INVESTIGATION OF SOME FACTORS RESPONSIBLE FOR GULLY EROSION ACTIVITIES ALONG RIVER YASHI, MINNA, NORTH-CENTRAL NIGERIA

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Abstract
Investigation of some factors contributing to the propagation of gully erosion along River Yashi, Minna, North-Central Nigeria has been conducted. Field observations of anthropogenic factors and geotechnical properties of soil along River Yashi were determined. The anthropogenic factors observed to contribute to the gully growth include soil excavation along the river bank and on the river bed, building on the flood plain and farm practices. Geotechnical field index properties of soil were determined followed by some laboratory index and performance tests. The outcome of the investigation indicated that; the natural moisture content varied from 8.49 to 18.21% with an average of 12.93%; the uncompacted bulk density (UBD) is between 0.98 to 1.23kg/m^3 with an average of 1.10kg/m^3 and the compacted bulk density (CBD) is from 1.27 to 1.52kg/m^3 with an average of 1.38kg/m^3; the specific gravity varies through 2.15 to 2.68 and an average of 2.35; the sieve analysis result showed that coefficient of uniformity (C_u) is from 0 to 20.45 with an average of 7.63 while coefficient of curvature (C_c) is from 0 to 1.01 with an average of 0.64; the plasticity index extend from 0 to 5.63% while the average is 5.54%; the compaction result shows that the optimum moisture content (OMC) varies from 9.90 to 12.39% with an average of 11.39% while the maximum dry density (MDD) ranges from 2.14 to 2.42mg/m^3 with an average of 2.28mg/m^3; the triaxial shear test result shows that the angle of internal friction (AF) is from 6^0 to 11^0 with an average of 9° and the cohesion (C) is from 19 to 32kg/m^2 with an average of 26.33kg/m^2; The permeability ranges from 1.93 × 10^{-3} to 2.49 × 10^{-3}cm/sec and the average is 2.14 × 10^{-3}. The results of geotechnical tests show favourable soil condition for gully erosion growth. Slope stability, construction of rip-rap with weeping holes, cultural or vegetation method among others has been suggested as control measures.

Keywords: Geotechnical, Soil, Gully, Index, Performance

Introduction

Gully erosion is one of the environmental challenges globally. The Nigerian case is not different as the phenomenon is ravaging many parts of the country. But the most affected area is the south-eastern part of the country (Abdulfatai *et al*, 2014). There is therefore, concentration of researches in the south-eastern part compared to other part of the country especially north-central Nigeria to which Niger state belongs. Thus, little knowledge exists on the factors that aid the propagation of the gully erosion along Rafin Yashi.

This situation prompted this research to investigate anthropogenic factors and soil geotechnical properties that aid the propagation of gully erosion in Rafin Yashi area of Minna, Niger state, Nigeria. River Yashi which happen to be the major river draining the area and a tributary of River Chanchaga was chosen for this investigation.

The study area is located between latitudes 09°39'00" to 09°42'00"N; and longitudes 006°30'00" to 006°33'00"E covering an area of 36Km^2. The relief of the area is between 200m – 295m. The most visible landform in the area is the Minna Batholith which is located in the Eastern part of Minna where River Yashi takes it source. This batholith is surrounded by gently sloping plains.

The previous work done is mainly regional by Falconer (1911) who concluded that tectonism and uplift have contributed to the drainage pattern of Nigeria. Climate and anthropogenic has been suggested as factors that causes and promote gully erosion (Grove, 1951; Floyd, 1965 and Oformata, 1965). Biological and hydrogeotechnical factors also contributed to gully propagation in Nigeria (Nwajide and Hoque, 1979; Egboka and Okpolo, 1984; Egboka and Nwankwor, 1985; and Imasuen et al, 2011). Low silt/clay content in the soil along stream banks also contributed to gully enhancement (Obiefuna et al., 1999 and Opara *et al.*, 2011).

Geology of the Area around Rafin Yashi, Minna.

Rafin Yashi is within the Older Granite of Minna with rocks of predominantly granodioritic composition and they form rugged topography (Alabi, 2011). Alabi (2011) remarked that Minna is characterised by rugged granitic batholiths and ridges. Ajibade *et al,* (1989) reported that the textures of rocks in Minna are predominantly medium to very coarse grained while some are fine grained. However, others are porphyritic in texture and the main minerals are plagioclase, microcline, muscovite, biotite, and some accessory minerals such as zircon and apatite (Ajibade *et al,* 1989). The field relations show that the Older Granites intruded the migmatite-gneiss complex and schist belts. The evidence for this was made from the following observations: sharp contact between the outcrops and the surrounding rocks and evidence of contact metamorphism as shown by the presence of hornfels in some of the area, some relics of migmatite-gneiss complex and schist that can be seen on the granites (Ajibade *et al,* 1989).

Methodology

Field observations were carried out at River Yashi's flood plain and along its channels to investigate the effects of human (anthropogenic) activities on the river system. Geotechnical field index tests were employed to establish the field index properties of soil samples along the bank of River Yashi through visual identification. The index field property determined included dry strength, dilatency, toughness, plasticity, colour, odour, moisture condition, consistency, particle sizes, presence of roots and soil type/name on seven points along the river. Seven representative soil samples were selected from points between the depths of 0.6m – 1m along the river bank for analysis. The choice of the depth was base on the opinion of Brice (1996) who opined that gully occur at a width greater than 0.3m and a depth greater than 0.6m. Five geotechnical laboratory index properties (moisture content, specific gravity, bulk density, Atterberg limit and sieve analysis) were determined for each sample. Three performance tests (compaction, permeability and triaxial test) were determined for three carefully selected samples (RY3, RY4 and RY6). The selections were based on the outcome of geotechnical laboratory index properties determined earlier. Therefore, performance test for RY1, RY2, RY5 and RY7 were not determined (ND). All laboratory analyses were performed at the Civil Engineering Department of Federal University of Technology, Minna, Nigeria. The procedures used for all the laboratory tests were derived from Arora, (2007); Ara et al, (1997); and Brian, (1978).

Results

Possible factors observed to propagate gully erosion along river Yashi channel and within its flood plains include failure of remedial measures that was taken to control runoff which would have in turn help in reducing erosion along River Yashi (Plate 1 and 2). Sand and gravel excavation were noticed along the river bank (Plate 3) and on the river bed (Plate 4) by people living around the area.

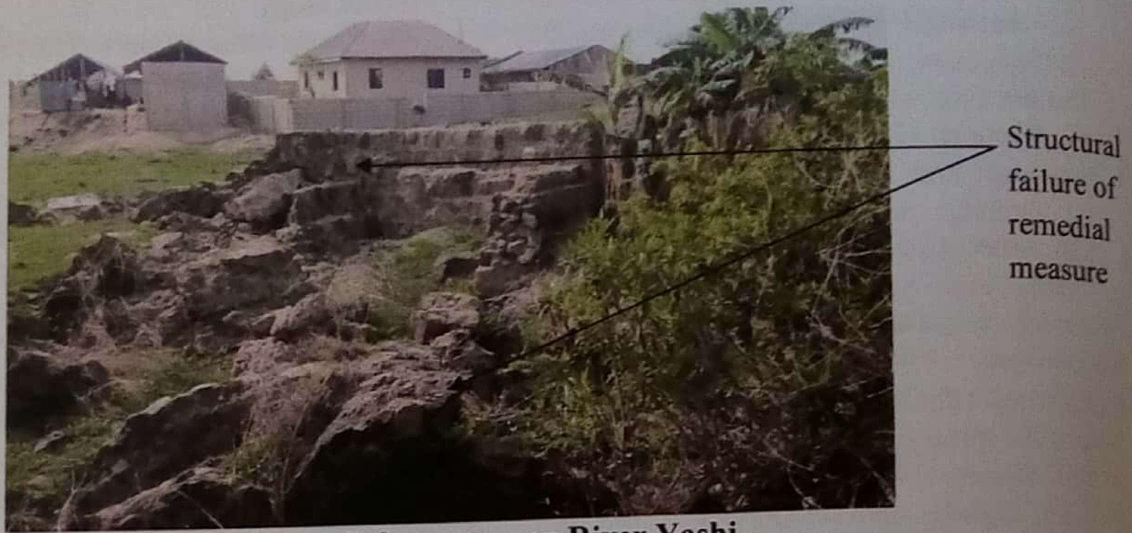

Plate 1: Failure of remedial measure on River Yashi

Plate 2: Another structural failure of remedial measure on River Yashi

Plate 3: Excavation of soil and gravel along the bank of River Yashi

Plate 4: Excavation of soil and gravel on the bed of River Yashi

Buildings on Flood Plain/River Bank were observed. Houses at various stage of development were noticed on the flood plain of River Yashi is shown in Plate 5. This practice is inimical to the river system as it can encourage erosion generally and gully erosion in particular.

Plate 5: Buildings on flood plain

Farming around the floodplain was observed. Farm practice on and around the flood plain does not really favour gully erosion mitigation. The farmers in the area prefer heaping (Plate 6) and ridges parallel to the slope of the river bank rather than making ridges perpendicular to the slope. This action encourages runoff which in turns lead to gully expansion.

Plate 6: Farming on the flood plain of River Yashi

River Yashi flows from the North – Eastern to South-Western direction mainly. Table 1 shows the identification codes of samples, coordinates, depth and width of River Yashi gully site at various sampling points. The seven samples selected for analyses are shown in the sampling map in Figure 1. The outcome of geotechnical field index properties as presented in Table 2 shows that the dry strength varies from none for RY1 and RY2; medium for RY5 and RY7; and high for RY3, RY4 and RY6. The dilatency varies from low for RY3, RY4 and RY6 to medium for RY5 and RY7 to rapid for RY1 and RY2. The toughness varies from low for RY1 and RY2 through medium for RY5 and RY7 to high for RY3, RY4 and RY6. Only low plasticity for RY1 and RY2 and medium plasticity for RY3, RY4, RY5, RY6 and RY7 were recorded on the field. The in situ colour comprised of dark for RY4 and RY6; brown for RY1, RY2, RY5 and RY7 and mottled for RY3. Odours were recorded for all samples except sample RY5 which was odourless. The in situ moisture conditions were damp except sample RY5 which was dry. Soft consistencies were recorded for all samples except for RY3 and RY5 that were firm. The samples were all made up of fine grained soil. Presences of few roots were recorded in all samples except RY5. The soil types included sandy-silt for RY1, RY2, RY5 and RY7; sandy-clay for RY3; silty-sand for RY4 and sand with silt for RY6.

The results of geotechnical laboratory index properties of soil along River Yashi are presented in Table 3 and 4 below. The natural moisture content for RY varies from 8.49 – 18.21% with an average of 12.93%. The uncompacted bulk density (UBD) is between 0.98 – 1.23kg/m^3 with an average of 1.10kg/m^3 while the compacted bulk density (CBD) is between 1.27 – 1.50kg/m^3 with an average of 1.38kg/m^3. The specific gravity ranges from 2.15 -2.68 while the average is 2.35. The sieve analysis results show that coefficient of uniformity (C_u) ranges from 2.71 – 20.45 with an average of 7.63 while coefficient of curvature (C_c) ranges from 0.18 – 1.01 with an average of 0.64. The Atterberg limit results show that the plastic limit is between 14.70 -22.27 while the average is 19.12%, liquid limit ranges from19.80 - 27.66 while the average is 24.65%. The plasticity index ranges from 0 – 5.63% with an average of 5.5. The relative consistency varies between 0 – 3.56 and the average is 2.06. The graph of Plasticity Index (PI) against Liquid Limit (LL) shows plots that are slightly above A - line for RY3, RY4 and RY6. They all plotted at clay – silt boundary (Figure 8). The sand content ranges from about 6% for RY6 to about 43% for RY3. Atterberg limit were however not attained by samples RY1, RY2, RY5 and RY7.

Table 1: Identification codes of samples, coordinates, depth and width of River Yashi gully site

S/NO	Identification Code of samples	Coordinates	Elevation (m)	Depth (m)	Width (m)
1	RY1	N09°41'07.8" E006°30'39.4	304	6	48
2	RY2	N09°40'46.0" E006°30'33.1"	292	5	25
3	RY3	N09°39'57.3" E006°30'15.1"	276	8	23
4	RY4	N09°38'59.6" E006°30'23.2"	264	3	15
5	RY5	N09°37'59.8" E006°30'37.9"	249	3	18
6	RY6	N09°36'48.4" E006°30'37.9"	238	4	21
7	RY7	N09°35'46.5" E006°31'17.5"	222	3	23

Table 2: Geotechnical field index properties

Tests	RY1	RY2	RY3	RY4	RY5	RY6	RY7
Dry strength	None	None	High	High	Medium	High	Medium
Dilatency	Rapid	Rapid	Low	Low	Medium	Low	Medium
Toughness	Low	Low	High	High	Medium	High	Medium
Plasticity	Low	Low	Medium	Medium	Medium	Medium	Medium
Colour	Brownish	Brownish	Mottled	Dark	Brown	Dark	Brown
Odour	Smell	Smell	Smell	Smell	Odourless	Smell	Smell
Moisture Condition	Damp	Damp	Damp	Damp	Dry	Damp	Damp
Consistency	Soft	Soft	Firm	Firm	Soft	Soft	Soft
Particle sizes	Fine	Fine	Fine	Fine	Fine	Fine	Fine
Presence of roots	Few	Few	Few	Few	None	Few	Few
Soil type/name	Sandy - Silt	Sandy - silt	Sandy – clay	Silt - Sandy	Sandy - silt	Sand with silt	Sandy – silt

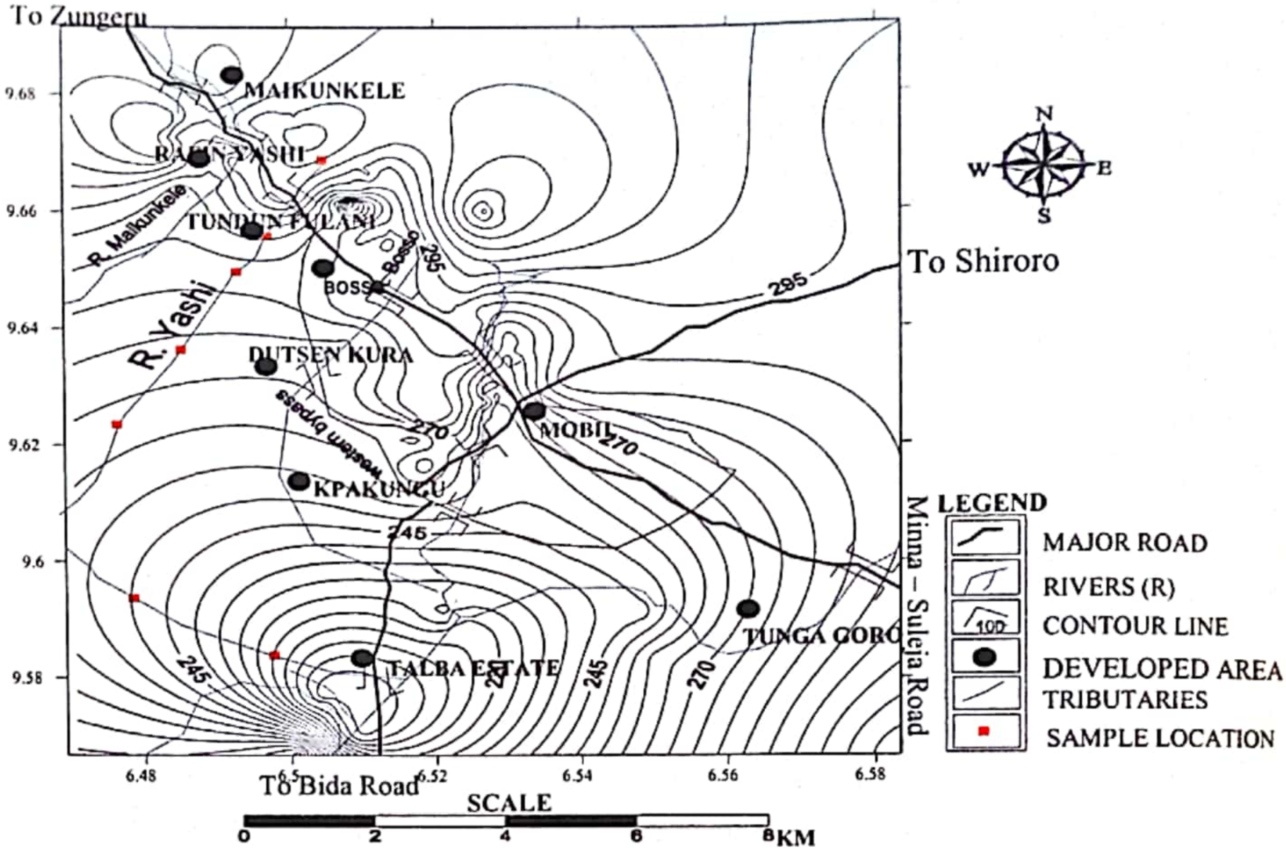

Figure 1: Samples map of River Yashi (Modified after Abdulfatai, 2014)

Table 3: Geotechnical laboratory index text result

				Bulk Density			Sieve analysis result	
Sample location	Dept h (m)	Width (m)	Natural Moisture content (%)	Uncom pacted, kg/m^3	Compact ed, kg/m^3	Specific Gravity	Coefficient of uniformity	Coefficient of curvature
RY1	6	48	16.2	1.06	1.42	2.36	4.00	0.60
RY2	5	25	15.11	1.19	1.33	2.66	20.45	0.18
RY3	8	23	8.49	1.23	1.5	2.19	2.67	0.92
RY4	3	15	12.97	1.01	1.33	2.16	3.50	1.01
RY5	3	18	9.46	1.23	1.52	2.25	2.71	0.79
RY6	4	21	18.21	0.98	1.27	2.15	3.40	0.79
RY7	3	23	10.04	0.99	1.32	2.68	16.67	0.21

The geotechnical laboratory performance test results for RY3, RY4 and RY6 are presented in Table 4. The compaction result shows that the Optimum Moisture Content (OPC) ranges from 9.90 – 12.39% with an average of 11.39% while the

Maximum Dry Density (MDD) ranges from 2.135 -2.420mg/m^3 with an average of 2.28. The triaxial test result shows that the Angle of internal friction (AF) is between 6° - 11° with an average of 9° while the Cohesion, C is from19 – 28kg/m^2 with an average of 26.33kg/m^3. The permeability, ranges from 1.93 × 10^{-3} - 2.49 × 10^{-3} and the average is 2.14 × 10^{-3}.

Table 4: Geotechnical laboratory index (Atterberg Limit) test result

Sample location	Depth (m)	Width (m)	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index (%)	Coefficient of relativity
RY1	6	48	-	-	-	0
RY2	5	25	-	-	-	0
RY3	8	23	22.27	27.66	5.39	3.56
RY4	3	15	14.17	19.8	5.63	1.21
RY5	3	18	-	-	-	0
RY6	4	21	20.91	26.5	5.59	1.4
RY7	3	23	-	-	-	0

Table 5: Geotechnical laboratory performance test result

Sample location	Depth (m)	Width (m)	Compaction		Triaxial test		Permeability, K (cm/sec)
			Moisture Content, OMC (%)	Dry Density, MDD (mg/m^3)	Friction, AF (°)	(kg/ m^3)	
RY1	6	48	ND	ND	ND	ND	ND
RY2	5	25	ND	ND	ND	ND	ND
RY3	8	23	11.89	2.135	6.00	28.00	1.93 × 10^{-3}
RY4	3	15	ND	ND	ND	ND	ND
RY5	3	18	12.39	2.284	10.00	32.00	1.99 × 10^{-3}
RY6	4	21	9.90	2.42	11.00	19.00	2.49 × 10^{-3}
RY7	3	23	ND	ND	ND	ND	ND

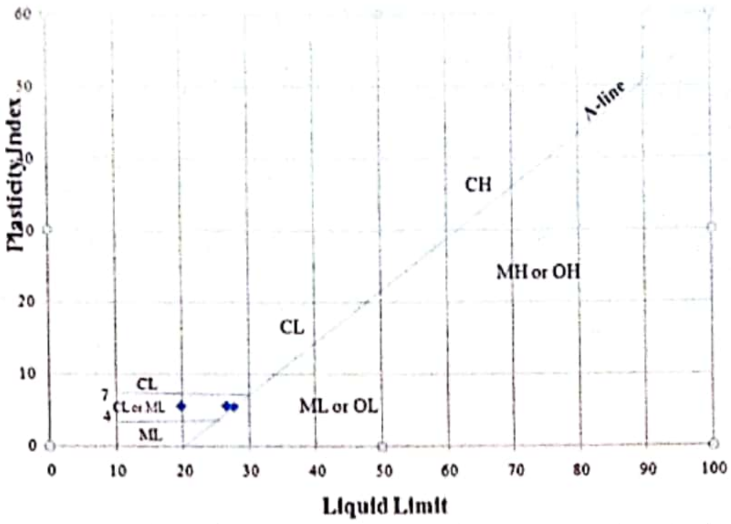

Figure 8: Graph of Plasticity Index (PI) against Liquid Limit (LL)

Discussion

Structural failures of barriers constructed on various parts along the river Yashi channel to control flooding and erosion were observed in the area due to either poor construction or the velocity and volume of flowing water. Excavation of sand and gravel for construction purposes is a common practice in the area. These activities have rendered the water in the river to be less useful and have also contributed to the increase in the gully activity along River Yashi. Construction of any structures that will have impermeable surfaces such as roof, parking lots and roads on the flood plain/river bank is inimical to the river system. This is because the amount of water that would have flown on the river channel and its flood plain will be restricted to the river channel alone. This can result in the increase in the velocity of water flowing along the channel and thereby increasing the erosive power of the flowing water. It can also result to flooding.

High dry strength and high toughness exhibited by RY3, RY4 and R6 indicate that they are more resistant to erosion than RY5 and RY7 that have medium dry strength while RY1 and RY2 are least with no dry strength and low toughness. Medium plasticity of RY3, RY4, RY5, RY6 and RY7 shows that they have more clay content than RY1 and RY2 with low plasticity. Dark colour of RY4 and RY6 could be as a result of the presence of abundant organic matter and moisture content in the soil. The odour observed in all samples except RY5 could be due to the presence of organic matter and the moisture condition. The field consistency shows that RY3 and RY4 are more consistent than the rest. The values of natural moisture content indicate high sand content in all the samples. This implies that the soils along River Yashi are susceptible to large consolidation settlement because all samples have moisture contents that are lower than the liquid limit of all the soil tested (Ara et al, 1997).

The Atterberg limit results indicated low plasticity for all sample tested. The result also show that the liquid limit for RY1, RY2, RY5 and RY7 were not attained after five trials, thus, they have no plasticity. The relative consistency values signified that the soil cannot be remoulded which is also an indication of low plasticity for all samples. The sieve analysis results show that samples were poorly graded except for samples RY2, RY4 and RY6 that were well graded. The sieve analysis along with Atterberg limit results had aided the classification of the entire soil analysed as Sandy – Silt. The bulk density results indicated that the soil samples have relatively low bulk density and therefore, the soil along this stream is highly porous with low compaction. The specific gravity for RY1, RY3, RY4, RY5 and RY6 are particularly low when compare to the specific gravity of normal soil which is between 2.5 – 2.9 according to Bell, 2007. This could be as a result of presence of organic matter in reasonable amount in these samples.

The compaction results are within the range classified as sandy clay by O'Flaherty (1988) except for RY4 and RY6. RY4 and RY6 values correspond to those classified by Ogunsanwo (1989) as sandy clay with lateritic content. The triaxial test results which included AF and C are low which signified that soil along River Yashi can only offer little resistance to the effect of surface and base flow. The permeability, K values are within the range of permeability of coarse sand classified by Domenico and Schwartz, 1990 and indicate that there are high base flows which could result in piping that could have resulted in the collapse of stream wall and thereby increasing gully erosion.

Conclusion

Human activities (such as soil excavation along the river bank and on the river bed, building on the flood plain and farm practices) were observed to be factors in the continuous expansion of River Yashi. Geotechnical tests of soil samples show results that favour gully erosion propagation along River Yashi. High sand content and low plasticity are some of the geotechnical factors that have contributed to the growth of erosion along River Yashi. The permeability values indicate high base flow which could have been part of the reason for the low shear strength and low compaction exhibited by all samples tested. High base flow which could result in piping was thought to be responsible for the collapse of stream wall noticed in some part. Attempt should be made by relevant authorities to control human activities in the area. Any remedial or control measures should make slope stability a priority to ensure that the amount and velocity of runoff is reduced. Other methods that aid the stabilization of soil such as construction of rip-rap with weeping holes to control base flow which prevent collapse of the stream wall should be applied. Cultural or vegetation method may also be adopted for the same purposes.

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