Fifth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCEI'2007)
"Developing Entrepreneurial Engineers for the Sustainable Growth of Latin America and the Caribbean: Education, Innovation, Technology and Practice"
29 May – 1 June 2007, Tampico, México.

POTENTIAL FOR THE USE OF COIR FIBRES IN TRINIDAD AND TOBAGO FOR GROUND ENGINEERING WORKS

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Abstract

Beside Cocoa and sugarcane the other major export crops in Trinidad and Tobago are coconut, and its main derivative such as copra which is the second most important crop in Tobago. The by product of the copra extraction process coir fiber is usually thrown out as waste. Today more than 97% of Trinidad and Tobago area is experiencing light to intensive soil erosion. Coir fibre could be specifically important material for ground improvement in Trinidad and Tobago not only because the coir fibre is relatively water-proof and is the only natural fibre resistant to damage by salt water but coir fibre is resistant to acidic water. Soil test results for the period 1998 - 2000 performed in Trinidad and Tobago indicated that more than three quarters of samples where moderately to strongly acid. The analytical work conducted in this paper has shown that Vegetable Fibre Geotextiles such as coir could be used to reinforce flatter slopes. In this paper the author will explore the potential for the use of coir fibre for ground improvement in Trinidad and Tobago.

Keywords: coir fibres, geotextiles, reinforcement, embankment, pore pressure,

1. Introduction

Vegetable fibres has been part of culture for all human society. The well-developed masonry technology of Mesopotamia was used to build large structures of great masses of brick, such as the temple at Tepe Gawra and the Ziggurats at Ur and Borsippa (Birs Nimrud), which were up to 26 metres (87 feet) high. Allinger-Csollich Agar-Quf ziggurat, which stands five kilometres north of Baghdad, was constructed of clay bricks reinforced with mats of reed laid horizontal on a layer of sand and gravel at vertical spacing varying between 0.5 and 2.0 m. (Jones, 1998). The reeds used to reinforce the Ziggurat were in the form of plaited ropes approximately 100 mm in diameter which passed through the structure and acted as reinforcement. According to Jones (1998) the Great Wall of China, parts of which was completed circa 200 BC, contains examples of reinforced soil, in this case bricks were made of mixture of clay and gravel reinforced with tamarisk branches. Natural fibres were used in construction in the 5th and 4th millennia BC, when dwellings were formed from mud/clay bricks reinforced with reeds or straws. This is supposedly recorded in the Bible (Exodus 5, V 6-9). The Bible states that in Egypt, builders were obliged to work in clay for the formation of bricks, and others to gather straw for the same purpose**,** because straw is the bond by which the brick is held together. However Verse 7 clearly creates some conjecture concerning the use of straw in making bricks. Some people support the idea that straws were used merely for burning them, other believe that the bricks found are made of clay and straw kneaded together, and then not burned, but thoroughly dried in the sun.

Within the last 50 years there has been rapid development of construction techniques, analytical methods and the development of material for use in ground engineering. One of the major techniques that have been developed is soil strengthening or reinforcement whereby man-made elements developed products are include within geological material to provide a stabilized mass. With increasing environmental awareness lead to investigation/consideration of substitute using vegetable fibre for the man-made material in the situation where there is requirement for the short-term reinforcement. The existing Beetham Highway in Port of Spain (Trinidad and Tobago) was constructed on the swampy soil between 1955 and 1956 (Michael, 2001). This major highway was reinforced using mangrove planks

The most important properties of vegetable fibres, especially for soil reinforcement, are that vegetable fibres posses a high initial tensile strength. Widespread use of vegetable fabrics in ground engineering has not happened due to biodegradability of these fabrics and existing chemical fibres, which are superior to vegetable fibre. The overall aim of this paper will be to investigate the behaviour of an embankment reinforced using Vegetable Fibre Geotextiles.

2. Vegetable Fibre production in Trinidad and Tobago

Agricultural output in Trinidad and Tobago during the 1970s and 1980s was inversely related to the performance of the oil sector: depressed during the oil boom, stimulated during oil's decline. Increasing wage costs, shortages of labor, and oil wealth all directly affected agricultural output. Coconut, and its main derivative, copra, was another major export crop and was the second most important crop in Tobago. Like other export crops, output of coconuts declined in the 1970s, making the island no longer self-sufficient in oils. All coconuts went to the local processing industry for soaps and oils. Copra output in 1985 exceeded 4,000 tons. The coir fibres found between the husk and the outer shell of a coconut are usually discarded as waste only a small amount were used for making mattress. The importation of synthetic foams mattresses has completely replaced the use of coir in Trinidad and Tobago.

2.1 Structure of the coir fibre

Coir (Etymological origin: from Tamil and Malayalam - *kayaru* - cord) is a coarse fibre extracted from the fibrous outer shell of a coconut. The individual fibre cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature but later become hardened and yellowed as a layer of lignin is deposited on their walls. There are two varieties of coir. Brown coir is harvested from fully ripened coconuts. It is thick, strong and has high abrasion resistance. It is typically used in mats, bushes and sacking. Mature brown coir fibres contain more lignin and less cellulose than fibres such as Flax and Cotton and the fibres are resilient, strong and highly durable but less flexible. Coir fibres are made up of small threads, each about 1 mm long and 10 to 20 micrometer in diameter. White coir fibers are harvested from the coconuts before they are ripe. These fibers are white or light brown in color and are smoother and finer, but also weaker. They are generally spun to make yarn that is used in mats or rope.

The coir fibre is relatively water-proof and is one of the few natural fibres resistant to damage by salt water. Fresh water is used to process brown coir, while sea water and fresh water are both used in the production of white coir.

2.2 Cultivation of Palm trees

Coconuts are the seed of the palm trees, these palms flower on a monthly basis and the fruit takes 1 year to ripen. A typical palm tree has fruit in every stage of maturity. A mature tree can produce 50-100 coconuts per year. Coconuts can be harvested from the ground once they have ripened and fallen or they can be harvested while still on the tree. A human climber can harvest approximately 25 trees in a day, while a knife attached to a pole can up the number to 250 trees harvested in a day. Green coconuts, harvested after about six to twelve months on the plant, contain pliable white fibres. Brown fibre is obtained by harvesting fully mature coconuts when the nutritious layer surrounding the seed is ready to be processed into copra and desiccated coconut. The fibrous layer of the fruit is then separated from the hard shell (manually) by driving the fruit down onto a spike to split it . A well seasoned husker can manually separate 2,000 coconuts per day. Machines are now available which crush the whole fruit to give the loose fibres. These machines can do up to 2,000 coconuts per hour.

2.3 Fibre extraction

2.3.1 Brown fibre

The fibrous husks are soaked in pits or in nets in a slow moving body of water to swell and soften the fibres. The long bristle fibres are separated from the shorter mattress fibres underneath the skin of the nut, a process known as *wet-milling*. The mattress fibres are sifted to remove dirt and other rubbish, dried in the sun and packed into bales. Some mattress fibre is allowed to retain more moisture so that it retains its elasticity for 'twisted' fibre production. The coir fibre is elastic enough to twist without breaking and it holds a curl as though permanently waved. Twisting is done by simply making a rope of the hank of fibre and twisting it using a machine or by hand. The longer bristle fibre is washed in clean water and then dried before being tied into bundles or hunks. It may then be cleaned and 'hackled' by steel combs to straighten the fibres and remove any shorter fibre pieces. Coir bristle fibre can also be bleached and dyed to obtain hanks of different colours.

2.3.2 White fibre

The immature husks are suspended in a river or water-filled pit for up to ten months. During this time micro-organism break down the plant tissues surrounding the fibres to loosen them - a process known as retting. Segments of the husk are then beaten by hand to separate out the long fibres which are subsequently dried and cleaned. Cleaned fibre is ready for spinning into yarn using a simple one-handed system or a spinning wheel.
Uses

2.3.3 Uses

Brown coir is used in floor mats and, mattresses, floor-tiles and sacking. A small amount is also made into twines. Pads of curled brown coir fibre, made by *needle-felting* (a machine technique that mats the fibres together) are shaped and cut to fill mattresses and for use in erosion control on river banks and hillsides. The major use of white coir is in rope manufacturing. Mats of woven coir fibre are made from the finer grades of bristle and white fibre using hand or mechanical looms. White coir also used to make fishing nets due to its strong resilience to salt water.

2.4. Basal reinforcement of an embankment erected on the soft ground

Basal reinforcement of embankment on the soft ground has being used to provide additional stability for embankments constructed on soft ground, stability and prevent the settlement of embankment on soft foundations and to prevent collapse and limit vertical movement of the embankment surface following the formation of a void in the foundation. This additional stability enables the embankment to be constructed quicker, enables steeper slopes to be utilised and reduces embankment fill quantities.

Basal reinforcement provides additional stability to an embankment prior to foundation consolidation and then after the need of reinforcement diminishes with time since the foundation can fully support the embankment loading. Depending on the embankment characteristics and foundation soil properties the period over which the reinforcement is required is relatively short compared to the design life of the embankment. In order to understand the time dependent behaviour of an embankment on the soft soil an analytical model was created.

3. Methodology

3.1 Analytical Model

The practical situation considered is an embankment constructed over soft soil. To investigate the geotechnical aspects of an embankment containing basal reinforcement a typical configuration of an embankment over soft ground has been defined and typical values have been assigned to the relevant parameters.

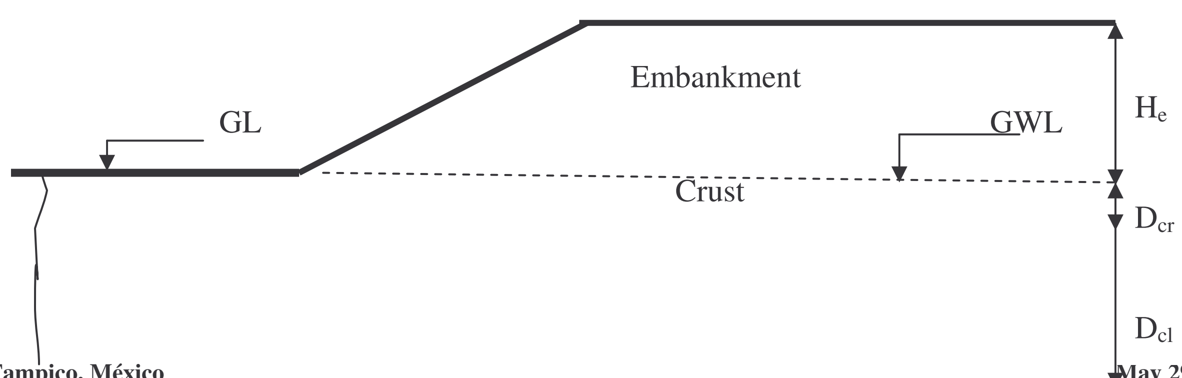

Figure 1 Typical embankment

From the review of typical cases of embankments built on soft clays, the idealized situation that will be analysed is as shown in Figure 1 where H_e is embankment height, D_{cr} crust depth and Dcl soft soil depth. The ground water level (GWL) is at the original ground surface.

In order to analyse this situation numerically it was necessary to assign physical quantities for relevant parameters. This was achieved by selecting physical values for the situation considered. The embankment was assumed to be H_e=3 m high and was composed of free-draining material D_{cl}. The soft clay of the foundation soil was taken as fully saturated and groundwater was at ground level.

3.2 Analytical method

In general there are three predominant types of slope instability or failure, i.e. translational slide, rotational failure and wedge failure. Only rotational failure is considered in this paper. Modes of failure are usually rotational (often with an essentially circular slip surface) and non-circular slip surface normally develop because of the influence of ground stratigraphy. Rotational instability is usually a deep-seated failure mechanism with the sliding surface often being more or less circular.

The Factor of Safety against rotational failure is the ratio of total resisting moment to total disturbing moment. The Bishop Simplified method of analyses is acknowledged as providing a reliable and accurate estimate of the Factor of Safety as shown in equation 1

$$FOS = \frac{\sum_{i=1}^{i=n}[c\ b_i + (W_i - u_i b_i)\tan\phi]\frac{1}{M(\alpha)}}{\sum_{i=1}^{i=n} W_i \sin\alpha_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Therefore overall analytical procedure adopted in this paper has focused on rotational failure. In order to investigate the stability of this analytical model the Bishop method of slices was used**.** Two cases were investigated to identify the effects of consolidation on Factor of Safety and to investigate the need for reinforcement as the soil consolidates.

4. Results

4.1 Initial analytical procedures

Initially three points having different depths-ratios (D_{cc}/D) were selected i.e.0.333, 0.5 and 0.67 (identified as shallow, middle and deep) where D_{cc} is critical slip circle depth and D is the foundation depth. For each point selected a slip circle was drawn (for all three points to be investigated). The slipping mass was then divided into slices (6-12) considering the configuration of an embankment. The slope and parameters considered in this case were (Vertical:Horizontal) V:H = 1:3 (Tv=0.00, $\phi'_f = 15°$, $\phi'_e = 35°$ and crust cohesion 4kN/m^2).

Since in this work the analyses were performed using effective stress, then it was essential that the pore pressure dissipation at the base of each slice was determined. As the water pore pressure dissipates the degree of consolidation increases. The predicted minimum Factor of Safety at Tv = 0.00 was 0.97(deep penetration). The Factors of Safety after 100% consolidation were 1.86, 1.90 and 2.15 for deep, middle and shallow circles respectively, therefore the most unstable surface of rupture was found to be the one passing deep in the soft clay. The geotextile strength needed to ensure Factors of Safety of 1.1 and 1.5 was back calculated for the deep circle.

In order to show the effect of consolidation on Factor of Safety, an example was performed whereby the actual Factor of Safety due to consolidation was compared with the initially required FOS 1.1 as shown on Figure 2 due to the effects of consolidation. The actual FOS at the Tv = 0.00 was below unity (for a circle penetrating deeply into the foundation soil). FOS equals to 1.1 was reached after 15% consolidation of the foundation soil and at the end of consolidation FOS had increased almost twice as much as compared at the end of construction.

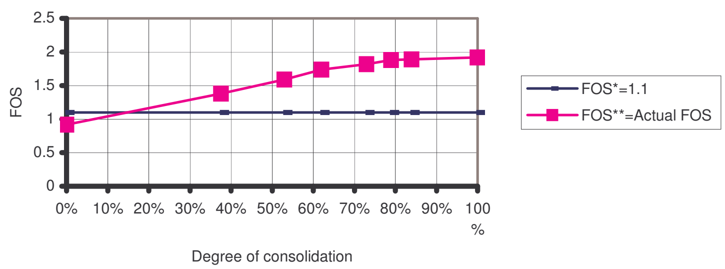

Figure 2 Effect of consolidation on Factor of Safety

The global Factor of Safety, i.e. incorporating the contribution of soil shear strength and the geotextile reinforcement to equation 1 gives equation 2 which can be written as.

$$\frac{\text{Total stabilizing force} + \frac{T_R Y}{R}}{\text{Total turning force}} = FOS \quad \text{--------------------------------2}$$

Where T_R is the required force from the reinforcement while R and Y is the critical slip circle radius and reinforcement lever arm respectively.

From the analysis it was found that the stabilizing force equals 111 kN/m and the total disturbing force is 115.8 kN/m. The FOS at Tv equals to zero was found to be 0.97

On putting these data in equation 2 for FOS = 1.1 the results are as shown in equation 3 and 4.

$$\frac{111+\frac{T_R Y}{R}}{115.8}=1.1 \quad \ldots\ldots 3$$

$$16.4 = T_R Y/R \quad \ldots\ldots 4$$

In this example the lever arm of the acting reinforcement Y = 6m and the radius of the slip circle R = 7.6 m. Hence the tensile force required to be provided by the reinforcement at the end of construction (Tv = 0.00) is 20.7 kN/m.

The same procedure maybe repeated in equation 5 and 6 for the required FOS of 1.5.

$$173.7 - 111 = 61.7 = T_R Y/R \quad \ldots\ldots 5$$
$$T_R = 7.6/6 \text{x } 61.7 = 78.42 \text{ kN/m} \quad \ldots\ldots 6$$

In order to maintain a FOS 1.5 at the end of construction the reinforcement was required to provide additional force of 78.42 kN/m. This analysis was repeated for 1, 2, 3, 4, 5 to 6 years for the FOS of 1.1 and 1.5. Thus it can be demonstrated that by increasing the FOS from 1.1 to 1.5, an additional stabilizing force of 57.72 kN/m was required. After two years there will be no reinforcement required to achieve FOS =1.1 but as shown in Figure 3 in order to achieve global FOS of 1.5 more tensile force was required equivalent to 20kN/m after 2 years.

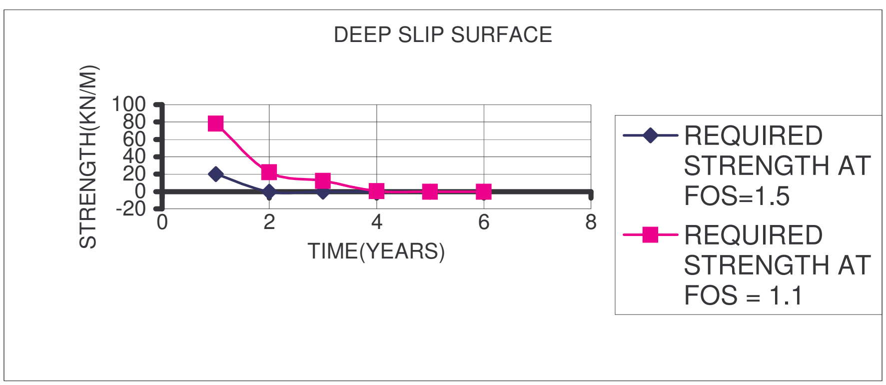

Figure 3. Reinforcement strength required maintain a specified Factor of Safety

This analysis indicates the suggested shape of the strength-time envelope postulated for basal reinforcement in embankment over soft clays and supports the concept of 'Limited Life Geotextiles' as engineering technical materials.

4.2 Second analytical series

In the second analytical series as shown in Figure 4, the calculations were repeated by determining the Factor of Safety for three different conditions i.e. slip surface cutting ground surface at the toe, 1 m from the toe and 2 m from the toe.

Table 1 FOS at different depths (immediately after construction, Tv= 0.00)

Position	FOS at depth (m)						
	0.05	0.5	1	1.5	2	2.5	2.99
TOE	2.05	1.6	1.23	0.84	0.89	0.94	1.02
1 m Beyond TOE	2.7	1.7	1.22	0.89	**0.78**	0.84	0.86
2 m Beyond TOE	4.5	1.97	1.34	0.94	0.92	0.84	0.94

Table 2 FOS at different depths (after complete dissipation of pore pressure, TV= 2)

Position	**FOS at depth (m)**						
	0.05	0.5	1	1.5	2	2.5	2.99
TOE	2.05	1.99	1.69	1.46	1.24	1.82	2.35
1 m Beyond TOE	2.7	2.64	1.92	1.45	**1.18**	1.47	1.82
2 m Beyond TOE	4.	2.	1.	1.	1.	1.	1.

	5	3 3	8 5	5	5 3	5 4	8

The most critical slip circle was found to be the one cutting 1 m from the toe, as shown in the Tables 1 and 2. The minimum FOS was found to be 0.78 and 1.18 at Tv = 0.00 (end of construction) and Tv = 2 (at infinity) for $D_{cc}/D = 0.67$, i.e. the lowest part of the circle which is 2 m. deep.

To investigate the critical slip surface for the three cases the variation of FOS with
Time Factor was plotted against depth ratio. The minimum FOS was given by the slip circle cutting the ground surface 1 m beyond the toe as illustrated in Figure 4.

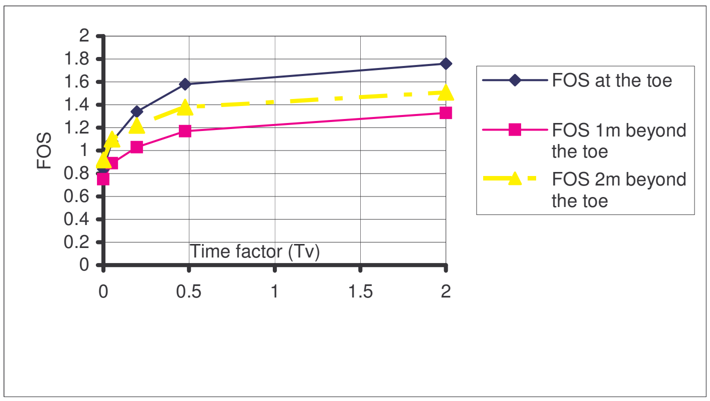

Figure 4 Variation of FOS with Time Factor (Tv) at various depth ratio (D_{cc}/D)

The effect of reinforcement on Factor of Safety for this critical slip surface was investigated by plotting the variation of FOS 1.2, 1.5 and 2 as shown on the Figure 5
Figure 5 Estimation of required reinforcement strength with varying Time Factor (Tv) at critical slip surface ($D_{cc}/D = 0.67$, 1 m beyond the toe)

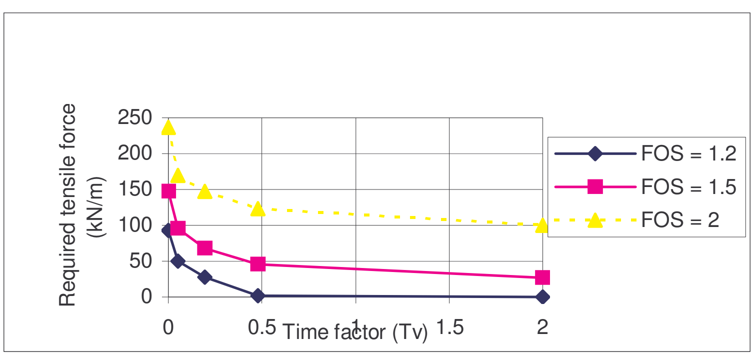

Figure 5 Estimation of required reinforcement strength with varying Time Factor (Tv) at critical slip surface ($D_{cc}/D = 0.67$, 1 m beyond the toe)

The determination of tensile force required from reinforcement for a given FOS was calculated using back analysis as conducted for the first analytical series. From this investigations, it was found that no reinforcement was required to maintain a FOS of 1.2 after Tv = 0.5 and for the FOS (1.5 and 2) the need for reinforcements was considerably reduced as shown in Figure 5.

In order to illustrate the proportion of reinforcement strength required with time at given critical slip surface, a ratio of the required tensile force to initial required tensile force (T_{Rt}/T_{R0}) was plotted against time. From this analysis, it was found that in 5 years there was no need of reinforcement to achieve global FOS of 1.2. But for global FOS of 1.5 and 2.0 the reinforcement were required throughout up to the end of consolidation. Figure 6 illustrates the proportion of reinforcement strength with time (at critical slip surface D_{cc}/D = 0.67. 1m beyond the toe)

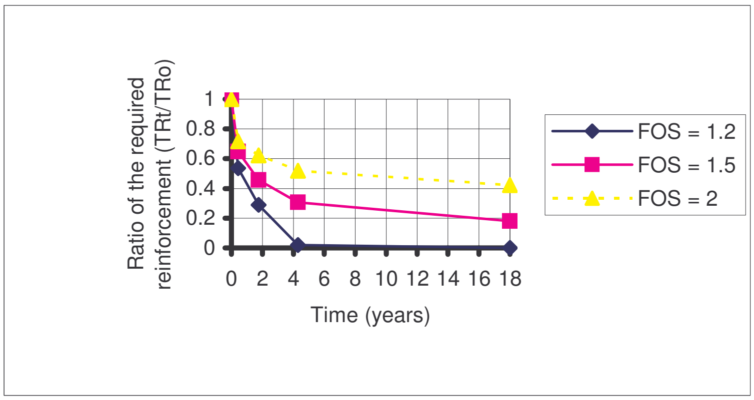

Figure 6 Proportion of reinforcement strength with time (at critical slip surface D_{cc}/D = 0.67. 1m beyond the toe)

5. Conclusion

The analytical work conducted in this work has showed that the stability of the embankment would improve in time as the pore pressure in the underlying soft soil dissipates and the effective stress increases with time. As the underlying soil strength increases so does the stabilizing force (which has to be provided by the geotextile) diminishes with time. The amount of required geotextiles can be selected whenever the loss in strength of the geotextile due to degradation corresponds to the reduction in the required stabilizing force. The design concept is based on the point that the embankment and foundation soil are stable in the long-term with the geotextiles only being required to bolster short-term stability. The analytical model has been successful and shows that geotextiles with limited lives, e.g. Vegetable Fibre Geotextiles such coir fibre, can be used provided that the strength requirement decreases with time.

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