Rehabilitation with “Zero Hindrance” and Innovative Rehabilitation Measures – Compendium of Tools and Methods

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ABSTRACT
Heavy traffic in congested urban areas and increasing goods transport on land and water requires rehabilitation measures for existing infrastructure like roads, railway, tunnels and bridges with a minimum hindrance for the daily passenger traffic and commercial transport.

Innovative construction techniques, communication methods, and advanced procedures provide nowadays time and cost effective maintenance.

The main objective of the project is to describe the state of the art of innovative tools for maintenance and rehabilitation measures. The compendium gives an overview over worldwide existing methods, materials, instrument and installations which provide environmental friendly, cost and time effective solutions without or at least with minimised hindrance for the infrastructure users.

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FOREWORD

Nothing is easier than being busy and nothing more difficult than being effective.

Alec Mackenzie

This report is a result of a research in the framework of the Strategic Institute Program “Future Rehabilitation Strategies for Physical Infrastructure” financed by the Norwegian Research Council. The report provides examples for worldwide existing innovative tools and methods which are used for the rehabilitation of different infrastructure in order to minimise the hindrance for traffic participants.

It should be inspiring for infrastructure owners. Some of the described tools and methods are already used in Norway; other might be used in the future.

Trondheim, February 2010

[Signature]

Arnstein Watn

Research Director, SINTEF Building and Infrastructure
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1. INTRODUCTION

Mobility is the fundament of the economical development. The target is to ensure a safe and payable transport and logistic system for the entire community. Every day millions of people benefit from the invention of a highly developed community. A functional infrastructure is a precondition for smoothly organisation of transport, communication, water and electricity supply. According to our limited time we expect that the systems work without failure and the level of tolerance to accept traffic jams, delays in the railway system and power breakdowns becomes lower in an industrialized world. Transport policy is on a big scale also economic policy. The transport net must be organised efficient and sustainable. However construction sites cause ever day thousands of kilometres of traffic jam, which wastes time, money and pollutes the environment on a big scale. The infrastructure owner is asked to find solutions to keep the hindrance for the traffic participants and the environmental pollution as low as possible. There is a strong need for mobility on streets, railway lines, waterways and air transport.

There are two main tasks for sustainable infrastructure engineering, on the one hand to construct new roads, bridges, railway tracks, tunnels and underground tubes, and on the other hand to maintain and retrofit existing structures which bear traces from heavy traffic, intensive abrasion, strong precipitation during summer and winter, de-icing salt, studded tires and general ageing. There is a permanent need for inspection, repair, maintenance and replacement. However, these measure can not been conducted without influencing the daily use of the infrastructure. For that reason densely populated areas and increasing traffic in congested urban areas require rehabilitation measures for numerous infrastructures with a minimum hindrance for the daily passenger traffic and commercial transport. Innovative construction techniques, communication methods, and advanced procedures provide time and cost effective maintenance and are used already in different application areas. Methods and materials that last longer and perform better with minimized disruption would be a great gain for the travelling and trading public.
The first priority for the rehabilitation of infrastructure should be to maintain and modernise the system on that way, that it will last for the next hundred years and will be efficient to carry heavier loads, to handle larger amount of personal and goods transport and to fulfil the increasing requirements on safety. Facing these challenges multidisciplinary and collaborative approaches are required. Active involvement of stakeholders from all levels of government and close collaboration with construction companies and academia through applied R&D activities and technology transfer will conduct to new innovative methods, tools and asset management systems.

To reach the overall target of “zero hindrance” following topics are relevant for design, construction, maintenance and rehabilitation:

- Faster solutions provided by the contractors
- Off-site fabricated materials
- Longer lasting materials that provide more durability and reliability
- Effective monitoring system, inspection, preservation, and rehabilitation
- Integrated planning, design contracting, construction and maintenance

The present compendium gives a status description with examples of innovative rehabilitation and maintenance measures which exist worldwide. Some presented solutions are already widely used and some innovative solutions are up to now unique. The described companies stay exemplarily for specific methods, instruments, tools and installations and we are convinced that many more companies are on the market which provide similar solutions and which can not be presented in this compendium.
2. ROADS

Highways are the lifeline in modern industrial countries. In Norway for example, the average transport distance per tonne goods traffic is four times higher today than in 1965, whereas the railway transport sunk over the last 40 years (Statistisk Sentralbyrå 2009, http://www.ssb.no/). Increasing goods transport and an increasing amount of cars request a sufficient developed road net. Traffic congestion is one of the most time and cost-consuming factor for road users. A tremendous amount of time and fuel is wasted every day in traffic jams. The congestion is a result of inadequate capacity, weather events, accidents and construction work. Most of the customers which use public transport and the public transport net have to accept traffic jam, delays, road blocking, and alternative routeing. The infrastructure owners expect high tolerance from the daily road net users and accept in contrast that the traffic participants reach their destinations stressed and exhausted. Advanced technologies and better system management can help to avoid traffic jam. Main target must be to minimize the impact of construction activities on highly frequented highways and to optimise the overall cost benefit factor for the specific infrastructure.

2.1. Cold in place recycling

Since the latest eighties the Cold-In-Place-Recycling CIR gained worldwide increasing recognition and popularity in respect to advanced performances in road rehabilitation. The CIR method is defined as a rehabilitation method in which the pavement is reused in place. In special milling-drum existing pavement is crush by tungsten-tipped steel teeth. In a mixing chamber the reworked pavement is mixed with stabilising agents, such as cement slurry, bitumen emulsion and foamed bitumen (US Department of Transportation, 1997).

![Image of Cold-In-Place-Recycling machine](image)

*Figure 1: Schematic illustration of a Cold-In-Place-Recycling machine (US Department of Transportation, 1997)*
The cold in-place recycling incorporates the preparation of construction area, milling the existing pavement, addition of recycling agent, material storage, compaction, and placement on the road. The recycled pavement can be used for special pavement designs, to eliminate existing wheel ruts, potholes and other roughness. The process, presented in the flow chart in Figure 2, ensures a high rate of production within a small time span (US Department of Transportation, 1997).

\[\text{Figure 2: Flow chart for the CIR method (US Department of Transportation, 1997)}\]

Compared with traditional pavement measures, the CIR is cost and time effective and environmentally friendly throughout the reuse of in-place bitumen and aggregates. The simultaneous recycling process of the pavement doesn’t require transport of waste material from and new aggregates to the construction site. Under the use of CIR, the hindrance for the traffic participants become less with decreased construction time and the costs per road unit is significantly lower compared to other methods (Lewis and Collings, 1999).

\textit{Nanoplan}

Recycled road material is mixed with an environmentally friendly polymer (nanoSTAB®-method), which increases the compression strength in comparison to other traditional procedures. The nanoSTAB®-method is characterised throughout technical innovation, increase in production, economic efficiency, environmental friendliness, low CO2-emission and protection of primary products (http://www.nanoplan.eu).

\[\text{Figure 3: Cold In-Place Recycling machine produced by Nanoplan GmbH (http://www.nanoplan.eu)}\]

\[\text{Cross-Roads Asphalt Recycling}\]
The Cold In-Place recycling process can cut 40%-50% of the project costs. All work can be done on the job site and there is no requirement for additional virgin material. The burden for the roads and the environment is minimised (http://www.crossroadsasphalt.com).

![Figure 4: Cold In-Place Recycling machine (http://www.crossroadsasphalt.com)](http://www.crossroadsasphalt.com)

**Wirtgen Group**

The heart of this cold milling machine is a milling drum with point-attack cutting tools. The pavement is granulated by the cutting tolls, while the machine travels in forward direction. 100% of the reclaimed material can be reused (http://www.wirtgen.de).

![Figure 5: Operating principles of cold milling (http://www.wirtgen.de)](http://www.wirtgen.de)
2.2. Road retexturing

Heavy congestion leads often to poor friction characteristics. It has been estimated that only in the United States 13,000 of the annual 43,000 highway fatalities can be traced back to inadequate pavement conditions. Poor pavement friction leads to more wet-weather crashes, an increase in fatalities, more serious personal injuries, and significant traffic delay. Especially critical becomes this issue on two-lane roadways with general lower geometric standards and more conflicting movements, particularly at curves, intersections and steeper grades. The retexturing of the macro and micro structure of roads is a method which is known already for over hundred years. However, the primary use started in the 80’s when the first mobile installation was used (Larson 2008).

Figure 6: Example for a mobile road retexturing machine and a retextured pavement (http://www.tracblast.ie)

Tracblast System

The Tracblast System, developed in cooperation with a Dutch company especially for Irish roads, removes excess bitumen and surface contaminants and retextures the surface which is polished by traffic. The fully computerised, safe and environmental friendly system does not use any water, solvents or chemicals, emits no pollution or dust to the atmosphere (http://www.tracblast.ie).

Figure 7: Shot Blasting (http://www.tracblast.ie)
The removed material can be fully recycled. Any excess bitumen and other contaminants were removed by directing metal shot at high velocity at a precise angle at the road surface. That process creates the required micro and macro texture. Grip tests have shown that the skid resistance value, a parameter which describes the pavement condition, was improved up to 60% after retexturing. The method increases the life span of the road surface and increases consequently the amount and duration of big constructions sites.

2.3. Rehabilitation of manhole cover

*Hitthaller*

The Austrian company Hitthaller is due to an innovative system able to lower the time, which is necessary to renew manhole covers. A special milling machine excavates in a short time period manhole covers, which are damaged by heavy traffic, subsidence or frost almost without traffic hindrance (http://www.hitthaller.at/).

![Figure 8: Manhole rehabilitation (http://www.hitthaller.at/)](http://www.hitthaller.at/)

2.4. Traffic simulator

*Stress Tester*

One of the key parameter for road maintenance is to determine the right moment for rehabilitation measures. Detailed knowledge about the quality and lifetime of the pavement is required. The mobile “stress tester” was developed at the University of Stellenbosch, Cape Town. The machine simulates an “artificial ageing” equivalent a traffic volume of 6000 cars per hour. The machine can inflict in about two weeks the same level of wear seen in a whole year by a heavily used road.

EMPA, a research centre of the Swiss Federal Institute of Technology (ETH Zurich) is the first institution, which will test the machine on European highways.
The traffic simulator inspects the pavement and detects the best time for maintenance. The simulator is a tool to define the rest value of the asphalt covering. Based on these data the optimal time for rehabilitation measure can be defined. In addition new construction material, like for example “whispering asphalt” which increases the noise of the vehicles driving on that road, can be tested with the traffic simulator (http://www.empa.ch/).

2.5. Software solution in road management

Construction Analysis for Pavement Rehabilitation Strategies

The university of California Pavement Research Center developed through the UC Berkeley Institute of Transportation Studies a software called CA4PRS, Construction Analysis for Pavement Rehabilitation Strategies. The software is a schedule and traffic analyses tool that helps planners and designers select effective, economical rehabilitation strategies. It reduces the highway construction time and its impact on traffic.

Figure 9: The mobile “stress tester” (http://www.empa.ch/)

Figure 10: The CA4PRS analysis framework (left) and what-if scenario parameters (right) (http://www.dot.ca.gov/newtech/roadway/ca4prs/index.htm)
The software can estimate highway project duration (total number of closures), incorporating alternative strategies for pavement designs, lane-closure tactics, and contractor logistics and quantify traffic module (using the Highway Capacity Manual demand capacity model) quantifies the impact of construction work zone closures on the travelling public in terms of road user cost and time spent in queue. Transportation agencies gain the highest benefit from the use of the software when it is implemented during the planning and design stages of highway project development in order to balance schedule (construction production), inconvenience (traffic delay), and affordability (agency budget) (http://www.dot.ca.gov/newtech/roadway/ca4prs/index.htm).

Traveller information System

A traveller information system is available already in 28 states in America and will be implemented until 2015 in 50 states. Passengers receive via telephone real time estimates about travel time and parking availability. In that way the traffic in areas, which are under construction can be better organised and diverted (American Association of State Highway and Transportation, (http://www.transportation.org/).

2.6. Special consultancy for optimizing the rehabilitation process

Porsche

The Porsche Consulting GmbH a spin-off of the famous roadster producer Porsche was funded 15 years ago to optimize the chain between suppliers and producer. System orientated solutions avoid wasting of time and ensure that the right parts are intergraded on the right time and the right place into the production process. An optimised operating sequence leads to a continuous workflow of high quality and cost effectiveness. The experiences, which the Porsche Consulting GmbH gained during the last decade, were used to develop to optimise the rehabilitation process of a highway construction site in Germany. Together with a road construction company they developed a time precise and organisational sequences of operations work flow. Already a first analyses of the current status showed that the machines could provide 300 tons asphalt per hour but only 180 tons were delivered. The reason for that were long standby times of the special machines due to a gab in the supply chain. The Porsche Consulting developed a precise time schedule for all lorry drivers which supplied the construction side with necessary material. On that way the entire process time can be reduced up to 40%. Precise planning of the whole rehabilitation processes, also transformable into other infrastructure sectors, leads to an efficient use of human power, machines and material and consequently to remarkable cost savings and improvement of the quality. And last but not least the traffic congestion can be minimised. (http://www.unitednetworker.com/2009/07/03/porsche-macht-autobahnbaustellen-schlanker-und-schneller/)

2.7. Performance indicators for the road sector

OECD expert group

In addition to new advanced technologies the authorities, which are responsible for the different infrastructure sectors have to be improved in response to human needs and technical development. The road administrations contribute to the quality of life, the quality of the environment and to the economic performance of both public and private sector in order to optimize the processes and to minimize the costs. Since the early 90-ties researchers and road administration have developed performance indicators to evaluate the road administration’s performance. In 1997 an OECD
An expert group on Performance Indicators for the Road Sector was established to provide a comprehensive framework for self-evaluation of the performance of road administrations (Talvitie, 1999). 15 indicators were selected by the expert group, in which also Norway was represented.

These performance indicators can be useful in:

- measuring the success of individual processes or groups of processes due to process management
- management by results to set targets and to evaluate the achievement of goals and objectives
- benchmarking to achieve superior performance
- to aid the development or improvement of the functions or specific engineering tasks of the road administration.

Over the period 1997-1999 the indicators were field tested under several aspects like average road users costs, level of satisfaction regarding travel time and its reliability and quality of road user information, protected and unprotected road user risk, environmental policy/programmes, allocation to resources to road infrastructure, satisfaction with road condition etc. (OECD 2001).

2.8. Ground Penetrating Radar

The Ground Penetrating Radar (GPR) is an instrument which provides insight into the composition of buried material like roads, walls, roofs or other built structure. The instrument is a non-destructive, electromagnetic ranging measurement technique to determine the location and electromagnetic characteristics of buried targets or weak points in natural or man made materials. (European GPR Association, http://www.eurogpr.org/)

Ground penetrating Radar at SINTEF and the Norwegian University of Science and Technology (NTNU)

Figure 11: Ground penetrating Radar at SINTEF and the Norwegian University of Science and Technology (NTNU)
SINTEF and the Norwegian University of Science and Technology have access to one of the most advanced Ground Penetrating Radar including an innovative antenna technology which allows obtaining a three dimensional picture of the road underground. The modern technique provides a quick and effective profile from the subsurface and condition of the layers of the existing structures.

The GPR can be used to:

- study the necessity for maintenance and rehabilitation measures
- determine the pavement layer thickness
- control the quality of new pavement construction
- locate pipes and other equipment buried under the road
- locate of freezing fronts and ice lenses

(http://www.sintef.no)
3. BRIDGES

Increase in traffic flows and weight of vehicles lead to deterioration of the existing bridge stock. Most of the bridges have been in use for 20-30 years and compared to the time, when the bridges were built, the utilisation became more frequent. The intensity and the speed of the road traffic as well the concentration of loads by the heavy vehicles have enormously grown during the last few decades. Beside the traffic, environmental parameters force the aging of bridges. The most relevant factors are shown in Figure 11 (Radomski 2002).

![Factors which forces the ageing of bridges](image)

**Figure 12: Factors which forces the ageing of bridges (Radomski 2002)**

Maintenance of the transitions section between bridges and the earth dam

3.1. The Raubacher shoulder

Damages on the transition section between bridges and the earth dam occur due to heavy duty vehicles frequently. Lowering, disruptions and distortions occur. Formations of cracks pervade the pavement. Conventional rehabilitation measures cover the pavement with a new asphalt layer whereas cavities and contusion of the former asphalt layer still exist beneath and cause continuously the occurrence of damages. This lead to after a couple of month again to maintenance measures with hindrance for traffic and noise disturbance for the residents. A new method promises remedy. The Raubacher shoulder is an armoured concrete construction, which bypasses the sensitive transitional zone between bridge and the earth dam. The maintenance intervals are not longer existent; the hindrance for traffic and passengers become zero (www.dizwo.de/Downloads/Die_Stahlbetonschulter_nach_Raubacher.pdf).
3.2. Bridge Management System (BMS)

The condition of bridges was traditionally examined by load tests and special inspections. Since the computer era special software helps road authorities to define the right moment for construction, operation and maintenance. BMS are expected to ensure different aspects (Adamsone, 2002):

- Fast access to necessary data
- Adherence of traffic safety rules
- Cost effectiveness
- Prioritising special repair and construction measures
- Assessment of future needs

Brutus, Norwegian Road Administration

Several European Countries developed a computer based, standardized inspection methods for bridge inspection. The Norwegian Public Roads Administration uses a bridge management system with the name BRUTUS for inspection reports, forms, terms and ratings and to determine the best time for rehabilitation measures. Initial point is the Handbook for Bridge Inspection. With the help of BRUTUS it is possible to compare previous inspection results and to report changes in the structural condition since the last inspection. Thereby play digital photos an important role. The modular Bridge Management System is a cost-effective aid for achieving goals and documenting results. It provides a basis for superior control and administration in the management and maintenance of bridges (Strait Crossings 2001).
3.3. **Ground Penetrating Radar**

In addition to the investigation of road underground conditions the Ground Penetrating Radar is also an efficient tool to identify and spatially map the location of deteriorated concrete in abutment walls and bridge deck soffits.

*Penetrador Corporation*

The Penetrador Corporation located in the US manufactures has since more than 25 years used GPR systems that provide information of the subsurface environment of roads, bridges and tunnels ([http://www.penetradar.com/](http://www.penetradar.com/)).

*Figure 14: GPR system for bridge inspection ([http://www.penetradar.com/](http://www.penetradar.com/))*

The GPR system collects series of longitudinal scans along the length of a bridge, at high speed and without traffic interruption. The entire lane is covered by multiple antenna array which ensure that all antenna scans are properly correlated and that detections are properly identified in location and size. The GPR system can be used effectively on overlaid bridge decks and exposed concrete ([http://www.penetradar.com/](http://www.penetradar.com/)).

*Figure 15: GPR system for inspection of the bridge ([http://www.penetradar.com/](http://www.penetradar.com/))*
4. TUNNELS

In 2000 opened the world largest road tunnel in Norway with an entire length of 24.5 kilometres. On many places in Norway tunnels connect two places where passing high mountains during the winter period is impossible and often no alternative ways exist. Interruptions of service are rarely permitted. Therefore the tunnel rehabilitation must be extremely effective and time saving. The time window which is available for construction work amount sometimes of only a few hours (1-8 hours). Maintenance while keeping the traffic going requires tremendous efforts according planning, coordination and the right choice of construction equipment and methods. The requirements on tunnel rehabilitation are in some cases due to a lack of as-built drawings and documentation of the construction process. These circumstances make the choice of maintenance measures difficult (Parker et al. 2002).

4.1. Tunnel rehabilitation with Shotcrete

Typically there are no alternative routes; therefore the tunnel rehabilitation has to be conducted with the minimum possible time. In many cases the tunnel is open for one lane, in other cases the whole tunnel must be closed. The maintenance work has to be done in a very short time period. A special working train helps to keep the construction time short and allow rehabilitation on the entire tunnel (www.shotcrete.org).

![Diagram of a special work train](www.shotcrete.org)

*Figure 16: Example for a special work train for a railroad tunnel (www.shotcrete.org)*

The use of a particular rapid-hardening steel-fibre mixed shotcrete with micro-silicia in combination with an innovative work train enables tunnel rehabilitation without taking the tunnel fully out of services (Parker et al. 2002).

4.2. Rehabilitation of immersed tube tunnels

All over the world are immersed tube tunnels used as road and rail crossings in rivers, estuaries, channels and harbours. The rehabilitation of such underwater tunnels is expensive. In general steel panels were used to cut off the water. This requires very often frogman divers which are exposed to difficulties in operability and safety with increasing water depth.
**Penta Ocean Construction Company**

The Penta Ocean Construction Company located in Japan has successfully solved these problems. So called V blocks, a section of a tunnel, are prepared on shore, transported to the site and dropped in place by remote control. This eliminates the need for divers, eliminates potential hazards and reduces dramatically the construction time. The method is applicable even for very deep locations (http://www.penta-ocean.co.jp/english/).

![Installation procedure for a V-block into an immersed tube tunnel](http://www.penta-ocean.co.jp/english/)

**Figure 17:** Installation procedure for a V-block into an immersed tube tunnel (http://www.penta-ocean.co.jp/english/)

![Section of an immersed tunnel (left) and special crane for the placement of the new V-block](http://www.penta-ocean.co.jp/english/)

**Figure 18:** Section of an immersed tunnel (left) and special crane for the placement of the new V-block (http://www.penta-ocean.co.jp/english/)
4.3. **Ground Penetrating Radar**

*Penetrader Corporation*

Like presented in previous chapters the Penetrader corporation provides also Ground Penetrating solutions to examine the condition of tunnel linings. The instrument can detect many problems that occur relative to tunnels including deterioration of inner linings, subsurface and source moisture ([http://www.penetrader.com/](http://www.penetrader.com/)).

*Figure 19: GPR system for tunnel inspection ([http://www.penetrader.com/](http://www.penetrader.com/))*
5. RAILWAY

In many European countries the railway freight transportation has increased significantly over the last years. The result of this development is reduced traffic congestion at the highway network. The other side of the coin is that more intensive wear of track components takes place as more and heavier trains are in traffic. For example, in 2006 the railway transportation in Germany increased around 11%. Prognoses show a growth of 41% between 2004 and 2015. The German Rail has to replace around 5500 km of rail and 2000 switches at 3000 construction sites. (www.spiegel.de). In Norway the number of train passengers have increased by 14 % from 2004 to 2008, while for domestic freight the increase is 29 % with regard to the transported tonnage. The Norwegian National Rail Administration (Jernbaneverket) plans for a doubling of capacity for rail freight transport in the year 2020 and a triplication in 2040 as compared with the level of 2009. (www.jernbaneverket.no)

During rehabilitation measures entire parts of the railway net have to be closed. Alternatively, for double tracked lines, the train traffic in both directions may temporarily run on one track at a time while the other track is being maintained. In both cases it is hard to avoid a delayed and reduced train service.

Trends in maintenance in order to reduce track possession time, thus increasing the time available for the trains, are described in the following.

5.1. Preassembly

Preassembling saves track possession time, but often requires more heavy-duty installing equipment. Examples of preassembly are the following:

- Premounting of fastenings at the sleepers before installing them into the track.
- Complete, preassembled switches. These are transported directly to the site using special purpose cars.
- Premade, insulated rail joints ready to be welded into the track.
- Complete, preassembled track sections.
- Constructing bridges alongside the track, cut the track and then skid the bridge into it’s correct position.
- Smaller, precast concrete trough bridges. Makes it easy to replace an older bridge if the abutments can be reused without major reconstruction.
- Preassembled steel culverts. Installed depths must be moderate for a fast installation.
Figure 20: Part of a switch, preassembled. Picture from www.plassertheurer.com.

5.2. More mechanised maintenance

Examples hereof include maintenance operations as the following:

- Mechanised tamping. The first automatic tampers that replaced the manual work tamped one and one sleeper at a time. Today, double tampers, i.e. that tamp two sleepers at a time, are common. The newest and most advanced tamping machines tamp four sleepers at a time.

- Rail grinding. The early versions of rail grinders needed several passes to grind the rail, as opposed the present technology where one single pass normally suffices. Today’s grinders have several grinding stones in order to produce a smooth rail profile without too distinct facets at one pass only.

- Ballast cleaning. A ballast cleaner is basically a large, mobile sieving machine that excavates the ballast material, removes the fines by sieving and then places the usable material back into the track. Before the ballast cleaners were available the only alternatives were to remove the track and either doze the old ballast aside or take it away by excavators or by wheel loaders.

- Combining several types of maintenance in one operation. For instance, levelling and lining (tamping) is necessary to do right behind the ballast cleaner in order to temporarily restore the track geometry (at least one more pass with the tamper is required, though, to restore the final geometry).
5.3. Technologies that need less maintenance

There are several technologies available in order to obtain a track with a lesser need of maintenance. Some of them are listed below.

- Slab-track solutions instead of ordinary ballasted tracks. There are several systems for slab tracks, but their common feature is that the rails are fastened to concrete slabs rather than to sleepers. In this way the need for an ordinary ballast layer is reduced. A slab track is considered more stable than a conventional track, thus needing less levelling and lining. However, a slab track is more expensive to build, and geometrical adjustments, when needed, are more cumbersome.

- Rail grinding strategies for prolonging the life of the rails. It is of utterly importance to maintain an optimal rail profile in order to minimize rail wear and obtain a high-quality riding comfort. Especially in curves, the wheel-rail contact has to be optimised, and often so by introducing asymmetric grinding strategies. Asymmetric grinding implicate different rail profiles for the inner and outer rail, hence accommodating an optimum wheel-rail contact patch also when the wheel set shifts laterally because of the radius difference between the two rails in curves.

- Harder and more durable rails and switch frogs. Because of the additional lateral wheel forces, the rails in curves are frequently of a higher hardness than in straight sections. Harder material is also used in switch frogs (the crossing point of rails in switches) in order to provide enough strength at this heavily loaded point of the track.

- Tunnels in stead of snow sheds, or in stead of heavy rock fall or landslide protective measures of open line. With today’s tunnelling technology it is normally, although not always, more cost-effective to construct a tunnel than to deal with the problems while keeping the railway line at the surface.
5.4. Providing track access from outside the track

Maintenance trains occupy time slots on the track that otherwise could have been made available to ordinary trains. Using maintenance roads and road vehicles circumvent this problem and may be effective. A service tunnel parallel to the train tunnel is a similar concept for tunnels. Even helicopters may be used – for instance for renewal of catenary (overhead line) posts at heavily trafficked lines where no roads are available.

Also maintenance vehicles with dual wheel systems, i.e. with the possibility to leave the track, fall into this category. Such vehicles are particularly effective when there is limited possibility to divert to sidings or other tracks in order to let the ordinary trains pass – provided that the railway safety and signalling system is designed in a way that allows fast access to the track after a train passage. Examples of vehicles equipped with dual wheels sets are excavators and inspection vehicles.
5.5. No-dig methods for culverts

No-dig methods are very suitable for rehabilitation of culverts at existing lines. These methods may also be relevant for cables, pipes etc. Some of the methods described in chapter 6 may be used for railways as well.

Some of the most common methods:

- To press or drill a steel tube through the embankment. One or more of these steel tubes then replace the existing culvert.
- Installing an inner lining in existing culverts. This lining could typically be of polymer or mineral (e.g. concrete) origin.
6. WATER AND WASTE WATER SYSTEM

Trench less pipe rehabilitation

All over the world pipes for sewer, gas and water suffer from deterioration and ageing. However, in heavily populated areas it is often extremely difficult to install new pipelines and often is the repair by excavation almost impossible. One possible solution to keep the disturbance for the traffic participants low is the use of trench less technology methods which ensures minimal surface disruption. These methods allow installing pipelines while pulling through the old pipeline even if the old one is partly destroyed.

Figure 24: Schematic Figure of a pulling unit (http://www.alpha-plumbing.com/services-trenchless.htm)

The pulling unit pulls engine-driven the new pipe through the soil with a rate of approximately two feet per minute up to four feet per minute. (http://www.alpha-plumbing.com/services-trenchless.htm)

Figure 25: Pulling process of a new pipe through the underground . (http://www.alpha-plumbing.com/services-trenchless.htm)
6.1. CIPP Cured-in-place-pipe

*Nu Flow*


![Figure 26: Example for cured in place pipe (CIPP)](http://www.nuflowtech.com/Products/STRUCTURALLINING.aspx)

The CIPP method creates a permanent pipe inside the host pipe which is used to rehabilitate sanitary drain and storm sewer lines. An epoxy soaked, felt-lined bladder is inserted into a cleaned pipe. The method which was previously considered as an “outside” or external repair methods is commonly used for the rehabilitation of underground installations. http://www.nuflowtech.com/Products/STRUCTURALLINING.aspx

6.2. SPR method

*SEKISUI*

The SEKISUI construction company located in the US uses a wider range of underground rehabilitation technologies with a minimum impact to the above ground environment. The Superior Pipe Rehabilitation (SPR) method which is worldwide patented allows shortening the construction period. Almost no noise disturbance appears. The method is suited for areas with heavy traffic and dense population. The SPR method for the rehabilitation of pressure less sewer pipes is cost efficient and environmental friendly. Deguchi et al. summarised in a paper from 2006: “In the SPR (Sewage Pipe Renewal) method, a rigid PVC liner is formed inside an existing pipe by using a specially designed winding machine that is placed inside the existing pipe. A rigid PVC profile strip is fed through a manhole entrance above ground, and the winding machine is used to wind and interlock the profiles together to form a liner. Rehabilitation technologies are needed that can cope with various existing installation site conditions; i.e. long or curved pipelines, with round, square or horseshoe shaped cross sections.
Under such circumstances, SEKISUI developed a new technology to form the PVC liner in which self running winding machines travel around a frame that is set inside the existing pipeline, and which is made to conform to the interior cross sectional shape of the pipe.” (www.sekisui-corp.com

**The SPR Pipeline Renewal Product**

- Ideal for larger diameter circular and non-circular pipeline renewal projects
- Can be installed in live flow conditions
- Negotiates bends & curves
- Existing entry points can be used
- Can be installed in a wide variety of host pipe materials
- Excellent abrasion resistance
- Improved flow capacity
- Provides excellent corrosion resistance
- Installed by local certified installers

![Image of SPR Pipeline Renewal Product](http://www.sekisui-spr.com/)

**Figure 27: Superior Pipe Rehabilitation (SPR) ([http://www.sekisui-spr.com/](http://www.sekisui-spr.com/))**

### 6.3. Ramming and boring systems

**NanoSTAB method**

Special soil displacement hammers, steel pipe ramming machines, steerable boring systems and rigs for renewal of existing sewer pipes enable trench less installation and replacement of pipes. Extensive excavation work and the transport of the excavated material don’t occur. The costs decrease and the regular traffic is influenced on a minor level ([http://www.grabenloses-bauen.de](http://www.grabenloses-bauen.de)).

![Image of NanoSTAB method](http://www.grabenloses-bauen.de)

**Figure 28: NanoSTAB method ([http://www.grabenloses-bauen.de](http://www.grabenloses-bauen.de))**
6.4. Pipe Inspection

Breivoll Inspection Technologies

The Norwegian company Breivoll Inspection Technologies carries out inspections of steel and cast iron water pipes via an acoustic resonance technology known as Breivoll Entrance Pipe (BEP). The method makes it possible to estimate the thickness and indicate the internal and external corrosion on water pipes (http://en.breivoll.no/service_-_condition_evaluation/cms/14).

![Inspection process of the Breivoll resonance technology](http://en.breivoll.no/service_-_condition_evaluation/cms/14)

An inspection device, called a “Pipescanner” and equipped with 64 ultrasound transducers, is fed into a pipe. The “Pipescanner” is pulled to a water filled pipe and enables a data acquisitions process of the whole pipeline and the entire pipe wall (360 degrees).

![Breivoll “Pipescanner” technology](http://en.breivoll.no/service_-_condition_evaluation/cms/14)
7. COASTAL STRUCTURES

7.1. Neo-Dry-Repair (NDR)

The Penta Ocean Construction Company, which provides already existing solutions for the rehabilitation of immersed tube tunnels, develops also advanced techniques for surveying, repairing and reinforcing underwater structures in rivers and harbours. In former times these structures were surveyed and repaired using underwater gear or temporary cofferdams with steel sheet-piles. These methods were time consuming and expensive. Penta Ocean Construction provides with its temporary steel caissons solutions for underwater construction work in a complete dry environment (http://www.penta-ocean.co.jp/english/business/civil/ndr.html).

Figure 31: Steel caissons from Penta Ocean Construction, Japan (http://www.penta-ocean.co.jp/english/business/civil/ndr.html)

7.2. Coastal Protection

Numerous climate scenarios predict a decrease in temperature and a global sea level rise; this influences the condition along the coastlines and estuaries. The coastal areas belong to the ecological and economical most important areas worldwide. In Norway many effects of raising temperature like changes in the precipitation and wind pattern have been observed already. Severe storms will appear more often with a higher intensity. All constructions along the Norwegian coast, which are located offshore, will lay lower when the sea level rises and all building and constructions, which are located close to the shoreline, will be flooded more often. In areas, where wave heights are limited by the water depth, the wave heights will increase and the coastal structures will be exposed to higher stress. To decrease future social and economical loss due to the results of climate change the coastal infrastructure has to be renewed and retrofitted.
Elastogran

Elastogran, an associated company from BASF The Chemical Company in Germany, provides under the name Elastocoast® a new plastic for cramping the rubble on dikes and breakwater. The new created layers protect the building against the waves and decrease the wave dynamic. Elastomeric polyurethane produces a durable and elastic composition with the rubble surface (http://www.elastogran.de/de/content.phtml?siteid=376).

Figure 32: Dike and breakwater stabilisation with Elastocoast®

(http://www.elastogran.de/de/content.phtml?siteid=376)
8. CONCLUSIONS

Every day traffic participants spent tremendous time in congestion. The traffic hold up can spread over a miles long distances during the office-hour traffic and holiday seasons. There is a tremendous requirement for intelligent traffic concepts and solutions to avoid congestion, noise, delays and pollution of the environment.

Many advanced tools and methods exist worldwide which provide rehabilitation measures for infrastructure with a minimum of hindrance for the traffic participants. Some examples of technical and organisational innovative strategies for avoiding congestion caused by construction sites are described in the report. Most of the methods, machines and materials are already in use; some are quite innovative and will eventually change the outlook of construction site in the near future. Worldwide several research projects are focused to analyse the reasons and consequences of congestion, the hindrance for traffic participants and the environmental impact. It is possible to recognise measures which are taken to improve the daily situation.

However, we experience still congestion which is caused by enormous construction sites and it is difficult to see which actions the infrastructure owners take to minimise the hindrance for traffic participants. Economical pressure and limited budgets lead to the fact that most of the operators conduct maintenance and rehabilitation on a common way and do not consider the consequences for the public traffic.

The present report should serve as a thought-provoking impulse for politicians, authorities, infrastructure owners and operators. The near future should provide us a safe, clean and environmental friendly traffic system.

This research was supported by the Norwegian Research council research in the framework of the Strategic Institute Program “Future Rehabilitation Strategies for Physical Infrastructure”. We thank Kristin Hilde Holmøy, Leif Sigurd Hafskjold and Bjørn Ove Lerfald for their comments and contribution.
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## 10. SOURCES FROM THE WORLD WIDE WEB

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<tr>
<td>Nanoplan</td>
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<td>Cross-Roads Recycling</td>
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<td>Wirtgen Group</td>
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<td>Tracblast</td>
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<td><strong>Rehabilitation of manhole cover</strong></td>
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<td><strong>Traffic simulator</strong></td>
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<td><strong>Software solution in road management</strong></td>
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<td>Construction Analysis for Pavement Rehabilitation Strategies</td>
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<tr>
<td><strong>Special consultancy for optimizing the rehabilitation process</strong></td>
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<td><strong>Ground Penetrating Radar</strong></td>
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<td>European GPR Association</td>
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### Preassembly

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### More mechanised maintenance

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### Technologies that need less maintenance

|----------|-----------------------------------------------------|

### Providing track access from outside the track

| Mitchel Rail Geer | [www.mitchell-railgear.com](http://www.mitchell-railgear.com) |
|

### Tunnels

| Tunnel rehabilitation with Shotcrete | [www.shotcrete.org](http://www.shotcrete.org) |

### Rehabilitation of immersed tube tunnels

|----------------------------------|--------------------------------------------------------------------------------|

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### Water and waste water system

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### CIPP Cured-in-place-pipe

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<td>SPR method</td>
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