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Gronda di Genova slurryduct for transport of excavated material

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ABSTRACT: SPEA Engineering, has prepared the Definitive Project for the adaptation of the Genoa motorway junction for the A7/A10/A12 motorways, also named "La Gronda di Genova". The construction of the Gronda involves, among the various activities planned, the treatment of approximately 6.8 million cubic meters of potentially asbestos-containing debris deriving from the excavation work carried out mostly by two Tunnel Boring Machines (TBM). The excavated material will be temporarily stored, analyzed and, if having low asbestos content, reutilized for the enlargement of the airport landing strip.

This material will be transferred in the form of a slurry through a special pipeline having a length of 9 km, For reducing wear and pump power consumption the transporting media will be a bentonite based fluid.

1 INTRODUCTION

In September 2017, the Italian Ministry for Infrastructures and Transport approved the project for the construction of "Gronda di Genova"(Figure 1). The final project was approved and the works recognized as of public interest. Works are expected to start in October 2018 and last for 10 years with an investment of nearly euro 4.3 billion. The project is the result of a long-term design and discussion process that had involved also the Regional and the Genoa City Authorities.

The new infrastructure will connect to the existing junctions just outside the urban area (Genova Est, Genova Ovest and Bolzaneto) and link up with the Motorway A 26 in Voltri and the Motorway A 10 in Vesima. This infrastructure will not only relieve traffic congestion on the Motorway A10,but also improve Genoa's potential and logistic competitiveness and it represents an opportunity for growth for the entire North-West region.

Here below are the figures that provide an idea of the complexity of the project:

- 54 km in tunnel, nearly 90 % of the entire infrastructure;
- 23 tunnels;

Figure 1. General view of "Gronda" project.

– 13 new viaducts;
– 11 existing viaducts to be extended;
– 10,000,000 m^3 of excavation material.

Particular attention was paid to environmental sustainability, due to the orographic complexity, the high urbanization of the area and the presence of asbestos in the rock formations that will be subject to excavation.

The excavation material will be treated in accordance with the asbestos contained and the geotechnical characteristics. Most of the excavation material will be used for:

– The construction of an infrastructure on the seaside that will allow developing a 50 m wide backfilling to ensure the adjustment of the shoulder of the runway strip of the Genoa airport.
– filling of the motorway tunnel invert.

The material which is not suitable for the above listed applications will be destined to a waste disposal area.

2 MATERIAL HANDLING

The main part of the material, nearly 8,000,000 m^3, will be excavated by means of TBMs, the remaining by means of conventional method such as drill and blast and hydraulic breaker. Two TBMs, EPB type, will be used and their relevant excavation will start from Bolzaneto site (named C1) towards East up to Vesima. The excavation work to be carried out by conventional method will be for the tunnels on the west side of Bolzaneto towards Genoa East and West and some minor sites which are located close to Voltri area. What above means that almost all the material excavated has to pass through Bolzaneto site which becomes the natural heart of the transport system. All this material has to be transported to its final destination and many difficulties have to be overcome for what concerns:

– Asbestos. The risk related to the occurrence of natural asbestos is a major issue affecting the highway plan, which is expected to cross potentially asbestos-bearing rock units. The asbestos is supposed to cross the path of the Tunnels located in Voltri and Vesima areas which will be excavated mostly by means of the two TBMs and partially by conventional method. The asbestos presence is a big problem for what concern environmental aspects and health aspects of workers who might be in contact with this material. Furthermore, considering that the main working sites are located in the metropolitan area, it has been necessary to scout the optimal solution to carry out basic and simple operations such as crushing, loading, unloading and, of course, define the proper and suitable transport mean which has to be environmentally safe and does not interfere with an already congested local road network. Furthermore, the excavated material has to be characterized in order to evaluate the asbestos content and based on this value to dispose it to the final destination.
– Lack of space. The area available to stock, analyze and prepare the excavated material before transport to the final destination site, is very limited. This means that all the activities to be carried out on the material excavated, including transport to the final destination, must rely on suitable systems having a very high availability since there is no possibility to have a bigger buffering area.
– Transport. As soon as the material excavated has been characterized, it has to be transported to the final destination site. The biggest portion of the material will be used to create a safe area aside the runway strip of the Genoa airport which is located on the seaside. Between the working sites and the airport area there is Genoa city, which, in case a road transport solution would be adopted, has to be crossed through. Genoa has a really congested traffic system which would be incapable to absorb the extra traffic as the road transport for the material excavated would generate. Furthermore it has to be considered that the airport strip has to be enlarged on the sea side and this means that whatever

transport system would be adopted this cannot interfere with the limitation of the airport activity.

– Between Bolzaneto and Genoa Airport, the only free area to be used for transporting the material, without using the existing road network, is the river bed of Polcevera. Furthermore the transport system, in accordance to the agreement taken with the local authorities, have to be environmentally safe in order to avoid any type of pollution due to asbestos fibers and material spillage. Polcevera river bed is crossing all the urban area and furthermore has many bridges and height limitations.

Considering what above, among the possible transport solutions, the transport system chosen is the following:

a) Convey/Transport the biggest part of the excavated material to Bolzaneto;
b) Place in Bolzaneto site a plant properly designed in order to fit into the small space available and suitable to fulfill to the following targets:
   – capability to characterize the excavated material;
   – capability to host all the process systems necessary to treat the material excavated in accordance to its final use;
   – Having a stocking and reloading capacity suitable to allow the characterization of the material and a minimum buffering to absorb the material production in case some problems in the transport system chosen might occur.
c) Use a slurry system utilizing sea water as transport medium from Bolzaneto site to Airport site. By means of this solution the following targets will be achieved:
   – No contact of the material with the environment;
   – No impact on the road network of the city;
   – Easy adaptable to the area available.

3 DESCRIPTION OF THE SYSTEM

The system, as a base, will operate as per simplified Flowsheet indicated in figure 2. The quantities indicated have been based on the theoretical maximum advance rate of the two TBMs, 15 m/day each. Considering a tunnel section of 168 m^2 the total volume produced per day per TBM will be roughly 2550 m^3/day, to this has to be added also 1300 m^3 produced from the tunnels excavated by conventional methods (drill and blast or hydraulic breaker). Based on what above the total capacity required will be 6400 m^3/per day which corresponds to an average hourly production of 270 m^3/h.

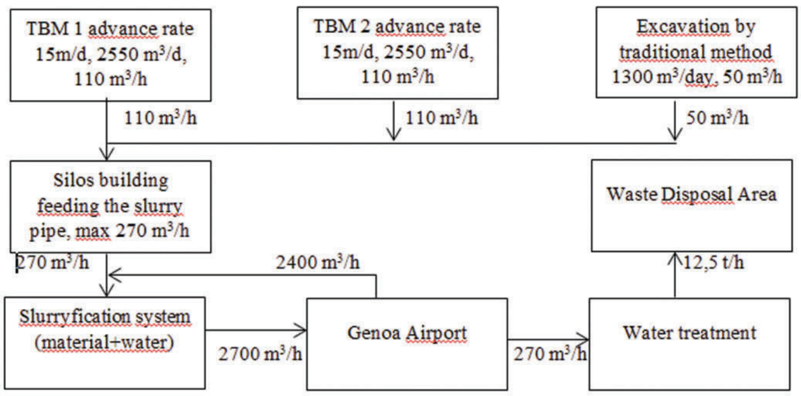

Figure 2. Slurry duct system simplified mass flow.

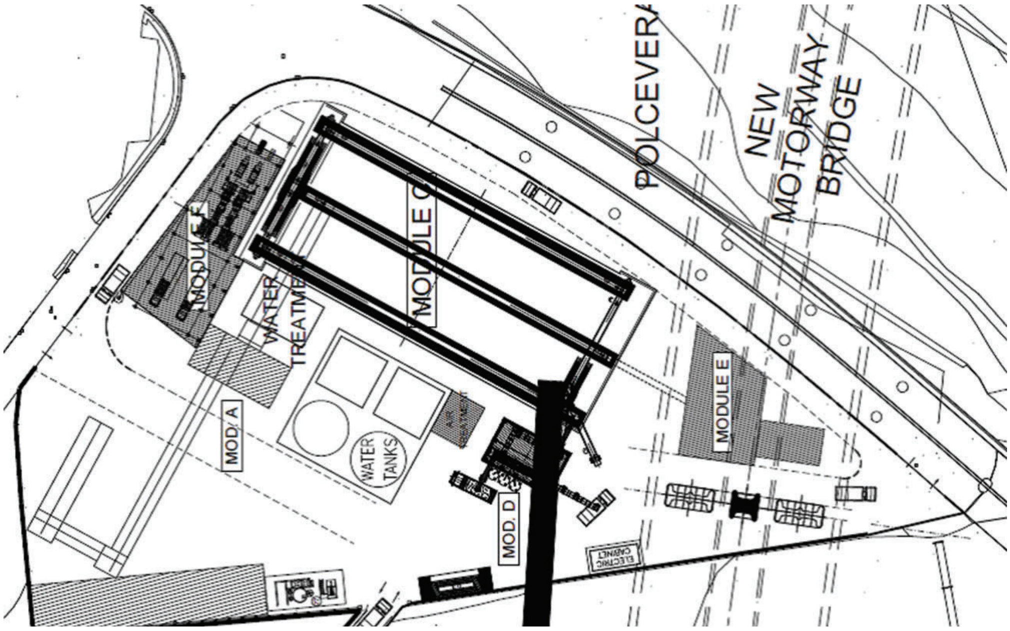

Figure 3. Bolzaneto plant area.

The total area available for the plant of Bolzaneto (Figure 3) is only 15,000 m^2 and furthermore there is also a height limitation since the area will remain under the new Gronda bridge which will cross Polcevera bridge

As a base the Bolzaneto working site will be composed of the following main 5 modules:

- Module A: Crushing system for the reduction to desired size of the material excavated in traditional method and transported to the site by trucks; sampling section for material characterization;
- Module C: Made of 24 silos. Each silo will have a capacity of 900 m^3. The stored material, in accordance to the analysis carried out, will be conveyed to the inertisation for filling the tunnel invert, or bagging to be sent to a waste disposal area, or sent to slurry section to be pumped down to the Airport site;
- Module D: Inertisation of the material having a content of asbestos higher than 1gr/kg will be threated but which can be reused for the Tunnel consolidation work;
- Module E: Slurry preparation. The material is mixed with sea water (asbestos content lower than 1gr/kg) in order to be pumped down to the airport area;
- Module F: The material is bagged, sealed and sent to dedicated waste disposal areas.

4 SLURRY TRANSPORT SYSTEM

4.1 *Slurry transport system by sea water*

A deep analysis has been dedicated on the slurry transport system, which, as a base, is the critical part of the system. The solid transport via pipeline is rather common in the mining industry, many processes in mineral treatment use water (milling, flotation, screening, magnetic separation etc) and water allows to move the material through the various steps of the process in an easy and environmentally safe way. Furthermore pumping of solid is commonly used for handling the tailings of mineral processing as for transporting the mineral ore concentrated to the final destination. By this transport system, many million tons of material have been conveyed for distances which are by far higher than the one required to the Gronda Project. On the other side it has to be considered that the Gronda Project has some peculiarities that standard applications do not have. The main differences are the following:

– The material to be transported has a high geological variability, as it will be explained in the following section, while in a mineral processing projects the system is sized for almost a constant type of feed;
– The top size dimension in a mineral processing slurry transport is typically not more than 5-6 mm while in our case the aim is to transport a slurry having a dimension equal to the top size produced by the two TBMs which is 75 mm;
– The material to be transported is really poor of fines since the fraction below 75 microns is not separated from the bentonite separation system placed on the TBM's slurry system; fine particles act like a medium for coarser material increasing the ability to keep the material in suspension.

Solid transport via slurry pipe are used in other industrial processes, the main ones are oil sand and sea dredging. In the first case the material to be transported has a maximum dimension up to 100-120 mm, but the application, more than a transport system, is a process since the pumping is used for dissolving the crust of oil sand in order to minimize its dimension and to facilitate the separation process between oil and sand and the slurry characteristics got modified during the pumping. The solid pumping in the dredging field, is used also for long conveyance, the biggest difference with our system is that the water to be added to the slurry is practically endless and this has, as a consequence, that in case of increasing of the head loss it is sufficient to lift the pump and dilute the slurry to flush the pipe without the constrain of pumping a certain amount of solid continuously.

The study has been commissioned to one of the most known engineering company active in this sector: a first study has been carried out considering a solid fraction having a top size of 8mm, but the solution has been immediately discarded since there was no space available in Bolzaneto for placing the necessary crushing and screening plant. A second study has been analyzed considering a top size of 25 mm. and the results achieved are as per table 1.

As an explanation of the results indicated in table 1 what follows has to be considered

Critical velocity: in the preliminary steady state slurry flow modelling report, P&C calculated a critical stationary speed within a 450 NB pipe of 3.7 m/s. Due to the very coarseness of the slurry to be pumped, P&C therefore recommend operating at 1.5 times this stationary speed. The increase in minimum design stream flow to prevent particle settling has a big impact on all parts of the pipeline design, i.e.:

– Increases/decreases stream flow rate vs solids concentration vs solids mass flow rate;
– Significantly increases total dynamic head over the length of the pipeline;

Table 1. Solid pumping data sheet for max size of 25 mm.

Parameter	Value
Particle Top Size (D_{100})	25 mm
Solids Flow Rate	270 m^3/h
Differential height	+55 m
Pipe length	11000 m
Total Dynamic Head	1119 m
Pipe Specification	500NB MSRL
Maximum Pipeline Pressure	21.9 bar(g)
Pump type	20/18
Number of Pumps	22
Gland seal fresh water required	43 m^3/h
Total Installed Power	20,9 MW

– Limits increasing pipe size as larger pipe diameters increases required stream speed to prevent settling;
– Increases risk of pipeline failure or pumps from excessive abrasive wear.

Pump Impeller tip speed: as an industrial standard, it is recommended that pump impeller tip speeds for metal impellers to be limited to approximately 28 m/s. The reason for this limit is to prevent excessive wear on the impeller by the abrasiveness of slurries. The larger particle sizes in this application further motivates to lower speeds to prevent excessive wear and therefore maintenance costs. By limiting impeller tip speed to approximately 28 m/s, the limit of hydraulic head that each pump stage is capable of adding is limited given a particular flow rate. For a 20/18 pumping 3450 m3/h this limited each stage to 50 m of hydraulic head per stage.

Gland seal water on slurry pumps is preferred over mechanical seals or expellers, this is pump manufacturer recommendation. The reasons are the following:

– An expeller cannot be used given the series pumping arrangement required at each booster station and the large discharge head at each final stage.
– Mechanical seals may be specified if the seal manufacturer is willing to guarantee their life. They may be prohibitively expensive given the size of the 20/18 pump and the use of sea water as a transport medium would also necessitate special materials to limit corrosion from high chloride concentration. Mechanical seals require continuous maintenance to ensure the fine particles do not ingress and damage the sealing arrangement. Maintaining the 2x20 mechanical seals on these seals may be a complex task requiring potentially long downtime.
– Provided clean, potable water, used as gland seal water, can be supplied via gland seal pumps on site at the correct pressure and flow rate. Gland seal water also provides a suitable barrier between the slurry and shaft seal.

The results obtained are by far worse than it was foreseen in the preliminary study carried out. The reasons why this solution has been discarded are listed below:

– too high power demand for the local energy network system;
– too many boosters pumps to be installed on the river bed and impossibility to find areas easily accessible to allow for maintenance of the equipment;
– high consumption of fresh water for the pump gland seal;
– very high wear on pumps due to the slurry speed, 5,5 m/s, necessary to avoid sedimentation in the pipeline;
– necessity to install a crushing and screening system suitable to reduce the top dimension of the material fed to the plant down to 25 mm. Problem connected to the space available, to the geological variety of the material to be fed, to the impossibility to have a second crushing line in standby position;
– value of investment and running cost higher than what foreseen;
– last but not least the results obtained have to be considered theoretical since there is not any simulation program suitable to evaluate the data of a slurry duct pumping material having dimension higher than 10 mm and a pilot test is necessary to validate the data.

4.2 *Slurry transport system by bentonite*

Alternative solutions to sea water slurry system have been scouted and it has been decided to adopt the same system used by the TBMs for transporting the excavated material from the working face to the tunnel adit. In this project the two TBMs are pumping 110 m^3/h of solid at a distance of roughly 16 km using as transporting media a mix of water and bentonite. To apply this technology to our case is not that easy, first of all for the capacity required which is by far higher than what done up to this moment using this type of transport system, secondly for a series of different aspects which are completely new such as the slurryfication procedure and the separation system to be used. Another point considered is that there is not a real well proven calculation to validate the sizing of the system. The slurry transport by using bentonite as media has been used for decades in well drilling and later in other fields such as diaphragm walls, piling and finally in TBMs. The bentonite, mixed with water, creates a viscous mud which allows to reach the following targets: maintains hydrostatic pressure against the borehole/excavation wall keeping it from collapsing; seals the excavation walls; cools and lubricate the drilling bits and, finally, the muds helps remove cuttings from the bore-hole/excavation. This last point is the characteristic which has the bigger impact on our application. The following example will better explain how the process works: if we consider to have a tube filled with water and drop inside a stone in the tube, the stone will have a settling velocity of a certain value. If the tube is filled with oil the settling speed of the same stone will be lower even though the oil density is lower than water. What above is connected to another parameter of the fluid which is viscosity.

This characteristic, if applied to our case, increases the dragging force of the medium which means that, using a bentonite mixture, it is possible to apply a lower speed than what is necessary by using water only and the consequences are relevant for what concern power consumption and, of course wear.

Obviously there are some modifications to be applied to the previous project, the material transported by means of sea water as a medium can be discharged directly in the basin to be filled, if bentonite is used a separation plant has to be installed at the discharge end of the slurryduct to separate the bentonite from the excavated material. To this have to be added a series of equipment such as fresh bentonite preparation plant, tanks for the used and fresh bentonite and finally tank for empting the slurryduct pipeline. The area necessary for all this has to be created close to the airport strip area taking into account all the limitations in terms of heights and activities imposed from Airport Authorities. Many simulation have been carried out and the results obtained have been in general positive. The system has been sized assuming a total solid transportation of 350 m3/h which is 30% higher than the value indicated for the system using sea water as medium. The pipeline length has been reduced since it was not possible any more to pump the material up to farthest area to be filled, but to the separation plant which has been foreseen almost in the middle of the filling area.

The data obtained are per table 2.

The advantages connected to this solution are various:

- it is possible to transport material having a top size of 75 mm. By this system it is not necessary anymore to install a crushing and screening plant in Bolzaneto saving space and, even more important, removing a possible cause of low dependability since a single crushing line was foreseen;
- significant increase of solid percentage transported in the slurry;

Table 2. Slurry pumping data sheet, solid max size of 75 mm, medium bentonite.

Parameter	Value
Particle Top Size (D100)	75 mm
Solids Flow Rate	350 m^3/h
Slurry flow	2170 m^3/h
Solid concentration in volume	16,2%
Bentonite medium density	1,1 t/h
Differential height	+55 m
Pipe length	9100 m
Total Head	358 m
Pipe Diameter	450 mm
Pump type	20/18
Number of Pumps	5
Total Installed Power	5,5 MW

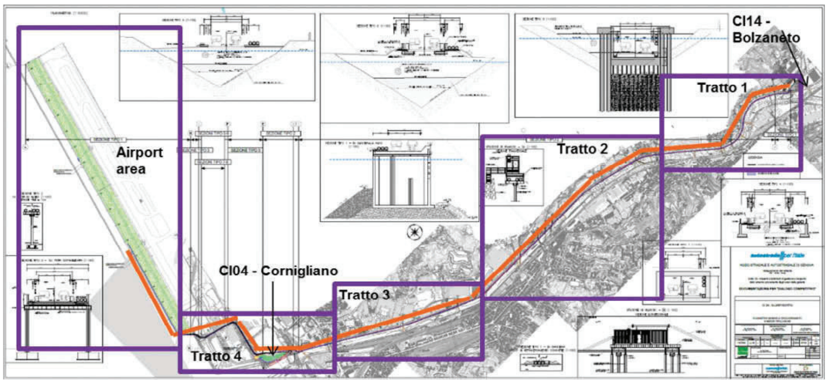

Figure 4. Slurry duct lay out.

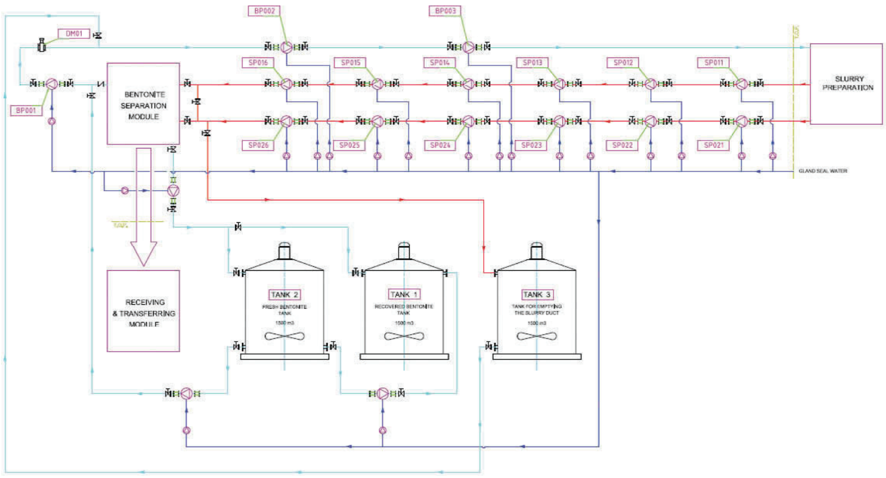

Figure 5. Piping and Instrumentation Diagram of slurry duct.

- production suitable to handle the maximum production of the two TBMs;
- well proven system utilized for material transports in hundreds of application and able to handle solids having different geological characteristics;
- by the separation system all the material having dimension lower than 75 μm is removed. In general the asbestos fibers are mostly included in this material fraction;
- less fines amount increase the settling speed of the material in the landfill operation;
- possibility to separate the transport phase from the land fill operations creating a buffer in the between.

In order to grant a high dependability to the transport system two complete slurryducts, will be built. In the figure 4 is represented the slurryduct layout and in figure 5 a simplified P&ID.

5 SLURRY SEPARATION SYSTEM AND LAND FILL

One of the main topics to be tackled with has been the separation plant necessary to separate the bentonite from the excavated material and the system to be used for distributing the excavated material for the land fill.

As previously mentioned the land fill has to be done aside of Genoa Airport and it is indicated in green in figure 4. By means of concrete elements to be sunk and filled with material, will be created three artificial basins having dimensions as per table 3.

Table 3. Artificial basin dimension.

Basin	Length (m)	Width (m)	Depth (m)	Asbestos content
A1	805	150	10	> 1gr/m^3
A2	1040	150	10	< 1gr/m^3
A3	1475	150	10	< 1gr/m^3

The basins will be completely compartmented one from the other and from the sea as well. Between basins 1 and 2, will be installed the "Receiving and Separation plant". To the plant will be transported all the material to be utilized for filling the basins for the land reclamation activity. The material will be transported mainly by the slurry duct, but also by means of conveyor and rubber tire vehicles. At this reference it has to be considered that the material, excavated by conventional method (drill and blast) in small working sites, will be transported mainly by truck to the Airport area (Figure 6).

The plant (Figure 7) is composed of two main modules: a) separation module; b) receiving and transferring module. The Separation Module treats the slurry to separate the excavated material, biggest than 75 microns, from the bentonite medium which is recovered and pumped back to Bolzaneto site. The plant is composed of screens, pumps and cyclones working in three parallel production lines. The second module is located aside of the first one and it is an

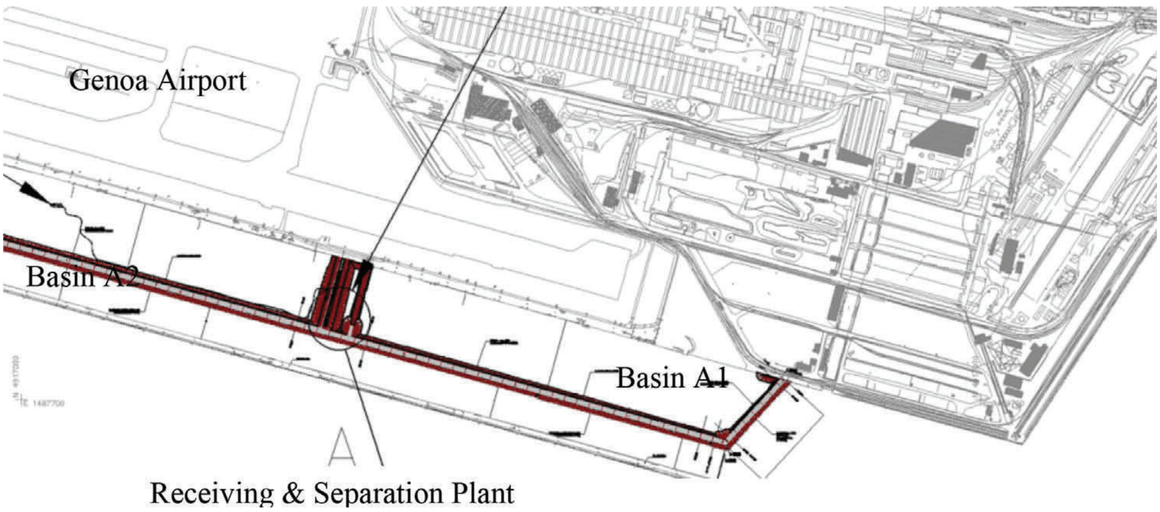

Figure 6. Basin Plant closed to Genoa Airport.

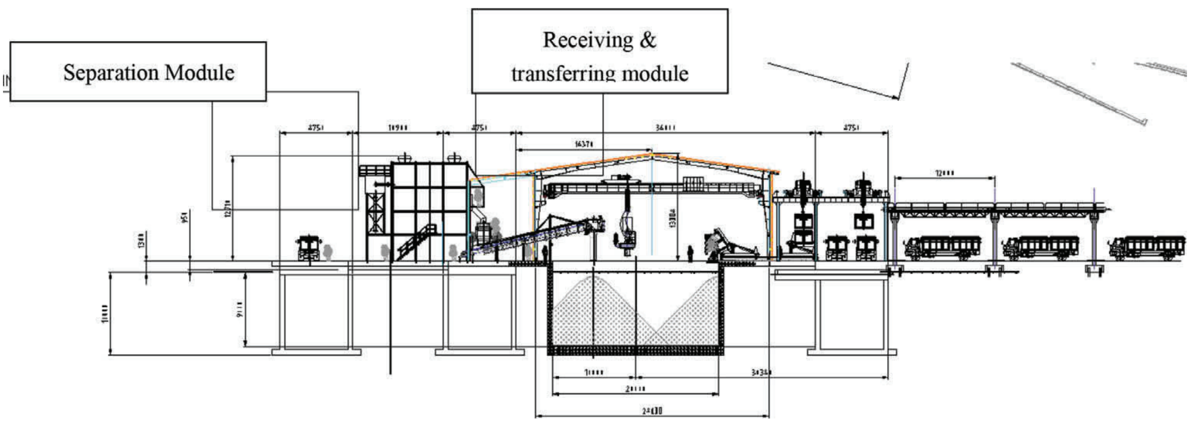

Figure 7. Detailed view of the treatment plant.

industrial building containing two basins in which the material, separated by means of the separation module, is discharged. In the basins is discharged also the material transported by means of the rubber tire vehicles. The two basins have a volume of approximately 7500 m^3 and each one is serviced from a dedicated double girder overhead crane complete of submergible pump.

The material transported by rubber tired vehicles is loaded inside closed containers. The vehicles, each one transporting two containers having a capacity of 8 m^3, are unloaded by means of automatic cranes and, via horizontal movers, the containers are discharged inside the basins. A double door system grant the total insulation of the building from the environment.

The first basin (A) is dedicated to the material containing more than 1gr/$m^3$of asbestos, the second one (B) for the material lower than 1 gr/m^3. In order to avoid any material contamination, the building is divided by a separation wall. The complete building, as well the separation module, are kept slightly depressurized to avoid that asbestos fibers might be liberated in the environment.

The pumps, moved by the overhead crane, convey the material from the basins inside the building to the land fill basins. The water overflowing from the landfill basins, either keeps constant the water level inside the basins inside the "Receiving and separation plant", either feed a water treatment plant. The material discharged is then distributed in the basin by means of dredgers and delivery self-propelled units.

By this system it has been created a good buffering between the transport and the land fill activities so that it is possible to grant a high availability of the whole system.

In the following figure (Figure 8) is represented a simplified P&ID of the system.

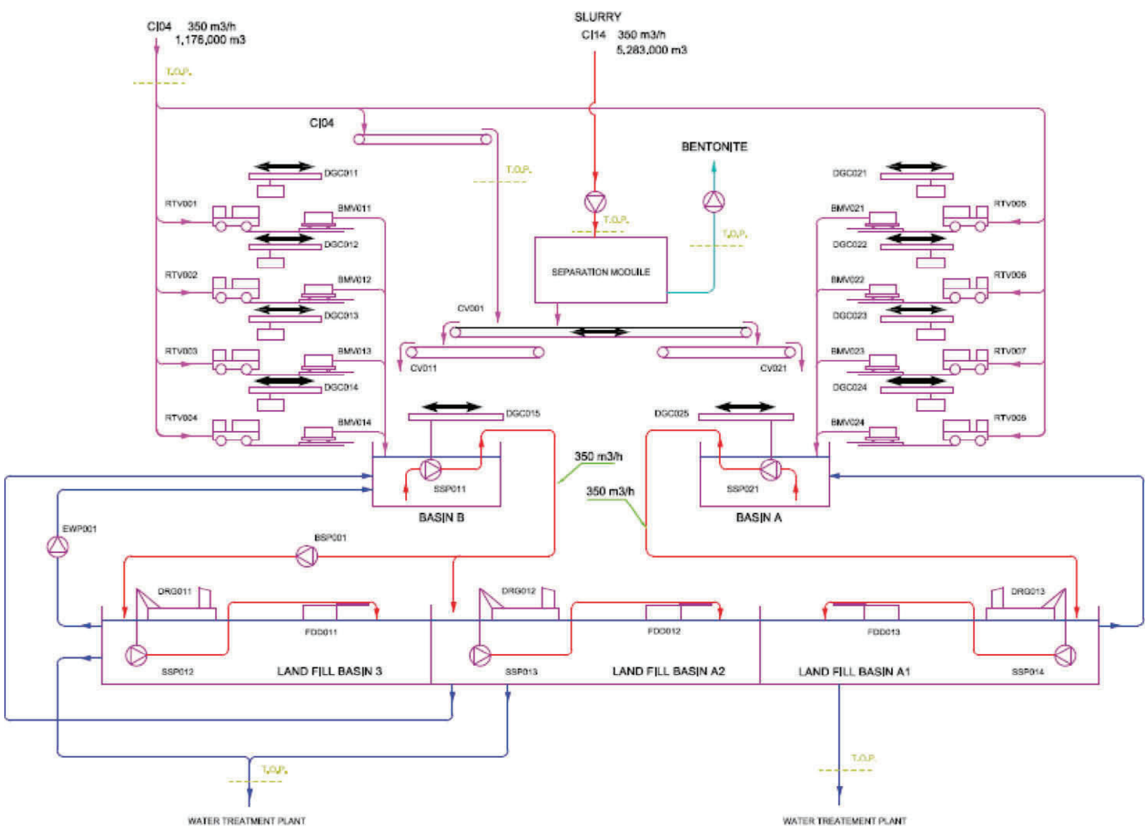

Figure 8. P&ID of the system.

6 CONCLUSIONS

The system studied from Spea is a miscellaneous of different know-how which are used in really different working fields such as mineral processing, dredging and maritime works and solid transport via pipeline. To this it has to be added that the geological variability of the material to be transported generates really big difficulties in sizing the proper transport and stocking system.

It has to be considered that many of the processes, which will be applied, are by far bigger in size and performances than what it has been done up to now. Nevertheless the innovation of the project lies in the use of these technologies all together to face all the limits connected to the application.