CONTROLLING THE SUBSOIL RELATED PERFORMANCE OF DUTCH HIGHWAYS

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ABSTRACT

This paper presents an overview of ongoing activities to increase control of the subsoil related performance of the Dutch highway network. Differential settlement of road embankments on soft soil is causing an estimated 35 million Euros to be spent on maintenance annually. A back analysis of experiences allows the identification of critical elements in the process of construction and maintenance. Rijkswaterstaat, the Dutch road administrator, research institutes and construction industry are cooperating to improve these critical elements.

1. CURRENT SITUATION

1.1. Introduction

A substantial part of the Dutch highway network is built on soft soil deposits typical for the deltaic setting of the Netherlands. Differential settlements, stability of slopes of embankments, lateral deformations of soil under embankment loading and ground water control are the main subsoil related factors controlling construction and operation of the highway infrastructure on soft soil. Both embankment raising and elimination of differential settlements by surcharging require considerable time, typically in the order of a year. Thus, the availability of the future infrastructure is determined by the subsoil characteristics. Differential settlements, if not properly eliminated, will continue to cause problems with respect to longitudinal and transverse evenness of pavements for a long time after completion of the works. Maintenance works to restore evenness to acceptable values will adversely affect the availability of the infrastructure.

Rijkswaterstaat is the road administrator responsible for construction and maintenance of road infrastructure and management of the highway network. With requirements for availability of the network becoming stricter Rijkswaterstaat has started to increase the control of subsoil related factors in construction and maintenance. This paper will give an overview of problems to be addressed, ongoing research and actions, and the current state of implementation of these actions.

First, the organisation and roles of Rijkswaterstaat and construction industry are described. Next, this paper describes the results of an analysis to quantify the costs of subsoil related damage, as compared to costs due to other damage mechanisms. The analysis shows that at present subsoil related damage to pavements is substantial. Back analysis of a number of failures highlights some of the technical, procedural and organisational causes of poor control on subsoil related performance.

Next, the present process of performance specification, construction, monitoring and maintenance is analysed. Some essential elements are identified which prevent the effective control of the subsoil related performance of the Dutch highway network. These elements are elaborated and actions are defined which help the road administrator to get a better grip on management of their assets. Many of these actions require the development of new and dedicated tools, work procedures and increased attention to the organisation of data, knowledge and skills. The current state of implementation of the actions in the Netherlands is presented.

1.2. Organisation of the Netherlands road administration

Rijkswaterstaat acts as an agency under the Ministry of Transport, Public Works and Water Management, a situation that is becoming more common in Europe. As an agency, Rijkswaterstaat is responsible for construction, maintenance and management of their assets within established budgets. Service Level Agreements define the state of the infrastructure that should be maintained at all times. Monitoring of the technical performance of the infrastructure, availability to users and satisfaction of the public allows evaluation of the process.

The construction industry is intimately involved in the tasks of Rijkswaterstaat. All contracts for construction and maintenance works nowadays are issued as Design and Construct contracts, contractors being held responsible for the technical performance of their products for a period of seven years after completion. From 2010, Service Level Contracts might become standard, in which contractors will be responsible for the availability of larger parts of the network. Public-Private Partnerships will become more common; already some pilot projects have been initiated. This will mark a transition from technically oriented performance specifications to specifications that are more directly related to the interests of road users and the public.

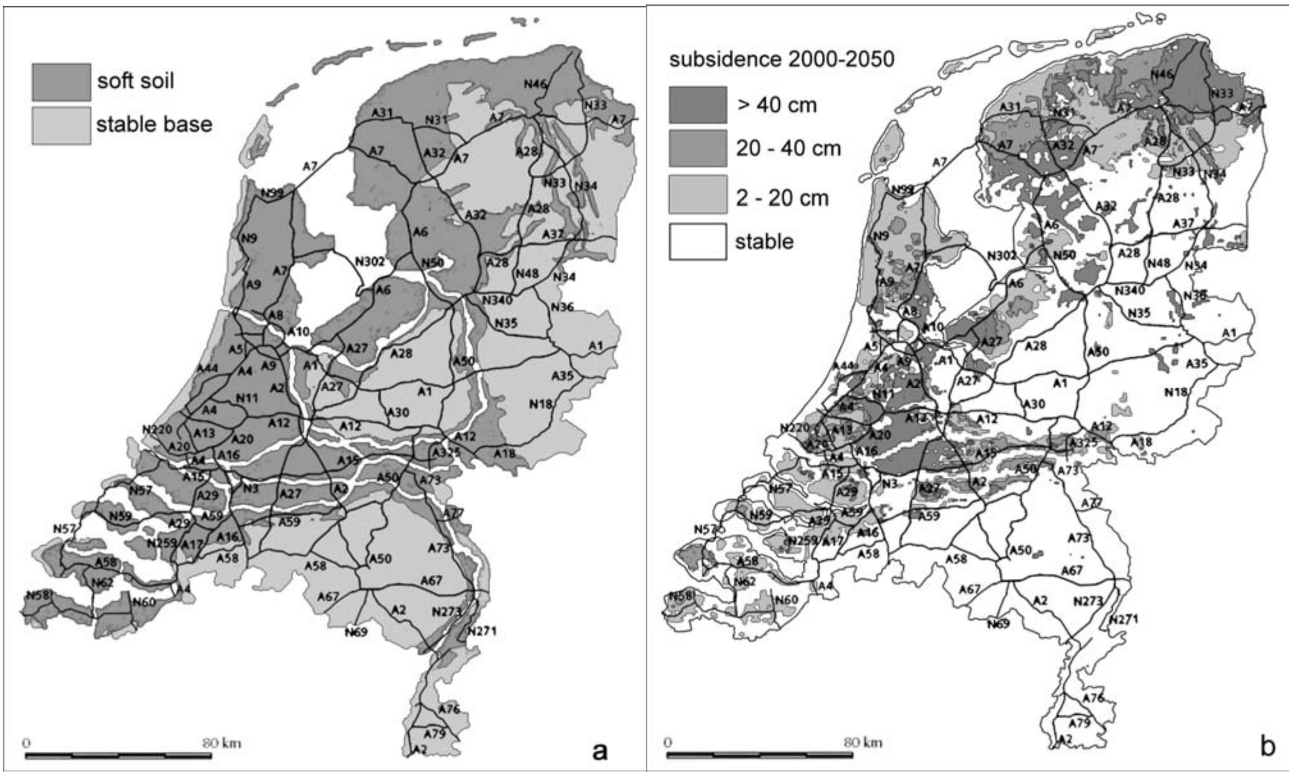

Figure 1 - The Netherlands highway network plotted on the geological map (a) and on the map of land subsidence (b)

In the current situation, the activities of the construction industry consist of assisting Rijkswaterstaat in feasibility studies, preliminary design and contract preparation (engineering consultants), final design and construction (contractors) and maintenance (contractors). The industry is expected to initiate research to develop innovative solutions to meet the performance specifications set by Rijkswaterstaat, and participate in precompetitive research.

The current activities of the road administrator are limited to directing the construction industry in pre-contracting activities, acting as an interface with the Ministry, the public and third parties surrounding the projects. After contracting, the road administrator supervises the construction and maintenance works according to specifications, and directs the communication with the public. The road administration monitors the condition of the infrastructure for short term and long-term maintenance planning, and also evaluates its own performance in attaining the goals set by the Ministry. Contract research is limited to the development of knowledge and tools to improve the primary activities. Precompetitive research is stimulated by funding and exchange of knowledge, aiming at creating conditions for construction industry to develop the best solutions.

1.3. Subsoil related maintenance costs

1.3.1 *The Dutch highway network*

The highway network in the Netherlands consists of 3200 km of trunk roads and seven tunnels. Approximately 3000 bridges, culverts and other structures are embedded in the network. About 60 % of the highway network is located on Holocene marine and fluviatile organic clay and peat deposits, with a thickness up to 15 m (Figure 1a). The soft deposits are underlain by a sand layer of Pleistocene age, which provides sufficient bearing capacity for piled foundations.

Construction of embankments on these weak and compressible soils cannot be controlled without due attention for the short term and long-term behaviour. Embankment raising should proceed at a rate sufficiently slow to allow the increase of bearing capacity during consolidation, and prevent slope failure. Soil improvement or soil reinforcement will be required in most cases to speed up the settlement process and minimize differential settlements after completion of the road. Differential settlements will become apparent at transitions to piled structures and at the transitions between existing and new embankments built to accommodate road widenings (Figure 2).


Photograph: RWS DWW

Figure 2 - Pavement cracking at road widening project

Mitigation measures may be required to prevent damage to structures or underground infrastructure by lateral deformations caused by embankment loading. With groundwater tables within 1 m below ground surface, drainage of the embankment must be provided to prevent frost damage.

Many roads are located in polder areas, where the water table is kept artificially at such level that the land can be used for agricultural purposes. This drainage exposes organic soils to the air and induces volume loss by oxydation, thus driving a continuous process of settlement and further lowering of the ground water table (Figure 1b). Road embankments will partly follow this movement, leading to differential settlements at transitions to piled structures and existing embankments. In the northeast of the Netherlands, subsidence is due to extraction of hydrocarbons. In this case also piled structures subside, with no net effect on differential settlements.

1.3.2 *Estimate of subsoil related maintenance costs*

During the lifetime of road embankments, differential settlements are the most common cause of damage. The effects of differential settlements are most pronounced at transtitions to bridges and other structures with pile foundations at the Pleistocene sand layer, and at road widening projects. In the latter case, the settlements may be accompanied by lateral movements of the new embankment because of lack of lateral support. In severe cases, the combined vertical and lateral movements have caused longitudinal cracking of the pavement. In the experience of the authors, poor maintenance of drainage systems is not exceptional. Frequently, high ground water tables have been observed in road embankments. Curiously enough, the expected associated signs of pavement distress are rarely found.

Every two years Rijkswaterstaat monitors the condition of entire highway network by an Automatic Road Analyser (ARAN) vehicle operating at traffic speed. The data is stored and reduced to produce an estimate of damage development over time, using the Pavement Maintenance Information System IVON. The subsoil-induced damage described earlier is expressed in insufficient evenness along the road axis (differential settlement at transitions to piled structures), excess transverse slope and pavement cracking (road widening).

Grashuis [1] presents an analysis of the data in IVON, revealing that these types of damage are dominant in approximately 4% of the length of the highway network. Because the total annual pavement maintenance budget is 200 million Euros, this percentage represents approximately 8 million Euros spent every year. In the other 96% of the cases, other damages are dominant, of which ravelling of the porous asphalt top layer is the most important. During replacement of the top layer, also subdominant damages are repaired. It is estimated that in 10% of these cases also subsoil related damage is present, representing another 19 million Euros annually. In addition, restoration of evenness at transitions to bridges is often part of minor maintenance projects, which are not included in IVON. The subsoil related maintenance costs for these projects is estimated at 6 million Euros per year. Thus, the total amount spent on maintenance of the Dutch highway network due to subsoil related factors is estimated to be in the order of 35 million Euros annually.

The estimate of subsoil related maintenance costs is relatively inaccurate for a number of reasons. First, IVON stores the IRI (International Roughness Index) measurements of evenness as averages over 100 m road sections. Because differential settlements at transitions to bridges occur over much shorter distances, even severe cases frequently remain undetected in the 100 m average. Second, the IVON system is primarily designed for maintenance planning, not for checking the actual maintenance actions. This makes extraction of the desired information cumbersome. Finally, the nature of minor maintenance works is not recorded systematically, which makes any estimate a matter of expert judgement.

1.3.3 *Back analysis of failures*

Since the subsoil related causes of maintenance are known, it would seem that a combination of proper site investigation, state-of-the-art design and construction methods and appropriate maintenance actions could minimize costs and loss of availability of the infrastructure. However, a limited inventory of the authors' experience shows ample room for improvement.

Back analysis gives the following causes of excessive differential settlements at transitions to bridges:

- Untimely removal of surcharge and part of the embankment at future transitions to bridges to accommodate pile driving equipment, leading to excessive differential settlements after completion.
- Underestimating the magnitude of the differential settlements after completion by application of models for soil behaviour that have not been properly validated, or assuming overly optimistic values for critical parameters.
- Running out of time for construction.
- Failing to communicate changes during construction to designers.
- Opting for a standard solution without consideration of site-specific conditions, such as restoring the longitudinal profile by filling with asphalt; the additional weight will induce further settlement.
- Ignoring historical data about settlements and subsidence in the area.
- Ignoring the consequences of actions taken to solve other problems, such as draining to keep electrical conduits dry. The increase in weight will induce settlements.
- Poor execution of ground improvement (e.g. sand drains) or ground reinforcement (mix-in-place methods in organic soil).
- Reluctance to perform the appropriate maintenance in order to avoid lane rental fines or receive 'no claim' bonuses.

Some recorded causes for pavement cracking are:

- Opting for a standard solution without consideration of site-specific conditions, such as adding fill on the slopes of an existing embankment; for lack of lateral support the fill will continue to subside.
- Failing to consider construction history, such as vibratory driving of sheet pile walls into the loosely packed sand of a road embankment constructed by sand tipping.
- Failing to recognize the effect of actions, such as removal of stability berms to make room for water storage bassins.

This limited inventory of failures does not permit a reliable estimate to be made of potential cost savings. Most of these defects could be well controlled against reasonable cost if proper risk management and technical audits had been applied. Thus, a large part of subsoil related maintenance costs could be attributed to procedural and organisational causes rather than technical causes. Reducing maintenance costs will usually increase costs for construction. In the opinion of the authors, there will be a net reduction of total costs. However, the main benefit of a better control of subsoil related performance would be the increase in availability and reliability of infrastructure for the public.

2. CRITICAL ELEMENTS IN CONTROLLING THE SUBSOIL RELATED PERFORMANCE

Back analysis of past failures allows the identification of critical elements in controlling the subsoil related performance of highways on soft soil. Design, construction and maintenance of the Dutch highway network can be visualised as a circular process (Figure 3).

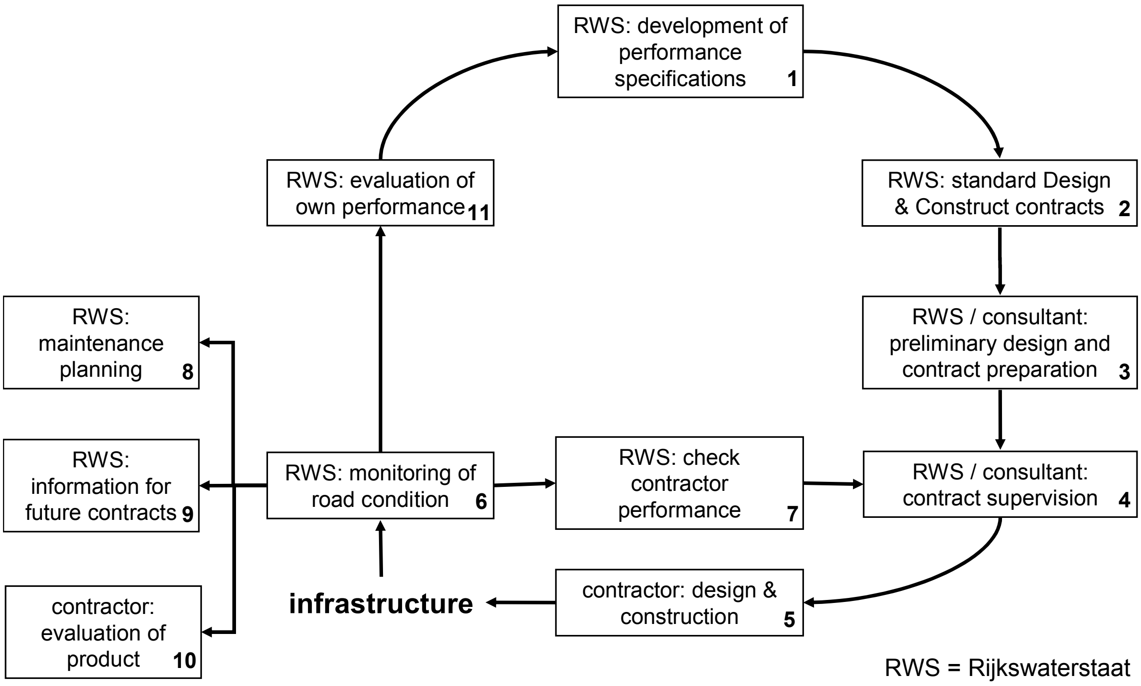

Figure 3 - Process chart for design, construction and maintenance of Dutch highways

The critical elements in this process are elaborated below, the numbering referring to Figure 3.

1. The current set of performance specifications for construction projects states that longitudinal evenness, transverse slope, cracking, skid resistance, ravelling and rutting should not exceed intervention values for maintenance. Future Service Level Contracts will also contain end user specifications in terms of availability and capacity of infrastructure. Additional requirements concern drainage, availability of future and existing infrastructure, construction time, effects on structures and slope stability. The current specifications for drainage and slope stability are considered conservative. As explained before, the current IRI criterion (100 m average) is insensitive to localised differential settlements at transitions to piled structures.
2. Rijkswaterstaat has developed a standard Design & Construct contract, to be used nationwide. In practice, some contracts require tailor-made modifications. A check should be made to verify that the modifications are still consistent with the general policy.
3. The preliminary design should contain a check on the consistency of performance specifications, construction time and budget. Building low-maintenance infrastructure on soft soil generally takes a lot of time or a lot of money. If availability of infrastructure is paramount, a consistent set of specifications should stimulate contractors to offer innovative solutions for rapid construction, rather than standard methods at the lowest price.
   An inventory of risks and their distribution between principal and contractor is the basis of risk management. This is especially important if innovative solutions are to be stimulated. Advanced techniques may be required to assess and manage the risks of innovations in the pre-contracting stage.

4. Rijkswaterstaat should implement their risk management plan, based on risk management by the contractor, using a balanced mix of product, process and system audits.
5. Contractors should have access to data and experiences from previous projects in the area and be given sufficient time for a proper site investigation.
   Contractors should know how to translate the performance specifications in the contract into specifications for design and quality control. At present, no explicit design rule is known relating subsoil heterogeneity, differential settlements at road surface level and IRI value. State-of-the-art methods for design, construction and monitoring should ascertain that specifications for design and quality control are met.
   Specifications in terms of availability and capacity of road infrastructure in the upcoming Service Level Contracts will require new tools for assessing the impact of construction and maintenance on availability.
   Contractors should know how to predict pavement damage of existing roads in widening projects (Figure 2), and the effects on road capacity. Current design methods are inaccurate and incomplete.
6. Monitoring of the condition of the road should include all information relevant to checking performance specifications (7), maintenance planning (8), risk assessment in future contracts (9), and evaluation of performance of innovative solutions (10). The current combination of measurements with ARAN and skid resistance trailer supplemented by visual inspection must be extended with data on drainage to complete maintenance planning.
7. Reduction of monitoring data should be aimed at checking the performance of work carried out by contractors. The present Design & Construct contracts specify three different measures for longitudinal evenness, but only one is included in the standard monitoring procedure.
8. Based on the monitoring data the maintenance planning system IVON predicts the development of damage over time and allows informed decisions to be made concerning maintenance planning at network level. The Calculation Model for Optimal Maintenance Strategies ROOS combines the IVON pavement maintenance planning with similar planning for maintenance of bridges, signalling systems and other objects around the road. The ultimate goal is to perform all maintenance in a single action over a larger part of the network, minimising both costs and impact on capacity of the network (de Temmerman [2]). In future Service Level Contracts contractors will be responsible for this task.
9. Knowledge of the current conditions of the infrastructure will be a critical factor in the introduction of Service Level Contracts. Contractors tendering for these contracts will need to have access to all relevant data on existing materials and constructions and their past performance, to optimise their activities and assess their financial risk. The existing data from pavement monitoring will provide valuable insight in the future maintenance need, but are insufficient to predict the behaviour of newly constructed embankments. Data currently acquired on a routine basis for monitoring of embankment construction will allow the calibration of parameters for the design of future works. Combination of construction and pavement monitoring data involves data reduction, formats and systems tailored to suits the needs of the contractors.
10. Rijkswaterstaat expects contractors to invest in innovative products that can be applied rapidly under all circumstances, with longer lifetimes under ever-increasing traffic load. Evaluation of the performance of these products is a prerequisite for their continuous improvement. Monitoring of the condition of the road should provide all data relevant to this evaluation, and may require reduction and presentation of the monitoring data in new formats.

11. Both Rijkswaterstaat as external government bodies will perform periodical assessments of the efficiency and effectiveness of the organisation in meeting its high-level targets. Among these targets are the fulfilment of end user needs, public satisfaction, availability and capacity of the network, progress of innovation, return on investment of knowledge development, accountability and transparency, degree of involvement of construction industry. At a lower level, Rijkswaterstaat performs audits and evaluations of internal standard procedures, risk management and development and dissemination of knowledge. However, the final question remains: are the performance specifications effective in producing the desired results? An answer to this question will require the development of relevant indicators for subsoil related performance, and collection of the associated data. The reference frame method (van Koningsveld [4]) could be useful to derive such indicators from the high-level targets. Rijkswaterstaat previously applied the method successfully in the field of coastal zone management.

3. CURRENT ACTIVITIES TO INCREASE CONTROL ON SUBSOIL RELATED PERFORMANCE

Table 1 gives an overview of the critical elements in the control of subsoil related performance, based on the analysis presented in the previous chapter. The table also highlights ongoing activities of Rijkswaterstaat, Delft Cluster and GeoDelft to improve control over these elements. Delft Cluster is a combination of Delft based research institutes, in which GeoDelft participates. Delft Cluster runs several research programs aimed at durable development of deltaic areas. The program 'Perpetually smooth roads' (Blijvend Vlakke Wegen) concerns highway infrastructure and receives financial support of Rijkswaterstaat and construction industry.

Table 1 classifies the actions in technical (related to methods for site investigation, design, construction and monitoring, data), procedural (related to work processes in contracting, design, construction and maintenance) and organisational (related to training and education, decision making, evaluation, communication).

Subprocess (cf. Figure 3)	Technical improvement	Procedural improvement	Organisational improvement
1. Development of specifications	Development of unified measures for longitudinal road evenness		
2. Standardisation of contracts			(Audits on specific-ations used in con-tracts nationwide)
3. Preliminary design / contract preparation		Development of guidelines for site investigations	(Training of principals and consultants)
	Development of a tool for checking the consistency of specifications, time and budgets		Training of principals and consultants

Table 1 - Ongoing actions to improve critical elements

Subprocess (cf. Figure 3)	Technical improvement	Procedural improvement	Organisational improvement
3. Preliminary design / contract preparation		Evaluation of risk inventories, risk sharing, risk management plans	(Organisation of community of practice, CoP)
	Development of specifications for testing innovative products	Development of procedures for risk management of innovations	(Organisation of CoP)
4. Contract supervision		Evaluation of risk management	(Organisation of CoP)
5. Final design and construction	Development of a tool for rapid selection of construction methods on the basis of life cycle costs and availability		
	Development of design tools for prediction of longitudinal road evenness, lateral ground deformation		
	Development of design rules and tools for piled embankments, interaction between pavement and embankment, transitions at bridges		
		Evaluation of risk management	(Organisation of CoP)
6. Monitoring of road condition	(Include monitoring of drainage systems)		
7. Check on work of contractor	Modify data reduction to match contract specifications		
8. Maintenance planning	no actions needed		
9. Information for future contracts	Analysis of data need, acquisition of monitoring data from embankment construction, development of data reduction, formats and storage		

Table 1 (continued) - Ongoing actions to improve critical elements

Subprocess (cf. Figure 3)	Technical improvement	Procedural improvement	Organisational improvement
10. Evaluation of innovations	(Analysis of data need, include monitoring of relevant data)	(Adjust risk management procedure for specific product)	(Organisation of CoP)
11. Evaluation of performance	Collect information for better estimates of impact of subsoil on cost and avail-ability and potential improvements	Development of procedures and indicators for evaluation of subsoil related performance	Implementation of audits and evaluation of high-level and low-level targets

Table 1 (continued) - Ongoing actions to improve critical elements

Actions between brackets have not yet started. Training and sharing of knowledge and experiences are crucial in accomplishing real progress. An analysis of the current state of the knowledge infrastructure in the Netherlands by PSI Bouw [3] shows that knowledge at construction industry, principals, research institutes and universities is highly fragmented, each party only catering for its own needs. The study considers sharing knowledge and experiences between all participants in the process essential for changing this situation. Also, the study suggests to adopt big projects as learning ground for testing new tools or methods. This will create opportunities for researchers to meet practitioners, focussing the development of specialist knowledge on the end user needs. In the other direction, contractors and consultants have direct access to state-of-the-art knowledge. An example of this approach is the Delft Cluster program 'Perpetually smooth roads' that has adopted the widening of highway A2 between Amsterdam and Utrecht as their learning ground.

In the opinion of the authors, the key success factor in successful implementation of the suggested improvements is the cooperation of all parties involved in the process of construction and maintenance.

4. CONCLUSIONS AND RECOMMENDATIONS

This paper identifies controls on subsoil related performance of the Dutch highway network. Initial estimates of annual subsoil related maintenance cost and back analysis of failures show potential for cost savings and increase in availability and reliability of infrastructure. A breakdown of the current process of construction and maintenance identifies technical audits, training of principals and consultants, and organisation of a Community of Practice as the actions to be realized. A joint effort of road administration, research institutes and construction industry will be a key factor in the implementation of these actions. An evaluation of the effectiveness of these actions will involve development of indicators, to be derived from organisational targets.

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