ON FACTORS INFLUENCING GROUND SUBSIDENCE: A CASE STUDY OF MUNROE ISLAND

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ABSTRACT: Munrothuruthu ('Munroe Island') is a place renowned for continuous settlement, in the Kollam district of Kerala. The Indian Ocean earthquake and Tsunami of 2004 triggered this major problem. The island is located at confluence of the Ashtamudi Lake and the Kallada River. Low lying regions of the island are facing progressive settlement which has become pronounced since the occurrence of Tsunami. The area has been affected by upward seepage of saline water during High Tide events, denoting the axial lowering of land mass. The salinity intrusion of Ashtamudi Lake in island has become recurrent phenomena in the region resulting in several environmental issues. The island is on the verge of sinking and settlement is rapid with time. The foundation on the site has settled and few residents have abandoned their dwelling units.

This desk study and walk over survey analyses the geological processes, their risk and damage perceived in past few years. It attempts to improve understanding of changes in island, causes and implications, with comparison to reported land subsidence worldwide. This paper deals with the settlement issues observed at the site. Some recommendations are proposed in the paper to overcome and manage the existing issues and difficulties in the island.

Keywords: High tide, Munroe Island, Settlement, Internal erosion

1 INTRODUCTION

Land (or Ground) subsidence is the lowering of the land, due to changes that occur underground. The common reasons for this are tectonic forces, loading of the earth's crust which are the natural factors; and from human activity, are pumping water, oil and gas from underground reservoirs, formation of sinkholes (limestone aquifers), collapse of underground mines, drainage of organic soils, initial wetting of dry soils etc. A survey of literature reveals the identification of this phenomenon in various parts of the world like Mississippi, California, Florida, and Mexico in the United States, Venice and Netherlands in the Europe, Bangkok, Bangladesh and Jakarta in South East Asia. (Butterfield, 2004; Milliman et al.,1989)

Munroe Island is an amalgamation of eight small islands. It is a typical backwater Island village of Kerala, India located at the confluence of Ashtamudi Lake and Kallada River. The geographical area of the island is 13.4 sq. km. During the tenure of Colonel John Munro, appointed by East India Company as administrative head of Travancore, the land reclamation efforts in the delta where Kallada River joins Ashtamudi Lake was done and the reclaimed island was named after him as Munroe Island. Since the Tsunami of 2004, this island, which has a population of around 10000 men and women, is facing subsidence leading to loss of shelter and occupation for many residents. In addition, there has been a reduction in the sediment load deposited by the Kallada river in the flood plains owing to the construction of the Thenmala dam.

Fig 1 Location Map of Munroe Island

2 GEOLOGY

The area surrounding the Munroe island is a part of Asthamudi estuary which forms an important geological segment of the South Indian peninsular shield, both crystalline rocks and tertiary sediments are major components of the estuary (Kurian et. al, 2001). Sedimentary rocks belonging to the Warkalli and Quilon formation constitute the dominant lithology of the main island and nearby area. The quaternary sediments are of marine and fluvial origin and are mostly seen in the low lying are mostly by the side of Kallada River and to western part in proximity with the Asthamudi Lake and the numerous tidally active creeks. The lithological association and thickness of Quaternary strata in the areas as reported by Padmalal et. al. (2013) is as follows:

Table 1: Soil Profile (adapted from Padmalal et al., 2013)

Depth (in m)	Soil Type
0-2	Clayey mud(organic)
2-6	Medium to fine sand
6-14	Silt clay
>14	Medium to fine sand

The top soil of Munroe Islands is acidic saline soil as per the classification of soils by the Department of Soil Survey and Soil Conservation. This soil is commonly observed in low-lying marshes, waterlogged and poorly drained areas near the rivers and streams, which are subject to tidal waves. Sea and backwater tides make these soils saline. During monsoon season, when rainwater and fresh water from rivers enter the fields, salinity is partially washed off. A wide variation in texture from sandy loam to clay is noticed with dark grey to black color.

3 FIELD STUDY

The field observations are listed below:

- The regions that showed considerable settlement had variations of submerged, saturated and highly moist topsoil. The topsoil is acidic saline and composed of organic clay matter.
- 'Boiling' was observed during high tide. The Arabian Ocean is directly connected to the Ashtamudi Lake by a strait which is about 12 km away from Munroe Island system. Near the water front areas, tidal ingress would generate seepage pressures in the sand and clay layers that would pull off the particles while receding. This results in settlement of structures near the backwaters.
- The residences underwent settlements to the extent that doorsteps sunk into the soil, the walls have cracked and openings have separated from the main structure (Fig.2, Fig.3 and Fig. 4). Many occupants have raised the floor level to counter this issue but it resulted in lowered roof level and further settlement due to increase in stresses.
- The settlement did not show any obvious pattern except that it was most pronounced near the interface with water of Ashtamudi Lake and impact decreased with distance.
- The area was subjected to heavy sand mining.

Fig 2 A residential building settled nearly 40cm in Kidaparam South as on 5th Jan 2016. Note that the steps at the entrance have settled into the soft clay.

3.1 Settlement of Structure

The settlement of buildings by more than 50cm is reported and has become evident during field inspection. In certain areas, this is apparently due to construction of structures on the clay layer without proper piling in an area where the soil structure consists of top layer of 2 m thick clay. The difference in elevation of these areas compared to the average river water level/backwater level is less than 30cm in most cases. The clay in the area is getting saturated during the semi-diurnal tides as well as due to the capillary rise. It is noted that the construction with heavy concrete structures are settling faster compared to light weight structures.

Fig 3 The residential building showing cracks due to differential settlement.

The provisions of CRZ (Coastal Regulation Zone) notification 2011 indicate that mangrove areas and its buffer up to 50 m forms CRZ-I, where constructions are prohibited. The constructions which have settled and are affected by tidal flooding are mostly in the CRZ area.

Tidal fluctuations have certainly induced piping and erosion, considering that the soil profile shows clay layers confining sand layer. The experimental study on piping in sandy gravel foundation considering effect of overlying clay (Shuang Wang, et al, 2015) considered the clay- sandy gravel bilayer which closely resembles the in situ condition at Munroe Islands. The high hydraulic gradient applied in the study is similar to that caused by the Ashtamudi Lake, Kallada River and tidal variation. The high and variable hydraulic gradient causes rapid progression of internal erosion by piping and diffusion. The study reported that the initial instability and internal erosion might have been set up as a result of unscientific sand mining. The progression of piping is complicated and an iterative process involving erosion of fine particles, clogging of pores and subsequent flushing of pores. Other studies also report strength reduction due to upward seepage flow, due to migration of fine particles (Lin Ke and Akihiro Takahashi). The observations made at Munroe Islands are consistent with the same.

The presence of organic matter also supplements the subsidence rate because clay (particularly montmorillonite mineral) and diatomaceous deposits (materials that contain a high percentage of siliceous skeletal remains, or frustules of phytoplankton) are often highly compressible and subject to rearrangement of grains, depressurization resulting in more subsidence than that of less compressible, coarse grained deposits.

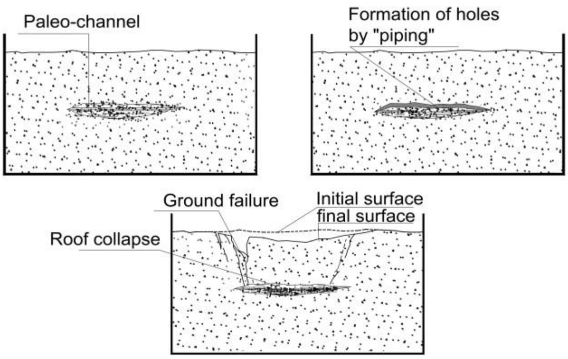

Fig 4 Different stages on the formation of ground failures related to buried paleo-channels. Fine soil in the paleo-channel is carried away by subsurface runoff, causing the formation of voids. Eventually, sediments above the paleo-channel can collapse generating a ground failure. (Jesus et al., 2013)

The origin of this ground failure can also be associated with the dragging of fine sediments in buried paleo-channels, causing the removal of mass and the subsequent formation of large voids, similar to the piping effect described before (Jesus et al., 2013). Paleo channels are former streams that became incised into the underlying material, later became abandoned by shifting of flow patterns and subsequently became filled with alluvium (Fig.4). The presence of such channels can be established by conducting a series of resistivity and gravimetric surveys (Fig.5).

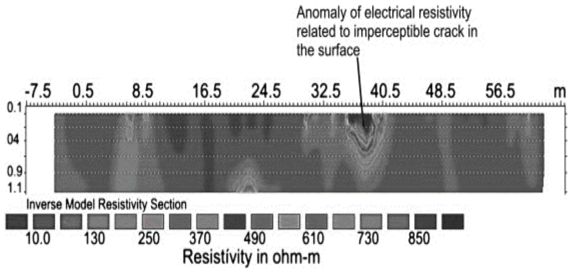

Fig 5 Profile of resistivity used for detecting hidden or incipient ground failures. High values of resistivity (red tones) can be interpreted as discontinuities in the subsoil, whereas the low valued zones (blue tones) as a homogeneous soil (Jesus et al., 2013)

3.2 Construction Practices and Sand Mining

The traditional structures were light weight in nature with wooden side walls and thatched roofs but in last 20 years this had changed to concrete structures with concrete roofing. Traditional house required only localized techniques of piling and not beyond a depth of 2m. However, new concrete structures, requires piling up to the sand strata which is not done as the traditional farmers in the region cannot afford such costs of construction. Hence the clayey layer which consolidates due to the load gives away and seeps out to the adjacent water bodies over time. State of Environment Report Kerala (2007) reports heavy sand mining in the Kallada River bed. The report states that the river bed lowering rate as 11 cm/year. The unscientific sand mining practice has made the region unstable.

3.3 Reduction in Natural Deposition

Ever since the Thenmala dam was built, river flooding stopped and thus the supply of nutrient rich deposits and fine grain sand also substantially reduced. This implies that natural depositions in the deltaic land in the region have reduced as compared to the historical times. The resultant reduction in flood water has made the acidic saline soil even more acidic as the acidic residue doesn’t get washed away. Michael D. Blum and Harry H.

Roberts (2009) have reported a similar case about the drowning of the Mississippi delta due to insufficient sediment load obstructed by the construction of dam. They have also estimated a submergence of around 13,500 km^2 of land by the year 2100 due to subsidence and sea level rise. To overcome this, 18-24 billion tons of sediments need to be drawn which is significantly more than can be achieved, considering that the sea level is rising 3 times faster than during the delta-plain construction

4 RECOMMENDATIONS

Considering the multi-causal problem of subsidence of Munrothuruthu, submergence of the island is inevitable. Since there seems to be certain areas more susceptible to rapid settlement, it is mandatory that a deep ground investigation study is taken up to categorize the areas. The following measures are proposed.

- A network of GPS and space borne differential interferometric SAR and precision leveling technique (Chatterjee et al., 2015) to monitor subsidence of the rapidly and slowly settling areas may be conducted for long duration, such that a clear picture may be evolved regarding the stability of the island chain.
- Once the highly vulnerable areas are identified rehabilitation measures may be implemented to safely relocate its residents. While designing the new constructions, steps must be taken to keep the stresses to a minimum. This can be achieved by using light weight construction materials.
- Electrical Resistivity and Gravimetric surveys may be conducted in order to detect hidden or incipient ground failures. In areas where paleo-channels are identified, grouting or deep cement mixing measures may be undertaken to stabilize the area.
- Raising mangroves along the river banks and backwaters can tackle shoreline erosion. A diversion plan may be devised in order to allow the sufficient passage of fluvial sediments from the Kallada dam.

5 CONCLUSION

The sinking phenomenon in Munrothuruthu can be attributed to various factors like rising sea level, tidal ingress, piping and erosion, presence of paleo-channels and organic matter, and absence of deposition of fluvial deposits. The field visit indicates that many houses are sinking at a consistent rate that poses threats to many of its inhabitants. It is concluded that substantial characterization and ground studies may be undertaken to quantify the factors leading to subsidence. Further rehabilitation and ground improvement measures may be resorted to tackle the housing issues. The intervention of the state is sought in order to allot sufficient funding for carrying out the extensive subsidence studies in this area.

REFERENCES

Butterfield R (2004), “On subsidence and Eustachy in relation to Venice”, Advances in Geotechnical Engineering: The Skempton Conference, Vol 2, pp. 1231-1242

Milliman D., James M.,Broadus and Gable F. (1989) “Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples”, Ambio, Vol. 18, No. 6, pp. 340-345

Martínez J. P. ,Marin M. H. , Cervantes N. G(2013) , “Land subsidence and ground failure associated to groundwater exploitation in the Aguascalientes Valley, México”, Engineering Geology, Vol.164, pp.172-186

Kurian N.P., Mathew J., Hameed T.S. and Prakash T.N. (2001) “Bathymetry of Ashtamudi estuary”, Developing a management plan for Ashtamudi estuary, Kollam, India, Technical Memoir, Centre for Earth Science Studies, Thiruvananthapuram, pp.363-431

Lin K., Takahashi A. (2012),"Strength reduction in cohesionless soils due to one-dimensional upward seepage flow", Soils and Foundation, 52(4); 698-711.

Michael D. Blum and Harry H. Roberts (2009), “Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise”, Nature Geoscience, Vol.2, pp 488-491

Padmalal D., Maya K. and Mohan V. (2013) “Late Quaternary climate, sea level changes and coastal evolution – A case study from SW India”, Monograph, Centre for Earth Science Studies, Thiruvananthapuram, ISBN 81-901842-1-0

Chatterjee R. S., Thapa S., Singh K. B., Varunakumar G, Raju E. V. R. (2015), “Detecting, mapping and monitoring of land subsidence in Jharia Coalfield, Jharkhand, India by spaceborne differential interferometric SAR, GPS and precision levelling techniques” Journal of Earth System Science, (124), Issue 6, pp 1359–1376

State of environment report- Kerala 2007, Vol-1, www.moef.nic.in/sites/default/files/Kerala_SoE2007-V1_0.pdf

Wang S., Chen J., He H., He W. (2015), "Experimental study on piping in sandy gravel foundation considering effect of overlying clay", Water Science and Engineering, Vol.9, Issue 2, pp 165-171