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Assessment of the Rehabilitation of Watercourses (Study Case)

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Abstract: ***The goal of this study is to assess the rehabilitation of Bahr Awlad Mohamed canal.The canal was rehabilitated by installing lining trapezoidal cross-sections. Before and after the rehabilitation process, a field investigation, hydraulic and hydrographic measurements, and a mathematical model (Sobek – 1D) were conducted. According to the findings, the canal's rehabilitation improved average water velocity from 0.18 m/s to 0.32 m/s, the average Manning roughness coefficient from 0.065 $m^{-1/3}s$ to 0.020 $m^{-1/3}s$, the water surface slope from 17 and 50 cm/km to 2 and 6 cm/km, the average areas of cross-sections reduced from 3.37 m^2 to 3.07 m^2, the average water width was reduced from 5.84 m to 4.83 m, the water losses were decreased by approximately 27.31 % from the canal's inlet discharge. Additionally, the water level fulfilled the requirements for water distribution, the canal banks were restored and widened, the hydraulic efficiency of the study canal was improved, alleviating downstream farmers' concerns and conserving water that could be utilized for irrigation, and saving time and maintenance cost. Finally, canal rehabilitation necessitates periodic maintenance, appropriate maintenance equipment, and a strategy of canal preservation. In addition, other canals in Egypt must be improved to determine the irrigation network's water-saving potential.***

Keywords: ***Irrigation; Lining; Open Channel; Rehabilitation; Water.***

I. INTRODUCTION

The nature of water losses from canals can be better understood, which leads to better water management resources. Most countries, including China, use concrete and geomembrane to line canals [1]. Over time, the permeability of lining materials increases, resulting in increased seepage loss and a noticeable decrease in canal water efficiency [2]. When concrete and geomembrane were used to line the canals, seepage water losses were reduced by 75% and 95%, respectively [3]. Furthermore, canal seepage compact was decreased by 96.33 percent in the main and branch canals, and by 76 percent in the lateral canals, due to geomembrane lining. [4] investigated the solutions to come up with a generalized trapezoidal section in the shapes of sharp-cornered trapezoids, rectangles, triangles, and semicircles. A guide was issued by [5] to address the design and construction of protective works to avoid erosion of river banks and dike slopes from stream flow. [6] studied primary canals of three traditional irrigation systems in the southern plains of Nepal. They offered a scientific interpretation of the indigenous technology applied to the systems, which facilitates to use of the same channel network for irrigation, drainage, and flood management. The effect of lining canals with geomembranes on seepage was explored [7], the geomembrane coating reduced seepage from the canal by 90%, while concrete-coating the geomembranes increased their durability, although at a heavy price. According to the findings of [8], average seepage losses in unlined and lined canals are 0.415 cumecs, 0.0511 cumecs in Brick lined canals, 0.0028 cumecs in P.C.C. Lined canals, and $1.2*10^{-4}$ cumec in P.C.C. with LDPE film lined canals. [9] developed a method for determining the best canal dimensions for a given discharge, as well as a nonlinear water loss function for the canal. The best canal dimensions for the lowest water loss were also established using Lagrange's method of undetermined multipliers. [10] highlighted the Lebanese government's actions in the context of national water management and gave recommendations for building an appropriate plan. [11] provided a detailed evaluation of the advantages and disadvantages of rehabilitation of a representative small-holder, community-managed irrigation scheme in Mauritania, as well as a general discussion of rehabilitation and design approaches. Some experts believe that the lining's age or service period played an evident impact in increasing seepage losses [12]. These investigations revealed the seepage effect of the newly installed lining, but they did not account for variations in the lining's performance in preventing seepage loss over time. The lined canal under service times of 1–5 years reduced seepage by 47%, while it decreased to 30% under service times of 21–25 years compared with unlined canals [13]. [14] employed ponding tests to investigate the relationship between the seepage control effect change in the canal lining and service time, as well as the reduction factor and service time. In comparison to unlined conditions, a canal liner with a 1% crack area has a 70% seepage rate, according to World Bank experts [15]. [16] proceeded to show that if only 0.01 percent of the concrete canal lining is destroyed, seepage in lined and unlined canals is the same (i.e., no effect of the lining). [17] stated that Vegetation decreases the effective flow area and increases the roughness. Vegetation growth is more pronounced in clear water; however, the nutrients in water with sediment may help the growth of weeds. The degree of obstruction by vegetation is highly variable and depends upon the type, height, density, and flexibility of the vegetation, submerged or un-submerged conditions, water level, and flow velocity.

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Vegetation growth is more obvious in clear water, however, nutrients in water with sediment may promote weed growth. The type, height, density, and flexibility of the vegetation, as well as submerged or non-submerged conditions, water level, and flow velocity, all influence vegetation blockage. The flow velocity decelerated in vegetation zones but accelerated and deviated toward the opposite bank in non-vegetated zones [18]. According to the comparison in figure (1), geomembrane is the best lining material since it reduces pollutant extension by 91 percent at a lower cost than concrete, which reduces contaminant extension by 93 percent at double the cost of geomembranes [19].

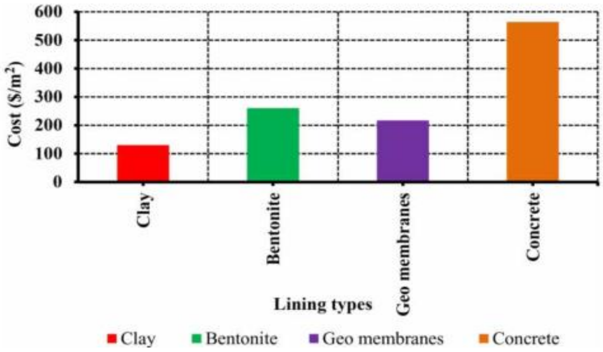

Figure 1: Comparison between costs of different lining materials

In Egypt, Farmers always are under stress due to the shortage of water and unfair water distribution. the irrigation network suffered from irregular cross-sections, spreading aquatic weeds, solid wastes, encroachments, and water seepage. All of these problems decrease the hydraulic efficiency. The rehabilitation of the Bahr Awlad Mohamed Canal in the El Fayoum Region was selected as a study case in this study to assess the watercourses rehabilitation process.

II. STUDY AREA DESCRIPTION

Bahr Awlad Mohamed canal is an unlined earthen canal and a branch of Bahr El Gharkq canal in Fayuom governorate, as indicated in the figure (2). It is approximately 4.500 kilometers long and feeds twenty-two sub-branch canals of weirs inlets. The canal's side slope is 1:1 in the designed cross-section. From the inlet to km 2.490, the bed width is 3.50 meters, and from km 2.490 to km 4.500, it is 3 meters (the end of the canal). The water surface slope varies between 3 cm/km and 11 cm/km, with a maximum discharge of 1.32 m^3/s (41.63 million m^3/y), according to the weir located at Km 2.490. In Egypt, different types of lining materials such as ripraps, stone masonry, gabions, cement concrete, and geomembranes were applied in open channels and drains. Due to the availability of materials and local skills, a new lined trapezoidal cross-section was designed and applied using a 30 cm thick riprap coated by a 10 cm thick layer of plain concrete in the bed. In this case. The process of the lined trapezoidal section with side slope 1:1 were conducted through four reaches; i) reach 1, from the inlet to km 2.490, ii) reach 2, from km 2.490 to the km 3.360, iii) reach 3, from km 3.360 to the km 4.260, and iv) reach 4, from kilometer 4.260 to the end. the bed widths were 3.50 m,3.00 m,2.50 m, and 2.00 m respectively.

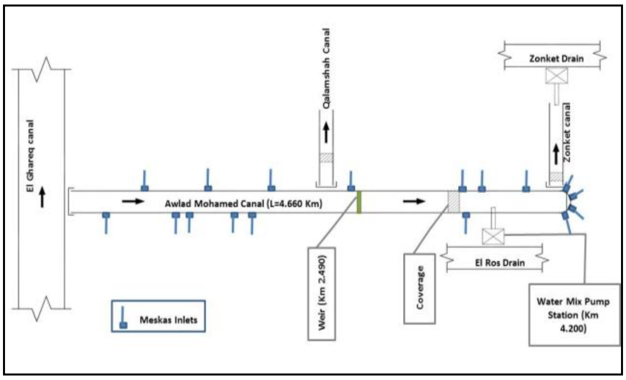

Figure 2: The schematic shape of Bahr Awlad Mohamed Canal

III. METHODOLOGY

A detailed program was carried out to evaluate the rehabilitation process, which included the following:

- Field investigation of the canal.
- Hydraulic measurements comprised water levels, water slope, flow velocity distribution at five cross-sections using an electro-magnetic current meter, and water discharge determination before and after rehabilitation.
- Survey instruments were used to conduct a hydrographic survey for eighty-eight cross-sections (total station, GPS, Echo-Sounder).
- Using software (Sobek-1D) to help find changes in hydraulic parameters.

IV. RESULTS AND DISCUSSIONS

the following outcomes of the implemented activity were analyzed and discussed in order to clarify the canal's improvement as a result of rehabilitation:-

A.Field Investigation

As shown in photo (1), some issues were discovered during the canal investigation before rehabilitation, including the spread of aquatic weeds and solid wastes, the illegal use of irrigation water pumps due to low water levels, unfair water distribution, water user encroachments, water seepage, deterioration of sub-branch canal inlets, water shortages, decreasing water conveyance to the canal's end, narrow canal banks, irregular cross-sections, and the presence of illegal irrigation water openings, all of which harm the canal's performance.

Photo 1: Bahr Awlad Mohamed Problems before rehabilitation

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As shown in photo (2), after the canal was rehabilitated, the lined cross-sections were regular and reduced in size, the aquatic weed infestation was reduced, the canal's banks were increased and levelled, the sub-branch canal's inlets were improved, water conveyed easily to the canal's end, water entered the sub-branch canals by gravity without the use of illegal pump units for irrigation, the illegal irrigation openings were closed, and the farmers complain were decreased.

Photo 2: Bahr Awlad Mohamed after rehabilitation

B. Hydraulic Measurement

The hydraulic parameters were determined before and after rehabilitation processes as shown in table I, table II, and figures (3 to 5).

Table - I: hydraulic parameters at Bahr Awlad Mohamed canal before rehabilitation

Sec No	Sec. (Km)	Y_m (m)	A (m^2)	P (m)	R (m)	V (m/s)	S (cm/km)	Q (m^3/s)	W.L (m)	n ($m^{-1/3}s$)
1	0.150	0.56	3.46	6.77	0.51	0.23	17	1.260	15.79	0.022
2	2.360	0.73	5.57	8.23	0.67	0.20	17	1.140		0.072
3	2.860	0.67	2.73	5.96	0.46	0.13	30	0.360		0.086
4	4.110	0.44	1.70	5.79	0.29	0.12	30	0.196		0.068

Table II: hydraulic parameters at Bahr Awlad Mohamed canal after rehabilitation

Sec. No	Sec. (Km)	Y_m (m)	A (m^2)	P (m)	R (m)	V (m/s)	S (cm/km)	Q (m^3/s)	W.L (m)	n ($m^{-1/3}s$)
1	0.150	0.88	3.783	6.10	0.67	0.33	2	1.252	16.08	0.021
2	2.360	0.84	3.286	6.24	0.70	0.28	2	0.929		0.018
3	2.860	0.75	2.991	5.93	0.67	0.31	6	0.890		0.020
4	4.110	0.65	2.228	4.73	0.47	0.35	6	0.529		0.020

Where: (Y_m) is the mean water depth (m), (A) is the cross-section area (m^2), (P) is the wetted perimeter (m), (R) is the hydraulic radius (m), (V) is the water velocity (m/s), (S) is the water surface slope (cm/km), (Q) is the inlet water discharge (m^3/s), W.L is the water level (m), (n) is Manning coefficient ($m^{-1/3}s$).

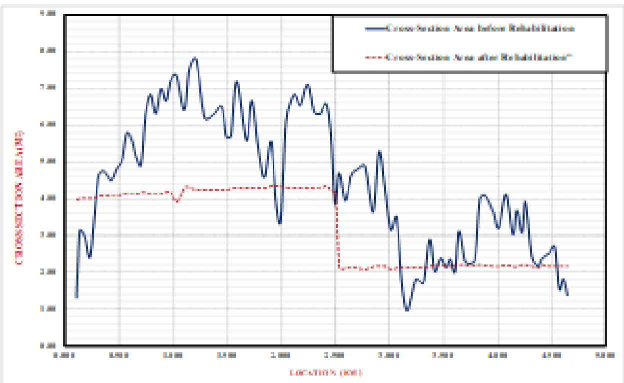

Figure 3: Cross-Section Area before and after rehabilitation

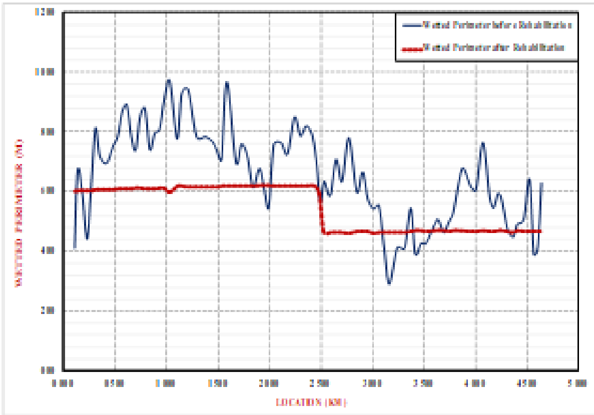

Figure 4: Wetted Perimeter before and after rehabilitation

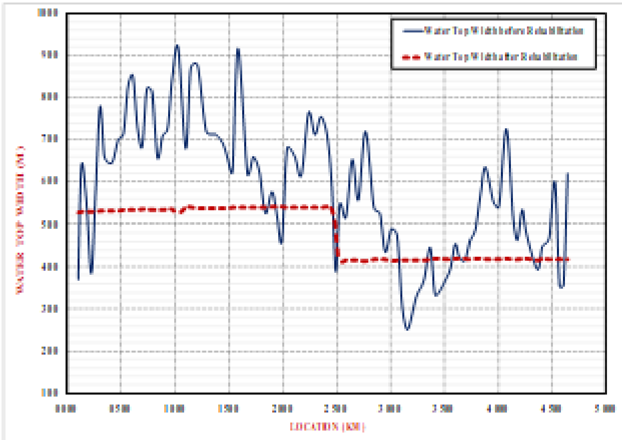

Figure5: Water Top Width before and after rehabilitation

C. Hydrographic Measurements

Before and after rehabilitation cases, 88 cross-sections and longitudinal cross-sections were surveyed and plotted every 50 meters. The comparison of the two cases in Figures 6 and 7 indicated that before rehabilitation, many sites' cross-sections were much wider, the bed and the two banks were irregular, the removal of around 14728 m3 of sediments to restore the designed sections were required, and the water surface level was below the sub-branch canals' inlets which obliged the farmers to use the pumps for irrigation.

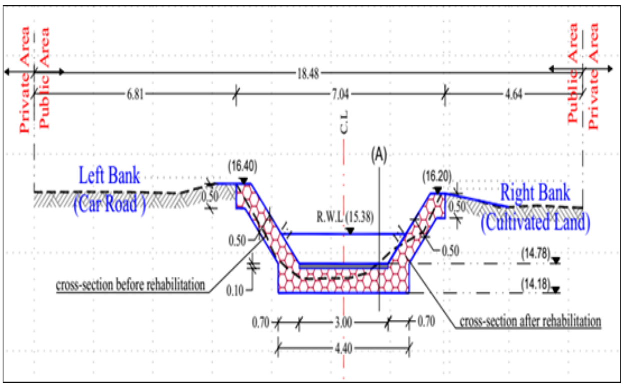

Figure 6: Surveyed Cross-section at km 0.481

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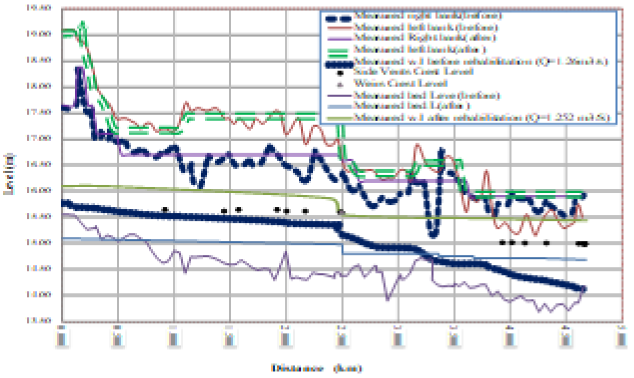

Figure 7: Measured Longitudinal Cross- Section before and after rehabilitation

D. Quantifying the water losses measurements

The inflow and outflow at four cross-sections along the canal were measured before and after the rehabilitation process, as shown in tables III and IV.

Table III : Water Loss for canal before rehabilitation

Sec. (Km)	$Q_{i.canal}$ (m^3/s)	$Q_{sub-branches}$ (m^3/s)	$Q_{c.out}$ (m^3/s)	$Q_{m.out}$ (m^3/s)	Q_{loss} (m^3/s)	Q_{loss} (%)
0.0 (inlet)	1.260	0.669				31.62
4.110			0.596	0.196	0.400	

Table IV : Water Loss for Canal after rehabilitation

Sec. (Km)	$Q_{i.canal}$ (m^3/s)	$Q_{sub-branches}$ (m^3/s)	$Q_{c.out}$ (m^3/s)	$Q_{m.out}$ (m^3/s)	Q_{loss} (m^3/s)	Q_{loss} (%)
0.0 (inlet)	1.252	0.669				4.31
4.110			0.583	0.529	0.054	

Where: (Q i.canal) is the canal' inlet discharge, (Q sub-branches) is the total discharge for sub-branches, (Q c.out) is a calculated out water discharge for the canal, (Q m.out) is the measured out discharge for the canal, (Q loss) is the difference between the Q c.out and Q m.out, and (Q loss %) is ((Q loss / Q i.canal)*100). In comparison to the inlet water discharge, the water loss before and after rehabilitation was 31.62 % and 4.31 %, respectively. The canal rehabilitation reduced water loss by approximately 27.31 % from the canal' inlet discharge; rehabilitation of the canal will save (11.360 million m3/y) of the maximum inlet discharge through the canal 1.32 m3/s (41.630 million m3/y) due to seepage, evaporation, evapotranspiration, and uncontrolled irrigation by using illegal pumps. Whatever quantity of water saved can be used for irrigation.

E. Applying Mathematical Model

The case study area on the Bahr Awlad Mohamed Canal was simulated using the Sobek-1D Rural model. Sobek is a rural and urban management software package. It consists of seven applications that work together to mimic and manage waterways. Delft Hydraulic Institute produces it, and it's frequently utilized for comparable research both internationally and in Egypt. The main benefit of using the Sobek-1D hydrodynamic model in this study is the relationship between model behaviour and reality, as well as its effectiveness and familiarity with the problems being examined. Sobek-Rural is a programme that may be used to simulate irrigation and drainage systems. Irrigation, flood management, crop productivity, and water quality control are among areas where applications are used. The hydraulics parameters were simulated using a mathematical model in two cases (before and after rehabilitation). Eighty-Eight cross-sections, inlets of sub-branches, and the hydraulic structures were simulated in the model. In the case of the canal before rehabilitation, the model was calibrated using a 1.26 m3/s water discharge at the canal inlet and a water level of 14.15 m at the canal's end, as shown in figure (8), and verified using a measured 1.03 m3/s inlet discharge with measured 15.50 m water level at the end of the canal as in figure (9), which shows the convergence of the results between the measurement in nature and the model. In the model, scenarios of delivering the measured discharges with the water levels at the canal's ends in the two cases were run, as illustrated in figure (9). The findings revealed that the water depth was improved after rehabilitation to cover all of the sub-branch canal weir crests inlets by 40 to 50 cm and meet the levels for water distribution to inter the sub-branches by gravity without depending on illegal pump units for irrigation, as well as an increase in the freeboard between the water levels and the two banks.

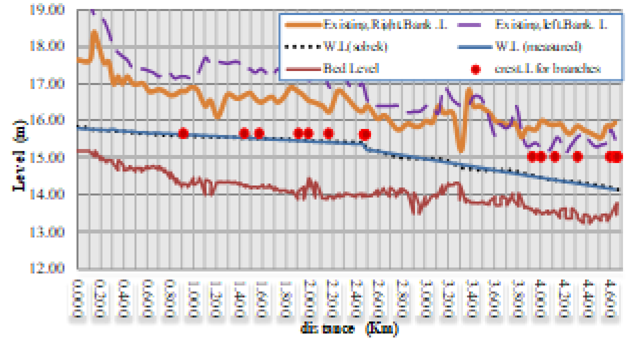

Figure 8: Mathematical Model Calibration for the canal

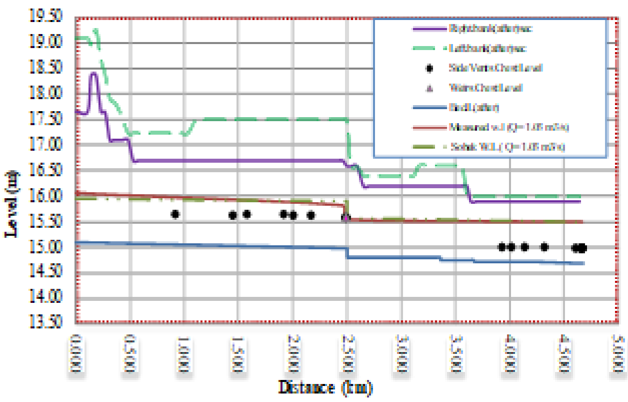

Figure 9: Mathematical Model Verification for the canal

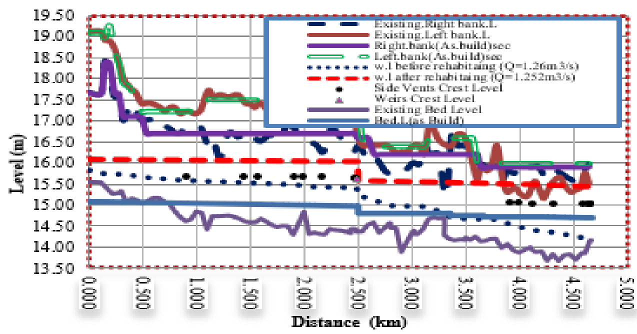

Figure 10: The Water level in the model before and after the canal rehabilitation

V. MAINTENANCE PROCESS

There is a remarkable difference in the maintenance process between the earthen and the rehabilitated canal. The earthen canal was used to maintain three times a year, removing aquatic weeds, solid wastes, and silt to improve the canal's performance. The canal's rehabilitation led to sediment control, and less dredging maintenance is predicted. In addition, the time and cost of maintenance were decreased, the equipment's features were changed. Finally, lined canals do not require dredging, for plant species and algae growth, limit the presence of soil particles that can harbor fecal coliforms and infections, and have lower turbidities during maintenance operations [20].

VI. CONCLUSIONS AND RECOMMMENDATIONS

The applied rehabilitation process of riprap covered by a layer of 10 cm plain concrete improved the hydraulic parameters of the study canal in terms of improved average water velocity from 0.18 m/s to 0.32 m/s, the average Manning roughness coefficient from 0.065 $m^{-1/3}s$ to 0.020 $m^{-1/3}s$, the water surface slope from 17 and 50 cm/km to 2 and 6 cm/km, the average areas of cross-sections reduced from 3.37 m^2 to 3.07 m^2, and the average water width was reduced from 5.84 m to 4.83 m. Also, water depth after rehabilitation was improved to cover all of the sub-branch canal weirs crests inlets by 40 to 50 cm and met the levels for water distribution to inter the sub-branches by gravity without depending on the illegal pump units for irrigation, the freeboards were increased, the canal banks were rehabilitated and increased in width, prevent the illegal irrigation openings, and water losses were reduced by approximately 27.31 % from the canal' inlet discharge. All of the improvements resulted in decreased bed silting, infestation, and spread of aquatic weeds, increased transportation between villages, facilitated the movement of farming and canal maintenance tools, increased water distribution efficiency, reduced canal maintenance costs, saved water that could be used for irrigation, and saved time. Finally, canals rehabilitation has a positive effects for countries suffer from shortage of water and need saving water. Other canals in Egypt must be rehabilitated in order to determine the irrigation network's water-saving potential, and Rehabilitated canals requires periodic maintenance, appropriate maintenance equipment, and method to preserve the canal.

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