The Swelling Soils of the Quiroz Canal System

Les sols gonflants des canaux d'irrigation du Quiroz

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Summary

The Quiroz Irrigation Project, in northern Peru, South America, has a total length of 184 km of main canals and 554 km of branch canals.

A considerable length of these had to be lined to prevent excessive water losses.

During early field investigations and construction operations, soils with detrimental swelling characteristics were identified. The identification tests, characteristics of the materials, preventive measures, repairs carried out, and some conclusions are given by the author.

Sommaire

Le Projet d'Irrigation du Quiroz, au nord du Pérou, Amérique du Sud, présente 184 km de canaux principaux et 554 km de canaux secondaires.

Ces canaux ont du être revêtus sur une longueur considérable pour éviter des pertes excessives de l'eau d'irrigation.

Pendant les premiers essais sur le terrain et les premières opérations de construction, on a décélé des terrains présentant des gonflements dangereux.

L'auteur indique comment ces terrains ont été identifiés, quelles étaient leurs caractéristiques, quelles mesures de prévention ont été prises, quelle réparations ont été effectuées; il y ajoute quelques conclusions.

The project

The Second Phase of the Quiroz Irrigation Project has a water distribution system which comprises 180 km of main canals and 554 km of branch canals which irrigate 50.000 hectares of land; the Project is situated in the Department of Piura, northern Peru.

The problem

During field investigations and early construction operations it was noted that the terrain through which the main canals called "Tablazo" and "Tambogrande", and the Tablazo branch canals 15·8 and 31·7 (see Fig. No. 1), had soils which displayed possible troublesome swelling characteristics. During the design stage it was deemed necessary to line a considerable lenght of the main and branch canals to reduce seepage losses through pervious strata; the lining for the main canals and wide branch canals is 4 in thick and was placed by means of lining machines (Figs No. 2 and 3).

The problem facing the author was to determine the reaches of the canals where the concrete lining and the stability of the embankments were likely to be endangered.

The consultant for the Government of Peru on this Project was R.J. Tipton Associated Engineers who in turn had as soil mechanics consultants, Woodward, Clyde, Sherard and Associates, the direction of the laboratory work and of the field work was in charge of the Department of Structures and Soil Mechanics, Bureau of Irrigation, Government of Peru, in close cooperation with R.J. Tipton Associated Engineers.

Consultant's Recommendations to Cope with the Problem :

The soil consultants set up the following criteria and tests to govern the identification of the possible troublesome soils along the trace of the canals :

" Any clay which has both a liquid limit greater than 40 per cent and a shrinkage limit less than 12 per cent or any clay with a liquid limit greater than 60 per cent is a material which could possibly damage a concrete canal lining.

1. The sample should be loaded to a low pressure (about 200 lbs. per/square foot). After equilibrium is reached under this pressure, water should be allowed to reach the sample through the upper and lower porous loading stones. At this time the sample will probably show some tendency to swell and sufficient pressure should be continiously added in increments to prevent any swelling of the sample, and equilibrium is again reached, the pressure should be removed in increments and the resulting swell measured.

2. When the results of these tests are plotted in a manner as shown on the attached sketch (Fig. No. 4), the area under the curve to the left of any value for thickness of the Stratum (abcissa on the curve) will be approximately the heave which can be expected for a stratum of that thickness. Experience has shown that if the calculated heave exceeds a maximum of about 3 in., buckling of the lining may occur."

The Soils

Geological Origin :

The geological history of the zone has not been determined, but there are indications that the zone may have been submerged under the sea, and that, after emergence, through centuries of hot tropical weather accompanied by seasonal heavy rain there has been considerable chemical decomposition of the parent rock, leaving residual soils in different stages of weathering and having various properties; in some places these weathered soils have been transported by the action of wind and water.

The materials in question have not been altered to true clays, but are similar to shale, and in some districts they resemble fine sand.

The topography of the country varies from hilly country,

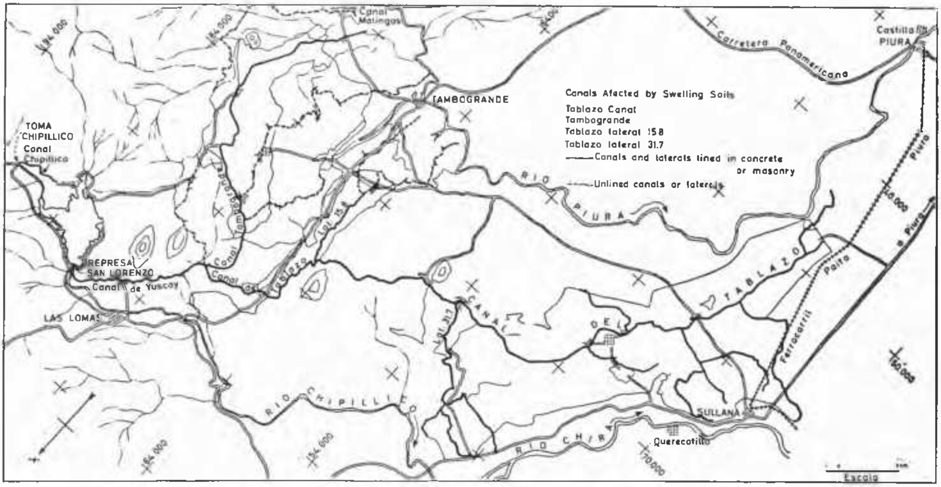

Fig. 1 General plan-Quiroz Irrigation Project.
Plan Général du Projet d'Irrigation du Quiróz.

Fig. 2 Trimming Machine.
Machine à profiler.

Fig. 3 Lining Machine.
Machine pour la mise en place du revêtement.

where the canals pass through fairly deep cuttings and over embankments to flat semi-desert country; the hilly country is where residual soils are found, and the semi-desert country is composed mainly of fine wind blown sand.

Standard Properties :

The troublesome soils have a shale like appearance, their colours are varied, with a predominance of the brown, dark brown, pale brown and green colours. They are fissured and on exposure to the atmosphere become subject to a process similar to exfoliation ; in the flat country, some of these soils have a sandy appearance and texture, but on being wetted they acquire the predominant features of fat clays, some of the rock like soils having a soapy feel and its typical lustre.

The Atterberg limits of the materials apt to cause trouble ranged from P_L 25, L_L 48, to P_L 33, L_L 102.

Tests and Results :

In the field there were two practical problems to be surmounted, namely :

(*a*) rapid determination of the dangerous zones starting from the time when excavation of the canal was finished;

(b) interference of seasonal rains with sampling operations, followed by consequent possible erroneous interpretation on altered samples.

The procedure adopted was to identify visually all possible trouble zones, obtain representative samples, find the Atterberg limits, and natural moisture contents; then, considering that a liquid limit of 50 per cent would identify a dangerous soil, the reaches affected by this criteria were marked on the maps. Those zones marked were immediately sampled for swelling tests, and the tests were performed as recommended. Under these conditions some samples required up to 7 000 lb.

Table 1

Typical Main Laboratory Identification Tests

Material and Color	*Station*	*Swelling under* 50 lbs./ sq. ft. load *and water* (per cent)	*Consolidation under* 200 lbs./ sq. ft. *and no water* (per cent)	*Load orequiredo to prevent swelling under water*	Per cent *Swelling under* 50 lbs./ sq. ft. *on discharge*	*Sample change on contact with air*	*Unit* Wt. *in* lbs./ cub. ft.	*Limits in* per cent					
								L_L	P_L	P_I	*FM*	S_L	*Vol. Change*
Clay Greyish Br.	6 + 780	—	0·12	1 057	2·28	consol.	103·5	29·4	17·17	11·7	23·4	15·1	36·1
Decomposed Rock Br. and White Veins	8 + 410	3·58	0·11	563	1·23	swelled	100·0	63·4	29·7	33·7	36·1	24·0	19·2
Clay Yellowish Green and White	8 + 910	—	0·30	7 250	8·65	consol.	111·0	75·0	42·9	32·3	52·5	22·4	50·5
Clay Brown	16 + 010	14·4	1·20	7 175	8·25	—	114·5	55·6	29·4	26·20	32·10	12·50	24·5

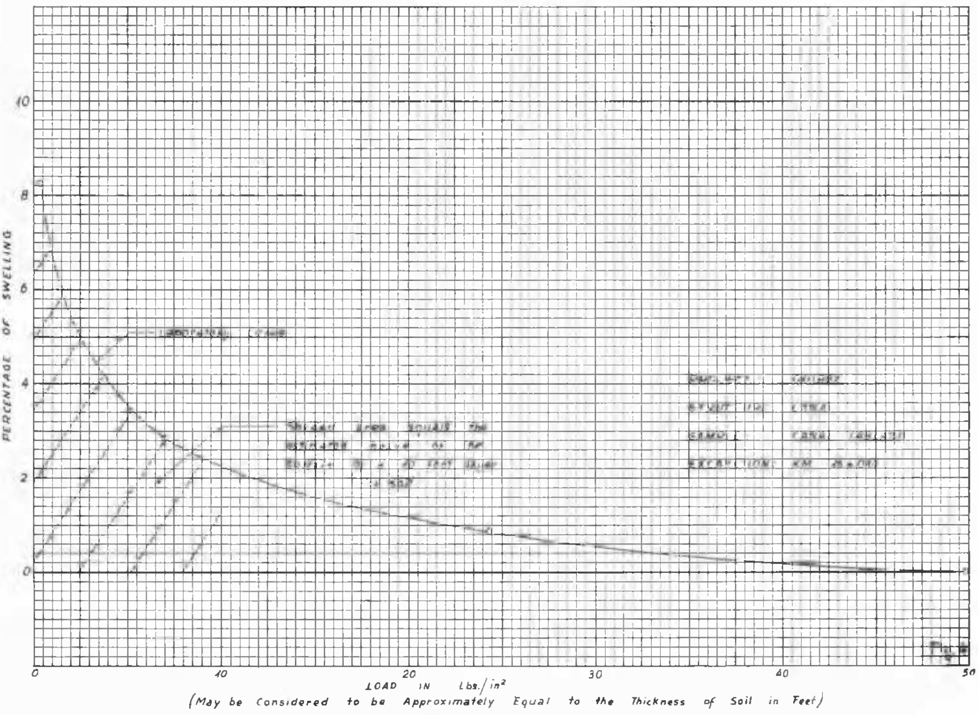

Fig. 4 Plot of load against swelling.
Graphique du gonflement en fonction de la charge.

per square foot of pressure to prevent swelling, and had 8·5 per cent of swelling on being unloaded to 50 lb. per sq. ft.; tests were also carried out at the same pressure on similar samples and they showed maximum swelling of 14·5 per cent. (Figs 4, 5 and 6 and Table 1).

In view of the urgent necessity to proceed with the identification of troublesome zones, the author recommended that as soon as the determination of the Atterberg limits indicated any possibility of danger, the soils should be sampled for swelling tests and simultaneoulsy soil samples should

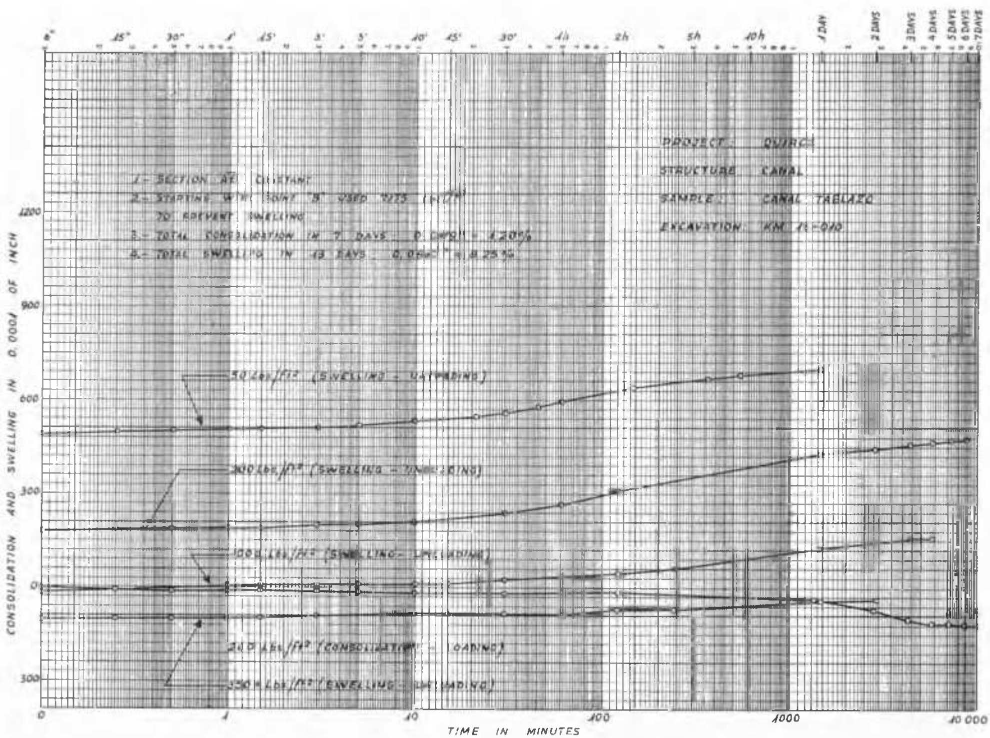

Fig. 5 Plots of loads to prevent swelling under fixed load-sample submerged.
Graphiques de la charge nécessaire à éviter le gonflement, et du gonflement sous charge fixe-échantillon sous l'eau.

be obtained at different depths of the same location in order to determine their natural moisture content. The swelling tests were to be carried out under a load of 50 lb. per sq. ft. until stability was reached; the equipment used for this test was the ring of a Casagrande consolidometer, two porous stones, a receptacle with a stem, and a Federal dial which read to 0·001 in.; soils having 5 per cent swelling and over were considered to be dangerous. In order to obtain a practical evaluation of the swelling characteristics, a 4 in. thick concrete plate with prongs on the underface and having a centre nail on the upper part be placed at the bottom of the canal. A fixed reference point was established by precise levelling and the canal was flooded so that the soils tested would be under water and would therefore swell.

Members of the field staff had been instructed to allow for a reasonable soaking period, from 15 to 30 days, to drain the water, check the levelling of the concrete plate, check the depth of moisture penetration and the moisture content in terms of percentage of dry weight, compared with the saturated water content of the same soil: thus the programme was provided with the necessary means for checking the efficiency of treatment, and to provide for possible changes required to correct deficiencies.

A considerable number of Atterberg tests were carried out, representative figures for which are given in Table 2, as well as the percentages of swelling.

The laboratory swelling tests were carried out for the soils of the Tablazo Canal when the seasonal rains floded it and interfered with them since the samples became disturbed on being soaked by water and the swelling figures were therefore affected. The rains were so violent that the canal banks were disrupted to such an extent that some reaches of the canal were practically eliminated. All field tests were upset with the exception of one which showed a swelling figure of 2·95 in.

Measures to prevent damage

The objective of all investigations was to control possible damage to the canals and their lining due to slides or swelling of the soils.

There was no fear of slides in general, and in order to prevent damage to the lining, the consultants recommended that in the dangerous zones the soil should be excavated on the surface and replaced by compacted non-expansive soils, which would provide a suitable foundation for the lining. After observing the construction operations, the author agreed to this procedure only in extreme cases, and suggested instead that the reaches should be soaked for a period of from three to four weeks under a minimum depth of 3 ft. of water.

This recommendation was based on the assumption that the soils could be soaked to sufficient depth during the time prescribed, and that from the time that the canals were lined,

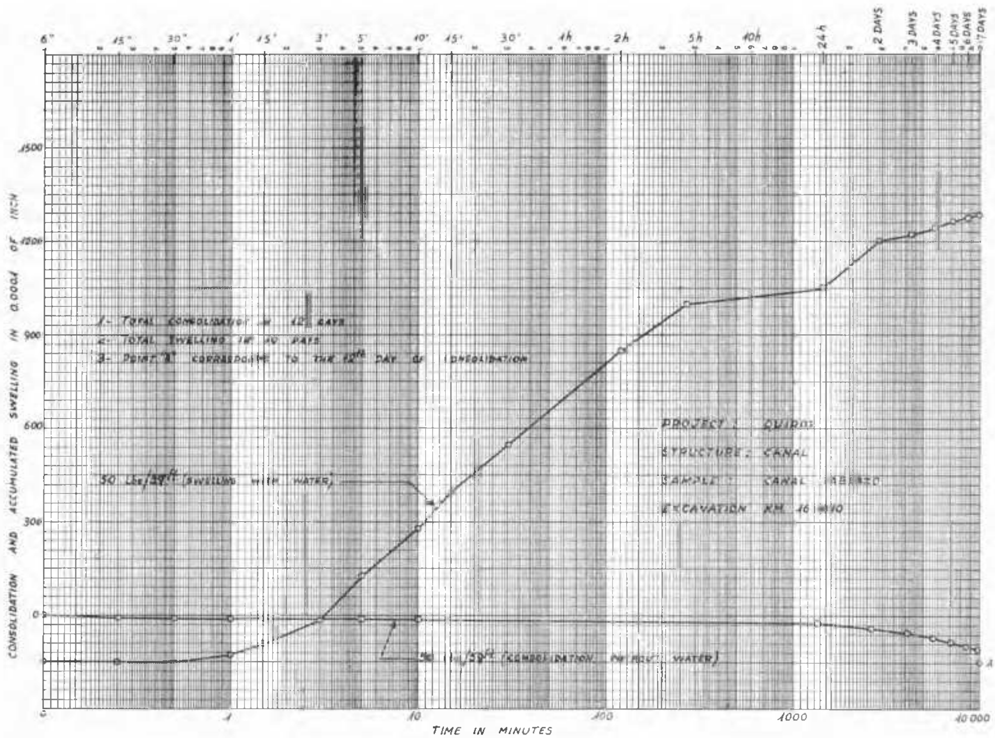

Fig. 6 Plots of consolidation under fixed load-sample dry, and swelling under fixed load-sample submerged.
Graphiques de consolidation sous charge fixe-échantillon sec, et gonflement sous charge fixe-échantillon sous l'eau.

they would have enough water to keep the soils permanently moist. The triming and lining sequences of construction would no be upset, and the cost of treatment would be reduced to a minimum.

The drawbacks from the point of view of the contractor were the large quantities of water that had to be carried by tank lorries to be ponded in the different sections of the canals, and the periodic bottlenecks that developed when the sections had not been treated for a sufficiently long period of time and the construction equipment had reached the spot.

Damage

All the zones in which the soil had potential swelling characteristics were flooded for periods which ranged from a minimum of 7 days to a maximum of 29 with an average of 15 days, the exception being the Tablazo Canal in which the soaking due to particularly heavy rain was considered to be sufficient over practically the whole length.

As the 1958 rainy season came to an end, it was noted that the lining in some sectors of the Tablazo Canal had been cracked, and in two more months there were 950 metres of canal disrupted, of which 875 metres were due to heavy swelling of the soils; the rest was due to hydrostatic pressure (see Fig. 7). The damage was impressive in some sectors, but of minor consequence considering the magnitude of the project and the aggregate length of those in which there were heavily swelling soils.

The author tried to find the reason why the lining was cracked in these reaches, and he came to the conclusion that treatment was short and the head of water sometimes inadequate.

Remedial measures

In the damaged zones it was decided to postpone repairs for as long as it would be practicable to do so, allowing the water to flow through those sections and to soak them thoroughly, checking this treatment by tests (Table 3).

After the water had been flowing for some months, the sections were repaired by reinforcing the concrete lining with No. 4 steel bars spaced at 12 inch. centres both ways. This procedure was adopted in order to prevent further cracking of the lining, but in the author's opinion this work was superfluous (Figs 8 and 9).

Recommendations and conclusions

On similar situations, the author recommends the following procedure :

1. The soils should be identified by visual means and by their standard properties.

Table 2

Typical field laboratory identification tests

Key. — Br. : Brown ; *P* : Pink ; *C* : Clay ; *Co* : Conglomerate ; *S* : Sand ; *G* : Green ; *B* : Black.

Material	*Station*	*Atterberg limits*			*Swelling test*				*Treatment-days*		*Moisture* (per cent)				
											Depth				
		P_L	L_L	P_I	*Field moist* per cent	*Dry den.* p.c.f.	*Swelling* per cent	*Saturation moisture* per cent	*Artif. Ponding*	*Ponding by rain*	12 in.	24 in.	36 in.	48 in.	60 in.
						Tambo grande canal									
GC	9+850— 9+902	14·6	32·0	17·4	22·8	94·0	7·4	34·6		over15					
SBC	11+147—11+240	13·7	28·7	15·0	10·9	122·3	8·2	19·0	10		16·5	16·1	15·2	14·6	13·9
SBC	13+540—13+580	13·7	28·7	15·0	10·9	122·3	8·2	19·0	10		15·9	15·0	14·8	13·8	sand
G Br and *BC*	16+490—16+510	11·0	33·8	22·0	12·7	108·8	6·9	31·6	20		17·9	14·9	*Co*	*Co*	*Co*
Br. and *GC*	17+955—17+972	21·5	38·3	16·8	12·8	112·4	8·9	22·9	13		17·0	16·6	15·1	13·9	13·6
Br. *C*	18+070—18+080	30·1	52·7	22·6	19·2	103·1	6·9	28·2	13		22·2	21·3	20·2	19·5	18·8
SBC	22+100—22+163	15·1	33·0	17·5	8·7	122·5	6·1	16·5	15		16·4	15·4	12·0	sand	sand
						Tablazo lateral 15·8									
Br. *C*	0+030—0+055	25·3	54·4	29·1	13·0	115·0	9·6	22·3	11		20·1	18·7	17·1	16·0	15·0
GSC	0+610—0+640	20·2	45·2	25·0	18·8	112·2	5·4	24·1	13		28·2	26·6	24·8	23·3	21·9
PC	1+460—1+478	41·6	102·8	61·2	41·5	70·8	5·2	54·4	14		44·5	69·0	71·1	73·0	53·8
Light Br. *C*	3+218—3+248	20·3	62·3	42·0	17·8	111·2	10·5	25·9	14		21·4	20·5	16·1	15·5	13·2
GC	3+526—3+630	32·9	63·8	30·9	24·7	102·7	10·1	35·1	16		30·0	26·9	21·1	21·0	20·1
BC	5+440—5+490	11·9	31·2	19·3	8·6	135·1	8·0	21·1	18		30·8	28·6	27·6	24·3	24·0
						Tablazo canal									
	8+890— 8+910	42·9	75·0	32·1	—	—	8·7	—		*ov.30	—	—	—	—	—
Br. *C*	16+010—16+200	29·4	55·6	26·2	—	—	14·4	—		over30	—	—	—	—	—
	30+000—30+460	41·9	93·9	52·0	—	—	28·1	—	20		—	—	—	—	23
	23+480—32+580	34·6	70·6	36·0			20·5		14		—	—	—	—	20
						Tablazo lateral 31·7									
Br. *C*	0+160—0+204	17·4	46·0	28·6	20·0	105·1	8·8	29·9	17		33·9	31·4	26·1	21·4	20·2
GC	1+312—1+360	24·2	48·6	24·4	15·8	109·3	10·2	29·8	17		26·2	24·6	21·8	20·6	20·1
GSC	3+400—3+410	19·8	51·8	32·0	20·0	104·2	7·2	—	15		28·3	27·2	24·2	23·1	22·1
Br. *C*	6+365—6+440	31·9	53·0	21·1	—	—	—	—	13		23·8	22·5	20·6	18·3	16·6

* The bed of the canal was excavated to a depth of 18 inches and the soil replaced by sand and gravel; the concrete for the lining had an extra bag of cement per cubic yard of concrete.

Table 3

Sample of swell tests and moisture contents in repaired zones after treatment Tablazo canal

Station	*Field moisture* (per cent)	*Humidity of saturation* (per cent)	*Dry density* lbs./cu. ft.	* *Residual swelling* (per cent)	*Kind of material and moisture content*				
					0-1′	1′-2′	2′-3′	3′-4′	4′-5′
2+050	32·8	34·5	101·0	0·3	*G C* 35·2	*G C* 34·0	*G C* 32·1	*G C* 28·6	*G C* 24·6
9+730	29·5	32·1	97·0	1·7	Br. *C* 30·2	Br. *C* 28·2	Br. *C* 26·5	Br. *C* 23·2	Br. *C* 20·1
27+785	47·5	51·5	75·8	2·5	Br. *C* 46·8	Br. *C* 42·9	Br. *C* 34·6	Br. *C* 22·5	Br. *C* 20·4
27+890	29·3	30·8	94·7	0·2	*G C* 30·6	*G C* 32·4	*G C* 35·0	*G C* 41·4	*G C* 32·9
27+960	44·3	51·8	77·2	6·3	Br. *C* 45·2	Br. *C* 52·8	Br. *C* 48·6	Br. *C* 45·1	Br. *C* 37·6
28+600	30·1	33·1	91·8	1·4	Br. *C* 29·2	Br. *C* 29·1	Br. *C* 26·6	Br. *C* 25·5	Br. *C* 24·6
29+650	50·4	56·5	74·5	5·2	Br. *C* 49·6	Br. *C* 39·0	Conglomerate	Conglomerate	Conglomerate
29+710	62·8	65·4	63·8	2·3	*P C* 72·8	*G C* 63·9	Conglomerate	Conglomerate	Conglomerate
30+430	32·1	34·8	92·4	1·0	Br. *C* 24·2	Br. *C* 25·9	Sand	Sand	Sand

* This is the amount of swelling which remains in the soil after treatment.

Fig. 7 Disrupted lining. Tablazo Canal.
Revêtement fissuré. Canal du Tablazo.

Fig. 8 Trimming to line swollen section.
Mise au profil d'une section gonflée.

Fig. 9 Lining with reinforcement.
Pose d'un revêtement avec armatures.

2. The swelling properties as to amount and expansion force should be evaluated.

3. Once the soils have been classified in a general way, one or two simple tests should be used to identify the dangerous soils.

4. The dangerous zones should be sampled for moisture content at different depths, and treatment by flooding should be applied at the end of which the depth of penetration of the moisture should again be checked. The moisture content at different depths can be compared with the saturation moisture content in order to evaluate the probable residual swelling remaining in the soil.

In case the soils are so impervious and free from cracks that the moisture would not have relatively fast access to promote swelling, it is suggested that a series of holes properly spaced and of suitable diameter be bored to the necessary depth, that they be filled with sand and water in the most convenient sequence and that the canal be flooded until the treatment has been completed.

The conclusions reached for the soils encountered in this project are : that any soil of which the liquid limit exceeds 50 per cent is potentially dangerous, that any soil swelling 5 per cent or more should be treated, and that the soaking treatment is both practicable and efficient for the soils and conditions in this particular case