Geotextiles and Geomembranes 45 (2017) 702–706

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Professional Practice Paper

Development and management of geomembrane liner hippos

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A R T I C L E I N F O

Article history:
Received 17 April 2017
Received in revised form
15 August 2017
Accepted 15 August 2017
Available online 23 August 2017

Keywords:
Geosynthetics
Geomembrane
Hippos
Case histories

A B S T R A C T

The paper describes the authors experience with the formation of geomembrane liner hippos, which is the spherical deformation of the liner within a liquid or viscous medium. The paper presents a summary of six case histories, describing the key features of the hippo and how it formed. The paper also describes the management measures introduced to address the hippo feature.

1. Introduction

Geomembrane liner hippos are defined as the deformed spherical shape of a geomembrane liner separated from the intended contact with the liner subgrade. A geomembrane liner hippo "liner hippo" can be small (a few hundred millimeters) to many meters in diameter. Most liner hippos, due the mechanism involved, are generally round in plan. Liner Hippos can exist fully or partially submerged and may be visible on the surface of a facility, as shown in Fig. 1.

The development of a liner hippo can occur through either the entrapment of air/gas or water under the liner, or a combination of both. A liner hippo generally forms within a liquid or viscous material that can readily deform due to pressure differences between the upper and lower surfaces of the geomembrane liner. The purpose of this paper is to present our experience with the investigation and remediation of hippos on a number of lining projects.

2. Background

The use of polyethylene as a geomembrane liner for storage of liquid and residues is wide spread due to the low cost of the material relative to other liner materials, and the wide spread experience in the installation of this type of liner material. Most of the facilities described in this paper comprise exposed geomembrane liner, with some of the facilities including a cover material over the liner. The decision to adopt an exposed liner appears to largely be related to construction costs and to reduce the risk of liner being damaged during the placement of cover soil layer.

The specific gravity or density of typical polyethylene (all density grades) liner is less than water, so the liner will float in water or any other more dense liquid. Similarly air below the liner will tend to impose buoyancy loads to the liner. A common misconception is that the water above the liner will restrain or counter any buoyancy loads from the below the liner.

Liner hippos can form when the pressure below and above the liner are in balance and the buoyancy of the liner relative to the liquid provides the net uplift pressure, although often a very small net uplift pressure. Any air trapped under the liner provides additional net uplift pressure. Any difference in hydraulic pressure between the top and bottom of the geomembrane can either increase or decrease the net uplift pressure. The net uplift pressure results in the liner deforming often to a concave upwards shape, lifting the geomembrane liner off the subgrade. The mechanics and analysis of the forces and pressures related to Liner Hippos is a subject of a separate paper.

This paper presents a number of case histories in which the author investigated and provided advice on the mechanism and remediation of the Liner Hippos.

3. Case histories

Case 1: A linear low density 2 mm thick polyethylene geomembrane was installed in a large residue storage facility located

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http://dx.doi.org/10.1016/j.geotexmem.2017.08.007
0266-1144/

Fig. 1. Typical liner hippo.

on a site in a region with high rainfall and cyclonic climate. The residue deposited in the facility was a hydraulically deposited low solids content residue. Due to weather and the low solids content of the residue, the facility also included a large body of runoff water from the catchment of the facility. During cyclone events the area routinely received more than 300 mm rainfall, resulting in large volumes of rainfall runoff into the lined facility.

The facility included an extensive groundwater drainage system below the geomembrane liner due to periodic high groundwater levels below the basin of the lined storage facility. The installation of the lining works for the facility extended through a number of wet seasons. During one of the rain events a breach occurred in the construction stage stormwater management system resulting in some of the rainfall runoff flowing into the groundwater drainage system. Due to the flow rate into the groundwater system exceeding the design flow capacity, the system became pressurised. The relative elevation difference between the groundwater drainage system and the breach of the stormwater management system resulted in a pressure in the ground water drainage system that exceeded the hydrostatic pressures of the stored liquid and residue on top of the geomembrane liner.

This event resulted in the formation of numerous large hippos in the geomembrane liner, which extended to the surface level of the liquid within the storage area. The stormwater runoff also entrained some air in the runoff that flowed into the groundwater drainage system.

The Liner Hippos varied in size from approximately 2 m diameter to very large.

The small Liner Hippos dissipated over a period of a few days, however the large Liner Hippo reduced in size slightly, but then remained in place. It was decided to lower the water level in the storage during the following dry season and to deflate and potentially repair (if required) the large liner hippo. It was our experience from other projects that the seams in the geomembrane liner associated with large hippos generally are excessively strained and require repair or replacement.

Fig. 2 shows the shape of the liner after lowering the storage water level and exposing the liner. The hippo deflated when the water level in the storage was lowered, as the trapped water in the hippo seeped into the groundwater drainage system. The edge of the deformed shape is along the circular line in the photo formed by the edge of the exposed liner (light brown compared to dark brown of sediment). The raised geomembrane near the centre of the circular area shows the approximate location of the crest of the spherical shape of the liner hippo, when it was submerged. This area of the geomembrane was extensively crumped after the deflation process. The geomembrane was covered by a thin light brown layer of dried sediment on its surface. As assessment of the geomembrane indicated that it had been strained substantially by the hippo and it was decided to replace the area of the geomembrane liner. The damaged geomembrane liner was cut out and replaced with fresh geomembrane, and all upstream openings in the groundwater drainage system were closed.

The lesson learned from this is that a deformed liner resulting from a large Liner Hippo is likely to deform a geomembrane liner to an extent that requires replacement of the liner. The critical size of a hippo that may require liner replacement is not evident.

Case 2: A storage pond system was designed to retain low pH liquor for a processing facility. The facility was designed with a HDPE geomembrane liner overlying a locally available compacted clay layer. The compacted clay layer was engineered to form a low permeability liner, as part of a composite liner system for the pond. The clay included some calcium based minerals. The geomembrane liner was exposed, and the pond was approximately 3.5 m deep.

The pond comprised a leak collection sump near the lowest area of the pond floor. The leak collection sump was constructed below the clay liner component of the composite liner system.

During the operation of the pond it was noted that a liner hippo started to form. The size of the liner hippo progressively increased to a size that a surface expression of the geomembrane liner of approximately 5 m in diameter appeared above the liquid level of the pond. Fig. 1 in the introduction shows the bubble. The owner believed that the Liner Hippo was related to trapped air or gas and requested some assistance from a Contractor. The Contractor attempted to deflate the bubble by inserting a flexible pipe between the geomembrane and clay liner, but was unsuccessful in deflating the Liner Hippo. The author of this paper was then engaged to investigate the issue. Following the emptying of the pond it was evident that the size of the Liner Hippo had been much larger than expected by the owner. Fig. 3 shows the size of the remnants of the Liner Hippo, which can be seen by the circle in the dried sludge that had formed on top of the geomembrane liner. The thickness of the sludge within the circle on the geomembrane was generally only a few millimeters. The Liner Hippo was approximately 35 m diameter on the pond floor and a few meters diameter at the surface of the stored liquor.

The sludge on the liner remote from the hippo was generally undisturbed, suggesting no deformation of the liner had occurred. However a few small sludge disturbed areas were noted where small Liner Hippos may have existed. The thickness of the sludge varied over the pond, with areas where the sludge only a few millimeters and others a few hundred millimeters thick.

The thicker areas of sludge trapped pockets of air below the geomembrane liner as the pond was emptied. These air pockets remained in place for weeks after the pond had been emptied. Analysis of the gas in the pockets confirmed that they were not just air but included high concentration of carbon dioxide and other gases that indicated that the gas was a by-product of the reaction between the low pH liquid in the pond and the calcium minerals of the clay liner.

An inspection of the geomembrane liner at the deflated hippo located a separation in a seam of approximately 1 m length. This separation was located within the large Liner Hippo footprint. A close inspection of the seam suggested that it had separated by brittle failure and likely to be associated with stress cracking of the heat affected zone in the geomembrane seam. The geomembrane liner material itself showed no other mechanical distress from the hippo formation.