AIR-POLLUTION MANAGEMENT FOR THE TUNNEL LUGANO

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SYNOPSIS: Air-pollution management is a major issue in all new road tunnel projects, particularly in urban areas. The present paper documents the extensive investigations carried out for the new tunnel Vedeggio-Cassarate (Lugano, Switzerland) in order to ensure full compliance with the environmental legislation as well as achievement of the environmentally best possible solution within the given conditions.

A number of simulations of pollutants generation and dispersion have been carried out for different exhaust management concepts and were essential for ventilation design for normal operating conditions. The solution adopted is expected to minimize the environmental impact of the new tunnel while satisfying all other constraints, particularly with respect to tunnel safety. Additionally, an extensive measurement campaign was started. This allows for a comprehensive monitoring of the environmental conditions before beginning the tunnel construction, during the whole construction phase and after tunnel opening.

Based on the extensive theoretical and experimental data available it was decided that specific equipments for exhaust treatment are not needed in this particular case. The monitoring of the environmental conditions will continue during tunnel operation. Depending on the results from the first three years of operation it will be decided if an upgrade of the ventilation system with a state-of-the-art exhaust treatment system is necessary. Ventilation design was adapted in order to leave this path open.

1 INTRODUCTION AND OBJECTIVES

An increasing sensitivity towards environmental concerns, mostly related to air quality, is consistently observed in recent tunnel projects, particularly in urban areas. The pollutants emitted in the tunnel are expelled in a concentrated manner at the tunnel portals or through ventilation stacks. In many cases a dilution strategy, realized using ventilation stacks with sufficient height and exhaust velocity, is entirely adequate. In other situations this strategy needs to be combined with exhaust treatment.

The present paper describes the investigations carried out for the new 2.6 km long tunnel in Lugano, in southern Switzerland. The key objective is to ensure that the goals established in the national legislation will be respected after the realization of the new tunnel.

The investigations steps carried out before, during and after the realization of the tunnel included:

- Traffic modelling and evaluation of motor-vehicle emissions.
- Numerical simulation of different exhaust-management strategies.
- Result analysis and identification of the best alternative.
- Implementation in the design process.
- Investigation on the necessity of an exhaust-treatment system.

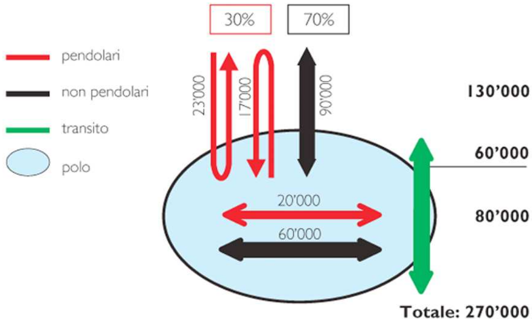
The present paper focuses on the environmental investigations carried out for the tunnel. Particular attention was devoted to the investigation of exhaust treatment. The state-of-the-art of exhaust-treatment technologies was investigated and its applicability and benefits, general as well as related to the project considered, were critically assessed. The best available technologies were investigated in terms of needs, feasibility, technological and economical risks. Based on a cost-benefit analysis it was concluded that, at the current state of knowledge, the benefits from an exhaust system for the tunnel Lugano would be limited and would not justify the additional investments.

The technological and design-related aspects will be treated in a companion paper by the same authors: “Exhaust-Treatment Technologies for the Tunnel Lugano – An Investigation on the State-of-the-Art” [1].

2 THE TUNNEL LUGANO

The tunnel described in this article is embedded in an extensive project concerning the reorganisation of the mobility (Transport management of the Lugano area) for the agglomeration of the city of Lugano (approx. 100’000 inhabitants). This area, which is characterised by a very unbalanced modal-split towards the individual traffic, by problems with traffic management, by having one of the highest pollution levels in Switzerland caused by the unfavourable topography as well as by pollutions from the adjacent areas (Lombardia). The agglomeration is characterised by a high concentration of inhabitants and employment opportunities in the city centre, by intense commuter traffic also from the close-by Italy, obliged to cross the whole agglomeration to arrive at their destination, and by very few access roads that make traffic management difficult.

Since the beginning of the 90^{th}, the Canton Ticino and the communes of the agglomeration of the Lugano area have faced the mobility problem of the area by elaborating a comprehensive mobility plan (PTL) followed by a series of documents concerning special aspects like urban management (COTAL), road transport (PVP), public transport (OTPLu), air quality (PRAL), parking politics (PPP) and accompanying environmental measures - all coordinated among each other.



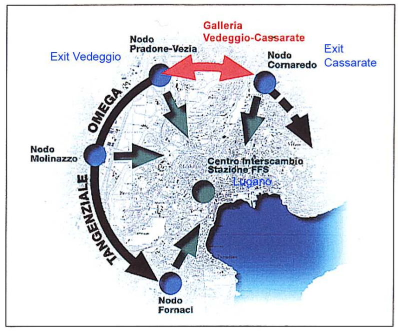


Fig. 1: Left: Traffic flow towards and across the centre of Lugano [7]. Right: Organisation and position of the new communication road of Lugano ("Omega") [7].

Among the main objectives of the PTL, the following three are considered as the most important for this study:

- improving the access and relocation possibilities inside and towards the agglomeration of the Lugano area;
- reducing total emissions;
- reducing the environmental impact for the most populated area and possibly shift towards other less conflict-laden areas.

The new organisation of the road traffic is based on a communication road outside the city, which is supposed to channel the traffic flows in order to reallocate it in different sectors according to its destination.

This communication road is defined as "Omega" (Fig.1) according to its shape. The tunnel Vedeggio – Cassarate is the main connection for the access flows between the valley of Vedeggio (highway) and the valley of Cassarate (north of the city).

The tunnel is composed of a single traffic tube of about 2.6 km length with bidirectional traffic on two lanes and a safety and technical duct parallel to the tunnel, with 8 cross connections. In normal operating conditions, exhaust is extracted in the central part of the tunnel. In case of fire it is possible to extract the smoke through dampers in a false ceiling and expel it through the stack.

The expected traffic volume will amount to approximately 27'000 vehicles per day with a relatively low percentage of heavy-goods vehicles (approx. 4%) caused by the scarce activity of handcrafts-industrial enterprises within the city and by the prohibition of transporting dangerous goods through the tunnel. The share of diesel-engined vehicles rises constantly and should reach 30% within a short time. The increase of this vehicle category occurred only recently in Switzerland, thus this mostly concerns modern vehicles of the newest generation, mostly equipped with carbon-particulate filters.

Four possible layouts of the ventilation system have been considered:

V0: Realisation of a ventilation station with vertical shaft and exhaust stack in the middle of the tunnel (base solution adopted in the final design), see Fig. 2.

V1: Realisation of two ventilation stations with exhaust stacks, one at each tunnel portal, Fig. 3.

V2: Realisation of one ventilation station only, with expulsion stack at one portal, Fig. 3.

V3: Tunnel without stacks and exhaust expulsion directly through the portals Fig. 3.

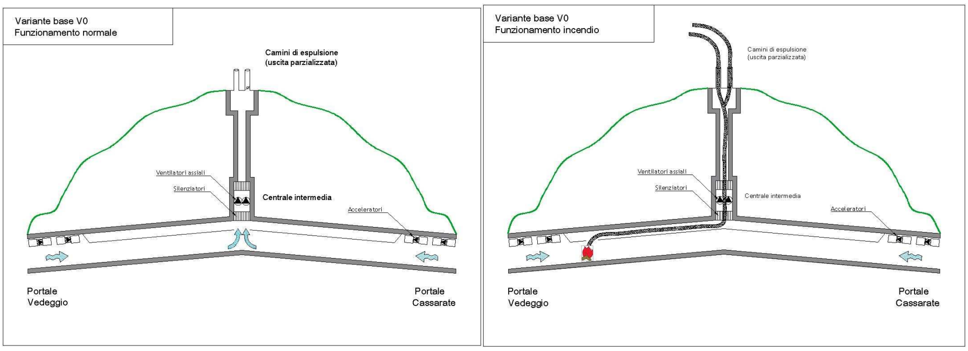


Fig. 2: Version V0 (approved solution). Normal operation (left) and fire operation (right).

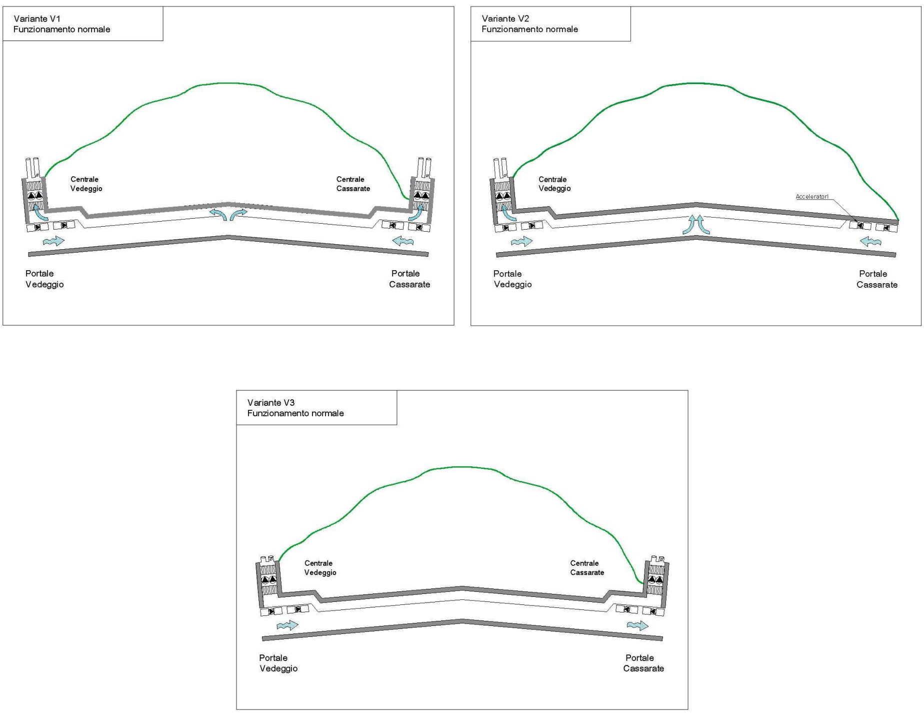


Fig. 3: Alternative layouts considered (V1 – V3, normal operation).

The selection of layout V0 was based on the considerations summarised in Fig. 4.

Layout	*Description*	*Evaluation*	*Remarks*
V0	Basic layout: one ventilation station, expulsion from the central stack	Approved version	Approved and in realisation Best compromise from the environmental point of view
V1	Two ventilation stations with stacks at the portals	Very unfavourable	Very expensive Very unfavourable regarding the environment without application of filters Would require a new approval process of the projects
V2	One single ventilation station with stack at one portal	Unacceptable	Not in line with the Swiss regulation on road-tunnel ventilation Would require a new design approval process
V3	Without stack, exhaust through the portals	Unacceptable	Unacceptable from an environmental point of view (uncontrolled emissions of pollution at the portals) Would require a new design approval process

Fig. 4: Comparison of the different layouts and selection of version V0.

3 LEGAL BASIS

The main environmental standards concerning the management of exhaust air are:

– Federal Act of 7 October 1983 (state 4 July 2006) on the Protection of the Environment (Environmental Protection Act, EPA);

– Ordinance of Air Pollution Control (OIAt) of 16 December 1985 (state 23 August 2005).

Some important principles are stated in the EPA:

– The atmospheric pollution, noise, vibration and radiation should be limited by measures applied at the source (limitation of emissions);

– Independently from the existing pollution load, the emissions have to be limited as much as possible within the bounds of technological improvements, operating conditions and economical possibilities.

– The existing law prescribes that the costs for the measures adopted are sustained by the polluter (“polluter pays” principle).

The main allowable immission levels stated in the OIAt are:

– Nitrogen dioxide (NO_2) (annual average value) 30 µg/m^3

– Particulate matter (PM10) (annual average value) 20 µg/m^3.

4 ENVIRONMENTAL CONDITIONS

The available environmental data within the project area are summarised in Fig. 5. The data clearly show that the legal values for NO_2 are generally respected but the allowable PM10 concentrations are consistently exceeded.

YEAR	Origin	Pollutant	Limit OIAt µg / m³	Immission µg / m³
2002	Surface roads and other sources	NO_2	30	30
		PM10	20	35
2010	Surface roads and other sources	NO_2	30	25
		PM10	20	28

Fig. 5: Current (2002) and predicted immission values at the time of tunnel opening (2010), excluding the effect of the tunnel.

It is interesting to estimate the contribution of the tunnel emissions from the new tunnel Lugano in comparison to the estimated traffic emissions of the agglomeration of the Lugano area.

The estimated emissions of nitrogen dioxide for the Lugano area are approximately 1’180 t/year. The estimated emissions for the tunnel reach 8.6 t/year. This corresponds to 0.7% of the total traffic-related emissions.

The PM10 amount is even lower. The most recent evaluations estimate the total emissions for the Lugano area at approx. 177 t/year, whereof approximately 86 t/year are caused by traffic (Fig. 6).

Category	Origin	Emission (kg / year)	%
TRANSPORTATION	Light vehicles	57'247	32.2%
	Heavy vehicles	29'868	16.8%
	Other means of transportation	16’979	9.5%
TOTAL TRANSPORTATION		**104'094**	**58.5%**
HOUSEHOLDS		**16'525**	**9.3%**
INDUSTRY AND HANDCRAFT		**48'299**	**27.2%**
AGRICULTURE AND HANDCRAFT		**8'919**	**5.0%**
TOTAL EMISSIONS		**177’837**	**100%**

Fig. 6: Estimated emissions of primary PM10 [kg/year] for the Lugano area [3].

The estimated total PM10 emission from the tunnel Lugano is 199 kg. This corresponds to 0.2% of the whole traffic-related emission and 0.1% of the total emissions in the area. It is worth mentioning that the basic load imported from outside account for approximately 20 µg / m^3 in the Lugano area.

As a further contribution to the description of the actual and predicted situation, taking into account the measures included in the PTL and in other plans, the measured and predicted loads for nitrogen oxides and PM10, now and at the opening of the tunnel, are presented.

Fig. 7 (left, current situation) shows that the allowable limits for NO_2 are currently clearly exceeded within the city and along the main communication roads, particularly along the highway located in the valley of Vedeggio. Conversely, the allowable limits are mostly respected elsewhere. Fig. 7 (right) summarises the effect of implementing all measures planned with the PTL on the total NO_2 immissions. In particular a clear improvement, especially in the centre of Lugano and, more generally, in other residential area can be noted. Two points of degradation can be observed, which correspond to the tunnel portals. The local negative trend is caused by the creation of new traffic axis. However, there is no negative impact in the neighbourhood of the stack. The increase of the emissions derived from the stack is compensated by the reduction of the traffic on the superficial roads.

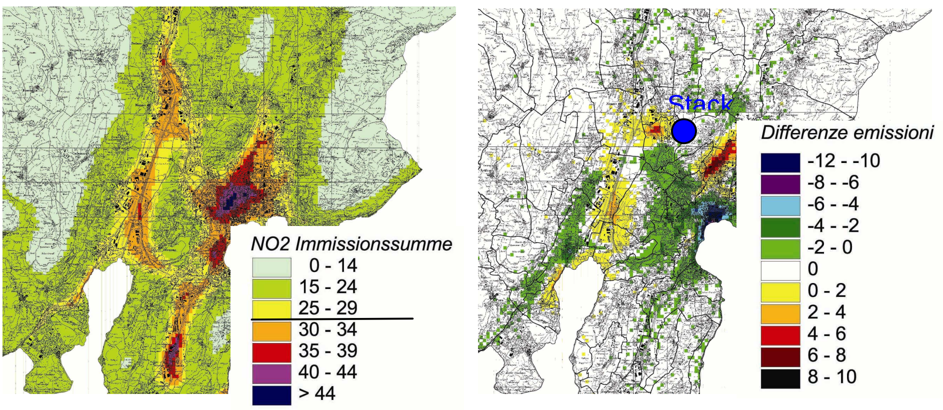


Fig. 7: Left: current immissions of NO_2 [5]; Right: Evolution with the realisation of the PTL [6].

A similar positive immission development can be observed for the PM10 in the entire Canton. The mobility management and the modernised vehicle fleet result in a general decrease of the immissions, however still not sufficient for respecting the allowable limits (Fig. 8).

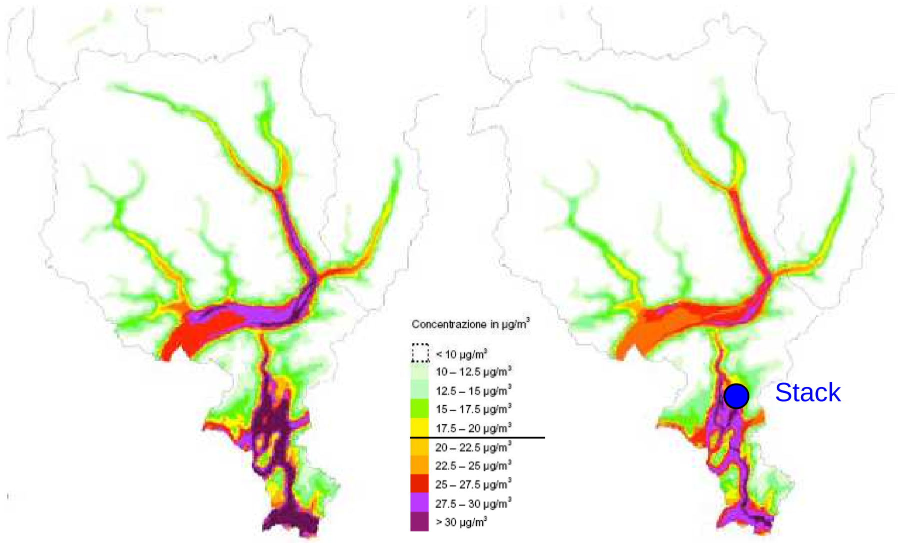


Fig. 8: PM10 immissions in µg/m^3. Comparison between the situation in 2000 (left) and the forecast for 2010 "business as usual", which includes the new tunnel (right) [4].

5 POLLUTANT-DISPERSION ANALYSIS

5.1 Analysis

Simulations were carried out in two steps in order to assess the pollutants dispersion and their concentration:

- In 1998, when the tunnel project was published, using two different pollution-dispersion models, Gaussian and Lagrangian. The analysis was based on the worst cases (stack 15 m high and small exhaust flow rate, 40 m^3/s).
- A second verification was carried out in 2003 based on the Gaussian model, in order to quantify the benefits resulting from two improvements, a higher stack (20 m) and an increased flow rate (160 m^3/s).

In order to calculate the dispersions, local parameters, measured at 4 different sites over a period of two years, were used. Two measurement sites were located at the portals, the other two at the possible positions of the stack.

The investigations reveal poor dispersion conditions at the portals: on the west side there are unfavourable inversion conditions with formation of cold air lakes, on the east side low wind velocity caused by the topography. The central position (Comano) is exposed to wind systems and it is better suited regarding the cold air lakes (Fig. 9).

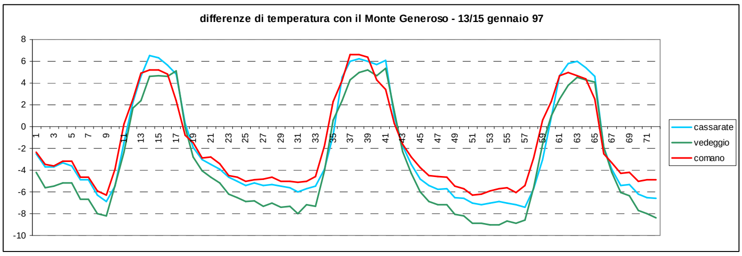


Fig. 9: Example of thermal inversion conditions at the three reference points at the tunnel exits. Temperature difference relative to Monte Generoso. The effect is weaker at Cassarate than at Vedeggio because of the heat island caused by the city of Lugano.

The two pollutant-dispersion models have produced substantially similar results (Fig. 10).

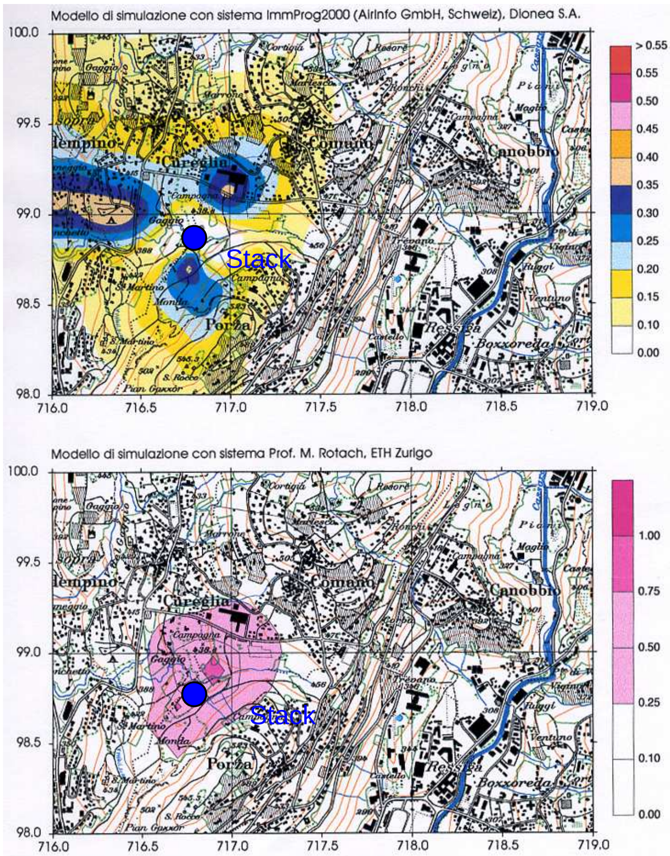


Fig. 10: Comparison of immissions caused by the new stack in Canobbio – Campagna, simulated with the ImmProg 2000 model (top) and Cal Puf models (bottom), minimum exhaust rate (40 m^3/s), height 15 m, µg/m^3 NO_2, additional load, annual average.

5.2 Results

The different project phases of the tunnel Lugano allowed developing an optimised ventilation system. The current approach guarantees that the immission limits for NO_2 close to the ventilation stack at Comano are never exceeded. This goal could be achieved owing to the following effects:

- environmental conditions, with immission levels far below the values measured at the tunnel exits;
- favourable conditions for pollutant dispersion due to the periodic breezes and the reduced incidence of cold air lakes;
- technical provisions adopted, in particular the height of the exhaust stack and a double pipe, which allows increasing the exhaust velocity by reducing the outflow section.
- increased air fluxes expected during normal operating conditions (up to 200 m^3/s), which allow an optimised dispersion of the exhausts of the stack.

Under these conditions, the simulations based on numeric models revealed that the maximum average additional contribution from the stack is less than 1% of the current NO_2 load. The analysis showed that the environmental impact of the tunnel Lugano is very small in comparison to the pre-existing situation.

Year	Source	Substance	Limit OIAt µg / m^3	Base Load µg / m^3	Additional immission max µg / m^3
2002	Surface roads	NO_2	30	30	3.15
		PM10	20	35	0.37
2010	Surface roads	NO_2	30	25	1.33
		PM10	20	28	0.19
2010	Stack h = 15m, Exhaust flow rate 40 m3 / s	NO_2	30	25	0.75
		PM10	20	28	0.1
2010	Stack h = 20 m, Exhaust flow rate 160 m3 / s	NO_2	30	25	0.15
		PM10	20	28	0.0046
2010	Surface roads + stack h = 20 m, Exhaust flow rate 160 m3 / s	NO_2	30	25	1.41
		PM10	20	28	0.19

Fig. 11: Summary of environmental conditions related to the stack.

The map of supplementary immissions confirms that the additional load can be considered as not influencing if compared to the base load.

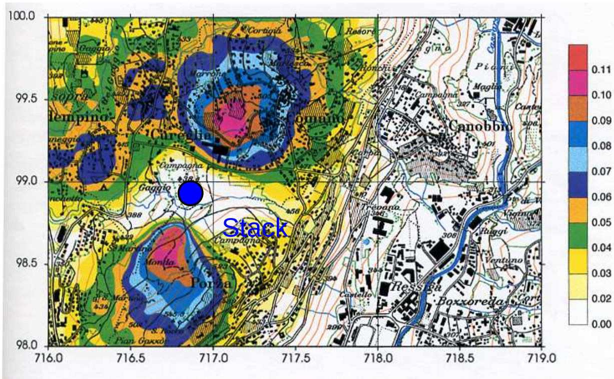


Fig. 12: Immissions caused by the new stack in Canobbio in µg/m^3 NO_2 (additional load, annual average) simulated with the ImmProg 2000 model, exhaust flow rate 160 m^3/s, stack height 20 m.

Fig. 13 shows for comparison that without stack and exhaust at the portals, the immissions might increase not only in the vicinity of the portal, but also in the area of the stack.

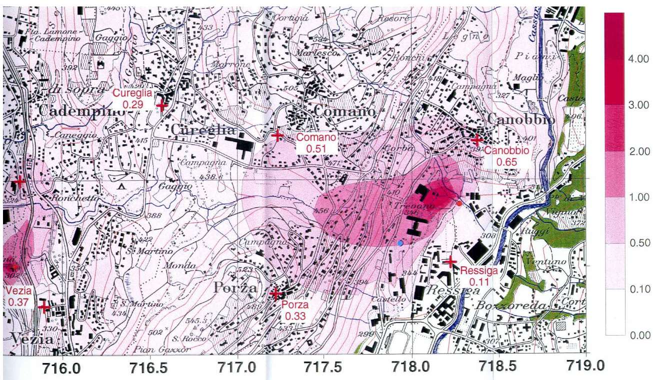


Fig. 13: Immissions caused by the air expulsion at the portals simulated with Cal Puf model, minimum operation regime, µg/m^3 NO_2, additional load, annual average.

The environmental situation for particulate matter is different, because in the entire territory the immission limits are exceeded. In this case, the additional load from the tunnel is expected be less than 0.2% of the total load and can be considered as unimportant.

In these simulations possible improvements of the overall situation due to the reorganisation of the traffic following the PTL were not taken into account.

5.3 Conclusions

The analysis of the actual situation, the expected evolution and the calculation of the contribution from the stack for various emission scenarios lead to the following conclusions:

- The PTL and the other programmes allow achieving the objective of reducing the emission load, in particular by improving the situation in the densely populated areas.
- The exhaust stack is necessary not only in case of accidents, but in particular because the portal would produce much worse immissions in the entire area, because of the unfavourable climatic conditions with higher immission rates.
- The effect of the stack on its neighbouring area was strongly reduced by technical measures as well as by the favourable climatic conditions.

6 ENVIRONMENTAL MONITORING

Parallel to the planning of the PTL and the tunnel, the Cantone Ticino had decided to set up an air-quality monitoring system consisting of continuous measuring stations and passive sampling devices.

This monitoring system allows

1. To control the evolution of the atmospheric pollution.
2. To verify the results of the planned measures, for example the opening of the tunnel Lugano.
3. To adopt emergency measures if the immission values are exceeding the thresholds drastically.

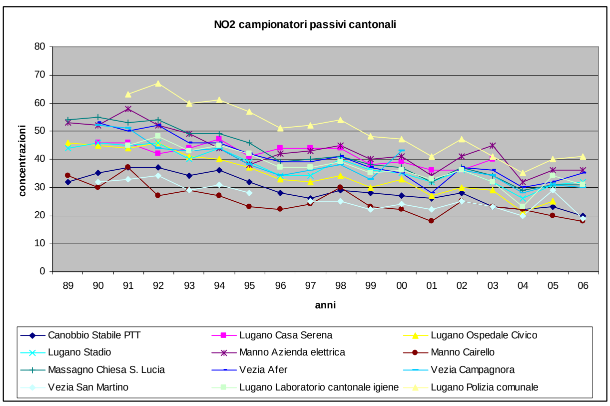


Fig. 14: Average annual concentration of NO_2 measured with the passive sampling devices of the specific PTL monitoring network (µg/m^3).

The values measured are constantly provided to the public through the media (radio and newspapers) as well as online in Internet.

The monitoring system has for example allowed verifying that during the last 10 years the immissions values are constantly decreasing (Fig. 14).

7 EXHAUST TREATMENT

The topic of filtering the exhaust at the stack of the tunnel Lugano is described comprehensively in the article "Exhaust-treatment technologies for the tunnel Lugano – an investigation on the state-of-the art" [1].

The analysis of the current state of technology has shown that treatment systems for PM10 are mature and performing, allowing for a reduction of emissions by up to 90%. However, in this particular case, the practical benefits are insignificant, as shown by the immission modelling. This is related to the excellent dispersion at the stack and the extremely low concentration of PM10 in the tunnel exhaust, typically of the order of 0.05 mg/m^3.

The treatment of other gaseous pollutants is currently in its initial operational stage. Up to now no reliable data are available concerning the real efficiency as well as operational costs and durability of the active carbon filters, which are generally used in this type of application.

Layout	Emissions				Immissions max			
	NO_x		PM10		NO_2		PM10	
	t / a	(1)	kg / a	(1)	µg/m^3	(2)	µg/m^3	(2)
Stack without air treatment	8.2	0.70%	199	0.22%	0.15	<1%	0.0046	<0.2%
Stack with PM filtration	8.2	0.70%	19.9	0.02%	0.15	<1%	0.00046	0.02%
Stack with complete filtration	3.28	0.28%	19.9	0.02%	0.038	0.40%	0.00046	0.02%

Fig. 15: Emissions and immissions balance for different exhaust treatment technologies. Notes: (1) % of the stack emissions with respect to the total road immissions of the Lugano area; (2) % of current immissions measured in the area.

The cost estimates for the realisation of exhaust-treatment systems were assessed based on supplier's data. The total cost for the filtration of particulate matter using an electrostatic precipitator over a period of approximately 10 years mounts up to at least 4'700 CHF/kg. On the other hand, the estimated costs for the utilisation of vehicle filters are about 78 CHF/kg. In addition to the lower cost of individual pollution-control measures on the vehicles it should be considered that such measures are effective everywhere and not only within the limited area of the tunnel. Thus, their beneficial effect is noticeable on the entire territory.

Regarding the practical effects, Fig. 15 indicates that in this particular case the effects of exhaust-treatment systems, either only for particulates or for all pollutants, are irrelevant from the environmental point of view and impossible to measure.

8 CONCLUSIONS

The investigations summarized in the previous chapters lead to the following conclusions:

– The benefit from an exhaust-treatment system installed at the stack of the tunnel Lugano would be very modest.
– The currently available technology can be used with limited technologic and economic risks only for particulate matter.
– The treatment of gaseous substances is still under development and doesn't yet justify realisations at full scale.

Based on the conclusions mentioned above, the following procedure is recommended:

– Completing the realisation of the current project.
– Take into account the possibility of upgrading the ventilation system with exhaust-treatment facilities in the future.
– Conducting an air-quality monitoring.

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THE AUTHORS

Attilio Gorla, MS, graduated in Civil Engineering from the Swiss Institute of Technology (ETH) in Zurich in 1974. Former owner of an engineering office, he joined the road authority of Canton Ticino in 1994. He is responsible since then for the planning and realization of the new combined transportation systems for the Lugano area, in southern Switzerland. He is the overall project leader for the tunnel Vedeggio-Cassarate in Lugano, in construction.

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Marco Bettelini, Ph.D., graduated in mechanical Engineering from the Swiss Institute of Technology (ETH) in Zurich in 1984. He obtained a Ph.D. in Engineering at the Swiss Institute of Technology (ETH) in Zurich in 1990 and subsequently followed a post-graduate curriculum in Safety Engineering at EPF Lausanne, ETH Zurich and HSG St. Gall. After a Post-Doc at Brown University, he held positions with ABB (Baden, Switzerland), HBI Haerter (Zurich, Switzerland) and INELMEC (Minusio, Switzerland, as CEO). He is currently safety specialist with Lombardi Ltd. He is responsible since 2002 for tunnel safety, ventilation and equipment design for the tunnel Vedeggio-Cassarate in Lugano, in construction.

Luca Colombo is responsible of the “Ufficio protezione Aria, UPA”, air protection agency of the Cantone Ticino, in Bellinzona, Switzerland. He holds since 1987 a M.Sc in organic chemistry from the ETHZ (Swiss Federal Insitute of technology of Zurich), Switzerland and since 1991 a Ph.D. in natural sciences from the ETHZ (Swiss Federal Insitute of technology of Zurich), Switzerland.

During the period 1991-2003 he was vice-director of the Ufficio Industrie, of the Cantone Ticino and in 2003 he was nominated director of the UPA.