The development of a new road design method in Sweden

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ABSTRACT: Since 1998, Sweden has been conducting a strategy for developing a new model for road design, including implementation of ethis model.

Today a new model for calculation of stress and strain is ready. It can do calculations for asphalt pavement with viscous elasticity and unbound material with non-linear elasticity. In spring 2005, the model is to be supplemented by calculation modules for permanent deformations in bituminous bound layers and in unbound layers, based on the theories behind the new AASHTO "Design Guide".

Implementing this model has involved three years of continuous training of new road designers in Western Sweden, with participation of consultants and contractors.

During the winter and spring of 2004/05 six different projects were chosen to demonstrate the new model. Road quality is to be improved by "active design" on site. Unbound material is to be tested by triaxial tests, and there are to be calculations of future permanent deformations. The results are to be used in deciding pavement thicknesses for different parts of the road. Road pavement optimizationroad in this way will save a lot of money. A better design method and relating test methods should also make it possible to avoid most of the problems of early failure of roads.

KEY WORDS: road design, function, VagFEM, active design, implementation, incentive.

1 BACKGROUND

The design of road structures may be divided into three different methods:

- The simplest method uses tables of prescribed thickness for the various layers, and the important design criteria are traffic load, frost condition and a rough classification of the subgrade material.
- A more advanced method is basically a computer program that is based on multilayer linear elastic theories and calculates stress and strain in different parts of the road structure where certain stress and strain levels are permitted. These levels depend on the amount of heavy traffic, and both they and the spots for measuring them are chosen on the basis of empirical experience.
- The most sophisticated method today is to calculate the stress and strain by means of a finite element program based on a more realistic non-linear elasticity modulus for the unbound material and on the viscosity of the asphalt layer. The calculated stress and strains are then used to calculate future permanent deformations, ruts, and cracks in the asphalt surface. These calculations use test results from different test methods, especially triaxial tests etc.

Before the year 2000, all road design in Sweden was based on tables. A computer design model based on multilayer theory was introduced in 2000 and is known as, ATB VÄG. A new design model being implemented is intended to make it possible to calculate road performance in terms of certain future functional values such as ruts, cracks and unevenness. The theories behind this model are largely based on the AASHTO “Design Guide”.

2 DEVELOPMENT OF THE MODEL

The Swedish model being developed is described in two papers both entitled “Mechanistic Model for Road Design in Sweden” from BCRA02 and from the workshop before this conference (Huvstig 2002).

During 2003 and 2004, SRA produced a new user friendly finite element program, “VägFEM”, which is based on ABAQUS and was developed by the consultant Volvo IT. It is a 3D FEM program in which it is possible to describe the real geometry of the road. It also makes it possible do calculations with non-linear elasticity for the unbound materials, and viscosity for the bituminous bound materials. The model used today for the description of the non-linearity is: $M = k_1\theta^{k2}$. Burger’s model is used for describing the viscosity of the bituminous bound layers.

One important aspect of a FEM program usable for road design, especially for active design on construction sites, is the calculation time. “VägFEM” is simplified in some respects, resulting in calculation times of less than 20 minutes. It takes only a couple of minutes to write the input data, which are then sent to the computer. The results are delivered as a PDF file with diagrams and values for stress and strain, see section 3 below. Description of “VägFEM”.

In “VägFEM”, a special part of the program can also simulate the plate loading test on unbound material. It has proved possible to analyze the whole curve from the plate loading test in order to decide the values of k_1 and k_2. This can be done by running the program three or four times, until the curve from the program is similar to the curve from the test on the material in situ.

The next step in the development of “VägFEM” is to deliver the output data in the form of a digital file with a view to these data, denoting stress and strain at certain levels in the road structure, becoming direct input in a new Excel program for calculating the permanent deformations (in the first version, rutting). This program will use the theories from the “Design Guide”. It is also possible to use some other material models, in certain developed Excel programs, for comparison with the results on actual roads.

3 DESCRIPTION OF “VÄGFEM”

The Swedish “VägFEM” is a 3D FEM program designed to be simple and give a short user time. A test was done on a test section, see next chapter. The resilient modulus M_r was calculated on the basis of measured values from the plate loading test. The resulting value of M_r was used in “VägFEM” to calculate the stress and strain in the test road structure. Compared with the actual results, these calculated stresses and strains were within 20 % of the measured values from the test section.

“VägFEM” may be briefly described as follows. The input data comprise road geometry, thickness of layers (see figure 1), position of loading, elasticity modulus (and viscosity) for the bituminous bound layers and elasticity or resilient modulus for the unbound layers. The weight of the road material is included in the model.

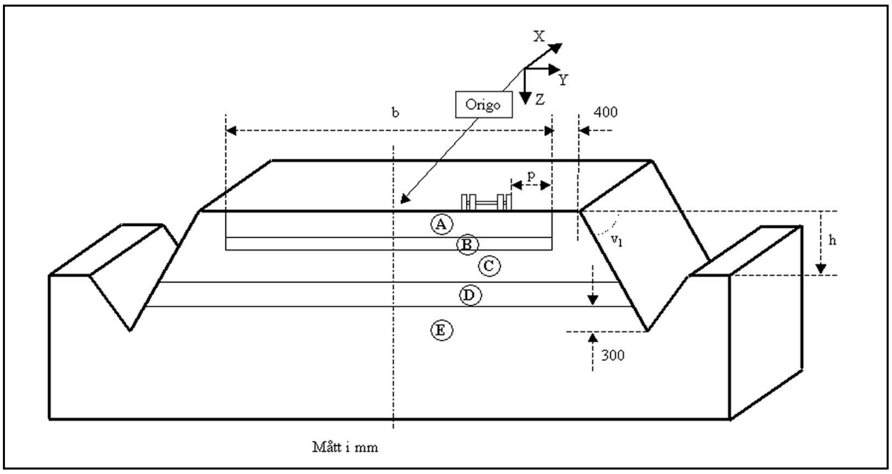

Figure 1: Road geometry

The output data comprise diagrams of deformation, stresses and strains in different parts of the road structure. See figure 2 – 5 for examples.

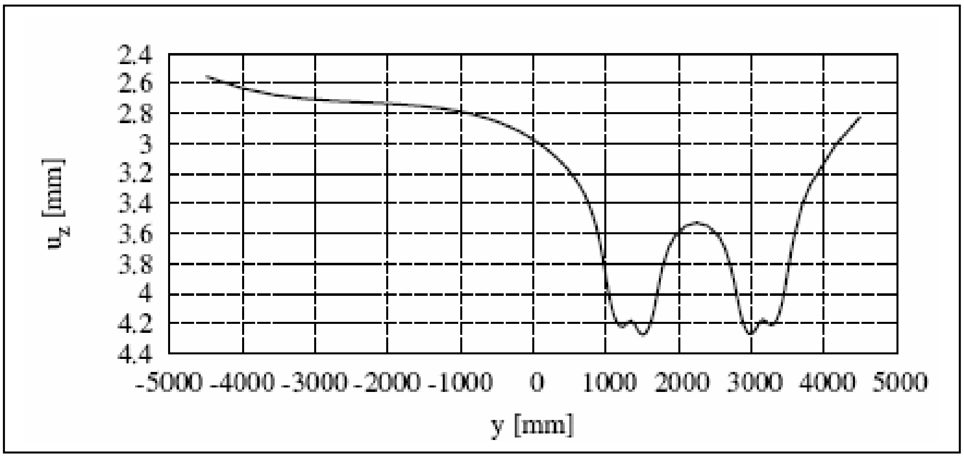

Figure 2: Road surface deflection

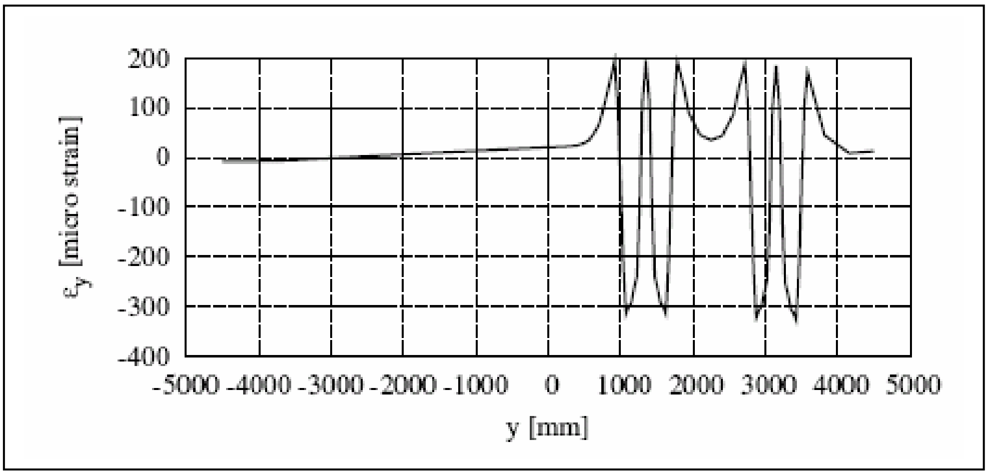

Figure 3: Strain in the lower surface of asphalt pavement

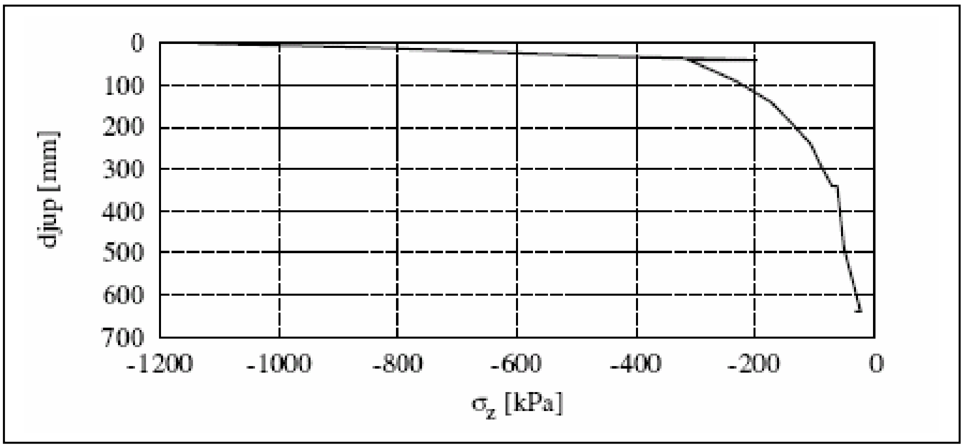

Figure 4: Stress as a function of the depth under the wheel

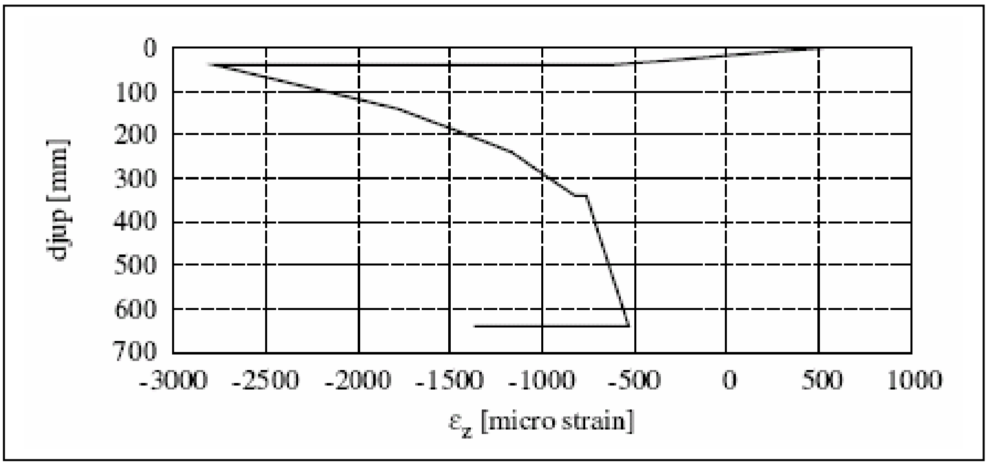

Figure 5: Strain as a function of the depth under the wheel

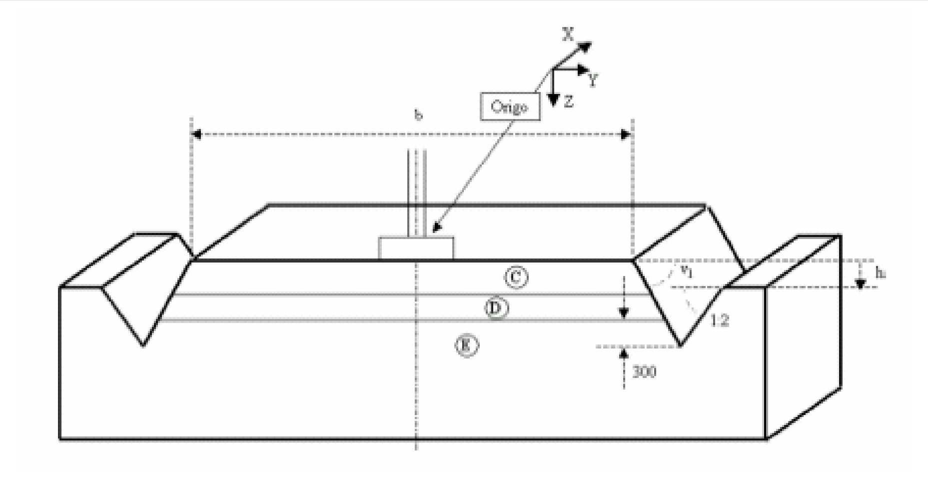

Figure 6: Geometry for the plate loading test

”VägFEM” also includes a module for calculating step by step the deflection during plate loading test, see figure 6. Its purpose is to make it possible to calculate the resilient modulus for the unbound layers. To this end, the resilient modulus of the subgrade needs to be ascertained, which involves plate loading tests at on the top of the subgrade and at the top of the base layer. The calculated values of the resilient modulus for these layers become input data for calculating the next layer.

The output data from the calculations in this module comprise the deflection beside the plate (figure 7) and a diagram for the various load steps under the plate (figure 8).

One possibility is to compare results from FWD with the curve in figure 7 in order to estimate the dynamic resilient modulus of the unbound layers.

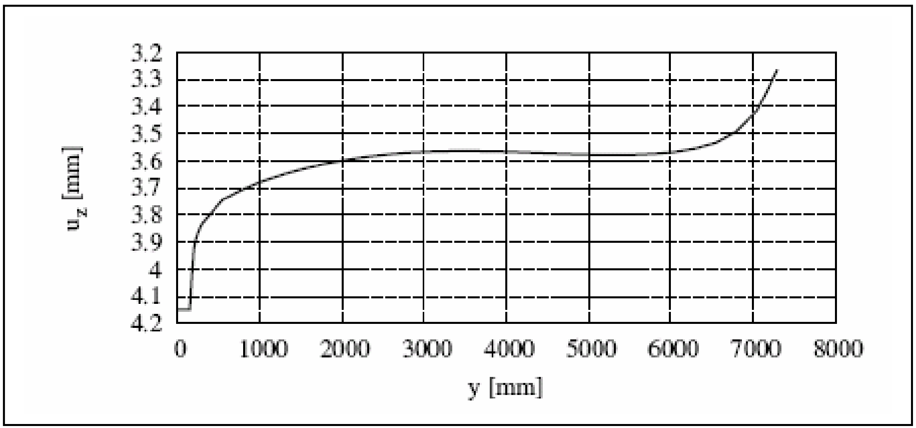

Figure 7: Deflection beside the plate at full load

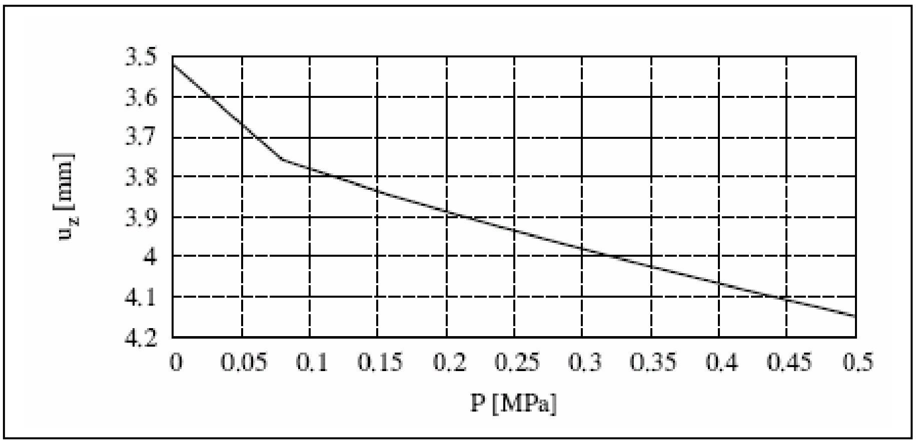

Figure 8: Deflection under the plate at the various load steps

4 VALIDATION OF THE MODEL WITH RESULTS FROM A TEST SECTION

During the summer of 2003, SRA did a large test of unbound material on a test site on European Motorway E6 about 100 km north of Gothenburg. The test site consisted of eight instrumented test sections, which were tested with the Swedish-Finnish heavy vehicle simulator (HVS). One reason for this test was to compare different material models for unbound material. Researchers from several countries were invited to calculate the rutting in advance, and also the stress and strain at the levels where the instrumentation was situated. Three different researchers presented their predictions of stresses and deformations in advance, based on three different models:.

- The model from the AASHTO “Design Guide.” used by”. Professor Charles Schwartz.
- A model developed by Professor Sigurdur Erlingsson in Iceland.

- A model developed at LCPC, used by Dr Pierre Hornych.

Another interesting material model is that developed in Delft and Dresden.

All the results were presented at a special workshop, not far from the test site, where the results from the three models were compared with the actual results from the test site. One important conclusion was that it is possible to calculate the rutting in advance with satisfactory accuracy. The models used and some of the results from that workshop were presented at UNBAR 6 (Ekdahl, Hansson, Huvstig, Thorén 2004).

5 ACTIVE DESIGN

Material used for road construction is inherently uneven in quality. This makes it difficult, or almost impossible today, to design and construct a road with "optimized design" such that the quality of the whole surface will remain uniform for many years and that the whole road will need the same maintenance after a predicted number of years. One method that might solve most of these problems is to work with "Active Design", which means that design of the road is changed during construction as follows:.

Present-day practice is: Before the construction of a road, the subgrade material is only classified on the basis of small samples. There are specific requirements for the materials in the unbound, bituminous bound and cement bound layers. These are minimum quality requirements and most test results have not been usable for the prediction of road deterioration. What is more, there is no extra payment for better performance, which means that there is no incentive to better quality.

If the thickness of the various unbound and bound layers could be decided on site, using knowledge of their real characteristics as an important basis, it should be possible to minimize the use of expensive road material, while at the same time preventing premature failure by strengthening the weakest parts of the road. Results from the USA show that the service life of pavements increases by about 60 % when they are subject to functional requirements. If better design increased the service life of pavements by even 20 %, the saving in Sweden should be about € 40 million a year. Broad use of the "Design Guide" is estimated to save over 10 % of the life cycle costs of road superstructures in the USA. This is probably the strongest reason for introducing a new method for road design.

Working with "Active Design" entails certain precautions:

- There must be people on site who have broad expertise and knowledge of road design, test methods and soil mechanics. It is important to understand the theories behind the material models used.
- Today it is possible to use results from triaxial tests for unbound and bituminous bound materials for calculating the future rutting of a road surface. Simpler test methods usable on site would be an advantage. Simple test methods need to be related to the more complicated test methods such as triaxial tests, and have a clear relationship with the design model. Roller compactors also need to be equipped with GPS and instruments for providing bearing capacity measurements, which could be presented for all parts of a surface that requires compacting.
- A design model is needed that might be used for calculating future road deterioration. Such a model needs to be simple and do the calculations reasonably fast. One possible model is the "Design Guide" from the USA. One problem with that model is that it is time consuming to run. Another problem is that many calculations are done in one step, which makes it difficult to follow and understand them.
- There needs to be an incentive for contractors to provide better quality.

- People on site must have practical experience of road construction methods and their influence on the future quality and deterioration of a road.

6 METHOD OF IMPLEMENTATION

Implementing a new technique is always difficult, because it involves many measurements.

SRA's Western Region has for several years been working on the implementation of a new and better method for road design. This work may be summarized as follows:

- Development of expertise through training. For the last four years, 25 men and women representing consultants, contractors and clients have had regular training in the theories behind mechanistic road design, combined with practical work.
- Development of measuring methods. It is important to know the characteristics of the materials in the actual road. It is possible to certify an asphalt pavement formulation by thorough testing, and to use simpler tests to confirm the characteristics of pavement on site. With good planning, and at relative low cost (0.1 to 0.2 € /m^2), it is currently possible to use the triaxial test as a standard test for unbound material. There is a need to develop simpler tests that could be used on sites. GPS and instruments on roller compactors have been used with good results on a road project in order to measure bearing capacity. Roller compactor measurements also provide information about bearing capacity variation across surfaces.
- Development of a better model for design of roads. A design model needs to be able to use test results from the site in order to predict the future performance of a road. The "VägFEM" model is described in this paper. Such prediction is possible by using "VägFEM" in combination with some material models for prediction of rutting, unevenness and cracking of the pavement. Some useful material models are already described in the new AASHTO "Design Guide". These models are to be used in the form of relative simple computer programs with digital output data from "VägFEM".
- Development of incentives to better quality. With properly compacted good quality subgrade and properly compacted base layers it is possible to reduce the thickness of the asphalt pavement by 1 – 2 cm, subject to doing some extra tests (triaxial tests etc.) on the unbound material. The cost of 1 – 2 cm of asphalt pavement is much higher than the cost of new tests and extra work on the subgrade and the road base. The difference could be shared between client and contractor and used as an incentive to better quality.
- Training in construction methods with a view to better quality. In Sweden, four documents have been produced that describe how to use construction methods in order to achieve better road quality. They describe road design, road construction, pavement construction and maintenance operations. These documents are being discussed in a broad dialogue with almost all the site engineers who work for SRA and the various contractors. There will also be a similar dialogue with consultants.

SRA's Western Region will start to design roads in a new and more cost effective way that will also result in fewer failures of relatively new roads. This design model will include pavement thicknesses being decided on the basis of test results from triaxial tests, plate loading and instrumented roller compactors. One requirement could be that the E_{V2} value from the plate loading should be higher than 200 MPa. A second could be that the highest stress in the unbound layers should be less than 80 % of the "shake down" load. A third requirement could be that calculated permanent deformations should be less than a certain value. For the unbound base layers, further requirements might relate to water sensitivity, resilient modulus and deformation characteristics. Other requirements might relate to subgrade quality and to drainage conditions.

7 VALIDATION TESTS

Roads can be built in a much more cost effective way if "Active Design" is used. To verify this, some roads in Western Sweden are to be constructed in a new way, involving the following steps on site:

- Initial agreement between client and contractor about the following steps and co-operation with a view to achieving the objectives.
- The best excavated soil or rock material should be placed highest in the embankments, even if this means longer transport runs.
- If the soil is weak, e.g. clay, it may be economic to stabilize the soil or use a thicker layer of unbound base material. The surface of the subgrade should be compacted with a roller compactor and, if possible, by transport vehicles traveling over the whole surface.
- The resilient modulus should be measured and calculated at the top of the subgrade by means of instrumented roller compactor, plate loading and "VägFEM".
- The material in the unbound layers should be tested by triaxial tests. The characteristics of the permanent strain relative to the elastic strain, the "shake down" load and the water sensitivity should be measured.
- The unbound material in the base layers must be properly compacted (perhaps 20 – 30 times with the roller compactor) with the right amount of moisture.
- The resilient modulus should be measured and calculated at the top of the unbound base layers by means of instrumented roller compactor, plate loading and "VägFEM".
- All the necessary calculations outlined in this paper should be done.
- The thickness of the asphalt pavement should be decided for different parts of the road. This must be done realistically, e.g. it is not possible to change pavement thickness over small areas.
- This means that it is possible to save quite a lot of asphalt pavement or give the pavement a longer average service life. The resulting savings should be shared between contractor and client as an incentive to achieving better quality (a win – win concept).

8 CONCLUSIONS

Today's knowledge can be used to build roads in a much more cost effective way.

- It is possible to calculate and predict the future rutting of a road surface on the basis of triaxial tests and by measuring the water sensitivity and resilient modulus of the subgrade and the base layers.
- It is also possible to measure and increase the bearing capacity of the unbound base.
- When the base layers are ready, before the pavement is laid, it is possible to choose pavement thicknesses in such a way as to achieve the same maintenance interval for the whole road with consequent saving of money (5 – 10 % of the pavement cost).
- The measurements also provide a lot of information that will make it possible to avoid early road failure problems.

Two very important factors for success are that:

- People working on road design and road construction must understand the theories behind the design and the relationships between the various measurements and the design model. It is therefore better to have design models that calculate results in small and understandable steps that make it easy for data to be transferred from one model to the next one.
- Some of the money saved should be used as an incentive for contractors to provide better quality. It will also be an incentive to research and development of better production methods and improved material (e.g. asphalt pavements).

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