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COST COMPARISON OF CONSTRUCTION METHODS FOR HIGHWAY WIDENING ON COMPRESSIBLE SUBGRADE

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Summary

Despite the proclaimed financial transparency for public investments, there are relatively few publications in the Netherlands about actual cost comparisons of alternative construction methods for infrastructural projects in the settlement-sensitive western part of the Netherlands. In order to gain a better insight and hence a substantiation of the financial consequences pertaining to various road construction methods on soft soil, the authors have defined representative structures for highway widenings, and have calculated the costs per alternative method. The report describes five of the most common alternatives: a) a conventional embankment (including surplus height) with vertical drains; b) an embankment in combination with vacuum consolidation; c) an embankment involving a load spreading layer based on sand columns with geotextile; d) a highway widening based on concrete piles; and e) a lightweight road structure using EPS blocks.

DESCRIPTION OF THE PROBLEM

In the Netherlands there are relatively few publications about cost comparisons for actual costs of alternative construction methods in soft soils at various locations in the western part of the Netherlands. The key figures for the official cost indications by the Ministry of Infrastructure and the Environment, for example, only pertain to highway widenings on stable sandy soil. Moreover, the cost calculations in fact only show the initial (construction) costs. Direct costs for (ongoing) traffic control measures during construction are often omitted. Finally, additional maintenance and/or social costs that come about due to traffic congestion during construction activities are excluded.

Use of innovative construction methods and materials are generally only eligible if there is a short construction period due to functional requirements or if it cannot be achieved otherwise. Without full and objective quantitative cost comparisons the benefits of alternative extrapolation methods are difficult to explain to potential clients. A consequence hereof is that the traditional construction methods almost automatically take preference.

In order to gain a better insight and hence a support of the financial ramifications pertaining to various methods of road construction on soft soil, we have defined representative structures for highway widenings, and have calculated the costs per alternative method. In order to portray a transparent and clear picture we have restricted ourselves merely to widenings of highways. The report describes five of the most common alternatives:

a) a conventional embankment (including surplus height) with vertical drains;
b) an embankment in combination with vacuum consolidation;
c) an embankment involving a load spreading layer based on sand columns with geotextile;
d) a highway widening based on concrete piles; and
e) a lightweight road structure using EPS blocks.

Highway widening

A representative cross-section of highway contains two symmetrical halves in respect of the centre line in the longitudinal direction. In our case, on both sides of such a road axis there are two traffic lanes that are 3.5 m wide plus an emergency lane of 3.5 m. Having three lane widths and a small strip along the median, the total width of the asphalt layer amounts to 12.0 m. The shoulder along the side is 3 m wide and half of the median up to the road axis is 3.5 m. This means 18.5 m per driving direction or a total width of 37.0 m on the upper (top) part of the highway. Underneath there is a variation between the fill width and the slope length and slope gradient (mostly 1:3). In the selected example the highway is positioned 1.0 m above the surface level with (1.0 m deep) canals on both sides.

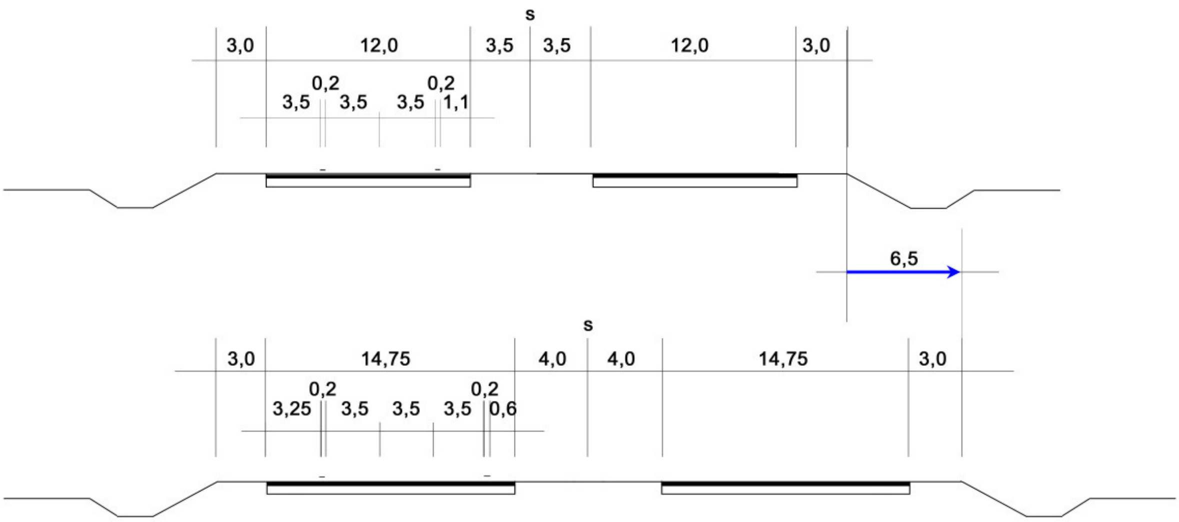

Figure 1 *- Diagrammatic cross-sections of a highway with a widening from 2×2 to 2×3 traffic lanes*

Due to the shift of the road axis, the asphalt layer on the side to be widened must be partially broken up along the median and relocated. These kinds of activities as such, are dependent on the filling method applied and would therefore have little to no influence on the comparative costs analysis. The cost difference and the difference in construction time come about because of the new 6.5 m wide road embankment and partially because of the 3 m wide shoulder. At those places the existing balance in the subgrade is disrupted due to an extra load of the own weight of the (conventional) highway widening, which results in settlements. (The only exception to this is an equilibrium/balanced structure which can only be realized with lightweight fill materials.)

Road structure and subgrade

A representative road structure of the highway, from top to bottom, is as follows:
a) a 0.3 m thick asphalt layer consisting of an PAC course (acronym for porous asphalt concrete) and three layers of gravel asphaltic concrete;
b) a 0.3 m thick unbound base course of aggregate;
c) 1.0 m thick sand bed;
d) subgrade.

The subgrade used consists of a 6 m thick peat deposit and a 4 m compressible clay deposit. Locally in the western part of the Netherlands there are softer soil deposits with peat deposits of up to ten metres and sometimes even more. More intensified groundwork would practically change nothing in the analysis. In cases of an increasing load, the maximum settlements in the selected subgrade do not provide any insight into the final consolidation anyway. By definition this concerns an unstable equilibrium. Each new reconstruction in which e.g. extra asphalt layers (= extra weight) are applied, will start up the consolidation process again.

Extra load due to highway widening

The magnitude of the vertical load brought about in the subgrade underneath the surfacing (at the level of reference: surface level -0.6 m) amounts to 25 kN/m^2. The input data used for this (surfacing structure and bulk density) are reflected in Table 1. The density of sand in a wet/saturated condition is normative because of the actual positioning of the sand bed near the groundwater level.

Table 1 - *Increase in the grain stress in the subgrade as a result of the construction of the surfacing structure in view of the highway widening*

material	course thickness [m]	underside in respect of surface level [m]	Density [kg/m^3]	grain stress [kN/m^2]
asphalt layer	0.30	0.70	2400	
unbound base course	0.30	0.40	2000	
sand bed	1.00	-0.60	1900	
(excavation) subgrade	-0.60		1200	25.0

Functional requirements for highway widening

Despite the complexity of the settlement issue, RWS (executive arm of the Ministry of Infrastructure and the Environment) has the tendency to maintain very strict functional requirements for current highway widenings. RWS publications mention the following relevant functional requirements for road structures that have been widened:

- differences in height up to 0.05 m across a length of 25 m (driving comfort requirement);
- transverse slopes on straight road sections between 1 and 5%;
- asphalt cracks not wider than 20 mm with a height difference of less than 10 mm (safety requirement);
- adequate stability of the fill (safety requirement);

- longitudinal slope at the place of the transitional structures between the fill and the settlement-free road sections (engineering structures) may change in time by 1% at most (safety requirement).

DESCRIPTION OF FILLING METHODS

Preloaded embankment and drains

The really conventional method of construction uses preload, sometimes in combination with drains. The envisaged effect of drains is a fifty percent reduction of the assumed pre-loading period. Instead of the assumed 1.5 years for only achieving a surplus height, thanks to the installation of drains, the construction of the highway widening can already commence after 9 months.

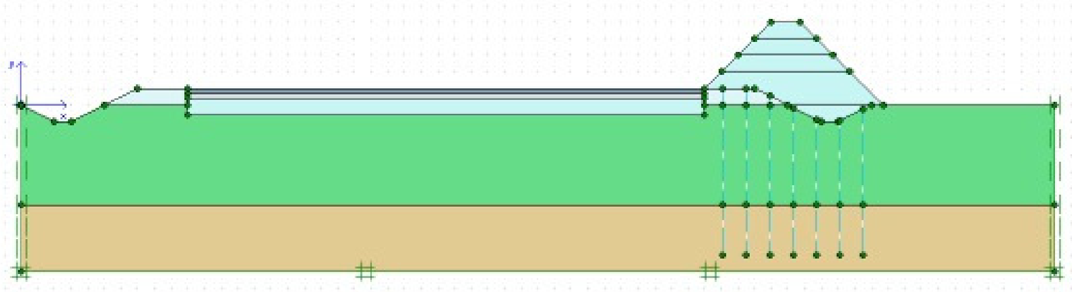

Figure 2 *-Model of the cross-section of the highway including preload and drains at the place of the highway widening*

Due to occurring settlements approximately 2.0 m of sand will be lost before work, which forms part of the highway widening, can be commenced on the surfacing structure. The particular volume means extra material costs in the construction phase and substantially increases the share of the sand costs in the total sum. Concerning the drains; these are spaced apart at a centre-to-centre distance of 1.2 m.

Vacuum consolidation

Vacuum consolidation serves exactly the same purpose as the use of surplus height. Instead of creating a top load the pressure difference in the ground water, due to the application of vacuum drainage, causes an extra pressure on the compressible subgrade. Taking into consideration that it concerns a consolidation accelerating method, it comes as no surprise that the most important disadvantages are the longer implementation time and the influences to the directly surrounding environment (groundwater extraction and settlements on the construction site). Consequently the method is mainly suitable for the independently situated parts of the route and far less suitable for highway widening. Yet the consolidation period is significantly reduced (6 months) and is shorter than for the application of surplus height in combination with drains (9 months).

Embankment based on sand columns in geotextile

The system comprises a base of sand/gravel columns encased in geotextile. Firstly, for the installation, casings are driven into the soil. Then these are emptied, after which geotextile is hung into it and filled with gravel or sand. For the analysis we have opted to use sand columns with a diameter of 0.6 m each spaced 2 m (centre-to-centre) apart. The function of the load spreading course is carried out by way of the natural arch action in combination with a gravel bed reinforced with geo-reinforcement (geogrids).

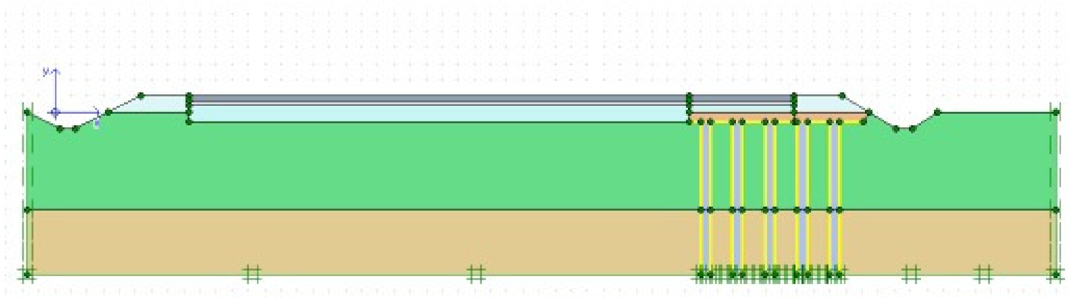

Figure 3 *-Model of the cross-section of the highway including sand columns at the place of the highway widening*

Highway widening based on concrete piles

The highway widening shown in Figure 4 is based on concrete piles which are 11 m long which extend into the depths of the stable Pleistocene sand deposit. As such the solution is settlement-free. Actually, this type of base course is normally used for engineering structures. The prefab piles used here are square and measure 0.2×0.2 m. The mutual spacing distance is 2.5 m centre-to-centre. Identical to the method with sand/gravel columns, a gravel bed encased with geo-reinforcement (geogrids), ensures there is adequate load spread between the pile heads.

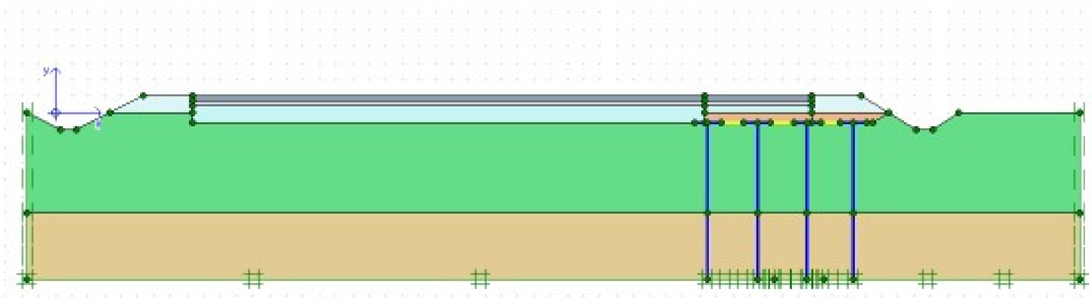

Figure 4 *-Model of the cross-section of the highway including the highway widening supported on concrete piles*

Lightweight road structure with EPS blocks

Highway widening using lightweight fill with EPS blocks provides a cause-oriented solution. The EPS thickness of 1.8 m is sufficient for a minimization of additional load on soft subgrade. Minimization is not understood to be an elimination of the additional load due to the construction, but to provide sufficient weight reduction in which final settlement, based on both the Plaxis as well as the Koppejan settlement calculations, is expected to be slightly more than 5 cm over 30 years. The increase in the grain stress due to the presence of such an EPS layer is mentioned in Table 2. By comparison to Table 1 the increase of grain stress in the subgrade is almost decimated.

Table 2 - *An increase of the grain stress in the subgrade as a result of the construction of a lightweight surfacing structure involving a 1.8 m thick EPS layer in view of the highway widening*

material [-]	layer thickness [m]	Underside in respect of surface level [m]	density [kg/m^3]	grain stress [kPa]
asphalt layer	0.30	0.70	2400	
unbound base course	0.30	0.40	2000	
sand bed	0.80	-0.40	1900	
EPS	1.80	-2.20	50	
(excavation) subgrade	2.20		1200	2.9
ref. level = surface level -2.20 m				

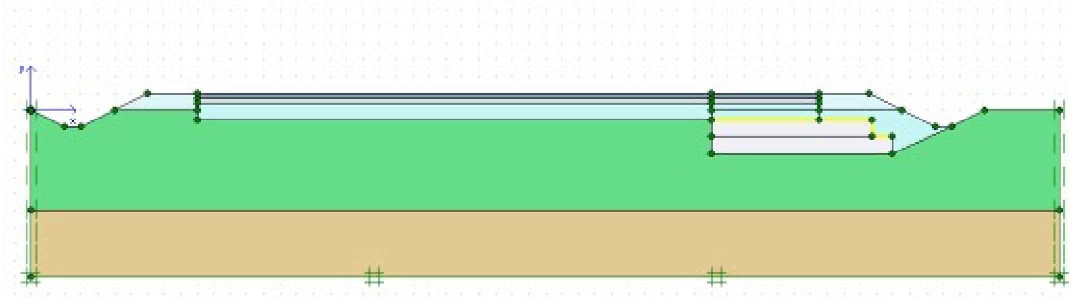

Figure 5 *-Model of the cross-section of the highway including a highway widening realised with lightweight EPS blocks*

Initial costs per filling method

Although the approach based on life cycle costs in principle should provide the most complete comparative results for alternative filling methods, in common practice a time horizon of 20 to 30 years is often too long. Consequently life cycle costs up to now play no or a very minor role in the selection of alternatives. The same applies for social costs as a result of traffic congestion. The emphasis here is mainly focused on the construction costs and costs for traffic measures. These two cost items form the basis for the choice of the relevant filling method for most of the tenders. Traffic measures such as extra safety precautions, barriers, adjusted markings and suchlike are necessary for longer construction periods, which also lead to damage/narrowing of the existing roadway. For methods that use conventional preloading (with lengthy construction periods), these kinds of costs could amount to approximately 15% of the total building costs.

It makes a big difference in the calculation of the total building costs if we include the financial consequences of long-term construction activities and the corresponding direct costs for traffic management. Alleged low initial costs for conventional methods of construction with surplus height are then no longer realistic. The same applies in the opposite sense for lightweight filling methods with EPS blocks. In this case, rapid construction leads to minimal traffic nuisance, there is no material loss caused by the subsidence of fill material (as is the case with preloading). In contrast to what one would traditionally think, such ingredients eventually result in the lowest initial costs.

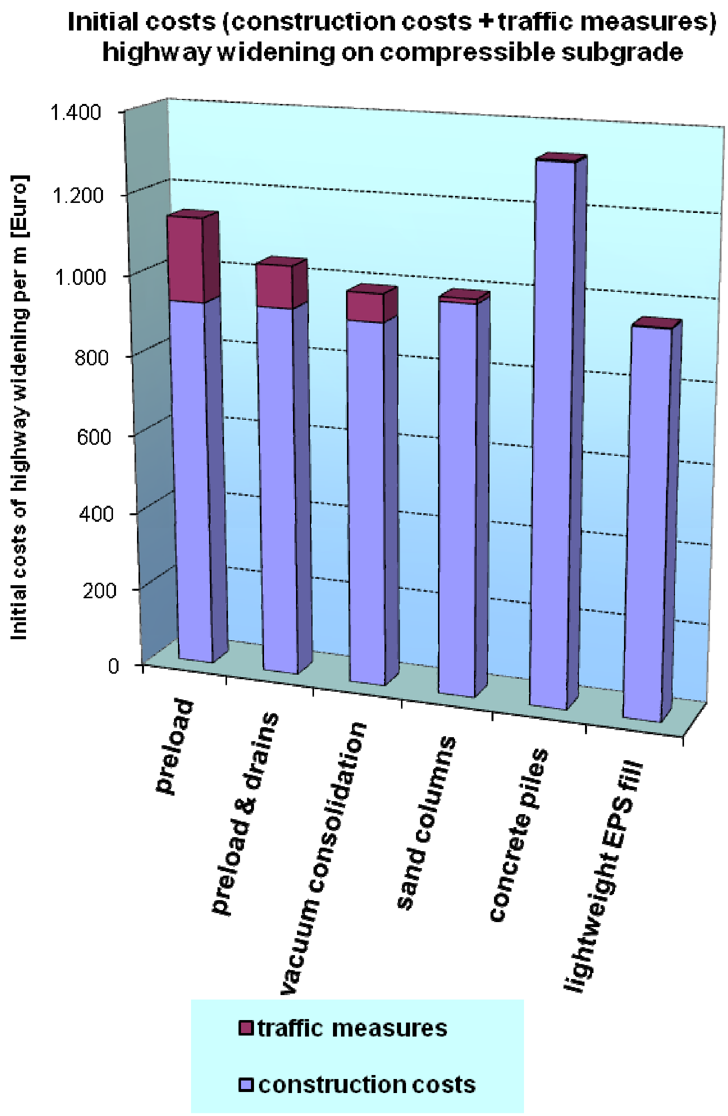

Figure 6 - *Total initial costs (construction costs plus direct costs for traffic measures during the construction period) for the widening of a representative highway using all the customary filling methods on compressible subgrade in the Netherlands*

Extra maintenance costs

Aside from the initial costs, the maintenance costs to be expected in the short-term are also included. Due to the fact that Design+Construct+Maintain contracts are being concluded more often, both road authorities as well as contractors have become more interested in occurrences of less frequent maintenance intervals as a result of (residual)settlements. Top layers of PAC surface treatments have to be replaced every 12 years. If the functional requirements are not complied with within this period, then it means extra costs which are not included in the maintenance budget. Generally, repair work also causes a great deal of traffic nuisance and congestion on very busy highways.

The inclusion of extra maintenance costs, in general, leads to even greater benefits due to low-settlement, settlement-free, cause-oriented filling methods, and particularly to lightweight fill structures. Such trends will continually be compounded if social (congestion) costs would also have to be calculated and added every time. Longer construction periods and more frequent maintenance, by definition, also cause more traffic congestion.

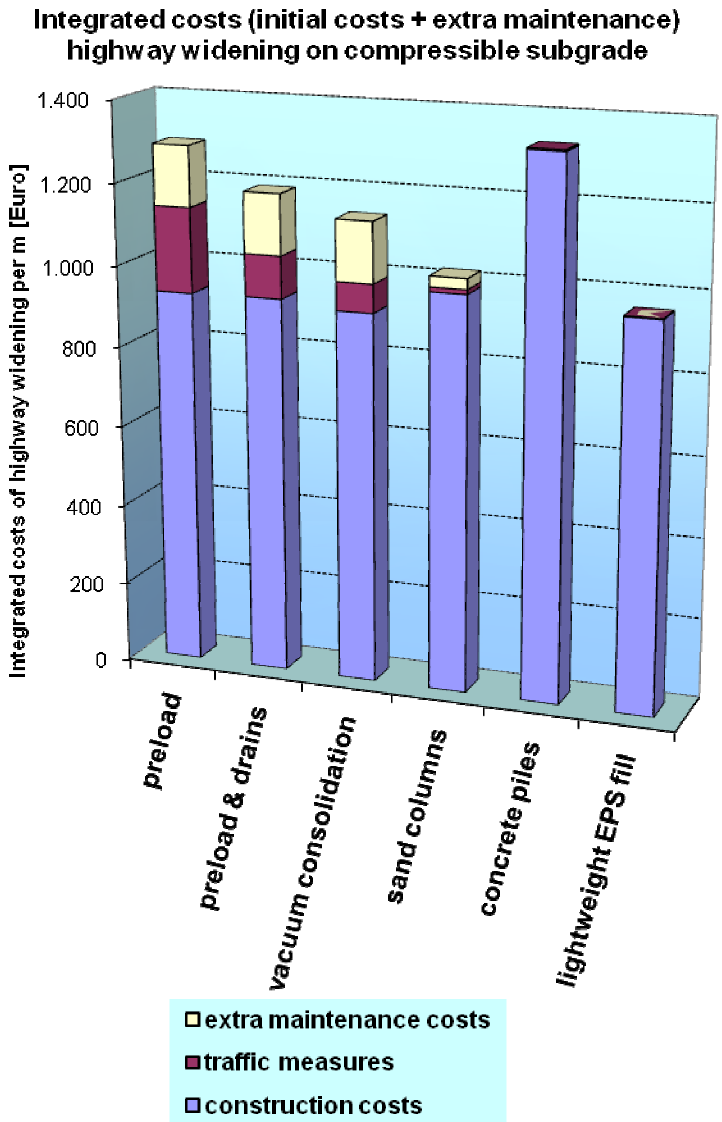

Figure 7 - *Integrated costs (total initial costs plus extra maintenance costs for repairs as a result of settlements) for the widening of a representative highway, using all the customary filling methods on compressible subgrade that in the Netherlands*

CONCLUSIONS

The estimation of initial costs for the widening of a highway on compressible subgrade, based on both the construction costs as well as the direct costs for traffic management, indicate that the conventional consolidation accelerating approach does not necessarily mean that it is economically beneficial. These findings are often contradictory to the dominant presumptions /assumptions held by the Dutch civil and hydraulic engineering sector (GWW). The reason lies in the consequences of long construction periods for road authorities which have been neglected until now. Direct costs for the necessary traffic measures to be taken when realising highway widenings using preload, amount to approximately 15% of the total initial costs.

The advantage of a short construction period and the omission of risk for damages to existing road sections results in a lower price of low-settlement filling methods using sand columns and lightweight road structures with EPS blocks. As a fill material EPS is slightly more expensive than other materials (though large-scale reusage influences the market price nowadays). The small surcharge however, is easily compensated by the much faster construction time and the minor settlement. The rapid construction time leads to a major reduction of the traffic control measures. The extremely minor settlement leads to rather low extra maintenance costs. If we include these aspects in the analysis then we cannot ignore the fact that, by comparison, a fill with EPS would be the best choice.

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