sawa

werkgroep
waterbeheer

stichting werkgroep waterbeheer, sawa, adviesgroep voor waterbeheer en gezondheidstechniek
consultancy group for sanitation and water management - groupe de conseil de gestion des eaux et de l'assainissement - colectivo de engenheiros no domínio de agua e de saneamento

telephone: (0)30-331328
telex : 70890 snm nl
bank : ABN - Utrecht
549.830.324

DONKERSTRAAT 17
3511 KB UTRECHT
THE NETHERLANDS

CONCRETE COROSION IN DUG WELLS

Simon Dermijn
Michiel van de Drift

Concrete corrosion in dug wells.

Summary

In West-Africa in Guinea-Bissau, dug wells are constructed in the frame-work of a number of rural water supply projects, for the greater part shallow, hand-dug wells. The wells are lined by prefabricated concrete rings or by casing, cast in the well.

On the aquifer, concrete is used without sand as an aggregate. This porous ("no-fine") concrete obtained in this way, improves the inflow of groud water to the well. For some time, concrete corrosion has appeared affecting the porous concrete filter rings. The cause of this corrosion turns out to be ground water with a calcium concentration too low or too acid, in combination with the velocity of water by porous concrete.

Introduction

This article deals with the corrosion of porous concrete filter rings used in the construction of dug wells. The filter rings serve to improve the inflow of ground water into the wells.
In a number of wells in Guinea-Bissau, these porous rings appear to have been affected by agressive ground water for some time.
The purpose of this article is in the first place to inform people involved in rural drinking-water projects on this form of concrete corrosion and secondly, to invite readers to react on this matter, especially those readers with similar experience who found solutions and alternatives. The text roughly deals with the phenomenon of concrete corrosion, it will not dwell upon the chemical aspects of this problem.

Construction methods (See figure)

The construction method widely used is the method with the lining of prefabricated concrete rings.
The rings are made in a central workshop or in the villages. Two metal moulds, an inner and an outer one, are used. The cement mortar is poured in between. The well-rings have an internal diameter of 85 cm, a height of 100 cm and a wall thickness of 7 cm.
The well-rings are dug in or lowered into the well by means of a tripod. The rings are slightly reinforced.

Another construction method is the method of casing, i.e. the lining with the supporting material in the well. Meter by meter down to the water level, the wall of the well is lined by pouring cement mortar between an inside mould and the wall of the well.
The internal diameter of the well is approximately 140 cm and the

wall thickness 10 cm. From the ground water level, prefabricated concrete rings are also here applied, lowered by a tripod within the existing lining. The reinforcement of this lining is slightly heavier than the reinforcement of the previous method. These rings have an internal diameter of 100 cm and an outside diameter of 120 cm.

In both methods so-called filter rings are placed on the aquifers. They must be constructed of porous (no-fine) concrete, i.e. concrete without sand as an aggregate. The remaining rings and the upper- and under-rim of the filter ring consist of concrete of Portland cement with aggregates sand and gravel. This gravel is iron-containing stone, it is called laterite.

Where gravel is not available, shales are used.

Because there is a lack of sand as an aggregate, a strongly porous concrete will be formed, the ground water can pass while the soil is prevented from passing through.

Cement and laterite are mixed to the proportions on 1:4.

Concrete corrosion

For some time, the concrete filter rings of a great number of wells have shown damage.

This compromises:
- the stone chippings fall out of the filter rings;
- gradually, the filter rings show holes;
- the filter rings will break.

This is not found in the case of solid concrete rings. It seems to be a process of corrosion as the heaviest damage, the broken filter rings, was found in the oldest wells (about 3 years old) and the lightest degree of damage, stone chippings fall out of concrete, was met in the latest wells.

There seemed to be a causal connection between the damage and the use of the wells. In some wells bucket and rope are used, whereas in other wells the hand or foot-pump is used. In this case mechanical decline occurs by the bucket hitting the wall of the well.

Subsequent consequences:
- sand from the sandy aquifers passes into the well;
- as a result, the well looses its function as a reservoir;
- by gradual collapse, the well cannot be used any more.

Assumed causes

At first, as the possible causes were supposed to be:
- wrong proportions of mixture of cement and laterite;
- acid and/or salt ground water;
- quality of laterite;
- ground pressure on the well ring is too much;
- aggregates expand by absorbing water and shrink when drying,

this will cause destruction;

- alkali- aggregate reaction, i.e. the aggregates react with alkali from the cement stone by expansion, which leads to destruction;
- the human factor;
- the type of cement;
- leaching of the cement stone by the passing water, the calcium is seperated and lost;
- the cement stone can dissolve in water if this is suffiently acid.

Real causes

Laboratory tests showed that the two last-mentioned causes must be the real causes. All remaining possibilities of concrete corrosion proved to be wrong. In conclusion we can say that decay of concrete, concrete corrosion, is mainly caused by: "percolating ground water with a low calcium concentration on the one hand, on the other hand by acid ground water, combined with the porousness of the concrete surface, in this case the accessibility of the cement stone". Moreover, replacement of the applied Portland cement by Blast Furnace cement could delay the corrosion process, but never avoid it.

Cement, concrete

Cement is a so-called hydraulic binding agent for gravel and sand in concrete. Hydraulic means that the concrete is hardened with water so that a stony composition is formed which is water resistent, the cement stone.
Cement is mainly composed of calcium silicates and calcium aluminates.
Portland cement is completely built up on the basis of Portland cement clinker.
In Blast Furnace cement 35-80% of the Portland cement clinker is substituted by furnace slacks.

Portland cement consists of calcium silicates (as essential constituents) for the greater part.
The calcium compounds are the main calcium-source, notably calcium carbonate (e.g. limestone, chalk or calcium mixtures).

The most important cause of the attack of concrete is the affection of the cement stone. Sand and gravel are virtually immune of chemicals.

Druring the hardening of cement as one of the phases of concrete preparation, after adding water, $Ca(OH)_2$ is formed during the hydration-process of C_2S and C_3S ($2CaOSiO_2$ and $3CaOSiO_2$) resp. dicalcium silicate and tricalciumsilicate.

$CA(OH)_2$, calcium hydroxide, causes a strongly basic environment in the concrete. (pH= 12,5). $Ca(OH)_2$ is "free calcium hydroxide".

Concrete corrosion manifest itself in a reaction of acids and salts with active calcium hydroxide.

Soft water (low calcium concentration)

The hardness of water is determined by the conncentration of calcium (Ca) and magnesium (Mg) ions from their respective compounds.
Actually, the degree of hardness of water indicates the capacity to dissolve calcium (from the cement stone). Soft water can dissolve calcium from cement stone and is therefore aggresive.

The calcium and magnesium hydrocarbonates, $Ca(HCO_3)_2$ and $Mg (HCO_3)_2$, give water the commonly named: carbonate hardness or transient hardness, i.e. total hardness. The hardness of water is be expressed in degrees of German Hardness, dH.
1° dH = 1 part by weight CaO in 100.000 parts by weight of water.
Acoording to carbonate hardness, the hardness of water can be roughly divided into the following classes:

very soft	0 - 4° dH
soft	4 - 8° dH
medium hard	8 - 12° dH

This classification can be extended by the degree of aggressiveness, i.e. the capacity to dissolve calcium. Soft and very soft water is rather aggresive (5° dH). However, there are factors adding up to the aggressiveness of water. In case of percolating water, it can be raised by one class.
In the case of porous concrete, the agressiveness increases strongly but the classification does not apply any more since this was drawn up for non-porous concrete. The corrosion of concrete, the cement stone, by soft, aggresive water is called: leaching.

Acid water

The acidity of ground water is mostly caused by dissolved CO_2 (a decomposition product formed by decomposition of organic matter in the soil). If a liquid has the temperature of 22° C, the degree of acidity - pH value - will show:

- a neutral reaction, if $pH = 7,00$
- an accid reaction, if $pH < 7,00$
- a basic reaction, if $pH > 7,00$

Ground water is considered to be:

- mildly aggresive, if pH is between 5,5 and 6,5
- strongly aggresive, if pH is between 4,5 and 5,5
- very stongly aggresive, if pH is under 4,5

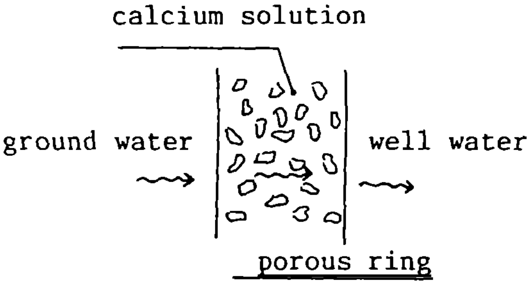
The corrosion process on account of soft water

From studies it appears that in situations with soft water passing through the concrete, porous, ring, a continous process of leaching and washing out takes place. This also turns out to

be the determining factor for concrete corrosion. The applied type of cement is of minor importance compared to this combination of soft and running ground water and a porous concrete surface.

The corrosion process goes through the following phases:
- From a piece of cement stone (in the porous ring) free calcium hydroxide, $Ca(OH)_2$, is dissolved
- then, also the calcium silicate hydrates dissolve since they lose their stability without a certain amount of free calcium, $Ca(OH)_2$. In fact they deliver calcium for the sake of the equilibrium.
- By this the compound is completely lost.

There is an almost continous flow of water through the concrete filter rings. Owing to this, the concentration of calcium in the water on the conncrete surface cannot become higher (by calcium building up) so that an equilibrium could develop. The dissolved calcium is however washed away and the calcium concentration remains low so that the leaching process goes on. In practice, the above process has been shown by comparing the calcium concentration of the inflowing ground water with the calcium concentration in the well. In all cases, the amount of calcium found in the well appears to be higher than found in inflowing water.



If there are chemical influences together with mechanical ones, the degree of attack may be higher . In the case of wells, this does occur. Field surveys lead to think that concrete corrosion is more serious when steel buckets are used in the wells (mechanical damage). This compared with other means to draw water. Apparently, the concrete wall is also damaged by the bucket hitting the wall of the well by which the corrosion process takes place faster.

Since the corrosion process is also dependent on the waterflow through the concrete, the amount of water passing through the conrete ruig, i.e. the total amount of water use per well, will strongly determine the degree of concrete corrosion and the probable life of the well.
Moreover, the nature of the surface the water has to follow, is also important: through how many porous rings does the total amount of required drinking water percolate?

Directive

A provisional directive advises against the use of porous ring when:

- the degree of hardness of the ground water is equal or less than 5° dH.
- the degree of acidity, pH, of the ground water is equal or less than 5.5.

Field survey

Recently, in Guinea Bissau, a study was completed which has to show the extent of concrete corrosion in several well-projects. In addition to this, the individual projects have finished their own studies. At this moment, the results are compared and analysed. The survey comprises both a visual part, the nature and the degree of damage are assessed, and a chemical test for which samples are taken from both the water in the well and the ground water outside the well.
The water is tested on hardness, pH, and EC (electrical conductivity). The samples from ground water outside the wells are obtained from exploratory boreholes around the well, water-gauges or, if this is impossible, from traditional wells in the direct vicinity. Care should be taken that the water samples are taken from the same aquifer.
There are several methods for testing, such as portable water testers and strips.
So far, the test results of the different methods cannot always be compared with each other. This must be paid attention to when drawing conclusions.
The results of the field survey will be the starting point for a more comprehensive study, carried out by e.g. TNO.

Alternatives, solutions

As an alternative for the porous well-ring, the perforated ring has already been applied. This ring has been perforated in a slanting way, by means of slanting holes of a diameter of 6-8 mm (see fig.). When a normal ring is poured, reinformced concrete rods are placed in the metal mould, through the holes. After some time, they are pulled out so that a ring with little holes is left.
This method seems to be less vulnerable to concrete corrosion than the porous rings, it is still being looked into.
Another alternative is the placing of artificial substances or metal filter parts in the rings to be cast on the aquifer.

A somewhat comparable alternative is the placing of filter stones in the concrete ring.
Instead of concrete rings, an altogether different construction would be a linking of concrete bricks, piled up, with the ground water infiltrating the chinks between the bricks.

At this moment, possibilities to repair already corroded wells are considered.
New concrete inner rings seem to be most appropriate. They must have a smaller diameter than the rings present.
Another possibility as alternative is the closing of the porous rings by concrete mixture or by an artificial substance.
For finding both a repair method and an alternative for the porous ring, the starting point must be in principle the concrete rings.

Documentation

1. Concrete corrosion concrete protection, by Imre Biczok.

2. The chemistry of cement and concrete, by F.M. Lea.

3. Betonniek nr. 5/13.

4. Publications CUR-VB nr. 86-4, 84-1, 96.

5. Design and control of concrete mixtures.

6. Constructions de puits en Afrique Tropicale - Burgeap.
7. TNO-report: Schade aan putfilterringen, 1985.

8. Project documentation.

Simon Dermijn
SAWA-consultant

Michiel v.d. Drift
CIPAC coordinator
Well-project Guinea Bissau

Postal address:

SAWA
Donkerstraat 17
3511 KB Utrecht
The Netherlands

For editor / Lay out: to place these parts in separate border.
i.e. 'Request' and 'Hardness of water'.

Request

This article aims at more information from all persons involved in well-projects in order to explain and solve the problems described above. Of special importance is similar experience in concrete corrosion and the solutions found.

Hardness of water

There are different expressions and units to indicate the hardness of water.
Below follows an explanation.

1 °dH	= 1.25 °eH	= 1.79 °fH	= 17.9 mg/l CaCo = Dtotal
German degree of hardness	English degree of hardness	French degree of hardness	

1 °dH = 10 mg/l CaO = 1 mg CaO/100ml

100 mg/l $CaCo_3$ = 40 mg/l Ca^{++} = 24.3 mg/l Mg^{++}
17.9 mg/l CaCo = 7.16 mg/l Ca^{++} = 4.35 mg/l Mg^{++}

Hardness

Mg/l CaO	°dH	
0-50	<5	soft (rather agressive)
50-100	5-10	rather soft
100-150	10-15	slightly soft
150-200	15-20	rather hard
200-300	20-30	hard
>300	>30	very hard

1 °dH = 10 mg/l CaO = 1 mg CaO/100ml

100 mg/l $CaCo_3$ = 40 mg/l Ca^{++} = 24.3 mg/l Mg^{++}
17.9 mg/l CaCo = 7.16 mg/l Ca^{++} = 4.35 mg/l Mg^{++}

Hardness

Mg/1 CaO	dH	
0–50	² 5	soft (rather agressive)
50-100	5-10	rather soft
100-150	10-15	slightly soft
150-200	15-20	rather hard
200-300	20-30	hard
³ 300	³ 30	very hard

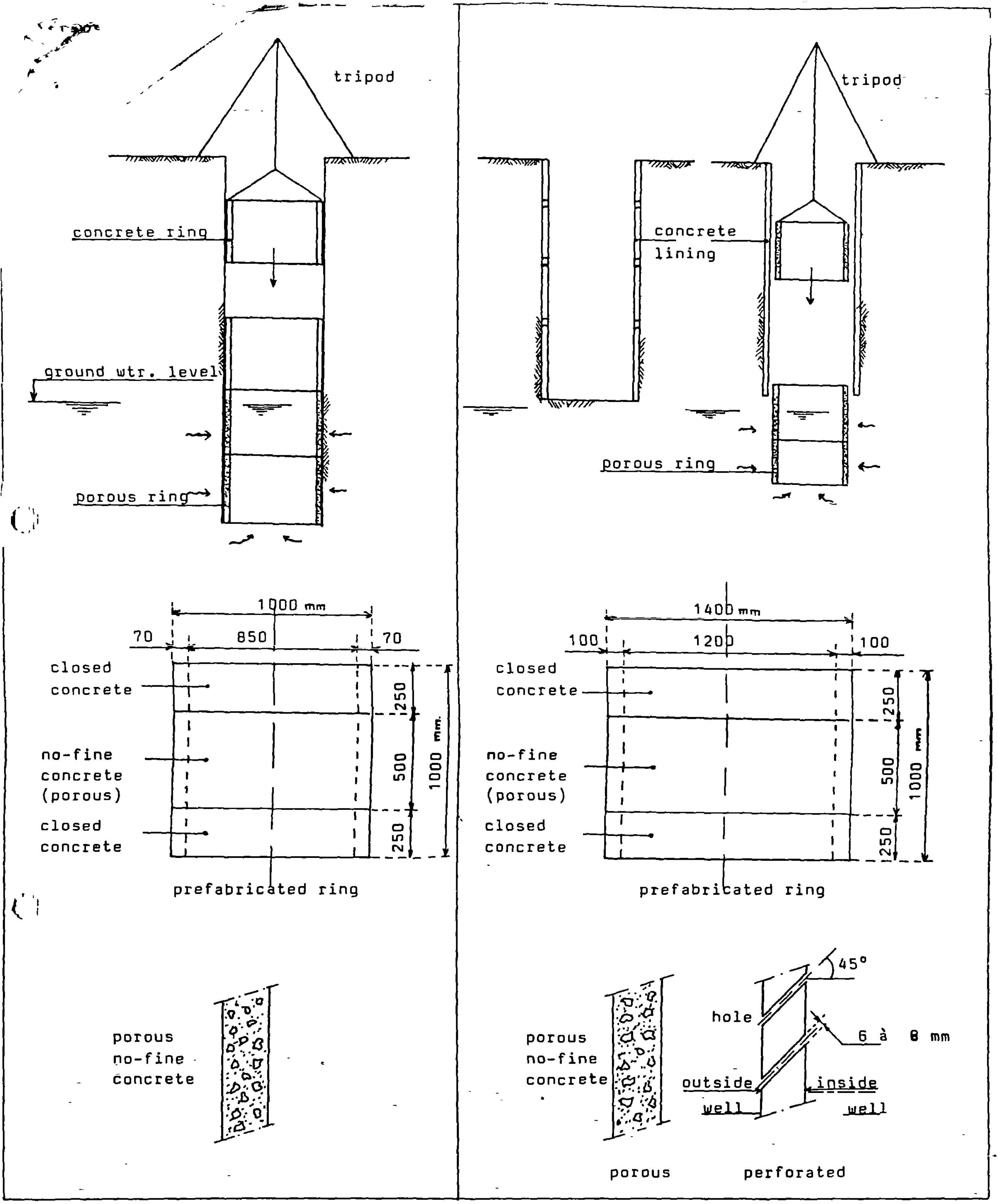


Fig. Well digging methods