# PRACTICES FOR CONSTRUCTION OF SUSTAINING HARD CANAL LININGS ON DEFORMABLE GRADES

# PRATIQUES DE CONSTRUCTION DU REVETEMENT DURABLE DES CANAUX SUR LES SOUS-SOLES DEFORMES

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## *ABSTRACT*

*Conveyance and distribution of water is an integral part of any irrigation project. Irrigation canals constitute a considerable portion of irrigation systems worldwide. Therefore, improvement of performance for small and large canals would contribute to productivity of available water. This article focuses on hard canal lining practice in Iran. Most of modern irrigation canals constructed in Iran utilize cement concrete linings, and a major concern regarding them is to maintain transmission performance where subsoil is problematic and deformable. In the first part of the paper, an idealized lining segment on a deformable soil is analyzed for minimum properties that would prohibit lining failure. The second part, lists some case histories of hard linings and checks applicability of analyses results to them. It is concluded that for a hard lining to remain functional on deformable soils, the designer has to take into account expected leakage rate from the canal. Integrating leakage rate and leakage pattern into lining design is initially motivated by our readily-acknowledged, short-term goals of preserving initial shape and transmission capacity of canals. Incidentally, it also means more productivity of total transmitted water, which is favorable to our long-term and sometimes less-acknowledged, goal: sustainable usage of water resources.*

***Keywords:*** *Hard canal lining, Portland cement lining, lining design, water productivity, leakage rate, problematic sub-soil, deformable grade, irrigation in Iran.*

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# *RESUME ET CONCLUSIONS*

*Les canaux d'irrigation constituent une partie importante de la trajectoire de l'eau des réservoirs sur les fermes. Par conséquent, les pratiques de la construction du canal qui se traduisent dans les garnitures à faible taux de fuite, permettrait d'améliorer la productivité globale de l'eau disponible. Toutefois, faible taux de fuite n'est pas toujours une préoccupation pour les propriétaires de projet d'irrigation, mais leur souci est d'avoir un canal qui maintient en forme depuis plusieurs années de la transmission de l'eau. Cet article a examiné les performances de certains revêtements en béton documentés construits en Iran. Ces études de cas ainsi que l'expérience accumulée dans la section générale de l'eau dans l'Iran montrent que, avec la méthode actuelle de construction de coffrage, la solution idéale pour maintenir au sol en passant par des problèmes de revêtements en béton dur, serait le remplacement du sous-sol problématique avec des matériaux de remplissage. Cette solution ne vise pas à réduire les fuites, mais il modifie le sous-sol de tolérer une fuite d'eau.*

*De sécurité fournies par le remplacement du sol, en termes de problème de sous-sol de façon permanente la résolution, a interdit d'autres solutions à devenir populaire. D'autres solutions, tenter de remédier à un problème sous-sol en contrôlant le taux de fuite et le motif. Si une approche robuste pour la conception doublure existe qui intègre taux de fuite, doublure propriétés et problématiques caractéristiques du sous-sol ainsi, de nouvelles garnitures composites qui lutte contre les fuites, pourraient devenir plus populaires.*

*Cet article présente quelques relations simplifiées pour l'intégration des propriétés du sous-sol, qui sont altérées par une fuite d'eau, dans la conception quantitative de revêtement des canaux difficiles. Les relations sont issus de deux scénarios d'échec doublure. Tout d'abord, il est supposé que les segments doublure rester en contact avec le sous-sol, et de forces internes pour un "faisceau sur élastique grade" cause de la doublure à se fissurer. Cette condition nous amène à un ensemble de courbes que pour une élasticité minimale attendue, produisent une gamme de «ratio de la doublure d'épaisseur à joints espacement" que la plupart être évitées. Deuxième cas de figure, on suppose que le revêtement a perdu le contact avec le sous-sol sur une longueur nommé la longueur en porte à faux. Un ensemble de courbes sont fournis, que la relation de contrôle entre l'épaisseur de revêtement et la longueur maximale probable en porte à faux. Lier la longueur maximale probable cantilever au débit de fuite et le motif de fuite pour un système de revêtement de sol dans une problématique reste une suggestion de recherche future.*

*On croit que cette approche conduit les concepteurs de doublure commencer à parler plus sérieusement, en termes de taux de fuite et le motif de fuite. Bien que ce soit d'abord motivés par notre facilement reconnu-, des objectifs à court terme de conserver leur forme initiale et la capacité de transmission des canaux, il peut aussi, fournir plus de productivité de l'eau transmis total, ce qui est favorable à notre long terme et parfois moins reconnu, objectif: l'utilisation durable des ressources en eau.*

***Mots clés:*** *Revêtement dur du canal, revêtement en béton Portland, conception du revêtement, productivité de l'eau, taux de fuite, sous-sol problématique, sous-sol déformé, irrigation en Iran.*

*(Traduction française telle que fournie par les auteurs)*

# 1. INTRODUCTION

Water losses in unlined canals may go up to 50 percent of total input (Ivy and Narejo, 2003). Therefore, it is possible to effectively increase water productivity by lining the canals, leakage remediation, and use of modern solutions to control and regulate water (Schultz and de Warchien, 2002). In Iran, the total arable land downstream to the dams and under natural regime of rivers is about 4.1 million acres , in which 1.67 million acres do have constructed modern and semi-modern irrigation networks, 260000 acres are under construction and 2.2 million acres are under preliminary investigation (Falahrastgar, 2010). Most of linings are hard, or more specifically, unreinforced Portland cement concrete linings. However, there are several observations about considerable leakage from hard linings, which even have lead to deterioration of existing land drainage scheme (Rahimi et al, 2004). Therefore, customary hard lining practice has a potential defect in irrigation systems, and simply, it should be revised. It is evident however, that change in practice is not taking place as smoothly as expected.

Factually, alternatives to current practice have failed to integrate into owners', consultants' and constructors' favorites. Several reasons exist for that, ranging from aesthetic issues or vandalism problems, to the fact that there are cases of customary hard linings which have been in operation successfully for decades. That means, neither of supporters of the old practice or supporters of modern solutions could deny other side's reasoning.

Ultimately, one may conclude that, different practices, either modern or old-fashioned, if constructed properly, are suitable for different projects (Snell, 2001). However, no robust approach is available towards quantitative design of canal lining, capable of incorporating characteristic properties of lining with comprehensive seepage-deformation analyses in the sub-soil. This has lead the designers to either totally discourage widely accepted customary hard linings or totally avoid "modern but costly lining solutions".

# 2. ANALYTICAL JUSTIFICATIONS: SLAB ON GRADE

It is possible to consider lining segments at the bottom of a canal as slabs on grade. Extensive analytical solution is available for solving displacements and forces in a slab on grade problem (Simvulidi, 1973). Effective parameters in elastic behavior of a slab on homogeneous grade may be listed as:

- *L*: slab length
- *q*: load on the slab
- *E*: modulus of elasticity of slab
- $E_0$: modulus of elasticity of soil
- *t*: thickness of the slab

And maximum moment occurs at the middle of slab. For unit width of slab:

$$M_{max} = \frac{1297\ \mathrm{q}\ \mathrm{L}^2}{53760+1392\ \pi\frac{E_0}{E}\times\frac{L^3}{t^3}} \qquad \text{(Equation 1)}$$

For an unreinforced concrete slab as in canal linings, in order to prevent cracks in the concrete we should have:

$$\frac{M_{max}\frac{t}{2}}{I} < f_t \qquad \text{(Equation 2)}$$

In which *I* is moment of inertia of slab. By making the following assumptions:

- Concrete resistance in tension (in MPa) : $f_t \cong 0.6\sqrt{f_c}$
- Concrete modulus of elasticity (in MPa): $E \cong 5000\sqrt{f_c}$
- Unit weight of water : 0.01 MN/m$^3$
- Depth of canal (in meters) : *h*

where, $f_c$ is concrete compression resistance in MPa, we will get:

$$148.2974\, h\left(\frac{t}{L}\right) - 61469\left(\frac{t}{L}\right)^3 \sqrt{f_c} < E_0 \qquad \text{(Equation 3)}$$

The above equation determines minimum acceptable stiffness for a homogeneous subgrade below a lining. Largest value of the term on the left hand side would occur at $\frac{t}{l} = 0.02836\sqrt{\frac{h}{\sqrt{f_c}}}$. At this value, largest demand for soil stiffness is produced which is equal to (in MPa) 2.8036 *h*(*m*) $\sqrt{\frac{h(m)}{\sqrt{f_c(MPa)}}}$. That means if minimum expected soil modulus of elasticity, is larger than 2.8036 $h\sqrt{\frac{h}{\sqrt{f_c}}}$, then, as long as homogeneity of the subgrade is retained, no failure will occur in the lining. However, In case of smaller soil stiffness, the *t*/*L* ratio should be checked. Diagrams in Figure 1 visualize Equation 3:

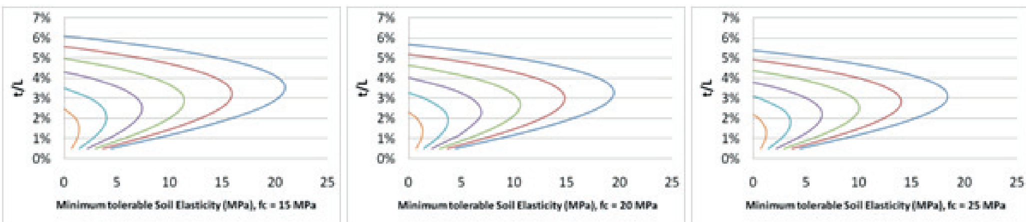


Fig. 1. Relation between t/L ratio and minimum acceptable sub-soil elasticity (Relation entre le rapport T / L et le minimum acceptable élasticité sous-sol)

The above diagrams show that for a given canal on relatively soft ground, there is a range of *t*/*l* which should be avoided. For example, for a canal with 3 meters water depth and $f_c$ = 20 MPa, if the minimum expected inundated elasticity modulus for soil is, say, 5 MPa, then the ratio *t*/*L* should be either smaller than 1.25% or larger than 3.25%. This is the only control required if soil homogeneity is guaranteed under the lining and if the lining remains in contact with the soil. However, this is not always the case.

Heterogeneities in soil may be attributed to variations in soil properties which either exist at the time of construction or are caused by the canal after construction. Figure 2 shows examples of Heterogeneous subgrade.

Finding the moment induced in concrete slab on a grade with arbitrary elasticity modulus distribution, with added random inelastic subsoil deformations, is a complicated problem. Here, we assume that, if soil remains in contact with lining, it is enough to take a conservative averaged $E_0$ for use in Equation 1. However, if random inelastic deformations and variation in E0 are so acute that contact with soil is lost, a different scenario should be analyzed. Thus, we define the 'cantilever length' of a lining system, as possible largest part of a segment which is disjointed from sub soil and is supported like a cantilever by other part of the segment. For example, in Figure 2(c) the cantilever length would be equal to the length of largest hole that might be formed beneath the lining by any type of subgrade deterioration.

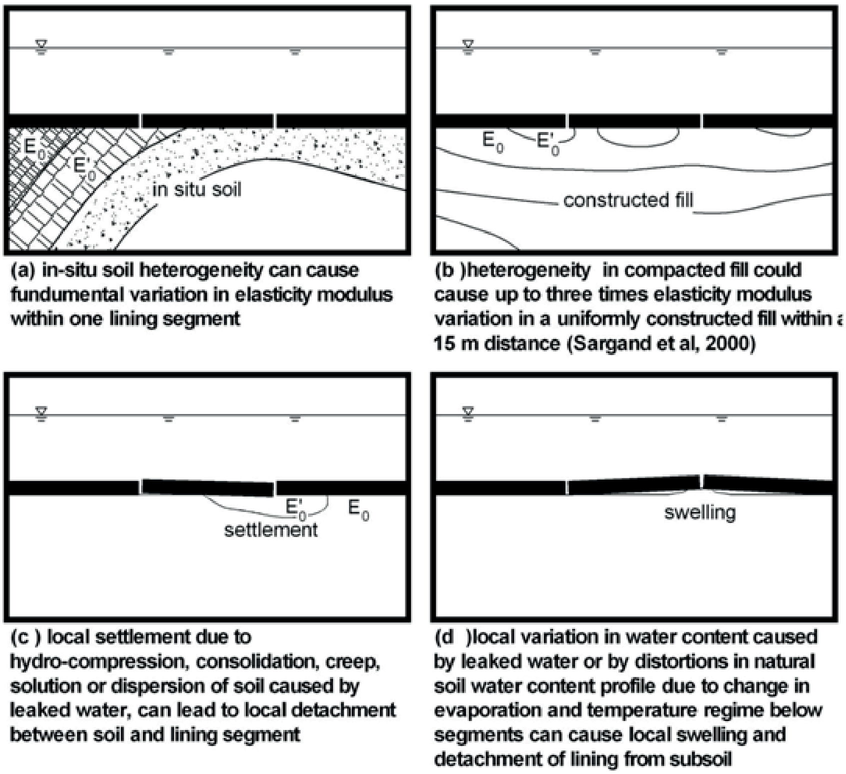


Fig. 2. Examples of heterogeneous subsoil (Des exemples de sous-sol hétérogène)

In case of a cantilever length equal to $L_c$, maximum moment exerted on the lining due to problematic soil deformations, would be as follows:

$$M = (\gamma_w h + \gamma_{conc}\, t) \times \frac{L_c}{2} \times \frac{L_c}{4} \qquad \text{(Equation 4)}$$

Again, from Equation 3 we get:

$$0.015\,\frac{{L_c}^2}{\sqrt{fc}} + L_c\sqrt{0.000225\,\frac{{L_c}^2}{fc} + 0.0125\,\frac{h}{\sqrt{fc}}} < t \qquad \text{(Equation 5)}$$

where $L_c$, $h$, and $t$ are in meters and $f_c$ is in MPa. The following diagrams show relationship between minimum thickness $t$ which is necessary for a lining system with cantilever length $L_c$.

As an example, for a canal with 3 meters water depth and $f_c$ = 20 MPa, if cantilever length is 75 cm, a minimum thickness of 7 cm is necessary.

Up to this point, we have two controls for two scenarios of loadings on linings. However, for the second scenario, the problem is what length should be taken as $L_c$ ? This parameter should be carefully judged based on the nature of ground and lining practice. Therefore, assessing a rational cantilever length is of outmost importance. To this end, case histories of constructed canals and documented observations of failed linings should be examined.

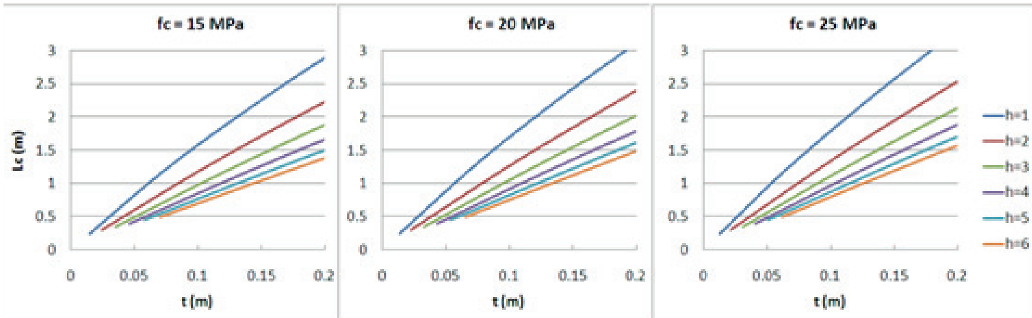


Fig. 3. Relation between lining thickness and maximum tolerable cantilever length $L_c$ (Relation entre l'épaisseur de revêtement et la longueur maximale tolérable cantilever $L_c$)

# 3. REVIEW OF DOCUMENTED CASES: HARD LININGS SUSTAINABILITY

There are several documented case histories of performance of canal linings built on problematic soils. However focus is not usually given on details of joint spacing and thickness of concrete linings. Normal practice is $f_c$ = 25 MPa, t ≅ 0.13 m, L = 3 m (t/l ≅ 4%).

Table 1 lists some documented cases of failed hard canal linings. In table 1, calculated minimum tolerable elasticity modulus is shown for selected cases. Also maximum tolerable cantilever length of the lining is derived based on diagrams of Figure 3. For example, in DashtAbbas main canal, we may infer that in failed areas, either soil elasticity has dropped below 17 Mpa or contact between lining and subsoil is lost in a length of more than 1.05 meters. These values are unavoidably approximate in nature. However this is a practical step towards quantitative design of hard canal linings.

In the case of DashtAbbas main canal, using these calculations, the designer could be able to remedy two possible scenarios of lining failures; that is, for soil elasticity, s/he could either alter the $t/l$ ratio, or strictly advice an inundated plate load test to keep a safe margin of subsoil elasticity modulus above 17 MPa. And, for the second scenario of failure, designer could either alter the thickness of lining or derive a maximum allowable leakage rate that keeps the formed holes within 1.05 meters in canal design life.

# 4. PROPOSED FRAMEWORK FOR QUANTITATIVE DESIGN OF LININGS

For hard canal linings to remain in good condition, we need to make sure that concrete does not crack under conditions imposed by deformable and problematic subsoil, nor the segments undergo sever displacements. As shown earlier, finding internal forces in general condition of arbitrary soil elasticity and contact conditions below a concrete segment would be complicated. Problem will be more difficult if we consider three-dimensional and longitudinal loadings and deformations.

Table 1. Case histories (Les histoires de cas)

| Project | | | Reported facts |
|---|---|---|---|
| SiminDasht to Garmsar water transmission project (Razmju, 2010) | Minimum tolerable soil elasticity modulus from diagrams of Figure 2 = N/A | Maximum tolerable cantilever length from diagrams of Figure 3 : 1.6 m | • initially constructed 1993 to 2004<br>• total Length: 37 km<br>• canal length: 24.2 km<br>• capacity: 15 $m^3/s$<br>• a 0.5 $m^3/s$ watering commenced the failures<br>• water usage: agricultural-drinking<br>• target irrigation area: 22000 $m^2$<br>• yearly water transmission volume: 275M $m^3$<br>• problematic soils: collapsible, expansive, gypsiferous, and salty soils, marn and shale<br>• gypsum caused initial swelling, then solubility and progressive formation of holes beneath the lining that has lead to collapse of lining in concentrated leakage points<br>• shallow groundwater depth in some areas has also contributed to solution of gypsiferous soil<br>• a gypsum content of below 4 percent is safe<br>• canal has a depth of 2m, bottom width of 1.65 m and side slope of 1:1.5<br>• active nature of adjacent slopes and corrosive hydrological site is a cause of problems<br>• securing alongside dikes are omitted in construction phase<br>• low clearance below elevated flume lead to seasonal floods accumulate behind the air canal section<br>• there are no designated farm turn-outs<br>• access roads are broken during precipitation season<br>• low compression of constructed fills caused catastrophic settlements<br>• steep slopes of spoils has failed toward the canal<br>• leakage from canal is at extent to cause local groundwater surface in bores near canal |
| DashtAbbas main canal (Falahrastgar et al, 2010) | Minimum tolerable soil elasticity modulus from diagrams of Figure 2 = 17 MPa | Maximum tolerable cantilever length from diagrams of Figure 2 : 1.05 m | • capacity: 80 $m^3/s$, depth of water: 6 m<br>• length: 15 km<br>• total target area of network: 20000 acres<br>• canal linings has failed in some points<br>• in 1400 m of canal, longitudinal cracks and side slope settlements along with deep cracks, lining failure and in some cases dislocation of lining segments is observed<br>• a remedial act has been applied consisting of removing failed segments and 40 cm excavation and replacement with lean concrete, then reconstruction of concrete lining<br>• cause of failure: loose sand and gravel with silt and clay has settled upon saturation, holes formed and lining failed<br>• layers in subgrade along canal are of diverse characteristics<br>• all failures are in sections that consist of excavation in one side and fill in the other side (steep transverse topography)<br>• Construction speed in failed parts was higher than safe parts (24000 $m^3$ per month comparing to 16000 $m^3$ per month) |

| | | | |
|---|---|---|---|
| Shadegan, Ghods, Zamzam irrigation network (Saham, 2010) | Minimum tolerable soil elasticity modulus from diagrams of Figure 2 = N/A | Maximum tolerable cantilever length from diagrams of Figure 2 : 2 m | • failure type: side slopes cracks<br>• bottom width: 2 m<br>• water depth: 1.65<br>• age of canal: 4 years<br>• in order to reduce lining cracks, a reduction in expansion joints spacing is advised |
| AbsharDasht transmission canal (Movahedan et al, 2010) | Minimum tolerable soil elasticity modulus from diagrams of Figure 2 = N/A | Maximum tolerable cantilever length from diagrams of Figure 2 : 1.3 m | • bottom width: 2 m<br>• side slope: 1:1.5<br>• water depth: 2 m<br>• constructed around 1975<br>• lining collapsed after 5 years due to dissolving of gypsiferous content<br>• a remedy design of a butyl-rubber geo-membrane sandwiched in two top and bottom layers of geo-textiles was practiced<br>• In 2010, in a 565m length, leakage was measured to be 97 $l/day/m^2$<br>• the main canal with 4 m depth and side slopes of 1:1.5 and 15 m top width is also constructed this way. Minor collapses are found to occur due to gypsum dissolution in some places. Overall the users are satisfied. |
| DarDai-Cheshmepar canal (Sakhai et al, 2010) | Minimum tolerable soil elasticity modulus from diagrams of Figure 2 = N/A | Maximum tolerable cantilever length from diagrams of Figure 2 : 2.3 m | • Bottom width: 0.8 to 1 m<br>• Depth: 0.8 to 0.9 m<br>• Side slope 1:1.5<br>• Capacity: $1m^3/s$<br>• Length: 18 km<br>• instability of natural slopes and gradual filling of canal with slope remnants<br>• cracks in lining due to settlement and holes are parallel to the canal axis and occur in middle one thirds of side slope<br>• cracks due to swelling occur in toe and in longitudinal direction<br>• cracks are formed within one year after construction and in cases even before water put in the canal |

However, we considered two simplified scenarios to handle the problem in two dimensions. First scenario, subsoil remains in contact with lining; and loading on the segment causes lining to crack. Second scenario considers a total detachment between subsoil and lining along a length of $L_c$. diagrams are provided to control the thickness and length of segments based on elasticity and detachment length of subsoil in Figures 2 and 3. Thus, a design procedure should consist of rational estimates of i) minimum inundated soil elasticity and ii) largest possible detachment length of subsoil and the lining within lining life.

Diagram in Figure 4 proposes a flowchart for design of linings based on above approach:

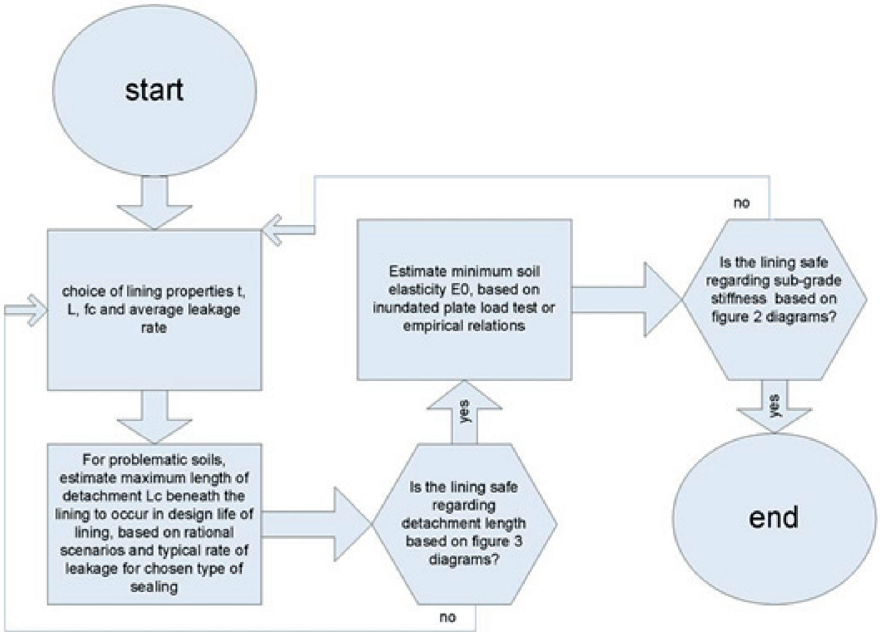


Fig. 4. Flowchart for quantitative design of linings (Diagramme de décision pour la conception quantitative de revêtements)

# 5. CONCLUSIONS

Irrigation canals comprise a major part of water path from reservoirs to farms. Therefore, canal construction practices which result in linings with low leakage rate, would improve overall productivity of available water. However, low leakage rate is not always a concern for irrigation project owners, but their concern is to have a canal that keeps in shape for several years of water transmission. This paper examined performance of some documented concrete linings constructed in Iran. These case histories along with general accumulated experience in water section in Iran show that, with current method of lining construction, the perfect sustaining solution for passing through problematic ground by hard concrete linings, would be replacing the problematic subsoil with appropriate fill material. This solution does not aim at reducing the leakage, but it alters the subsoil to tolerate leaked water.

Safety provided by soil replacement, in terms of permanently solving sub-soil problem, has prohibited other solutions to become popular. Other solutions, try to remedy problematic sub-soil by controlling leakage rate and pattern. If a robust approach for lining design exists that integrates leakage rate, lining properties and problematic sub-soil characteristics together, new composite linings which control leakage, could become more popular.

This paper presents some simplified relationships for integrating sub-soil's properties which are altered by leaked water, into quantitative design of hard canal lining. The relationships are derived from two scenarios of lining failure. First, it is assumed that lining segments remain in contact with subsoil, and internal forces for a "beam on elastic grade" cause the lining to crack. This condition leads us to a set of curves that for a minimum expected elasticity, yield a range of "ratio of lining thickness to joints spacing" that most be avoided. Second scenario, assumes that the lining has lost contact with subsoil in a length named the cantilever length. A set of curves are provided, that control relation between lining thickness and maximum probable cantilever length. Linking the maximum probable cantilever length to the leakage rate and leakage pattern for a lining system in a problematic soil remains a future research suggestion.

It is believed that this approach leads lining designers start speaking more seriously, in terms of leakage rate and leakage pattern. Although that is initially motivated by our readily-acknowledged, short-term goals of preserving initial shape and transmission capacity of canals, it could also, provide more productivity of total transmitted water, which is favorable to our long-term and sometimes less-acknowledged, goal: sustainable usage of water resources.

# REFERENCES

Falahrastgar, A., Naghibzade, B., and Baharideraknshan, S. 2010. Necessity of geotechnical investigations in water transmission systems and irrigation and drainage networks. Proceedings of second national seminar on geotechnical issues of irrigation and drainage networks. 557-568. Language: Persian.

Ivy, D., Narejo, D. 2003. Canal lining with HDPE. GFR 21(5):(1-4)

Movahedan M., Mamanpoush A., and Abbasi N. 2010. Case history: measurement of leakage rate from irrigation canals and reservoirs with geo-synthetic liners. Proceedings of second national seminar on geotechnical issues of irrigation and drainage networks. 285-301. Language: Persian.

Rahimi h., Sohrabi t, and Ghobadinia M. 2004. Use of geosynthrtics in irrigation and drainage. Iran Committee on Irrigation and Drainage. Language: Persian.

Razmju, M. 2010. Investigating challenges of SiminDasht to Garmsar water transmission project. Proceedings of second national seminar on geotechnical issues of irrigation and drainage networks. 579-596. Language: Persian.

Saham, B., MousaviJahromi, S., and ShafaiBajestan, M. 2010. Remedial measures for reducing lining cracks in irrigation networks: case history of Shadegan, Ghods and Zamzam networks. Proceedings of second national seminar on geotechnical issues of irrigation and drainage networks. 367-376. Language: Persian.

Sakhai, M., Ahmadi, A., and Nasrollahi, Z. 2010. Investigation of problems due to lack of geotechnical investigations in DareDai-CheshmePar canal. Proceedings of second national seminar on geotechnical issues of irrigation and drainage networks. 285-301. Language: Persian.

Sargand S. M., Masada T., Wasniak D. L. Variability of initial subgrade modulus at Ohio SHRP test road. Construction and controlling compaction of earth fills. ASTM STP 1384. D. W. Shanklin, K. R. Rademacher, and J. R. Talbot. Eds. American Society for esting Materials. West Conshohocken, PA. 2000

Schultz B., DE-Warchien D. 2002. Irrigation and drainage systems research and development in the 21st century. Irrigation and Drainage. 51: 311-327

Simvulidi, I. A. 1973. Analyses of structures on elastic foundations. Gothenburg publication centre. Language: Persian translation from Russian.

Snell M. 2001. Lining old irrigation canals: thoughts and trials. Irrigation And Drainage. 50: 139-157