Extended summary

Hydraulic and Physical Barriers in polluted sites

- In Situ Tests and Numerical Modeling -

Curriculum: Materials, Water and Soil Engineering

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Abstract

The thesis deals with the topic of physical-hydraulic barriers for polluted sites. After a first part of introduction to the environmental problems of the sites with high levels of pollution (SIN-Sites of National Interest), theory and state of the art at the base of the hydraulic barriers and physical barriers are reported.

Specifically, these topics has been used to the application of this technology in two SIN, contaminated by the presence of activities related to the processing of petroleum products. The two sites are still in operation and are located along the seacoast of the two largest islands in Italy (for a privacy request by the client, will not be provided more details about their exact location).

The first case of study, will be presented on an area with the presence of a preexisting hydraulic barrier. In this site it is projected the construction of additional wells and the construction of a composite plastic diaphragm. Both projects of system integration barriers of the site were required by the MATTM (Ministry of Environment). The study, consisting of in situ tests / laboratory and numerical modeling through calculation software dedicated, focused in this case on equivalence in terms of performance of an hydraulic barrier coupled to a physical barrier made of jet-grouting (new project) rather than made of a composite plastic diaphragm (original project) . The numerical model was formed from the existing general numerical model of the area, focusing in particular on the study area called "low area". This area is of particular interest as it presents particular stratigraphic and hydraulic conditions since it is situated on a soil with high conductivity. The high conductivity is a natural factor of increased risk both in case of malfunction of the hydraulic barrier (faster transport of contaminants), both in case of intrusion of salt wedge (quicker entry of chlorides) .

For this purpose has been also created an additional calculation model that is able to consider density dependent flows, in order to verify the position of the salt wedge during time, both in the presence of the two physical barriers both in the absence of them.

In the second case the results of the study on the efficiency of an existing hydraulic barrier will be presented. Also in this case the Ministry for the Environment (MATTM), in order to ensure the safety of the site has made the request of a physical barrier up to a depth of approx. -130 m s.l.m.. The study proposed in this second case, through the interpretation of in situ tests / laboratory tests and the development of a numerical modeling of the entire area, has the aim to verify the efficiency of the working hydraulic barrier in order to avoid the construction in the near future of the requested physical barrier (art 243 D.Lgs 152/2006).

Keywords

Barriers, saline wedge, diffusion, pollution, in situ tests, numerical modeling.

1 Problem statement and objectives

Pollution from oil product is a main problem in sites situated under oil refinery. A defense of the environmental system (soil and water) can be given by hydraulic and physical barriers, installed in the ground. The efficiency of this kind of barriers depend mostly from the design and from the ground condition of the sites. The design could be affined by numerical modeling and the ground condition by in situ specific tests.
Objectives of the thesis is to validate the numerical models based on the in situ tests so to have a powerful tool to study the different design possibilities and in situ conditions, affecting the efficiency of the barriers.
Moreover the aim of the thesis is to study the salt wedge intrusion in different conditions of pumping systems and the influence that a physical barrier can have, in long term condition, on the defense of the fresh water layer.
Modeling software are applied both to new installation both to integration of already working systems, with possibilities of implementation of the model to respond to every different condition.

2 Research planning and activities

The research is focused on two case of study. Both are sites interested by a strong contamination due to oil pollution products.

In the first case, the study concern the design of a physical barrier to improve the time of the pollutant to reach the sea and at the same time to avoid a massive intrusion of chloride in case of an increase of the pumping ratio. The study has began with different in situ tests, geological, geotechnical and hydraulics, specific to the proposed aim (aquifer pumping test, slug test, efficiency test, etc…). After the interpretation of the tests, the data were used as input for numerical model. The validation of the model based on the results of a bigger scale model (entire working area model), used already for other kind of investigation.

The second case of study deal with the request of the MATTM to build a physical barrier near the coast-line, down to a depth of -150 m s.l.m. With the modern technology is not possible to reach that deep, but it bring high costs and long time to realize it. This second aspect is a big problem because it would be needed to stop the working process for long times. For this reason it was studied the efficiency of the actual hydraulic barrier, so to demonstrate that a new physical barrier is not necessary. Also in this second case, the research starts with specific in-situ tests (Aquifer pumping test, slug test, efficiency test, etc…) that helped to create a numerical model. The validation of the model based on the water lever of the aquifer registered, comparing the numerical output with the in situ tests.

3 Analysis and discussion of main results

The analysis was carried out on two different steps : the first step on the in situ and laboratory tests and the second step , concerning the numerical modeling . The laboratory tests are of fundamental importance to obtain an optimal calibration of the numerical modeling. This calibration has allowed then to be able to validate the results obtained in two different case studies.
The analyzes were conducted in situ by means of specific geotechnical tests (surveys with undisturbed core samples), using geophysical evidence (MASV) and by means of hydraulic tests (aquifer pumping test, slug test, etc ...) .
As regards the first case study, the results of the above tests have outlined a trend fairly homogeneous soil (mainly in medium-large grain), allowing a subsequent numerical modeling quite simplified. The area where it was decided to locate the model number is located on a high conductivity soil. This choice ensures a position on the safety side because the permeability in this area are higher than the rest of the aquifer, thus allowing a greater speed of movement in the event of a malfunction or power failure of the physical barrier .

Evaluation of the effectiveness of the barrier has been carried out through four types of analyzes, each of which is divided into several possible scenarios:

1 . Capture efficiency of the pollutant in the ordinary operating conditions of the hydraulic barrier;
2 . Rise in piezometric levels upstream of the physical barrier in the event of power failure or malfunction of the hydraulic barrier;
3 . Migration of the contaminant in the dissolved phase in the event of power failure or malfunction of the hydraulic barrier;
4 . Density dependent analysis.

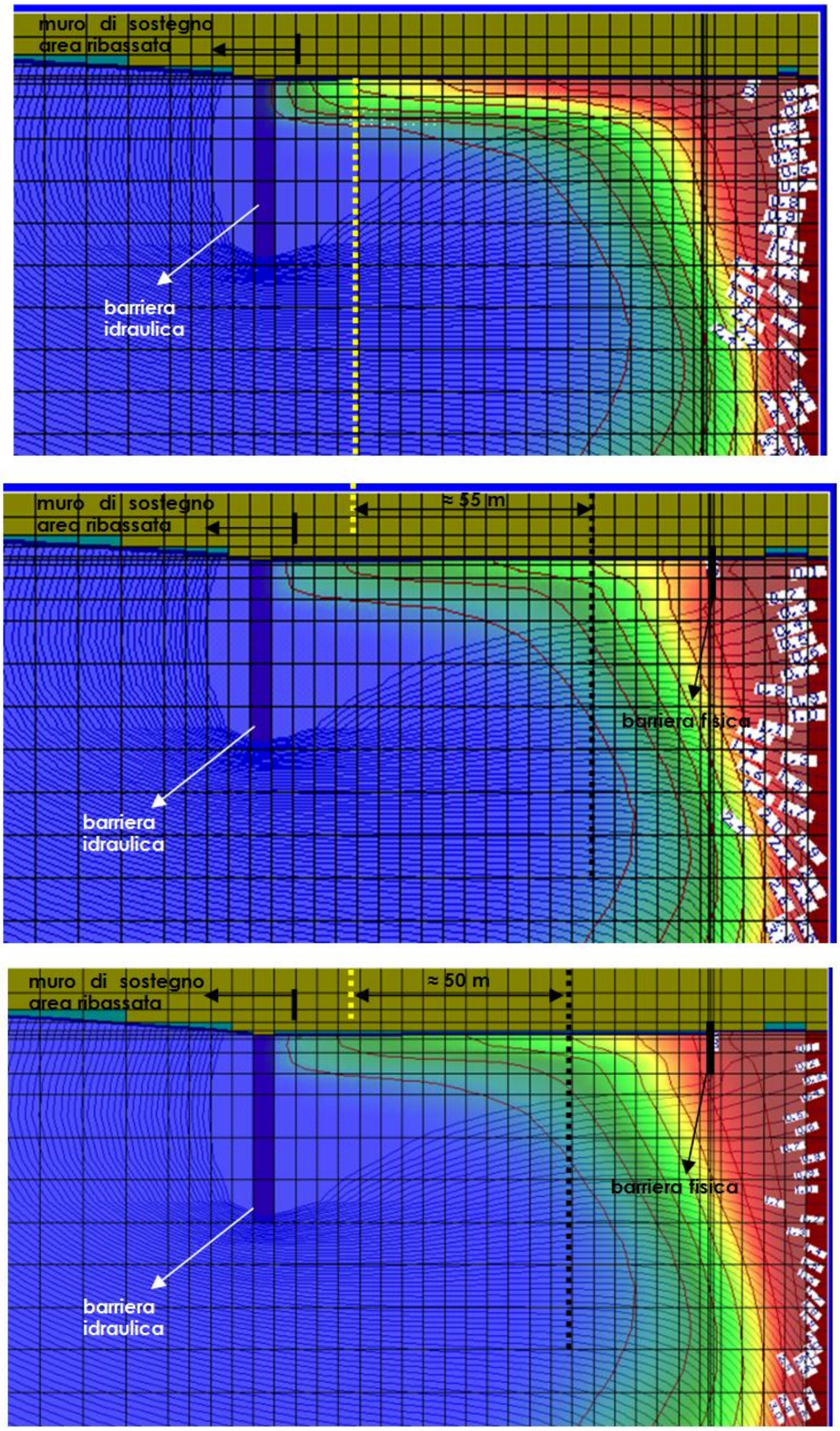

Figura 1: Results showing the distance of chloride intrusion in different scenarios (cross section)

In the analysis where it is expected the presence of pollutant (cases 1 and 3) , it is modeled as benzene at a concentration of 1 mg / l as C0 . This is issued immediately upstream of the physical barrier, and depending on the simulated scenarios, it is considered a continuous release or instant release . The checkpoint is located immediately downstream of the physical barrier .
The results of the first type of analysis (Capture efficiency of the pollutant in the ordinary operating conditions of the hydraulic barrier) and the second type of analysis (Rise in piezometric levels upstream of the physical barrier in the event of power failure or malfunction of the hydraulic barrier) show a substantial equivalence and in some cases also an improvement in terms of performance, between the two barriers in the different scenarios analyzed.
The results of the third type of analysis (Migration of the contaminant in the dissolved phase in the event of power failure or malfunction of the hydraulic barrier) and the fourth type of analysis (Density dependent analysis) show that in the case of a barrier realized in jet grouting it has a slight performance degradation compared to a barrier realized in bentonite.
As regards the second case study , the results of in situ tests have identified two zones of the model, with completely opposite characteristics: the northern area of the model , characterized by the absence or almost of layers of clays and the area south characterized instead by the presence of clay major banks , between 5 meters and 50 meters , counters that serve as partitioning between shallow and deep aquifer .
The evaluation of the efficiency of the actual hydraulic barrier has been carried out through three types of analysis:

1 . Continuous release of the pollutant at a distance of 550 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - only Layer 1 ;
2 . Continuous release of the pollutant at a distance of 200 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - only Layer 1 ;
3 . Continuous release of the pollutant at a distance of 200 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - Layer 1 to Layer 5 .

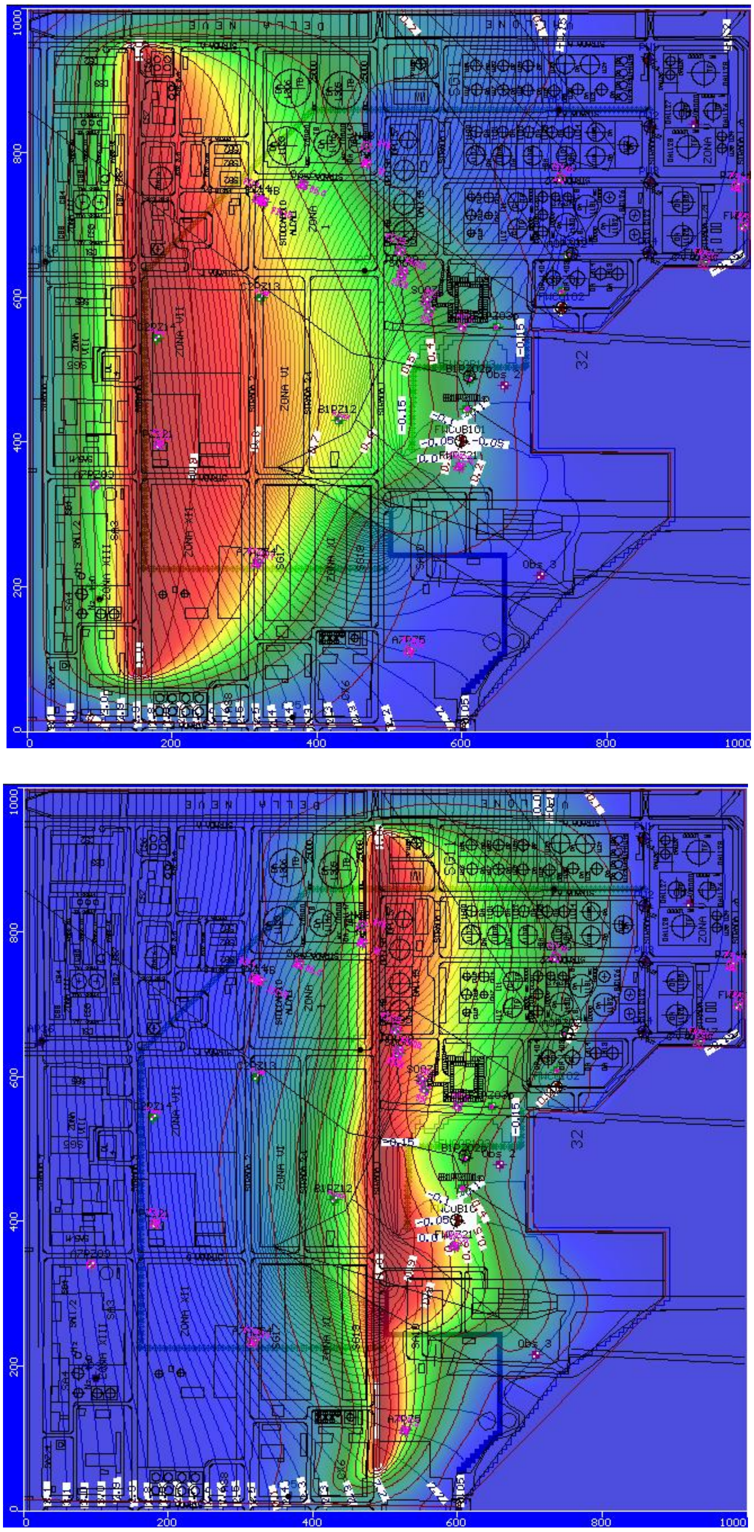

Figura 2: Results showing the area interested by the pollutant (plain view)

The results of the first type of analysis (Continuous release of the pollutant at a distance of 550 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - only Layer 1) shows that only in the central part of the model , there is a principle of passage of the pollutant at a time equal to approx. 2 years.
Going then to analyze the second type of analysis Continuous release of the pollutant at a distance of 200 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - only Layer 1), is known as in the case of release of pollutant near the hydraulic barrier, it has a more substantial passage of the pollutant at a time equal to approx. 6 months.
It is important to note that in both cases , the phenomenon of bypassing the hydraulic barrier is configured as an underpass of the same, due to the absence of local banks of clay that split the superficial aquifer from the deep one.
Finally was investigated through the third type of analysis Continuous release of the pollutant at a distance of 200 meter from the nearest coast (with benzene concentration C0 = 1 mg / l) - Layer 1 to Layer 5), if the deeper release of pollutant, could establish a quicker passage of the same below the physical barrier.
It is seen as the development of the phenomenon of the underpass is not substantially increased by the new boundary condition.

4 Conclusions

In the first case of study the output of the numerical modeling, demonstrate that the efficiency of the jet-grouting barrier is the same as the bentonite barrier.
The higher conductivity of the jet-grouting barrier helps the water to flow from outside the polluted site in direction of the pump station, creating a flux contrasting the diffusive flow. Moreover the higher conductivity produce smaller water rising level in case of a break-up of the pumping system and in case of black-out. On the other hand the crossing time of pollutant in case of bentonite barrier is higher than a jet grounting barrier.
Comparing the time of flooding of the area, is possible to notice the following results:

- 30 days in case of no barrier-wells;
- 150 days in case of presence of barrier-wells.

These times are compatible with the needed time to restore the pumping system.
The crossing times of the pollutant are ca. 200 days for the worst case.
Is important to notice that the critical time for the project is not due to the crossing time of the pollutant but by the time of flooding of the area.
The first case of study ends with a deeper calculation of the saline wedge intrusion in the area, made by a specific software (SEAWAT – 2000), in case of presence or not of a physical barrier (both jet-grouting and bentonite barrier).
The saline wedge is hampered by physical barrier as long as the convective phenomena are bigger than the diffusive-dispersion phenomena.
Also in this case the two kind of barriers bring to the same results in terms of efficiency.
Is therefore possible to state that in this first case of study, the two barriers have the same efficiency in all different conditions.

As regards the second case study, it was aimed to verify the efficacy in terms of performance of a hydraulic barrier already in work.
After a series of various in situ and laboratory tests, to deeper the characterization of the area of interest both from the point of view geotechnical , both from the hydraulic point of view, various design aspects were consider through a numerical modeling that used two different computing cores .
In fact it was used the core MODPATH to check the progress of the flow lines through the introduction of fictitious particles in the model. Once it was verified the lower limit of the area of influence of the wells, it has gone to work through the core MT3DMT, used to calculate the transport of pollutants. In this case it was decided to develop the research into three sub- cases:
- A - continuous release of the pollutant at a distance of 550 meter from the nearest coastline (with benzene concentration C0 = 1 mg / l) - only Layer 1;
- B - continuous release of the pollutant at a distance of 200 meter from the nearest coastline (with benzene concentration C0 = 1 mg / l) - only Layer 1;
- C - continuous release of the pollutant at a distance of 200 meter from the nearest coastline (with benzene concentration C0 = 1 mg / l) - Layer 1 to Layer 5.

This allowed to verify that increasing the time an underpass by the pollutant through the

phenomenon of diffusion and not by convection of the hydraulic barrier is created. It was also verified that the depth of the pollutant release (between Layer 1 and Layer 5), does not constitute a change in the final situation of the affected area on polluting . It should be recalled that in each case at a time of 10,000 days (ca. 27.5 years), the concentration detected downstream of the hydraulic barrier is maximum 20% of the initial C0 and that a continuous and constant release of 1 mg / l (value 1000 times higher than the legal limit) turns out to be very much in favor of safety, as it is registered at the site exceeded the maximum of 10 times the legal limit.
It should be borne in mind that as an additional safeguard is in any case present as physical barrier, consisting in a metal sheet-pile along the entire coast line that goes from the southern border to about the northern limit of the model.
It should also be noted that the results of a numerical modeling, as this accurate and consistent with the reality, can not constitute the only instrument on which base design decisions.
Indeed, the numerical modeling besides has to be supported upstream by an adequate number of in situ and laboratory tests, requires validation of the results obtained through the installation of a field tests of physical dimensions such as to obtain a reliable experimental result, field test that will allow even a possible optimization of the final design choices.

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