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***Corresponding Author:**
Rehamnia Issam

Email:
i.rehamnia@ensh.dz

Computation of Seepage through a Non-Homogeneous Earth Dam by Using (SEEP/W) Software

Rehamnia Issam[*1], Benlaoukli Bachir[1], Rassoul Abdelaziz[1], Imran Arshad[2]

[1]Laboratory of Water Resources Mobilization and Valorization (MVRE), National High School for Hydraulic (ENSH), BP 31, Blida, Algeria.
[2]SAA Technical & Specialized Services Establishment, Abu Dhabi, United Arab Emirates.

Abstract:
In this research paper, a seepage flow through a non-homogeneous earth dam at various hydraulic heads was computed by using finite element-based software (SEEP/W) and the simulated results were compared with the field observation respectively. The research work was executed on a Fontaine Gazelles dam, which is an embankment dam situated at about 35 km, northeast of Biskra province, Algeria. The outcome of the simulated results showed that the dam is safe against piping for all the scenarios, at its original design as the installation of a cut-off wall found working effectively in reducing internal pore water pressure within the dam and its foundation. The overall maximum and minimum seepage flow was recorded at the pond level 383m (5.04920 LPS) and 374m (2.100 LPS) respectively. The performance efficiency of the model was founded as 99.924%. The RMSE, MAE, and AMRE were found (0.0342015 LPS), (0.00511668 LPS), and 1.06667% respectively; which indicates that there was no major variation between observed and simulated seepage values.
Keywords: Seepage, Non-Homogeneous Dam, Fontaine Gazelles Dam, Finite Element Modeling, SEEP/W, Geo-Slope Software.

INTRODUCTION

One of the most serious dam safety concerns is the seepage and stability of the earthen embankment. Unsafe conditions could lead to a major slide that threatens the safety of the dam (Xinying *et al.,* 2012). A key factor to stability is the location of the phreatic line or the fully saturated zone of the soils within the embankment. In safe dams, this level is well confined below the surface (Durand *et al.,* 1999). Accident analysis shows that the most frequent cause is internal erosion consequence of seepage (Schleiss *et al.,* 2011). The amount of water seeps through and under the foundation of a dam, along with the distribution of pore water pressure, can be analyzed by using a theory of flow through a porous medium (Fisher *et al.,* 2017). The computed amount of seepage is useful in estimating the loss of water from the reservoir, while the pore water pressure distribution gives a rough idea to observe a trend of the hydraulic gradient (phreatic line) at a point of seepage discharge respectively. The phreatic line within the dam body is the line having negative hydrostatic pressure at above the line and positive hydrostatic pressure below the line respectively (Jie *et al.,* 2013; Arshad *et al.,* 2014 (a) and (b); Ghanbari *et al.,* 2014; Athani *et al.,* 2015; Roushangar *et al.,* 2016; Yuan *et al.,* 2016; Arshad *et al.,* 2017; Wei *et al.,* 2018; Soueid *et al.,* 2019; Mouyeaux *et al.,* 2019; Chouireb *et al.,* .2019; Rehamnia *et al.,* 2020).

It is necessary to find out the trend of the phreatic line as it will allow us to recognize a divider line between dry and submerged soil. The phreatic surface should be kept at or below the downstream toe to avoid piping and control exit gradient (Roushangar *et al.,* 2016). The trend of the phreatic line can be well controlled by designing a dam with a proper filter drain. The purpose of the filter drain is to restrict the phreatic line almost in the upstream side of the dam (Liu *et al.,* 2017). The filter preventsthe passing of fine particles into the drain, while the drain allows the removal of surplus amount of internal water to control pore water pressure within the dam body respectively (Wei *et al.,* 2018).

The modeling study carried out by (Rehamnia *et al.,* 2020) indicated that seepage losses were predicted using the LSSVM model with a correlation of R = 0,905 and showed that seepage flow was significantly affected by water level and piezometric level. Nowadays, before the implementation of a mega structural work, the finite element method is used to analyze the behavior of complex structures, as it will give an idea to an engineer about its stability and durability (Arshad *et al.,* 2017). In the present research work, a non-homogeneous section of an earthen dam (Fontaine Gazelles Dam) was selected to simulate a phreatic line for a non-homogeneous section of the dam; and to compare the results of seepage flux for different hydraulic heads respectively.

MATERIALS AND METHODS

Fontaine Gazelles Dam Description

The Fontaine Gazelles embankment dam is a small earthen dam situated in the El-Hai River in the Outaya region about 35 km northeast of Biskra city, Algeria (Figure 1). The dam construction was begun in 1986 and is operational in March 2000. This dam was constructed for a dual purpose; to provide drinking water to the population, and to irrigate 4000 hectares of agricultural land. It has a height of 42.5m with a Gross capacity of 55.5 million m^3. A Weir has been installed in the downstream dam and the measurements of the water level and seepage flow are collected every 15 days.

Steps to Develop a Numerical Model

Initially, SEEP/W software was used to generate FEM mesh for a non-homogenous section of the dam. The mesh is comprised of different types of elements, i.e. (square,rectangular, triangular, and trapezoidal) (Arshad *et al.,* 2018). Each element is of different sizesand orientations as described in (Figure 2). The upstream and downstream boundary condition was assigned as a Neumann and Dirichlet boundary nodes respectively. After the development phase, the numerical model was verified by SEEP/W and computation of water loss for various hydraulic heads i.e. (374m) until (383m), which was carried out accordingly. The hydraulic conductivities used at the time of construction were calibrated and assigned to the numerical model. The calibration of the hydraulic conductivities was made based on trial and error while comparing simulated seepage flow with the observed ones (Table 1).

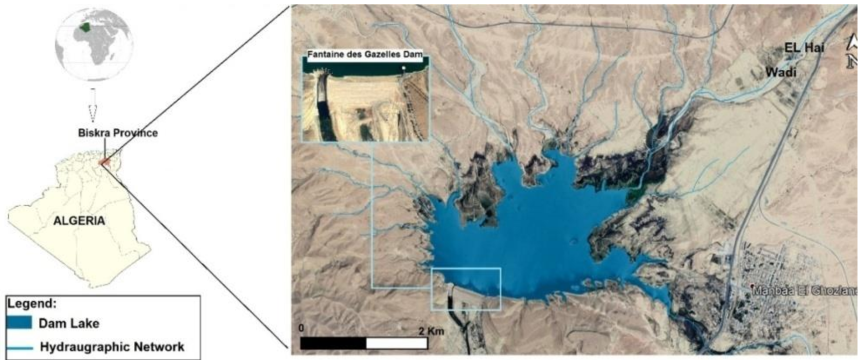

Fig. 1. Location of Fontaine Gazelles embankment dam, Algeria.

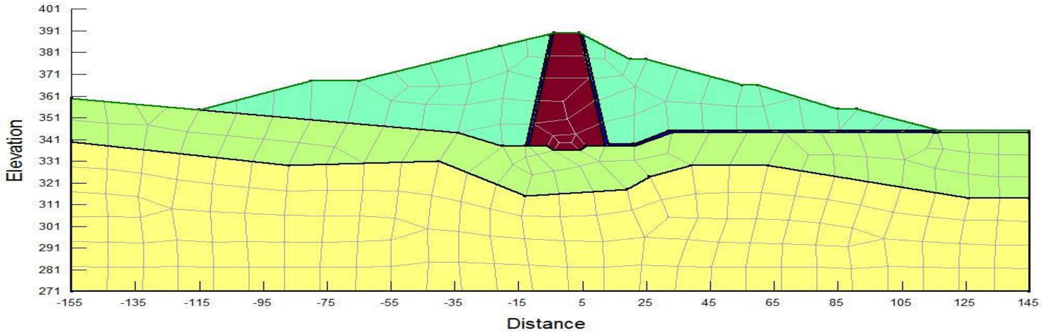

Fig. 2. Mesh Formation for Fontaine des Gazelles Dam.

Table 1. Fontaine des Gazelles Dam Material Properties used to develop FEM Model.

S. No.	Type of Material	Hydraulic conductivity (m / sec) Used in SEEP/W software
01	Foundation	1.0×10^{-7}
02	Shell (Fill Material)	1.0×10^{-4}
03	Core	1.0×10^{-8}
04	Filter Blanket	1.0×10^{-2}
05	Injected Area	1.0×10^{-3}

RESULTS AND DISCUSSION

SEEP/W Output Simulated Results

Seepage flow was computed at ten different pond level scenarios. The SEEP/W software gives output in terms of flow-net which comprises of equipotential lines, streamlines, the velocity vectors showing dominant flow (seepage) field, and the saturation line. The results revealed that the water level and piezometric level influence considerably on the seepage flow downstream of the dam. Due to the presence of the toe drain located at the downstream of the dam, the phreatic line is controlled and had a minimum chance to cut the downstream slope face of the dam. Therefore, the drain plays a key role in the safety of the dam. The overall maximum and minimum seepage flow was recorded at the pond level 383m (5.04920 LPS) and 374m (2.100 LPS) respectively. These results are according to the findings of (Arshad *et al.,* 2014a), who analyzed the behavior of an earthen dam (Hub Dam) while computing the seepage flow at the foundation and within the body of the dam for various pond levels. The simulated flow-net profile results at various hydraulic heads are elaborated in (Figure 3 – Figure 12) respectively.

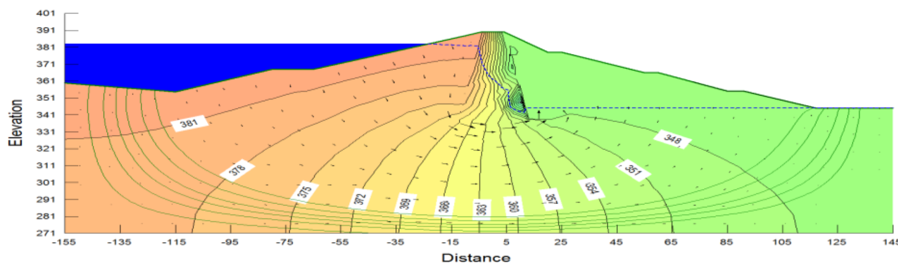

Fig.3. Simulated Flow-net Profile at EL 383 m.

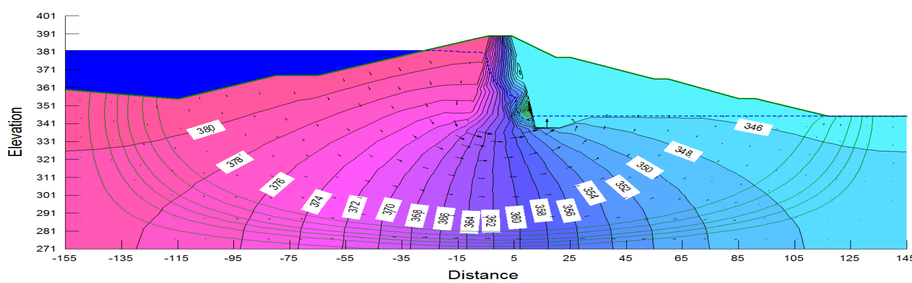

Fig.4. Simulated Flow-net Profile at EL 382 m.

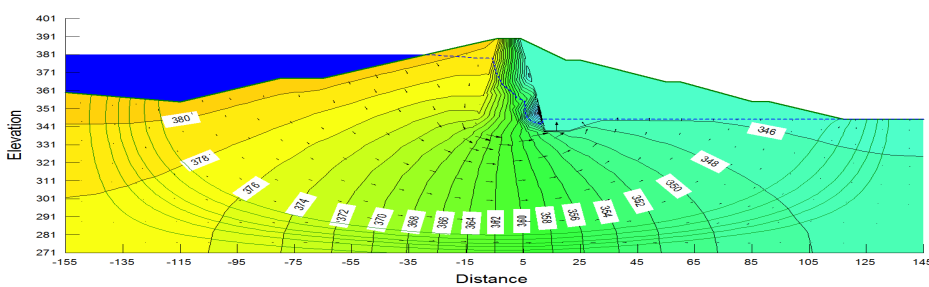

Fig.5. Simulated Flow-net Profile at EL 381 m.

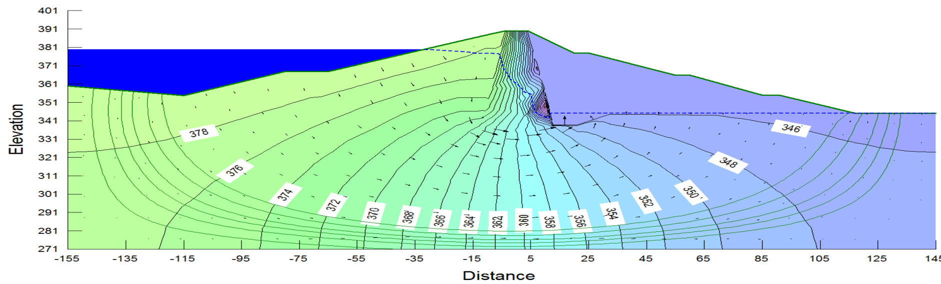

Fig.6. Simulated Flow-net Profile at EL 380 m.

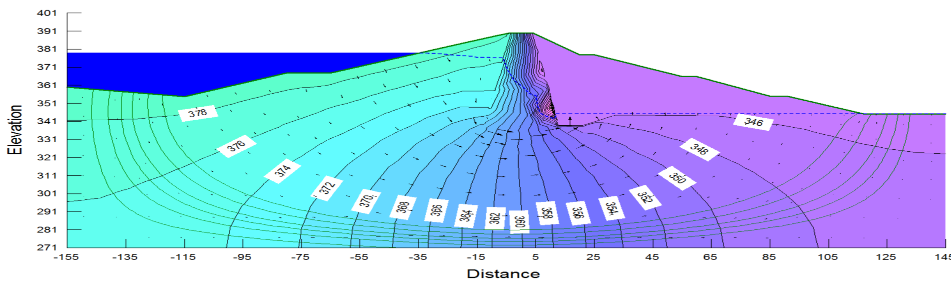

Fig.7. Simulated Flow-net Profile at EL 379 m.

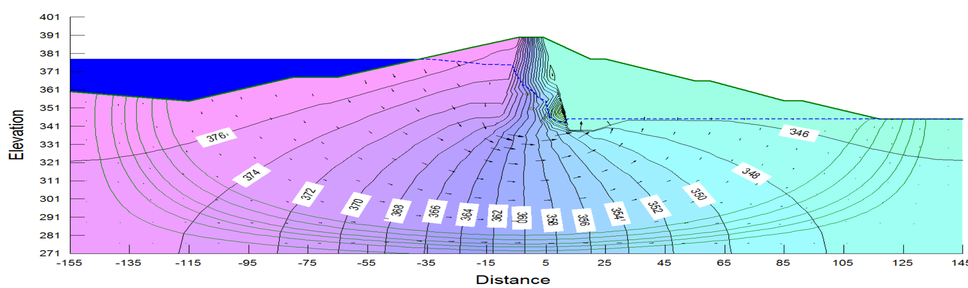

Fig.8. Simulated Flow-net Profile at EL 378 m.

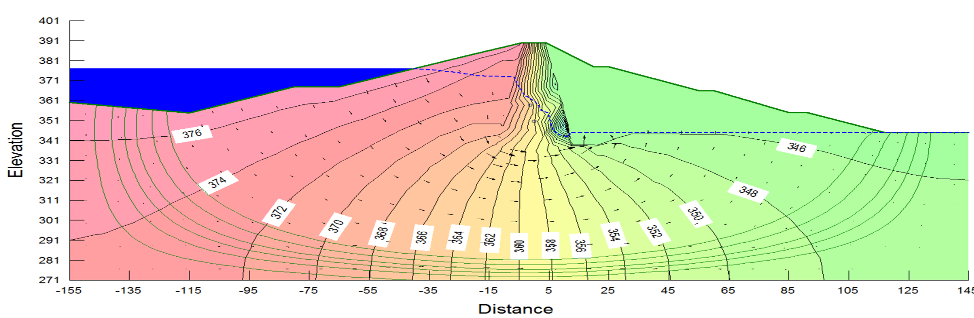

Fig.9. Simulated Flow-net Profile at EL 377 m.

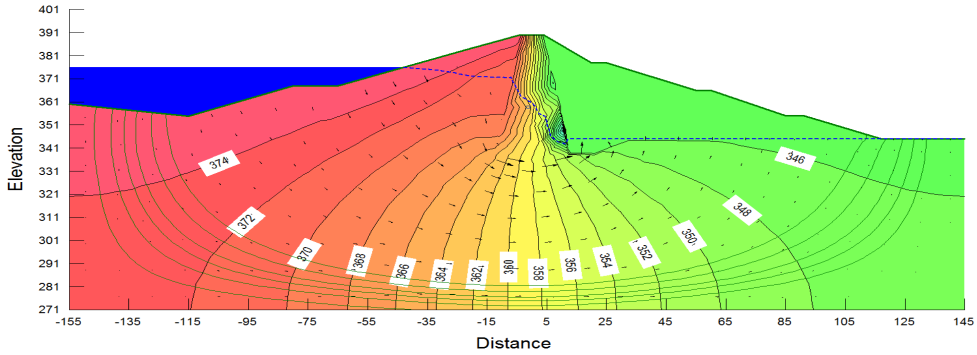

Fig.10. Simulated Flow-net Profile at EL 376 m.

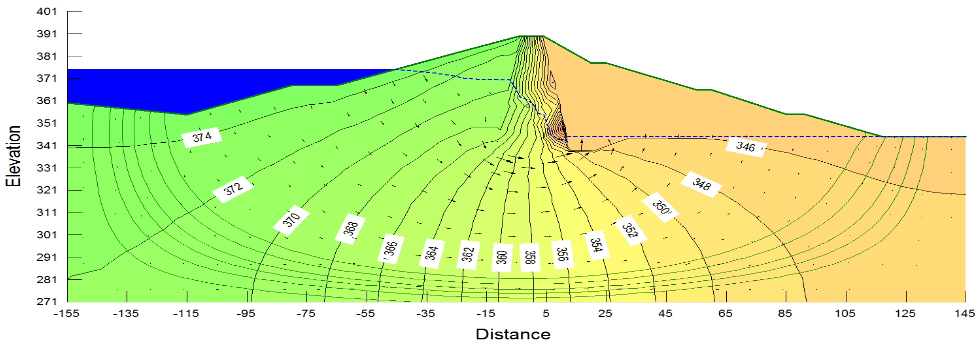

Fig.11. Simulated Flow-net Profile at EL 375 m.

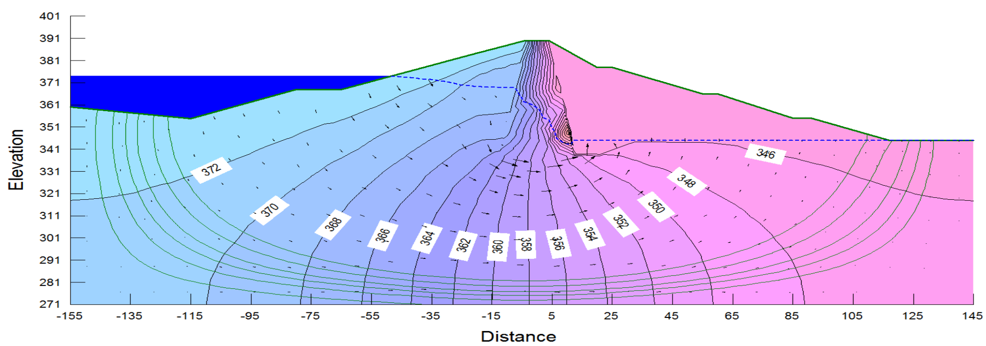

Fig.12. Simulated Flow-net Profile at EL 374 m.

MODEL VALIDATION

It is well known that the validation of any model needs the comparison between simulated and observed results at various hydraulic heads. If the comparison indicates a good coincidence the model can be recommended for practice. Table 2 contains the data pertaining to predicted seepage flow and measured ones and the relative error.

Table 2. Observed and Simulated Seepage at Different Hydraulic Heads.

S. No.	Reservoir Level	Observed Seepage Q_o	Simulated Seepage Q_s	Relative error $= \frac{(Q_o - Q_s)}{Q_o} \times 100$	$(Q_{si} - Q_{oi})$	$(Q_{si} - Q_{oi})^2$	$(Q_{oi} - Q_{oa})^2$
	m	LPS	LPS	(%)			
1	374	2.100	2.10730	-0.34783	0.00730	0.00005	2.587901711
2	375	2.193	2.20834	-0.69932	0.01534	0.00024	2.273050191
3	376	2.312	2.33041	-0.79643	0.01841	0.00034	1.919850147
4	377	2.321	2.29797	0.99216	-0.02303	0.00053	2.010803298
5	378	4.221	4.24134	-0.48197	0.02034	0.00041	0.275986146
6	379	4.250	4.27839	-0.66795	0.02839	0.00081	0.316280297
7	380	4.764	4.80821	-0.92797	0.04421	0.00195	1.192918982
8	381	4.988	4.93479	1.06667	-0.05321	0.00283	1.485460439
9	382	5.005	4.95820	1.01412	-0.05080	0.00258	1.543067411
10	383	5.009	5.04920	-0.88318	0.04420	0.00195	1.777430771

The accuracy and performance of the proposed model were evaluated by statistical parameters such as; the root mean square error (RMSE), the mean absolute error (MAE), and model efficiency (EF) (Williams, 1986); defined as follow:

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{n}(Q_s - Q_o)$$

$$\text{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(Q_s - Q_o)^2\right]^{0,5}$$

$$\text{EF} = 1 - \frac{\sum_{i=1}^{n}(Q_s - Q_o)^2}{\sum_{i=1}^{n}(Q_o - Q_{oa})^2}$$

Where:

Q_s= denotes ith value of simulated seepage flow

Q_o = denotes ith value of observed seepage flow and Q_{oa} denotes average or mean of seepage flow.

The results showed that amongst all the data sets the RMSE, MAE, and AMRE were found (0.0342015 LPS), (0.00511668 LPS), and (1.06667 %) respectively (Table 3). The performance efficiency of the model was founded as 99.924%. Similar results were reported by (Arshad *et al.,* 2018), who conducted their research work on the seepage behavior of an earthen canal i.e. (Jamrao Canal) by using SEEP/W and found RMSE (0.78 CUSEC), MAE (0.48 CUSEC), AMRE (2.01%), and EF (99.80%) respectively.

Table 3. Performances of the model developed in the modeling of seepage.

Statistical Parameters	Values
Mean Absolute Error (MAE)	0.00511668 LPS
Root Mean Square Error (RMSE)	0.0342015 LPS
Model Efficiency (EF)	99.924%
Absolute Maximum Relative Error (AMRE)	1.06667 %

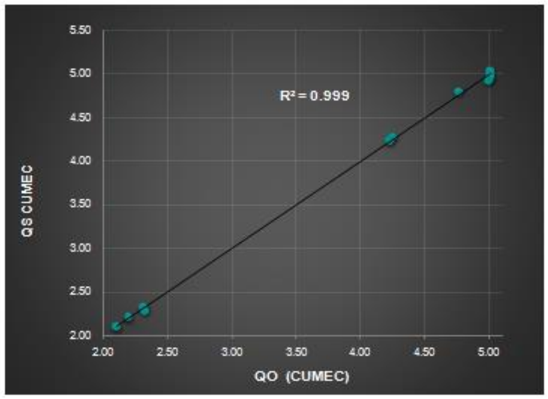

Fig.13. Relationship between observed and simulated Seepage at the different reservoir levels.

The graph in (Figure 13) helped to better understand the model accuracy developed and shows that the observed and simulated values are almost equal because the graph cut diagram in middle (45 degrees), through which the model is verified.

CONCLUSION

In the present study a numerical model of Fontaine Gazelles dam at ten different hydraulic heads was developed and analyzed by using FEM-based software i.e. (SEEP/W). The model has been used to compute the seepage flow through the Fontaine Gazelles dam. The comparison of field and simulated data shows that the results achieved from field study are almost as to the results obtained by SEEP/W simulations. The overall maximum and minimum seepage flow was recorded at the pond level 383m (5.04920 LPS) and 374m (2.100 LPS) respectively. The RMSE, MAE, and AMRE were found (0.0342015 LPS), (0.00511668 LPS), and 1.06667% respectively. The performance efficiency of the model was founded as 99.924%. The numerical model was also verified by comparing the observed and simulated values of seepage flow which showed that the slope line was observed to be approximately 45 degrees; which indicates that there was no major variation between observed and simulated seepage values. Thus, it is concluded that observed values of seepage flow are not much different than the simulated ones.

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CONFLICT OF INTEREST

There is no conflict of interest.

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