6 CONSTRUCTION OF IRRIGATION WORKS

Civil engineers face two severe problems when constructing irrigation works on and in gypsiferous soils and rocks, i.e.:
– the corrosive effect of sulphates on concrete
– deformation in hydraulic structures due to caving-in of the subgrade.

6.1 CORROSION OF CONCRETE

The free CaO in concrete reacts with sulphates dissolved in irrigation water under formation of etringite (calcium aluminium sulphate). Etringite contains 31 molecules of crystal water, and its formation leads to swelling and eventual slow disintegration of the concrete (Durand, 1956, Llamas Madurga, 1962, Beutelspacher and van der Marel, 1966). The corrosion of concrete by sulphates is a relatively easy problem to overcome. When the concentration of sulphates in the irrigation water is more than 300-400 mg SO_4/liter, sulphate-resistant cements such as ferrari cement or sulfadur should be used in the construction of irrigation works.
In a recent paper, Hobson (1968) correlated the sulphate content in the soil with the degree of corrosion of concrete structures. When the content of soluble sulphates (as SO_4^{--}) in the soil is higher than 1000 ppm (0.1 weight %), a corrosion hazard is considered to exist, and above 7000 ppm (0.7 %) the hazard is considered high. These values would correspond to about 1.7 g/l and 12.2 g/l soluble gypsum. Since the solubility of gypsum is only 2.6 g/l, it is clear that sulphates from gypsiferous soils, even when proper gypsic horizons are concerned, are only of minor importance as a cause of corrosion in concrete. Only when the more soluble Na- or Mg sulphates are present, as in coastal soils, can corrosion be serious

6.2 DEFORMATION IN HYDRAULIC STRUCTURES

If the ground on which the hydraulic structures are built consists of gypsiferous bedrock or gypsum-bearing alluvial or colluvial deposits the filtration of water through cracks in the canal lining or other irrigation structures, and the subsequent formation of cavities in the sub-grade, presents a serious problem. The suitability of gypsiferous rocks as a foundation for hydraulic structures depends largely on their lithology. Gypsiferous rocks may be stratified or solid, folded or unfolded, crystalline or amorphous, with or without intercalating layers of marl and fissures, weathered or unweathered. The rock may consist of gypsum or anhydrite. Fissured bedrock and bedrock with water-bearing layers are unsuitable as foundations because seepage water filtrates into the cracks in the rock. These cracks grow wider as the gypsum dissolves. As a consequence, the sub-grade is weakened and the hydraulic structures are undermined.

The use of gypsiferous deposits of alluvial or colluvial origin as foundations can constitute a real danger. Gypsum is often the cementing agent in such deposits, supplying the material with stability and cohesion. However, upon dissolution of even minute amounts of gypsum the sub-grade material loses its cohesion and stability, resulting in a collapse of the hydraulic structure. In the Ebro Valley much damage to hydraulic structures was encountered on loess deposits, containing only 3.5 % of gypsum. (Llamas Madurga, 1962).

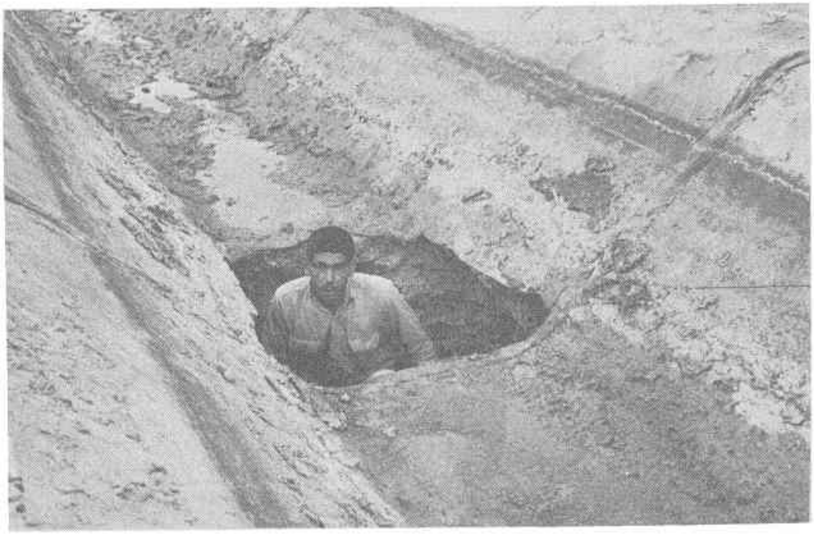
Breakdowns have occurred in several large irrigation canals in the Ebro Valley, e.g. in the Imperial, Aragon y Cataluña, Monegros and Violanda Canals, the capacities of which range from 15-90 cubic meter/sec. The Imperial Canal, one of the oldest canals in the valley, originally had a concrete-lined bottom and plastered side slopes. A section of the canal had to be abandoned due to frequent breakdowns, which naturally caused considerable problems to the farmers. Serious breakdowns in the Aragon y Cataluña Canal have been described by Herrero (1957) and in the Lodosa, Monegros, Violanda and Flumen Canals by Llamas Madurga (1962).

Undermining and breakdowns of irrigation works have also been observed in the USSR (Terletskaya, 1955). She proved in a laboratory experiment that cavities are formed in the subgrade by water seeping from irrigation canals and structures and that this process eventually causes the deformation of the canals and structures.

In general it can be said, that unsuitable for the foundation of hydraulic structures are not only gypsum rock and gypsic layers proper, but also any gypsiferous soils with more than 2 % of gypsum.

6.3 RECENT IMPROVEMENTS IN IRRIGATION STRUCTURES

In the Ebro Valley reinforced concrete was used in an attempt to improve the lining of canals and excellent results were obtained during the first 10-20 years of operation.



Breakdown of an irrigation canal in a gypsiferous soil.
Quatif Experimental Farm, Saudia-Arabia (Photograph by courtesy of ILACO, Arnhem, The Netherlands).

However, after this period serious breakdowns once more occurred. Better results were achieved by constructing the reinforced concrete canal linings on pillars forced deeply and strongly into the soil.

A more satisfactory solution recently introduced is to use a lining which is both flexible and impermeable. When the lining is flexible, any filtration and subsequent caving-in of the sub-grade are immediately noticed and repairs can be carried out as soon as they are needed and before the lining collapses. A flexible lining usually consists of an asphalt or plastic membrane covered by a layer of concrete slabs. When a filtration is noticed, immediate measures are taken to prevent a collapse of the canal lining, which would otherwise interrupt the transport of irrigation water. A metal tube with an internal diameter of 4.5 cm is inserted into the soil, parallel to the side slope of the canal. A mixture of clay, cement and water is injected into the soil under a low overpressure (less than one atmosphere) thereby plugging the filtration channel.

Irrigation canals of small dimensions were originally constructed – unlined – in the ground itself. This method, however, resulted in exceptionally high water losses, particularly in gypsiferous terrains. Seepage water percolating through the subsoil formed large subterranean cavities which emerged at terrace escarpments and local saggings occurred on the land surface. Where visible filtrations in the bottom of the smaller irrigation canals occur, a mixture of sand, clay and gravel is used to plug the filtration channel.

However, when the unlined irrigation canals are damaged too frequently a special technique is applied to repair the canal. The canal bottom is covered with concrete upon which concrete slabs of 50x50x6 cm are placed vertically along the canal sides and connected to the bottom with a light cementing agent. If breakdowns occur the concrete slabs can be disconnected and re-used. In more recent irrigation schemes in the area, use is made of elevated flumes, i.e. independently supported concrete canals of smaller dimensions, which are constructed overground. In the first overground constructions, the junction between two elements of the channel was placed upon the supporting pillars. Despite this special provision the pillar often subsided due to water filtrating through the junction and weakening the subsoil under the pillar. Nowadays, therefore, two canal elements are joined midway between two pillars.

ANNEX

SOIL PROFILE DESCRIPTION OF GYPSIFEROUS SOILS

Profile 1 (number refers to number in Table 1, p. 19)

Location:	Euphrates Basin, Syria, 50 meters west of Wadi Ogla, 800 meters north-west of Mata'b.
Author:	van Alphen.
Date of description:	April, 1966.
Topography:	Flat
Vegetation:	Fallow after cotton
0- 5 cm:	Sandy loam, light yellowish brown (10 YR 6/4)[1]) when dry, moderate fine platy, to:
5-22 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, moderate coarse prismatic breaking to moderate medium sub-angular blocky, slightly hard, many roots, clear and wavy boundary, to:
22-36 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, spongey structure, small pores (0.1-0.7 mm in diameter) in all directions, very friable, lime mycelium, few pockets of gypsum powder, many roots, clear and wavy boundary, to:
36-62 cm:	Fine sandy loam, light yellowish brown (10 YR 6/4) when dry, spongey structure, small pores (0.1-0.7 mm in diameter) in all directions, very friable, lime mycelium, pockets of gypsum powder, many roots, diffuse and wavy boundary, to:
62-90 cm:	Sandy loam, yellowish brown (10 YR 5/4) when slightly moist, spongey structure, very friable, some lime mycelium, pockets of gypsum powder, few large roots, clear and wavy boundary, to:
90-110 cm:	Sandy loam, yellowish brown (10 YR 5/4) when slightly moist, spongey structure, very friable, some lime mycelium, pockets of gypsum powder and gypsum mycelium, few pockets of reddish clay (Miocene red clay), diffuse wavy boundary, to:
+ 110 cm:	Sandy loam (10 YR 5/3) when moist, spongey structure, friable, pockets of gypsum powder and gypsum mycelium.

1) Colour notations according to Munsell's Soil Color Charts.

By augerhole	
130 cm:	Silt loam, pale brown (10 YR 6/3) when moist, gypsum crystals, few iron mottles.
170 cm:	Silt loam, pale brown (10 YR 6/3) when moist, decreasing amount of gypsum crystals.
180 cm:	Very fine loamy sand, few faint iron mottles.
220 cm:	Sand, light olive brown (2.5 Y 5/4) when moist.

Note: In the field, no high gypsum content could be discerned. However, laboratory analyses revealed:

5- 15 cm	trace
25- 35 cm	1.5 %
45- 55 cm	41.5 %
70- 80 cm	29.0 %
95-105 cm	43.5 %
115-120 cm	41.0 %
150-160 cm	19.0 %
180-200 cm	2.0 %
220-240 cm	1.3 %

Profile 2 (ref. Table 1, p. 19)

Location:	Euphrates Basin, Syria, 1 km east of Wadi Ogla, 1.5 km north east of Mata'b.
Author:	van Alphen.
Date of description:	April, 1966.
Topography:	Nearly flat.
Vegetation:	Fallow

0- 8 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, 0-1 cm strong medium platy, 1-8 cm moderate medium sub-angular blocky, slightly hard, some gravel, many small roots, clear and wavy boundary, to:
8-37 cm:	Loamy sand, light yellowish brown (10 YR 6/4) when dry, weak coarse prismatic breaking to weak-medium to fine sub-angular blocky, very friable, many pores (0.1-0.5 mm in diameter), small lime mottles, few small roots, some gravel, abrupt and wavy boundary, to:
37-82 cm:	Gypsum powder, very pale brown (10 YR 7.5/3) when dry, structureless and massive, very hard when dry, friable when moist, no roots, few pores (0.1-0.5 mm in diameter), below 68 cm re-crystallisation of gypsum, clear and wavy boundary, to:

82-98 cm:	Sandy loam, brown (10 YR 5.5/3) when dry, structureless, some gravel, pockets of gypsum and gypsum mycelium, clear and wavy boundary, to:
+ 98 cm:	Gravelly loamy sand, yellowish brown (10 YR 5/4) when dry, structureless, few pockets of gypsum.

Laboratory analyses

Depth	Gypsum content
2- 5 cm	–
20- 30 cm	0.1
45- 55 cm	52
85- 95 cm	23
105-115 cm	7

SUMMARY

Gypsum is a component common in soils of arid and semi-arid areas. Its presence in small percentages, up to 2 % or so, is favourable for plant growth. Higher percentages, up to about 25 %, have little or no adverse effect on crops, provided the gypsum is present in powdery form.
At still higher values the yield of most crops decreases substantially, due at least in part to imbalanced ion ratios.
Often, however, the gypsum occurs concentrated in more or less cemented and indurated layers. At gypsum percentages of anywhere between 14 and 80 %, such layers form a mechanical impediment to root growth, and the water-holding and water-transmitting properties are adverse.

When gypsiferous soils are used for irrigated agriculture, water should be applied with the utmost care. Gypsum may dissolve in the excess water percolating beyond the rootzone through the gypsum-rich subsoil, and this often results in surface subsidence. The subsidence pattern will be very irregular, which makes it necessary to re-level the land yearly. The construction of hydraulic structures in gypsiferous soils and rocks poses severe problems to civil engineers. Water seeping through cracks in the structure gradually dissolves gypsum in the subgrade. Hence, this subgrade is weakened, leading to final collapse of the hydraulic structure. A flexible lining should be used when constructing canals of larger dimensions. Under these conditions, curative measures can be taken as soon as the canal lining subsides. Canals of smaller dimensions should preferably be constructed overground.

RESUMEN

El yeso es un componente común de los suelos de áreas áridas y semi-áridas. Su presencia en pequeños porcentajes, hasta 2 % o algo similar es favorable para el crecimiento de las plantas. Cuando el yeso se encuentra en forma de polvo a mayores porcentajes, hasta 25 % aproximadamente, tiene poco o ningún efecto adverso sobre los cultivos. Pero a más altos contenidos de yeso, las cosechas de muchos cultivos decrecen substancialmente, entre otros debido al desbalance de la relación de iones. Sin embargo frecuentemente, el yeso se encuentra concentrado en capas endurecidas y más o menos cementadas. En cualquier punto entre 14 y 80 % de yeso tales capas dan lugar a impedimentos mecánicos para el crecimiento de la raíz, incluso para el almacenamiento del agua y propiedades adversas de trasmisibilidad.
Cuando se utilizan para la agricultura bajo riego suelos con altos contenidos de yeso el agua debe ser aplicada con mucho cuidado. El yeso podría ser disuelto por el exceso de agua que percola más alla de la zona de raíces, a través de sub-suelo rico en este elemento, que frecuentemente da lugar a subsidencias en la superficie. El patrón de subsidencia va a ser muy irregular y sería necesario nivelar anualmente los campos.
La construcción de las estructuras hidráulicas en suelos y rocas con mucho yeso causa grandes problemas a los Ingenieros Civiles, el agua que filtra a través de las rajaduras de las estructuras gradualmente disuelve el yeso de la zapata debilitándola, lo que da lugar al colapso final de la estructura hidráulica.
Cuando se construyen canales de gran dimensión debe ser usado revestimientos flexibles de tal manera que tan pronto el revestimiento del canal sufre una subsidencia, se pueden tomar medidas de corrección. Canales de pequeña dimensión deben ser construídos preferiblemente sobre el terreno mismo.

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