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Resilient city: The case of Bisagno diversion tunnel

G. Lunardi, G. Cassani, M. Gatti, B. Spigarelli & C.L. Zenti
Rocksoil S.p.A., Milan, Italy

ABSTRACT: In today's world of rapid environment changes, increasing urbanization and vulnerability, it is very crucial to embed the concept of resilience into the development planning of our cities in order to have a sustainable development. Planning a city without a robust resilience strategy to cope from disasters is equivalent to wasting resources and putting people, infrastructure, assets and economy at risk. Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner. The Bisagno Valley has been historically affected by a number of flood events, which became particularly frequent in the last decade. This is mainly due to the urbanisation of the valley since the 1950s and the recent climate changes, with increased flash flood events. The paper describes the approach used on the Bisagno Diversion Tunnel Project Management, which involved stakeholder relationships and integration at different levels, institutional frameworks and partnerships amongst all urban stakeholders, particularly planner architects, engineers, disaster and risk reduction management specialists, private sector, and communities to address risk reduction and resilience in a holistic manner. Risk reduction and resilience building save lives, enhance social and economic development, and provide equitable, prosperous and sustainable urban development.

1 INTRODUCTION

The enormous potential for disaster resulting from natural hazards has been well known in Europe since the final decade of the 20th century. These issues were highlighted, particularly for urban areas, by the European Union conference which took place in October 1993 exploring the development of cohesive civil protection policies as part of the United Nations International Decade of Natural Disaster Reduction (Horlick-Jones et al., 1995). Horlick-Jones (1995) has stressed the need for better dialogue between researchers and practitioners of civil protection issues, a field that involves several different scientific, socio-economic, psychological, cultural and practical factors. Increasing population density and numbers of settlements in hazardous areas make disasters more frequent, severe and expensive (Petak, 1985; Drabek, 2004; Barredo, 2007; Castaldini & Ghinoi, 2009; Alberto et al., 2010), and as a result, the role of communication becomes more and more important (Horlick-Jones, 1995, Pearce, 2003; Arattano et al., 2010).

2 GENOA AREA

The city of Genoa, currently home to around 650 000 people, represents an Italian national case-study of the issue of geo-hydrological risk. In fact, during the last century the municipality of Genoa has been affected by recurring flood events and landslides that have caused heavy damage and casualties. In 2001, the geo-hydrological critical condition of the Bisagno catchment was defined by the Italian Civil Protection Agency as a "national emergency". The

Bisagno Stream flows through the most urbanized part of Genoa, with around 100 000 inhabitants as well as associated economic and industrial activity. Geo-hydrological risk mitigation in the Bisagno catchment area is therefore currently one of the most important civil protection objectives in Italy (Agenzia di Protezione Civile, 2001). The occurrence of very short hydrological runoff times makes accurate weather forecasts vital, with the time window during which potential intervention could take place in an emergency being very narrow.

The area of Genoa is characterized by a complex morphology determined by the Alpine–Apennine system which hosts relief extending from peaks between 1000 and 2000 m, rapidly descending towards the Ligurian Sea. The resulting hydrographic network consists of numerous steep and short watercourses that can attain a concentration time of less than an hour during floods (Figure 1).

The two most important catchments are the Polcevera stream which is the largest and the most populous basin (140 km^2), located west of the historic amphitheatre, and Bisagno stream (95 km^2) flowing immediately to the east. Important urban areas are also located in the plain coastal basins of Leiro stream at Voltri (27 km^2), of Varenna stream at Pegli (22 km^2) and Chiaravagna stream at Sestri Ponente (11 km^2). Following an increasingly widespread practice in Liguria, many of the Genoa river beds are culverted (covered), sometimes for long stretches, especially the reaches towards the mouth. In these new narrow spaces, roads, parking areas and, in some cases, even homes, have been built.

The municipality land, with its orogenic complexity, has peculiar features that make it unique geologically and hydrologically. The main characteristics are briefly listed in Figure 2. In the coastal plain the main streams feature Quaternary deposits that are now largely removed by anthropogenic actions (Comune di Genova, 1997; Giammarino et al., 2002). The mountain area at its back exhibits its major feature in the sector between Sestri and Voltaggio, a tectonic system that joins the westward Alpine units and eastward Apennine units (Corte- sogno & Haccard, 1984). It can be split into two units: one made up of ophiolites with corresponding meta- morphic sedimentary cover and one of calcareous dolomite. West of the Sestri-Voltaggio area, the units of the Voltri Group are found: a meta-ophiolite and metasedimentary complex representing the southernmost sector of the western Alps. From a lithological perspective, lime-shale, metabasite and ultramafic units are found here (Capponi et al., 1994). East of the Sestri-Voltaggio area, where the Polcevera Valley is located, shaly and shaly-limestone

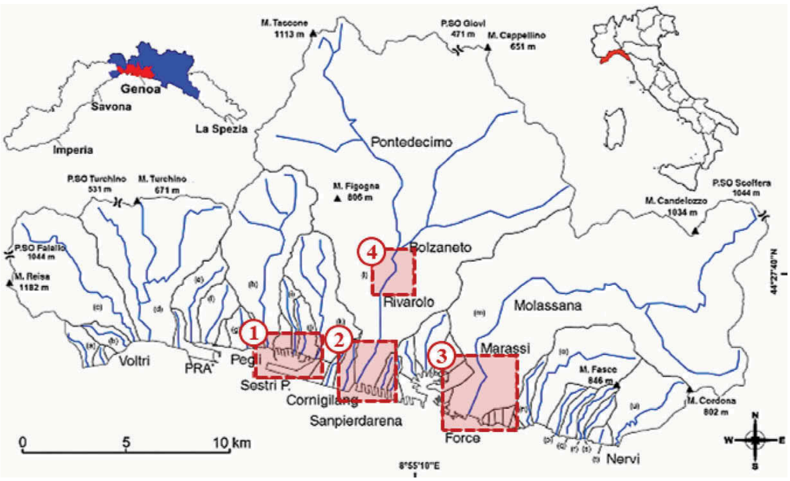


Figure 1. Main catchments and their streams, crossing Genoa in the stretch between the districts of Voltri (W) and Nervi (E): in the boxes (red dashed lines), from west to east: (1) Sestri Ponente and the mouth of Chiaravagna stream, (2) Cornigliano and the mouth of Polcevera stream, (3) Force and the mouth of Bisagno stream. In the centre of the figure, the red dashed box shows (4) Polcevera stream near Bolzaneto. (Faccini et al., 2015).

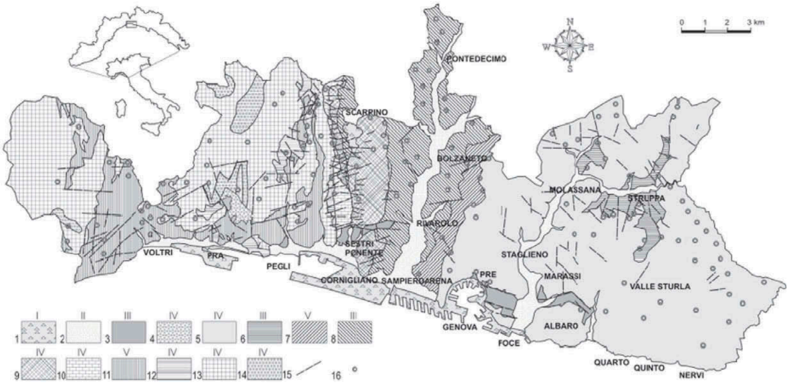


Figure 2. Geo-lithological sketch map with hydrogeological elements of Genoa Municipality. Legend: 1) embankment, dumps; 2) alluvial deposits; 3) stiff fissured clays; 4) ophiolitic conglomerates and breccias; 5) marly limestones with shale interlayers; 6) shales; 7) calcareous marls and silty shales; 8) shales with limestone interlayers; 9) pillows basalt and ophiolitic breccias, serpentinites; 10) dolomites, limestones, dolomitic limestones; 11) calcareous, micaceous and quartz-schists; 12) metabasalts and metagabbros; 13) serpentinites; 14) lherzolites; 15) fault, certain or covered; 16) main springs. Permeability classes: I) soils with variable permeability; II) permeable by porosity soil; III) waterproof formations; IV) permeable formations for cracks; V) medium-low permeability formation (Faccini et al., 2008).

flysch can be observed, whereas the shaly-marly fysch of Mt. Antola crops up on the left bank of Polcevera stream, reaching the eastern municipality boundary; locally it is broken up by the underlying shaly base complex or by the marly-shaly Pliocene lens above it, where the main tectonic directrixes are located (Limoncelli & Marini, 1969; Marini, 1981; Marini, 1998). The complex geological and tectonic configuration and the geographical position involve an extremely complex hydrologic setting that commonly features permeable rock masses next to less permeable masses.

2.1 *The Bisagno Valley*

The Bisagno stream rises near Scoffera Pass (675 m), The main stream has a total length of 25km, and its mouth is in Genoa city centre, east of the natural amphitheatre of the old town. The hydrographical network is characterised by particularly short streams within limited water-basins: the whole Bisagno catchment is < 100km^2, and maximum river length is < 20km. Therefore, concentration time during heavy rain-fall events is very short. The maximum elevation of the catchment is1034 m, and the average gradient is 31%; while 10% of the territory has a gradient of > 75% and only 5% has a gradient of < 10%. In the Bisagno Valley, 60% of the territory has a gradient between 35% and 75%, while almost 70% of the catchment is included between 0 and 500 m above sea level. Today the urban area covers 15% of the catchment, while 57% of the territory is wooded and this represents the main land use category for the higher part of the valley, which has almost entirely been abandoned since the end of the nineteenth century. The remaining part (28%) is composed by open area sand scattered cultivated fields on terraces.

The Bisagno valley is geologically characterised by marly limestone flysch of Mt. Antola (Upper Cretaceous) and related base complex of Montoggio shales. Ortovero Pliocenic clays feature only at the city centre. The main stream is incised to 11km from the mouth, while the flood plain is heavily urbanized. The maximum width of the floodplain is roughly 300 m before it reaches the main culvert, which encases the stream for the last 1.4 km as far as the stream mouth; while other minor culverts partially cover the stretch between the A12 motor way and Genoa football stadium. The whole basin is subject to intense erosion conditions affected by tectonic control. The reactivation of erosion processes is related to the last drop of the base level (Brancucci & Paliaga, 2005; Paliaga, 2015).

2.2 *The largest flood*

The city of Genoa (Liguria, Italy) and the Bisagno Valley are affected by frequent floods, often with loss of human lives. Historically characterized by high flood hazards, the Bisagno Valley was recently affected by a flood event on 9 October 2014, less than three years after the tragic flood event of 4 November 2011 when six people died, including two children. In the last 50 years, four destructive floods occurred in the Bisagno Valley, in addition to some other events that caused significant damage and economic losses.

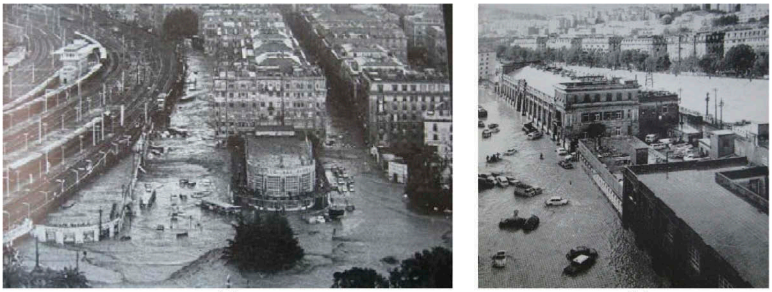
The Bisagno Valley is characterized by climatic and landform features that have been making the flood events historically common in the area. However, recent climate change and land-use variations, including some major modifications of the catchment basin, have progressively determined a decrease of the concentration time and an increase of runoff, solid transport, and flood hazard. Consequently, in recent decades a growth in the number of flood events occurred, to the extent that the Bisagno today is a famous case study on an international scale. The three largest flood events in terms of intensity and ground effects which affected the Bisagno Valley in the last two centuries (Table 1): the flood of 25 October 1822, well documented by contemporary sources, the flood of 8 October 1970, undoubtedly the most tragic on record, and the very recent event of 9 October 2014.

In 1822, the Bisagno stream occupied the entire alluvial plain from the city walls to the hill of Albaro. Its course was braided with many small channels. No buildings were along the riverbed, apart from a leper hospital and the village of Borgo Pila. By1970 the situation was completely different because of the building of the railway (1868) and urban sprawl to the east. The Bisagno stream is embanked upstream of the station and completely covered downstream, parallel to the stream are two roads.

The plain is completely built up. The bridge of St. Agata is 70 m wide and only five arches remain of the original 28. Ponte Pila does not exist anymore, and the riverbed is only 50 m. The culvert of the Bisagno stream was decided in the twentieth century: it was calculated by a group of three engineers on commission by the Genoa municipality in 1908 (Inglese et al., 1909):using definitely modest hourly values of precipitation, they calculated that the maximum flow rate of Bisagno could not exceed 500 m^3/s. Based on the underestimated data of 1908, a large project of urban development was carried out during the fascist period, and a large square was built that could celebrate the regime. In 2014 urbanization is complete; the embankments are characterized by roads, warehouses, and factories; while the alluvial plain and the sides of the valley are heavily built up with residential buildings. New culverts were built downstream of the cemetery of Staglieno at Genova Est motorway exit and near the football stadium. St. Agata bridge was repeatedly damaged and almost destroyed during the floods of 1970 and 1992. Of the ancient bridge, only two arches remain, located upstream of the final culvert, which is 50 m wide.

Table 1. Largest flood events of the Bisagno stream.

Storm event day	Rainfall event	Discharge	Flood event	Damage losses and other damage	Storm-related fatalities
1822-10-25	812 mm/24 h in the lower Bisagno catchment (Marassi)	1200 m^3/s	Regular flood. 15 h of violent rainfall a 3 h peak between 10 a.m. and 1 p.m	Many streams flooded: two bridges on the Bisagno collapsed. Mud and water reachedthe second floor of the houses at Foce district. Serious damage to shops, farms, factories and the public aqueduct. Estimated damage around half a million of Savoy liras. Not quantifiable by the historical sources	Un-know
1970-10-08	453 mm/24 h (PCAR) 394 mm/24 h (RGHI)	950 m^3/s end culvert underpressure	Regular flood. Flood of the Bisagno,Torbido, Geirato, Veilino, Fereggiano and Mermi streams	55 million Euros equivalent 1000 people left homeles 50,000 people without jobs 75 million Euros equivalent 250 people left homeless	10 fatalities only in the Bisagnovalley, 44 in the Genoa metropolitan area No reports of fatalities in the Bisagno basin, 2 fatalities in the close Sturla basin 6 fatalities
2014-10-09	141 mm/1 h (GEGR), 401/24 h (GEGR)	1000 m^3/s final culvert underpressure	Flash flood. Flood of the Bisagno e Fereggiano streams	300 million Euros, 250 people left homeless	1 fatality



(a) (b)

Figure 3. Inundations in Genoa October 1970 Bisagno overflowing: a) in the zone downstream the covering near the Genoa Brignole railway station; b) via Canevari.

3 RESILIENT CITY

Resilience is “the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner.” There is no one-size-fits-all solution to achieve resilience. Local government actors will determine how these actions apply to their own contexts and capacities. In the urban setting, risk management is an essential part of building resilience.

3.1 *Priorities for action*

The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries could be achieved following priorities for action:

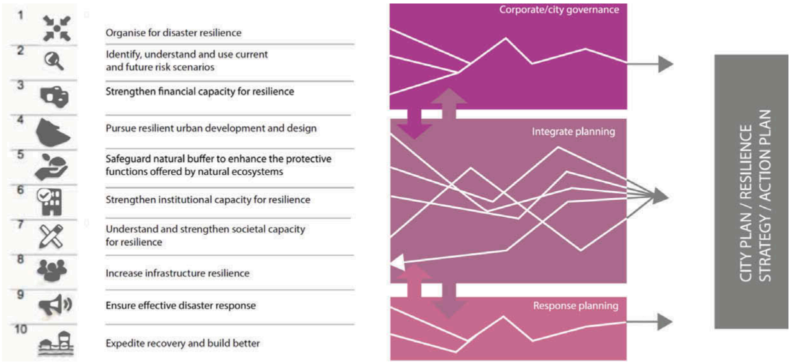
- *Understanding disaster risk*:
  Disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be used for risk assessment, prevention, mitigation, preparedness and response.
- *Strengthening disaster risk governance to manage disaster risk:*
  Disaster risk governance at the national, regional and global levels is very important for prevention, mitigation, preparedness, response, recovery, and rehabilitation. It fosters collaboration and partnership.
- *Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction:*
  The growth of disaster risk means that there is a need to strengthen disaster preparedness for response, take action in the anticipation of events, and ensure capacities are in place for effective response and recovery at all levels. The recovery, rehabilitation and reconstruction phase is a critical opportunity to build back better, including through the integrating of disaster risk reduction into development measures.

3.2 *The Ten Essentials for Making Cities Disaster Resilient*

An effective risk reduction could be achieved by applying the Ten essential (Figure 4) defined by United Nation through the Sendai Framework for Disaster Risk Reduction

- *Organize for disaster resilience*. Put in place an organizational structure with strong leadership and clarity of coordination and responsibilities. Establish Disaster Risk Reduction as a key consideration throughout the City Vision or Strategic Plan.

Table 2. City-Action Plan.



- *Identify, understand, and use current and future risk scenarios*. Maintain up-to-date data on hazards and vulnerabilities. Prepare risk assessments based on participatory processes and use these as the basis for urban development of the city and its long-term planning goals.
- *Strengthen financial capacity for resilience.* Prepare a financial plan by understanding and assessing the significant economic impacts of disasters. Identify and develop financial mechanisms to support resilience activities.
- *Pursue resilient urban development and design.* Carry out risk-informed urban planning and development based on up-to-date risk assessments with particular focus on vulnerable populations. Apply and enforce realistic, risk compliant building regulations.
- *Safeguard natural buffers to enhance the protective functions offered by natural ecosystems.* Identify, protect and monitor natural ecosystems within and outside the city geography and enhance their use for risk reduction.
- *Strengthen institutional capacity for resilience*. Understand institutional capacity for risk reduction including those of governmental organizations; private sector; academia, professional and civil society organizations, to help detect and strengthen gaps in resilience capacity.
- *Understand and strengthen societal capacity for resilience.* Identify and strengthen social connectedness and culture of mutual help through community and government initiatives and multimedia channels of communication.
- *Increase infrastructure resilience.* Develop a strategy for the protection, update and maintenance of critical infrastructure. Develop risk mitigating infrastructure where needed.
- *Ensure effective preparedness and disaster response.* Create and regularly update preparedness plans, connect with early warning systems and increase emergency and management capacities. 10. After any disaster, ensure that the needs of the affected population are placed at the centre of reconstruction, with support for them and their community organisations to design and help implement responses, including rebuilding homes and livelihoods.
- *Expedite recovery and build back better*. Establish post-disaster recovery, rehabilitation, and reconstruction strategies that are aligned with long-term planning and providing an improved city environment.

4 THE FLOOD PROTECTION WORKS OF GENOA: THE DIVERSION OF THE BISAGNO RIVER

4.1 *Introduction*

The diversion tunnel on the Bisagno River has been planned for flood protection in the city of Genoa. The first project was presented and approved in 2007, but despite the technical approval of the Superior Council of the Public Works, Ministry of the Public Works and Infrastructures, the works didn't start pending appropriate budget.

In November 2011 the city of Genoa was hit by a devastating flooding event, causing several deaths and strong damages to infrastructures, buildings, private and public goods. The most disastrous effects were due to the flooding of Bisagno River and Fereggiano creek. The Fereggiano estimated peak flow was in the range of 140 m^3/s, corresponding to a discharge flow with an associated return period T larger than 200 years.

After this event, in 2013 the City of Genoa granted the first allotment contract (I Lot – 50 million Euro allocated to solve the major hydraulic problems), that includes the safety measures for the Fereggiano creek and for the Rovare and Noce streams: among those, the Fereggiano tunnel to the sea outfall (diameter: 5.2 m; length: about 3700 m) and the catchment works by the Rovare and Noce streams (Ferrari et al. 2014). In 2017, according to the Government's Found for "Safety Italy", the detailed design for the Bisagno Diversion Tunnel was assigned, by the Special Commissioner, to a group of Designers, including three company: Rocksoil, as chief company, Hydrodata and Art, plus some specialists: Cangiano, De Sanctis, Gallo and Giomi.

4.2 *Project overview and construction systems*

The detailed design of II lot, strictly related to the Bisagno diversion tunnel and related civil works, started last August and now the project, after the exam of the Supreme Council of the Public Works, has been subjected to the study of environmental impact (VIA procedure). As for Lot I a revision of the final design, approved in 2007, has been necessary. Figure 4 shows the general overview of the project: the aim of the project is to intercept the flood flows of the Bisagno river, at the Sciorba sports complex, and discharge them into the sea through a diversion tunnel with a total length of about 6,500 m.

The project is divided into 3 main parts: upstream section, central section and downstream section. The main element of the *upstream section* (Figure 5) is the intake system, composed by the Bisagno river barrage and the lateral spillway; at this point the Bisagno's flow is splitted between the original culvert (renwed in the underground strech from Brignole Station to the sea outfall) and the diversion tunnel. The upstream side of the diversion tunnel will be bored by conventional excavation method (645 m) starting from the area of the former kennel of Genoa, located near the Sciorba stream. In this area will be located the working site and an adit tunnel will start to reach the diversion alignment by means a conventional tunnel, 398 m long. The adit will intersect the diversion tunnel into a big cavern, which will be used to assemble the TBM and to launch the mechanised tunnel to south towords the sea outfall; the mechanised bored section of the diversion tunnel is 5785 m long with a diameter of 10.7 m. Starting from

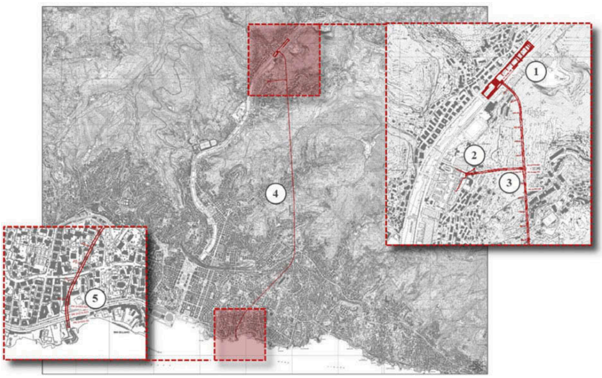


Figure 4. II lot project overview: (1) Intake system with Bisagno River Barrage and lateral Spillway; (2) Sciorba Intake; (3) Service tunnel and cavern; (4) Diversion Tunnel; (5) Link to the sea outfall.

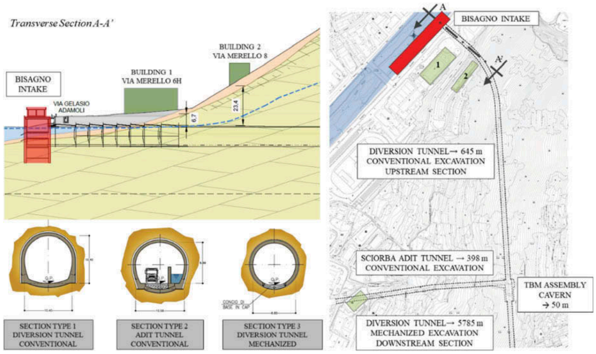


Figure 5. Bisagno diversion tunnel: upstream section.

the cavern the north section, up to the Bisagno river, will be excavated too, by conventional method. The last part of this upstream section will underpass Merello and Adamoli Streets, where some residential buildings are located, together with the football and swimming sports center. The adit will be used to spillway the Sciora strem too. The final stretch of the Sciorba stream flows in an urban area, at the right of the Bisagno River and it is located about 650 m downstream of the Bisagno intake. The Sciorba stream flows underground in correspondence with the planned construction site area, because in the past the Sciorba stream has been channeled and trimmed to allow the construction of a series of service buildings in that area.

The construction of the Bisagno diversion tunnel offered the opportunity to realize the spillway of the Sciorba in order to reduce the flow rates in transit along the underground section, which in the past caused flooding due to hydraulic inadequacy of its culvert. The figure 5 shows the different section type designed for the described tunnel stretches, considering the specific tunnel function and the applied excavation method. The construction system for these strectches provides the use of the "drill&blast" method, placing a prelining after excavation, composed by steel bolts or ribs and shotcrete layers and casting in situ the final lining. For the last stretch, near the Bisagno river, where low overburden is present, grouting treatments will be executed before excavation and low vibration system will be used to reduce noise and interference with the buildings ("super-wedge" and "smooth blasting" systems).

The diversion tunnel located downstream to the cavern will be excavated by TBM up to the sea outfall and it is identified as the *central section* of the project. The excavation will be executed by an open "hard-rock" TBM, equipped by drilling systems, able to execute probe drilling, forepoling and grouting activities in advance of the core-face and radial bolting for the excavated cavity. The TBM will advance by grippers and the prelining will be mainly composed by radial bolts and steel wire-mesh; the shotcrete layer will be placed by a robot system about 40–50 m far from the face, in fractured rock-mass the shotcrete could be placed immediately back to the face by a manual system. The back-up of the TBM will place the invert segment, equipped with tracks to manage the following formworks to cast in situ the final lining. Waterproofing will be placed, together with drainages, located radially the final lining, to dewater the groundwater level up to a water-pressure to be supported by the final lining.

The *downstream section* defines the sea outfall system. The final section of the spillway (50 m) will underpass the promenade of Corso Italia and will be bored by conventional excavation method from the arched structure that supports the promenade.

The excavation will start from the Corso Italia beach and will be executed by grouting treatments to create the "arch effect" around the excavation profile and waterproof the fractured rock-mass: the sea-level intersects the tunnel section. In Figure 6 (left) a longitudinal profile of the tunnel is shown, with the grouting activities in green, and (right) the section of the diversion tunnel under the arches of Corso Italia. Note on the left the section of the Fereggiano

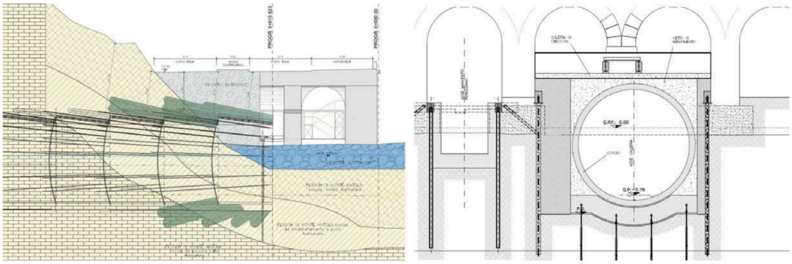


Figure 6. Bisagno diversion tunnel: downstream section. Longitudinal and transverse sections.

channel, which reaches the sea in the same point of the Bisagno diversion by means of a common portal.

The TBM coming from upstream will be stopped at the arrival shaft, located in the beach, passing throught the conventional downstream section. The barrier delimiting the construction will be conver by information panels which will update the public about the state of work (Figure 7).

4.3 *Hydraulic dataset*

The Bisagno diversion has been designed in order to take a flow of 450 m^3/sec, so that the flow in the final section, near to the mouth of the Bisagno, does not exceed 850 m^3/sec (considering the whole flow, with an associated return period T of 200 years, is 1300 m^3/sec taking into account the rainfall statistics).

The tunnel capacity has been checked with reference to a flow of 460 m^3/sec, considering the flow derived from the Sciorba stream, equal to 8 m^3/sec. The capacity has been verified by both numerical analyses and physical modelling in real tests. The degree of filling, considering a Strickler coefficient equal to 65 $m^{1/3}$/s, is always less that 75%; it is not foreseen a "in pressure" behavior of the tunnel. The inset provides a slide with a Creager profile and a dissipation tank to introduce the water into the tunnel diversion. The flow diverted into the tunnel is regulated by a barrier with adjustable gates; in this section the pavement of the river is coated with stones and new banks will be made; upstream a selected bride is located, to stop any solid transport. Near the intake, a building will be constructed with the operational equipment and with a control room.

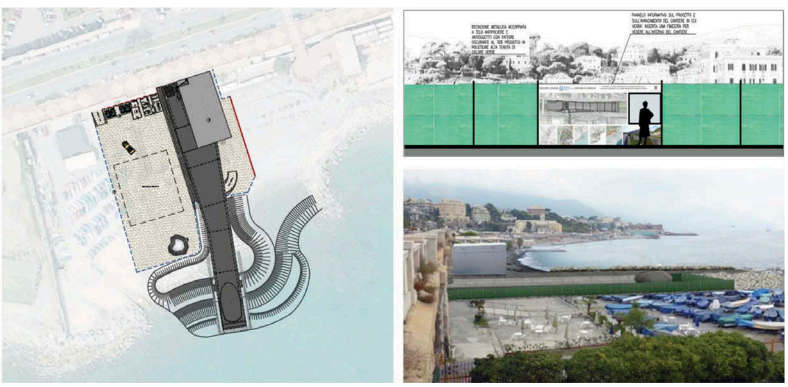


Figure 7. Bisagno diversion tunnel: downstream section. Plan and area overview.

Figure 8. a) Nourishment of Quarto Bolivar beach. b) Outfall area of the Bisagno diversion.

4.4 *Geological and Environmental aspects*

The alignment of the Bisagno diversion is mainly affected by limestones and marls of the Formation of the "Flysch del Monte Antola", with overburdens ranging from 10–20 m up to 280 m. Just a strict section, about 200 m long, is interested by shale and claystones of the Formation of the "Argilliti di Montoggio" with overburden of 40–45 m.

The upstream section, where the diversion tunnel is connected with the Bisagno river, passes throught alluvional deposits too, composed by gravels and sands, as well as the downstream section which is interested by the fractured limestones rock-mass and by the sandy beaches of Corso Italia. The characteristics of the limestones are suitable to use the materials resulting from the excavation to produce shotecrete and concrete for the tunnel constructions. Furthermore the excavated material, appropriately shattered and washed, will be used for the nourishment of the beaches along the coasts of Genoa. Properly projects have been prepared to manage the activities for the beaches, transforming the usual problems of the relocations of the excavated materials in a social opportunity for the community of Genoa.

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