Composite Traffic Ducts Can Help Improve Air Quality in Cities

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***Abstract*-The quality of ambient air is an issue of growing concern, particularly in cities. In many parts of Europe, the most severe threat to this quality comes from intensive road traffic. This article presents some ideas of improving the air cleanness by isolating the heavy traffic at the most populated areas in the so-called "traffic ducts". Modern technology makes it possible to realize such ducts in both new construction and improvement projects of roads and bridges. The materials that allow crossing frontiers in this field are fibre-reinforced polymers (FRPs. In this article, a number of possible traffic duct solutions employing FRPs are globally presented, followed by some general notes and predictions of future developments.**

Keywords- Bridge Engineering; FRP Structures; Composites; PM Emissions; Air Pollution; Sustainability

I. INTRODUCTION

Growing urbanization and welfare are legitimate aspirations nearly all over the world. There is a general agreement that these aspirations should be realized in a sustainable manner. In Europe, one of the sustainability issues that receive much attention in recent years is the quality of ambient air in highly urbanized areas, particularly in cities. This has been expressed in various documents and programs of the European Union, like the URBACT II program [1]. One of the top recommendations of this program is "Make sure the metrics reflect the mobility of the future by using environmental indicators, such as CO_2 emissions reduced, air quality improved, day and night time noise reduced, energy saved and fossil fuel dependence reduced".

The concern about air quality in the European cities is not new. It has been on the agenda for several decades already. In 2005, it resulted in the EU directive [2] that aims at bringing the acceptance level of PM[1] pollution back from 40 to 20 μg/m^3 in 2020. The EU directive admits that this particular kind of air pollution brings the biggest harm to human health in urban areas, resulting in considerable reduction of life expectancy (Fig. 1).

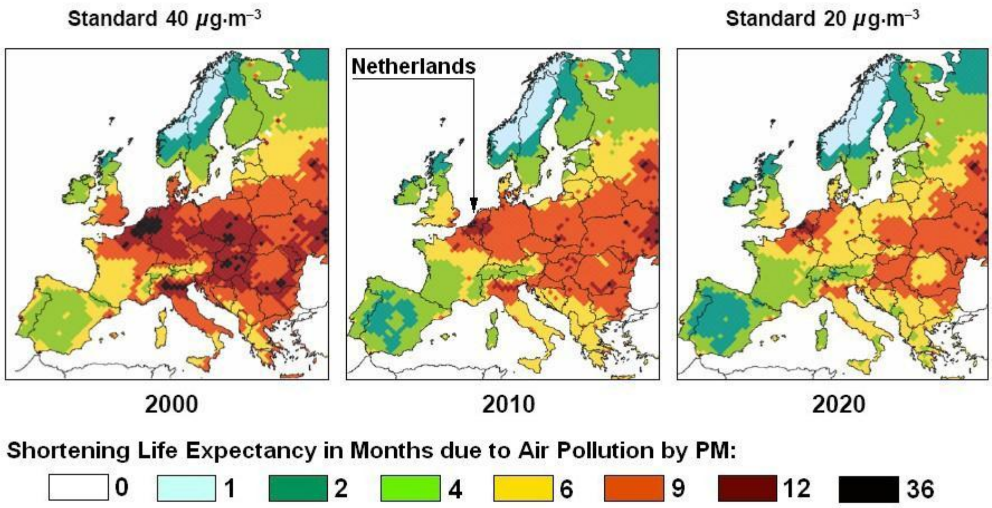

Fig. 1 Reduction of life expectancy in Europe due to air pollution by PM over the period 2000 - 2020 [2]

As shown in Fig. 1, Netherlands is one of the countries with the highest rates of air pollution by PM in Europe. This is not surprising considering the highest population density and the country's location in the delta of main European rivers, which earned it the name of a "gate to Europe" throughout the centuries. The traffic intensity on the Netherlands' roads is by far the highest on the continent; and so is the emission of air pollutants like PM by this traffic. Nonetheless, the publication of the EU directive caused political turmoil in the country. It also inspired engineers to seek technological solutions that would improve the air quality. This article presents some structural solutions aiming at isolating the traffic from ambient air.

[1]PM (Particulate Matter) is the air pollution by fine dust particles – in European cities mainly sooth from combustion engines of cars and other vehicles. The pollution by PM is the major component of air pollution in European cities.

II. WHY TO ENCASE THE TRAFFIC?

This section focuses on improving the quality of ambient air in densely populated urban areas, with the purpose to provide better and healthier living conditions for people. This narrows the problem down because there can also be other areas and other reasons worthwhile improving the air quality, e.g., unique natural habitats, wildlife migration routes and breeding grounds, heritage areas that deserve protecting, etc. There are also, obviously, other air pollutants than PM and other sources of air pollution by PM than traffic that is the main concern of this article.

One can consider several actions in order to decrease the air pollution by traffic. In the most general sense, these actions can be categorized into three main strategies: decreasing the road traffic, making the vehicles cleaner and intercepting the pollution. The exemplary actions of these strategies are shown below (Fig. 2):

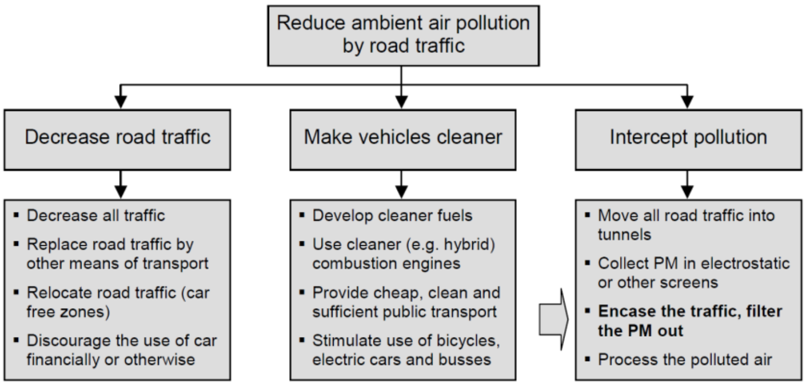

Fig. 2 Three strategies to reduce the pollution of ambient air by road traffic

It is certainly advisable to make a thorough assessment that results in the selection of the most efficient actions. However, the lessons learnt from the latest decades indicate that such assessments – no matter how thoroughly performed – remain disputable. The significance of many actions strongly depends on the local situation. Moreover, the issue is politically sensitive, the discussions are often emotional and the parties involved tend to point at each other before taking action by themselves. Meanwhile, there is a continuing health damage going on in the residential areas crossed by intensive traffic roads, like the one that connects Rotterdam with The Hague (Fig. 3) [3]. Therefore, no comprehensive assessments are presented in this article. The discussed action – encasing the traffic and filtering the PM out – should be seen as an ultimate measure, justified by the fact that nearly all other measures have already been applied to some extent. In this sense, it is not the measure that pretends to replace the other ones, but that completes them.

Fig. 3 Highway A13 from Rotterdam to The Hague crossing the residential areas (photo Walter Herfst) [3]

This article presents some conceptual solutions to highway encasing projects that are currently discussed in the Netherlands. The focus lies on the structures that employ fibre reinforced polymers (FRPs) for this purpose, as the applications of these new materials stimulate innovation and extend the feasibility frontiers in construction engineering. The conceptual solutions from this group of materials are mostly the author’s own. The solutions in other, more conventional materials – predominantly by well-known Dutch engineering companies – will, however, briefly be presented too.

III. DISCUSSED PROJECT LOCATIONS IN THE NETHERLANDS

As mentioned, encasing of a motorway is an ultimate measure. It will certainly not be recommended at all locations, but only at those where the hindrance, health impact and other harmful effects to the surrounding are unquestionably damaging. Unfortunately, this is the case at several locations in the Netherlands, particularly in the so-called “Randstad”. This name refers to the agglomeration of cities in Western Holland, roughly between Rotterdam and Amsterdam, inhabited by over 7 million people, which is nearly the half of the entire country’s population. There is simply no space there to replace the highways that cross the residential areas, like the one in Fig. 3, somewhere else. Randstad is also the economical motor of the Netherlands, which means that these highways and their traffic are of vital importance to the whole country. Although there is no official list of the country’s unwholesome motorways, the most urgent are probably the following sections of highways:

- A13 highway Rotterdam – The Hague, section in Rotterdam-Overschie;
- A20 highway Rotterdam – Utrecht, sections in Overschie and Spaanse Polder;
- A12 highway The Hague – Utrecht, sections in The Hague and Voorburg;
- A10 ring highway of Amsterdam, diverse sections;
- A27 highway Utrecht – Hilversum, sections between Veemarkt and Vianen;
- A28 highway Utrecht – Amersfoort, diverse sections.

The prior concern at nearly all (about 80%) these locations are the health of people living or working in the neighbourhood of motorways. Protection of nature and recreational values are main concerns only in some sections of the last two highways. These relations will, probably, not much vary in other highly urbanized countries or regions that suffer from air pollution by traffic. Although there is some difference between curing this problem for the sake of human health and for the sake of nature (in the second case other pollutants than PM and other hindrances, e.g., noise, are more relevant), we will ignore it right now.

The discussions about tackling the problem take place at various levels in the Netherlands – from the local municipalities to the central government. So far, they have resulted in a number of investigation reports, feasibility studies, publications and long-term programs, but few realized projects. In some cases, long motorway tunnels have been constructed. This conventional option does eventually solve the problem, but in urban areas it proves to be very complex and costly or even infeasible. Encasing an existing motorway is a better solution in such areas, but it cannot be called “conventional” as there is not much experience in this field. Nevertheless, the actual launching of the first large-scale motorway encasing project comes closer and closer. The public demand and political pressure in this direction grow steadily. Also, the construction market and the potential investors have largely been convinced already. At the time of this article being written, the cost-benefit analyses and conceptual design drawings lie on the desks of numerous local governments, awaiting final approvals.

So far, most of the proposed highway encasing solutions employs traditional materials, predominantly glass and steel. This should not surprise considering the existing experience with these materials in roofing large and complex spaces, like shopping malls, stations and stadiums. The technology of nowadays allows for the use of both flat and cold bent glass for this purpose. The advantages of glass-and-steel structures are further: relatively wide range of available complex forms (Fig. 4) that might help to roof complex traffic junctions, good daylight arrangements and a quite fair safety – also in case of fire. One can also consider a psychological reason for choosing these materials: roofing of a highway is an unconventional step in itself, thus allowing the construction with unconventional materials might be asking too much from the licensing authorities.

Fig. 4 Roofing of a shopping mall “Golden Terraces” in Warsaw, Poland (photo author)

IV. SOLUTIONS IN CONVENTIONAL MATERIALS

There is a significant difference in costs between roofings composed of flat sections and the ones that are built of curved sections. Both steel profiles and construction glass are much cheaper when the roofing is straight and flat. Additionally, the cold bent glass of considerable thickness is only available in multi-layer technology, which increases its strength but also the costs. The first thing coming into mind when considering a glass-and-steel roofing of a motorway is a structure composed of flat panels. An additional argument for this choice in the Netherlands is that the country is the Europe's leading producer of greenhouses and greenhouse-grown vegetables. Therefore, there is very much experience in roofing large areas with flat glass panels and in maintaining such roofing structures.

Not coincidentally, the motorway roofing similar to the existing greenhouse structures was among the first to be proposed in the Netherlands. It was developed by the engineering company Oranjewoud that now carries the name Antea Group. The designers were focussed on a light type of roofing. They also performed costs estimations, which gave about M€ 15 for simple, greenhouse-type roofing per one kilometre of a highway with three lanes in both directions, like the one shown below (Fig. 5a). Depending on material grades, structural systems and local conditions, the indicative range of construction costs for this family of structures was M€ 15 to 65, while the heavy (e.g., concrete) roofing of such a highway would have cost M€ 200 to 300 [4]. Obviously, these costs of light roofing were still quite considerable, but they could be justified compared to the benefits in terms of human health, according to the authors.

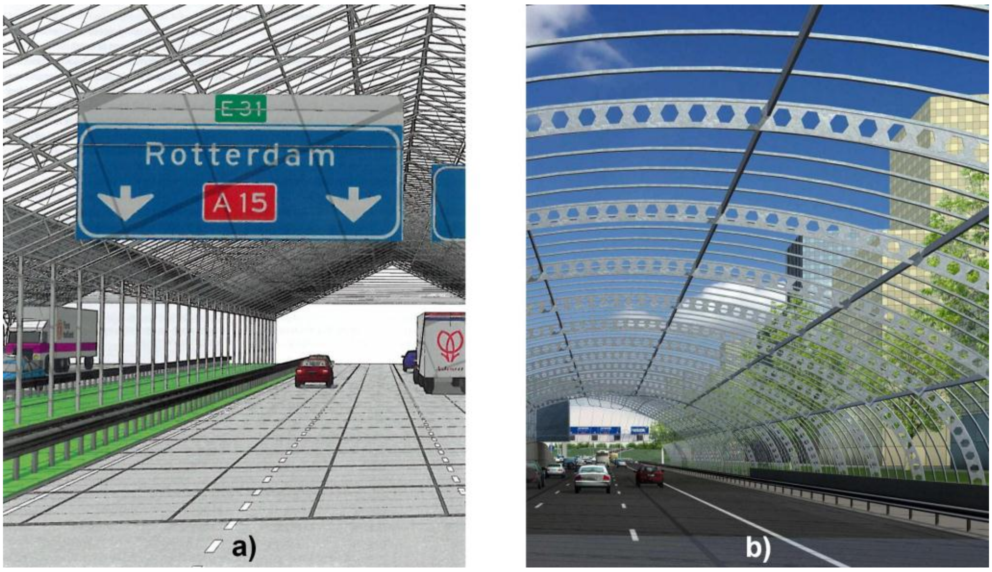

Fig. 5 Glass-and-steel encasing of highways, conceptual designs
a) in flat glass panels by Oranjewoud [4], b) in cold-bent glass panels by Movares [5]

A more sophisticated and, perhaps, architecturally preferable conceptual design was developed by the engineering company Movares. The glass panels applied were not flat but cold-bent this time (Fig. 5b). Cold-bent glass of considerable thickness is, naturally, only available in multi-layer technology that reduces residual stresses. This increases the costs, but it also improves the safety. The engineers from Movares developed a special material, called Freeformglass® for such purposes. The performed costs estimations of this roofing gave construction costs of M€ 28.7 per one kilometre of a highway with three lanes in both directions [5], roughly twice as expensive as the roofing in Fig. 5a. The estimated construction costs comprise, in both cases, only the roofing structure and its foundations, i.e. not the other system components, like ventilation, possible air filtering, necessary safety and maintenance provisions, etc.

In these and other similar conceptual designs, the engineers usually paid attention not only to the explicit structural aspects, like strength and stiffness, but also to other issues like traffic comfort and security, sensitivity to vandalism, fire resistance, access for emergency services, behaviour under extreme weather conditions, maintenance issues, etc. The Dutch tunnel low requires, e.g., that – in tunnels of moderate length – the load bearing structure must remain intact at least 60 minutes when exposed to fire. This time is considered sufficient for the evacuation of people inside the tunnel. The feasibility studies performed for the roofing structures in Fig. 5 showed that they can be realized in compliance with this requirement. Similarly, all other appropriate legal requirements can be satisfied. An advantage of this family of structures is also that they – under normal circumstances – provide sufficient daylight for the motorway traffic.

Nevertheless, the glass-and-steel encasings of a motorway do also have some disadvantages. One of them is that they are not as light as we often like them to be. Both glass and steel are not materials of extremely low specific gravity in relation to their strength. This is particularly important in densely populated areas, where the motorways often run on viaducts (like in Fig. 3) or so-called flyovers. There is usually no space there for a free-standing roofing structure; and supporting it to the viaduct superstructure introduces overly high dead load.

V. COMPOSITE MATERIALS AS A COMPETITIVE OPTION

The relatively high own weight is not the only disadvantage of roofing structures in conventional materials, like concrete, steel and glass. Another one is the also relatively high need of maintenance as a result of corrosion, large amount of joints in the structure, their seals, etc. In addition, the idea of providing sufficient daylight for the encased traffic, admirable as it is, will only work when the glass panels are frequently washed. The motorways that are worth encasing are only the ones that carry intensive traffic; and such traffic does not, generally, allow for frequent maintenance works – also not when these works do not immediately lead to traffic blockages or congestions.

The above does not suggest that conventional materials are not fit for the purpose here. They are, but their application requires much care, additional provisions and investments. Therefore, it is sensible to consider other, less conventional materials for motorway encasing. The materials that first come into mind are fibre-reinforced polymers (FRP), particularly fibreglass reinforced polymers (FGRP) and – to a lesser extent – carbon fibre reinforced polymers (CFRP). The main reasons for the consideration of these materials are their following properties:

- very high strength, about 6 ÷10 times higher than that of steel;
- low specific gravity, about 4 ÷ 5 times lighter than steel;
- chemical stability, with very low maintenance requirements;
- favourable sustainability indicators [6], [7] and design freedom.

The favourable character of these properties can be observed by comparing the data in Table 1, in which the most essential mechanical, physical and chemical properties are set together for 5 groups of materials that can be used in motorway roofing structures. Similar comparisons, supported by detailed multi-criteria analyses, have earlier been performed for other structures, for example utility buildings [8] or bridges [9]. The latter are probably the most similar to the motorway roofing structures in both service conditions and performance demands.

TABLE 1 PROPERTIES OF POTENTIAL MATERRIALS FOR MORORWAY ENCASING

Property	Structural steel	Structural glass	Reinforced concrete	Aluminum	Composites
Mechanical properties					
Strength	**High**: 400÷600 MPa, details (bolts, shafts, stay cables) higher, favorable yield behavior.	**Fair**: Most sorts 30÷70 MPa, some still higher, brittle, no yield behavior.	**Fair**: Concrete 25÷50 MPa (compressive), reinforcement as for steel.	**Moderate:** 150÷300 MPa, some alloys higher, favorable yield behavior.	**Very high**: E-glass 2500 MPa, carbon fibre 3000÷ 5800, composite **lower** dept. on fibre content.
Stiffness	**High**: E = 210 $\cdot 10^3$ MPa, very constant and stable.	**Fair**: E = 62÷76 $\cdot 10^3$ MPa, constant and stable.	**Fair**: E = 15÷45 $\cdot 10^3$ MPa dept. on compression level, **stiff** due to large sections.	**Moderate:** E = 70 $\cdot 10^3$ MPa, quite constant.	**Fair**: Dept. on fibre content. For FGRP E = 25÷100 $\cdot 10^3$ MPa, for CFRP higher.
Isotropy	Nearly fully **isotropic**, but rolling etc. can cause some irregularities.	**Isotropic** when in single layer, **anisotropic** when multi-layer.	Concrete **isotropic** in compressed zone, outside dependent on presence and direction of rebars.	Nearly fully **isotropic**, rolling, extrusion etc. can cause some irregularities.	**Anisotropic**, properties depend on direction, quality, content, plait etc. of fibres.
Thermo-stability, fire resistance	**Good**: Stable in temp. until about 400 ℃, not inflammable.	**Good**: Stable in temp. until about 500 ℃, often higher, not inflammable.	**Very good**: Warmth well absorbed due to massive sections, uninflammable.	**Fair**: Stable in temp. until about 150 ℃, low melt point, normally not inflammable.	**Fair**: Inflammable (can be reduced), properties rather thermo-instable.
Physical, chemical and environmental properties					
Own weight	**Heavy**: w = 78.5 kN/m^3, structures not so heavy due to relatively small sectional areas.	**Moderate**: w = 24÷28 kN/m^3, structural glass 25 kN/m^3.	**Very heavy**: w ≈ 25 kN/m^3 but structures very heavy due to large sectional areas.	**Light**: w = 27 kN/m^3 and small sectional areas → light structures.	**Light**: w = 17÷19 kN/m^3 for FGRP and 15÷16 kN/m^3 for CFRP, small sectional areas.
Weathering	**Corrosive**: Needs coating (environmental pollution, costs), sensitive to e.g. seawater.	Quite **resistant**, also against most chemicals, aging may be a problem.	Concrete **sensitive** to ASR**,** chlorides and frost, rebars **corrosive**.	**Resistant**, can corrode in acidic or other metallic contacts, anodic reaction.	**Resistant**, surfaces sensitive to UV-rays, some organic solvents may be a problem.
Warmth and electricity	Good **conductor** of both (usually handicap), minor thermal expansion α = 12 $\cdot 10^{-6}$ K^{-1} (favorable).	Bad warmth **conductor**, good electrical **isolator**, thermal expansion α = 8.5 $\cdot 10^{-6}$ K^{-1}.	Concrete bad, steel good **conductor**, nearly equal, low thermal expansion.	Very good **conductor**, thermal expansion α = 24 $\cdot 10^{-6}$ K^{-1} higher than steel, melt point lower.	Good **isolator** (except CF), thermal expansion can be 'tailored'.
Environment [7]	Relatively **good** except energy input, coating gives pollution problems.	**Fair**: Energy involved and pollution rates high but low maintenance.	**Fair**: high impact during execution (air pollution, energy input), but low maintenance.	**Bad**: Energy involved and pollution rates high, high stock required.	**Good**: Low energy impact, low pollution to both water and air.

Composite bridges have been advancing for about 30 years already. There exist considerable methodology and experience in their design, manufacturing and maintenance. The advance of composites has been particularly impressing in pedestrian bridges and somewhat modest in road traffic bridges and viaducts. The main reason for the latter is the relatively low stiffness of composites; see the E moduli compared in Table 1. The use of conventional cross-sections results then in large deflections, which may decrease the comfort of road traffic. Nevertheless, there are many successful applications of composites in road bridges of small spans and in deck subassemblies of steel and concrete large-span bridges. An example is the viaduct with a composite bridge deck over the A27 highway nearby Utrecht, the Netherlands. Thanks to its very small weight, the launching of the superstructure was performed fast, cost-effectively and with nearly no hindrance for the traffic (Fig. 6) [11].

Fig. 6 Launching of a viaduct with composite deck (supplied by FiberCore Europe) over the A27 highway nearby Utrecht, the Netherlands [11]

While considering composite materials in the struggle for clean ambient air, one cannot avoid asking what burdens to the environment are involved in the manufacturing of composite structures themselves. Also in this field, composites generally perform better than other conventional materials. This has been investigated in a case study of four different material selections for a footbridge in the Dutch province of Zeeland [9], [12]. The choice for a composite bridge appeared to generate lower pollutions to both air and water than the choice for a bridge of steel, aluminium or reinforced concrete (Fig. 7). In addition, in terms of energy consumption, the composite bridge scored better than the other three bridges.

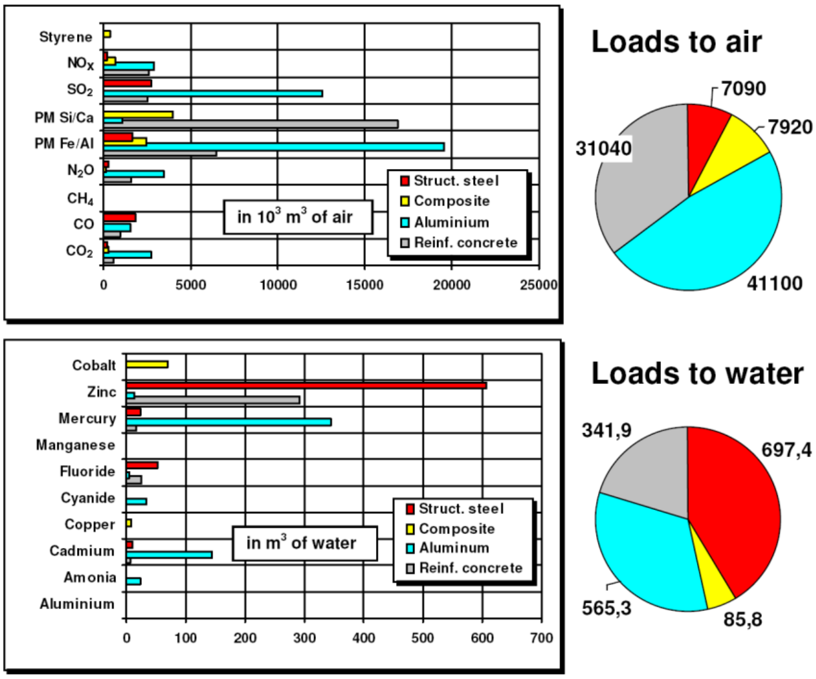

Fig. 7 Total loads to air (up) and water (down) as result of four different material choices for a pedestrian bridge [12] in m^3 of respectively air and water polluted up to the legal thresholds

All the data and investigation results mentioned above lead to the conclusion that composites present a favourable – in any case interesting – option for encasing a motorway. This does not mean that composite roofing does not introduce any risks. One of such risks is fire hazard, which will be discussed later in this article. In the following sections, some conceptual designs of a motorway encasing by composite structures will globally be presented.

VI. ENCASING AN EXISTING CONCRETE VIADUCT

Let us consider the situation similar to the one that is shown in Fig. 3. That particular highway section is politically the most controversial in the Netherlands at the time this article is written. The social discomfort and unrest it causes are very high. It is not the intention now to compete with other measures that have already been proposed for that situation (such as limiting the allowable vehicle speed to 80 km/h), nor to discuss the effectiveness of those measures. In addition to them, the following general concept of a highway encasing (Fig. 8) can be brought into consideration [13], [16].

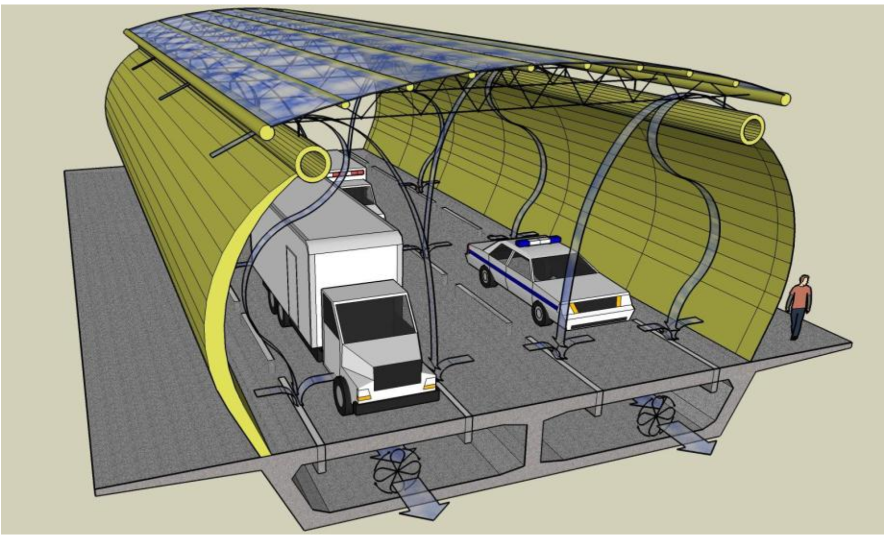

Fig. 8 Encasing of a 3-lane highway section, including the global idea of air-conditioning (Arrows indicate the air flow)

The concrete viaduct superstructure assumed in this concept has a typical box-shaped cross-section, as frequently applied nowadays in pre-stressed or post-tensioned bridge girders. Upon that deck, high composite screens are installed, which in turn give support to a light roofing structure. The roofing can possibly be of glass, composite or the combination of both materials. Steel is a less favourable option due to higher maintenance requirements (corrosion). The sketch in Fig. 8 gives a general idea of the system. All dimensional proportions, road verges, safety precautions, etc. are of secondary concern at this moment.

In order to provide direct support for the roofing, the screens in this concept are much higher than the acoustic screens that are currently applied in similar situations. The function of sound boarding comes here in the second place. Nevertheless, the high screens will, obviously, serve this function even better than the screens of conventional height as pictured in Fig. 3. In accordance with the desired sound damping level, the screens can be constructed as a single composite sheet (right in Fig. 8) or a double sheet with sound damping material, e.g., foamed polymer, in between them (left in Fig. 8). Interesting for this option are also the sandwich panel sections developed by various composite construction companies, like the FiberCore Europe [14] in the Netherlands or the Alcan Baltek Corp. [15] in the USA.

Ventilation and air cleaning can be realized in various ways in this concept. The idea that is schematically drawn in Fig. 8 is not the only possibility. It aims at capturing the PM as close as possible to the place of its emission: the vehicle exhaust pipes. A logical choice is then to install the capturing devices (filters) directly in the viaduct deck, e.g., in the traffic lane markings. This must, of course, be arranged in such a way that the deck plate maintains its required strength under the traffic loads. More discussion on the issue of air cleaning is given in the following section.

VII. CONSTRUCTING AN ENCASED COMPOSITE VIADUCT

A step that goes further towards encasing the traffic in densely populated areas is to construct not only the roofing but also the entire viaduct superstructure of composites. Such a step costs more, but it has four major advantages:

- It leads to a still lighter superstructure, allowing for higher traffic loads on the existing substructure;
- It gives more freedom for the best deck shaping that will also house the air cleaning system;
- It is feasible in nearly all local conditions, which may not be the case when utilising the existing superstructure;
- It gives a new, durable superstructure, which will especially be valued when the old one approaches the end of its service life anyway, or when there is need to modify its geometry, design loads, etc.

These advantages should be seen as additional to the general advantages of composites when compared to conventional materials, as mentioned in section V. Therefore, there will be cases in which replacing the entire superstructure of a viaduct or bridge represents a better choice than roofing the existing concrete or steel structure. The new, all-composite superstructure with encased traffic lanes can then be shaped as drawn in Fig. 9 [13], [16]. Like in Fig. 8, all yellow coloured components are composites. However, their grades, particularly fibre content, can vary due to different strength and stiffness requirements.

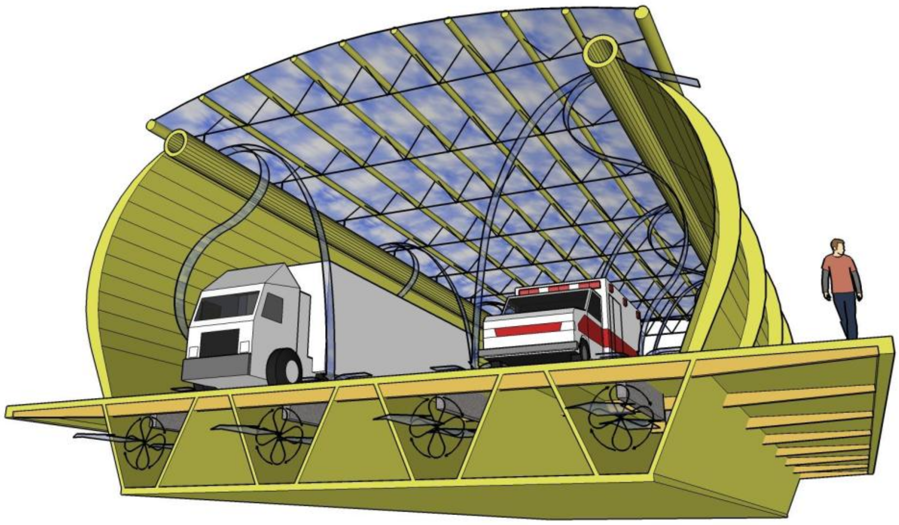

Fig. 9 Encased 3-lane highway section on a composite superstructure (Arrows indicate flow of air in the conditioning system)

The side screens and the roofing structure are basically the same as on the concrete viaduct shown in Fig. 8. The difference is that the heavy concrete box girders have been replaced by light composite girders, here also of box cross-sections. In this concept, the deck plate and the bottom plate of the box sections are of solid composite material, but a sandwich construction (as the FibreCore or Alcan Baltek decks, see references in section V) can possibly give a better solution at the cost of some more thickness. Such an optimising as well as further detailing can be performed in the next design stages.

The basic concept of the air-cleaning system here is also the same as in Fig. 8. The author believes that capturing the air pollution as close as possible to the place of its emission is a design strategy worth following, even at the cost of additional strengthening of the bridge deck around the filter openings. The filters can be installed in cells of any desired dimensions. Such cells are commercially available on the market already now. An example can be the so-called pocket or box filter cells as shown below (Fig. 10) developed and supplied by American Air Filter AAF® International [17].

Fig. 10 Examples of commercially available filter cells

There is an additional advantage of placing the air filters in bridge decks and using the box girders as exhaust ducts, as schematically shown in Fig. 9. The entire air cleaning system, i.e. filter cells, fans, control hardware, etc., can then be made accessible for inspection and maintenance (e.g., exchanging the filters) with no hindrance to the traffic. The air cleaning ducts in the bridge superstructure are fully separated from the "traffic duct" above the deck. Due to the high number of uniform and relatively simple components (filters), their maintenance can be highly automated, so that little or no human labour in the duct is required. The ducts that are not used for clean air exhaust (interstitial in Fig. 9) can house cables and control devices or even other facilities that do not necessarily serve the function of encased traffic. They can also partly or entirely be filled with structural material if more system strength is required.

VIII. INTEGRATED ENCASED VIADUCT OF COMPOSITE

The conceptual "traffic ducts" presented in sections VI and VII are based on a presumption that the load bearing of a viaduct should be performed by other structural components than the encasing. There are good reasons for such an approach. An important reason is the structural safety of the system in case of vehicle collision, possibly with fire. Designers must take such scenarios into account, which can, e.g., be seen in the photograph in Fig. 11. It shows the fire of an acoustic screen near Dordrecht, the Netherlands, after a vehicle collision. The 40 m long screen section changed there into a wall of fire within minutes after the ignition of the colliding vehicle. That screen was considered "incombustible" in the design [18]. Fortunately, the fire brigades came soon in action and proper lessons have been learnt from this incident afterwards.

Fig. 11 "Incombustible" acoustic screen along the A16 highway near Dordrecht on fire (May 08, 2001)

Nevertheless, the ongoing development in technology continues to move the frontiers in construction engineering. It can, therefore, no longer be considered infeasible to combine the functions of load bearing and traffic encasing in one structure. The result is then an integrated cross-section of a viaduct, as the one presented in Fig. 12. The main advantage of such structures in composites is their global stiffness. Thanks to the integrated high load bearing cross-section of the bridge deck and its roofing, the global deflection of a viaduct span is very low. As the deflections have been considered the main disadvantage of composites when compared to steel or concrete (see discussion by Table 1), such integration removes this disadvantage.

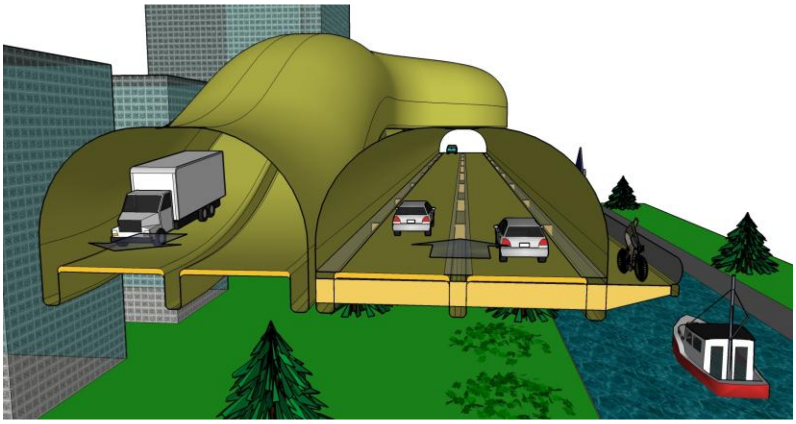

Fig. 12 Integrated composite "traffic ducts" in highly urbanized areas

It also solves the problem of air pollution. The air cleaning system can be designed here in a way similar to Figs. 8 and 9. This would require providing openings in the roofing part of the structure. Another way is to benefit from the airflow induced by the traffic and to exhaust and clean the polluted air by strong conditioning devices at certain distances, indicatively 1 ÷ 2 km. This way is similar to the current practice in long traffic tunnels and does not need to be discussed here.

Note that the solution in Fig. 12 not only cleans the ambient air, it also reclaims much space for other purposes like housing, green zones, recreation, etc. Rigid, integrated cross-sections allow for extreme long spans and little hindrance by viaduct pillars. This is a considerable advantage for densely populated areas, where the ground prices are very high.

IX. CONCLUDING REMARKS

The concept of "traffic ducts" presented in this article is not specific to the Netherlands. It can be interesting for various areas in the world where many people live, work and recreate in relatively small areas. In nearly all such areas, the quality of ambient air presents a problem and this problem will likely intensify in the years to come. Its solution depends obviously on economical factors, but also on the vision and courage of engineers, planners, politicians and, in fact, the whole societies. It is important to adopt an innovative approach while seeking this solution because traditional methods have largely been applied already or they are not effective enough any more.

The readers will probably notice that the concept of traffic ducts was presented in stages here. The first stage (section VI) aims at preserving the entire existing infrastructure, the second (section VII) at replacing only the superstructure, and the third (section VIII) at replacing both super- and substructure and applying a new type of a traffic passage. This has deliberately been done in order to tailor this concept to the local needs and possibly different levels of acceptance. While considering this concept, it is good, however, to see it in a still broader sense. Its advantage is also that the problem of air pollution gets finally an owner. Today, it is a problem of everybody, which usually means of nobody. Traffic ducts make it primarily the problem of the ones who cause it, which are heavy transport companies, car drivers, vehicle producers, fuel suppliers and the entire car lobby. It will be that lobby – and not people living close to the motorways – that will have to cope with air pollution in traffic ducts. In the longer term, this will possibly stimulate more investments and efforts for clean, healthy traffic.

Furthermore, although the prior objective of this concept is the interception of fine dust (particulate matter, PM), the traffic ducts open the way to control more than that. In the long run, they can, e.g., also be used to intercept and process CO_2, N_2O, NO_X and other so-called "greenhouse gasses" produced by combustion engines of our vehicles. This would help solving not just local but also global environmental problems of today. Therefore, the support for and further development of the presented concept represent an investment in sustainable, healthy future on a global scale.

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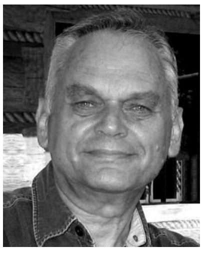

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