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Dewatering at the Port of Ngqura: A case study

Le rabattement pour le port de Ngqura: Une étude de cas

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ABSTRACT
Southern Africa's first Industrial Development Zone is taking shape near the city of Port Elizabeth. The Coega IDZ is a purpose-built industrial estate for local and international industrial developers. The new international deepwater port of Ngqura forms a vital component of the Coega IDZ. Its three mass concrete quay walls were constructed in a dewatered excavation on the beach next to the Coega River mouth.

This paper presents the design, installation and performance of the dewatering installation with specific focus on implementation of the observational method. A major challenge for the dewatering design was the timely draw down of resident water levels in two distinct aquifers ahead of the earthworks operations - the first quay had to be operational within 88 weeks. This was achieved through a combination of a cut-off against the sea, perimeter deep wells and surface pumping. Problem areas were dealt with by well pointing to stabilise excavation sidewalls and to locally control elevated seepage.

RÉSUMÉ
La première zone d'aménagement industriel d'Afrique du Sud prend forme près de la ville de Port Elizabeth. La Zone d'Aménagement Industriel Coega est un terrain spécialement destiné pour des aménageurs industriels locaux ou internationaux. Le nouveau port international en eau profonde de Ngqura est une composante vitale du projet Coega. Ses trois murs de quai poids furent construits dans une fouille asséchée par rabattement le long d'une plage proche de l'embouchure du fleuve Coega.

Cette communication présente le projet, l'installation et le fonctionnement de l'installation de rabattement en insistant sur la mise en oeuvre de la méthode observationnelle. Le défi principal du projet d'épuisement provenait du fait qu'il fallait rabattre deux nappes différentes dans les temps compatibles avec les travaux de terrassement, le premier quai devant être disponible dans les 88 semaines. L'association d'un écran étanche du côté de la mer avec des puits profonds en périmètre et un pompage de surface ont permis le succès de l'opération. Les zones délicates ont été traitées à l'aide de pointes filtrantes dans le but de stabiliser les parois de la fouille et de contrôler les infiltrations importantes.

1 INTRODUCTION

In August 2002, the South African National Ports Authority awarded the contract for the construction of the Coega harbour to a joint venture between an international company and two local companies. The contract incorporated the design of all temporary works, including dewatering.

To construct the quay walls *in the dry*, the site had to be dewatered to approximately 20m below sea level. In 1997/1998, the Ports Authority commissioned a geohydrological investigation which included five borehole pump tests. The abstraction scheme proposed in the tender documents consisted of shallow and deep wells arranged in a grid over the excavation footprint. The tender documents, in addition, made provision for a partial cut-off comprising a sheet-pile wall on the seaward side of the excavation to control recharge from the sea.

The contract award design, described in this paper, provided approximately the same installed pumping capacity, but concentrated on minimising disruption to the earthworks operations.

The project was ideally suited to implementation of the Observational Method (Peck, 1969). The *base design* was derived from the most likely conditions expected on site using available hydro-geological information. As a contingency, critical dewatering components were procured and stored on site in readiness to deal with unexpected conditions. The base design was modified during the execution of the works according to monitoring results and programme requirements.

2 SITE DESCRIPTION

2.1 *Location and infrastructure*

The port of Ngqura is located on the Coega River mouth approximately 20 kilometres north-east of the city of Port Elizabeth, South Africa.

The first phase of the development consists of three mass concrete quay walls, catering for container (780m), dry bulk (640m) and liquid bulk (440m) shipping. The draught of the first phase is 16m.

The bulk excavations for the three quay wall slots were formed first, followed by excavation of the main or inner basin (between the container and dry bulk quays) and the outer basin (liquid bulk quay). The quay wall excavations and the inner basin were excavated to an average depth of 20m below sea level by land based earthworks equipment, being more cost effective than dredging. The outer basin and approach channel were dredged.

2.2 *Geology*

The Coega area is underlain by sedimentary rocks of the Palaeozoic Table Mountain Group (Peninsula Formation) and the Jurassic/Cretaceous Uitenhage Group (Kirkwood and Sundays River Formations). Locally, these strata are overlain by recent sediments of the Algoa Group (Alexandria and Salnova Formations) of Tertiary/Quaternary age.

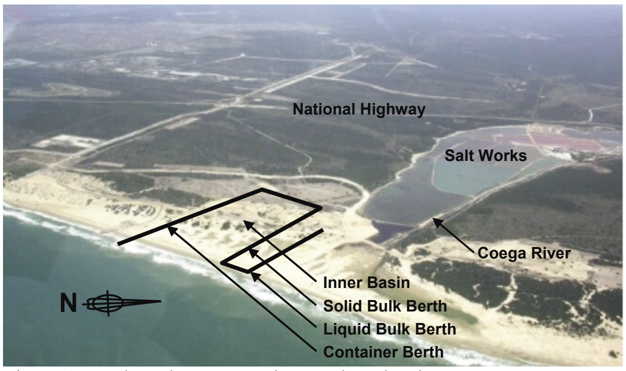

Figure 1: Harbour layout superimposed on the site.

The Kirkwood Formation, that forms the foundation bedrock for the quay walls, comprises mainly reddish-brown mudstone with inter-layered sandstone and siltstone. The rockhead dips from 8m to 24m below sea level towards the sea and the Coega River channel.

The overburden that overlies bedrock comprises calcareous sandstone (calcarenite), shelly arenite (coquinite) and limestone conglomerate of the Alexandria Formation with gravel and sand terraces of the Salnova Formation. The palaeo channel of the Coega River estuary has been progressively choked by sediments consisting of middle to late Pleistocene fluvial gravel (rounded to sub-rounded quartzite cobbles), overlain by younger estuarine sediments with recent beach sediments at surface. The thickness of the basal fluvial gravel layer varies from 0m (furthest away from the sea) to 7m (closest to the sea) with an average thickness of 3m.

3 DESIGN AND MODELLING

The dewatering design comprised (a) a review of available geotechnical and geo-hydrological data from earlier investigations, (b) planning, implementation and analysis of a trial dewatering installation on site, (c) setting-up and calibrating a three-dimensional numerical ground water flow model, (d) assessing the *most likely* dewatering requirements for the base design using combinations of deep wells, vacuum well points, open sumps and cut-off walls and (e) monitoring of the installation and calibration of the dewatering model to allow timely implementation of alternative or additional dewatering measures if required due to unexpected geo-hydrological conditions or programme requirements.

3.1 *Geo-hydrological units*

Information available at tender stage identified four major geo-hydrological units:

(a) *Upper unconfined sandy aquifer*: Alluvial, estuarine and beach sediments (0m to 22m thick) consisting of sand with isolated lenses of silt, clayey sand and sandy clay.

(b) *Semi-confined cobble aquifer*: Fluvial rounded and sub-rounded cobbles with a sandy, silty or clayey matrix.

(c) *Kirkwood aquaclude*: Mudstone, siltstone and sandstone of extremely low hydraulic conductivity and storativity.

(d) *TMG artesian aquifer*: Quartzitic sandstone of the Table Mountain Group, a known source of drinking water. Was not considered in the design due to sufficient cover of the Kirkwood Formation.

For the dewatering design, the basic geology was simplified to a two aquifer system comprising the surface sands and a basal gravel lag. The two aquifers are generally separated by a clayey sand horizon of relative low permeability.

3.2 *Design*

The temporary works contract was run on a very tight schedule and any delays in the dewatering installation could have delayed the 88 week start-to-finish period for the completion of the liquid bulk quay wall.

The base design (Figure 2), on which the contract was awarded in August 2002, comprised a full depth (to bedrock) bentonite-cement slurry cut-off wall on the seaward side of the excavation with deep dewatering wells on the remaining perimeter. Although the total capacity of the dewatering system was similar to the 380l/s of the tender design, the base design differed from the tender design in three respects. Firstly, a full depth seepage barrier (cutting off both the sand and cobble aquifers) was installed on the seaward side as opposed to sheet piles through the sand only. Secondly, all the deep wells were positioned outside of the excavation areas as opposed to a grid pattern over the site. Finally, all the deep wells were screened to draw water from both the sand and gravel aquifers simultaneously.

The base design made provision for confirming the validity of the tender information by trial installations and for installing additional deep wells, well points and/or cut-off measures if required.

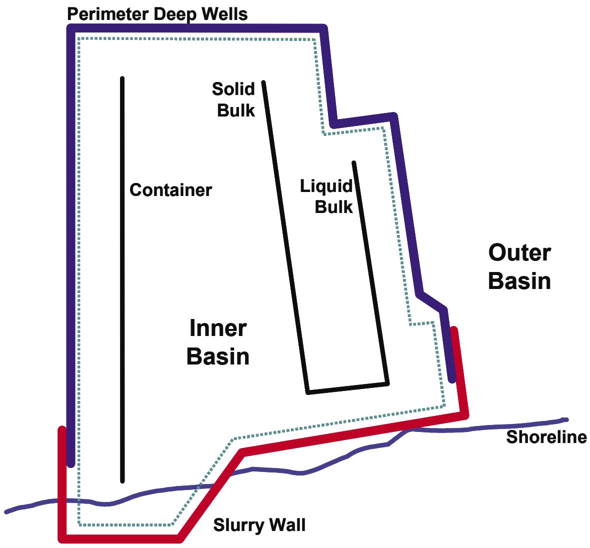

Figure 2: Base design dewatering measures.

3.3 *Trial installation*

As soon as access could be created on site, two sections of the perimeter well curtain were installed to serve as trial installations. The objectives of these trial installations were:

(a) To confirm the aquifer parameters and to develop a numerical 3D seepage model for the site.

(b) To gain additional information on the western side of the site where limited geo-hydrological information was available from previous investigations.

(c) To gather long-term pumping data against which the numerical model could be calibrated.

(d) To investigate the effectiveness of various drilling techniques and well designs (hole diameter, screen type, gravel pack, etc.).

The trial installations, which took place from October 2002 to December 2002, included eleven wells, seven next to the liquid bulk on the north-eastern side and four next to the container quay on the south-western side. Four piezometer pairs, each consisting of a deep piezometer screened for the high yielding cobble aquifer and a shallow piezometer screened for the overlying sand aquifer, were initially installed at distances of 5m and 10m from abstraction wells. Additional piezometers were later drilled for long term monitoring at distances of 23m, 42m and 60m from the abstraction wells.

Various well construction options were evaluated during the trial installations, i.e. 10" vs. 12¼" borehole diameters, uPVC well casings of 150mm, 169mm and 203mm inside diameters, 0.5mm vs. 5mm slot sizes with 0.5-2mm graded silica sand or 6-13mm stone chip gravel packs respectively and use of wedge wire screens in the cobble aquifer.

Pumping tests were performed on the trial wells, including yield calibration tests, stepped draw down tests, two long term (96-hour) pumping tests and two slug tests in the sand aquifer.

3.4 *Geo-hydrological modelling*

The pump test data from the trial installations were used to derive initial estimates of the two most important aquifer parameters: permeability and storativity. The estimates were refined as longer term pumping data became available, refer Table 1.

Table 1: Aquifer parameters.

	Sand Aquifer	Cobble Aquifer	
		Liquid Bulk	Container
Permeability *m/day*	1.7 - 2.2	60 - 100	20 - 40
Storativity %	10 to 15	0.5	0.5

The geo-hydrological characteristics described above were used to develop a numerical flow model. This model was then used explicitly to verify and adapt the base dewatering scheme and was periodically calibrated against monitoring results. The boundary conditions assumed in the model are summarised in Table 2.

Table 2: Geo-hydrological boundary conditions.

Boundary	Boundary Condition
South-east: Shoreline	Constant head from the sea
South-west: Container terminal	No flow at distance
North-west: Harbour back	Cauchy
North-east: Coega River & Salt Works	Cauchy

The following additional sources and sinks were identified:

(a) Rainfall recharge: estimated at 110 mm/a (18% MAP).

(b) Coega river estuary and mouth.

(c) Water storage in the salt works.

The storativity of the sand aquifer was found to be an order of magnitude higher than given at tender stage. This had a significant impact on the volume of water to be abstracted and controlled by the dewatering system.

4 IMPLEMENTATION

The data from the trial installations and the resulting seepage model were used to refine the well designs and to optimise the layout of the well fields with emphasis on drawing down the water table in advance of the earthworks programme.

The implemented scheme consisted of the following dewatering components:

(a) 43 perimeter deep wells spaced at 50m and screened for both the sand and cobble aquifers. Operational by end of December 2002.

(b) 28 internal deep wells positioned in two lines parallel but outside of the quay wall excavation slots, refer Figure 3. Operational by end of January 2003. These were added to the

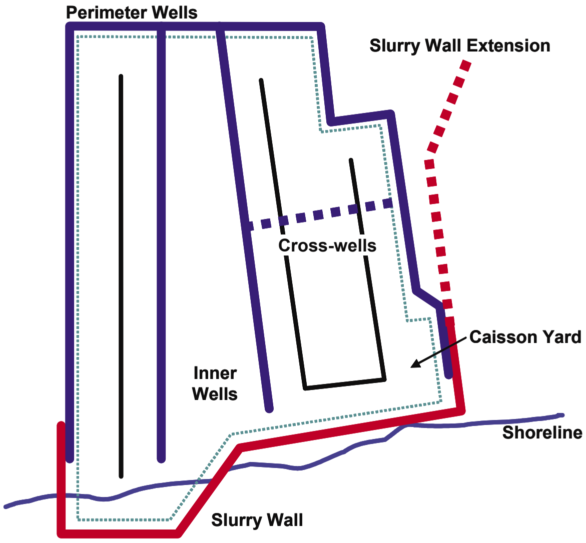

Figure 3: Installed dewatering works.

base design to deal with the increased storativity of the sand aquifer as determined during the trial installations.

(c) About 12 surface pumps draining internal trenches and open sumps.

(d) 1,2km of bentonite-cement slurry cut-off wall (0.6m thick and 20m deep on average) between the excavation and the sea. The cut-off was returned 200m inland on both sides and was completed by end of March 2003. The slurry wall was protected from the surf and storm waves by a rockfill bund wall.

The perimeter wells acted as a curtain barrier to ground water recharging into the excavation from all boundaries other than the sea and produced the drawdown required for stability of the adjacent excavation side walls. Most of the dewatering occurred through the cobble aquifer with its high permeability, which also acted as an under-drain to the sand aquifer.

For programme reasons, the excavation of the slots required for the construction of the quay wall foundations, preceded the bulk excavation of the inner basin, These excavations commenced at the landward end of the site and were carried out simultaneously with the installation of the slurry cut-off along the seaward face. Two rows of internal wells were installed on the inner edges of these slots to ensure stability of the sideslopes and to empty the main excavation area of resident water.

The hydrological model showed that wells alone could not dewater the site in time. Allowance was therefore made for pumping from surface sumps and trenches excavated below the general level of the excavation floor. This pumping assisted in creating the hydraulic gradients necessary to accelerate the abstraction of water from the sand aquifer.

Based on the experiences with the trial wells, the production well design was standardised as follows:

(a) *Borehole*: 12¼" diameter drilled by the mud-rotary method using a synthetic (*Polyflip*) bio-degradable drilling mud. All wells were drilled to at least 4m into the Kirkwood mudstone to create a sump.

(b) *Casing*: Each well was equipped with a 203mm ID, 2.8m long solid sump, followed by 169mm ID 0.75mm slotted casing. In general a 1-2mm graded silica sand gravel pack was installed in the annular space between the well casing and the hole.

(c) *Development*: Wells were cleaned and developed by air lift and then calibrated by stepped draw down tests to measure the particular yield of the well.

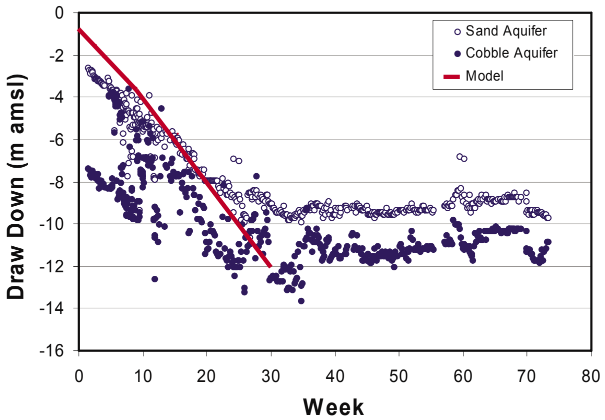

Figure 4: Predicted vs. measured draw down.

(d) *Pump*: Based on their yields, wells were equipped with submersible pumps of 2l/s, 6l/s and 15l/s capacity and pumped on a continuous basis.

4.1 *Monitoring and performance*

One of the most important aspects of design by the Observational Method is monitoring to assess the performance of the base design and adapting the design accordingly.

Ninety monitoring piezometers were installed to measure the draw down of the water table in and around the well fields and excavation areas. Figure 4 shows the close relationship between the predicted draw down of the calibrated flow model and the actual draw down levels as measured around the bulk quays area.

5 OBSERVATIONAL METHOD

The following points serve to illustrate the flexibility and value of the Observational Method as a design philosophy when applied to a suitable project.

5.1 *Bulk Quays Excavation*

The critical path on the temporary works programme focused on the completion of the liquid bulk quay.

Soon after the earthworks started, it was noted that the northern end of the bulk quays was not dewatering fast enough and could potentially delay the earthworks. At that stage, early January 2003, the slurry wall had not yet progressed far enough east to cut-off recharge from the sea to the bulk quays area. It was decided to install a line of ten closely spaced (25m) cross-wells to effectively box-in the critical area of excavation, refer Figure 3.

These were completed by end of January 2003 and were able to accelerate the dewatering and control recharge to allow the excavation to proceed on schedule.

5.2 *Liquefaction slump*

On the 22nd of June and again on the 3rd of July 2003 there were sudden releases of large volumes of water and sand (mudrushes) into the caisson casting yard at the southern end of the liquid bulk excavation. The system of trench drains and surface pumping were able to cope with the sudden inflow of water and kept the civil construction area operational throughout. However, the earthworks contractor had to pull out of the area until such time as the water flow had abated sufficiently to allow access for the dump trucks.

The flow was released from a level of -7m to -11m amsl from a layer of silty sand with abundant shells. This layer of relatively coarse material rested on top of a thick layer of silty clay that started at about -11m amsl.

To remedy the situation 184 well points were installed spaced 1m apart. The well points were serviced by five dual stage vacuum pumps. Each vacuum pump was connected to about 40 well points and maintained a vacuum of between 65kPa and 80kPa under normal operating conditions.

As all the necessary equipment was stored on site in readiness for just such a situation, the well point installation was operational by mid August and the excavation could be completed without delay to the overall programme.

5.3 *Slurry wall extension for dredging*

Originally the entire outer basin, except for the liquid bulk quay wall slot, would have been dredged. However, last minute extensions to the handover date and potential cost savings provided an opportunity to partially excavate the outer basin with land based equipment. The calibrated seepage model and experience gained up to that stage allowed careful planning and design of additional measures to ensure a safe working environment for both the earthworks and dredging contractors.

The risk of flooding was balanced against the costs of additional dewatering units and the potential savings to be made by land based excavation. The solution was to extend the slurry wall return on the eastern side by another 330m (refer Figure 3) and to limit the dredger from encroaching closer than 130m from the wall until such time as the inner basin had been flooded. The extension was completed between February and March 2003 and dredging commenced in April. Additional piezometers were also installed to verify the modelling calculations as the dredger approached the open excavation.

6 CONCLUSIONS

The dewatering works contract was successfully completed and decommissioned when the inner basin and quay walls were flooded on the 30th of June 2004.


Figure 5: Flooded harbour in August 2004.

REFERENCES

Peck, R.B. 1969. Advantages and limitations of the observational method in applied soil mechanics. *Géotechnique*, 19(2), 171-187.