennia by steady repair and maintenance. Through a series of walls (Fig. 2) these bundhs also did rainwater harvesting and canalized water to the river. These walls have survived floods, earthquakes, and even foreign conquests only to be destroyed in the name of technology and progress. Today concrete is replacing these long-established structures (Sonak, 2014).

Figure 1 Photograph of bundh

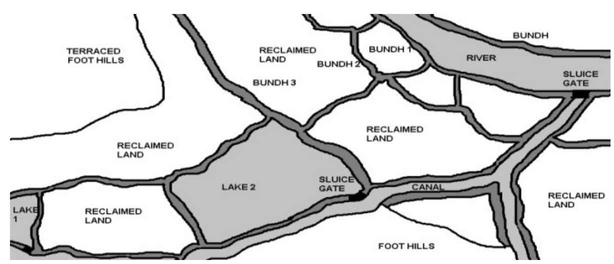

Figure 2 Schematic location map

1.3 Scope of this Study

Much expertise can be garnered from customs of our civilization when tradition and technology goes hand in hand. This paper studies the stability of these traditional structures by:-

Field studies; preparation of typical cross-sections; soil samples; stability analysis and suggested improvement measures

2 WALL CONSTRUCTION PRACTICES

Traditional Bundh construction practices amply illustrate that ancient Goan engineers had an implicit understanding of soil stabilization and soil reinforcement.

2.1 Traditional Methods of Construction

Primary Constituents of the bund were dredged clay from river bed. It was stabilized with burnt-shell-lime. The plastisizer used was coconut jaggery molasses. Cow dung and coconut leaf ash was used to increase cohesion and manage fine contents if the soil was too sandy in nature. Layers were laid in lift of 30 cm with rice-straw in-between. Rice straw layers were used as initial geofabric. Facing layer was made up of interlocking coursed lateritic rubble masonry. Compaction was done by using a line of 4 to 6 bullocks walking in a line. The compactive equivalent of 2-3 tonne sheep-foot rollers doing 10 passes per layer. Two lines of Coconut trees were planted on either side as a natural geogrid, to reinforce the structure by their fibrous root system (Fig. 3).

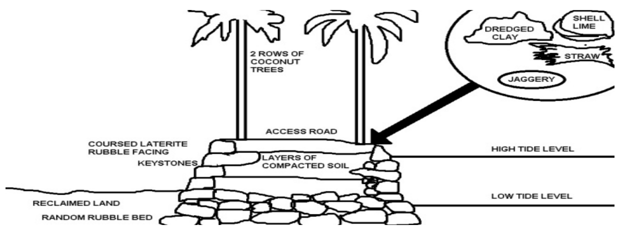

Figure 3 Bundh construction

2.2 Typical Bundh Sections

Typical traditional unit of measurement was '*hatt*'-one hand (approx. 50cm). Bamboo of required size was measured and cut and used for checking the size. Face inclination is generally 0.5-H : 3-V. while benching offset on seaward side is usually 0.5 m. and the offset on the leeward side is 1.5m. A freeboard of 1.5 to 2m was maintained for tidal fluctuations and flood absorption (Fig. 4).

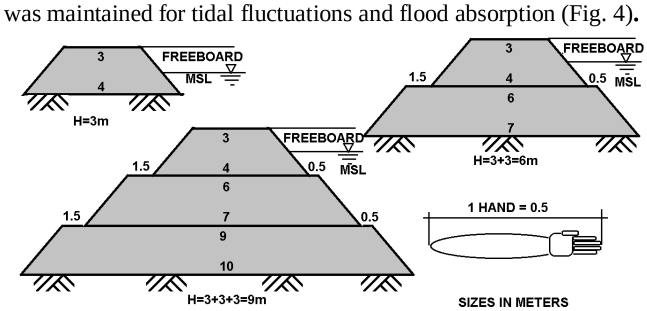

Figure 4 Typical Bundh sections showing maximum sizes.

2.3 Typical Usage

Geotechnical:- Land reclamation, river training works, soil erosion protection, Levees, flood protection, etc.

Non-Geotechnical:- Horticulture, Pisciculture, Salt farming, Recreation, tourism, water-sports, navigation etc.

3 DAMAGE TO WALLS

Today we find plenty of damage to these ancient structures as most people don't comprehend that these are marvels of Ancient Civil Engineering.

3.1 Cause of Damage

The principal reasons why these walls are damaged and disappearing is: Ignorance, Greed, Land grab, Money in real estate, Unscrupulous-unsustainable development, due to the lackluster attitude towards them, as not many take serious stock of the risks that are compounded by the destruction of these traditional retentive structures. Today community-based maintenance programmes which sustained them are nonexistence.

3.2 Repercussions of Damage

There are numerous negative effects of bundh damage: Invasion of mangroves, Changes of shoreline, flood, erosion and riverside stability issues, Disappearance of ancient historical technology (Fig. 5).

3.3 Need for Preservation

Goa is currently facing serious environmental crisis due to destruction of its watersheds and low lying 'Khazan' ecosystem. The sudden rise in population of Goa due to development in tourism industry has also added to destruction of these geotechnical structures. The modern practices of reclamation of land and increase in deforestation in the name of development are seen to be adversely affecting the ecosystem of Goa. Civil engineers must look back and learn about the traditional eco-friendly construction practices followed by our ancestors for stable and maintainable development.

4 FIELD INVESTIGATIONS

4.1 Topography

As the bundh topss were parallel to water level, simple tape measurements with plum-bob were used to measure cross sections. Most bundhs were found to be 3m wide and depths varying from 1 to 3 m. in rare cases as heights increased there was stepped berms (banquettes) as detailed in section 2.2 and Fig 4.

Figure 5 Invasion of mangroves, flooded outer bundh and disappearance of coconut trees at Borim on Mandovi river

4.2 Geomorphology

The landside was level and confined within ring-bundhs and secondary bundhs. The bundhs parallel the river and hill contours as applicable. The general slope of the reclaimed land was terraced in steps and staged (Fig. 2) between bundhs to approach low tide level at inner face of river side bund.

4.3 Metrology

Goa state being at the center of the landing range of the south west monsoons bears the brunt receiving the highest average rainfall in India, which is always in excess of 300 cm even in leanest season.

4.4 Regional Geology

Bundh Soil was of Lateritic, yellowish color sandy-silty-clay with high organic content. The soil was of riverside origin. The soil type was of uniform nature. Today red lateritic soil is used in some places while carrying out repair works.

5 LABORATORY INVESTIGATIONS

Laboratory investigation is an important step in determining the constants needed for slope stability analysis. Sampling method and. Laboratory tests were carried out as per IS: 2720 (Part 4) - 1983 Code. The following results were obtained (US Army Corps of Engineers, 2000).

5.1 General Soil Parameters

Three sets of soil samples A, B and C were collected from different locations. These were kept safe and dry in polyethylene bags in the soil-mechanics laboratory of the Department of Civil Engineering, Goa Engineering College and marked, indicating the soil description, sampling depth and date of sampling. Classification test (natural moisture content, specific gravity, Grain size analysis and Atterberg's limits,) and compaction test (optimum moisture content, Maximum Dry Density)were performed on the samples A, B and C to determine the geotechnical properties of the samples. The average values have been presented below in Table 1.

5.2 Soil Shear Strength Parameters

Engineering property test for shear strength were performed on the samples A, B and C and the values are indicated below in Table 2.

Table 1 General Soil Properties

Sample		A	B	C	Mean
Specific Gravity G_s		2.73	2.72	2.75	2.73
Moisture Content w%		12	14	14	13.33
Compaction test	OMC %	11	12	11	11.33
	MDD g/cc	1.92	1.95	1.93	1.93
Atterberg limits	Liquid Limit w_L %	19.5	22.6	21.5	21.2
	Plastic Limit w_P%	14.8	16.2	15.2	15.4
	Plasticity Index Ip	4.7	6.4	6.3	5.8
Grain Size Disribution	Gravel %	2.5	4.5	2	3
	Sand %	17.5	20	13.5	17
	Silt %	25	35	30	30
	Clay %	55	40.5	57.5	51

Table 2 Effective Shear Strength Parameters of Soil

Sample	c' (KN/m^2)	Ø' (^{0})
A	30	27
B	35	25
C	34	29
Mean	33	27

6 STABILITY ANALYSIS

Stability Analysis was performed for both seaward and leeward side for sudden drawdown conditions (worst case scenario) for typical cross sections 3m, 6m and 9m high, using average the γ, c-ϕ values found out above.

6.1 Slip Surface Analysis

Analysis was performed using Swedish method of slices and Fellenius method to locate center of slip circle using the formula

$$F = \frac{c' r\,Ø' + tan\,Ø' \Sigma N}{\Sigma T}$$

where

c' = Effective cohesion of soil for saturated condition

ϕ' = Effective friction angle of soil for saturated condition

N = Normal component of weight of soil

T = Tangential component of weight of soil

The results are tabulated in Table 3 below:

Table 3 Results from manual calculations

Wall height (m)	Seaward side			Leeward side		
	FOS	R (m)	θ (^{o})	FOS	R (m)	θ (^{o})
3	3.415	6.45	35	3.415	6.45	35
6	2.23	11.11	39	2.573	11.72	38
9	1.9	14.83	36	2.06	16.96	38

6.2 Numerical Analysis

Numerical analysis was done using commercially available software GEOSTUDIO-SLOPEW (Ikiensinma, 2005) showed factor of safety above 1.5. (Fig. 6). The Morgensen-Price Method of slope stability was chosen for the software and the γ, c-ϕ values chosen were the same as for slip circle analysis.

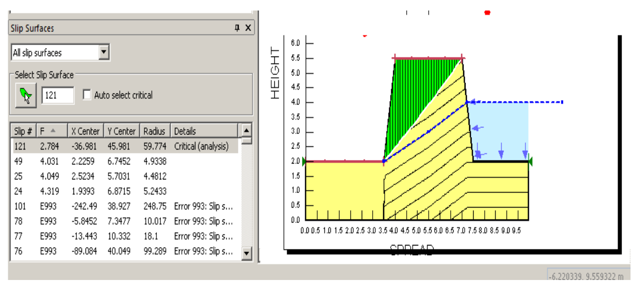

Figure 6 Screen shot from Geo-Studio leeward side showing FoS = 2.784

Table 4 Results from Numerical Analysis

Wall height	3 m	6 m	9 m
FoS leeward	2.78	1.74	1.52
FoS Seaward	4.87	2.41	2.33

The factor of safety from both the slip surface analysis (Table 3) and the Numerical analysis (Table 4) were plotted on graphs and showed that the reduction in the values of Factor of safety with height of the embankment is a curve that levels out at 1.5 for worst case scenario. (Fig. 7)

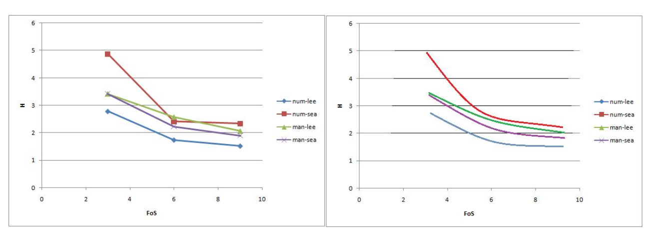

Figure 7 Graph of Factors of safety

There is an additional 10 to 15 % factor of safety due to the natural geo-textile effect of coconut tree root system. Further addition of 1 to 5 % is available to stability due to the friction between the rubble layers in the facing.

As the worst case scenario was well above safety limits (1.5) no further analysis need to be performed.

Seismic analysis were not carried out as the nearest earthquake (of magnitude greater than 5) to Goa as per IS 1893 is at distance 220 km away and the horizontal acceleration coefficient k_h was found to be a feeble 0.045.

6.3 Possible Cause of Failure

Though these structures have withstood the test of time they require regular inspection and maintenance. Failure can occur due to following reasons (:

Overtopping; jetting; internal erosion and piping; surface erosion; wave impacts; structural impacts from navigating boats; slope failures; sliding; under-seepage; liquefaction;
bottom heave; uprooting of trees; pilferage of facing materials (laterite) by locals; burrowing animals; unscientific land and river encroachment; haphazard development on/next-to bundhs.

7 IMPROVEMENT METHODS

These geotechnical structures are mainly composed of riverside organic sandy-silty-clay stabilized with lime and jaggery and reinforced initially by straw and then by coconut tree roots. Modern technology needs to be used to improve these traditional structures.

7.1 Improvement of Fill

Suggested fill materials include:

Fly-ash stabilized soils (Sridevi et al., 2015); straw and coconut leaf ash stabilized soils (Amu et al., 2011); geo-net and geo-grid reinforced soil; stabilized municipal waste landfill; stabilized mining waste landfill; stabilized crusher dust landfill; soil-crete.

7.2 Improvement of Facing

Although today plain concrete gravity wall is being used to replace the traditional interlocked coursed rubble facing, it has failed repeatedly. Even coursed smooth ashlar masonry and brick masonry is a failure. Suggested facing materials include, Gabion walls; interlocking precast concrete blocks; rubber tire retaining walls; geo-grid walls; mechanically stabilized retaining walls.

7.3 Modern equipment

Modern equipment may be used to replace customary machines and tools for efficiency and economy in time. Suggested equipment include Total-Station for precise surveying and positioning; excavators, hoes, shovels, clamshells and such equipment for mud excavation and leveling; Latest rollers and tamping equipment for compaction.

8 SCOPE FOR FURTHER STUDIES

There is a vast scope for further studies in traditional rubble-faced-compacted-earth retentive structures called 'Bundhs' as shown below:

1. Proper numerical modeling and testing with alternative fill and facing material can be explored.
2. Slope stability with more parameters and seismic stability needs a look into.
3. The exact proportion of clay : lime : jaggery used as a fill material is lost in history and needs to be studied.
4. Modern admixtures be used to augment the strength needs further investigation.
5. Role of geotextiles in replacing the function of rice-straw and fibrous roots of coconut trees has to be seen, vis-a-vis their stability and engineering lifespan.
6. Resistance of these bundh to dynamic and shock loading needs further study.

9 CONCLUSIONS

As can be seen from above deliberations these bundhs in addition to their historical significance serve very important civil-geotechnical purposes. Their destruction can affect the very existence of Goa by manmade natural disasters of floods and erosion. Modern RCC walls are quite ineffective and need expensive repair and maintenance as compared to traditional walls and levees. Corrupt field practices further compound this problem. This leads to their repeated failure. Ancient methods that have stood the test of time must be preserved and maintained. These traditional earthen levees embankments and revetments have stood the test of time. Goa being a strategic ancient port has gone through repeated invasions with cannon bombardment, many earthquakes, and flooded rivers – yet these bundh-systems absorbed all these shocks.

The results of Stability Analysis shows that the factor of safety against slope failure is higher than 1.5 for highest bundh (9m) at rapid drawdown condition, which is safe at worst condition. This ratifies geotechnically the reality of the stability of the bundh. As seen above, such rubble-faced-compacted-earth retentive-structures with their natural-sustainable-coconut-root-reinforcement system can withstand severe damage and can be easily and economically repaired. We need to think back to look forward.

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