Improving low-volume road construction and performance

Validity of using the heavy vehicle simulator in evaluating the reinforcement of low-volume roads

Dina K. Kuttah
Preface

The main goal of this report is to highlight the benefits of using the heavy vehicle simulator (HVS) in verifying the validity of the proposed design of roads before construction which in turn leads to more efficient and economical road constructions. Furthermore, this report discusses the main advantages of using the heavy vehicle simulator in the evaluation of construction issues and the determination of the relative engineering properties of the materials used in roads constructions. The mechanistic analysis of all pavement structures can be assessed using the HVS test. In addition, the monitoring of the long term performance of the geosynthetics reinforced sections under road traffic can also be performed.

The other purpose of this report is to exemplify the use of geotextiles and/or geogrids as a cost-effective solution to enhance the performance of low volume traffic roads. Basically, using of geosynthetics in roads construction reduces the thickness of unbound layers required over soft soil, which in turn reduce the costs of constructions. Therefore, this report sheds line on the importance of studying the effects of using geosynthetics to reinforce low volume roads by using the HVS test.

However, this report is not intended to replace the excellent literature works and papers used in this subject but it is hoped that the report will give the reader a greater understanding of the needs of full-scale roads testing to ensure the usage of new road design approaches and materials.

Finally, it is important to mention here that regardless of whether the road is paved or unpaved with asphalt, reinforced or unreinforced with geogrids, tested or untested with HVS, we should not forget that the research road should be paved with high ambitions, reinforced with patience and tested with respect to work ethics.

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Dina Kuttah
Projektledare
Kvalitetsgranskning


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**Improving low-volume road construction and performance**

by Dina Kuttah

VTI, Swedish National Road and Research Institute

SE-581 95 Linköping, Sweden

**Summary**

Sweden has a wide network of unpaved low-volume roads which suffer from frost-thaw problems as well as insufficient drainage. As more water is penetrating down into the subgrade soil under the freeze-thaw seasons, the bearing capacity will decreases and deterioration of road increases. Approximately, one-fifth of pavement failures occur due to insufficient structural strength. Inadequate bearing capacity of underlying weak subgrade and inefficient load transfer from the base course are two of the main reasons for roads failures. The road will suffer a small deterioration every time a vehicle travels over it and overloading of a vehicle will accelerate this process.

Since the unpaved roads consist of unbound materials, they are susceptible to erosion. This erosion (due to traffic loading or change in climate conditions) will negatively affect the minimum road grade required to drain out the surface water due to rainfall or melt frozen snow. The cross sectional road slope should promote surface drainage and prevent ponding on the road surface that can promote softening of subgrade materials.

Correspondingly, geosynthetics are specially fabricated to be used in transportation engineering applications and to reduce the aforementioned roads problems. It is convenient to identify the primary function of a geosynthetic as being one of: separation, filtration, drainage, reinforcement, and erosion control. In many cases the geosynthetics may serve dual functions. However, the validity of using geosynthetics as a cost-effective alternative for constructing unpaved roads could be examined by accelerated load testing (ALT). Water contents and the change of subgrade shape and road grades can be monitored during the accelerated loading testing.

Therefore, the use of geosynthetics in order to keep the shape and slope of subgrade soil as well as to stabilize the road structure is highly recommended to be examined in detailed under different loading and environmental conditions using the heavy vehicle simulator (HVS). This testing can result in significant cost and construction time saving, better and durable unpaved roads as well as encourage the use of geosynthetics in Sweden as a less expensive alternative in producing stable roads. In addition, the HVS can be used to evaluate the cost differences in conventional and new construction technique using the geosynthetic materials and to develop guidelines for road design and construction as well as to provide some input for the development of roads modeling software.
Förbättring av konstruktion och prestanda för lågtrafikerade vägar
av Dina Kuttah
VTI
581 95 Linköping

Sammanfattning
Sverige har ett omfattande vägnät av oasfalterade, lågtrafikerade vägar som påverkas av tjäll- och upptiningsproblem samt otillräcklig dränering. När vatten kan träna ned i undergrunden under vintersäsongen kommer bärigheten att minska och försämringen av vägen att öka. Ungefär en femtedel av beläggningsskadorna uppstår på grund av otillräcklig hållfasthet i konstruktionen. Otillräcklig bärighet i en svag undergrund och ineffektiv lastöverföring från bärlagret är två av de viktigaste orsakerna till vägskador. Vägen kommer att försämras gradvis varje gång ett fordon passerar och överbelastning av fordon kommer att påskynda denna process.

Eftersom grusvägar består av obundet material är de känsliga för erosion. Erosionen (orsakad av trafikbelastning eller förändrade klimatförhållanden) kommer att negativt påverka det minsta tvärfall som krävs för att dränera bort ytvattnet från regn eller smått snö. Tvärfallet bör underlätta avrinning och förhindra oönskade vattensamlingar på vägbanan som kan orsaka uppmjukning av undergrunden.

På motsvarande sätt är geosyntetiska material speciellt tillverkade för att användas i transporttekniska tillämpningar och för att minska de ovan nämnda problemen. De primära funktioner hos ett geosyntetiskt material är: uppdelning, filtrering, dränering, förstärkning och erosionsskydd. I många fall kan de geosyntetiska materialen tjäna dubbla syften. Emellertid bör nyttnan av att använda geosyntetiska material som ett kostnadseffektivt alternativ vid byggnation av grusvägar undersökas genom accelererade belastningsprov (ALT). Vatteninnehåll, förändringar i undergrundens form och vägens tvärfall kan övervakas under det accelererade belastningsprovet. Vid användning av geosyntetiska material för att bevara form och lutning på undergrunden samt för att stabilisera vägkonstruktionen rekommenderas en detaljerad undersökning av olika belastnings- och miljöförhållanden med hjälp av tunga fordonssimulatorn (HVS).

Ett sådant test kan resultera i betydande besparningar vad gäller kostnader, konstruktion och tid, ge bättre och mer hållbara grusvägar samt uppmuntra till användningen av geosyntetiska material i Sverige som ett billigare alternativ vid produktion av stabila vägar. Dessutom kan HVS användas för att utvärdera skillnaderna i kostnad mellan konventionella och nya konstruktionstekniker vid användande av geosyntetiska material, att utveckla riktlinjer för vägkonstruktion och utförande samt att ge input i utvecklingen av vägmodelleringssystem.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AADT</td>
<td>Annual average daily traffic</td>
</tr>
<tr>
<td>ABb</td>
<td>Asphalt Concrete in Binder Courses</td>
</tr>
<tr>
<td>AC</td>
<td>Asphalt concrete</td>
</tr>
<tr>
<td>APT</td>
<td>Accelerated pavement testing</td>
</tr>
<tr>
<td>ASG</td>
<td>Asphalt strain gauges</td>
</tr>
<tr>
<td>ATB</td>
<td>General technical description, Swedish road specification</td>
</tr>
<tr>
<td>ATPB</td>
<td>Asphalt-treated permeable base</td>
</tr>
<tr>
<td>FEACONS</td>
<td>A Finite Element computer program</td>
</tr>
<tr>
<td>FWD</td>
<td>Falling weight deflectometer testing</td>
</tr>
<tr>
<td>HVS</td>
<td>The heavy vehicle simulator test</td>
</tr>
<tr>
<td>LCC</td>
<td>Life-cycle cost analysis</td>
</tr>
<tr>
<td>LVDT</td>
<td>Displacement transducers (Linear Variable Differential Transformer)</td>
</tr>
<tr>
<td>MLET</td>
<td>Multilayer Elastic Theory (MLET)</td>
</tr>
<tr>
<td>RLT</td>
<td>Repeated load triaxial testing</td>
</tr>
<tr>
<td>SLR</td>
<td>Spring load restrictions</td>
</tr>
<tr>
<td>SPC</td>
<td>Soil pressure cells</td>
</tr>
<tr>
<td>Standard axle</td>
<td>An imaginary axle with a couple of the wheels of 100 kN axle load distributed between the wheels. Each wheel has a circular contact between the tire and the road with contact pressure of 800 kPa</td>
</tr>
<tr>
<td>VTI</td>
<td>The Swedish National Road and Transport Research Institute</td>
</tr>
<tr>
<td>VTT</td>
<td>Technical Research Centre of Finland</td>
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1 Introduction

It is well known that geosynthetic basal reinforcement has been used in paved and unpaved roads to limit the occurrence of rutting, fatigue, and environmental-related cracking, as well as to permit reduction in base course thickness. Nevertheless, the lack of a representative, cost-efficient test that can be used to evaluate the behavior of large-scale pavement trial sections has prevented detailed analyses of variables that may affect the performance of basally-reinforced flexible pavements or unpaved roads. The most important parameters that should be examined in such cases are the base thickness, subgrade and base soil properties, geosynthetic materials properties and functions, depth of geosynthetic placement, stress state, corresponding traffic loading and the corresponding environmental conditions.

Accordingly, the main objective of this study is to highlight the importance of using the heavy vehicle simulator to characterize the full-scale, geosynthetic reinforced pavement response.

This report includes a description of the methodology and historical use of the HVS all over the world with a focus on the results from Swedish case studies that have been implemented using the HVS owned by the Swedish National Road and Transport Research Institute (VTI).

In addition this report highlights the cost-benefit analysis from using the HVS as a testing approach as well as the use of geosynthetics as an effective and economical approach to enhance the performance of low traffic volume roads.

Usually, the pavements are designed to support an expected amount of traffic over the desired design life, but unfortunately most of the pavements suffer from mechanical failure before they reach the desired design life due to unexpected loadings, environmental interaction, drainage problems, etc.

Consequently, in order to reach the lifetime of paved and unpaved roads, pavement engineers have incorporated thicker layers of base material into flexible pavements.

However, this strategy has led to excessive cost in some situations (Cox et. al. 2010). Accordingly, alternatives such as geosynthetic reinforcement of the base course have been used in flexible pavements as well as unpaved roads (Steward et al. 1977).

Field studies have indicated that geosynthetic reinforcement of pavement base course layers can lead to reduced differential settlement, reduced base course thickness, extend the service life, and improved stress distribution (Hufenus et al. 2006), but most of these studies based on short term laboratory tests and initial costs assessments. Therefore, long term roads performance evaluation based on life cycle cost analysis is highly recommended.
2 Purpose of the Study

The objective of this study is to highlight the benefits of using the HVS to verify the subgrade soil reinforcement under long term traffic conditions. Correspondingly, provides a better understanding of the importance of using large scale tests (e. g. the heavy vehicle simulator test) to simulate traffic associated deterioration of a road over its design life (usually 20 years) in as little as three months.

Furthermore, this study deals with general aspects related to road’s problems associated with low volume traffic in order to provide a better understanding of the problems that addresses the needs of testing new roads design approaches using full scale tests. In addition, this report presents a systematic step-by-step method for design and repair of roads suffering spring thaw weakening using geosynthetics.

Consequently, the report will discuss whether and under what conditions geosynthetics (geogrids and geotextiles) increase the structural capacity of pavements and under what conditions geosynthetics increase the service life of pavements. At the same time this report will give a historical overview about the use of accelerated pavement testing all over the world and open the access over new accelerating testing programs using the heavy vehicle simulator to verify the validity of new road design approaches like the use of reinforced materials in roads constructions to extend the service life of the road.

In principle, long term roads performance assessment will help in answering the most important pavement mysteries and questions, like:

The road looks good today, but how will it perform tomorrow?

What should we do in order to guaranty that the road everyday will perform as well as the first day of service?

What should we do in order to get a better road surface and reduce road maintenance with simplified construction and lower costs?

What test can give dependable results that reflect the full-scale performance of roads and could be the bases for pavements design guide?

What materials should we use to construct environmentally acceptable roads that can service over the whole design life?
3 The Accelerated Loading Testing

According to Byron and Choubane (2003), the accelerated loading testing is a controlled application of a realistic wheel loading to a pavement system simulating long-term loading conditions. This technique allows the monitoring of a pavement performance and response to accumulated load damage within a shorter time period (Byron and Choubane, 2003).

The need for faster and more practical evaluation methods under simulated in-service conditions prompted several transportation agencies, including the Swedish National Road and Transport Research Institute (VTI), to consider accelerated pavement testing (APT).

One of the large scaled accelerated pavement tests is the Heavy Vehicle Simulator, HVS, which can be simulate traffic associated deterioration of a road over its design life (usually 20 years) in as little as three months. The HVS is used to study how different types of road constructions manage heavy traffic while exposing the full-scale roads to accelerated traffic. Prior to the HVS, researchers had to wait many years to see if new laboratory test methods or field tests would indeed provide reliable results for pavements under actual truckloads and traffic.

Regarding the HVS test, the mechanism of working is based on the rolling of a truck tire over a patch of asphalt or any type of road construction material. It goes back and forth to simulate years of traffic in just weeks or months while verifying whether a pavement structure will last or fall apart.

Consequently, the following paragraph is intent to present a description of the HVS testing program all over the world with a focus on the main usage and findings of the Swedish HVS testing program.

3.1 The uses of the HVS test all over the world

The following paragraphs address in details many of the experiments that have been carried out all over the world to evaluate the new road construction materials and design approaches using the heavy vehicle simulator. The literature review presented in this subject covers just few research studies carried out using the heavy vehicle simulator. Nevertheless, there are more studies in this area but unfortunately; it is not possible to address all of them here.

Correspondingly, a research study has been carried out in Florida to evaluate the long-term performance of superpave asphalt mix design and modified superpave asphalt mix design using the HVS. The main objectives of this study were to evaluate the operational performance of the Heavy Vehicle Simulator, and its possible use in evaluating the rutting performance of pavement materials and/or designs under typical Florida traffic and climate conditions. As a result, the rutting performances of a typical superpave mixture used in Florida were sufficiently evaluated using the HVS as reported by Tia et al. (2002).

Kohler et al. (2004) described the evolution of precast concrete pavements in various countries and, in particular, in the United States. The design, construction, and installation of a particular system of precast slabs called Super-Slab™, was explained, and an overview of the results of accelerated load testing with a heavy vehicle simulator (HVS) performed in California were presented by Kohler et al. (2004).
According to Kohler et al. (2004), the HVS results indicate that the evaluated system of precast slabs can be safely opened to traffic in ungrouted condition, so that the panels can be installed in consecutive nights rather than completing the entire installation at one time. In addition, Kohler et al. (2004) pointed out that the life of this system of precast slabs, is estimated to be between 142 and 242 million equivalent single-axle loads, equivalent to 25 to 37 years of service and the failure mechanism did not differ from the failure mechanism of cast-in-place jointed concrete pavements.

Moreover, the Heavy Vehicle Simulator (HVS) was used to test pavements on two roads in South Africa that were recycled in place and treated with foamed bitumen and emulsified bitumen. The HVS testing was performed on road P243/1 near Vereeniging, Gauteng Province, and on the N7 road outside Cape Town in the Western Cape in order to characterize the foamed and emulsified bitumen treated materials. The other purposes of the test were to identify distress mechanism and to investigate how the distress progressed with increasing load repetitions. In principle, the APT testing has provided the tool for early assessment of a relatively new pavement technology such as foamed bitumen treatment and deep in situ recycling as described by Theyse et al. (2004).

The California Department of Transportation requires that all new flexible pavements should include a 75-mm layer of asphalt-treated permeable base (ATPB) between the asphalt concrete and aggregate base layers to block off the entering of water to the pavement structure, either through cracks in the asphalt concrete or through high-permeability asphalt concrete. This layer will transport the cracks out of the pavement before it reaches the unbound materials. The validity of using the ATPB layer was examined using heavy vehicle simulator (HVS) to evaluate the performance of drained and undrained flexible pavements under wet conditions. Results of the accelerated pavement testing indicate that ATPB strips under combined conditions of wet base and heavy loading and the drained and undrained sections have similar pavement lives; however, the primary mode of failure for the drained section was surface rutting and for the undrained sections was fatigue cracking (Bejarano et al., 2004).

According to Tia and Kumara (2005), in Florida, full slab replacement is a common method for repair of badly deteriorated concrete pavement slabs. However, there were certain requirements on the compressive strength as well as uncertainties on the optimum concrete mixtures to be used; therefore the Florida Department of Transportation requested research in this area using the HVS. For this purpose, five test concrete slabs were tested by the HVS and the results of this experiment helped the researchers to decide which slab could perform better than the other. Tia and Kumara (2005) found that the performance of the test slabs was independent of the cement content of the concrete used. Therefore, the HVS gave the researchers a complete idea about the factors that influence the concrete slabs performance. In addition, the tests parameters resulted from the HVS test were used to develop a Finite Element computer program (FEACONS) to model the response of the test slabs and to predict the stresses in the concrete slabs caused by the applied loads and the temperature differentials in the concrete slabs (Tia and Kumara, 2005).

Plessis (2008) highlighted the benefits achieved from using the heavy vehicle simulator in roads testing. Plessis (2008) reported that the HVS had been used in verifying the validation of a new large stone mix design method; use of modified binders in mixes; in situ recycling of materials; upgrading of gravel roads as well as block paving and rehabilitation procedures for concrete roads. Moreover, Plessis (2008) added that the use of HVS had allowed a better (optimal) use of funds and natural resources.
3.2 Swedish case studies in using the VTI's heavy vehicle simulator

3.2.1 Background

The HVS of the Swedish National Road and Transport Research Institute has been used since 1998. The acquisition of the machine was planned in co-operation with the VTT.

In many respects, the VTI's heavy vehicle simulator testing programme has contributed and is still contributing significantly to technological development in a number of areas, such as materials design, pavement structural design; materials test methods and several innovative modeling methods. The VTI's heavy vehicle simulator focus research areas involve the following fields:

- Mechanistic design of semi-rigid pavements
- Stability tests of modified AC-layer
- Evaluation of the Swedish pavement design specification
- Evaluation of different strengthening strategies on existing roads in some European countries

3.2.2 Sweden’s HVS facility

The VTI’s heavy vehicle simulator configurations are reported in details in Table 1. It can be seen from Table 1 that the VTI’s heavy vehicle simulator can apply wheel loads between 30 and 110 kN (using dual or single tires) along 8 m test strip within any given test track.

The effective test segment within this test span is approximately 6 m in length. The remaining 2 m, at either end of the test strip, allows the load wheel to reach programmed parameters controlling load and speed levels. These 2 m sections are referred to as the acceleration/deceleration zones.
The VTI’s HVS works 24 hours a day, during the nights and weekends without human control. Consequently, the VTI’s HVS is electrically powered (using external electric power source or electricity from an on-board diesel generator), fully automated, and mobile and its functionality includes laser profiling and test track temperature control capabilities, as shown in Figure 1.

Table 1 The VTI’s heavy vehicle simulator configurations

<table>
<thead>
<tr>
<th>Model</th>
<th>MK IV</th>
</tr>
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<tbody>
<tr>
<td>Test wheel</td>
<td>Dual or single</td>
</tr>
<tr>
<td>Load range</td>
<td>30-110 kN (corresponds to 6-22 tones axle load)</td>
</tr>
<tr>
<td>Capacity</td>
<td>150,000 passes/week</td>
</tr>
<tr>
<td>Loading direction</td>
<td>One or two directions</td>
</tr>
<tr>
<td>Max. test speed</td>
<td>12 km/h</td>
</tr>
<tr>
<td>Total lateral wander</td>
<td>0 - 0.7 m</td>
</tr>
<tr>
<td>Pavement temperature</td>
<td>0 – 30 °C</td>
</tr>
<tr>
<td>Power</td>
<td>Diesel or electricity</td>
</tr>
<tr>
<td>Length</td>
<td>23 m</td>
</tr>
<tr>
<td>Width</td>
<td>3.7 m</td>
</tr>
<tr>
<td>Height</td>
<td>4.2 m</td>
</tr>
<tr>
<td>Weight</td>
<td>Approx. 50 tones</td>
</tr>
<tr>
<td>Test length</td>
<td>8m (of which 6 m of constant speed and load)</td>
</tr>
<tr>
<td>Test width</td>
<td>0.5-1.25m</td>
</tr>
</tbody>
</table>
Moreover, the tested pavement can be instrumented with transducers to measure strains, stresses, surface rutting and deformations as shown in Figure 2. As the strain gauges need a lot of caution during the laying phase, it is very important to deal with them with high accuracy.

Figure 1 The VTI’s heavy vehicle simulator with track temperature control capabilities.

Figure 2 Instrumentation used during projects carried out by the VTI’s heavy vehicle simulator.
This paragraph is devoted to shed light on European usage of the VTI’s HVS during REFLEX project. In this project, three full-scale accelerated tests have been performed, two in Sweden during the summer of 2000, and one in Finland in late year 2000. The main goal of the project was to develop a new road construction and rehabilitation technology. The idea was to reinforce the asphalt roads by steel fabric reinforcement to make road structures more cost effective by improving the lifetime of new constructed roads (Wiman and Gustafson, 2000).

During REFLEX project, response measurements were made at the beginning of the test and during and after the test at selected intervals. One of the important findings of the project was that the rut depths were reduced by approximately 24% at the area where steel net was used (Wiman and Gustafson, 2000).

Moreover, the VTI’s HVS test has been performed to evaluate the existing design of A2 motorway semi-rigid pavement in Poznan, Poland, as shown in Figure 3. The tested pavement consisted of an unbound drainage layer (frost protection layer), a cement-bound sub-base course (the lower layer), and a cement-bound main base course (the upper layer). The asphaltic package consisted of an asphaltic base course and an asphaltic surface layer. A comprehensive test program was carried out; comprising a HVS experiment on two instrumented test fields, see Figure 4.

![Figure 3 Transporting of the VTI’s heavy vehicle simulator.](image-url)
The pavements on the test sites were instrumented with strain gauges, soil pressure cells and deflection gauges in order to evaluate the road response under the load and to compare these response measurements with values calculated from theoretical pavement models. The accelerated loading of both test fields was performed by means of the Nordic Heavy Vehicle Simulator (HVS), nowadays it is called the VTI’s heavy vehicle simulator. Accelerated loading tests took place from July to September 2002, as shown in Figures 2 and 3. After the loading period, the final deflection measurements were conducted and material samples were taken from the pavement layers for carrying out laboratory tests. Based on analytical calculations the most realistic ranges of the elastic modulus of the pavement layers, especially of the cement treated base layers as the main bearing element, were determined and used for comparative pavement design calculations (Blab et. al, 2004).

In addition, according to Ingason et al. (2002), two typical Icelandic low volume road structures were tested using the Heavy Vehicle Simulator facilities at VTI in Sweden in 2002. At that time, the HVS is jointly owned by Finland and Sweden. However, the two low volume roads were surface dressed structures, one with a target 20 cm thick unbound granular base course layer and the other with a base divided into a 10 cm bitumen stabilized base over 10 cm unbound base. Furthermore, the two structures were designed empirically in accordance to the Norwegian design method, taking into account the materials had been chosen. One structure had unbound base course, for traffic up to 300 AADT, and the other had a bitumen bound base course, for traffic up to 1500 AADT. For the bituminous bound base course it was decided to use emulsion fulfilling Swedish specifications (BE 65M B180) with rest bitumen of 4%. Correspondingly, the response from the different sensors was measured for various set of test parameters; single/dual wheel; different load and tire pressure; different speed of wheel; different lateral position of wheel and for the structure with bitumen bound base course.
course also for different temperatures. Consequently, the results showed that using bitumen to stabilize “unstable” material increases the lifetime of the pavement structure. In addition it was concluded that constructing one 20 cm thick layer of unbound base material with same grain size distribution is not advisable. It should be divided in two layers using coarser materials.

Moreover, Erlingsson and Ingason (2004) modeled the pavements response using the Multilayer Elastic Theory (MLET) and the Finite Element (FE) and compared the modeling results with the results obtained from the aforementioned HVS test. For both techniques linear and non-linear behavior of the base has been assumed. The material properties used in the response analyses were based on back calculation from a plate load (PL) testing and falling weight deflectometer (FWD) testing as well as on results from repeated load triaxial (RLT) testing. Erlingsson and Ingason (2004) added that for the thin unbound structure, much better agreement was found between the nonlinear response and the actual testing results, but both the linear and the non-linear responses gave similar results for bitumen bounded structure. In addition, good agreement was found between the numerical simulations and the testing results for the two tested structures using the HVS. Erlingsson and Ingason, (2004) recommended the use of the HVS-tests in developing a mechanistically based pavement design method and increasing the understanding of the thin pavements performance.

Lenngren and Hansson (2004) pointed out that the Western Region of the Swedish Road Administration decided to do a thorough field test of mica-rich materials and light-fill materials in 2003. After the laboratory tests of the materials in question, the field test was carried out using the Swedish heavy vehicle simulator. The test sections were each instrumented with six accurate deflectometers and two pressure cells at different depths. Moreover, temperature and soil moisture readings were also achieved. The preliminary results showed that the influence of moisture affects the deterioration of the road when mica is present. However, at dry conditions prevailed during the field test, the presence of mica does not influence the results much. Lenngren and Hansson (2004) added that even if this outcome was less desirable, the data was nevertheless interesting to analyze from other aspects. The deflections gathered with the falling weight deflectometer indicated that the cells were subjected to different degrees of compaction, in turn affecting the rutting rates. However, the data collected by Lenngren and Hansson (2004) established a good start for developing a relationship between the initial and long-term rutting depths.

Furthermore, the HVS was used to examine the differences in permanent deformation between crushed and uncrushed material when subjected to loading using the Swedish Heavy Vehicle Simulator (HVS) test (Odermatt, et. al., 2004 and Wiman 2006). Correspondingly, accelerated loading tests on a test section constructed with two different base course materials were conducted at the Swedish National Road and Transport Research Institute (VTI), using the Nordic Heavy Vehicle Simulator (HVS-Nordic). During the HVS test, stresses and strains in the base course were measured together with the rut depth at the surface, when the test road was subjected to a 60 kN dual wheel load by means of bi-directional loading. The main finding obtained from the HVS tests is that the permanent deformation was larger for the crushed material than for the uncrushed materials (Odermatt, et. al., 2004 and Wiman 2006).

According to Wiman (2010), another attempt to use the VTI’s HVS in predicting the pavements response was performed under the period of December 2004 to March 2005.
Full-scale road structures were constructed in the VTI’s HVS site on a subgrade of fine graded sand. Totally, about 0.5 million loadings were carried on in three different pavement temperatures (+10°C, +20°C and +30°C).

The aim of the test was to study the stability characteristics of two pavement structures with different binder courses in relatively thick bitumen pavements in different temperatures. Polymer modified bitumen was used in the binder course in one of the structures, and in the other a conventional bitumen (ABb22, 70/100, according to the Swedish design manual for pavements (ATB Road). As expected, the structure with the polymer modified bitumen in the binder course showed less rutting on the surface. After the first two periods (with temperatures of +10°C and +20°C) the rutting was measured to be 13 mm, compared to 20 mm (+50%) in the reference structure, Wiman (2010).

3.2.3 Detailed example of data and results obtained from the HVS Test

All the tests results given in this paragraph presents summary of research carried out by Wiman (2006) using the VTI’s heavy vehicle simulator. The purpose of illustrating this example here is to give an idea about the instrumentations that could be used in carrying out the HVS test using the VTI’s heavy vehicle simulator regardless of the road structure and materials tested. In addition, this paragraph highlights part of the results obtained by research carried out by Wiman (2006) in order to give the reader of this report an idea about the findings obtained from using the HVS in testing roads structures.

According to Wiman (2006), a HVS test was performed at the VTI test facility in Sweden during 2003 under the name of SE05 test. The objective of this test was to investigate the deformation behaviour of two different unbound base materials. Half of the test area was constructed with a base layer of natural granular material (named “Olivehult”) and the other half with a base layer of crushed rock aggregate (named “Skärlunda”). Hence, the two structures were tested simultaneously.

The test set-up

Table 2 shows details about layer thicknesses, instrumentation of the test sections and material properties and characteristics. Correspondingly, the thickness of the subgrade was 2.5 m on a rigid bottom of cement concrete.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Planned thickness</th>
<th>Actual thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Natural granular material (Olivehult)</td>
</tr>
<tr>
<td>Asphalt concrete</td>
<td>40 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>Unbound base</td>
<td>450 mm</td>
<td>462 mm</td>
</tr>
<tr>
<td>Total thickness</td>
<td>490 mm</td>
<td>512 mm</td>
</tr>
</tbody>
</table>

The total thickness of the unbound bases was 450 mm. In fact, it was believed that this thickness could give a clearer and more distinct difference between the two materials used as compared to thinner base layers on a sub-base layer.
**Instrumentation**

Sensors were installed in the structures during construction to be used in the response measurement programme, as shown in Figure 5.

It is important to note that most of the sensors were located in the center line of the loaded area (6x1 m). Correspondingly, the following sensors were used in test SE05:

- H-shaped asphalt strain gauges (ASG)
- Soil pressure cells from the University of Nottingham (SPC)
- LVDTs for vertical deflection and deformation
- Inductive coils (eMU) for vertical deformation and strain (static and dynamic)
- Water content reflectometers (WCR)
- Temperature gauges.

**Figure 5** Longitudinal cross section of SE05 instrumentation (after Wiman, 2006).

Sensors for measurement of volumetric water content were installed at different depths. A diagram of this outline appears in Figure 6. On the other hand, the sensors in the centerline were installed outside the test area but in the area where the loading wheel changes direction.
Figure 6  Positions of volumetric water content measurement sensors (after Wiman, 2006)

The test procedure

According to tests carried out by Wiman (2006), the response measurement programme consisted of significant measurement of stresses, strains, and deflections at different positions, at different test loads, speeds, lateral positions as well as temperatures, using different test-wheels and tire pressures. After the response measurement programme, the HVS test was performed. Normal running was 24 hr a day, for five days a week with breaks only for daily service of the machine, which means about 22,000 loadings per day, in both directions.

The pavement performance has been studied by visual inspections and measurements of cross profiles at fixed test structures locations for the purpose of rut depth measurements.

The test was divided into two phases; the first one was carried out in dry condition and the second in wet condition. At the beginning of the test, the subgrade soil was not soaked with water, but after about 350,000 passages, the test was stopped and the subgrade and structure were filled with water. Initially, the water level was raised to the top of the pavement and then lowered to 30–40 cm below the subgrade surface (Wiman, 2006).

The surface rut depth results

The surface rut depths were calculated from cross profile measurements at three fixed longitudinal positions on each structure. Wiman (2006) reported that the equipment used was a beam with a moving laser, taking readings every 2 mm over a total length of 2,500 mm.

As illustrated previously, the test was performed in dry condition at the beginning and after about 350,000 passes; water was added to the subgrade soil and the structures. The rest of the test was performed in wet condition with ground water level at 30–40 cm below the subgrade surface, as shown in Figure 7.
Figure 7 Rut depth propagation in SE05 test, structure 1 (Natural granular material) and structure 2 (Crushed rock aggregate), after Wiman (2006).

The average result from the three cross profile measurements on structure 1 before and after the test is shown in Figures 8.

For the reason of water content measurements, WCR sensors (water content reflectometers) were placed at different depths in the test structures.

Figure 8 The average cross profile before and after test of Structure 1 (after Wiman, 2006)

Figure 9 shows the results during the period when ground water level was raised from the bottom of the subgrade to the top of the pavement and then lowered to 30–40 cm below the subgrade surface.
It is clear from Figure 9 that the water content was only raised 0.5% for both materials, from 3.0% to 3.5% for the natural gravel and from 3.4% to 3.9% for the crushed aggregate.

![Figure 9 Water content by weight, at a depth of 15 cm from the base layer surface, during raising and lowering of the ground water level (after Wiman, 2006)](image)

Figure 9 shows the results from two water sensors placed at a depth of 15 cm from the base layer surface.

**Results regarding the unbound base layer deformation**

Wiman (2006) reported that the nominal thickness of the unbound base layers was 450 mm. The change in thickness due to the loading was measured using inductive coils (εMU-coils).

Wiman (2006) added that the measurement was subdivided into three-thirds of the thickness as 0–150 mm, 150–300 mm, and 300–450 mm. The measurements of the changes in these thicknesses at the end of the test (573,000 wheel passes) were compared with the surface rut depth measured at the same time, as illustrated in Figures 10 & 11.
Wiman (2006) concluded that more than half of the difference in rut depth on the surface was reflected from the difference in the base layer deformation, and most of the deformation of the base layers are related to the upper part (0–150 mm) of these layers.
4 Low Traffic Volume Roads

4.1 General information

Pratico and Giunta (2011) defined the low-volume roads as facilities outside built-up areas with a traffic volume of less than 400 annual average daily traffic (AADT). In spite of the fact that these roads are of lower use because of their location, low-volume roads play an important social and economic role and sometimes represent a large part of the regional and national road network (Russell and Kornala, 2003 and Pratico and Giunta, 2011). In Sweden, the design of low traffic volume roads is governed by “Dimensionering av lågtrafikerade vägar - DK1, 2009” for roads up to 500 000 standard axle. Nevertheless, for traffic volume more than 500 000 standard axel, design method DK2 is used as referred to in TRVK Väg.

4.2 Feature of unpaved low traffic volume roads

It is well known that the unpaved roads are roads built without an asphalt or concrete wearing surface, so they derive all structural support from their aggregate base layers. In principle, the unpaved roads are used for many purposes including industrial and private roads, temporary roads, detours and rural roads.

Because unpaved roads have no asphalt or concrete wearing surface to help support traffic loads, they require a greater depth of aggregate base than the paved roads. This is applicable in designing roads for the same traffic.

However, it is important here to mention that because of the increasing cost associated with asphalt repaving, interest has been rising in turning back damaged asphalt roadways into maintainable aggregate driving surfaces (Shearer and Scheetz, 2011).

4.3 Feature of paved low traffic volume roads

According to Wayne et al., (2011), the flexible pavement structure for a low traffic volume road (LVR) consists of a relatively thin asphalt-concrete wearing course and an aggregate base course constructed on subgrade layer. An asphalt wearing course provides a good riding surface and moisture protection for the base course. Service life of a thin asphalt pavement depends on material quality and thickness of granular layers (Wayne et al., 2011).

4.4 Design principle for low traffic volume roads

In spite of the fact that there are similar basic principles for pavement design, each country has adopted individual methods and structures that suits their requirements according to their experience.

In general, unpaved-road construction using gravel requires that the material meet certain basic engineering demands. These demands include the following categories:

- Adequate cohesion to resist erosion,
- A particle size distribution that assists a tight engagement of the individual material particles, and
- Adequate strength to support the applied traffic loads without significant deformations.
Insufficiency in any of these demands may result in poor riding quality which in turn leads to subsequent high agency maintenance costs.

Consequently, road agencies have increasingly been faced with the demand of relying upon marginal materials in the construction of low-volume roads. However, the use of these materials necessitates that stabilization be used to alter the material’s engineering parameters to ensure that erosion, rutting, dust, and bearing capacity problems are minimized (Paige-Green and Netterberg, 1987).

4.5 Problems behind unpaved roads

4.5.1 In general

Mahgoub et.al. (2011) reported that motorists traveling on a gravel road will encounter the problem of corrugation. Nevertheless, there is no long-term solution for this problem which require continual maintenance to control its appearance.

Mahgoub et al. (2011) added that traffic volumes, subgrade and gravel properties, and vehicles speeds are factors that may cause corrugation. Research results have shown that when the aggregate base and subgrade soil intermix, this will reduce the effective thickness and in turn, the load-bearing capacity of the road structure will outcome ruts that must be periodically refilled with aggregate.

Zilioniene and Vorobjovas (2011), noticed during the implementation of gravel roads that horizontal alignments of the roads were slightly changed. Here, it is important to note that the horizontal alignment of a road is an important issue of gravel road sections.

4.5.2 Problems caused by melting snow

Usually, roads exhibit uneven frost heave and longitudinal and transverse cracking, but the most important thing is that roads suffer from softening of the roads structures and permanent deformations during the thawing period. Sometimes, driving on these roads can be impossible. In principle, thaw weakening damage is the largest problem on unpaved roads but it also causes major problems on paved roads and especially on weak roads with a surface dressing pavement.

In fact, these problems become especially apparent if the road is paved later. Aho and Saarenketo (2006) reported that the term “spring thaw weakening” has different meanings in different languages. In general, spring thaw weakening is referring to the decrease in the bearing capacity of a road during the thawing of the frozen layers of the road during the spring season. Aho (2004) pointed out that the factors affecting the development of thaw weakening involve environmental and design related factors (i.e. the local factors related to the location of the road and its surroundings). Aho and Saarenketo (2006) added that the spring thaw weakening may appear if the road or subgrade freezes or during the thawing period when the water released by melting snow stays in the subgrade soil. Other factors that may cause spring thaw weakening could be due to the fact that the road is subjected to loads during the thawing period or may be the roads materials are frost susceptible.
5 Management of Low Traffic Volume Roads

The management of roads is a complex issue and requires a comprehensive set of relevant indicators. Yearly, the Swedish paved road network is monitored by road surface testers in order to supply the Swedish Transport Administration with documentary condition data. The data is used to measure how well the road condition standard is achieved (Sjögren and Lundberg, 2011).

In regard to Aho and Saarenketo (2006), there are several policies and techniques for managing a road during spring thaw weakening depending on the scale and scope of the spring thaw weakening problem. In general, the management tools can be divided into different maintenance techniques used to decrease the effect of spring thaw in addition to load restrictions and different tools to minimize the problems caused by these restrictions. However, strengthening weak road sections to the extent that load restrictions can be removed or used only in extreme conditions can also minimize the problem (Aho and Saarenketo, 2006).

Aho and Saarenketo (2006) added that road administrators traditionally have attempted to prevent spring thaw damage by implementing load restrictions or even closing the road. Basically, the use of spring load restrictions increases the pavement service lifetime but on the other hand, this action causes major extra costs for industries using heavy transport vehicles.

In Finland the extra costs to the forest industry, due to spring thaw weakening, has been calculated to be 100 Million €, of which 65 Million € comes from the public roads. Thus, the most economical and sustainable solution for managing thaw weakening problems is to strengthen the weak road sections (Aho and Saarenketo, 2006).

Liu et. al. (2011) supports what is given by Aho and Saarenketo (2006) with respect to the action of highway agencies by applying spring load restrictions (SLR) to limit the damage caused by heavy loads during the spring weakening period. Liu et. al. (2011) pointed out that an alternative to minimize truck loads during the spring is the reduction of truck tire pressure since reducing the tire pressure decreases the tire-pavement contact pressure and hence, the associated damage during the spring period will be decreased.

In general, better design and construction methods can prolong pavement service life and result in lower maintenance and rehabilitation costs (Sirivitmaitri et. al., 2011). However, the following paragraph will shed light on several design and construction materials/methods that may use to lower maintenance and rehabilitation costs.
6 Improving Unpaved Low Traffic-Volume Roads

6.1 In general

Low-volume roads are an important part of the world's transportation infrastructure and a direct cause of the economic development of small city and rural communities. Therefore, the construction, maintenance, and rehabilitation of these roads are major tasks and require a major part of the public works budget (Sirivitmaitrie et. al., 2011).

However, road agencies are increasingly faced with the necessity of relying on marginal materials in construction of low-volume roads. Use of these materials requires that stabilization be used to improve the engineering parameters to ensure that, for example, erosion, rutting, dust, and low-bearing capacity structure are avoided. Soil stabilization is increasingly being used as an unpaved road asset management tool in an attempt to minimize the impacts of these matters (Campbell and Jones, 2011).

Therefore, this report aims to enhance relatively large investigations of alternative stabilizing materials that may lead to a durable and longtime pavement performance. These stabilizing materials can be validated using the accelerated pavement testing to verify the validity of unpaved road strengthening under long term loading and various environmental conditions.

6.2 Improving unpaved roads by using geosynthetic materials

6.2.1 Background

Previous evaluations of the structural benefits of base-course reinforcement have been conducted on road sections that are designed to fail with relatively low volume traffic.

Recently, geosynthetic materials have been used in pavement sections to reinforce the base course to support vehicular traffic during the life of the pavement structure (base-course reinforcement). Qian et. al. (2011) reported that when geosynthetics used as base-course reinforcement, they provide significant structural benefits, resulting in improved pavement life and/or equivalent performance with a reduced structural section. Qian et. al. (2011) added that increasingly, geogrids have been successfully used to improve soft subgrade and reinforce weak base courses for low-volume roads by providing lateral confinement.

In addition to the above, geosynthetics are widely used as filters, separation layers, and subgrade restraint to facilitate construction on weak subgrades.

Together with load-induced damages, pavements are subjected to environmentally induced damages, since seasonal variations in soil temperature and moisture content may lead to significant change in the construction materials mechanical properties which in turn will affect the support capacity of the base course and subgrade soils. Such seasonal variations should be considered in evaluations of the base reinforcement benefits of geosynthetics.

In principle, the use of geosynthetics to support construction over weak subgrade soils is well documented. Geogrid and geotextile manufacturers claim that base course reinforcement will provide increased pavement service life and/or equivalent performance with a reduced structural section. However, these claims should be supported by long-term and dependent LCC studies based on different pavement designs requirements. Shedding light on such studies in Sweden has become necessary.
In addition, such studies will provide, in a timely manner, the critical missing data required for the successful development of the Swedish specification regarding the uses of geosynthetics to reinforce the gravel roads structures.

6.2.2 Types of geosynthetic materials

Koerner (2005) defined a geosynthetic material as a synthetic material manufactured from polymers such as polyethylene, polypropylene, or polyester. Although geosynthetics have many forms and uses, the two forms of geosynthetics that are specifically used for basal reinforcement are woven geotextiles and geogrids (Koerner 2005).

Geogrids

A geogrid is a geosynthetic material consisting of connected intersecting ribs with opening sizes into which soil particles can enter, enhancing interlocking between the soil and geogrids (Koerner 2005).

The interlocking aspect of geogrids makes them ideal for use in granular soils such as the pavement base course. If the surface of a pavement having geogrid basal reinforcement is loaded vertically, the dense soil particles at first want to expand laterally due to the Poisson effect under elastic strain levels, and then dilate and expand under higher strain levels. Perkins and Ismeik (1997) observed that geogrids may restrict this lateral movement through interlocking. This mechanism may indicate that stiffer geogrid polymers may yield improved lateral confinement. In this mechanism, the geogrid does not likely go into tension unless higher strains are observed in the system (Giroud and Noiray 1981).

Geotextiles

According to Koerner (2005), the geotextiles usually used for reinforcement applications are woven filament sheets. Moreover, the main reinforcement mechanism of woven geotextiles is separation since woven geotextiles are used to separate two dissimilar materials, and preventing intermixing (Fannin and Sigurdsson 1996, Perkins and Ismeik 1997, and Al-Qadi et al. 1994). For this reason, most geotextiles are placed between the subgrade and base layer. Here, it is important to note that separation allows a stiff material placed on a soft subgrade to maintain its full thickness throughout the life of the pavement. The principle of work is similar like in the case of geogrids, in order to mobilize tension, the soil and geotextile must deform a certain amount to mobilize the tensile strength of the geosynthetic. Consequently, Cuelho and Perkins (2009) suggested that the puncture resistance of the geotextile should be taken into account, as penetration of particles through the geotextile will reduce its strength and stiffness.

6.2.3 How the geosynthetic materials work as roads stabilizer?

Researches carried out on using geosynthetics in roads constructions have showed that the progressive downward movement of aggregate into the subgrade and the associated upward pumping of subgrade soil into the aggregate base layer will result in intermixing between the dissimilar road layers (Archer, 2008). This intermixing decreases road base thickness which leads to reducing the design strength and load-bearing capacity, which can result in the failure of the road as shown in Figure 12.
In specific, using of geosynthetic materials stabilize and strengthen unpaved roads by providing a permeable separation layer between the aggregate base and the subgrade layer which in turn preserving the original design and life expectancy of the roadway (see Figure 13).

When the geotextiles are involved in the design, between the aggregate sub-base and subgrade soil, intermixing is decreased and any allowance of aggregate base for intermixing can then be reduced.

It is important here to highlight the fact that the geosynthetics durability and tensile strength also confines the subgrade (see Figure 14), which significantly increases the road’s load-bearing capacity (Archer, 2008). Over time, the geosynthetics minimizes intermixing, which prevents deterioration of the base.
6.2.4 Theoretical concept of road stabilization using geosynthetics

It is well to mention that the information given in this paragraph is based mainly on Berg et al. (2000) article. However, minor reforming has been performed. The figures given in this paragraph are originally cited from Haliburton, et al., (1981), but redrawing of the figures has been implemented.

Berg et. al. (2000) reported that geogrids and geotextiles provide reinforcement through three possible mechanisms, as described below:

Provide lateral restraint of the base material and subgrade soil through friction and interlock between the aggregate, soil and the geosynthetic, as shown in Figure 15.

Increase the system bearing capacity by forcing the expected bearing capacity failure surface to develop along alternate, higher shear strength surfaces (see Figure 16).

Membrane support of the wheel loads, as shown in Figure 17.
When an aggregate layer is loaded by a wheel or track, the aggregate tends to move or laterally, as shown conceptually in Figure 15, unless it is restricted by the subgrade or geosynthetic reinforcement.

Weak subgrade soils provide very little lateral restraint, so when the aggregate moves laterally; ruts develop on the aggregate surface and also in the subgrade. This problem can be overcome by using a geogrid with good interlocking capabilities or a geotextile with good frictional capabilities in order to provide tensile resistance to lateral aggregate movement.

Figure 16 Possible reinforcement functions provided by geosynthetics in roadways, the bearing capacity increase

Another possible geosynthetic reinforcement mechanism is illustrated in Figure 16. Using the same analogy of a wheel load to a footing, the geosynthetic material forces
the proposed bearing capacity failure surface to follow an alternate higher shear strength path. This phenomenon tends to increase the bearing capacity of the roadway.

The third function of geosynthetic reinforcement is the membrane effect support of tire loads. A diagram of this outline appears in Figure 17. In such a case, the tire load stresses should be high enough to cause plastic deformation and develop ruts in the subgrade. If the geosynthetic material has an adequate tensile modulus, tensile stresses will build up in the geosynthetic. As a result, the vertical stress component generated in the membrane will assist to support the applied tire loads. Since the tensile stress within the geosynthetic cannot be built up without some elongation, tire path rutting of more than 100 mm is required to generate membrane support.
7 Cost Benefit Study from using the Geosynthetics in Road Construction

According to Berg et al. (2000), there are many advantages from using the geosynthetics in road constructions. However, it is recommended that an economic assessment of a proposed reinforced pavement project be provided with life-cycle cost analysis. Berg et al. (2000) added that only when examining of initial construction costs demonstrate a cost savings with geosynthetic reinforcement, in this case, a detailed life-cycle cost analysis (LCC) may not be required. In several cases when the total savings over the project life should be quantified, a detailed life-cycle cost analysis could be performed even if the examining of initial construction costs shows a cost savings with geosynthetic reinforcement. For example, the use of LCC analysis is required to compare the savings in road thickness reduction as compared to maintaining the thickness and increasing the design life.

Regarding the construction over low subgrade conditions, the general procedures used in evaluating the cost-benefit from using the geosynthetic reinforcement typically will result in demonstration of cost savings. Nevertheless, for some moderate subgrade conditions, cost savings also may be computed in terms of base thickness reduction (Berg et. al., 2000).

On the other hand, maintaining the thickness and extending the design life may provide greater cost savings as reported by Berg et al. (2000). Correspondingly, the design method and geosynthetic type do not affect the approach to quantifying the cost savings.

Nevertheless, there are many costs and factors to be considered in a life-cycle cost analysis. Berg et al. (2000) pointed out the major initial and recurring costs that should be taken into account in the economic assessment concerning the use of geosynthetics in roads reinforcements. Berg et al. (2000) reported that the major cost that should be considered in a LCC analysis is the agency costs which involve the initial construction costs, future construction or rehabilitation costs, maintenance costs, residual value at the end of the design period, engineering and administration costs as well as traffic control costs, if any are involved.

The other important cost factor in LCC analysis is the use costs which take into account the travel time, vehicle operation, accidents, discomfort, time delay and extra vehicle operating costs during resurfacing or major maintenance (Berg et al., 2000).

Additionally, factors that should be clearly characterized for a life-cycle analysis include the analysis and performance periods; equivalent single axle loads (ESALs) over initial performance period; annual maintenance costs; initial construction costs, initial and terminal serviceability values; discount rate; pavement component thicknesses; pavement components structural coefficients; subgrade resilient modulus; as well as rehabilitation construction costs. In principle, pavement management systems can greatly assist in assessing the cost of alternatives and can be used to estimate the cost of extending service life through use of geosynthetic reinforcement. However, such an analysis can be summarized in the following example (Berg et al., 2000).
**Example of life-cycle cost analyses**

Berg et al. (2000) showed an example about the life-cycle cost analyses performed using AASHTO DARWIN™ computer program. This LCC analysis deals with the beneficial use of geosynthetic materials in road constructions. The calculations are based upon 5,000,000 equivalent single axle loads (ESALs) over the analysis period. The first computation carried out by Berg et al. (2000) is for an unreinforced pavement structure in order to provide the basis for comparison with the geosynthetic reinforced sections.

The second analysis was related to base course thickness as the geosynthetic reinforcement is usually used to decrease the required aggregate base course thickness. The third computation carried out by Berg et al. (2000) was to verify whether the geosynthetic reinforcement can be used to increase the road service period (i.e., time to rehabilitation) with respect to the same base course thickness as the unreinforced example. Moreover, Berg et al. (2000) evaluated the beneficial use of geosynthetics in road constructions when both the base course reduction as well as extension of the performance periods would be taken into account.

Berg et al. (2000) found out that the percent savings regarding the reduction of base course thickness as compared to unreinforced section is 4%. This percentage increased to 11% when a comparison was carried out between the reinforced and unreinforced sections regarding the time required to rehabilitation. The percentage jumps to 17% when percent savings computation combines a base course reduction and extension of the performance periods. Note that Berg et al. (2000) used subgrade CBR to carry out the given LCC analysis. In general, LCC analysis based on long term performance data (including the whole road service life) is recommended to verify the long term cost saving by using geogrids in roads constructions.

According to Al-Shamisi (2012), the municipality of Abu Dhabi city has conducted studies regarding the use of geosynthetics in road projects, in particular the use of the network plastic (Geogrids) to strengthen the pavement layers in several projects. Al-Shamisi (2012) has concluded that the use of the geogrids network within the pavement layers yield several benefits, including:

The use of geogrids provides effective solutions to poor soil, high water levels and other relevant issues:

- Offers the possibility of increasing the time period for the service road paving,
- Reduces the thickness of the pavement while providing the same service life period,
- Reduces stress on the asphalt layer, cracks and surface ruts,
- Reduces the cost of constructing roads shoulders,
- Shorten the time required to construct the road.
- Reduce the risks related to the construction of high quality pavement.
- Providing raw materials and energy, and reduces the carbon emission and preserve the natural environment and public health.

The geogrids have now become one of the most important design alternatives of roads in the city of Abu Dhabi and have been adopted in further projects Khalifa Port project and Industrial Zone project in UAE as reported by Al-Shamisi (2012).
Al-Shamisi (2012), added that the use of geogrids in pavement design for the road projects in the municipality of Abu Dhabi city has achieved the following benefits:

- Reduce the thickness of asphalt pavement in the range of (30-50) %,
- Reduce the cost of asphalt manufacturing in the range of (10 - 20) % (a total value of about 27 million dirhams (e.g. 5,622,032 €),
- Shorten implementation time for paving operations by 30%,
- Providing raw materials and energy, and reduce the carbon emission by up to 20%. 
Cost- Benefit Study from Using the HVS in Road Testing

As with many pavement analysis concepts, when carrying out the rehabilitation process, it is important to have in mind that the data, once collected on the road network, can be utilized for many years not only in the design and fix of freeze-thaw damaged road sections but also in observing how well the repaired road sections are working.

In fact, reliable survey and follow-up data can be extremely important for learning to identify the weak road sections, but the follow-up process is likely to be time consuming and costly. Therefore, the ability of the HVS to supply results in a relatively short time period has not only produced a significant contribution to the development of pavement engineering but has also saved the road authorities and the tax payer significant amounts (Rust, 1997).

For example, the HVS has played a significant role in the reduction of pavement construction costs in South Africa. It has been reported that in South Africa, the HVS programme yielded a benefit/cost ratio of 12.8 (Rust, 1997). Basically, it is well recognized that the construction and initial materials costs of South African pavements are in the order of 40 % less than those in the areas of the United States with corresponding climatic conditions. This is largely due to the fact that pavement innovations could be rapidly evaluated using the HVS as reported by Rust (1997).

Moreover, according to a case study implemented by the VTI team before the construction of a 100 km highway (part of the Berlin - Warsaw highway) in Poland, the Polish authorities wanted to use about 30 cm cement stabilized gravel layer in the pavement structure. The HVS team found that 15 cm was sufficient. With the help of the HVS equipment, the VTI team could show that a design depth of 15 cm managed the specified traffic loads. If the Polish authorities implemented the 15 cm design depth, money saving of up to 10 million € could be achieved (compared to the cost of about 0.5 million € for the entire test project where the HVS equipment was used).
9 Future Situations: Needs and Challenges

This report highlights the importance of using the HVS test in a wide experiment programme to employ a mechanistic approach to determine any structural benefits provided by using geosynthetics as base-course reinforcement for low volume pavements in Sweden. The following parameters could be methodically varied to examine their influence on road performance, like: base thickness, moisture conditions, subgrade type, and presence or absence of base reinforcement. Results collected from carrying out such studies can be used to evaluate the cost-effective benefits from using geogrids reinforcement in low volume roads construction based on long term road performance results (e.g., the possible reduction in measured stresses and strains, ruts depths at the end of the road service life). Therefore, in conjunction with structural benefits, the cost effectiveness of using geosynthetics in roads construction in Sweden should be assessed.

A test programme can be conducted at the VTI in order to utilize their world-class facilities and state-of-the-art heavy vehicle simulator (HVS). With accelerated traffic loading, controlled environments, and full-scale testing could be carried out, during which, each test section can be instrumented with temperature, moisture, stress, and strain sensors. The deformations in the base and subgrade can be measured using coil gauges or linear variable displacement transformers (LVDTs), and geosynthetic strain can be measured with strain gauges or LVDTs. Correspondingly, the results will be obtained in a matter of months, thereby providing worthy information to the transportation community in a timely matter.
10 Conclusions and Recommendations

It can be concluded from the collected studies that the accelerated pavement testing can produce early and beneficial results that lead to improving pavement technology and provide better understanding of the application and effectiveness of new materials used to enhance the pavement systems performance.

It is clear that using of geosynthetic materials in roads construction will result in reducing the thickness of the road pave layer and hence reduces the cost of construction. In addition, using of geogrids will decrease the intensity of stress on the subgrade and providing raw materials and energy, and reduce the carbon emission.

When carrying out HVS test to validate the use of geogrids in roads construction, the impact of the subgrade strength and base course layer thickness will be crucial factors during the results analysis. Additionally, geosynthetics location and properties should also be considered during the analysis.

In general, more research regarding the beneficial use of geosynthetics in roads construction should be conducted taken into account the HVS testing result according to the aforementioned issues. Such a study will result in recommendations regarding the performance of different types of geosynthetic materials under different loading conditions which in turn will result in economic economic analyses of the different options.
References

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The Swedish National Road and Transport Research Institute (VTI), is an independent and internationally prominent research institute in the transport sector. Its principal task is to conduct research and development related to infrastructure, traffic and transport. The institute holds the quality management systems certificate ISO 9001 and the environmental management systems certificate ISO 14001. Some of its test methods are also certified by Swedac. VTI has about 200 employees and is located in Linköping (head office), Stockholm, Gothenburg, Borlänge and Lund.