Design Aspects of Proposed Alternative Solutions for Tertiary Irrigation Canal

Mohammad Farouk Abd-elmagied, and Fahmy Salah Abd-elhaleem

Abstract—This study presents five alternative systems for the protection of old lined mesqas. The main causes of damages were identified and laboratory calculations for mesqas were carried out. The suggested technical alternatives for old lined mesqas were: 1- U-shape reinforced concrete section under the ground level; 2- U-shape reinforced concrete section above the ground level; 3- Reinforced concrete pipe mesqa; 4- Fiber reinforced concrete lined mesqa; and 5- Grouted stone pitched lined mesqa. The design aspects of these five alternatives were analyzed and deliberated. The most promising alternative for protecting old lined mesqas is fiber reinforced concrete lining. Also, the grouted stone pitched lined mesqas economically recommended.

Index Terms—Irrigation Canal, Lining-Crack of Concrete, Lining-Problematic, Soils-Maintenance Technique, Protecting Alternative, Kafr El-Sheikh, Egypt.

I. INTRODUCTION

The present study was prepared following the results revealed from field investigations and laboratory tests. The study describes four different alternatives to protect the old lined mesqas. Moreover, the proper maintenance techniques for the new lined mesqas are introduced.

A. Hossain and et. al. [1] studied the relationship between cohesion of soil and the factor of safety for slopes under different vertical and horizontal coefficients for a pure homogeneous clay using GEO5 software.

Ashfaque A. Memon and et. al. [2] were investigated the Dadu Canal in Pakistan to be redesigned as an adjacent lined canal which involves design of cross section for various lining options at locations where changes in the hydraulic conditions occur at cross regulators and fall structures.

Filipe Morgado and et. al. [3] were presented the main conclusions of a survey undertaken in Portugal which concluded that in most situations using concrete cast on site, precast concrete slabs and prefabricated membranes (polymer bitumen or synthetic).

II. CAUSES OF LININGS DAMAGE

According to the results obtained in-situ, field investigation and laboratory tests, the main causes of the concrete lining damage in the study area are previously mentioned in progress Evaluation of Tertiary Irrigation Canals' Lining Mutobes District, Kafr El-Sheikh Governorate, Egypt and can be summarized as follows:

- Unavailability of tertiary drains (farm level) around mesqas except some subsurface drains performed by farmers.
- High water levels in secondary and main drains (higher than the designed values).
- Very erodible and cohesionless soil texture.
- High salinity values of water and soils.
- High saline groundwater levels.
- Most of reclaimed lands are at higher levels than the irrigation mesqas.
- Insufficient thickness of the concrete lining to resist the underlying hydrostatic pressures of the groundwater.
- Application of inadequate design and construction methods to the lined mesqas.

The new lined mesqas had been damaged due to the abovementioned problems. Therefore, solutions should mainly focus on how to tackle the issues of soil texture in the subgrade layers, the high depth of saline groundwater, and the drainage problems. For this study under investigation, it is recommended to redo a detailed design for the whole drainage system. Secondary and main drains should be dredged and cleaned every two or three months. The pump station at the main drain should operate within the design limits.

The proper technical alternatives suitable for the safe guard of old mesqas and the appropriate maintenance techniques for the new lined mesqas are demonstrated and discussed in the following sections.

III. HYDRAULIC CALCULATIONS

A. Designing discharge

Design discharges along mesqas were determined based on water duty and the area served according to the Egyptian Code for water resources and irrigation (ECWRI, 2002), as described below:

- Water duty (W.D.) ranges from 1475.42 to 7041.81 m³/fed/year
- For flood irrigation, field losses = 30%
- The conveyance losses = 10%
- Area served (Aₜ) for each mesqa ranges from 50 to 100 feds
- Irrigation water is supplied based on a four days rotation (Munawabah) system
- The discharge, Q

\[ Q = A_{t} \times W.D \]
• Q = 0.064 m³/s, take the design discharge, Q = 0.07 m³/s.
• Design capacity of mesquas according to a design water duty is 70 l/s.

B. Designing cross-section
• The design discharge, Q = 0.07 m³/s.
• Manning roughness coefficient for concrete lining canal according to (ECWRI, 2002), l/n = 62, for Chow (1964), n = 0.011 - 0.015.
• Longitudinal bed slope of mesqa of served area ≤ 100 feds, S = 16 - 24 cm/km
• Side slope of canal, Z according to soil type, Z = 1.50.
• By applying Manning’s equation,

\[ Q = \frac{1}{n} AR^{2/3} S^{1/2} \]

where, Q is the design discharge (m³/s), n is the Manning roughness coefficient, A is the cross-section area (m²), S is the water surface slope, (cm/km) and R is the hydraulic radius, R = A/P (m), P is the wetted perimeter (m).

- For the best hydraulic section, R= y/2, b= 0.606y, A= 2.106y², and P=4.212y², the bed width, b = 0.20 m, and the water depth, y = 0.35, then A= 0.25 m², the mean flow velocity, V = 0.27 m/s, the velocity is lower than the allowable. (declined)
- For mesquas, b/y= 1 – 2, take b/y = 1.0 and Q = 0.07 m³/s, the bed width, b= 0.167 m, y=0.167 m, Z =1.5, and V = 1.0 m/s.

C. Design constraints

According to field observations, there are two main constraints to the requirements for the hydraulic calculations of the mesquas:
• Mesqa receives its water form a branch canal via a pipe concrete culvert of 50 cm diameter, the mesqa bed level thus should be with the invert level of the feeding pipe culvert; (the feeding pipe has a fixed level that is defined by the irrigation administration).
• The feeding pipe culvert has no gate, mesquas thus often operate as a storage canal with a maximum water depth of 0.70-1.0 m.

IV. SOIL BEARING CAPACITY AND SLOPE STABILITY ANALYSIS

Based on soil investigations and laboratory tests performed by the Soil Mechanics and Foundation laboratory at Faculty of Engineering, Alexandria University, the angle of internal friction varied from 36.1° to 25.4° and the unit weight of the soil material ranged between 1.71 t/m³ and 1.08 t/m³. The soil bearing capacity was calculated using the equation of Terzaghi \[ \phi = 36.1° \]

\[ \gamma = 1.58 \]

\[ t/m^3 \]

\[ \phi = 28.4° \]

\[ t/m^3 \]

\[ \phi = 25.4° \]

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\[ \gamma = 1.27 \]

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\[ \gamma = 1.00 \]
The slope stability analysis was performed to the worst case (critical analysis). The results revealed that the factor of safety in case of empty canal is 0.97, and it equals to 1.02 for the case of full canal. The side slope of 3:2 (H:V) implies a medium risk level. Therefore, the subgrade soil has to be compacted and a 50 cm of backfill soil of gravel-sand mixture with a percentage of 2:1 (gravel: sand) should be laid under the concrete lining. The lining thickness shall resist the hydrostatic pressure of the groundwater; it thus should be accurately determined.

V. PROTECTION OF OLD LINED MESQAS

The most types of lining are:
- Concrete (in-situ construction)
- Precast concrete
- Lime concrete
- Shotcrete (Gunit Lining).
- Brick tiles.
- Asphalt:
  - Buried asphalt membrane.
  - Asphaltic concrete.
- Stone blocks, concrete blocks undressed stones.
- Earth materials:
  - Compacted earth.
  - Soil cement.
- Prefabricated light-weight membranes.
- Bentonite-soil and clay membranes.
- PVC films.

The selection of lining material primarily depends on:
- local costs,
- durability,
- availability of materials, and
- Availability of local skills.

According to hydraulic calculations and taking into account the associated problems in the study area, the proposed alternatives to replace the old lined mesqas are as follows:

A. U-section under the ground level (1st alternative)

The existing cross-section of mesqa shall be replaced by a U-shape reinforced concrete (RC) section. The U-shape section has a bed width of 1.0 m and a height of 1.25 m, Fig. 4. The bed level of the section would be at the same level of the lower lip of the feeding pipe from the branch canal. The bed slope of the proposed section is 20 cm/km. The mesqa has RC walls at the entrance and the outlet, the boundary of the U-section shall be provided with control sluice gates. The U-shape reinforced concrete section is designed according to ECP (203-2001), and the structural and design calculations are shown below:

1) Design data:
- Mesqa width = 1.0 m
- Mesqa height= 1.25 m

2) Assumptions:
- Comprehensive strength of a concrete cubic after 28 days, $F_{cu} = 250$ kg/cm$^2$
• Unit weight of concrete, $\gamma_c = 2500 \text{ kg/m}^3$, (Reinforced concrete)
• Soil bearing capacity, B/C = 0.8 kg/cm$^2$

3) Calculations:
• Soil subgrade reaction (Area spring) = 0.8 x $10 \times 100 = 800 \text{ t/m}^2$ (maximum at bed)
• Water pressure (Triangle pressure) = 1.0 t/m$^2$
• Active earth pressure factor, $K_a \approx 0.30$
• Soil Pressure = $\gamma_c \times K_a \times h_s = 1.54 \times 0.30 \times 1.25 = 0.58 \text{ t/m}^2$
• Surcharge = 1500 kg/m$^2$

Figures from 5 to 13, present the results of the 3D structural analysis program, momentum due to soil, water pressure, and the surcharge. Fig. 14 depicts the reinforcement details for the proposed mesqa.

4) Checks:
Actual stress capacity = 7.08 t/m$^2$, (Allowable B/C = 8.0 t/m$^2$)

5) Design of sections:

<table>
<thead>
<tr>
<th>Section</th>
<th>M (t/m')</th>
<th>N (t/m')</th>
<th>Thickness $t_s$ (cm)</th>
<th>Area steel, $A_s$ (No.-diameter)</th>
<th>case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>1.24</td>
<td>-2.82</td>
<td>20</td>
<td>6- d12 mm</td>
<td>Water section</td>
</tr>
<tr>
<td>Base</td>
<td>1.30</td>
<td>-2.82</td>
<td>40</td>
<td>6- d12 mm</td>
<td>Water section</td>
</tr>
</tbody>
</table>

a) Design of wall sections (crack control section)

 DOI: http://dx.doi.org/10.24018/ejers.2019.4.5.1330
b) Design of base sections (crack control section)

In this alternative, the U-shape reinforced concrete mesqa is designed to be placed above the ground level. The existing cross-section of the mesqa should be filled and compacted with a suitable soil. The backfill soil shall be compacted to obtain 95% of the modified proctor test. Fig. 15. The U-shape section has two RC walls at the entrance and the outlet. The U-shape section has a bed with of 0.50 m and a height of 0.75 m. The considered dimensions are greater than the design ones for easy maintenance and
emergency cases. The irrigation water shall be lifted from the branch canal to the proposed mesqa by a pump of 60 l/s discharge. All pumps are to be electric (mobile diesel pumps are to be used in case of emergency). The minimum number of pumps for a mesqa is two.

1) Design data:
   - Mesqa width = 0.50 m
   - Mesqa height = 0.75 m

2) Assumptions:
   - $F_{cu} = 250$ kg/cm$^2$
   - $\gamma_c = 2500$ kg/m$^3$, (Reinforced concrete)
   - Soil bearing capacity = 0.5 kg/cm$^2$

3) Calculations:
   - Soil subgrade reaction (Area Spring) = $0.6 \times 10 \times 100 = 600$ t/m$^2$
   - Water pressure (Triangle pressure) = 1.0 t/m$^2$ (Maximum at bed)
   - $K_a = 0.3$
   - Soil pressure = $\gamma_c \times K_a \times h_s = 1.54 \times 0.30 \times 1.80 = 0.85$ t/m$^2$

4) Checks:
   - Actual stress capacity = 1.15 t/m$^2$, (Allowable B/C = 6.0 t/m$^2$)
   - Allowable compression stresses = 2500 t/m$^2$, Tension stresses = 300 t/m$^2$

5) Design of sections:
   According to the first alternative, all sections have the minimum dimensions. Therefore, the current U-shape is designed as the same as the previous section including the design thickness and reinforcement area.

<table>
<thead>
<tr>
<th>Section</th>
<th>$t_i$ (cm)</th>
<th>$A_i$ (No. diameter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>20</td>
<td>6- d12 mm</td>
</tr>
<tr>
<td>Base</td>
<td>40</td>
<td>6- d12 mm</td>
</tr>
</tbody>
</table>

C. RC pipe mesqa (3rd alternative)

A reinforced concrete pipe with a diameter of 80 cm was selected according to the Egyptian standard (958-1/2006), Grade 1(20/30), $F_{cu}$ = 27.6 MPa (mega pascal) as shown in Fig. 16. The pipe diameter of 80 cm is greater than the design one. The selected diameter is also considered for maintenance. The selected pipe shall be placed at the same level of the feeding pipe from the branch canal. The connection between two pipes is executed through manholes provided with control gates at the entrance and outlet. Inspection chambers should be provided every 100 m along the pipeline system. The existing cross-section of the mesqa should be filled around the RC pipe with a selected backfill soil. The flow through the pipe mesqa is a free flow. The structural analysis was employed to check compliance with Egyptian standards under the considered loads, Fig. 17 to 20.

1) Assumptions:
   - $F_{cu} = 250$ kg/cm$^2$
   - $\gamma_c = 2500$ t/m$^3$ (Reinforced Concrete)
   - Soil bearing capacity = 0.6 kg/cm$^2$

2) Calculations:
   - Soil subgrade reaction (Spring area) = $0.6 \times 10 \times 100 = 600$ t/m$^2$
   - Water pressure (Triangle pressure) = 1.0 t/m$^2$ (Maximum at bed)
   - $K_a = 0.3$
   - Soil pressure = $\gamma_c \times K_a \times h_s = 1.54 \times 0.30 \times 1.80 = 0.85$ t/m$^2$

3) Checks:
   - Actual stress capacity = 1.15 t/m$^2$, (Allowable B/C = 6.0 t/m$^2$)
   - Allowable compression stresses = 2500 t/m$^2$, Tension stresses = 300 t/m$^2$
   - Total pressure = $\gamma h + P + \gamma_a h$
   - Stress = $(6.11 \times 2.34 \times 1) / (0.06 \times 0.8 \times 2) = 14.83$ kg/cm$^2$
Fig. 17. Soil surface pressure

Fig. 18. Water surface pressure

Design load for crack width of 0.30 mm = 800 x 20 = 16000 N/m
Maximum design load = 800 x 300 = 24000 N/m
According to the Egyptian Standard specification (958-1/2006)
The inner diameter, \( D_{in} = 800 \) mm, the outer diameter, \( D_{out} = 920 \) mm,
thickness, \( t_w = 60 \) mm, Circular hoops \( 5.2/0.5 = 11 \phi 8/m' \), and the longitudinal reinforcement = \( 5 \phi 10/m' \)

<table>
<thead>
<tr>
<th>Max Stresses</th>
<th>S1-1</th>
<th>Safe/unsafe</th>
<th>S2-2</th>
<th>Safe/unsafe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>+5.3</td>
<td>Safe</td>
<td>+22.7</td>
<td>Safe</td>
</tr>
<tr>
<td>Compression</td>
<td>-4.4</td>
<td>Safe</td>
<td>-26.8</td>
<td>Safe</td>
</tr>
</tbody>
</table>

4) Check for RFT:
Circular hoops = 5.2 /0.5 = 11 φ 8/m' (M1-1)
Moment Resistant = 0.64 t.m/m²
Longitudinal Reinforcement: 5 φ 10/m' (M2-2)
Moment Resistant = 0.46 t.m/m²

The selected section according to the Egyptian standard specification is SAFE

For the abovementioned three alternatives, the first and the third alternatives are the most expensive. The second and the third alternatives need agreements and licenses as they propose to change irrigation system. The second alternative needs pumping units to lift the irrigation water.

D. Concrete lined mesqa (4th alternative)

In this alternative, the old mesqa shall be lined by a fiber reinforced concrete, FRC, Fig. 21. FRC is an ordinary concrete reinforced with fibers with a dosage of 0.9 to 1 kg per a cubic meter of concrete or according to the manufactures' recommendations. It is recommended to isolate all concrete faces under the ground from the pore water according to implementation roles. Natural filter materials of 30 cm thickness composed of gravel and sand, (2 Gravel: 1 Sand) should be placed under the concrete.
lining. As the study area is characterized by high saline groundwater levels, PVC solid and perforated pipes shall be placed through the canal lining on the canal side slopes at level of 0.75 m from the canal bed to solve the problem of uplift pressure relief. The PVC drain pipes shall be surrounded by natural filter/drainage materials. When the groundwater raises to the level of PVC pipes, it will be collected by the perforated PVC and directed through the solid PVC to the mesqa. Joints (contraction, expansion, and construction) shall be provided with dimensions, and filling materials (sealant, backfilling and water stop) according to (EC WRI-2002). As irrigation lands and roads in the study area are often above the mesqa, the vertical distance from the top of mesqa to irrigation lands and/or roads shall be pitched with mortar. According to the following data, the proposed lined mesqa was structurally designed, Fig. 22 and 23.

1) Design data:
- Mesqa bed width = 0.50 m
- Side slopes = 3:2 (H: V)

2) Assumptions:
- $F_{cu} = 250$ kg/cm$^2$
- $\gamma_c = 2200$ t/m$^3$ (plain concrete)
- $t_s$ (Lining thickness) = 0.15 m
- Soil bearing capacity = 0.6 kg/cm$^2$
- Work (combination) = 1.0 DL + 1.0 Water
- Ultimate (combination) = 1.4 DL + 1.6 Water

3) Calculations:
- Soil subgrade reaction (Spring area) = 0.6 x 10 x 100 = 600 t/m$^2$
- Water pressure (Triangle pressure) = 1.0 t/m$^2$ (Maximum at bed)

4) Checks:
- Actual stress capacity = 2.13 t/m$^2$, (Allowable B/C= 6.0 t/m$^2$)
- Allowable compression stresses = 2500 t/m$^2$, Tension stresses = 300 t/m$^2$

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<tr>
<th>Max Stresses</th>
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<tbody>
<tr>
<td>Compression</td>
<td>+178</td>
<td>Safe</td>
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<td></td>
<td>-189</td>
<td>Safe</td>
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<td>-185</td>
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</table>

Concrete lining for mesqa presents excellent durability, but long-term effectiveness was only 70 percent because of random cracking.

A predicted service life of concrete lining is 40 to 60 years. Ponding tests show an effectiveness seepage reduction of 60 to 90 percent and an estimated long-term effectiveness of about 70 percent. Concrete lining is initially quite watertight, although concrete does have a measurable permeability.

However, within the first couple of years, concrete starts to develop cracks because of shrinkage during curing and thermal movement (temperature differences). Moreover, concrete often continues to crack over time because of subgrade movement. The proposed FRC lining could minimize the cracks.

E. Stone Pitched lining of mesqa (5th alternative)

Twenty irrigation water samples were collected form the main canal (Sedi Yusuf), the secondary canals (grouted pitched lining), which administratively managed by the irrigation districts. Samples were also collected from the old and new lined mesqas (plain concrete lining). The chemical investigations for the collected water samples were carried out by the faculty of Agriculture, Alexandria University. The results revealed that there are insignificant tolerances between the properties of water samples that collected from grouted pitched lining or plain concrete lining canals.
According to the results of chemical investigations for the collected irrigation water samples from pitched and concrete canal lining, this alternative was proposed. The old mesqa shall be lined by a grouted stone pitching, Fig. 24. The subgrade soil under the lining shall be compacted to obtain 95% of the modified proctor test. The surface against which the work is to be placed shall be moistened with clean water a little in advance of construction and covered with a layer of cement mortar about 50 mm thick. Stones shall then be firmly set by hand into the mortar, densely packed against adjacent stones and built up to form a stone structure of more or less uniform thickness which shall nowhere be less than the thickness. All the while that stones are being placed, all voids in the structure shall be packed solidly with mortar and stone spalls; however, the surfaces of stones in the exposed faces and edges shall not be covered with mortar. The volume of the mortar should be more than one third (1/3) the volume of the stones. The exposed surfaces and edges of the structure shall be constructed such that they have as large a proportion as practicable composed of stone faces. Weep holes shall be provided as shown in Fig. 24. A permeable Geo Textile membrane should be laid under the stone pitching. As irrigation lands and roads in the study area are often above the mesqa, the vertical distance from the top of mesqa to irrigation lands and/or roads shall be lined by a 30 cm ungrouted pitching.

This alternative is the most financial wise. Maintenance requirements for this alternative are relatively inexpensive, and Egyptians are familiar with stone pitched lining, and they can easily perform required maintenance.

Stone pitched lining of canals is useful in the following circumstances, provided it is economically feasible i) Prevention of erosion, and ii) Where the groundwater level is above the bed of the canal and there is possibility of occurrence of damaging back pressures since this type of lining allows water pressure to be released through the interstices.

VI. CONCLUSIONS AND RECOMMENDATIONS

The mesqa lining works at Mutoube District in Kafr El-Sheikh Governorate were evaluated and the main causes of concrete damages were also identified. Five suitable technical alternatives were presented for the replacement of the old lined mesqas. Financial wise, the grouted stone pitched lining mesqas are strongly recommended.

REFERENCES