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Design method for temporary roads at residential construction sites in the Netherlands

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Preface

Hereby I present my graduation paper on the subject 'temporary roads on residential construction sites'. This paper is the final concept version of my submission to the "Advances in Civil Engineering 2008, 8th edition" (ACE 2008) congress at the Eastern Mediterranean University on Cyprus. At this time the authors' instructions for this congress are unknown. This paper is accompanied by an explanatory report (Harms, 2007). In this report you can find a more detailed description of my activities of the past 8 months.

During the research period I received help from many persons. It is not possible to name all of them here. Especially, I would like to thank the following persons for their contributions and support:

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This study is based on temporary roads on residential construction sites in the Netherlands but the results can be used in other fields and countries. I hope that this study provides a good initial study in the development of a temporary road design model in the renewed guidelines for the construction ready stage.

Sido Harms

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Design method for temporary roads at residential construction sites in the Netherlands.

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ABSTRACT

In this study we will investigate current practice of temporary roads construction in the Netherlands. Currently available know-how and pavement design methods are investigated and integrated into a design model for temporary roads on residential construction sites. Temporary roads are mainly designed on the basis of local experience and general pavement engineering, however there is no design method available for temporary roads, suitable for current conditions in residential sites.

Construction and maintenance costs of temporary roads are indirect costs in a construction project. For this reason we base pavement selection, after certain pre-conditions are met, mainly on the construction cost of the different pavement types and on the ‘upgrade’ costs to a permanent road. An integral approach for temporary and permanent roads can lead to a significant increase in the quality of the temporary road and a reduction in project costs.

Road design requires estimates of the expected traffic loads and the foundation soil conditions at a site. Data on moving loads for modern temporary roads in residential sites are scarce or absent. Therefore we have developed a model to estimate the traffic load on residential construction sites as a function of the project characteristics. For the description of the foundation soil characteristics we adapt the eleven standard sub-grade profiles, typical for various parts of the Netherlands. These profiles are recommended for pavement selection and design by C.R.O.W. “kennisplatform voor infrastructuur, verkeer, vervoer en openbare ruimte” (2006).

1. Introduction

In 2006 the number of newly constructed houses raise with 8 percent to 72.000 houses and totally 96.000 building permits were issued (CBS-statline, 2007). The number of newly constructed houses is increasing again since the historical low in 2003 (59.600). In the building estimates from to the Ministry of Housing, Spatial Planning and the Environment until 2011, it is estimated that the number of construction permits could rise to 100.000 permits per year. There are almost six times more residential construction permits issued per year than non-residential construction permits in 2006.

During the past decades construction projects are becoming more complex, bigger and higher. Increasingly heavier machinery and transport vehicles are used to build these projects. This heavy machinery needs to be able to reach the construction site and move on it. However, in large parts of the Netherlands the subgrade has not enough stability and bearing capacity to support the construction activities. Locations with better sub-grade are, especially in the western parts of the Netherlands, already constructed. Therefore construction sites are made construction ready first. This process includes the construction of temporary roads to make the sites better accessible for construction traffic. In this research, the design and construction of the temporary roads on residential construction sites is investigated. The following definition is used for a temporary road on a construction site:

- A paved or unpaved strip of land;
- on which transportation is possible;
- providing access to and/or on a construction site;
- during a limited amount of time.

Temporary roads on construction sites are characteristic for construction sites in the Netherlands. Five main reasons can be named for this. Firstly, the Netherlands has one of the highest construction densities in the world, leading to more traffic load on the roads creating the need for temporary roads. Secondly, in many countries no distinction is made between the utilisation and construction stage. In this case the permanent road serves also as temporary road. Thirdly, a small element pavement is often the preferred permanent pavement in the Netherlands where asphalt is the preferred pavement in many other countries. Small element pavements are not suited for temporary roads. Fourthly, the public roads in the Netherlands are relatively small in the utilisation phase of the project (sometimes only 4,5 metre while at least 5,5 metre is required), creating the need for wider temporary roads. Finally, buildings in the Netherlands are constructed using more heavy construction materials (i.e. concrete) then other countries (i.e. wood in Sweden), leading to heavier loads.

There are three key differences between temporary and public roads in the Netherlands. Firstly, the weight of the vehicles during the construction process is much higher during construction than during the utilisation phase. Secondly, the traffic volume on a temporary road is lower then on the permanent road. Thirdly, the temporary road's lifespan is much shorter then the permanent road. These main differences are summarised in Table 1. These three aspects are also key design aspects in road designs.

Table 1: key differences between temporary roads and roads in the final state in residential area's.

Aspect	Temporary road	Public road
Vehicle weight	High	Low
Traffic intensity	Low	High
Lifespan	Short	Long

There is a preference for constructing temporary roads on the same route as the permanent roads. Therefore an integral approach for the temporary and the permanent road can lead to an increase in quality and a reduction in project costs. Currently, temporary roads are mainly designed on experience because there is no design method available to estimate the traffic load on temporary roads. This can result in over- or under dimensioned roads leading to unnecessary project costs or bad conditions on construction sites.

A special point of attention is water management on the construction site. If not enough attention is paid to water management, significant waterlogging on the construction site can occur. The combination of low permeability soils and inadequate drainage system is the main cause for waterlogging on construction sites in the Netherlands. The height of the temporary roads surface level in comparison to the ground level can also cause waterlogging problems. Temporary roads above ground level with low permeability embankments or with bad drainage systems can start acting as dikes which can lead to waterlogging on the whole construction site. Roads that are constructed under the ground level can start acting as waterways. Soaked roads have a strongly reduced bear capacity, which will shorten the roads lifespan. Biron (2004) also underlines the importance of water management in his research.

This paper provides a first exploration into a design method for temporary roads. It fits in the renewal of aged guidelines for the construction ready phase written by Segeren (1984). This research (Web page: http://www.bouwrijp.nl) is called "Beter Bouw en Woonrijp" in which many large actors active in the construction ready stage in the Netherlands (like Geodelft, Grontmij, SBR, Sterk-consulting, TU-Delft and Witteveen+Bos) combine their knowledge and resources.

In this article the results of this research is reported. Section 2 starts with the findings regarding the current use of temporary roads. Possible design aspects, which can be present in temporary road design, are discussed in section 3. Section 4 provides a progressive scheme that can be used to make a proper temporary road. The results of a case study are reported in section 5. Conclusions are made in section 6 and recommendations for future research are presented in section 7. For this article a detailed explanatory report is available; Harms (2007).

2. Current situation

Two main sources were used to investigate the current application of temporary roads in the Netherlands. Firstly, research performed by Biron (2004) on the construction ready stage is used. In this research the construction ready stage of eleven projects were analysed, including the temporary roads and compared to an older study by Dijk et al. (1977). There are four main conclusions in Birons' research:

1) There are 2 main methods to make a site construction ready: the integral or the embankment method. Either way the expected consolidation is reduced to the allowed limit before the temporary roads are constructed. The sand layer under the roads can be used as embankment and will ensure good drainage.
2) The application of small element pavements dropped significantly compared to 1977 as pavement method on temporary roads. This is largely because of cost reasons. Asphalt paved and unpaved roads are becoming more popular.
3) The permanent pavement is no longer used as temporary road pavement. Temporary roads can however be upgraded with a permanent pavement.
4) Temporary roads can cause waterlogging on the construction site due to badly constructed embankments, bad drainage systems or mismatched road height compared to the surroundings.

As second source, three large residential construction projects in the Netherlands were studied: IJburg – Amsterdam, Floriande – Hoofddorp and Duyfrak - Valkenburg (2.4). Three types of temporary roads were encountered: unpaved, asphalt and prefabricated concrete plate roads. A RAMS analysis is performed (Reliability, Availability, Maintainability and Safety) to judge the performance of the road types currently in use in the Netherlands. In Table 2 it can be seen that paved roads deliver better conditions on the construction sites then unpaved roads. However, they do this at higher cost.

Table 2: overview RAMS-aspects of temporary road types (++ : excellent, + : good, - : bad, -- : very bad).

Aspect	Unpaved	Asphalt	Small elements	Concrete plate
Reliability	-	++	+	++
Availability	+/-	++	+	++
Maintainability	+	+	+/-	+/-
Safety	-	+	+	+

During the study into the application of temporary roads the following points were also noticed:

- When possible, the resident traffic should be separated from the construction traffic. This will increase the safety on the construction site and minimise the hindrance for residents.
- Roads with both resident and construction traffic are public roads and should be treated as such. Damage to the roads should be repaired as soon as possible.
- Parking should not be allowed on temporary roads. In severe cases this can cause congestion and can do more damage to the temporary roads.
- When possible, it is preferred to install the lead-up services before the temporary roads are constructed.
- The quality of unpaved roads is strongly weather dependant.

3. Design characteristics

In literature many different terms are used to describe parts of the road's construction. The terminology as shown in Figure 1 is used throughout this article.

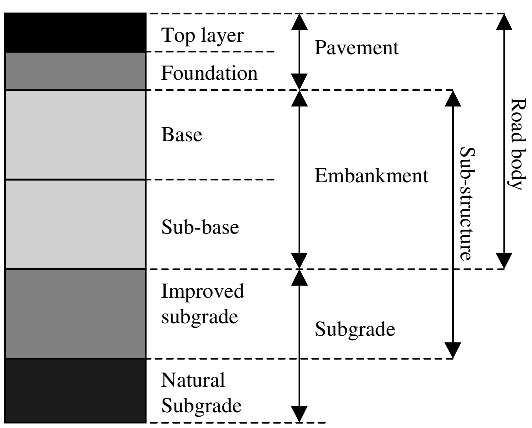

Figure 1: schematic cross section of a road construction with terminology.

There are several aspects that influence the temporary road design. These aspects are called preconditions (see Figure 2). These preconditions vary per project or location and can also vary in time. Variation per project can be found in the expected traffic load and sub-grade. Variation in time can be resident traffic and hindrance to the surroundings. The following preconditions are possible design aspects for temporary roads.

- *Project location and design*. The layout of the construction project will largely determine the location of the temporary roads and their traffic load. It will also determine the way construction (and resident) traffic will be distributed on the project.
- *Traffic distribution plan.* The traffic distribution plan largely determines the traffic load that can be expected on each temporary road and it determines on which roads resident traffic can be expected.
- *Sub-grade*. The sub-grade under the road has a large influence on the roads' design. On weak sub-grades, thicker and sometimes lighter road constructions are necessary. This model utilises the standard sub-grade profiles developed by C.R.O.W. (2006).
- *Traffic load*. The road has to bear the load applied without showing unacceptably large deformations. This research provides a model that can be used to estimate the traffic load.
- *Residential traffic*. Requirements set for temporary roads with residential traffic are the same as set for public roads. Requirements at temporary roads where no resident traffic can be expected can be lower.
- *Allowed damage*. Temporary roads that are only used by construction traffic are 'allowed' to show more damage than public roads. When resident traffic is present, eventual damage should be repaired as quickly as possible.
- *Lead-up services*. Lead-up services are often installed under the roads. Opening up roads can lead to structural damage and is hard to restore. NEN 1738 and 1739 (1964) deal with the location of lead-up services under or next to roads in the Netherlands.
- *Combination with permanent road.* When the permanent road is combined with the temporary road this will generate an extra set of design requirements at the temporary road design.

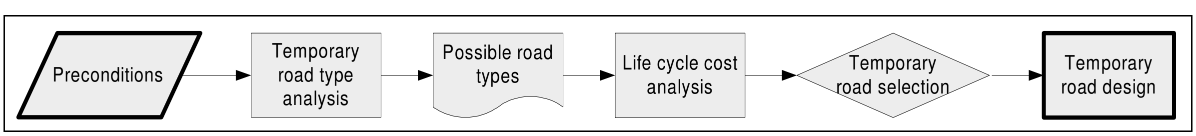

Figure 2: temporary road design process

- *Parking spaces*. Parking on the temporary road can cause congestion on the construction site. When one lane is blocked, due to parking on the road, the traffic load on the other lane will double, which can cause damage to that lane. Therefore enough parking spaces should be created on or nearby the construction site
- *Hindrance to surroundings.* Unpaved roads can cause hindrance to the surroundings in dry time due to dust. When the project is situated in populated area's dust control is required in dry times.
- *Life cycle costs*. Temporary road costs are indirect project costs. This means that these costs have no direct added value to the project, but have to made in order to construct the project. Therefore these construction costs have to be minimised.

When there are multiple temporary road types available, after the other pre-conditions are met, life cycle costs is the deciding criteria. The design-process for temporary roads is shown in Figure 2. The preconditions, set for a temporary road determine which road types can be used. By performing a life cycle cost analysis of the construction cost the cheapest solution that fulfils the preconditions can be found.

4. Construction costs

Four types of cost can be distinguished: construction, removal, upgrade and maintenance costs. When the temporary road is not combined with the permanent road the total costs consists of construction and removal costs. These costs can be found for several temporary road types in Table 3. For this cost analysis the pavement costs per square metre are determined based on an example project of 3000 m^2 (500m long and 6m wide). The GWW-costs (2006) books are used for this analysis.

When the temporary road is combined with the permanent road, the total cost consists of construction costs for the temporary road and the upgrade costs to the permanent road. In this research it is assumed that paved roads do not require maintenance. Unpaved roads do require maintenance but this can be performed quickly and cheaply. Therefore these costs are neglected. A summary of these calculations can be found in Table 4

Table 3: temporary road construction and removal costs.

Pavement type	Construction [€/m²]	Construction costs Incl. removal [€/m²]
Unpaved road	2,50 – 4,50	6,50 – 12,00
Prefab concrete plates	7,50	12,50
Asphalt	11,00 – 16,50	11,50 – 22,00
Small element	24,50 – 27,00	28,00 – 36,00
Concrete	29,00 – 31,00	31,50 – 38,00

Table 4: Combination temporary and permanent road coasts.

Option	Road pavement		Construction costs [€/m²]
	Temporary	Permanent	
1	Unpaved	Asphalt	16,50 – 19,00
2	Asphalt	Asphalt	16,75 – 23,00
3	Concrete plate	Asphalt	25,50 – 28,50
4	Unpaved	Small element	26,50 – 29,00
5	Concrete plate	Small element	34,50 – 39,00
6	Asphalt	Small element	36,50 – 43,00

5. Progressive scheme

To make a good temporary road design the following progressive scheme is proposed. The progressive scheme is based on the flow-chart in Figure 3. A more elaborate explanation of these steps is available in the explanatory report Harms (2007)

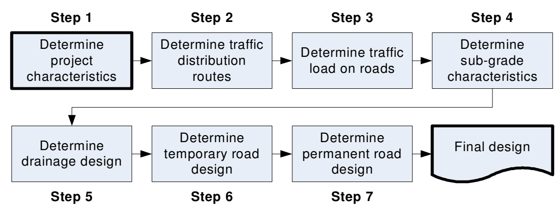

Figure 3: proposed flow-chart for temporary road design model.

Step 1: project charaterisics

The first step of the model deals with the determination of preconditions and design aspects required later in the model. The following are determined in this step: Project location and layout, Lead-up services and Hindrance to surroundings. These preconditions are very general and differ much between projects. Therefore this step is not further elaborated. However it is important that details regarding these preconditions are clear before the other steps are taken. Figure 5 provides a flow-chart for step 1.

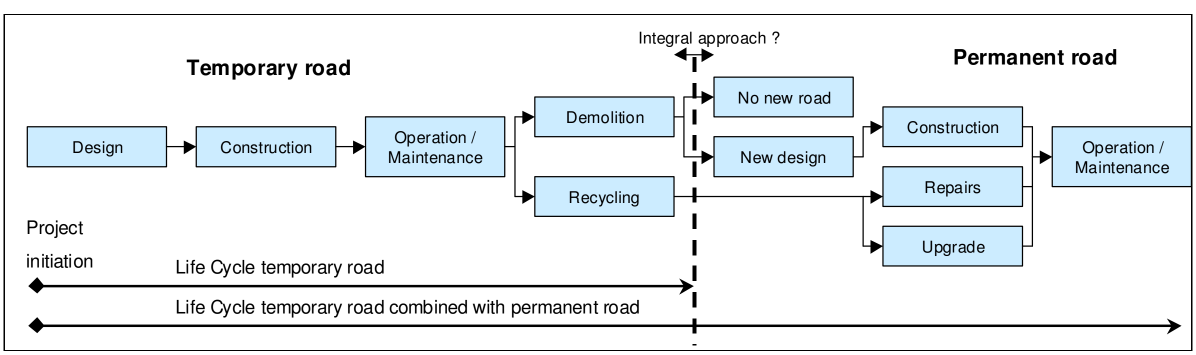

Figure 4: life cycle of a temporary with the possibility of combining with permanent road.

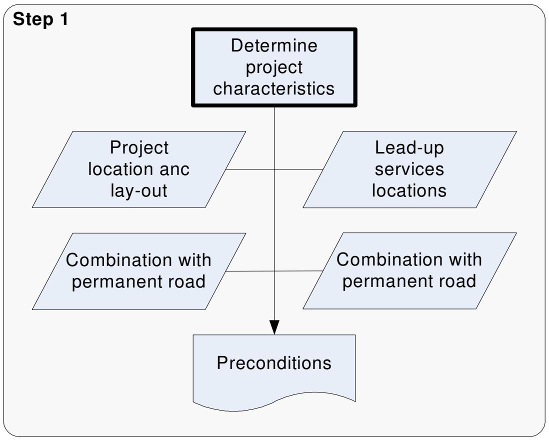

Figure 5: flow-chart step 1.

Step 2: traffic distribution

The traffic distribution plan for the construction site needs to be formulated before the traffic load on the temporary roads can be calculated. Transport routes for resident and construction traffic should be separated as much as possible. It is recommended to classify the temporary roads into categories. Three categories can be distinguished on construction sites. First order roads provide the main access to the complete project site. When the project is divided in two or more zones, the second order roads provide access to those zones. The first and second category roads are mainly under the supervision of the local government. The third category roads can be found on the separate construction sites in a zone. Mostly these are constructed and operated by construction companies. Figure 6 provides the flow-chart for step 2.

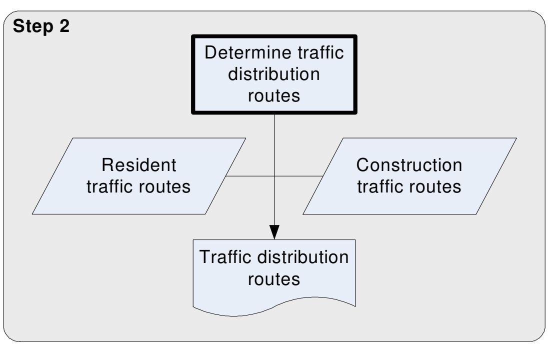

Figure 6: flow-chart step 2.

Step 3: expected traffic load

Data on moving loads for modern temporary roads in residential sites are scarce or absent. Therefore we developed a computer model (written in HTML and JavaScript) to estimate the traffic load on residential construction sites as a function of the project characteristics. The flow chart for step 3 is displayed in Figure 7.

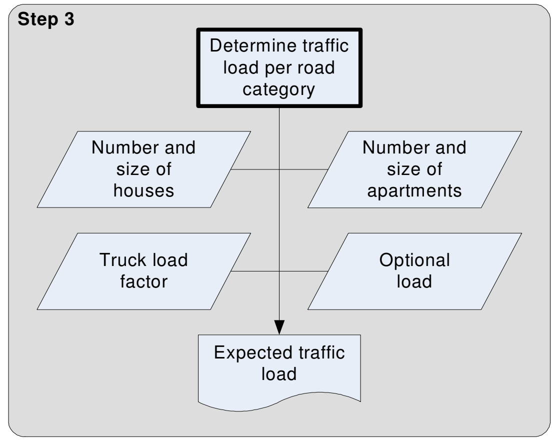

Figure 7: flow-chart step 3

The model is based on the transportation of construction material. The total load on the road is assumed to be a combination of the weight of the material that needs to be transported and the dead weight of the transport vehicles. The weight of the material can be calculated by looking at the project characteristics. This weight is transported by a certain number of trucks, which have a certain dead weight. In this research it is shown that it is highly likely that a relation between the weight of the transport material (TW) and the generated dead weight (DW) of the transport trucks exists. A more detailed description can be found in Harms (2007). The dead weight of transport trucks [kg] can be calculated using the following equation:

$$DW = 0{,}53 * TW + 1191 \qquad (1)$$

This relation is only valid if all trucks are 100% loaded, which is mostly not the case. If not all trucks all fully loaded than additional trucks will be necessary, thus increasing the total dead weight. To compensate for this, a truck load correction factor ($TL_{cor.f.}$) is introduced into the model. Table 5 can be used to compensate for this factor.

Table 5: load correction factor [-].

LF [%]	70	80	90	100	110
$TL_{cor.f.}$	1,22	1,13	1,06	1,00	0,95

To simplify the use of the traffic load model (which requireds a significant amount of input and is rather complex), design tables are calculated for ‘standard’ houses and apartment buildings to quickly estimate the traffic load. Houses can be classified into two categories: free-standing and row houses. In row houses the distinction can be made between end houses and between houses. Apartment buildings can be distinguished in end and between columns. Figure 8 shows this difference. Houses and apartments can also be categorised based on their size. This is done is Table 6.

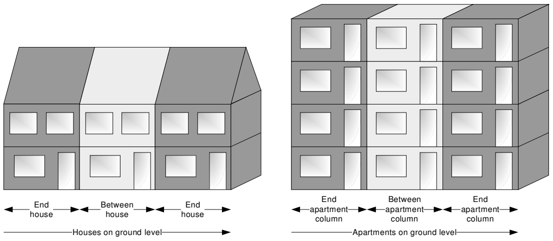

Figure 8: explanation of end and between houses / apartments.

Table 6: building categories based on floor space

What	Size	Floor space [M^2]	Average [M^2]
House	Small:	50 – 100	75
	Medium:	100 –150	125
	Large:	150 – 250	200
Apartment	Small	< 50	40
	Medium:	50 –100	75
	large:	100 –150	125
	Extra large	> 150	175

The following equation can be used to calculate the expected traffic load for a certain temporary road. The determined traffic load is the total load on the temporary roads during the construction period.

$$N = TL_{cor.f.} * \left(\sum_{n}^{Houses} X_n * H_n + \sum_{m}^{Aparmtments} X_m * A_m + \sum_{p}^{Optional} X_p * O_p \right) \quad (2)$$

In which:
N = Expected traffic [100kn axle loadings]
$TL_{cor.f.}$ = Truck load correction factor [-] (Table 5)
n = House type(s)
m = Apartment type(s)
p = Optional traffic load type(s)
X_n = Number of houses in category n
H_n = Traffic load per unit in category n (Table 7)
X_m = Number of apartments in category m
A_m = Traffic load per unit in category m (Table 8)
X_p = Number of units in optional category p
O_p = Optional load in category p (Table 9/Table 10)

The following design tables are based on a load factor of 100% for the transport trucks. A safety factor of 1,3 has been applied in the following tables, since it is not possible to calculate the precise transport weight. All tables are expressed in 100 kN axle loads.

Table 7: traffic load design table for house types (H_n).

Size	Roof type	Free-standing	Row house End	Row house Between
Small	Flat	45	38	30
	Pointed (45^o)	40	33	27
Medium	Flat	63	53	41
	Pointed (45^o)	57	48	38
Large	Flat	87	72	58
	Pointed (45^o)	82	68	53

Table 8: traffic load design table for apartment columns (A_n).

	Small		Medium		Large		Extra large	
Floors	E	B	E	B	E	B	E	B
2	51	40	80	65	112	99	154	141
3	66	50	105	86	147	132	206	188
4	80	62	130	107	183	162	258	235
5	95	72	155	129	219	193	309	284
6	109	84	181	148	254	226	361	330
8	138	106	231	191	325	289	465	424
10	168	126	281	234	396	353	568	520

Table 9: traffic load design table for sheds (O_n).

		Shed size [m]			
Wall type:	Floor:	2x2	2x3	3x3	3x4
Wood	Wood	0,06	0,08	0,11	0,13
	Concrete	0,19	0,28	0,41	0,53
Clay bricks	Concrete	0,46	0,62	0,81	1,00

Table 10: traffic load design table for garden heightening (O_n).

Extra	Garden size [m^2]								
height	5	10	20	40	80	160	320	640	1280
0,05	0,1	0,1	0,2	0,4	0,8	1,7	3,3	6,7	13,3
0,10	0,1	0,2	0,4	0,8	1,7	3,3	6,7	13,3	26,6
0,15	0,2	0,3	0,6	1,3	2,5	5,0	10,0	20,0	39,9
0,20	0,2	0,4	0,8	1,7	3,3	6,7	13,3	26,6	53,3
0,25	0,3	0,5	1,0	2,1	4,2	8,3	16,6	33,3	66,6
0,30	0,3	0,6	1,3	2,5	5,0	10,0	20,0	39,9	79,9

Step 4: Sub-grade charaterisics

Temporary roads are constructed in or on top of the sub-grade present at the project location. The sub-grade has to support additional weight of the embankment, pavement and traffic load applied to it, without showing unacceptably large deformations. Therefore, consolidation and stability of the sub-grade determines largely the design and performance of a road. Thus it is important to know the characteristics of the sub-grade and what consequences this has for the road design. Figure 9 shows the location of different sub-grades in the Netherlands.

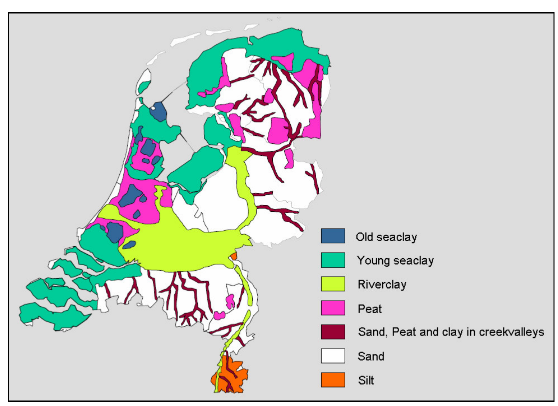

Figure 9: global distribution of soil types in the Netherlands (C.R.O.W., 2006)

For this research the eleven standard sub-grade profiles for the sub-grade of the Netherlands developed by C.R.O.W. (2002, 2006) are used. These profiles are mainly based on the expected consolidation and the bearing capacity. Consolidation is the gradual reduction in volume of a saturated, low permeable soil due to slow drainage of the pore water. Consolidation is not the same as compaction. Compaction is the change of volume due to the reduction of air voids in the soil. Consolidation is a slow process, it may take decades or even centuries for a soil to come into equilibrium with stresses. Construction sites on consolidation sensitive soil are first made construction ready to reduce the settlements. Soil that is likely to largely deformed in time, can mainly be found in the Western parts of the Netherlands. The standard sub-grade profiles are shown in Figure 10.

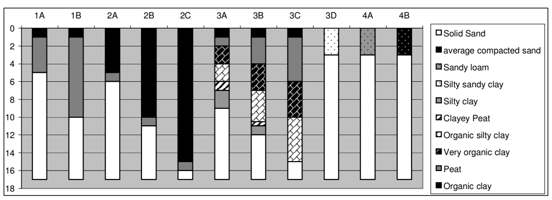

Figure 10: standard sub-grade profiles for the Netherlands (C.R.O.W. 2006).

Consolidation calculations in the Netherlands are mostly made according to the Koppejan method. The Koppejans equation yields the magnitude of the total settlement, thus the primary settlement (obtained at the end of the consolidation process) plus the secondary settlement (resulting from creep of the grains). Consolidation calculations have already been made by C.R.O.W. for the standard sub-grade profiles, based on the design height above the old ground level (0,1, 0,4 or 0,7 metre). The consolidation calculations are based on the assumption that the intended construction height is reached after consolidation. The natural consolidation is assumed to occur in 10.000 days. This mechanism is shown in Figure 11.

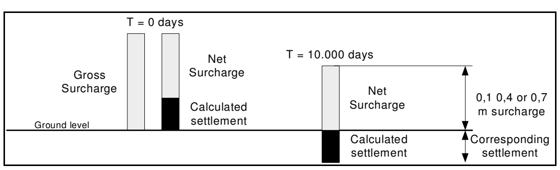

Figure 11: mechanism behind settlement calculation.

Using the program MSettle (version 7.3, developed by GEO-Delft), also used for the original calculations (version 6.3), control calculations were made. When the same soil parameters and subgrade compositions as displayed as used by C.R.O.W. (2006) are entered into the program the results are slightly different but comparable to the results of C.R.O.W. However, when the standardised soil characteristics as described in NEN 6740 (2006) are entered, large differences occur. This is caused by the use of 'experience' data. Calculations with MSettle show that for subgrade 1B the settlement decreases from 3,10 metre (as calculated by C.R.O.W.) to a more realistically 1,54 metre based exclusively on NEN 6740. The main reason for this is the conservative presentation of the sub-grade characteristics by C.R.O.W. and GEO-Delft (2006) which caused larger settlements. The main reason for this might be that these profiles were developed to broaden roads. Therefore it is recommended to perform cone penetration tests and make consolidation calculations using the program MSettle and not to use the C.R.O.W. data regarding consolidation. For the design of temporary roads, the sub-grade characteristics displayed in Table 11 are proposed to be used in temporary road design.

Table 11: soil characteristics of the standard sub-grades.

Profile:	E [MPa]	$\Phi'_{e;d}$ [°]	t_e [m]	$f_{undr.}$ [kPa]	k [m/d]
1A	20	21,4	7,5	14,51	0,05-0,1
1B	20	15,3	6,1	14,60	0,05-0,1
2A	20	16,9	7,1	26,84	0,2-0,5
2B	20	15,0	6,0	25,00	0,2-0,5
2C	20	15,0	6,0	25,00	0,2-0,5
3A	20	17,2	6,5	25,49	0,2-0,5
3B	20	15,4	6,1	22,08	0,2-0,5
3C	20	15,0	6,0	21,53	0,2-0,5
3D	50	29,3	9,7	40,00	1,0-2,0
4A	75	31,6	10,4	50,00	1,0-2,0
4B	100	32,7	10,8	0,0	10,0

Figure 7 provides the flow-chart for step 4.

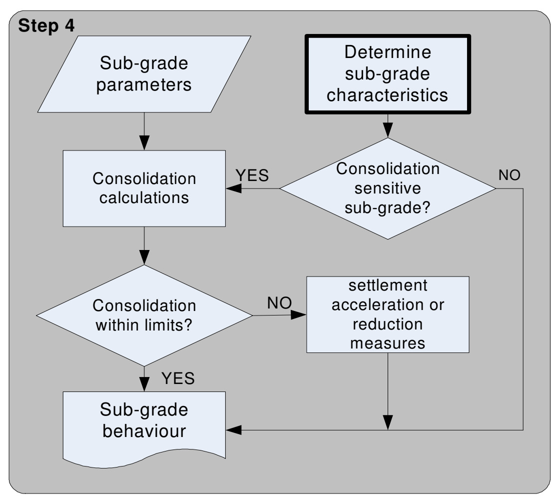

Figure 12: flow-chart step 4.

Step 5: Drainage design

About half of the Netherlands is only 1 meter above sea level, and most of the other half is actually below sea level. A substantial part of the Netherlands, for example, the whole province of Flevoland and large parts of Holland have been reclaimed from the sea and lie below sea level, making watermanagement on construction sites important. Biron (2004) and SBR (2007) also underline the importance of water management in their research. If not enough attention is paid to water management, significant waterlogging on the construction site can occur. Figure 13 provides the flow-chart for step 5.

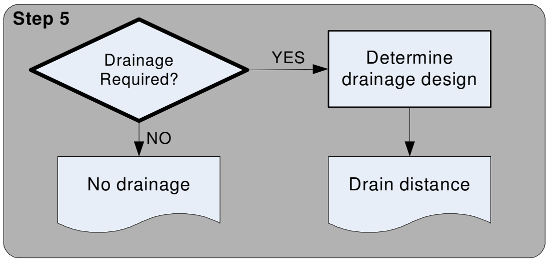

Figure 13: flow-chart step 5.

Temporary roads can not only experience damage resulting from waterlogging, they can also cause it as described in the introduction. By installing drains in the road not only the road is drained, but also the surrounding construction site as can be seen in Figure 14. This will result in better conditions on the construction site.

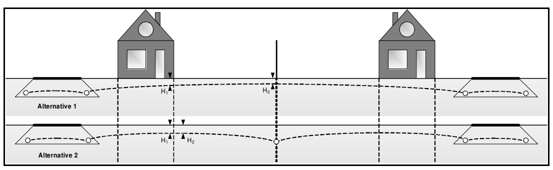

Figure 14: drainage tubes in residential area.

To calculate drainage, data regarding the required drainage head (during the construction and the utilisation phase) is necessary. Table 12 shows indications for the required drainage heads. Temporary roads and permanent roads are classified as secondary roads.

Table 12: indications for drainage heads (SBR, 2007)

Construction phase	
What	**Drainage head**
Buildings	0,6-0,7
Service cables/tubes	0,5-0,6
Primary roads	1,0
Secondary roads	0,7
Parking spaces/squares	0,4
Accessibility site	0,5-0,7
Utilisation phase	
Houses with crawl space	0,7
Cables and tubes	0,6-1,0
Primary roads	1,0
Secondary roads	0,7
Gardens/parks	0,5

The distance between drains can be calculated using the Hooghoudt equation (Segeren 1984). Calculating the drain distance is an iterative process.

$$L^2 = \frac{8*K_2*d*h+4*K_1*h^2}{q} \quad (3)$$

With:

$$h = \frac{D}{1+\frac{8*D}{\pi*L}*\ln\left(\frac{D}{\pi*r_0}\right)} \quad (4)$$

In which:

L = Distance between parallel drains [m]
K_1 = Permeability above the drain depth [m/day]
K_2 = Permeability below the drain depth [m/day]
d = Thickness of the equivalent layer [m]
h = Curving of the water table [m]
q = Specific discharge [m/day]
D = Layer thickness below drains [m]
r_0 = Diameter drain [m]

For the required discharge the values provided by Segeren (1984) can be used. Calculations have to made with a discharge of 10 mm/day during the construction phase. Because more terrain will have a pavement (and additional drainage systems) during utilisation, calculations can be made with a discharge of 5 mm/day. However there it is currently discussed whether or not to use the discharge of 10 mm/day also in the utilisation phase. In case a drainage system is only necessary during the utilisation phase, it is recommended to install the system in the construction ready phase. This will lead to better construction site conditions.

The standard sub-grade profiles provide also values for the permeability of the sub-grade. These values are shown in Table 13. There is however significant doubt about the correctness of these values. The values as suggested by C.R.O.W. are most likely based on a virgin terrain with undisturbed and compressed layers, which is hardly the case on construction sites and in top layers. Drainage calculations are usually made with higher values. It is proposed to use the suggested values for the permeability as shown in Table 13. For these profiles it is assumed that the whole layer is homogeneous, that the influence depth of the drainage system is the thickness of the top layer, and that $K_1 = K_2$.

Table 13: permeability for the standard sub-grade profiles determined by C.R.O.W. (2006) and the suggested value.

Profile:	Layer thickness [m]	K [m/day]	
		C.R.O.W.	Suggested
1A	5	0,0086	0,05 – 0,1
1B	10	0,0086	0,05 – 0,1
2A	6	0,0432	0,2 – 0,5
2B	11	0,0432	0,2 – 0,5
2C	16	0,0432	0,2 – 0,5
3A	9	0,0043	0,2 – 0,5
3B	12	0,0043	0,2 – 0,5
3C	15	0,0043	0,2 – 0,5
3D	3	0,0864	1,0 – 2,0
4A	3	0,8640	1,0 – 2,0
4B	3	43,2000	10,0 – 20,0

There are two main locations for drainage tubes under a road: on both sides of the road or under the centre of the road. When the drainage tubes are installed on both sides, water will flow directly into the drainage tubes. The tubes are also easier accessible in case they get clogged. Drainage tubes can be installed on different depths in the road body. When the drain is installed deeper this will result in larger distances between two parallel drains, and thus to cost reductions. Installing drains below the ground water table is not recommended unless the drains can dispose their water on waterways with a lower water table.

Step 6: Temporary road design

Construction and maintenance costs of temporary roads are indirect costs to a construction project. For this reason the pavement selection, after certain preconditions are met, is largely based on the construction cost of the different pavement types and on the 'upgrade' costs for a temporary road to a permanent road. Figure 15 shows a flow-chart for the temporary road design as used in this step.

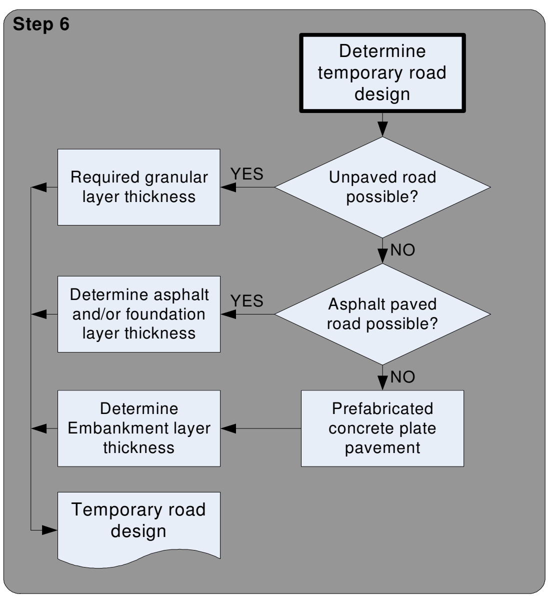

Figure 15: flow-chart step 6.

There are numerous materials available for use as a foundation in road construction. All can be classified in one of the following three categories: unbound, slightly bound or self-binding and bound foundations. Unbound foundation materials have only a slightly higher (150 MPa) constructive value than sand (100 MPa). Therefore unbound foundation materials are not recommended as unpaved road or in the foundation layer. For temporary roads, a bound foundation layer can cause problems if cables and tubes need to be laid in the roads' body because these layers are stronger and more expensive to restore. Therefore bound foundation layers are also not recommended.

From the slightly bound foundation materials, mixed granule is a lot cheaper than the other materials. Therefore mixed granule is used for unpaved roads and as foundation layer in this step.

Unpaved roads

An unpaved road is a road without a top layer of asphalt, concrete, small elements or another top layer material. A commonly used road on construction sites in the Netherlands is the mixed granule road. Unpaved roads are much cheaper to construct than paved roads, but require more maintenance, especially on weak sub-grades (due to rutting), in case high traffic loads can be expected or in dry (dust prevention) and wet (damage to the top layer) times. Unpaved roads require the regular addition of granule, grading and shaping in wet times. The construction and maintenance costs increase as traffic load increases, stiffness of the sub-grade decreases and depends strongly on the weather conditions.

Research by Giroud and Noiray (1981) shows that the required thickness of a self-binding (mixed granule) foundation layer during the construction phase can be calculated using the equation below. This equation is only valid up to 10.000 axle loads and on cohesive soils.

$$h_g = \frac{125{,}7 * \log(N) + 496{,}52 * \log(P) - 294{,}14 * SP - 2412{,}42}{(f_{undr.})^{0{,}63}} \qquad (5)$$

In which:

h_g = Recommended thickness foundation layer [m]
N = Expected traffic load during construction phase
P = Average axle load [N]
SP = Acceptable rutting depth [m]
$f_{undr.}$ = Undrained shear strength of sub-grade [Pa]

Figure 16 is a graphical representation of the equation developed by Giroud and Noiray (1981) and can be used to quickly determine the required foundation thickness based on the undrained shear strength of the sub-grade, allowed rutting depth and the expected traffic load. Rutting in temporary roads is easy to restore and will take place under the road. Therefore it is proposed to allow 0,2 m rutting in unpaved roads.

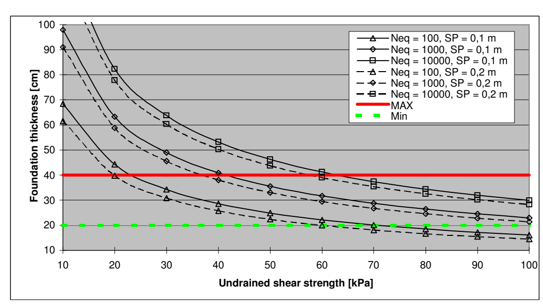

Figure 16: determination of the grain layer thickness (Giroud and Noiray, 1981).

If the undrained shear strength is unknown the result of a cone penetration test can be used to calculate the undrained shearstrength with the following equation (ten Hagen & Stam, 1997):

$$f_{undr.} = q_c / A \qquad (6)$$

In which
$f_{undr.}$ = Undrained shearstrength [kPa]
q_c = Cone tip resistance [kPa]
A = Soil factor (normal consolidated soils: 12 - 15)

Figure 16 shows that when a very weak sub-grade is present on the construction site (standard sub-grade profiles 1A to 3C), a very thick grain layer is required. When a very stiff sandy sub-grade is present than an unpaved road can even handle rather heavy traffic loads. The study into the current situation showed that never more than 35 cm of grain material was applied on a temporary road. Grain layers thicker than 40 cm need to be constructed in two separate layers, this is more expensive and not desired. Therefore the maximum layer thickness of the grain material is set to 40 cm (MAX), this is also confirmed in VBW-Asfalt (2000). RWS (1998) recommends a minimum foundation layer thickness of 20 cm (MIN).

When a layer is required thicker than 40 cm, then a sand layer is constructed instead. The thickness of a layer material can be converted into an equivalent thickness using the "Method of Equivalent Thickness", developed by Ullidtz (1987), with the following equation:

$$h_e = f_i * h_{sub}\left[\frac{E_{sub}}{E_{base}}\right]^{\frac{1}{3}} \qquad (7)$$

In which:
h_e = Equivalent layer thickness [m]
f_i = Correction factor (for two layer system f_i = 0,9)
h_{sub} = Thickness of the original layer [m]
E_{sub} = Modulus of original material [MPa]
E_{base} = Modulus of substitute material [MPa]

On projects with a weak, often consolidation sensitive sub-grade, the site is first made construction ready by adding an extra sand layer. Temporary roads are usually constructed on this layer which means this sand layer can be used for the road embankment. Under other circumstances (high traffic load, weak sub-grade) it is possible that an unrealistically thick sand layer is required. In such cases a paved temporary road is required.

Asphalt pavement
Asphalt pavements are also called flexible pavements. The viscous nature of the bitumen binder allows asphalt pavements to sustain significant plastic deformation without significant damage to the pavement. Most asphalt pavements are built on a granular foundation but it is also possible to construct an asphalt pavement directly on sand. Asphalt paved temporary roads are more expensive than unpaved roads but can handle more and heavier traffic and are easy to re-use in the permanent road and are much more weather resistant than unpaved roads, thus requiring less maintenance and better availability.

There are many different types of asphalt mixtures available. Not all of them are suited as temporary road pavement. The best choice according to VBW-Asphalt (2000) is the crushed-stone asphalt concrete mixture. Especially the 0/22 mixture, with large crushed-rocks is well suited on a temporary road. The minimum layer thickness, based on the grain size, is 5 centimetre on a foundation layer and 6 centimetre when applied directly on sand. This mixture can be applied in relatively thick layers, which is required when constructed on sand. When the temporary road is re-used as permanent road, the close-textured asphalt concrete mixture is the best choice.

To make asphalt pavement calculations, the computer model CARE can be used, which stands for 'Computer Applications for Road Engineering', and is developed by the Highway and Hydraulic Engineering Department of the Ministry of Transport, Public Works and Water Management (RWS 1998, 2006). The pavement design module of CARE can be used for the structural design of new asphalt pavements, constructed in one or two phases (this can be seen as temporary and permanent pavement). Calculations can be made in two different ways after the preconditions and traffic load are provided. The first method is to only specify the sub-grade and, if present, the foundation and let CARE calculate the asphalt layer thickness. This only works with asphalt layers thicker then 8,5 centimetre. Most temporary roads do not require such thick asphalt layers, thus this option cannot always be used to calculate the asphalt layer thickness. The second method is to guess a road design and let CARE calculates the roads' lifespan. This can then be compared to the required lifespan of the road. By adjusting the foundation of asphalt layer thickness the desired lifetime can be found in an iterative process.

To calculate the estimated lifespan it is first necessary to define when a road is at the end of its lifetime. In CARE this is done with the structural damage factor. This factor can be explained as the maximum allowed crack-initiation (damage) to the road. This is the length of crack initiation occurring on the road as a percentage of the total length. The bureau of Public Works and Water Management utilises 15% crack initiation as design criteria the roads' life span (RWS, 2006). With only 15% structural damage, it is possible to 'regenerate' the road with an extra asphalt layer to extent the roads' lifetime. When resident traffic can be expected on the temporary road it is not recommended to use more than 50% structural damage. When the road is purely used as road for construction traffic, this factor can be increased to 80 or 90%. The increase in lifetime by allowing more structural damage is shown in Figure 17.

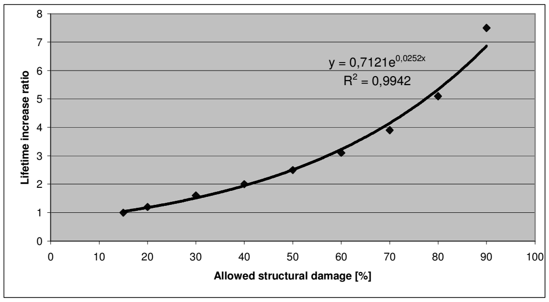

Figure 17: ratio of lifetime increase at different structural damage percentages (calculated using CARE).

Prefabricated concrete plate pavement

Prefabricated concrete plates are easy to install and to remove, can resist heavy traffic, require hardly any maintenance and can be re-used multiple times. A commonly used size for a prefabricated concrete plate used in temporary roads is 2 by 2 meters, and they are available in different thickness. Prefabricated plates are available with or without steel edging for extra strength. However, if the steel edging is broken it can cause flat tires. It is recommended to chose plates that can handle heavy axle loads up to 200 kN without steel edging because sometimes trucks are over-loaded on construction sites. Prefabricated concrete plates are installed using a lift truck with a seam of 5 mm. After placing, the seam has to be filled with sand. In the Netherlands the most famous type of prefabricated plates is Stelcon, created by De Meteoor B.V.

According to the specifications of Meteoor, Stelcon plates are installed on a 10 cm thick bedding sand layer (specified according to the RAW (2005) standard conditions). The embankment layer has to be well compacted to a depth of 1 meter with a minimum proctor-value of 98%. The crest constant of the embankment layer has to be at least 0,06 N/mm3 (= CBR15 ≈ 150 MPa). This value corresponds with an unbound foundation material.

However an unbound foundation layer is almost impervious, which will cause water accumulation in the embankment layer. This will cause damage to the road because of 'pumping' under the plates. A better solution, which is mostly used when concrete plates are used as or in temporary roads, is a sand embankment. This is possible because calculations by Meteoor assumed a long design lifetime, while the lifetime of a temporary road is much shorter. The sand layer thickness has to be substantial, in order to have the characteristics of a sand sub-grade. On places with a high ground water table extra drainage might be required.

Prefabricated concrete plates are not only applicable as pavement but also as protection for lead-up services or as reinforcement in unpaved roads. Lead-up services under prefabricated concrete plates are easily accessible. Unpaved roads cannot handle torsion forces applied by the wheels of the trucks in corners and connections to existing infrastructure. This will quickly lead to damage on the unpaved road surface. Prefabricated concrete plates can handle these forces very well. Applying these plates in corners and on connections to existing infrastructure can increase the lifespan of the unpaved roads. This can result in a temporary road partly paved with concrete plates and partly with another pavement material or unpaved. This is applied on Floriande and Duyfrak. Finally, prefabricated concrete plates can also be used to widen a small existing road.

Geosynthetic materials

A road construction is only stable when the maximum load capacity of the sub-grade is not reached. Good load spreading in the road is necessary to prevent the road from showing displacements or other forms of damage. On weak soils this often results in extra thick foundations and/or embankment layers. Geotextiles are permeable fabrics, which have the ability to separate, filter, reinforce, protect, or drain and can be used to improve the road characteristics. Research performed by C.R.O.W. (2002) on the application of geosynthetic materials is currently applied in road design in the Netherlands. If a geosynthetic material can be applied, the effects can be expressed in the Foundation Reduction Factor. There are three requirements set for the foundation reduction factor:

1) The maximum value of the foundation reduction factor is 0,5.
2) The maximum foundation reduction is 150 mm
3) The layer thickness of the reinforced foundation is al least 150 mm.

Figure 18 can be used to select the geosynthetic material and determine the foundation reduction factor. When the roads' foundation is multiplied with the foundation reduction factor and all three above described requirements are met, the new foundation thickness for the temporary road can be determined. More information about geotextiles can be found in C.R.O.W. (2002). There are also design programs available to design a road with geotextile.

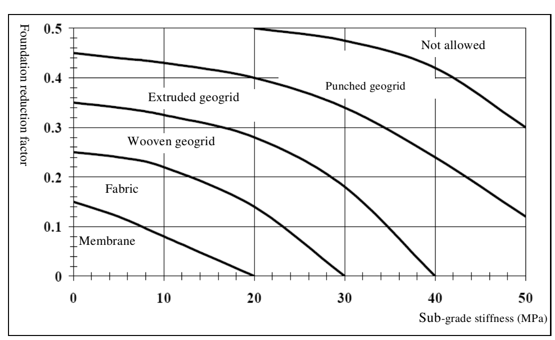

Figure 18: foundation reduction factor (C.R.O.W. 2002).

The costs for geotextiles can be estimated at €1,50 per m^2. This corresponds with a mixed granule layer with a thickness of 135 mm. This is within the set limit for the maximum reduction of 120 mm. Therefore it can be cost neutral to construct a geosynthetic layer under the foundation layer. Applying geosynthetic layer can also result in better maintainability and thus in higher availability of the road. However, geotextiles are also used to increase a road drainage capacity therefore it has additional positive effects.

Step 7: Permanent road design

There is a preference for constructing temporary roads on the same path as the permanent road. An integral approach for temporary and permanent roads can lead to a significant increase in the quality of the temporary road and a reduction in project costs. There are some additional design requirements present when a temporary road is upgraded to a permanent road. The most obvious one is that the temporary road dimensions and routes should be the same. Besides this aspect there, are three other aspects. Firstly, it has to be structural possible to combine the permanent road with the temporary road. Secondly, it should be checked that the drainage criterion (step 5) for the utilisation phase is met. Thirdly, the frost penetration criterion has to be met. Figure 19 provides the flow-chart for step 7.

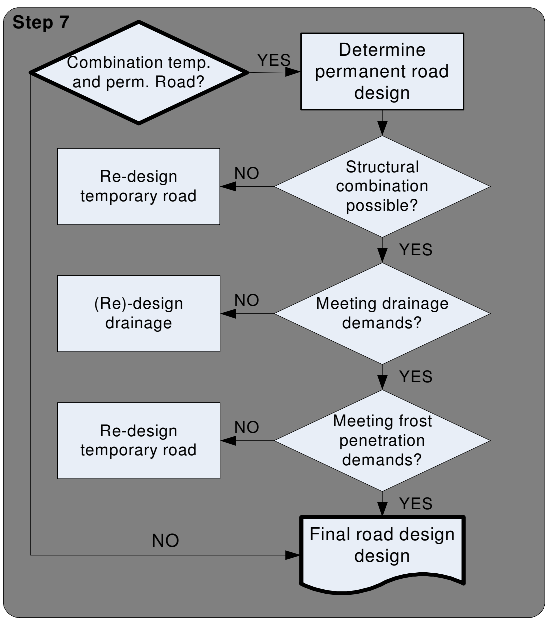

Figure 19: flow-chart step 7.

The frost penetration depth is the second design aspect necessary to properly design the permanent road. Several climate zones can be distinguished in the Netherlands, each having a specific frost penetration depth. Historical research by C.R.O.W. (2002) shows that the Netherlands can be split in three zones as shown in Table 14. The probability of occurring is once every 10 years. This is in accordance with lower class roads (residential roads) where slight damage to the road is not critical.

Table 14: frost penetration depth (C.R.O.W. 2002).

Zone	1x per 10 years
Coast	0,5
South and west	0,5 – 0,6
Middle and north-east	0,6 – 0,7

Now the minimum drainage head required preventing frost damage can be calculated with the following formula:

$$z_{pav} - z_{gwt} > h_{fpd} + h_c \qquad (8)$$

In which:
z_{pav} = Pavement height compared to NAP [m]
z_{gwt} = Ground water table compared to NAP [m]
h_{fpd} = Frost penetration depth [m]
h_c = Capillary rise [m] (Table 15)

Table 15: capillary rise height (C.R.O.W. 2006).

Soil type	Average grain size [d50, μm]	Capillary rise height [m]
Sand	600-2000	0,03-0,1
	100-600	0,1-0,3
	60-100	0,3-1,0
Silt	20-60	1-3
	6-20	3-10
	2-6	>10
Clay	<2	>>10

6. Case study

In this case study the project Duyfrak is analysed.

Step 1: The following preconditions were present:

- Residential traffic can be expected on all roads.
- Small elements are chosen as permanent pavement.
- Permanent road have to have high permeability.
- Lead-up services are installed before construction starts.
- Estimated construction time: 2 years.

Step 2: The temporary roads were classified into the three categories as shown in Figure 20.

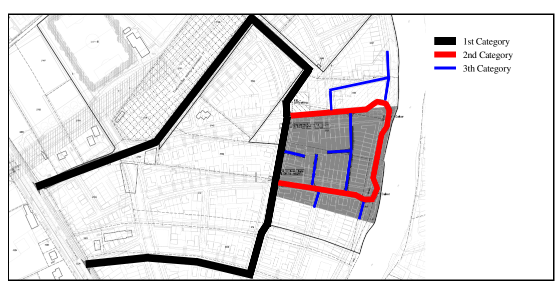

Figure 20: temporary road categories on Duyfrak.

Step 3: The leading traffic load (N) on the third category road is estimated to be 1.900. The load on the second category road is estimated to be 7.900. Using interpolation (currently no information is available about zone 2 to 6) the load on the first category road is estimated to be 61.500.

Step 4: The standard ground profiles were used to quickly determine some important sub-grade characteristics necessary to make road design calculations. The sub-grade selected was profile 3A. The location was heightened with 0,7 metre sand to make Duyfrak construction ready. No settlement acceleration measures were necessary.

Step 5: The top layer on Duyfrak is sand. Still, drainage is required due to the high ground water table and the possibility of a high fake water level during heavy showers. Calculations show that the drain distance is 35 m. Drainage under the roads is sufficient to drain the construction site.

Step 6: The best design for the third category roads is still asphalt on sand (Figure 21). The asphalt layer can be reduced from 80 to 70 millimetre. Calculations for the second category roads showed that the current road design might be insufficient to sustain the construction activities. The new design is shown in Figure 22. The plans for the first category road are unchanged. The construction costs were also analysed. This resulted in a slight reduction of about €1.000,- (-1,2%) in construction costs for zone one. This is inclusive the new, more expensive road design for the second category road.

Figure 21: design third category road.

	Depth* [m]	Description.
	0,00 – 0,07	Asphalt
	0,07 - 0,93	Sand (E=100 MPa)
	0,93 - …	Natural sub-grade: weak-clay (E=20 MPa)
* Below ground level [m]		

Figure 22: design second category road.

	Depth* [m]	Description.
	0,00 – 0,05	Asphalt
	0,05 – 0,25	Mixed granule
	0,25 - 0,93	Sand (E=100 MPa)
	0,93 - …	Natural sub-grade: weak-clay (E=20 MPa)

Step 7: Based on the preconditions and C.R.O.W. (2006) the permanent road design is estimated to small elements on 0,20 metre mixed granule on 0,50 metre sand. Thus it is structurally possible to combine the temporary and permanent road designs. The foundation layer in the second category road has to be removed before the permanent pavement can be constructed. The estimated frost penetration demand is met: 0,5 (coast zone) + 0,2 (capillary rise) = 0,7 metre < 0,93 metre (sand layer thickness). In step 5 it is determined that the drains under the road in combination with the sand layer are sufficient. Thus the demands to combine the temporary road with the permanent road are met.

7. Conclusion

Temporary roads are characteristic on construction sites in the Netherlands. This study provides a good start in the development of a temporary road design model. Important results of this study are the model to estimate the traffic load based on the projects characteristics, the combined pavement design methods and the suggested flow-chart for the final design model. However further research is recommended. Therefore some suggestions are included in section 7.

8. Future research

The following is recommended for future research.

- *Standard sub-grade characteristics.* During the performed research, significant doubts about the correctness of the corresponding parameters raise. Therefore it is recommend to further investigate these standard sub-grade profiles and to improve their characteristics.
- Several companies are developing *artificial textiles with flexible fibreglass tissues*, which can detect moister and damage/deformation by monitoring changes in spectrums. This type of system could easily be installed under temporary roads and could stay a long time for monitoring changes due to traffic intensity on temporary roads.
- The developed *traffic load model* on temporary roads can be verified using traffic counters and classification equipment. The results can then be compared to the results of the developed model. This way the model can be further calibrated and improved for better traffic intensity estimations. Eventually, the model can also be extended to non-residential construction sites.
- Besides the pavement types studied in this research there are other, *innovative pavements* in development. A good example for this is the use of lime to stabilise the natural sub-grade. The application of steel and rubber plates as temporary road was also not investigated.
- The project *Duyfrak in Valkenburg* was used as case study. At the time this article was written, the project was made construction ready and the temporary roads were constructed. From this case study the conclusion was drawn thatthat not all roads were designed strong enough. Therefore it would be interesting to see the condition of the temporary roads after construction is finished. This can also be used to validate the model.

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PREFACE

Hereby I present my graduation thesis on the subject 'temporary roads on residential construction sites'. This thesis provides a background report to my paper, submitted to the "Advances in Civil Engineering 2008, 8th edition" (ACE 2008) congress at the Eastern Mediterranean University on Cyprus. In this report you can find a more detailed description of my activities of the past 8 months.

During the research period I received help from many persons. It is not possible to name all of them here. Especially, I would like to thank the following persons for their contributions and support:

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This study is about temporary roads on residential construction sites in the Netherlands but the results can be used in other construction fields and countries. I hope that this study provides a good start in the development of a temporary road design model in the renewed guidelines for the construction ready stage.

Sido Harms

Deventer, June 2007

ABSTRACT

In 2006 the number of newly constructed houses in the Netherlands raise about 8 percent to 72.000, with 96.000 building permits issued [W4] in that year. This increasing number comes along with a demand for larger buildings and more complex construction projects. To construct those buildings increasingly heavier machinery and transport vehicles are used. Heavy machinery needs high quality temporary roads for transport to and around construction sites. In many parts of the Netherlands, the ground can not coop with heavy vehicles due to low bearing capacity.

In this study we will investigate current practice of temporary road construction in the Netherlands. Currently available know-how and pavement design methods are investigated and integrated into a design model for temporary roads at residential construction sites. Temporary roads are mainly designed on the basis of local experience and general pavement engineering, however, there is no design method available for temporary roads that is suitable for current conditions in residential sites.

Construction and maintenance costs of temporary roads are indirect costs in a construction project. Thus, after certain pre-conditions are met, the pavement with the lowest construction costs and the lowest 'upgrade' costs from a temporary road to a permanent road is chosen from the different types of pavements. There is a preference for constructing temporary roads on the same path as the permanent road. An integral approach for temporary and permanent roads can lead to a significant increase in the quality of the temporary road and a reduction in project costs. There are three key differences between temporary and permanent roads. Firstly, the weight of the vehicles on the temporary road during the construction process is much higher than during the utilisation phase. Secondly, the traffic volume on a temporary road is higher than on the permanent road. Thirdly, the temporary road's lifespan is much shorter then the permanent road. These differences affect the final design of the pavement and sub-grade layers thickness and properties.

Road design requires estimates of the expected traffic loads and the foundation soil conditions at a site. Data on moving loads for modern temporary roads in residential sites is scarce or absent. Therefore we developed a model to estimate the traffic load on residential construction sites as a function of the project characteristics. For the description of the foundation soil characteristics we adapt the 11 standard soil profiles, typical for various parts of the Netherlands. These profiles are used for pavement selection and design in C.R.O.W. (2006).

The newly developed model is applied as case study to the project Duyfrak in the city Valkenburg (the Netherlands), which is currently made construction ready. The results are analysed and compared to the design of the constructed temporary roads. The model is easy to use and predicts that some of the temporary roads on Duyfrak are designed to weak.

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1. INTRODUCTION

In 2006 the number of newly constructed houses raise with 8 percent to 72.000 houses and totally 96.000 building permits were issued (CBS-statline, 2007). Figure 1 shows the historical trend of constructions permits over the last twelve years. In the building estimates from to the Ministry of Housing, Spatial Planning and the Environment till 2011, it is estimated that the number of construction permits can rise up to 100.000 permits a year. The number of newly constructed houses is increasing again since the historical low in 2003 (59.600). In the building estimates from to the Ministry of Housing, Spatial Planning and the Environment until 2011, it is estimated that the number of construction permits could rise to 100.000 permits per year. There are almost six times more residential construction permits issued per year than non-residential construction permits in 2006.

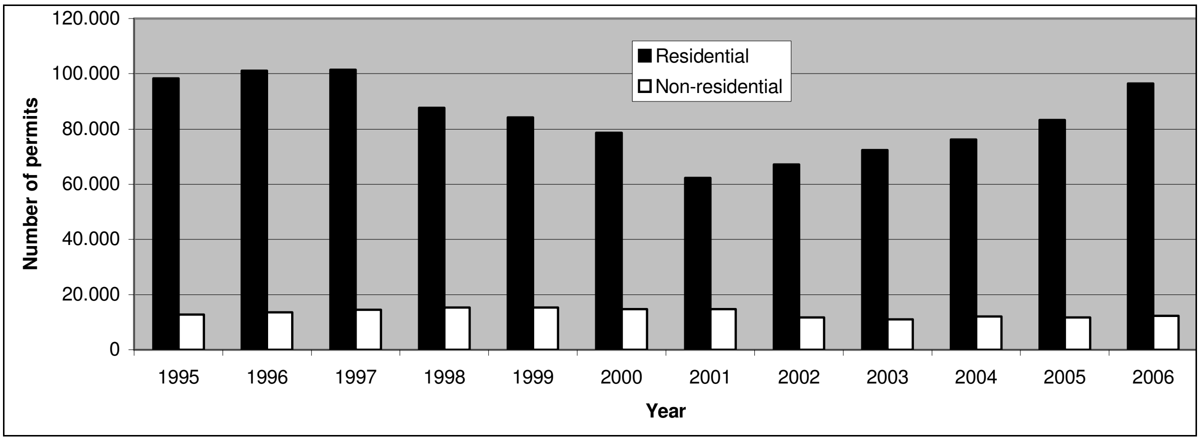


Figure 1: Historical trend of construction permits (CBS-Statline [W4])

During the past decades construction projects are becoming more complex, bigger and higher. Increasingly heavier machinery and transport vehicles are used to build these projects. This heavy machinery needs to be able to reach the construction site and move on it. However, in large parts of the Netherlands the subgrade has not enough stability and bearing capacity to support the construction activities. Locations with better sub-grade are, especially in the western parts of the Netherlands, already constructed. Therefore construction sites are made construction ready first. This process includes the construction of temporary roads to make the sites better accessible for construction traffic. In this research, the design and construction of the temporary roads on residential construction sites is investigated. The following definition is used for a temporary road on a construction site:

- A paved or unpaved strip of land;
- on which transportation is possible;
- providing access to and/or on a construction site;
- during a limited amount of time.

Temporary roads on construction sites are characteristic for construction sites in the Netherlands. Five main reasons can be named for this. Firstly, the Netherlands has one of the highest construction densities in the world, leading to more traffic load on the roads creating the need for temporary roads. Secondly, in many countries no distinction is made between the utilisation and construction stage. In this case the permanent road serves also as temporary road. Thirdly, a small element pavement is often the preferred permanent pavement in the Netherlands where asphalt is the preferred pavement in many other countries. Small element pavements are not suited for temporary roads. Fourthly, the public roads in the Netherlands are relatively small in the utilisation phase of the project (sometimes only 4,5 metre while at least 5,5 metre is required), creating the need for wider temporary roads. Finally, buildings in the Netherlands are constructed using more heavy construction materials (i.e. concrete) then other countries (i.e. wood in Sweden), leading to heavier loads.

There are three key differences between temporary and public roads in the Netherlands. Firstly, the weight of the vehicles during the construction process is much higher during construction than during the utilisation phase. Secondly, the traffic volume on a temporary road is lower then on the permanent road. Thirdly, the temporary road's lifespan is much shorter then the permanent road. These main differences are summarised in **Error! Reference source not found.**. These three aspects are also key design aspects in road designs.

Table 1: key differences between temporary roads and roads in the final state in residential area's.

Aspect	Temporary road	Public road
Vehicle weight	High	Low
Traffic intensity	Low	High
Lifespan	Short	Long

There is a preference for constructing temporary roads on the same route as the permanent roads. Therefore an integral approach for the temporary and the permanent road can lead to an increase in quality and a reduction in project costs. Currently, temporary roads are mainly designed on experience because there is no design method available to estimate the traffic load on temporary roads. This can result in over- or under dimensioned roads leading to unnecessary project costs or bad conditions on construction sites.

A special point of attention is water management on the construction site. If not enough attention is paid to water management, significant waterlogging on the construction site can occur. The combination of low permeability soils and inadequate drainage system is the main cause for waterlogging on construction sites in the Netherlands. The height of the temporary roads surface level in comparison to the ground level can also cause waterlogging problems. Temporary roads above ground level with low permeability embankments or with bad drainage systems can start acting as dikes which can lead to waterlogging on the whole construction site. Roads that are constructed under the ground level can start acting as waterways. Soaked roads have a strongly reduced bear capacity, which will shorten the roads lifespan. Biron (2004) also underlines the importance of water management in his research.

This paper provides a first exploration into a design method for temporary roads. It fits in the renewal of aged guidelines for the construction ready phase written by Segeren (1984). This research (Web page: http://www.bouwrijp.nl) is called "Beter Bouw en Woonrijp" in which many large actors active in the construction ready stage in the Netherlands (like Geodelft, Grontmij, SBR, Sterk-consulting, TU-Delft and Witteveen+Bos) combine their knowledge and resources.

Figure 2: examples of temporary roads.

1.1. Research objectives

The framework for this research is very extensive and allows many possibilities for research. However there is only a limited amount of time available to perform this research. To limit the research we will only concentrate on certain fields. The first step to limit the research field is to formulate the central objectives for this research. There are two main objectives for this research. The goal of this fist objective is to gain insight how actors currently deal with temporary roads on residential construction sites.

> To analyse the way temporary roads are currently designed, operated and maintained by performing case studies.

The second objective is about the development of the design model and has been divided into three parts to make it more readable. The second objective is formulated as follows:

- ♦ To develop a design methodology for selecting the best temporary road type depending on the projects characteristics, expected traffic load and the sub-grade present;
- ♦ by listing and classification of possible temporary road types and their corresponding characteristics and analysing the possibilities for combination with the permanent pavement;
- ♦ by taking the influence of a high and variable ground water table on the project location into consideration.

The result of this research will be implemented on a case study. By comparing the results of the current situation with the results of this research, insight can be gained about the functionality of developed design methodology.

1.2. Delimitation

The following delimitation is used for this research.

1) The design method is only valid for the Dutch situation.
2) The eleven standard profiles for the Dutch sub-grade will be used.
3) No juridical aspects will be included in this research.
4) Only currently available design methods are used for road design.

2. TEMPORARY ROADS IN THE NETHERLANDS

In this chapter the current situation of temporary roads in the Netherlands is presented. To gain insight into the current application of temporary roads, two sources are used. Firstly, the research performed by Biron (2004) about how land is made construction ready in the Netherlands is utilised. This research also discusses temporary roads on construction sites since this usually is the phase in witch temporary roads are being constructed. Information about eleven construction projects is used in this research. The most important results of this research regarding temporary roads are discussed in section 2.1.

To gain insight in temporary roads on construction sites, several construction projects were visited and analysed. In section 2.2 the project “Amsterdam – IJburg” is discussed, in section 2.3 “Hoofddorp – Floriande” and in section 2.4 “Valkenburg – Duyfrak”. A summary of this chapter is provided in section 2.5.

Amsterdam – IJburg

Hoofddorp – Floriande

Valkenburg – Duyfrak

Figure 3: examples of temporary roads on construction sites.

2.1. Biron's Research

Every year many construction projects are realised in the Netherlands. Making the new sites ready for construction is the first stage in the execution. Only little research is performed on this subject. The most recent publication on this topic dates back to 1984 (Segeren and Hengeveld). However there is allot, undocumented, of experience on this topic available by parties active on this field. In 2004, David Biron graduated on his thesis about the current situation of the construction- and delivery-ready stage in the Netherlands. According to Biron is the construction ready stage a combination of multiple specialisms. This is the main cause that the construction ready stage is largely undocumented. He detailed examined all aspects from the construction ready stage of eleven construction projects and compared them to a previous study from 25 years ago.

The definition of construction ready, according to Biron (2004) is "the preparation of the construction site so that construction activities can take place". Many activities take place during the construction ready stage, however the performed activities differ much between separate projects and locations in the Netherlands. The construction of temporary roads is also done in this stage of the project, making it interesting to take a closer look at this stage. Section 2.1.1 gives the headlines of Biron's research on this topic. How temporary roads fit in the construction ready phase and what problems occur, discussed in section 2.1.2.

2.1.1. Construction ready phase

Important parties involved in the construction ready phase are the local government, water boards and project developers. Traditionally the local government develops the structural plan of the project in consultation with the water board, who develops the water management plan. The local government is responsible for execution the construction ready phase and the water management plan. Next, the project developer buys the land and hirer's contractors to construct the project.

Three main methods can be distinguished to make a site construction ready: embankment method, integral heightening and a combination of both (see Figure 4). Which method is applied is mainly determined by the condition of the sub-grade, the groundwater table and the location in the Netherlands. These two aspects are called the soil condition and determine the accessibility of the location, the occurring settlement and the water permeability. The ground water table is important to prevent water logging on the construction site and to create a high quality environment after construction is finished. Controlling the groundwater table during and after construction is therefore essential for the success of the project.

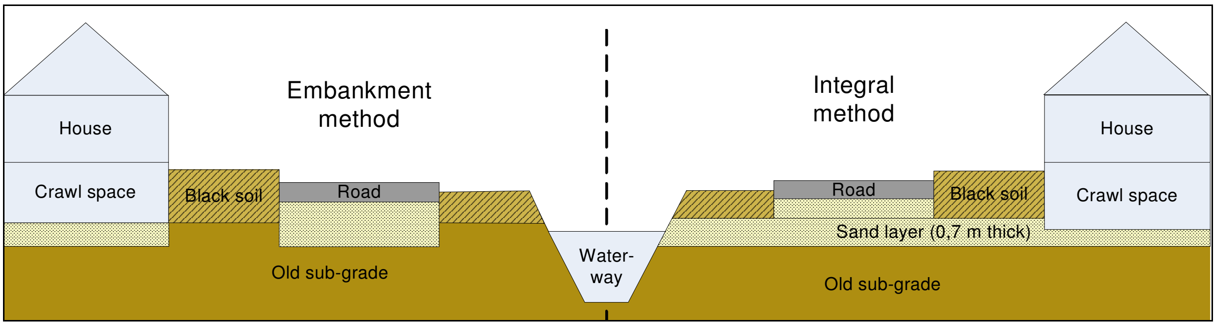


Figure 4: construction ready stage: embankment method (left) and integral heightening (right).

The first method of preparing the construction site is the embankment method. With this method an extra sand layer is placed on the construction site. This measure can be taken to improve the soil condition and thus the accessibility and bearing capacity. The minimal thickness for this layer is 0,7 meter. To meet the required drainage head, using drainage pipes is necessary using this method. The second method of preparing the construction site is the integral heightening method. With this method an extra sand layer is placed under the roads and under the buildings. The gardens and public spaces are raised using the soil from under the roads and building or is transported from outside the construction site. A combination between these methods results in the third method. In this method the construction site is heightened except for the public spaces and waterways. This way certain elements present on the construction site can be conserved unlike with the integral heightening method. The integral method is compared to the embankment method in Table 2.

Table 2: integral method compared to the embankment method.

Aspect	Embankment method	Integral method
Load bearing capacity	0	+
Possibility to chance spatial plan during construction	0	+
Construction speed	0	+
Remaining settlements ground level	0	-
Construction ready phase costs	0	-
Indirect costs (lower productivity, extra services, etc.)	0	+
Adaptation of existing elements	0	-
Water management provisions	0	-
Environment	0	-

The best method for making a project construction ready can be selected using weighting factors for each aspect of Table 2. The actual choice however is usually based on the direct costs. The integral method is more expensive then the embankment method in the construction ready phase, but if take the total life cycle of the project into consideration, then the integral method is cheaper (SBR, 1987). According to Biron (2004) this is usually not taken into consideration at selecting the best method.

The most prominent problem on construction sites today is water logging. Many elements of a construction site or residential area require a certain drainage head. Examples for this are: the temporary and permanent roads, crawl spaces, parks and some of lead-up services. Damage to these elements can occur and the overall quality of the new area will be lower if requirements are not met, leading to extra costs. Biron distinguishes ten main reasons for water logging on the construction site and thus also on or near the temporary roads.

1) Often drainage systems are constructed bases on experience and no project-specific plan for the drainage system is formulated
2) Design criteria and requirements concerning water-management on the construction site are inadequate or not specified for the construction phase.
3) If a design is made, on many occasions hydrolic processes like rain and seepage are insufficient taken into account.
4) Drainage tubes are not adjusted to the soil present on the construction site and the quality is sometimes insufficient
5) The influence of the project phasing (for example the excavation of waterways on the construction order) on the drainage head is not taken into account.
6) During project preparation sometimes agreements about the water level are made. However these are not always applied when construction commences, leading different levels then where the calculations are made with.
7) The influence of construction activities on the soils' permeability is not taken into account. Calculations are made with 'theoretical' values for permeability.

8) No attention is paid to water that is not able to infiltrate into the ground. Usually measures that prevent this are not set up until construction is finished.
9) Maintenance to drainage systems is insufficient during the construction phase, leading to an inadequate drainage system.
10) The quality of the temporary roads is insufficient and the ground level deteriorates the situation. The temporary road starts to act as a dike of as waterway, both leading to water logging.

There are currently no quality demands for the construction ready stage, leading different interpretations of the end result leading to uncertainty in quality of the construction site. Problems can occur with the start of the construction stage because the involved parties may have different expectations about what construction ready is. The way new construction site are prepared for construction, has a big influence on the final quality of the construction site and of the living space after construction is finished. Currently, research is performed to formulate guidelines[1] for the construction ready stage. This research focuses on the temporary roads, therefore now information about temporary roads in Biron's research is discussed in subsection 2.1.2.

2.1.2. Temporary roads

Temporary roads are part of the construction ready stage en therefore included in Biron's research. According to his research, a clear distinction between the construction stage and the delivery stage is noticeable unlike in the past, this is clarified in Table 3. It is clearly visible that in 2003 no permanent pavements are constructed before construction work is finished, unlike 1977 where 42% of the pavement is permanent. All roads used for construction are now temporary. It is also visible that the main distribution network of service companies mainly is installed in the construction ready phase. This makes it important to look at the influence of the lead-up services on the temporary roads, since they are laid under or next to the temporary roads.

Table 3: comparison between 2003 and 1977 (Biron, 2004)

What:	Yes		No		Unknown	
	2003	1977	2003	1977	2003	1997
Permanent pavement in construction ready phase	0%	42%	100%	58%	0%	0%
Lead-up services in construction ready phase	91%	82%	9%	18%	0%	0%
Gully's, etc, in construction ready phase	18%	*	73%	*	9%	100%
Temporary roads in construction ready phase	100%	84%	0%	16%	0%	0%
* Not researched						

Many different kind of temporary roads are used in the researched projects. It is also interesting to look at the kind of permanent roads that are used after construction is finished. Table 4 provides an overview of the design of the temporary road and the permanent road used on the projects. 10 of the 11 projects have a small element pavement, only one will have an asphalt pavement after construction is finished. It is interesting to see that on most projects a brick pavement was installed on top of the temporary road. On three projects the top layer (granule and/or asphalt) of the temporary road was removed before the permanent pavement was constructed.

[1] http://www.bouwrijp.nl/

Table 4: overview of temporary roads on the researched project by Biron (2004)

Nr.	Project	Construction temporary and permanent roads by:	Location temporary roads	Design temporary roads	Design permanent roads
1	Almere: Tussen de Vaarten	Municipality	Same as permanent roads	250 mm concrete granule sand	*Removing granule* Paving bricks 50mm bedding sand Sand
2	Amsterdam: De Akker	Municipality	Same as permanent roads	250 mm mixed granule sand	Paving bricks 50mm bedding sand Temporary road
3	Haarlemmermeer: Floriande	Municipality	Same as permanent roads and cycle-ways	300 mm mixed granule 350 mm sand	Paving bricks 50mm bedding sand Temporary road
4	Zeewolde: Horsterveld	Municipality	Same as permanent roads	90 mm asphalt 250 mm mixed granule 250 mm sand	70 mm asphalt Temporary road
5	‘s Hertogenbosch: De Groote Wielen	Municipality	Same as permanent roads	250 mm mixed granule 500 mm sand	Unknown
6	Ede: Kernhem	Municipality	Same as permanent roads	200 mm concrete granule sand	Paving bricks 50mm bedding sand Sand
7	Roermond: Oolder Veste	Oolder Veste development company	Same as permanent roads	30 mm asphalt 250 mm mixed granule 400 mm sand	*Removing asphalt* Paving bricks 50mm bedding sand Temporary road
8	Dronten: West	Municipality	Same as permanent roads	Concrete bricks 500 mm sand	Re-paving the temporary road
9	Leidschenveen	Leidschenveen CV development company	Same as permanent roads	250 mm mixed granule 500 sand	Paving bricks 50mm bedding sand Temporary road
10	Houten	Municipality	Same as permanent roads	100 mm asphalt 700 mm sand	*Removing asphalt* Paving bricks 50mm bedding sand Sand
11	Schoonhoven: Thiendenland	Thiendenland V.O.F. development company	Same as permanent roads	250 mm mixed granule sand	Paving bricks 50mm bedding sand Temporary road

It is visible that 27% (3 out of 11) of the temporary roads have an asphalt pavement, 9% (1 out of 11) a concrete brick pavement and 64 have a mixed granule top layer. If this is compared to 1977 there are some clear differences. In 1977, bricks were the most important pavement type for temporary roads, nowadays these are hardly used for temporary roads. Asphalt pavements were not used and industrial plates were still occasionally used. The differences are summarised in Table 5.

Table 5: pavement comparison 2003 – 1997 (Biron, 2004)

Year	Asphalt	Bricks	Industrial plates	Granule
2003	27 %	9 %	0 %	64 %
1977	0 %	67 %	16 %	16 %

Generally speaking, asphalt led to a better situation on the construction site the other road types, because they are not very sensitive for water logging and need less maintenance. With mixed granule roads the water logging and the surface level of the road compared to the ground lever are important. If the road is to wet, trucks will destroy the roads' surface. Therefore, roads made of granule should be constructed above ground level. It is important to notice that due to rain and dust, per year a couple of centimetre of granule will disappear of the road surface.

Water logging on temporary roads is a frequently occurring problem on construction sites. The causes are the same as the water logging causes for construction sites: low permeability of the road and the surrounding ground and bad drainage. Temporary roads can also cause water logging due to a mismatched road-height and ground level or due to bad embankment quality. If the road is constructed to high and the embankment is of bad quality (low permeability) then it will start to act as a dike resulting in water logging on the construction site. If the road is constructed to low then the water will stay on the road and acts as a waterway resulting in water logging on the road. If the road is made of granule this will quickly destroy the road.

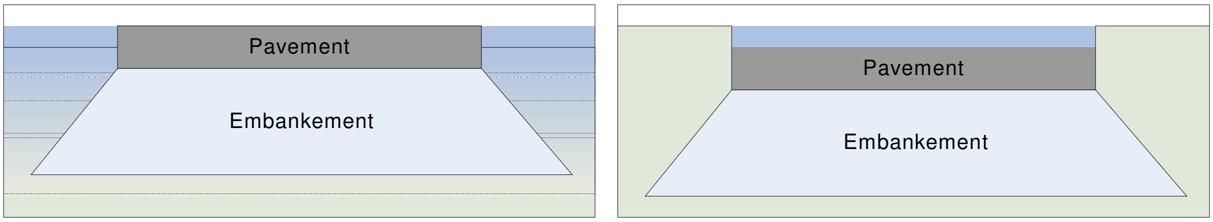


Figure 5: water logging caused by a temporary road.

The trend is to construct the temporary roads as cheap as possible because extra costs due to temporary roads are mostly uneconomic costs. This does have some negative side effects: bad performance, high maintenance costs, much water logging and dirty roads/material. Biron concludes that the lack of quality demands for construction temporary roads is the main reason for this problem. To improve the situation, Biron suggest developing minimum design requirements for temporary roads.

2.2. IJburg – Amsterdam

In this section the construction of the IJburg district in Amsterdam is analysed in detail. All details of this project concerning the temporary roads on IJburg are discussed in this section. First, a short introduction is provided.

Introduction

The first design for IJburg[2] as a city on Pampus Island in the IJmeer was made in 1965 by the architectural firm 'Van den Broek en Bakema'. However it never left the drawing table because the Bijlmermeer district and the nearby city's Almere, Zaanstad and Purmerend could easily accommodate the population growth of Amsterdam. In the eighties these locations in and around Amsterdam were no longer able to cope with the growing demand for accommodations. Thus, the government and the province of Noord-Holland reconsidered the building plans in the IJmeer. This location was particularly suited due to its close proximity to central Amsterdam and presence of good infrastructure nearby.

[2] http://www.ijburg.nl/

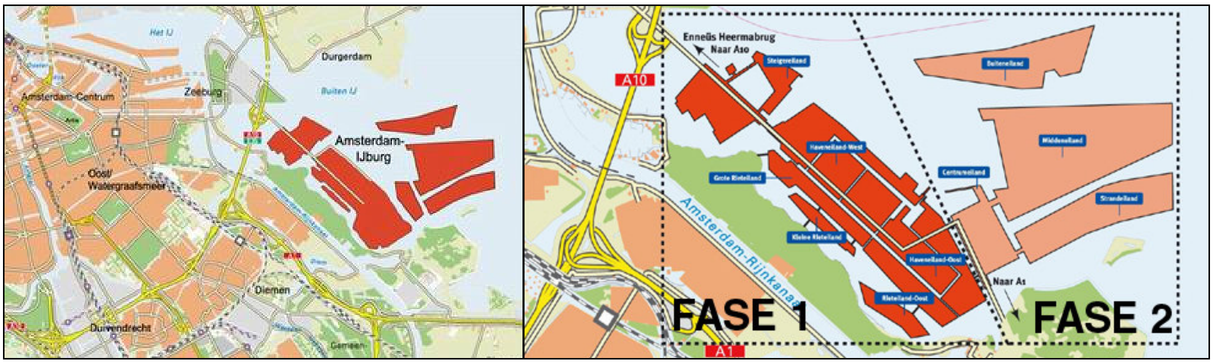


Figure 6: location IJburg Amsterdam

According to the Supplement to the Fourth Policy Document on Spatial Planning (VINEX), which was authorised by the government in 1990, new residential areas were to be concentrated near the large cities. This was implemented by the municipality of Amsterdam in their structure plan of 1991 which resulted in the elaboration obligation for the Amsterdam 'Nieuw-Oost' district. Later "Nieuw-Oost" was later renamed to IJburg. Figure 6 shows the location of IJburg and the two construction phases. IJburg consists of seven artificially created main islands: Steigereiland, Haveneiland, Rieteilanden, Centrumeiland, Middeneiland, Strandeiland and Buiteneiland. Every island has its own character and design. The IJburg Island's are multipurpose areas where living, working and recreation are combined. In total there will be around 18.000 new accommodations. Figure 7 gives an artist impression of IJburg when it is finished.

Figure 7: artist impressions of IJburg

The high demand for accommodations in Amsterdam and the limited available space on IJburg resulted in a high-density construction project with multiple storey buildings. Construction in cities is always complex, especially for voluminous, long-term, construction projects with many actors involved. To reduce nuisance for the surroundings during construction to an absolute minimum, s Witteveen+Bos developed an innovative construction logistics model and an elaborate consultation network, under commission of the Amsterdam municipality. Currently Phase 1 is being constructed (Steigereiland, Haveneiland and Rieteilanden) with a total of 9.000 residential, commercial and social areas.

Sub-grade

The IJburg district is being built on an artificially constructed sand island. The sub-grade present on this island is the thick sand layer used to create the island. Sand is well known for its good characteristics as a sub-grade on construction sites once it is compacted. This is done by vertical drainage and by putting an extra sand layer on top of the surface (extra weight). After compacting, the residual settlement will be well within the allowed limits.

Because of the sand sub-grade there will be no water logging on IJburg due to the good permeability. The highest ground water level on IJburg is calculated to be NAP +0,45 m. The ground level is at NAP + 1,0 m. Calculations showed that no extra drainage was necessary under the roads.

Construction process

During the construction of IJburg many developments caused a change in the predetermined construction planning. An important development was the decrease in economics during the construction of IJburg. This led to a changing demand for residential, commercial and recreational accommodations as construction companies follow the current market demand to construct certain types of buildings before others. The original planning was to start construction at the "IJburglaan" and construct from there outwards, but now the different blocks on the island are build according to market demands and thus not according to the planning. The mixture of different types of buildings on the spatial planning leads to a non-optimal construction order and, to non-optimal traffic routing and to problems with the planning of the service companies. For such large construction projects it is not possible to plan every detail of the construction ahead. There will always be unpredictable circumstances that may cause delays. Later this report, Figure 12 to Figure 15 shows the construction order on IJburg – Haveneiland.

An important stage during the construction period is the '13 weeks phase'. In this phase lead-up services are laid, the buildings are connected and the (provisional) definitive ground level is set up. After the activities of the 13 weeks phase are finished the buildings are delivered to their new owners.

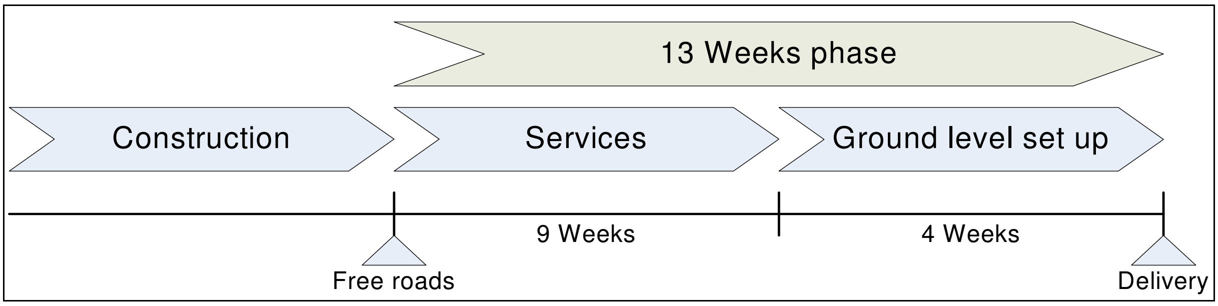


Figure 8: 13 week's phase in the construction proces.

Temporary roads

For IJburg a road-plan has been developed for different stages of the project. The three main stages in the project are: construction ready, construction and utilisation. Temporary roads are constructed in the construction ready and construction stage. For these two stages three different types of temporary roads can be distinguished on IJburg: main access roads, roads connecting the blocks to the access roads and roads on construction sites themselves. The main access roads and the roads to the blocks are under the supervision of the municipality of Amsterdam. The roads on the construction sites are under the supervision of the construction companies.

Figure 9: phasing temporary roads on IJburg East (Ingenieursbureau Amsterdam April 2005)

In the construction ready stage the islands are prepared for construction. The provisional temporary roads are constructed next to the route of definitive temporary roads. These roads enable the construction of the main sewer and district heating services network possible. These services are constructed under the route of the definitive temporary road (and therefore under the permanent road). The design of the temporary roads on IJburg is based on experience. The roads consists 35 cm mixed granule, six meters wide and is constructed on the sand sub-grade. The provisional temporary roads on Haveneiland East can be found in Figure 9.

After the sewer and district heating systems are constructed the definitive temporary roads are constructed to be used during the construction phase. These roads are also designed based on experience, exist out 35 cm mixed granule and are six meters wide. The choice for mixed granule was made for cost reasons. Mixed granule of the provisional temporary roads can be re-used for the definitive temporary roads. The municipality of Amsterdam tried to discourage the local population from using of the east access route to IJburg (see Figure 10). Dirty construction roads are not attractive to drive on. Another reason not to pave the temporary roads with asphalt is was that the service companies have to excavate trenches through the road when installing lead-up services. This is more expensive en time consuming in asphalt roads then in mixed granule roads. The definitive temporary roads on Haveneiland East can be found in Figure 9.

Figure 10: east access road to IJburg.

Two access roads to the construction area of IJburg were built. This was done to separate construction traffic as much as possible from residential traffic. Figure 10 shows the east access road to IJburg.

Permanent roads

As soon as the first buildings are delivered to their new inhabitants access roads in acceptable condition are required. These roads can be seen as public roads and therefore have to meet the requirements set for these roads. However it is still possible that construction traffic will also pass through the street. This might lead to unacceptable damage to the streets. Thus, the decision has been made to pave roads, where construction traffic is still likely to occur, with a provisional permanent pavement. The road is paved according to the permanent pavement but has to be repaved at the end of the construction period. Roads where no construction traffic is allowed anymore are directly paved with the permanent pavement layer. This choice is made to reduce the pavement costs as well as hindrance to other parties and to improve the quality of the road.

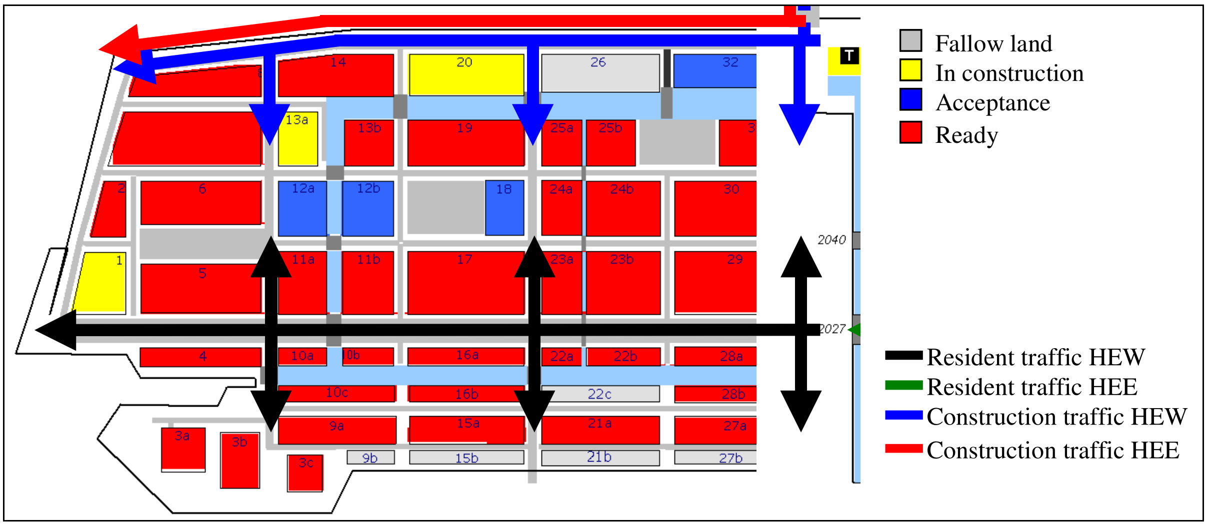


Figure 11: transport roads with provisional permanent pavement on Haveneiland West (01/2007 - 04/2008).

The pavement of the provisional permanent roads was made from concrete bricks and the permanent pavement from natural stones from China. Around 30 percent of the concrete bricks used on the provisional roads will be broken once the road needs to be repaved with the permanent, Chinese pavement. The bricks that are not broken can be reused on other places. As soon as the roads have been paved with the permanent pavement from China construction traffic is no longer allowed on these roads. Physical obstacles are put in place to prevent construction traffic on those roads. The main roads through IJburg, the IJburglaan (black line in Figure 11), the North and West Boulevard as well as the distribution roads have an asphalt pavement layer. This was done because these roads have a distribution function rather then a destination function.

Traffic routing

Not all buildings on IJburg will be ready at the same time as several construction companies are involved. To prevent construction traffic on roads with a permanent pavement a special traffic routing plan has been invented for IJburg. Figure 12 to Figure 15 show how the traffic routing on IJburg is planned during several stages of the construction work.

Legend for the next four figures (HEW = Haveneiland west, HEE = Haveneiland east):

Fallow land
In construction
Acceptance
Ready

Resident traffic HEW
Resident traffic HEE
Construction traffic HEW
Construction traffic HEE

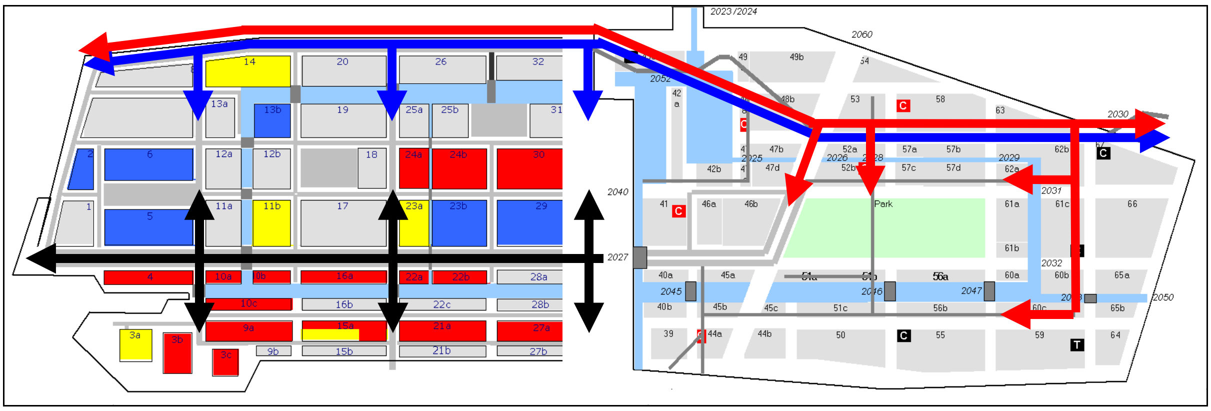


Figure 12: traffic on Haveneiland East and West till September 2005

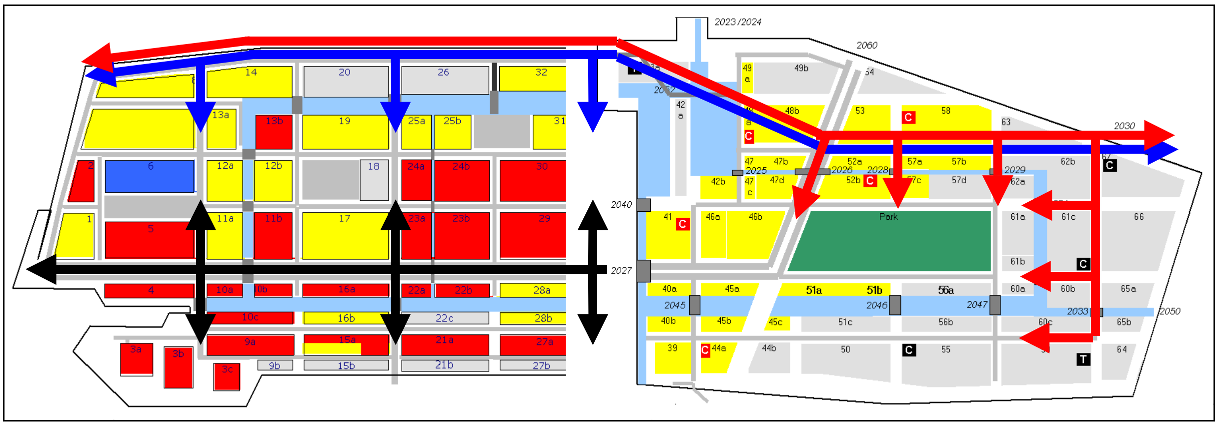


Figure 13: traffic on Haveneiland East and West September 2005 – January 2007

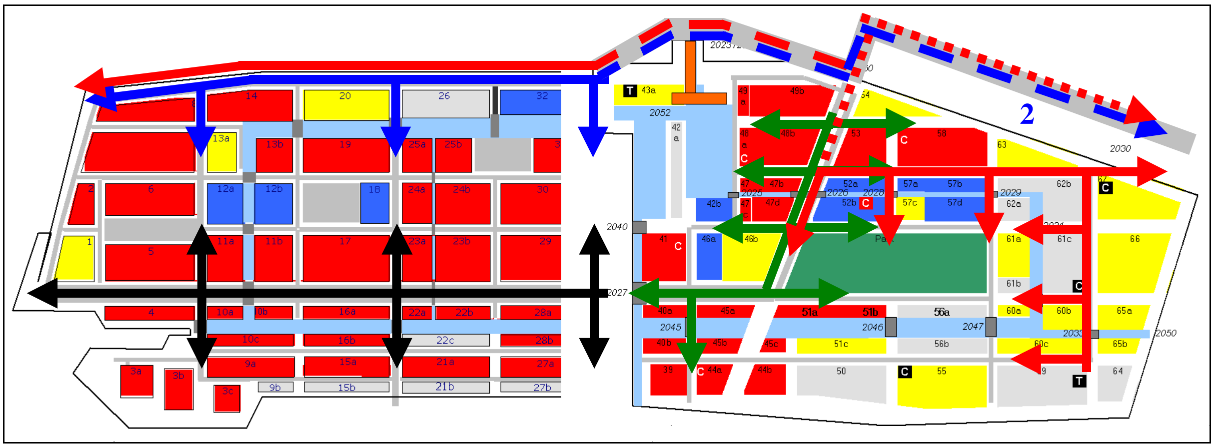


Figure 14: traffic on Haveneiland East and West January 2007 – April 2008

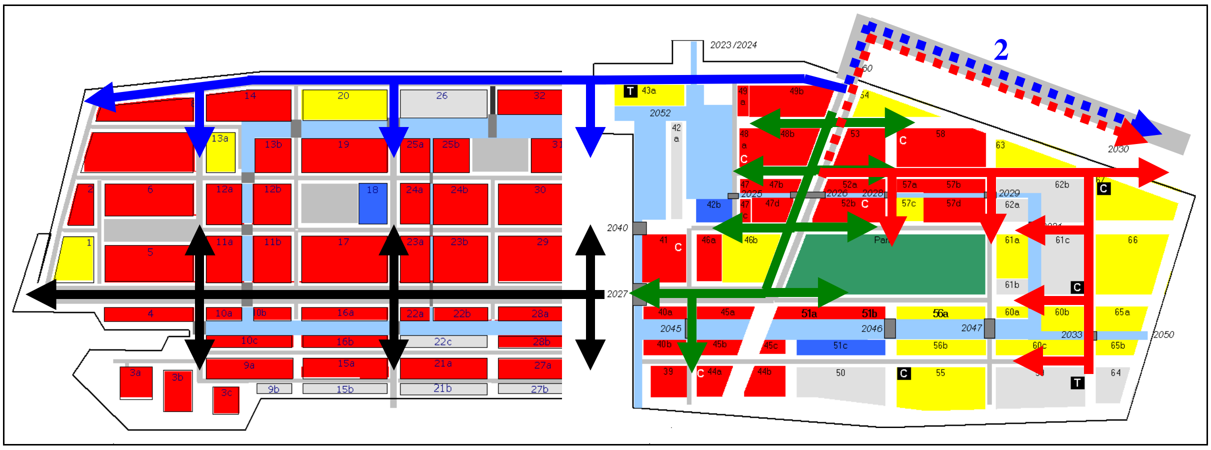


Figure 15: traffic on Haveneiland East and West after April 2008

The traffic routing plan for IJburg separates residential and construction traffic as much as possible. Construction traffic is routed via the entrance on Haveneiland East and the route in the north of the islands (blue and red lines) and residents will use the entrance on Haveneiland west and the route in the south of the islands (black and green lines). These roads are under the supervision of the municipality of Amsterdam.

In the first plan for IJburg, the construction companies had to construct all the temporary roads on IJburg. However due to changes in economics, in land use plans and due the unstructured construction order, the municipality of Amsterdam took the main road under their supervision to prevent chaos and irritations among construction companies. It is also the responsibility of the municipality of Amsterdam to ensure that the roads are available and in a good condition. The traffic routing on the different construction sites is the responsibility of the construction companies.

A signalling plan was made to guide trucks over the predetermined route to the diverse construction sites. Figure 16 shows the signalling plan for Haveneiland East and West.

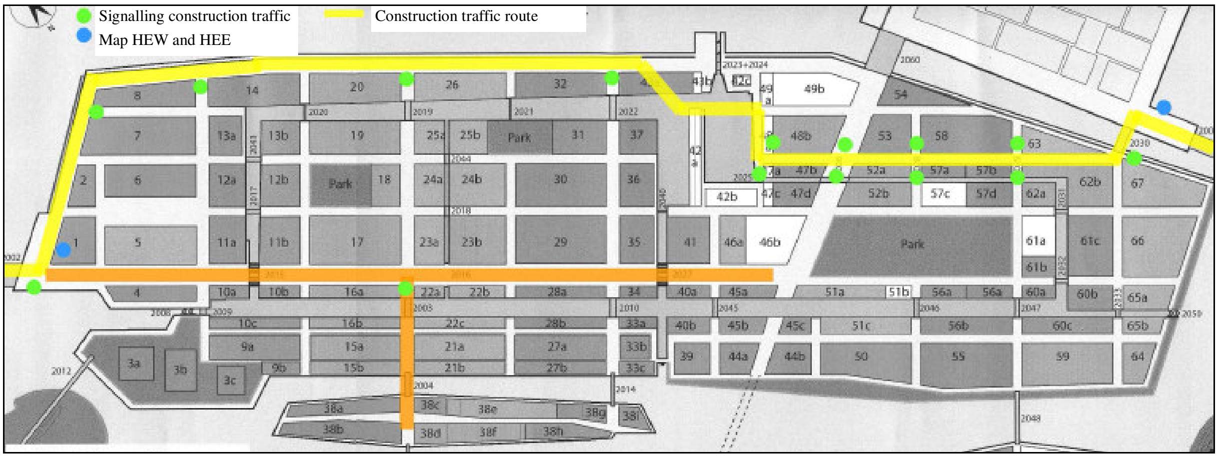


Figure 16: construction traffic signalling on Haveneiland West and East.

Parking spaces

The construction companies are responsible for providing parking spaces to their employees. In the original plans these parking spaces were situated on the construction site but due to the dense construction there was not enough space available. As parking on the roads would lead to unacceptable congestion, temporary parking spaces were assigned in consultation with the municipality of Amsterdam. Construction companies are also responsible for the creation of unloading and storage places for construction materials. In case this is not possible on the construction site itself, a road can be temporary closed for unloading in consultation with the municipality of Amsterdam.

Inhabitants

Construction companies want to deliver the new buildings as soon as possible to their new owners because disused buildings cost money. New residents also want to move into their new houses as soon as possible. Before the delivery of the new buildings a decent access route needs to be constructed. As discussed before, it is not possible to deliver all building simultaneously, therefore the choice was made to separate the residential traffic from the construction traffic as much as possible to reduce the nuisance for the inhabitants of IJburg. However, on some roads there still is some construction traffic present. These roads have a provisional temporary pavement during the time that construction traffic still passes over these roads. Since these roads are public roads now, they also have to meet the requirements set for public roads even when they are not yet permanent. When all construction is finished, these roads will be re-paved.

Lead-up services

IJburg is a high-density construction site with a high-diversity of buildings. Therefore it is almost impossible to lay all the lead-up services before the provisional permanent pavement or before the permanent pavement are laid. It is highly possible that roads need to be reopened to install additional lead-up services to fulfil the owner's demands. Re-opening a permanent paved road has a lot of disadvantages: it is expensive, will cause hindrance to the inhabitants and stays visible after re-pavement. On IJburg provisional temporary roads can be completely re-paved to overcome these disadvantages. There is also a high risk of damage to the cable's and tubes in the ground if they are laid before construction starts. For these reasons the decision has been made for IJburg to lay lead-up services at the end of the construction work and before the (provisional) permanent pavement are in place and the houses are being delivered.

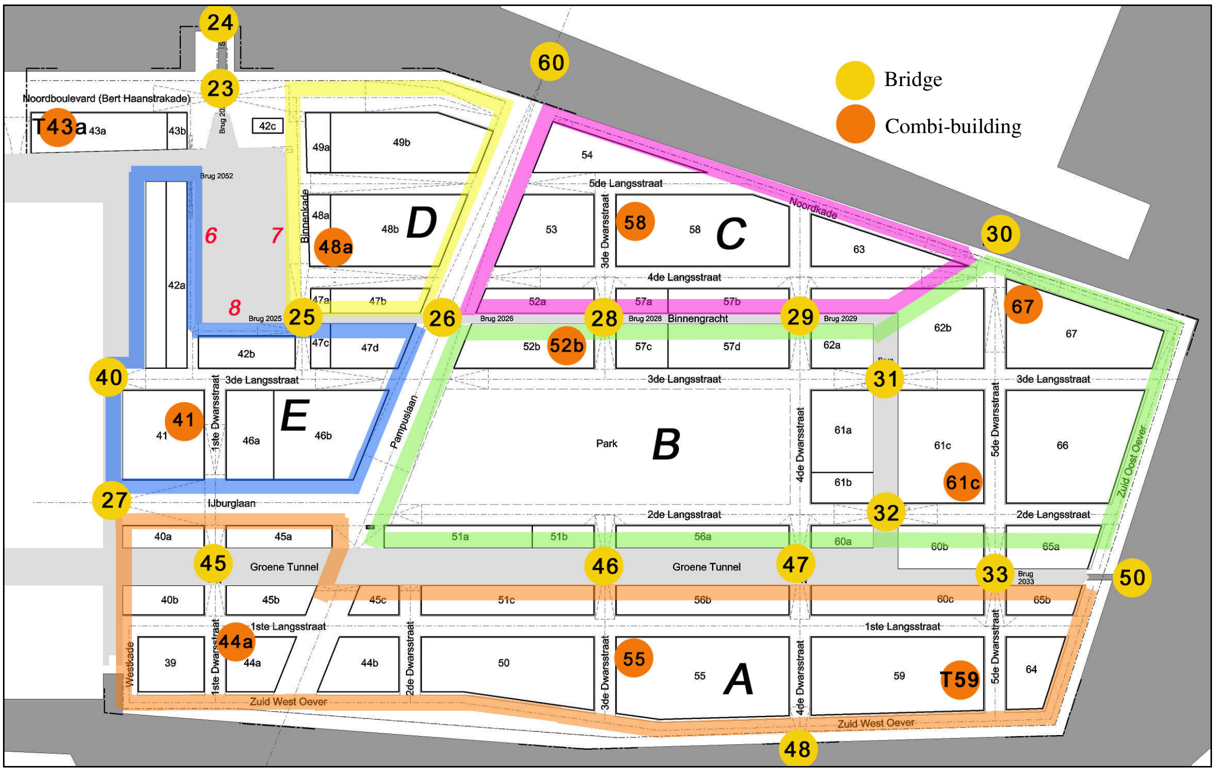


Figure 17: Haveneiland East, overview of clusters, bridges and combi-buildings.

In IJburg the main sewer-, city heating and water-pipes are laid under the road. They are installed early in the construction process before the temporary roads are constructed. The other services, lead-up services connecting the buildings are laid under the footway and cycle path. This is done because these parts of the road are relatively easy to open in case an additional cable or pipe needs to be laid. These lead-up services are installed during the so called "13 weeks phase", are the final 13 weeks of construction just before the buildings which are delivered to their new owners. All lead-up services that have to be laid on IJburg are documented in structural plans like Figure 18. This figure clearly shows the high number of lead-up services under the streets on IJburg.

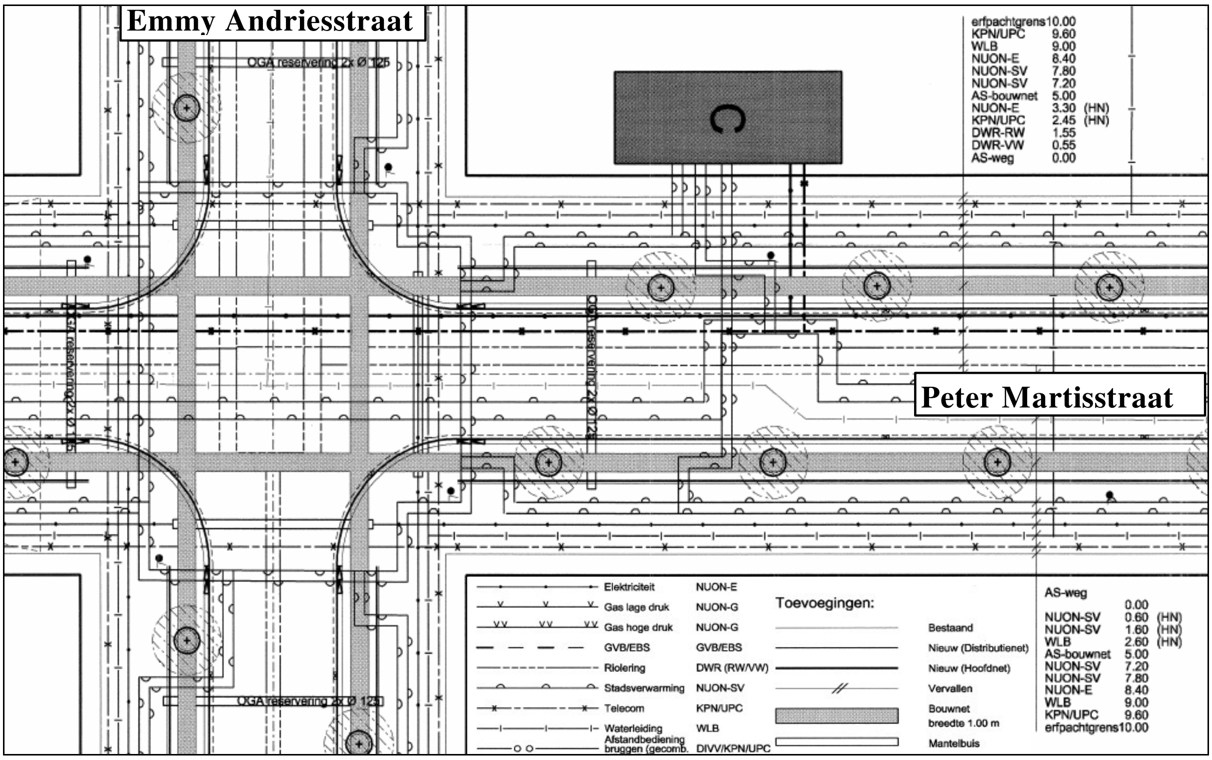


Figure 18: cable's and tubes under Emmy Andriesstraat and Peter Martisstraat. C stands for Combi-building

On IJburg all lead-up services for a number of blocks come out a so called "combi-building". It is important that the route from the combi-building to the building that has to be connected is free during the planned 13 weeks phase. If this route is not clear, unwanted delays with the delivery of the buildings are caused. Therefore the construction order and the delivery order have to be synchronised to the cable and pipe construction times. On IJburg, like all other dense construction projects with many involved parties, this led to some problems and tensions between inhabitants, the municipality of Amsterdam and the construction companies. For example service companies do not want to lay the pipes in an early stage because unused lead-up services are unprofitable lines, but this might be necessary to connect the blocks on time. Another example for this is construction work in-between the Combi-building and the building that has to be connected, due to which the ground for the lead-up services is blocked.

Figure 19 shows the schematic planning of the delivery order and connection order of block seven on Haveneiland West. The top left figure shows that the building that is furthest away from the combi-building has to be delivered first. The top right figure shows that this building is also the first to be connected. The bottom left shows the path of the lead-up services. Clearly, the ground above to the path of the lead-up services needs to be free during the 13 weeks period, such that the first buildings can be connected.

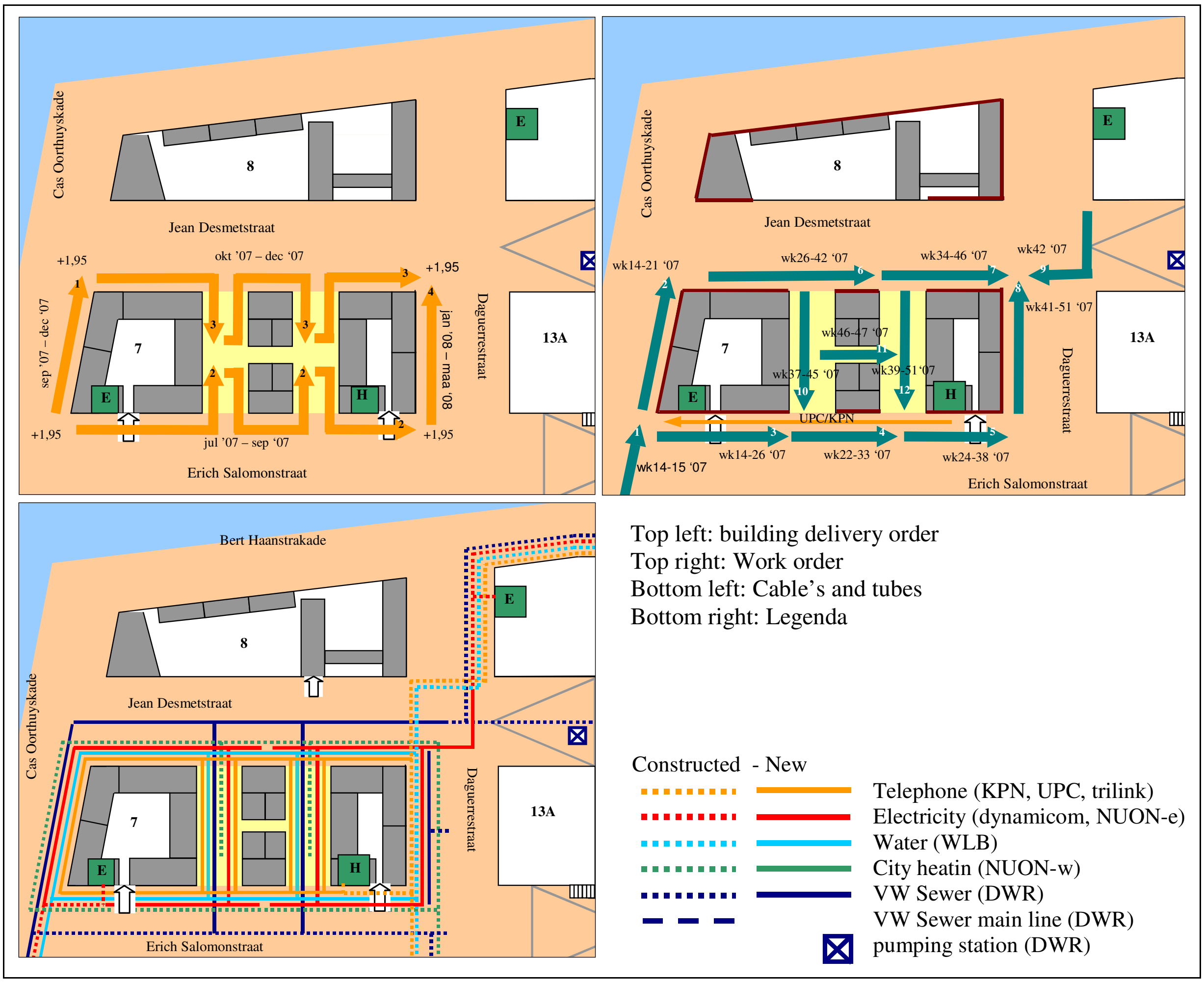


Figure 19: detailed cable and tube schematics for block 7 (Haveneiland East).

Maintenance

The moisture content of temporary roads made from mixed granule is very important. If the roads' surface is too dry there will be much dust, so dust control is necessary, which was also necessary on IJburg because of the open windy terrain. Keeping the road wet is often used as dust control. In wet times allot of damage will occur to the road. Especially heavy vehicles will destroy the road. Due to crushing of the mixed granule and spilling of materials like sand and clay on the road the top layer of the road will be impermeable, so water cannot drain though. If the fine fraction on the road is mixed with water, the soaked top layer will splash away, resulting in much damage to the road. After a wet period maintenance to the road is necessary. Therefore it is important that a mixed granule road lies above ground level so that as much water as possible water can flow of the road.

The provisional permanent roads also require maintenance. During construction, maintenance is reduced to a minimum as heavy construction vehicles are still passing over these roads. However these roads are public and therefore have to meet certain requirements. Any damage by the roads can be claimed at the municipality of Amsterdam. Therefore serious damage to the roads is to be repaired as soon as possible. Usually it is enough to repave the road.

Costs

The provisional set-up on IJburg is costing extra money. Usually these extra costs are not included in the exploitation scheme. Therefor it is important that those extra cost are reduced to an absolute minimum. In the end it are the new owners of the buildings that have to pay for these extra costs. A calculation was made what the difference is cost is between several pavement scenario's. The scenario's are:

1) Everything with permanent pavement, unless there still is construction on the other side of the street. Then everything with provisional permanent pavement. This is the current situation in the report;
2) Everything with permanent pavement, unless there still is construction going on the other side of the street. Then only a provisional permanent road;
3) Everything provisional permanent until all construction is finished.

Table 6: pavement scenario comparison

Scenario	Cost comparison	Quality permanent pavement	Hindrance for inhabitants	Overall score
1	100%	+	-	-
2	86%	+	0	+
3	125%	++	--	0

It is clear that the second scenario it the preferred choice.

Table 7 provides an overview of the maintenance cost of the temporary roads on IJburg. It is interesting to see that on average the maintenance costs in dry periods are about the same as in wet periods. As shown before, there is a significant amount of unpaved roads.

Table 7: maintenance cost for unpaved roads during one year.

Date	Description	location	Amount*
16-01-06	Bad state temporary roads	Haveneiland East	14.555,57
15-02-06	Regular maintenance	Haveneiland East	5.500,00
08-05-06	Keeping road wet preventing dust	IJburg	4.887,56
14-08-06	Maintenance due to bad weather	Haveneiland East	2.455,11
25-08-06	Keeping road wet preventing dust	IJburg	8.133,74
04-09-06	Regular maintenance	IJburg	362,88
09-10-06	Cleaning HEE, creating parking spaces	Steigereiland North	2.593,64
29-11-06	Maintenance due to bad weather	IJburg	1.032,50
30-11-06	Maintenance due to bad weather	IJburg	290,30
16-02-07	Regular maintenance	IJburg	383,06
Total:			**40.194,36**

2.3. Floriande – Hoofddorp

In this section the construction of the Floriande district in Hoofddorp is analysed in detail. All details of this project concerning the temporary roads on Floriande are discussed in this section. First, a short introduction is provided.

Introduction

Floriande[3] is the VINEX construction site of Hoofddorp. With a total of 6850 new accommodations Floriande is the largest VINEX-location of the municipality Haarlemmermeer. The Floriande district consists of three zones: “the islands”, “IJwijk” and “IJtochtzone". The islands (blue in Figure 20) are a series of twelve residential areas surrounded by waterways, between the N22, the IJtochzone, the Kruisweg and the Bennebroekerweg. On each island around three hundred houses are constructed. The IJtochtzone is the small red strip next to the IJtocht and the islands, with residential buildings and public facilities. IJwijk is the area between the IJtochtzone, the sport fields, and the Bennebroekerweg. IJwijk exists out of four zones “Sportdorp”, “Pleinen” “Archipel” and “Hoven”. Figure 20 shows the location of Floriande with the different zones of the project.

Figure 20: location and map of Floriande with the residential zones.

Construction of the islands is finished; currently “IJwijk” is being constructed. To receive more information about the temporary roads on Floriande Ron de Lange from the Municipality Haarlemmermeer was interviewed about this topic.

Sub-grade

[3] http://www.floriande.nl/

Hoofddorp is located in the west of the Netherlands, which is known for its bad construction sub-grade. The upper layer of Floriande consists of clay. This layer is around one meter thick. Under some parts however, this layer is thicker. Under the upper clay layer is a thick sand layer. Sand is known as a good sub-grade for construction, however on Floriande this layer was not well compacted and there are many thin layers of clay and peat present. Before construction could commence on Floriande the sand layer had to be compacted.

To make the site construction ready, the upper layer of clay was removed on places were temporary roads or lead-up services are constructed. On some parts of Floriande the clay layer was thicker then one meter. This layer had to be removed, not only because of the bad characteristics of clay as a construction underground, but also due to the worse characteristics of the underlying sand layer. After the top layer was removed, an extra layer of sand was applied to Floriande to quicken settlements (compaction and consolidation) in the sand layer.

The groundwater table on Floriande is around 80 to 90 centimetres below ground level. Multiple clay layers in the sand layer serve as impermeable layers, making extra drainage necessary on Floriande. The extra drainage was constructed under the roads. This is visualised in Figure 23. The drainage under the roads ends in one of the many waterways on Floriande.

Construction process

Floriande is partitioned in many small parts. The goal is to deliver these parts in stages to minimise the hindrance for the new inhabitants. The construction traffic is separated as much as possible from the residential traffic to minimise hindrance to new inhabitants. Figure 21 shows the delivery order of a part of the Hoven district of Floriande. In this figure it is visible that the delivery order is from left to right, from the IJweg to the Molenaarslaan. Residential traffic is routed to the left over the IJtocht and construction traffic it routed through Archipel towards the Molenaarslaan, as shown in Figure 21.

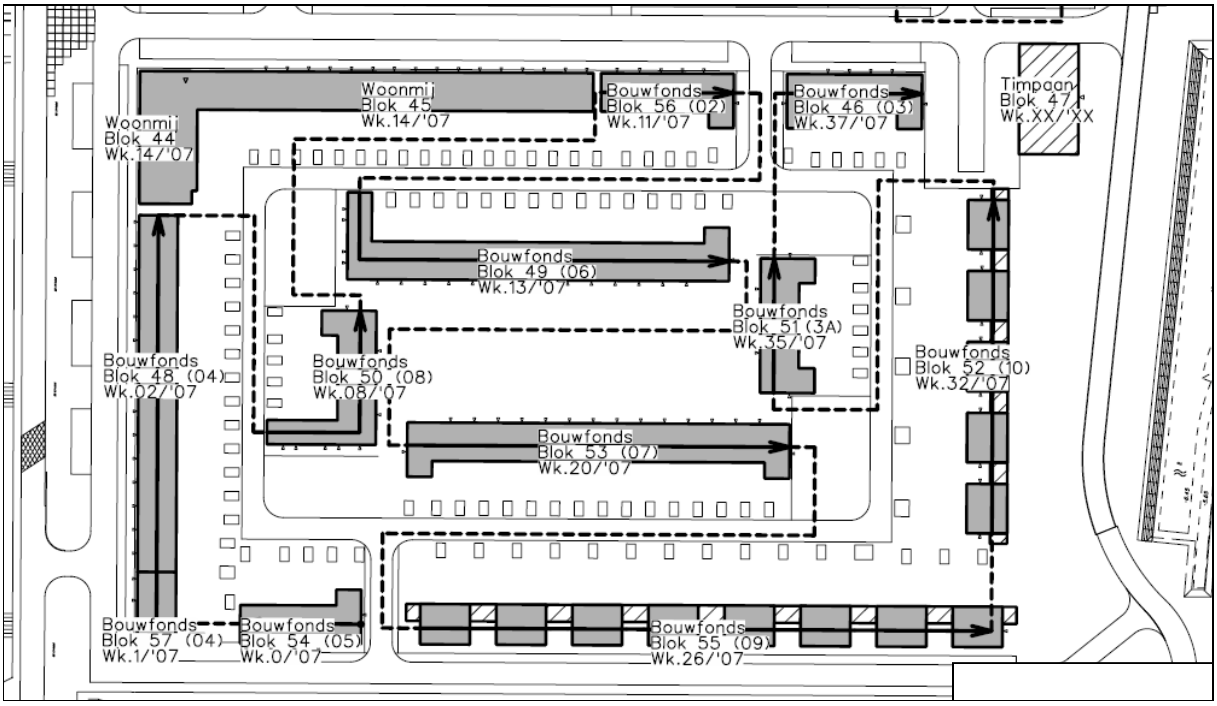


Figure 21: delivery order on one part of Hoven – Floriande.

Temporary roads

There was no research performed to select the best possible design for the temporary roads. The constructed roads were designed on experience. On Floriande three main types of temporary roads can be distinguished: the main access roads, the roads to different parts and the roads constructed by the construction companies on their construction site. Figure 22 shows the main access roads to Floriande. The main access roads and the roads to the different parts are under the supervision of the municipality of Haarlemmermeer.

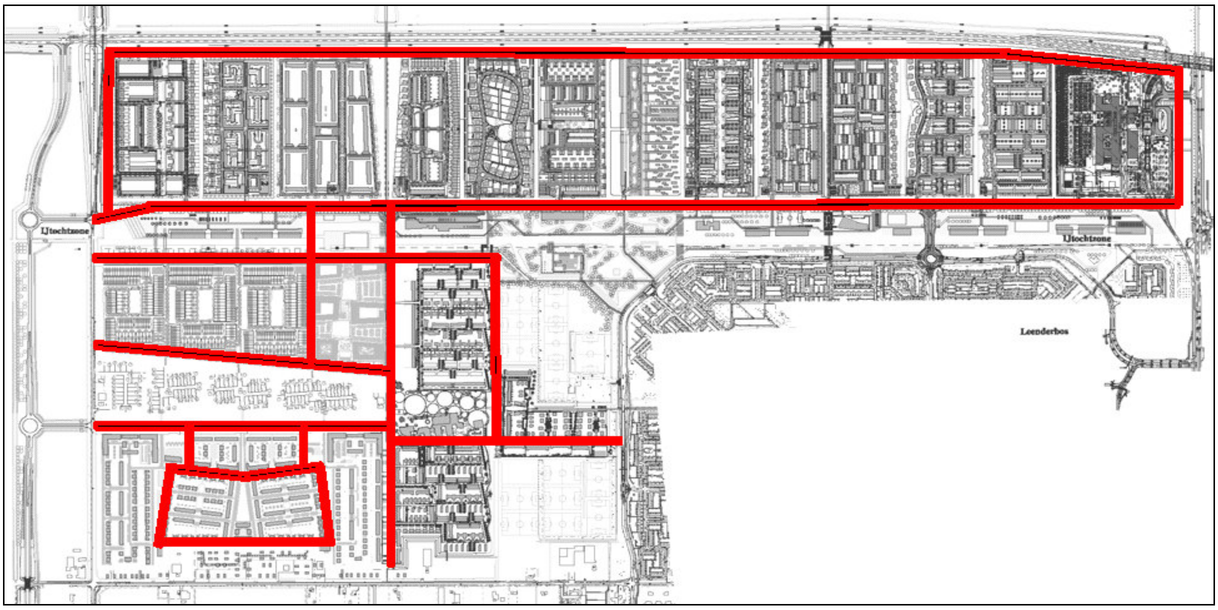


Figure 22: main access roads on Floriande.

The main access roads have been constructed with an asphalt pavement (STAB 0/22, 7 cm) on top of a mixed granule foundation (25 cm) and a sand embankment layer (50 cm) as shown in Figure 23. Originally, three drainage pipes in the road were planned to prevent saturation of the roads' embankment and to help drain the construction sites. Calculations however, showed that a single drainage pipe under the centre of the road was sufficient. This drainage pipe is located between the two sewer tubes.

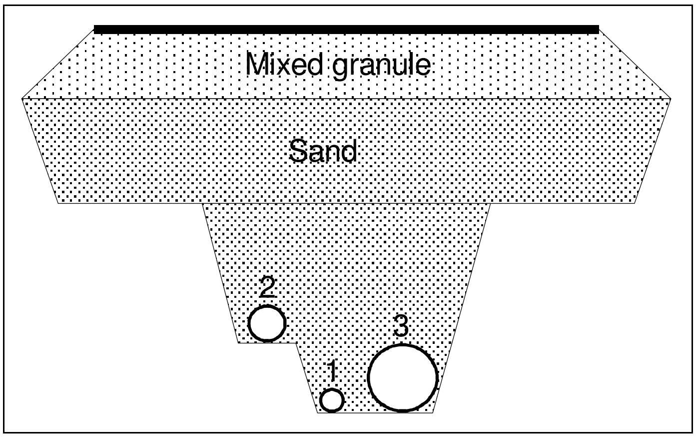


Figure 23: composition of a temporary asphalt road. 1 is the drainage pipe used to keep the road embankment and the construction site dry, 2 is the DWA sewer and 3 is RWA sewer.

The roads to the construction sites are constructed and managed by construction companies. All of these roads are constructed out of mixed granule (35 cm) on a sand layer (35 cm) and are around 5,5 meter wide. The width of the temporary roads is based on the size of the permanent roads. If the permanent road is only 4,5 m wide, then the width of the temporary road will be 5,5 m. The temporary roads are situated mostly on the same route as the permanent roads. Roads made of mixed granule need to be constructed above ground level to prevent water from soaking the road. This would shorten the lifetime of the road and would increase the maintenance necessary.

Intersections between the main access roads and the mixed granule roads are often made with Stelcon[4] plates. These plates (2 by 2 metre) can deal better with the large torsion forces, applied by the wheels of the trucks, in the corners of the road. This extents the life of the corners and helps minimising maintenance (and thereby reducing the construction site costs). It also prevents the main access roads from becoming extremely dirty. On places where temporary parking spaces are constructed sometimes geo-textile was used. Geo-textile makes it easier to remove the parking space.

On some places on Floriande temporary roads were constructed on places where, after construction is finished, no permanent road is constructed. However there are lead-up services under the road during construction. To prevent damage to those lead-up services, temporary roads were partly constructed out of Stelcon plates, above the lead-up services, and partly of mixed granule. Figure 24 clarifies this temporary road design.

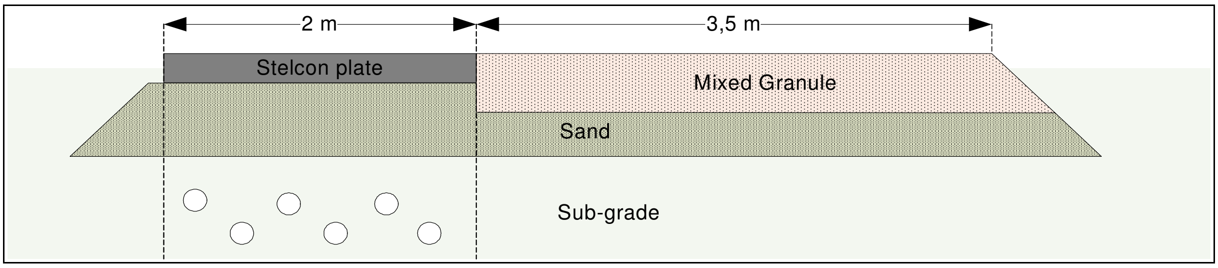


Figure 24: temporary road combination of Stelcon plates and mixed granule.

Permanent roads

The permanent roads on Floriande are paved with a small element pavement. Some of the temporary roads on Floriande are used as a foundation for the permanent road; others will be removed and replaced with sand. For each road the cheaper solution was chosen. Small element pavement needs a curb-stone on both sides of the road to keep the bricks in place. To install these curb-stones first a groove has to be made in the mixed granule layer. On streets with multiple rows of curb-stones (foot- or cycle-paths require extra curb-stones) it is more expensive to make multiple groves in the mixed granule layer, then removing the mixed granule layer and replacing it with sand. If the mixed granule layer is used as foundation for the permanent road then it is necessary to remove the thin mud layer on top of the mixed granule. This was not considered in the original exploitation design. The removal of this layer led to extra costs.

Places where has been dug in the temporary road will stay visible in the permanent road if the mixed granule is re-used. The reason for this is that those parts of the road will not be compacted as well as the rest of the road. To prevent this, lead-up services were constructed prior to the construction of the temporary road so digging in the road in later stages is limited to a minimum.

[4] http://www.stelcon.nl/

Once the permanent pavement is in place heavy construction traffic is no longer allowed to use these roads. This is done to prevent damage to the permanent pavement and prevent extra maintenance costs. The expected traffic load on permanent roads is 1,5 car per house per day.

Traffic routing

During the construction period of Floriande many houses are already delivered to new inhabitants. The delivery rate of new houses is around five to ten a week per part of Floriande. It is necessary to minimise the hindrance for inhabitants, due to construction work and traffic. The traffic in Floriande has been divided into two streams to separate the construction traffic from the residential traffic. Construction traffic is routed as much as possible to the west around Hoofddorp, while residential traffic is routed as much as possible to the east through Hoofddorp. A rough estimation of the construction traffic intensity is around 5 to 10 trucks a day per project of 200 to 300 houses (this is about the size of an island on Floriande), no exact figures are available.
 shows the traffic routing on Floriande.

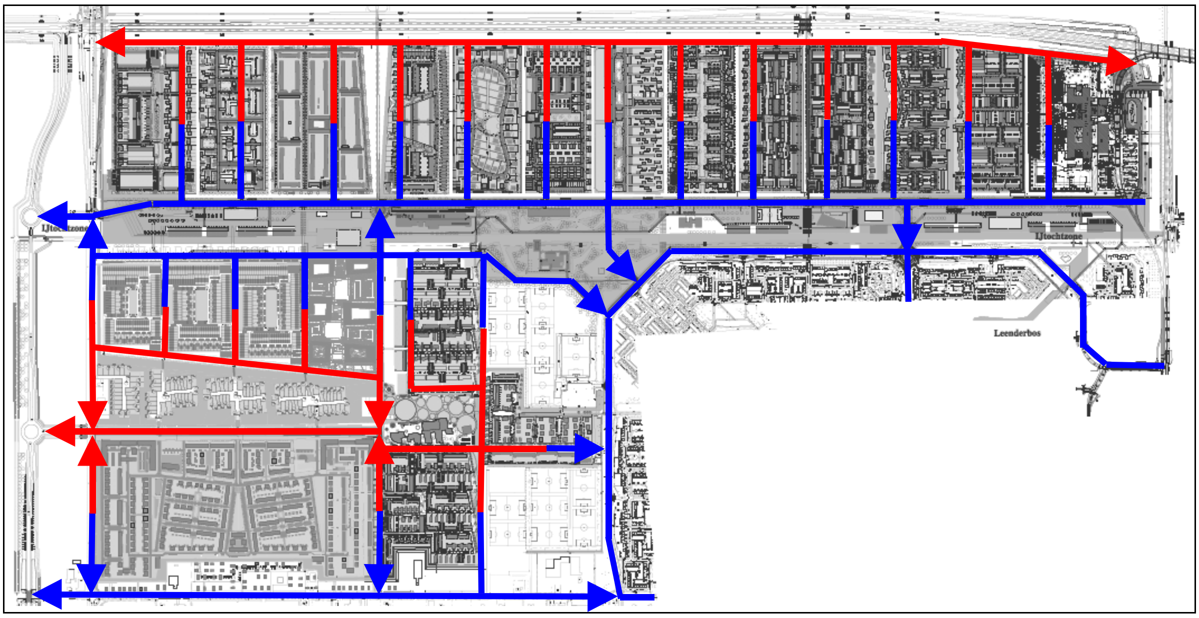


Figure 25: traffic routing on Floriande. Blue is residential traffic and red is construction traffic.

Parking spaces

Dense construction on Floriande not always left enough parking space for the construction companies. These spaces realised mostly on the construction site itself. Parking on the road can lead to congestion and is therefore not allowed. Thus, construction companies create temporary parking spaces in and around Floriande for their employees. This is done in consultation with the municipality of Haarlemmermeer. Temporary parking for unloading purposes is allowed in consultation with the municipality of Haarlemmermeer. Sometimes geo-textile was used to construct these parking spaces because the geo-textile makes it easier to remove the parking spaces after construction is finished.

Inhabitants

Paviors can keep up with a delivery rate of five to ten houses a week. Therefore the roads will have their permanent pavement before residents will move into their new houses. Since no construction traffic is allowed after the permanent pavement is in place and construction traffic is separated from residential traffic, residents will hardly have hindrance from the ongoing construction activities on other parts of Floriande.

Lead-up services

The main network of lead-up services is constructed during the construction ready phase, before the temporary roads are constructed. This is done to prevent routes to be blocked by other construction actives when cables should be laid. The sewer network is installed under the centre of the road, all the other lines are installed mostly under the footway. This is done because the footway is easier to open then the road itself.

The main drawback of the early installation of lead-up services is the increased risk at damage to the lead-up services during the construction period. It is also unprofitable for the service companies to install the lead-up services in an early stage because they are not in use. It has been stipulated how to deal with damage, caused by to the construction work, and the uneconomic extra costs. The actual connection of the houses on main service lines is done at the end of the construction period during the last 13 weeks (called: “13 week period”).

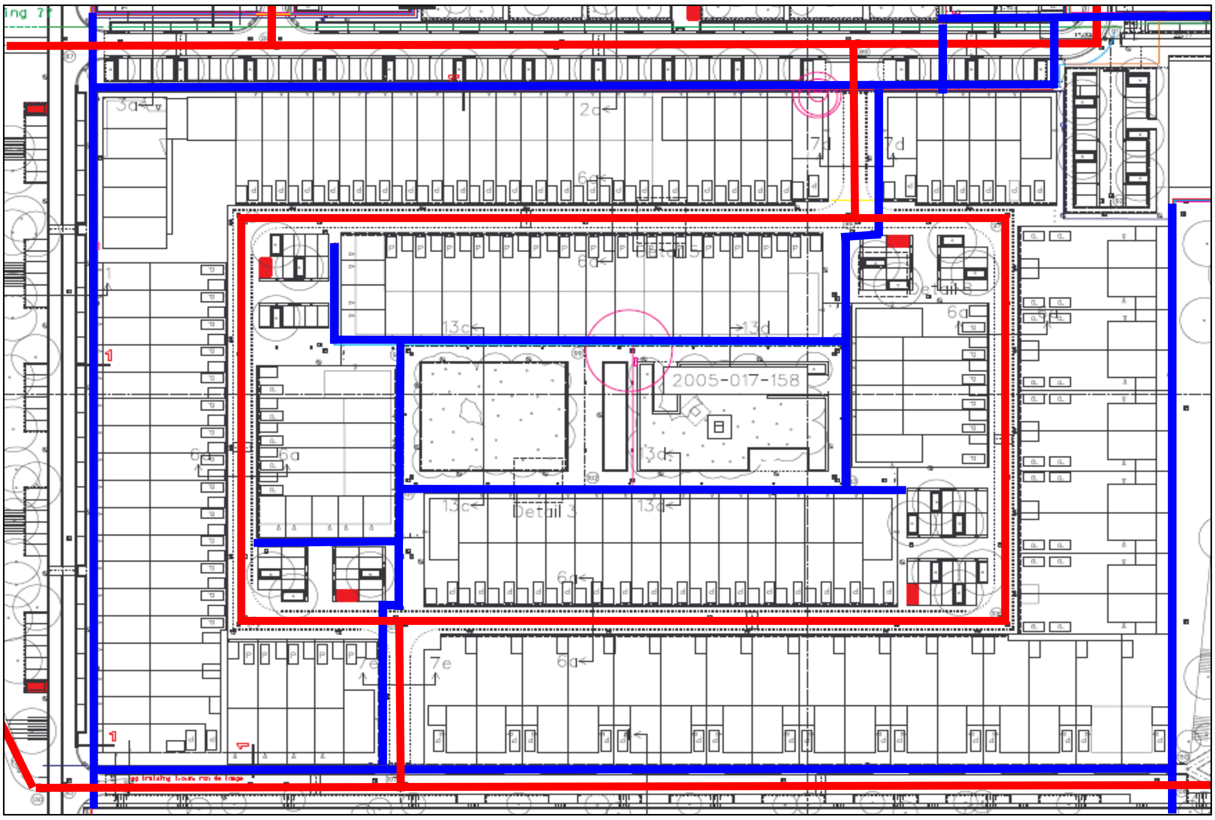


Figure 26: lead-up services on one part of Hoven – Floriande (blue = sewer, red = other).

Maintenance

The mixed granule roads need to be kept wet in dry times to prevent hindrance from dust. In wet times much damage occurs to the mixed granule roads, because the road is impermeable and water stays on the road. If this occurs the road will need maintenance after each wet period. Especially the corners need to be repaired after wet times. It is important that gardens are not higher than roads during operational time, as water would stay on the roads like a waterway, which is not desirable.

If there are large holes in the pavement (such that a wheel can fit into them) maintenance is necessary. Temporary roads with asphalt pavement are not repaired there are just cracks in the road. Hardly any damage occurred thus far to the roads paved with asphalt.

Costs

The costs for the construction materials for temporary roads were the main selection criteria for the choice of the temporary road design. No research was performed in terms of lifecycle costs or different types of temporary roads available. The maintenance costs for the temporary roads are, especially with mixed granule roads, dependent of the season and the amount of rainfall or dry periods.

2.4. Duyfrak – Valkenburg

Witteveen+Bos is involved in this project for consultancy during the spatial planning design process about the civil engineering aspect important in the development of Duyfrak. In the next step in the design process is the determination of the civil engineering aspects concerning to construction ready phase for the planning area. All this is done in the report “Civil engineering basis report ‘Duyfrak” (Witteveen+Bos 2005). In this chapter the plans for construction of Duyfrak in Valkenburg are analysed in detail. All the important details of this project concerning temporary roads are discussed in this section. First, a short introduction is provided.

Introduction

The municipality of Katwijk[5](formerly the municipality of Valkenburg) has commenced the redevelopment of the existing glasshouse horticulture area “’t Duyfrak[6]” to a residential area. This planning area is located near the existing village centre of Valkenburg and to the west of the “Oude Rijn”. The plan includes the construction of an area of 50 hectare with around 800 houses.

Figure 27: overview and artist impressions of Duyfrak.

Duyfrak exist out of six parts that will be delivered in six stages. Besides the municipality of Katwijk, there are three market participants involved in the development of this project: Van Zessen

[5] http://www.katwijk.nl/

[6] http://www.tduyfrak.nl/

Claer, BPF Bouwinvest en SpiritWonen. In the summer of 2006 zone 1 will be made construction ready. All six zones on Duyfrak are expected to be finished in 2012.

Sub-grade

On Duyfrak a soil investigation was performed before work started on the construction ready phase. This research determined that the following two ground profiles are representative for the parts Duyfrak (zone 1 to 5) and Tjalmastrook (Zone 6) and are taken on a virgin terrain.

Table 8: ground profile 1.

Soil type	Depth [m NAP]	γ_n	C_p	C_p'	C_s	C_s'	p_g	c_v
Clay, silty	–0,11	16	20	10	240	110	20	1,00E-07
Sand	–2	20	1000	1000	10000	10000	-	1,00E-04
Clay, sand layers	–2,5	17	30	20	400	240	32	1,00E-06
Sand	–5	20	1000	1000	10000	10000	-	1,00E-04
Clay, sand layers	–5,5	17	30	20	400	240	53	1,00E-06
Sand, clay layers	–7,5	20	1000	1000	10000	10000		1,00E-04

Table 9: ground profile 2.

Soil type	Depth [m NAP]	γ_n	C_p	C_p'	C_s	C_s'	p_g	c_v
Clay, sandy	–0,11	17	30	20	400	240	25	1,00E-07
Clay, silty	–3,5	16	20	15	240	160	38	1,00E-04
Clay, sand layers	–5	17	30	20	400	240	44	1,00E-06
Sand	–7	20	1000	1000	10000	10000	-	1,00E-04
Clay	–8,2	16	20	15	240	160	38	1,00E-06
Sand, clay layers	–9,2	20	1000	1000	10000	10000	-	1,00E-04

On Duyfrak the water table can be found at –0,55 NAP and the ground level at –0,11 NAP. To reduce consolidation and to heighten the ground level the planning area is heightened with 0,7m of sand. The ground level will be +0,4 NAP. Consolidation percentage wanted during the construction ready phase is 30%. This means the site will be construction ready after three months. The expected settlements over a 30-year period are calculated to be 0,23m. In the end situation the water table will be 0,9 m under ground level. It is recommended that the top soil layer (0,25m) is being striped to improve ground infiltration.

Construction process

The activities in the construction ready phase are performed under the management of the municipality of Katwijk. These activities include the following activities: construction of the temporary roads, installing drainage facilities and construction of the main sewer lines. In the civil engineering basis report is it also recommended that the excavation of the buildings is done in the construction ready phase. This will reduce the load on the temporary roads and thereby improve the quality and life-time of temporary roads.

Because of the size of Duyfrak not all the houses can be delivered at the same time. The plan consists of 30 % private construction. Delivery of the houses will be in stages to minimise the hindrance for the new residents. The new residents need to be able to reach their houses over a decent road. This makes the use of unpaved roads as main access roads not possible.

Temporary roads

In the development of the project the municipality of Valkenburg decided that the temporary road should have a small element pavement. However, choice was still open for debate mainly due to the application of water permeable pavement in the utilisation phase. The bricks that were to be used in the utilisation phase were not suited for used a temporary road pavement. Three main alternatives were studied: (1) concrete small element pavement on sand, (2) asphalt on sand and (3) prefabricated concrete plate pavement on sand. The application of mixed granule under the pavement or as unpaved road was not preferred for two reasons: the temporary roads were to be combined with the permanent pavement, which is required to be good permeable in the utilisation phase. If mixed granule is used, this layer is impermeable and has to be removed, which will lead to extra project costs. The other reason is that residents also have to use the temporary roads on the project because the project is delivered in stages. Mixed granule roads are not well suited for this purpose. Figure 28 shows the construction of the temporary roads on Duyfrak.

Figure 28: construction of temporary roads on Duyfrak.

The *concrete bricks*, used in a small element pavement, can be used multiple times on Duyfrak since the whole project is constructed in phases. This means that the purchases of the bricks can be written-off over these phases leading to a reduction of the construction costs. There are two main options available. Firstly the bricks can be paved upside down during the construction phase and re-used in the utilisation phase by repaving the bricks with the good side up. The main disadvantage with this option is the use of 'old' material in the utilisation phase. Good permeable bricks are also not suited for the use as temporary road pavement. The second option is the use of good 'old' bricks for the temporary road, which can be re-used on other parts of the project, and the use of new bricks for the permanent road. The use of a small element pavement was not recommended because the construction of small element pavement on sand is to light for construction traffic. Application of a small element pavement would result in large rutting, holes in the road and damage to the bricks. By normal use of a small element temporary road about 15% to 25% of the bricks would be damaged after construction is finished. If caterpillar track cranes are used, the loss of bricks can increase up to 50%.

The use of an *asphalt on sand* pavement has certain advantages and disadvantages. Asphalt paved roads are more user-friendly and better maintainable then most other pavement types. This type of pavement is well suited for the residents that are travelling over the temporary roads. Because the asphalt is paved directly on the sand there is a larger uncertainty about the evenness of the embankment material, which results in a thicker asphalt layer. Also if lead-up services have to cross the road this will lead to inaccessible roads and the obligation the repair the road. Holes in the asphalt pavement have to be repaired. Since the asphalt layer is removed for the utilisation phase, a large amount of damage to the pavement is allowed to occur.

Prefabricated concrete plates are not yet applied on many projects for the complete road. This pavement type is used mostly in temporary roads on intersections, crossroads, curves or as protection of the underlying cables an pipes. However a temporary road with a prefabricated concrete plate pavement is very user-friendly, good accessible and requires little maintenance. Experience tells that the strongest plates can be re-used four times. This means the initial costs of the stronger plates are higher than weaker plates, but the life-cycle costs when they can be used four times is lower. Due to the large forces between the plates a steel edging is recommended, however this steel edging, if damaged, can cause flat tires. Concrete plates are also well suited to increase the road width.

To select the best pavement the advantages and disadvantages were weighted against each other. The main selection criterions for this were the construction costs and the user-friendliness. This resulted in Table 10. The conclusion was that an asphalt pavement is over-all the best choice. To protect the lead-up services in the ground a strip of concrete plates was used. This can be seen in Figure 28.

Table 10: pavement comparison.

Aspect	Small element	Asphalt	Concrete plate
Costs [€/m^2]	22,20	19,60	19,10
Lifespan	0,5 – 1,0	1,0 – 2,0	1,0 – 4,0
Maintenance	-/-	+/-	+/-
User friendliness: residents	+/-	+/+	+/+
User friendliness: construction comp.	-/+	+/+	+/-
Construction lead-up services	+/+	-/-	+/-

The main temporary roads on public terrain on Duyfrak will be 5,50 m wide to allow the passing by of 2 heavy trucks on the road. The other, lower order, temporary roads will be 4,50 m wide to allow a truck and a car to pass by each other on the road. It is also suggested to keep a minimum space of 3 m between the temporary roads and the construction activities to minimise hindrance and increase safety on the construction site. The location of the temporary roads on Duyfrak is based on the existing infrastructure and the location of the roads in the utilisation phase. This will speed up the construction process en reduce the construction costs. Installing a row of Stelcon plates next to the road will widen the Duyfraklaan. This will make the road wide enough to allow 2 trucks passing by each other. Figure 29 shows the temporary roads as planned on Duyfrak.

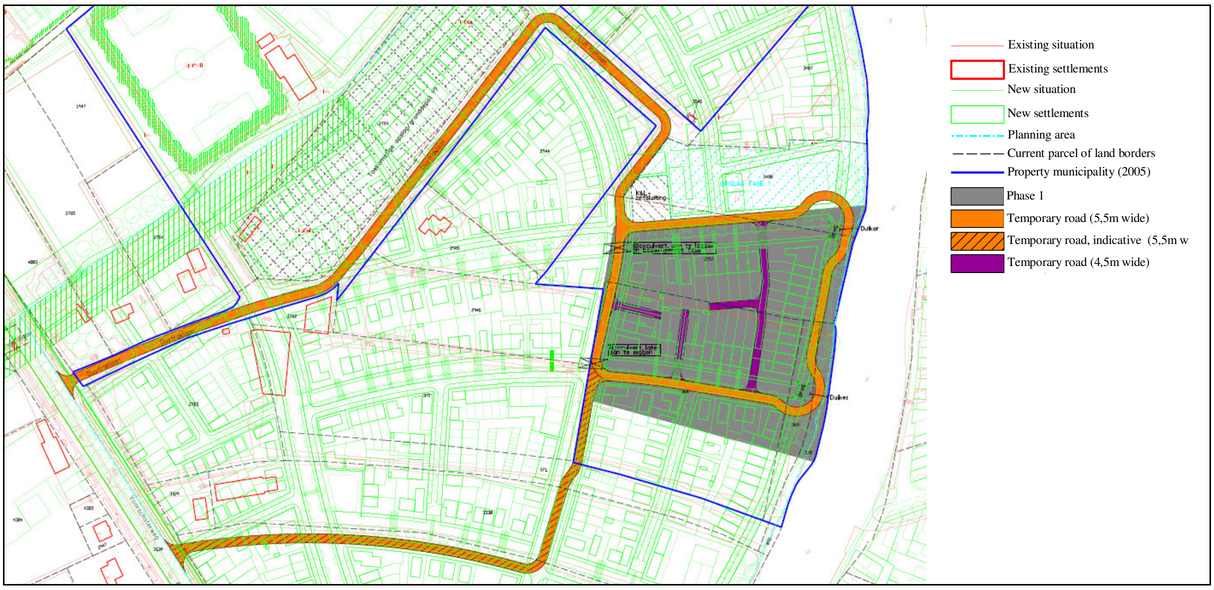


Figure 29: temporary roads on Duyfrak phase 1.

Data about expected traffic intensities on the temporary roads is not available. Therefore calculations are made regarding the maximum traffic intensities on different road constructions. A drainage system will be installed under the temporary roads next to the sewer pipes to ensure good drainage of the terrain.

Permanent roads

The permanent roads will also be paved with small element pavements. Since there will be no shopping centre in the district there is not much heavy traffic is expected. Frost penetration in the road is not a problem with chosen road design due to the location near the sea. The maximum frost penetration is about 0,50 to 0,60 m and therefore above the water table.

For the roads' design there was a preference for a foundation free embankment to ensure maximum permeability. Research shows that the thickness of the sand layer on stiff clay or sand with clay layers will be noticeable up to 0,5m. A thicker sand layer does still have some influence but very limited. The cost for this extra bearing capacity will strongly increase with greater layer thickness. Table 11 shows the complete design for both types of roads.

Table 11: road design

Residential road		Access road	
Thickness	Type	Thickness	Type
80 mm	Concrete bricks	80 mm	Concrete bricks
50 mm	Pavement sand	50 mm	Pavement sand
500 mm	Sand	200 mm	Mixed granule
-	Natural underground	500 mm	Sand
		-	Natural underground

Traffic routing

The separation of residential traffic and construction traffic is desirable to prevent unsafe situations from occurring. However due to the large amount of parties involved and the limited available amount of ground this is not always possible to realise. It is however recommended to realise an extra cycle path and to prohibit cyclists on the temporary roads to increase safety.

Parking spaces

Zone 5 to the north is ideal for parking and storage purposes during the construction of phase 1. Parking and unloading while standing on the temporary road is not allowed.

Inhabitants

Duyfrak is delivered in stages. Therefore residential traffic on the temporary roads is likely to occur. Therefore the condition of the temporary roads has to be good enough to allow residential traffic. Unpaved roads are not allowed for this purpose. If possible a separation of resident and construction traffic will be made.

Lead-up services

The currently in place lead-up services are not sufficient for the connection of the new district. Therefore new lead-up services have to be installed in order to connect the new houses. This can be done on two moments in the construction process: in the construction ready phase or in the delivery phase. For Duyfrak it is recommended to install lead-up services during the construction ready phase. Main reason for this is that the temporary road will be re-used as permanent road. Since all lead-up services lay on one side of the street it is necessary to lay cables under the road. If this is done after the temporary roads are laid this will stay visible with deformations of the pavement. Since the rest settlement is only 0,10 m and the same for the total area there is almost no risk of damage to the lead-up services. To ensure the availability of all the services it is desirable to construct a second cable and pipe connection to the north of Duyfrak.

Maintenance

The temporary roads have an asphalt pavement. The pavement is designed in such a way that maintenance should not be necessary. A significant amount of damage to the road is tolerated since the temporary road is not re-used as permanent road.

Costs

A cost comparison between the three options for the temporary roads was made. The results are shown in Table 12. Maintenance cost should be minimal since the pavement is designed to last the construction phase.

Table 12: construction cost per road-type.

Road type	Construction costs [m^2]
Concrete bricks on sand	€ 22,20
Asphalt on sand	€ 19,60
Prefabricated concrete plate pavement	€ 19,10

2.5. Summary

In this chapter the application of temporary roads in the Netherlands is analysed. In section 2.1 the research performed by Biron (2004) on the construction ready stage is discussed. In his research eleven projects were analysed and compared to an older study of 1977. Four main conclusions in his research are also relevant for this research. (1) There are 2 main methods to make a site construction ready: the integral or the embankment method. Either way the expected consolidation is reduced to within allowed limits before the temporary roads are constructed. (2) The use of small element pavements dropped significant as pavement for temporary roads. This is largely because of the high construction cost. Unpaved roads are becoming more popular. (3) The permanent pavement is no longer used as temporary road pavement. (4) Temporary roads can cause water logging on the construction site due to badly constructed embankments, bad drainage systems or mismatched road height compared to the surroundings.

In the next three sections the following three projects were studied: IJburg - Amsterdam (2.2), Floriande - Hoofddorp (2.3) and Duyfrak - Valkenburg (2.4). Table 13 provides a quick overview of the projects.

Table 13: overview studied project.

What?	IJburg	Floriande	Duyfrak
Temporary road width	6,0 m	5,5 m	5,5 m
Primary road design	- 35 cm mix granule - Sand sub-grade	- 7 cm asphalt - 25 mix granule - 35 sand	- 8 cm asphalt or concrete plates - Sand
Secondary road design	- 35 cm mix granule - Sand sub-grade	- 35 cm mixed granule or concrete plate. - 35 cm sand	- 35 mixed granule - natural sub-grade
Comb. temp and def. road?	Partly	Partly	Partly
Permanent pavement	Asphalt for main access roads. Rest: small element	Small element	Small element
Lead up services constr.	13-weeks phase	Before temporary road	After temporary road
Drainage	No	Yes	Yes
Phased delivery	Yes	Yes	Yes
Separation residential traffic	Yes	Yes	No

In our analysis three types of temporary roads were encountered: unpaved, asphalt paved or concrete plate paved roads. A short summary of our findings about these temporary road types is provided below.

- *Unpaved roads* cannot deal with large traffic loads, especially not on a weak sub-grade. For this reason on most of the researched projects this type of road was not used for the main access roads on the construction site. IJburg is the exception here. The sub-grade on IJburg is compacted sand since IJburg is artificially created. This allows the use of unpaved roads as main access roads. This road-type is cheap to construct and can be easily combined with the permanent road, however this road cannot be used for residential traffic. Lead-up services can be easily installed under the road. This type of road requires much maintenance but maintenance can be executed fast and cheap.
- *Asphalt paved roads* can handle larger traffic loads much better. Especially asphalt and concrete plates can handle heavy traffic loads. If designed correctly asphalt pavements do not require maintenance during the construction period. The use of an asphalt pavement increases the situation and work conditions on the construction site.

- *Small element paved roads* are hardly ever used anymore. The main for this is the high life cycle cost. Small element pavements are more sensitive to rutting and there is a high risk that many bricks are broken after construction is finished.
- *Concrete plates* are mainly used as a part of temporary roads. This can either be to widen roads, to reinforce parts of the road where large torsion are applied or to protect the underlying lead-up service lines.

The temporary road types are criticised in Table 14 and Table 15.

Table 14: overview pavement types (++ : excellent, + : good, +/- : undecided, - : bad, -- : very bad).

Aspect	**Unpaved**	**Asphalt**	**Small elements**	**Concrete plate**
Possible on weak sub-grade	--	++	+/-	+
Allowed traffic load	-	++	+	++
Residential traffic	--	++	+	+
Allowed damage	++	+	+/-	+/-
Lead-up services	+	-	+/-	++
Combination with permanent road	++	+/-	+	+
Hindrance to surroundings	--	++	+	++
Maintenance	-	++	+	++
Life cycle costs	**++**	**+**	**--**	**+**

The RAMS-aspects (see chapter 3) can be used to judge the performance of the road types. In Table 15 it can be seen that paved roads deliver better conditions on the construction sites then unpaved roads. They do this however at higher construction costs but lower maintenance costs.

Table 15: overview RAMS-aspects of temporary road types (++ : excellent, + : good, +/- : undecided, - : bad, -- : very bad).

Aspect	**Unpaved**	**Asphalt**	**Small elements**	**Concrete plate**
Reliability	-	++	+	++
Availability	+/-	++	+	++
Maintainability	+	+/-	+	+/-
Safety	-	+	+/-	+

The following points were also noticed during this research

- When possible residential traffic should be separated from the construction traffic.
- Parking should not be allowed on temporary roads.
- It is recommended to install the lead up services before the temporary roads are constructed.

3. DESIGN CHARACTERISTICS

In this chapter available theory that can be used to design temporary roads will be discussed. In section 3.1 the terminology that is used throughout this research is discussed. Then the definition for a temporary road is provided in section 3.2. In section 3.3 the RAMS methodology, which can be used to describe the performance of a road, is introduced. The possible functions of a temporary road are analysed in section 3.4 and the life cycle of temporary roads is discussed in section 3.5. Actors involved with temporary roads are discussed in section 3.6. Possible design aspects of temporary road are discussed in section 3.7. Sustainable construction is discussed in section 3.8. The construction of lead-up services is discussed in section 3.9. Finally a summary is provided in section 3.10.

3.1. Terminology

In literature many different terms are used to describe parts of the road's construction. Therefore it is important to define what is meant by each term used in this research. The naming used in this section is used throughout this report. Figure 30 shows the schematic cross section of a road construction with terminology used in the report.

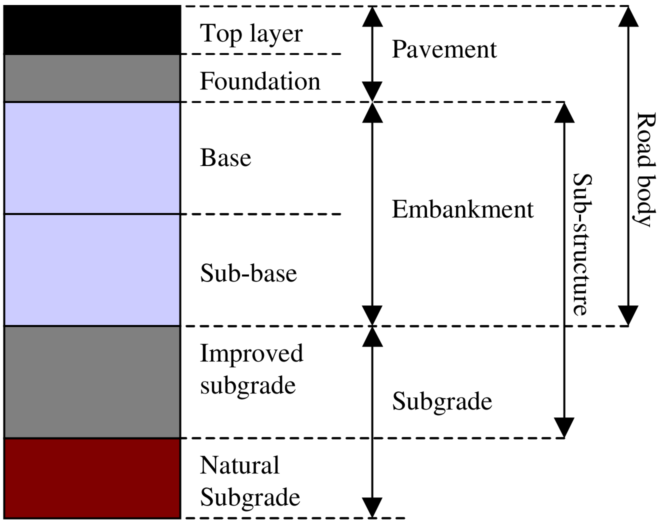


Figure 30: schematic cross section of a road construction with terminology

The top layer of a road construction is called the *pavement*. The pavement consists of a *foundation* layer and a *top layer*. For the top layer there are several options available like small elements asphalt or concrete. On construction sites it is also possible that no top-layer is used at all temporary roads. This type of road is called an unpaved road. The foundation is discussed in section 6.2 and the top layer is discussed in detail in sections 6.3 to 6.6. Under the pavement is the road's *embankment* is constructed. The embankment consists of a *base* material, which is mostly embankment sand. If necessary also a *sub-base* layer can be applied for example to increase to roads height or to substitute weak soils with light embankment materials. This however is never applied in temporary roads. The *road body* consists of the pavement and the embankment and is supported by the *sub-grade*. On extremely weak soils it is possible that the sub-grade has to be improved in order to support the road. An *improved sub-grade* is never been applied under temporary roads. The whole road is finally constructed on the *natural sub-grade*. The natural sub-grade is discussed in chapter 4.

3.2. Definition

In the studied literature there is no definition available for a temporary road on a construction site. To prevent misunderstanding about what is meant by a temporary road it is necessary to formulate a definition. However for a definition for ‘temporary’, ‘road’, and ‘construction site’ can be found. So as a starting point for formulating a general definition for a temporary road on a construction site the definition of these separate words is provided first.

According to the Van Dale[7] temporary means that it is not lasting, the amount of time that it will be used is limited. Depending on the size of the construction project, temporary can range between several months up to many years but the approximate construction time is known when construction commences. After the construction is finished the temporary road will be removed or replaced by a permanent road making the lifetime of the road known and limited.

Many definitions of a road can be found. Van der Velden (1999) defines a road as “a paved or unpaved strip including a foundation with the possibility of drainage on which transportation is possible”. VBW-Asfalt (2000) provides the following definition: *“A road is a small strip of ground in a landscape, used and made suitable for traffic use, providing a connection from one place to another”*. Van Dale defines a road as *“A road is a strip of land, smoothed or otherwise prepared to for traffic”*. So in general it can be said that a road is a paved or unpaved strip of land used, smoothed or otherwise prepared to enable transportation.

Van Dale provides a simple definition for ‘construction site’: *“area on which construction is possible”*. A more elaborate definition can be found in the multilingual term bank of the European Commission[8]: *“the lands and other places on, under, in or through which the temporary and permanent works are to be executed and any other lands or places needed for the purposes of construction”*. As the definition states a construction site might exists out of more then one area or construction project. So the temporary road has to provide access to and transportation on the construction site.

Since temporary roads are not only used on construction sites but also in other fields, these can also be used to find a good definition. In wood harvesting, many definitions can be found:

- *“A temporary reconnaissance road built along the route of a job, to provide means for moving equipment and men”* [W4.1].
- *“Any route used for the vehicular access to, and the transport of logs from the point of loading (log dump) within the plantation area”* [W4.2].
- *“A temporary or permanent road over which timber is transported from a loading site to a public road”* [W4.3].

A more construction specific definition for a temporary road was found for the construction of power-lines: “an unspecified road needed for short-term use during the construction of a power line” [W4.4].

Now these three partial definitions can be combined to find a definition for ‘temporary roads on construction sites’. For this research the following definition is used.

[7] http://www.vandale.nl/

[8] http://ec.europa.eu/eurodicautom/

Temporary road on a construction site is:
- a paved or unpaved strip of land;
- on which transportation is possible;
- providing access to or on a construction site;
- during a limited amount of time.

3.3. RAMS-Methodology

RAMS can be seen as a part of a quality management system approach used to describe the degree of Reliability, Availability, Maintainability and Safety and the process towards it. In essence, the RAMS-parameters can be used to explicitly make the performance of a system or project visible. To quantify the RAMS-parameters a risk analysis can be made. A risk analysis is about the possible project/product risks and expressing them in the consequences. The results of such analysis can then be compared to the desired numbers. By performing a RAMS-analysis, the performance of the product or project can be increased and discrepancies in performance can be adjusted. The RAMS-methodology can be applied to all stages of the life-cycle-analysis.

For the secondary functions in the function analysis of section 3.4 the concept of RAMS (Reliability, Availability, Maintainability and Safety) technique is used. RAMS is part of quality-management system with the main goal of quantifying and improving the reliability, availability, maintainability and safety of a specific product and to document the process towards that goal. For temporary roads this can be described as follows:

- *Reliability* is the probability that the road can keep performing the basic functions under certain circumstances during a time interval. The functions under reliability will try to ensure the dependency of the road. Reliability is usually expressed in a percentage.

- *Availability* is the ability of the road to perform its basic functions under certain circumstances on a certain time or during a time interval. Functions under availability will try to ensure the availability of the road. The availability is usually expressed in days per year.

- *Maintainability* is the probability that maintenance can be performed on the road functions under certain circumstances on a certain time or during a time interval within predetermined conditions and according to predetermined procedure and resources. Functions under maintainability will try to ensure that maintenance can be performed on the road when necessary. The maintainability is can be expressed as the time it would take to restore the road.

- *Safety* will make sure the road is free of unacceptable risks. Functions under safety will try to ensure that the road is as safe as possible at all times. The safety is usually expressed in accidents a year.

For new roads, the reliability percentage is high, but due to load applied to it this number slowly decreases. A lower reliability will usually lead to lower availability and to more maintenance and a lesser safety on the road. Lower availability will cause more congestion or unreachable construction sites, which is not desired. Regarding safety, a distinction needs to made between to possibilities: with or without residential traffic. The safety on temporary roads, which are only used by construction traffic, is allowed to be lower than temporary roads on which residential traffic is also allowed. At a certain point the road is no longer able to give the desired performance. At this point maintenance is required. After maintenance the reliability, availability, maintainability and safety will increase again. In general, more expensive roads will have a higher, longer enduring performance than cheaper roads.

Temporary roads can be divided into several categories, each category having its own performance criteria. There are many different types of temporary roads available. Each type of road has its advantages and disadvantages. For these types the RAMS-parameters can be used to make the performance of each road type explicit. This way the best road type for the project can be selected. This is done in chapter 6.

3.4. Function analysis

Lawrence Miles conceived of Value Analysis (VA) in the 1945 based on the application of function analysis to the component parts of a product. Component cost reduction was an effective way to improve value and the success of a product. The VA technique supports cost reduction activities by relating the cost of components to their function contributions. In VA basic and secondary functions are separated from each other. VA defines a "basic function" as anything that makes the product work or sell. Secondary functions, also called "supporting functions", described the manner in which the basic function(s) are implemented. Analysing functions of a project or product can contribute at describing of wishes and demands of clients, principals and users. To analyse which different functions a temporary road has the methodology of Functional Analysis System Technique (FAST) will be used as described by Snotgrass (1986) and Veenvliet (2004).

Function analyses can be seen as a dynamic design process aimed at the reduction of project costs and acceptance of design results. According to Snotgrass (1986) two types of FAST-techniques can be distinguished with each its own application: Task/customer FAST and Technical FAST. The advantage of the TASK FAST is the ability to describe the complete product design with one diagram. The TASK FAST emphasises the fact that success cannot be achieved unless users/owners needs and desires are recognised, understood and fulfilled. To analyse the functions of the temporary road a TASK FAST diagram has been created. The complete TASK FAST diagram is included in Appendix 1. For temporary road the following basic functions can be distinguished: providing access support vehicles and transport materials For the secondary functions the RAMS-methodology, as described in section 3.3 is used.

The technical orientated FAST diagrams are mainly used to describe and analyse a part of product or process. Temporary roads can be seen as the total product and the pavement can be seen a part of this product. No technical FAST diagram was created for temporary roads.

3.5. Life cycle costs analysis

Life cycle costs can be defined as “the process of economic analysis to assess the total cost of system investment en ownership taking into consideration the operational constraints and performance requirements of the system or product under study” (Boes, 2003). The purpose of a life cycle cost analysis (LCCA) is to estimate the overall costs of the project alternatives and to select the design that gives the lowest overall cost during its lifetime. The LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life-cycle costs (LCC). The impact on the life cycle cost during the lifespan of a project is visualised in Figure 31. Because temporary roads are indirect project costs, reducing them is important.

In this research the temporary road and to the combination of the temporary road with the permanent road are investigated. An integral approach for the temporary road and the permanent road might lead to significant cost reductions and an improvement in quality. The lifecycle of the temporary road is discussed in subsection 3.5.1 and the permanent road in subsection 3.5.2.

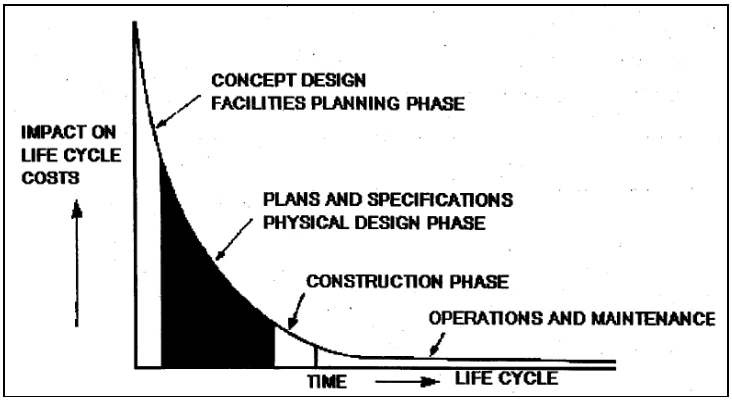


Figure 31: influence on life cycle costs during all stages of a project or product.

3.5.1. Temporary road

The life cycle costs of a temporary road consists of four main stages, see Figure 32. The first stage the life cycle is design of the road. This stage is the most important stage of the LCCA. Decisions made in this stage will influence all stages after. This is also clearly visible in Figure 31. Therefore the biggest cost reductions can be generated during this stage. The decision whether or not the permanent road is combined with the temporary road should also be made in this stage. This is mainly because the roads' body also need to be able the meet the requirements set for the permanent road like the support the permanent pavement for the desired lifetime, frost penetration and drainage requirements.

The influence on the life cycle cost during the last three stages of a temporary road is minimal. The second stage is the actual construction of the temporary road. In this stage the cost attached to the materials and manpower used are made. Depending on the pavement type, these cost vary strongly. Operation of the road takes place in the third stage. Operation costs for temporary roads are mainly maintenance costs. These cost vary also strongly depending on the selected pavement type. For the fourth and final stage there are two options: the road can either be demolished or recycled into the permanent road. By using an optimal design, costs that have to be made can be minimised during these stages.

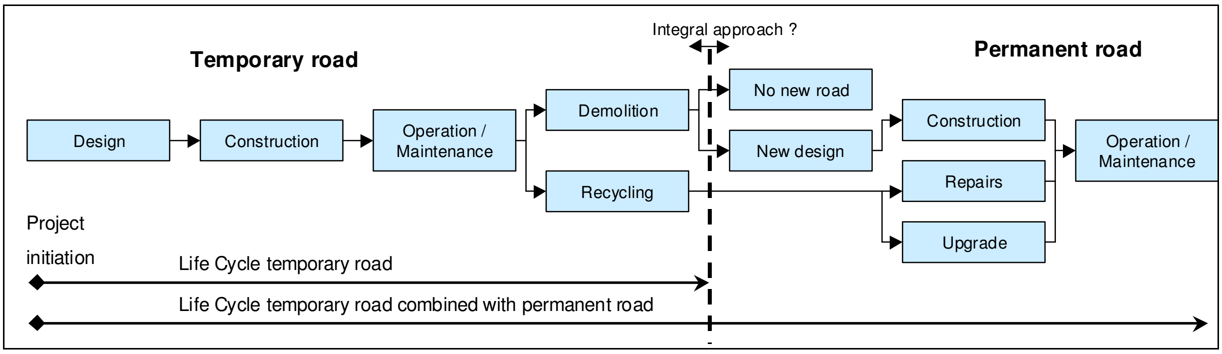


Figure 32: life cycle of a temporary, possibly combined with permanent road

3.5.2. Permanent road

If the temporary road is not combined with the permanent road, then the permanent road will have a life cycle similar to the life cycle of the temporary road. If will start with the creation of a new design, followed by the construction stage. Then the operation/maintenance stage will follow and finally at the end of the roads' lifetime it will be demolished. However, combining the temporary road with the permanent road can reduce the total construction costs and improve the quality of the temporary roads. This is often good possible because temporary roads are frequently constructed on the same route as the permanent road in the utilisation phase of the project. A combined design means that there is an extra set of requirements present at the design stage of the temporary road to make the upgrade from temporary road to permanent road possible.

In case a design integral approach is chosen, the costs made for the permanent road depend strongly on the design of the temporary road and the corresponding 'upgrade' costs. The construction costs of the temporary and permanent pavement are discussed in chapter 6. Also the upgrade costs for a temporary road to a permanent road are calculated.

3.6. Actor analysis

This research focuses on temporary roads on construction sites and the possibility of combining (parts) of the temporary road with the permanent road. Therefore it is necessary to look at the actors involved in these two stages because they can influence the design. In road construction there are several actors present in construction projects. All parties have their own interests, goals and means. Actor analysis provides a structured inventory of the parties and their interests to get an overview. Figure 33 displays an overview of the actors present during the possible life cycle of temporary roads and the permanent road on construction sites.

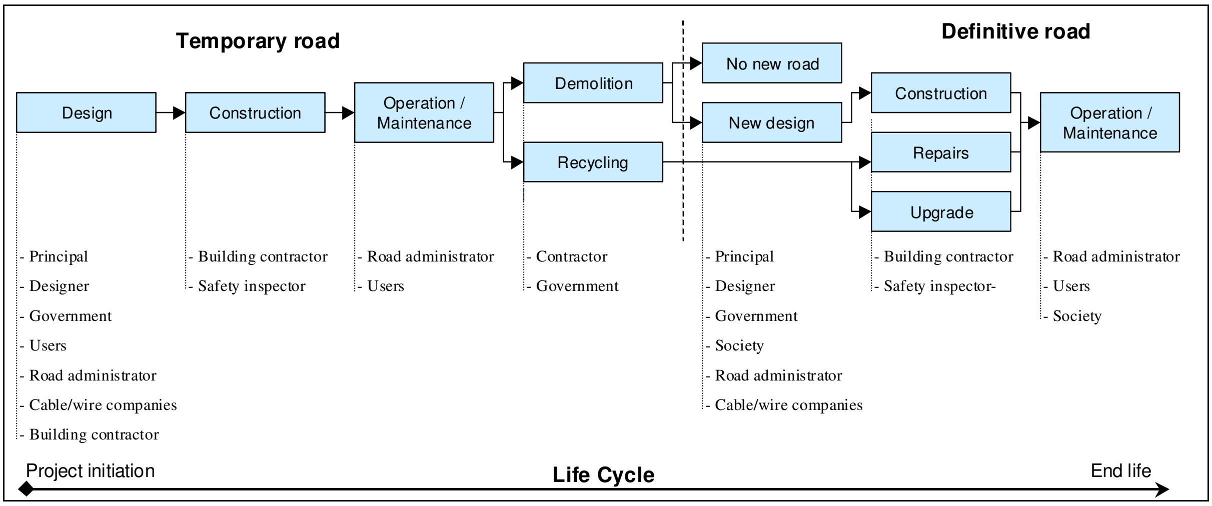


Figure 33: actors present in different life-cycle phases

All the actors are named in Figure 33 are discussed below.

1) The *principal* is most likely the actor with the biggest influence on the project. However, it is likely that the principal is not interested in the temporary road itself as long as meets the projects requirements and it does not exceed the costs. The main interest of the principal is economic profit.

2) To calculate what type of road is needed to suit the projects needs (during construction and after) a *designer* calculates the road dimensions. The designer possesses knowledge about road construction technologies. The road designer can be part of the principal's organisation, part of the building contractor or an advice/engineering company.

3) The *building contractor* is doing construction of the road. This actor wants to achieve the project's goals at lowest possible costs. The building contractor interest is like all other private company's economic profit. It will try to do so by maximising profit and reducing costs. The building contractor possesses the means to successfully realise the construction project. It

can be useful to include the building constructor in the design stage of the project. This can lead to cost reductions during the construction stage.

4) Governments have three main powers: legislative (the power to make laws), executive (the power to implement laws) and judiciary (the power to judge and apply punishment when laws are broken). Unlike private company's governments interests is social profit.

5) The *road administrator* is responsible for operation and maintenance of the road. His interest is also economic profit. It can be useful to include the building constructor in the design stage of the project. This can lead to cost reductions during the operation stage.

6) Its the *Safety inspector* job to ensure safety on the construction site. His interest is the well being of the construction workers on the construction site.

7) The influence of *society* is characterised by the presence of a wide range of organisations and (groups of) persons, who try to realise their own goals, to influence each other, and who use different instruments in doing so. Their main interest is to minimise hindrance for the surroundings.

8) Company's that have to use the road, it has to meet their demands. They need good roads to make their deliveries and need to be able to access the construction site.

Figure 34: actor analysis road construction.

Actor	Interests	Means
Principal	Economic profit Realisation on time Meeting demands	Financial Organisational skills
Designer	Optimal road design Reduce costs	Design knowledge
Building contractor	Economic profit High quality Realisation on time Meeting demands	Building knowledge Materials Manpower
Government	Social profit Enforcing law Minimising hindrance	Law/legislation
Road administrator	Economic profit High availability road Minimum maintenance	Maintenance knowledge Organisation skills
Safety inspector	Safety workers	ARBO-legislation
Society	Environment Minimising hindrance	Public opinion Law/legislation
Users	Access to/on site Good road	Demands

3.7. Design aspects

There are several aspects that influence the final temporary road design. These aspects are called preconditions. These preconditions vary per project or location and can also vary in time. Variation per project can be found in the expected traffic load and sub-grade. Variation in time can be seen as possibility of residential traffic and hindrance to the surroundings. In this section, possible preconditions are discussed and elaborated on their relevance and how they can be used them to make a good temporary road design.

- *Sub-grade data*. The sub-grade under the road has a large influence on the roads' design. On weak sub-grades, thicker and sometime lighter road constructions are necessary. The sub-grade is further discussed in chapter 4.

- *Traffic load*. Al roads are designed based on the expected traffic load. For temporary roads there is currently no data or model available about traffic load. Since this is important to know this research provides a model that can be used to estimate the traffic load. This model can be found in chapter 5.

- *Residential traffic*. On some roads it is not possible to separate the residential traffic from the construction traffic. However, the requirements at roads without residential traffic are significantly lower that road with residential traffic. If there is also residential traffic on the temporary road, the requirements for the temporary road are the same as on public roads. Thus, the presence of residential traffic has a great influence on the road design.

- *Traffic distribution plan.* The traffic distribution plan largely determines the traffic load that can be expected on each temporary road and whether or not residential traffic can is present. Because the requirements at temporary roads with residential traffic are higher it is important to determine these routes.

- *Allowed damage*. The requirements set for a temporary road used only by construction traffic are much lower then for a permanent road. Much more damage to the road is allowed if the temporary road is used by construction traffic only. In case there will also be residential traffic on the temporary road then the same rules apply as on public roads. Generally speaking: the more damage is allowed, the lower the construction costs.

- *Lead-up services*. To install lead-up services it is often necessary that open up the temporary road. This can lead to damage to the pavement and is hard to restore. There are better solutions available like installing a row of prefabricated concrete plates.

- *Combination with permanent road*. Combining the permanent road with the temporary road can lead to significant cost reductions. This combination can also lead to an increase in road quality of the temporary and permanent road. If the permanent road is combined with the temporary road this will generate an extra set of design requirements for the temporary road.

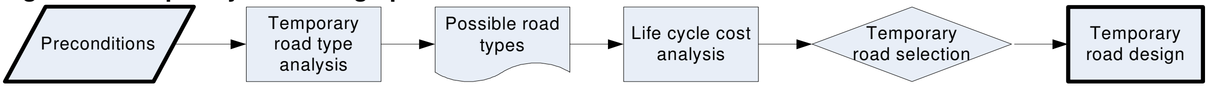
- *Parking spaces*. Sufficient parking spaces should be created on the construction site. It is not recommended that parking spaces are situated on the temporary roads since this can cause congestion and forces al traffic to use only one part of the road. This can shorten the lifespan of the temporary road.

- *Hindrance to surroundings.* Especially unpaved temporary road can cause hindrance to the surroundings in dry time due to dust. Therefore, if the project is situated in cities or if there are other object nearby then dust control is required. Also another type of temporary road, like an asphalt-paved road, prevent hindrance due to dust.

- *Life cycle costs*. The costs for temporary roads are indirect project costs. Therefore these construction costs have to be minimised. This means that they have no direct added value to the project, but these expenses have to made in order to construct the project. Therefore these costs should be minimised. It is also important to look at the lifecycle costs and the possibility of combining the temporary road with the permanent road.

All of the above preconditions influence the road design in some degree. However, from all these preconditions the life cycle costs are chosen to determine the final temporary road design. The design-process for temporary road is shown in Figure 35. The preconditions, set for a temporary road determine which road types can be used. By performing a life cycle cost analysis of the construction cost we can find the cheapest solution that fulfils the preconditions.

Figure 35: temporary road design process



3.8. Sustainable construction

The first initiative for sustainable construction in the Netherlands was made in the late eighties by the Dutch government. Sustainable construction can be described as *"the use of design and construction methods and materials that are resource efficient and that will not compromise the health of the environment or the associated health of the building occupants, builders, the general public or future generations".* There is an increasing demand, in both the private and public sectors, to understand sustainable construction practices. This demand is driven by a realisation that sustainable practices make sense to both owners and operators. The practices not only help the environment, but also can improve economic profitability and improve relationships with stakeholders.

Road construction is especially suited to apply recycled and "upgraded" waste materials in large quantities. Different types of granule and slag are frequently used as materials for unbound road bases. Upgrading old asphalt is also a very common technique in the Netherlands. In this research is influence or possibilities of durable construction regarding temporary roads are not further investigated. However we would like to note that temporary roads are well suited for the application of re-cycled materials because the requirement set for this type of road are often lower then for other roads.

3.9. Lead-up services

Lead-services are often installed under the roads in residential areas. The location of lead-up services in residential areas is arranged in NEN 1739 and outside residential areas in NEN 1739. The location of the lead-up services in residential areas is included in appendix 2.

Before houses can be delivered the lead-up services should be connected to the building. There are three main moments on which lead-up services are installed: (1) before the temporary roads are constructed, (2) after the temporary roads are constructed or (3) before the houses are delivered. The period of the construction of the lead-up services before the houses are delivered is also called the thirteen-week phase. Each moment has it advantages and disadvantages. If the services are installed early there will be large the uneconomic costs due to unused cables/tubes and the risk of damage due to settlements of the road. When the lead-up services are installed in the thirteen-week phase there is the risk of blocked paths caused by delays in the construction process and thereby the risk at extra delivery delays. When the lead-up services are installed after the temporary roads are constructed there is a high risk at damage to the roads and more repair costs to the roads.

If these three options are compared it becomes clear that the best options are to construct the lead-up services before the temporary road is constructed or before the houses are delivered. There is not a single best option available, however the risk of delays in the delivery of houses outweighs the added uneconomic costs. Also, if the terrain is made properly construction ready there is only limited risk at damage to the lead-up service cables and pipes and there are no repair costs which possible can be expected when the project is delivered in stages. Therefore it is recommend constructing the lead-up services before the temporary roads are constructed.

Table 16: comparing the possible moments for the construction of lead-up services.

Aspect	Before road constr.	After road constr.	Before delivery
Uneconomic costs	High	High	Low
Risk at damaged cables/tubes	High	High	Low
Risk at blocked paths	Low	Low	High
Damage to temporary road	Low	High	High

3.10. Summary

In this chapter possible design aspects of temporary roads are discussed. In the first section, the terminology as it will be used in this research is provided. In the next section a definition for a temporary road is formulated. A methodology that can be used to analyse, evaluate and compare different types of temporary roads is provided in the third section.

In section four to six possible functions of a temporary road, life cycle costs and actors in temporary road design are analysed. It is necessary to know the possible functions of a temporary road to satisfy the participants of a project. It is noticed that the construction and maintenance costs of temporary roads are indirect project costs, which means they have no direct added value to the project but are necessary to build to project. Therefore costs for the temporary roads should be minimised. When the temporary road and permanent road are combined in an integral design this can lead to cost reductions and improved road quality and improved conditions on the construction site.

The last three sections of this chapter dealt with general aspects in temporary road design. Possible design aspect that can influence temporary road design are: sub-grade data, traffic load, residential traffic, allowed damage, lead-up services, combination with permanent road, parking spaces, hindrance to surroundings and life cycle costs. It is noticed that temporary roads are good suitable for sustainable construction. Lead-up services are usually constructed under the road. The best point in time to construct the lead-up services is before the temporary roads are constructed.

4. SUB-GRADE

Temporary roads are constructed in or on top of the sub-grade present at the projects' location. The sub-grade has to support additional weight of the embankment, pavement and traffic load applied to it, without showing unacceptably large deformations. Therefore, consolidation and stability of the sub-grade determines largely the design and performance of a road. This makes it important to know what the characteristics of sub-grade are and what consequences this has for the roads design. In this chapter sub-grade characteristics that are required in other chapters of this research, thus necessary to make a temporary road design, are discussed.

For this research the eleven standard sub-grade profiles for the sub-grade of the Netherlands developed by C.R.O.W. (2002, 2006) are utilised. These profiles are mainly based on the expected settlements that are likely to occur in the sub-grade due to the applied extra load. Settlements of some sub-grades are unacceptably large and take too long to occur. Therefore construction sites on consolidation sensitive soils are first made construction ready to reduce the settlements before construction starts. The soils, which are likely to have large deformations in time, can mainly be found in the Western parts of the Netherlands. Figure 36 shows the location of different sub-grades in the Netherlands.

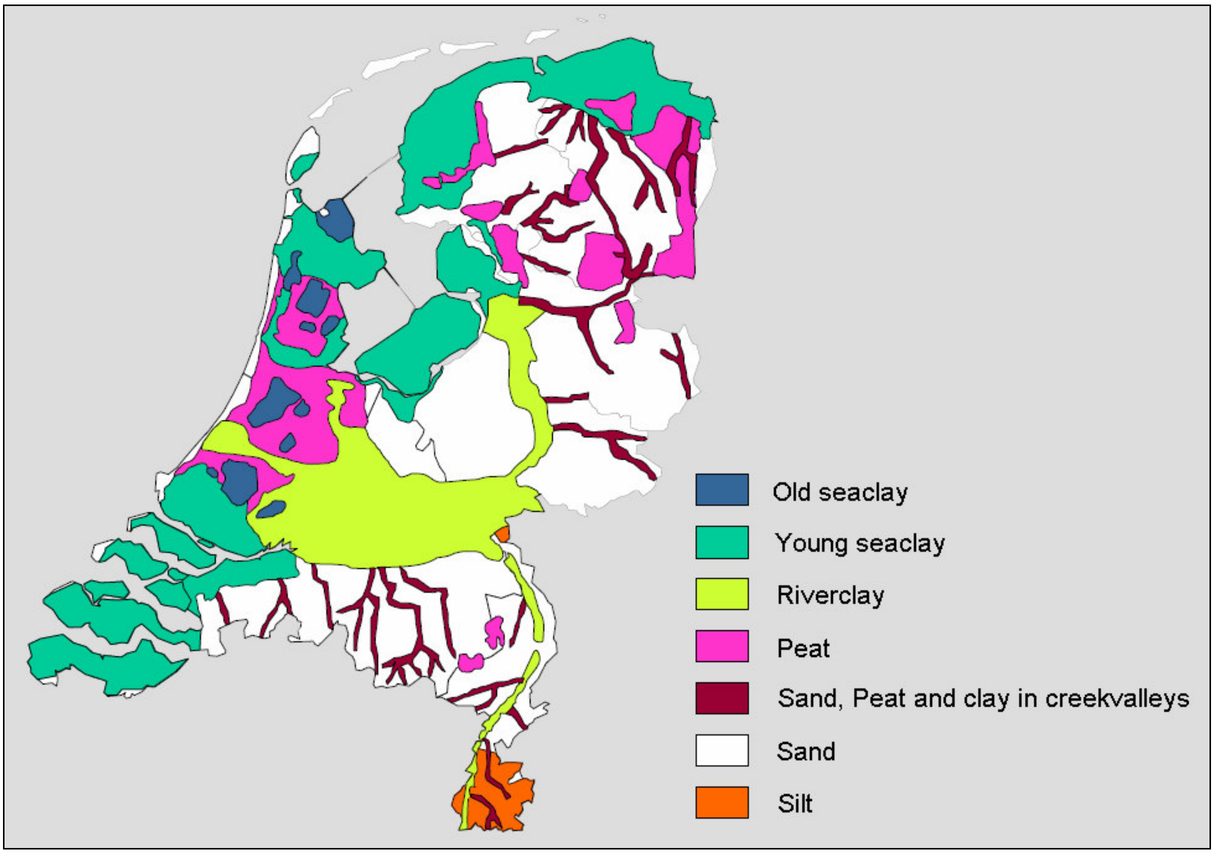


Figure 36: global distribution of soil types in the Netherlands (C.R.O.W., 2006)

The eleven standard sub-grade profiles that can be distinguished are discussed in section 4.1. The corresponding characteristics, determined by C.R.O.W. in combination with third parties, are discussed in section 4.2. Some of these charaterisics are not in agreement with other literature, therefore some suggestions for improvement are provided in section 4.3. Especially the undrained shear strength, which is used in chapter 6 to calculate the required granular layer thickness and internal friction angle are elaborated. Only characteristics relevant for this research are discussed. How the expected settlements in time can be determined for the standard sub-grade profiles is discussed in section 4.4. This chapter ends with a summary and a progressive scheme in section 4.5.

4.1. Standard profiles

The eleven standard sub-grade profiles are based on experience of C.R.O.W. and GEO-Delft. The first publication about the standard ground profiles was in the publication ‘standard sub-grade profiles for West-Netherland’ by Oostveen (1998). These eight sub-grade profiles were first used by C.R.O.W. in the publication ‘Design manual for widening of road and rail embankments’ (2001) and the ‘Thin asphalt layer design manual’ (2002). Because the profiles were only valid in western, northern and central parts of the Netherlands, three more profiles were added for better sub-grades in other parts of the Netherlands. This was done in the publication ‘Choice model for pavement design’ (2006).

The eleven standard sub-grade profiles in the Netherlands can be distinguished in four zones: peat (profile 1A and 1B), sea clay (profile 2A, 2B and 2C), river clay (profile 3A, 3B and 3C) and soils with better construction characteristics like stiff clay and sand (profile 3D, 4A and 4B). Profile 1A to 3C are consolidation sensitive sub-grades, profile 3D to 4B are not consolidation sensitive. The standard sub-grade profiles are created based on data from cone penetration tests. Therefore no ‘representative’ location can be designated for each profiles. The standard sub-grade profiles are graphically displayed in Figure 37. To select which profile fits best to a project location requires testing. Geo-technical data for these profiles is provided by C.R.O.W. (2006) is provided below in section 4.2.

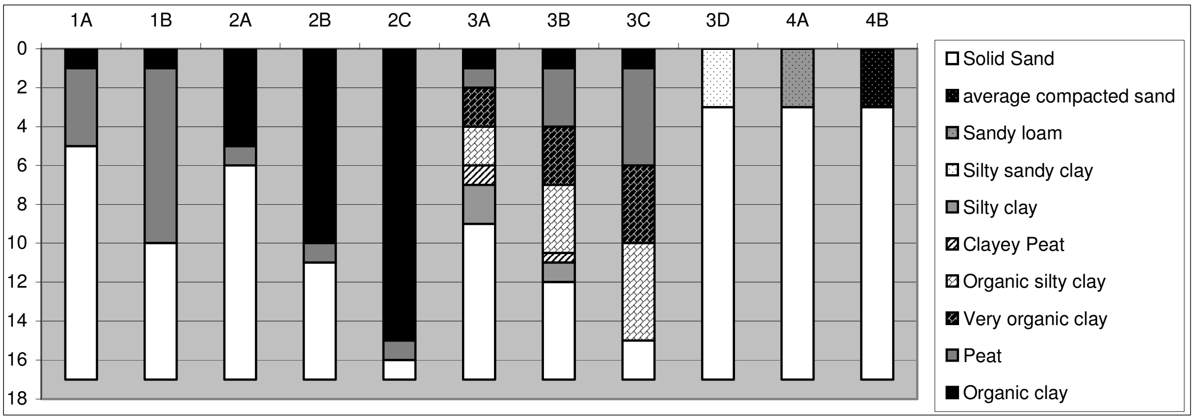


Figure 37: standard sub-grade profiles [depth in metre] for the Netherlands (C.R.O.W. 2006).

Table 17 shows the thickness of the layers present in the standard sub-grade profiles and the total thickness of the sub-grade. Under all profiles a well compacted sand layer is present.

Table 17: layer thickness [m] of the standard sub-grade profiles (C.R.O.W. 2006)

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	1	1	5	10	15	1	1	1			
Peat	4	9	1	1	1	1	3	5			
Very organic clay						2	3	4			
Organic silty clay						2	3,5	5			
Clayey Peat						1	0,5	0			
Silty clay						2	1	0			
Silty sandy clay									3		
Sandy loam										3	
low compacted sand											3
Well compacted sand	*	*	*	*	*	*	*	*	*	*	*
Total	**5**	**10**	**6**	**11**	**16**	**9**	**12**	**15**	**3**	**3**	**3**
* Present under all standard profiles.											

4.2. Sub-grade characteristics according to C.R.O.W.

Different sub-grades have different characteristics. To understand how a sub-grade will act under load it is important to know the characteristics of the soil types present in the sub-grade. Table 18 to Table 21 shows the Geo-technical data for the four main sub-grade categories (peat, sea clay, river clay and good construction sub-grades) as used by C.R.O.W. (2006) in developing the standard sub-grade profiles. These values are determined by GEO-Delft[9]. Some of the values differ compared to standard sub-grade characteristics determined by the Netherlands Standardisation Institute[10] and other literature. Therefore some proposals for improvement are included in sub-section 4.3. In this section in the following tables is:

γ_{sat} = Saturated specific weight [kN/m^3]
f_{undr} = Undrained shear strength [kPa]
C' = Cohesion [kN/m^2]
C_p = Primary compression coefficient under maximum stress value [-]
C_s = Secondary compression coefficient under maximum stress value [-]
C'_p = Primary compression coefficient above maximum stress value [-]
C'_s = Secondary compression coefficient above maximum stress value [-]
c_v = Consolidation coefficient [m^2/s]
φ = Internal shear angle [degree]
E = Youngs modules [MPa]

Table 18: layer thickness of the standard sub-grade profiles (C.R.O.W., 2006).

Layer	γ_{sat} (kN/m^3)	C_p (-)	C_s (-)	C'_p (-)	C'_s (-)	c_d (kN/m^2)	c_v (m^2/s)	φ' (º)	c' [kN/m^2]	1A (m)	1B (m)
Organic clay	14	25	90	10	35	3,1	10x10^{-8}	12,6	3,1	1	1
Peat	10,5	15	50	5	25	1,6	5x10^{-8}	16,9	1,6	4	9

Table 19: design values sea clay sub-grade profiles (C.R.O.W., 2006).

Layer	γ_{sat} (kN/m^3)	C_p (-)	C_s (-)	C'_p (-)	C'_s (-)	c_d (kN/m^2)	c_v (m^2/s)	φ' (º)	c' [kN/m^2]	2A (m)	2B (m)	2C (m)
Organic clay	15	30	110	13	50	3,8	7 x10^{-8}	19	3,8	5	10	15
Peat	11,5	20	60	6	25	3,8	2 x10^{-8}	16,9	3,8	1	1	1

[9] http://www.geodelft.nl/
[10] http://www.nni.nl/

Table 20: design values river clay sub-grade profiles (C.R.O.W., 2006).

Layer	γ_{sat} (kN/m^3)	C_p (-)	C_s (-)	C'_p (-)	C'_s (-)	c_d (kN/m^2)	c_v (m^2/s)	φ' (º)	c' [kN/m^2]	3A (m)	3B (m)	3C (m)
Organic clay	14	25	90	10	35	3,1	10x10^{-8}	12,6	3,1	1	1	1
Peat	11,5	20	60	6	25	3,8	7x10^{-8}	16,9	3,8	1	3	5
Very organic clay	13	22	80	8	30	1,6	5x10^{-8}	12,6	1,6	2	3	4
Organic silty clay	15	30	110	13	50	3,1	1x10^{-8}	12,6	3,1	2	3,5	5
Clayey Peat	11,5	20	60	6	25	3,8	2x10^{-8}	19,6	3,8	1	0,5	0
Silty clay	16	45	175	20	75	3,1	0,1x10^{-8}	12,6	3,1	2	1	0

Table 21: Design values good construction sub-grade profiles (C.R.O.W., 2006).

Layer	γ_{sat} (kN/m^3)	C_p (-)	C_s (-)	C'_p (-)	C'_s (-)	c_d (kN/m^2)	c_v (m^2/s)	φ' (º)	c' [kN/m^2]	3D (m)	4A (m)	4B (m)
Silty sandy clay	18	120	600	30	200	4,9	5x10^{-8}	21,5	4,9	3	-	-
Sandy loam	19	150	2400	45	800	2,5	2x10^{-7}	23,5	2,5	-	3	-
Average compacted sand	20	1000	-	300	-	0	1x10^{-2}	27,9	0	-	-	3

The undrained shear strength is expressed in a c'- φ' model. The calculated stiffness of the standard sub-grade profiles, expressed in the Youngs modules (E), is shown in Table 22. The Youngs modules must be estimated from the results of laboratory testing, in-situ loading tests or pressuremeter tests. According to C.R.O.W. (2002), in field-tests hardly ever show values under 20 MPa, even on very weak soils. Therefore values for E under 20 MPa are increased to 20 MPa. This is due to the short, dynamic loads on the road. However, on temporary roads the traffic is slower, thus increasing the load time and therefore decreasing the soil stiffness. These values for the Youngs modules are used throughout this research. If the soil is upgraded with an additional sand layer the Youngs modules increases as well. The values that can be used are also shown in Table 22.

Table 22: Youngs modules calculated by C.R.O.W. (2006) for the standard sub-grade profiles in MPa.

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
$E_{calculated}$ [MPa	10	9	19	19	19	10	10	10	54	76	100
E_{used} [MPa]	20	20	20	20	20	20	20	20	50	75	100
$E_{upgrade}$ [MPa]	80	80	80	80	80	80	80	80	100	100	100

To make drainage calculations (Chapter 7), the permeability of the standard sub-grade profiles and of the embankment sand is required. These values are shown in Table 23. These values are relatively low when compared to values given in other sources (Craig 1998; Segeren 1984). Still these values will be used for drainage calculations.

Table 23: permeability for the standard sub-grade profiles determined by C.R.O.W. (2006).

Number	Description	Permeability k [10^{-8} m/s]
1A	5m peat	1
1B	10 m peat	1
2A	6m seaclay	5
2B	11m seaclay	5
2C	16m seaclay	5
3A	9m riverclay	0,5
3B	12m riverclay	0,5
3C	15m riverclay	0,5

Number	Description	Permeability k [10^{-8} m/s]
3D	3m sandy and silty-clay	10
4A	3m loam	100
4B	3m average compacted sand	5000
Other	Sand	5000
	Well graded sand	1000
	Silty sand	100
	Embankment sand	300

4.3. Alternative sub-grade characteristics

As discussed in section 4.2, some of the variables determined for the C.R.O.W. design manuals are not in accordance with guidelines provided by the Netherlands Standardisation Institute (2006) or other literature like Craig (1998), SBR (1997) Segeren (1984). In this work we want to find more realistic values for the effective angle of friction and effective cohesion. Methods described in this section are only applied to the standard sub-grade profiles but can be used for all sub-grades. Generally accepted soil characteristics, as determined in the NEN 6740 (Netherlands Standardisation Institute, 2006) are provided in Table 24.

Table 24: soil characteristics according to NEN-6740 (2006) table 1.

Category		Consistency	γ_{sat} [kN/m^3]	E_{100}* [MPa]	φ [º]	$f_{undr.}$ [kPa]
Sand	Clean	Loose	19	15	30	-
		Average	20	45	32,5	-
		Dense	21 – 22	75 – 110	35,0 – 40,0	-
	Slightly silty		20 – 21	35 – 50	27,0 – 32,5	-
	Very silty		20 – 21	15 – 30	25,0 – 30,0	-
Loam	Slightly sandy	Soft	19	2	27,5 – 30,0	50
		Average	20	3	27,5 – 32,5	100
		Stiff	21 –22	5 – 7	27,5 – 35,0	200 – 300
	Very sandy		19 –20	3 – 5	27,5 – 35,0	50 – 100
Clay	Clean	Soft	14	1	17,5	25
		Average	17	2	17,5	50
		Stiff	19 – 20	4 – 10	17,5 – 25	100 – 200
	Slightly sandy	Soft	15	1,5	22,5	40
		Average	18	3	22,5	80
		Stiff	20 – 21	5 – 10	22,5 – 27,5	120 – 170
	Very sandy	-	18 – 20	2 – 5	27,5 – 32,5	0 – 10
	Organic	Soft	13	0,5	15	10
		Average	15 – 16	1,0 – 2,0	15	25 – 30
Peat	Non-preloaded	Soft	10 – 12	0,2 – 0,5	15	10 – 20
	Preloaded	Average	12 – 13	0,5 – 1,0	15	20 – 30
* Youngs modules under an effective stress of 100kPa.						

Procedure determination improved $f_{undr.}$

The influence depth of the road in the sub-grade has to be determined before we can determine the improved undrained shear strength. The (dynamic) load on a road is distributed in the sub-grade as shown below in Figure 38. In the figure is B_{ef} the roads width a_e the influence width and f_e the influence depth of the road (NEN 6744, 2006).

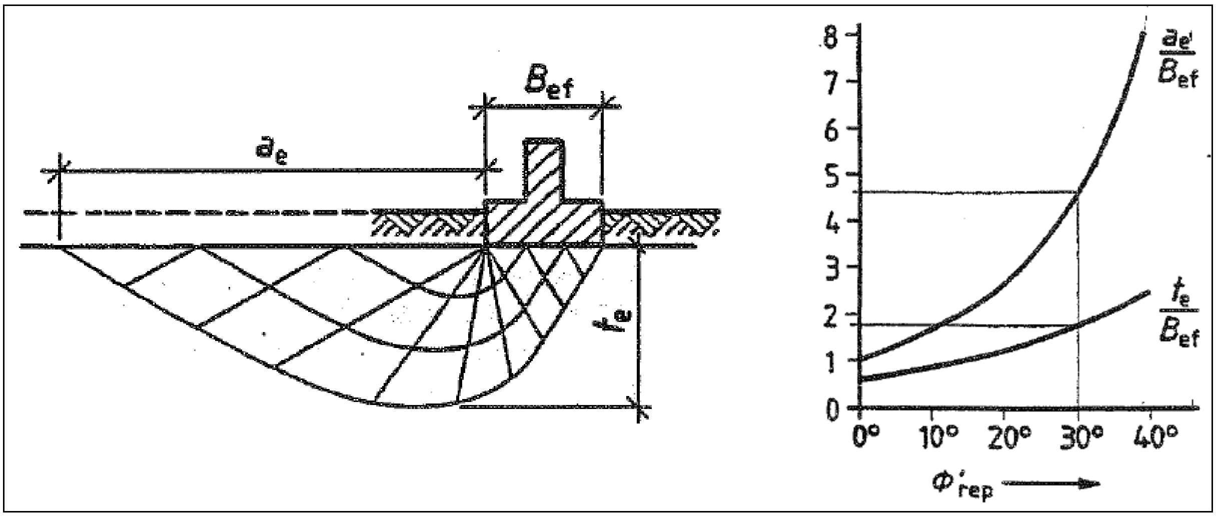


Figure 38: influence road on sub-grade (NEN 6744).

Previously it was discussed that the optimal temporary road width is 5,5 metre. When the internal shear angle is known, the influence depth can be calculated with the formula shown right in Figure 38. Table 25 shows the relation of the internal friction angle and the influence depth for a road 5,5 metre wide.

Table 25: influence depth under a 5,5 metre wide road, dependent on phi (NEN 6744).

φ [º]	**15,0**	**17,5**	**20,0**	**22,5**	**25,0**	**27,5**	**30,0**	**32,5**	**35,0**	**37,5**	**40,0**
t_e	6,0	6,5	7,2	7,8	8,5	9,2	9,9	10,7	11,5	12,3	13,2

For the standard sub-grade profiles, the average effective internal friction angle is not known. Because there are multiple layers in the sub-grade a weighted average, depending on the influence depth, needs to be calculated. NEN 6744 provides a method to calculate the weighted average for the effective friction angle for a sub-grade. The following equation has to be used:

$$\phi'_{e;d} = \frac{\sum_{i=1}^{i=n} H_i * \phi'_{i;d} * X_i}{\sum_{i=1}^{i=n} H_i * X_i} \qquad (1)$$

In which:
$\Phi'_{e;d}$ = Weighted average for the effective angle of internal friction [°]
n = Number of layers [-]
H_i = Thickness of layer i [m]
$\Phi'_{i;d}$ = Effective angle of internal friction of layer i [°]
X_i = Assistance variable for layer i, determined with the following equation:

$$X_i = t_e + 0{,}5 * H_i - \sum_{j=1}^{j=i} H_j \qquad (2)$$

In which:
t_e = Influence depth [m]
H_j = Thickness of layer j [m]

The calculation of the weighted average for the effective friction angle is an iterative process because the average effective friction angle is dependant on the influence depth and the influence depth is dependant on the average effective friction angle. Now, the calculated the weighted average for the effective friction angle for the eleven standard sub-grade profiles can be calculated. The complete calculation can be found in appendix 3. The result of the calculation is shown in Table 26.

Table 26: weighted average for the effective friction angle and the corresponding influence depth for the standard sub-grade profiles.

Profile:	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
$\Phi'_{e;d}$ [^{o}]	21,4	15,3	16,9	15	15	17,2	15,4	15	29,3	31,6	32,7
t_e [m]	7,5	6,1	7,1	6,0	6,0	6,5	6,1	6	9,7	10,4	10,8

With the influence depth known, the weighted average of the effective cohesion of the sub-grade can be calculated. NEN 6744 (2006) also provides an equation to calculate this:

$$c'_{e;d} = \frac{\sum_{i=1}^{i=n} H_i * c'_{i;d} * X_i}{\sum_{i=1}^{i=n} H_i * X_i} \qquad (3)$$

In which:
$c'_{e;d}$ = Weighted average for the effective cohesion [kPa]
$c'_{i;d}$ = Effective cohesion for layer i [kPa]
n = Number of layers [-]
H_i = Thickness of layer i [m]
X_i = Assistance variable for layer i (see above)

The calculations for the weighted averages of the effective cohesion in the standard sub-grade are shown in detail in appendix 3. The end-results are shown in Table 27. Sand sub-grades have no cohesion, therefore no value for the average effective cohesion of profile 4B is provided. The average effective cohesion parameter of the sub-grade is required to calculate the effective undrained shear stress. The undrained shear strength can be calculated with the following equation:

$$f_{undr.} = c'_{e;d} + \sigma'_z * \tan(\phi'_{e;d}) \qquad (4)$$

Undrained means that $\Phi'_{e;d} = 0^o$, so it can be concluded that the weighted average for the cohesion is the undrained shear strength. These values will be used for the determination of the granular layer thickness of unpaved roads in chapter 6.

Table 27: weighted average for the undrained shear strength of the standard sub-grade profiles.

Profile:	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
$f_{undr.}$ [kPa]	14,51	14,60	24,84	25,00	25,00	25,49	22,08	21,53	40,00	50,00	-

The procedure, applicable to every sub-grade, can be summarised as follows:

Step 1: Determine the internal friction angle ($\Phi'_{i;d}$) for each layer, using NEN 6740 (2006) table 1 in the sub-grade and select the highest value as starting value.
Step 2: Determine the corresponding influence depth (f_e) of the road (see Figure 38).
Step 3: Determine the average value for the internal friction angle ($\Phi'_{e;d}$) in the sub-grade.

Step 4: Determine the difference in between the new and old friction angle. If the difference is:

a. larger than 5% → go to step 2 and determine the new influence depth and the new internal friction angle in step 3.

b. smaller than 5% → continue to step 5

Step 5: Determine the average value for the effective cohesion and determine $f_{undr.}$.

4.4. Consolidation

When projects, such as roads or buildings, are constructed on consolidation sensitive soils (profile 1A to 3C), significant settlements may occur due to the consolidation of these soils under the added loads. This will result in a vertical displacement of the surface corresponding to the volume change (Craig 1999). Consolidation is the gradual reduction in volume of a saturated, low permeability soil due to slow drainage of the pore water. The process continues until the excess pore water pressure, set up by an increase in stresses, has completely dissipated. Consolidation is not the same as compaction. Compaction is the change of volume due to reduction air voids in the soil. Consolidation is a slow process, it may take decades or even centuries for a soil to come into equilibrium with the stresses applied to it, while compaction can be achieved relatively fast. Compressible soils often have low permeability (peat's, silts, clays), and water can not be easily or quickly removed, making the consolidation time unacceptably long.

Consolidation calculations are in most situations in the Netherlands made according to the Koppejan method. The Koppejans equation yields the magnitude of the total settlement, so the primary settlement (obtained at the end of the consolidation process) plus the secondary settlement (resulting from creep of the grains). For the standard sub-grade profiles, consolidation calculations have already been made. There are three main options available for the surface construction height of the road: 0,1, 0,4 or 0,7 metre above the old sub-grade level. If the project is build on a consolidation sensitive soil or on a location with a high sub-grade water table, then the terrain is heightened with sand to make it construction ready. Typical values for this are 0,4 and 0,7 metre, which means the roads' surface is also constructed at this height. If no additional sand is necessary, then the road is constructed 0,1 metre above ground level. The consolidation calculations are based on the assumption that the intended construction height is reached after consolidation. The natural consolidation is assumed to occur in 10.000 days. This mechanism is shown in Figure 39.

Figure 39: mechanism behind settlement calculation.

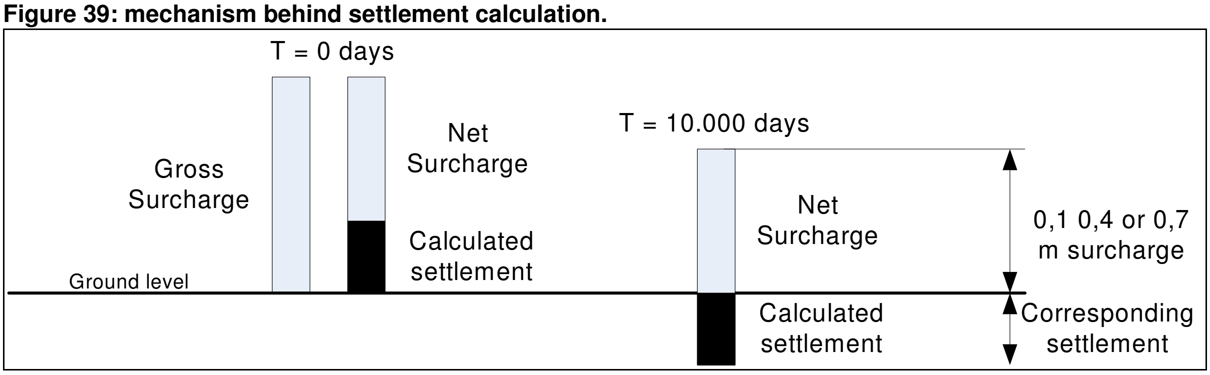


Table 28 to Table 30 show the settlements that can be expected for the standard sub-grade profiles (C.R.O.W. 2002). Two main possibilities can be distinguished: untouched terrain or terrain above a previous waterway, each having a different total settlement prediction. Profile 3D, 4A and 4B are assumed non-consolidation sensitive. The largest settlement is expected to occur under the centre of the road. The gross surcharge can be calculated by summarising the net surcharge and the calculated settlement.

Table 28: expected settlements per sub-grade profile 0,1 metre above old ground level in meter (C.R.O.W. 2002).

What \ Profile	1A	1B	2A	2B	2C	3A	3B	3C
Virgin terrain	0,65	1,40	0,35	0,40	0,40	0,55	0,65	0,70
Above waterway	1,35	3,70	0,60	0,70	0,75	0,95	1,55	1,95

Table 29: expected settlements per sub-grade profile 0,4 metre above old ground level in meter (C.R.O.W. 2002).

What \ Profile	1A	1B	2A	2B	2C	3A	3B	3C
Virgin terrain	1,10	2,45	0,35	0,40	0,40	0,70	1,05	1,30
Above waterway	1,55	4,05	0,65	0,80	0,90	1,25	1,90	2,50

Table 30: expected settlements per sub-grade profile 0,7 metre above old ground level in meter (C.R.O.W. 2002).

What \ Profile	1A	1B	2A	2B	2C	3A	3B	3C
Virgin terrain	1,40	3,10	0,50	0,55	0,60	1,10	1,50	1,95
Above waterway	1,70	4,25	0,80	1,00	1,20	1,50	2,25	2,95

Construction of the temporary roads can only start when the expected remaining settlements are within the allowed limit. For the remaining settlement, after construction is finished, in road construction values between 0,05 and 0,25 metre are common demands. For temporary road this value van be relatively high, because more damage can be allowed to occur to this type of road. Appendix 4 shows the total settlements that can be expected per sub-grade profile. As example the displacement design graphs for profile 2B are shown in Figure 40: natural settlement and if vertical drains are applied.

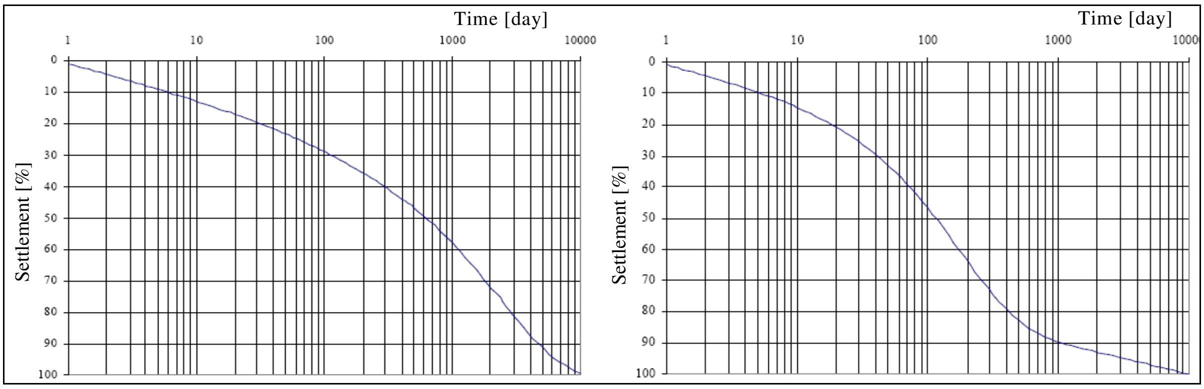


Figure 40: displacement design graphs for standard profile 2B. Left: normal consolidation, right: if vertical drains are applied (C.R.O.W. 2006).

The expected settlements for the standard sub-grade profiles, calculated by C.R.O.W. (2006), varies between 0,35 and 4,25 metre. Also the expected settlements times vary strongly. Before construction can start, the expected remaining settlements need to be reduced within the allowed limit. This is expressed in the settlement percentage, which we can calculate with the following equation:

$$S = \left(\frac{z - rz}{z} \right) * 100\% \qquad (5)$$

In which:
S = Required settlement percentage [%]
z = Expected settlement [m]
rz = Remaining settlement demand [m]

When we look at the displacement design graphs, it is visible that natural consolidation can take a long time (up to many years), which is in most cases not allowed or undesired. In such cases consolidation acceleration measures are necessary. For the standard sub-grade profiles there are three options are available to reduce the consolidation time: applying a temporary extra sand layer of 1m, vertical drainage and sand screens (for explanation of the last two, see chapter 7). For these measures, displacement design graphs are included in appendix 4. If vertical drains or sand screens are used then different displacement design graphs are necessary. These are also included in appendix 4. If temporary extra height is used, a new settlement percentage has to be calculated. The following equation can be used to calculate the settlement percentage. In this equation z_s is the expected settlement in metre if temporary surcharge height is applied.

$$S = \left(\frac{z - rz}{z_s} \right) * 100\% \qquad (6)$$

Table 31: Expected settlement with extra-added height (z_s) [m].

Surface height \ Profile	1A	1B	2A	2B	2C	3A	3B	3C
0,1 m above old ground level	1,25	2,10	0,70	0,80	0,80	1,05	1,25	1,35
0,4 m above old ground level	1,55	2,90	0,70	0,80	0,80	1,15	1,55	1,75
0,7 m above old ground level	1,75	3,45	0,75	0,90	0,90	1,45	1,90	2,35

Using the program MSettle version 7.3 developed by GEO-Delft, which is the same program that was used for the original calculations but then an older version (6.3), control calculations were made. When the same soil parameters and sub-grade compositions as displayed in section 4.2 are entered into the program the results are slightly different but comparable to the results presented in this section. However, when the standardised soil characteristics as described in table 1 of NEN 6740 (2006) are entered, large differences occur. This is caused by the utilisation of 'experience' data. Calculations with MSettle show that for sub-grade 1B the settlement decreases from 3,10 (calculated by C.R.O.W. according to NEN 6740 + 'experience data') to 1,54 metre based exclusively on NEN 6740 (2006). The main reason for this is the conservative presentation of the sub-grade characteristics by C.R.O.W. and GEO-Delft (2006) which is causing larger settlements. Additional sub-grade research is recommended on weak sub-grades. Using results from cone penetration tests and the program MSettle can easily do this.

Example: consolidation calculation.

Project:

Sub-grade: profile 2B, virgin terrain
Allowed remaining settlement: 0,20 m
Road construction height: 0,7 m above ground level.
Allowed settlement time: 200 days

Calculation:
Expected settlement: 0,55 m → required settlement percentage is
S = ((z-rz)/z)*100% = ((0,55-0,20)/0,55)*100%=64 %
Natural settlement will require more than 1000 days → too long.

If temporary extra surcharge is applied on the location to quicken settlements, the expected settlement increases from 0,55 to 0,90 m, so z_s = 0,90. The new settlement percentage becomes: $S = ((z\text{-}rz)/z_s)*100\% = ((0,55\text{-}0,20)/0,90)*100\% = 39\ \%$

The settlement will require 250 days → too long, thus other measures are necessary sand screens (190 days) or vertical drainage (180 days) can be used (Appendix 4). The final decision will probably be based on the construction costs.

4.5. Summary

In this chapter the eleven standard sub-grade profiles that can be found in the Netherlands are discussed. These profiles are assumed to be representative for the Netherlands. Corresponding sub-grade characteristics are provided by C.R.O.W. (2006). It is concluded that there is significant doubt about the correctness of the parameters as provided for the standard sub-grade profiles. In this research some suggestions for more suitable characteristics are made. The sub-grade characteristics displayed in Table 32 can be used to quickly estimate a temporary road design. It is concluded that standard subgrade profiles show much promise to quickly estimate a temporary road design. However, additional research on the sub-grade profiles is required.

Table 32: summary soil characteristics.

Profile:	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
E_{used} [MPa]	20	20	20	20	20	20	20	20	50	75	100
$E_{upgaded}$ [MPa]	80	80	80	80	80	80	80	80	100	100	100
$\Phi'_{e;d}$ [°]	21,4	15,3	16,9	15	15	17,2	15,4	15	29,3	31,6	32,7
t_e [m]	7,5	6,1	7,1	6,0	6,0	6,5	6,1	6	9,7	10,4	10,8
$f_{undr.}$ [kPa]	14,51	14,60	24,84	25,00	25,00	25,49	22,08	21,53	40,00	50,00	0
k [10^{-8} m/s]	1	1	5	5	5	0,5	0,5	0,5	10	100	5000

This chapter can be summarised with the following progressive scheme.

Progressive scheme:

Step 1: determine which standard profile fits best to the sub-grade of the project site and the corresponding sub-grade characteristics.

Step 2: determine the expected settlement, allowed settlement and the bearing capacities of the sub-grade

Step 3: determine the construction start date.

Note: The design table and sub-grade characteristics as presented in this chapter can be used for a quick approximation and will probably suffice for the design of a temporary road. This is because the requirements set for this type of road are lower than for permanent roads or buildings. A more precise sub-grade analysis is required for the design of rest of the construction project or when the temporary road is combined with the permanent road This is not included in this research.

5. TRAFFIC LOAD MODEL

This chapter deals with development of the traffic load model to estimate the traffic load on temporary roads on residential construction sites. Currently, temporary road design are based on experience en guesses because there is no data or model available about the traffic. This however, can lead to over- or under-dimensioning and thus to extra project costs due to extra material or to high maintenance costs. To quickly gain insight in the traffic load that can be expected on temporary roads, a computer model has been developed. The model can be used to quickly calculate the estimated load on temporary roads by calculating the approximate project weight that has to be transported over the road. The main idea of the model is that the weight of the material that needs to be transported over a certain road can be calculated. Construction material is transported using transport trucks, which will have a certain dead weight. If a relation between the dead weight and the load capacity of trucks can be found then the total dead weight of the transport trucks can be calculated given a certain transport weight. Adding the dead weight and the weight of the construction material will give an estimation of the total traffic load (expressed in kilogram or Newton) on the temporary road during the construction stage. Figure 41 shows the model to determine the traffic load.

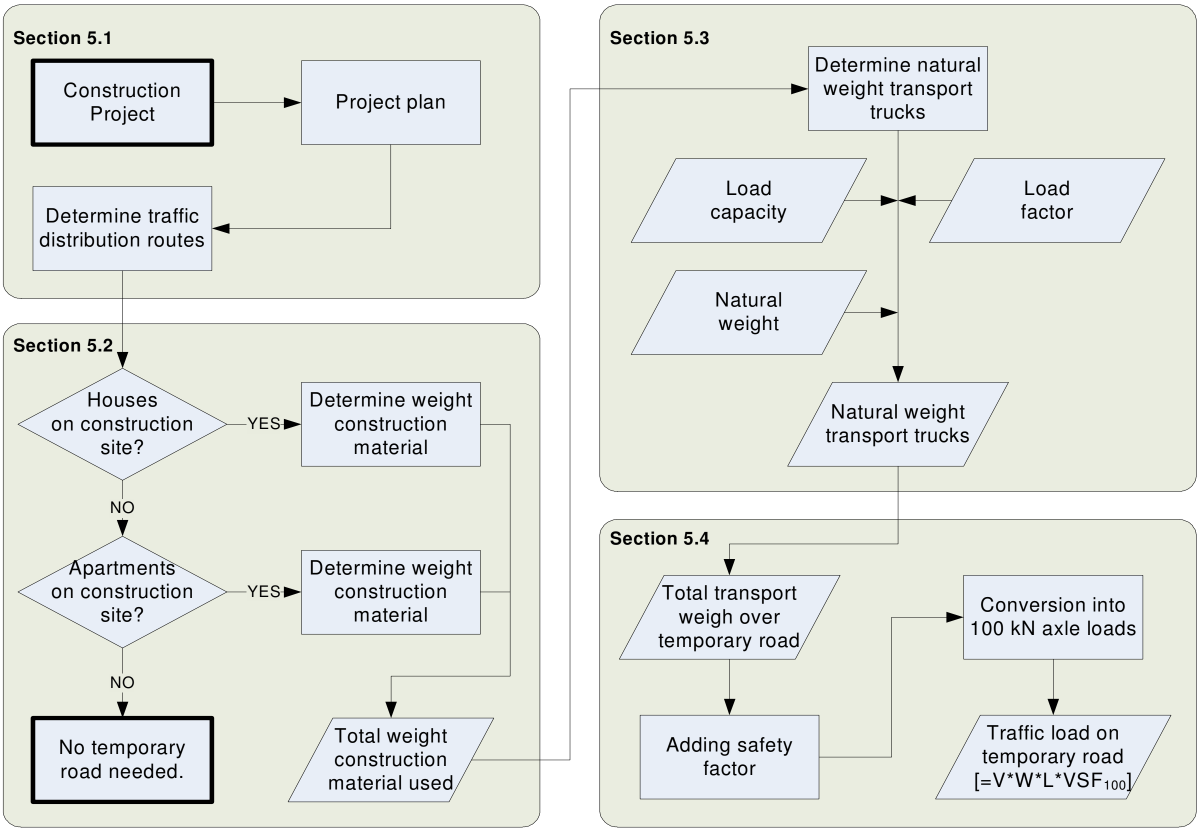


Figure 41: model to determine design load on temporary roads

Not all roads on a construction site have the same design load. To prevent over dimensioning of roads with less traffic, it is important to look at the traffic distribution on the construction site before calculations are made. In section 5.1 is explained how the model can be applied to the different roads on a construction project based on traffic distribution. Section 5.2 deals with the calculation of the total weight that needs to be transported in order to construct the project. In section 5.3 the relation between the dead weight of a transport truck and the load capacity and how this can be used to determine the dead weight of the trucks necessary to transport the construction material is researched.

The design load of the temporary roads is determined in section 5.4 as well as the input required in road calculation programs like CARE for asphalt pavements. To quickly gain insight in expected traffic load on the temporary road traffic load design tables for houses and apartment buildings are provided in section 5.5. Verification of the model is discussed in section 5.6. At the end of this chapter, in section 5.7, a summary and progressive scheme is provided.

Model assumptions

As a model is only a representation of the truth, the possible input of the model is limited. The following assumptions are made during the development of the model:

- The project's design is known. Therefore the project size, foundation type, buildings' dimensions, material used, etc… is known.
- Loaded and unloaded trucks use the same route, thus every truck passes twice over the road.
- Only trucks cause damage to the temporary road.
- The traffic on the temporary roads is heavy goods vehicle traffic (VSF_{100} = 2, RWS (1998))

5.1. Traffic distribution

Not every road receives the same traffic load on larger construction sites. The total amount of traffic due to construction activities is distributed over the roads on a construction site. Therefore it is not cost efficient to construct all roads with the same design. The case studies (chapter 2) learned that on larger construction projects, different kinds of temporary roads can be distinguished. Table 33 gives the three main types of temporary roads.

Table 33: types of temporary roads.

Type	Traffic Load	Description
First order road	High	First order roads provide the main access to the complete project site.
Second order road	Medium	If the project is divided in two or more zones, the second order roads provide access to those zones.
Third order road	Low	The third category can be found on the separate construction sites (parts) in a zone.

The categories of Table 33 are clarified in the example project as shown in Figure 42. The thick black line represents the main access road to the island. In the example project there are two main access points to the construction project. It is important to realise that one of the access points might not be available because of the possible separation of residential traffic from construction traffic. The first order road provides the main access to the four parts. All transportation's for the four parts will pass over this road. The second order roads are situated in the four parts of the project site and deal with the construction traffic for this specific part. If all four parts are equally sized, the traffic load on the secondary roads will be only a quarter of the traffic load of the first order road. On big projects it is common that construction companies use a third order road on their construction site. These roads have the lowest traffic load. The first and second order roads usually are under the supervision of the government, the third order road is under the supervision of the construction company.

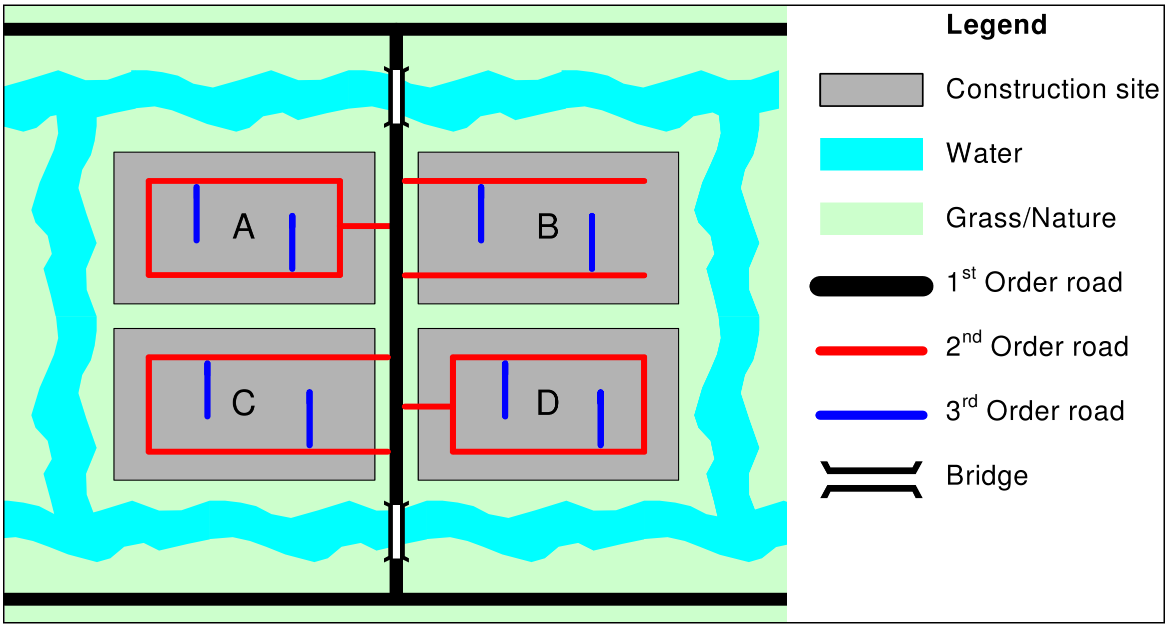


Figure 42: layout of an example project.

The first step when using the model is to make a classification of the roads that have to be constructed. The developed model can then be used to calculate the traffic load on all the different roads of the construction site. It is important to look at the traffic that possibly passes over that road and to fill in the different model parameters accordingly. The total project should be split up into several small projects, each having more or less the same design and use the same roads. Now the estimated traffic load on the temporary roads in that part can be calculated using the model. It is recommended to start with the determination of the expected traffic on the lowest order roads and then to work up to the highest order roads. This is because the traffic of a lower order road has to pass over a higher order road. For example, the project in Figure 42 can be split up in four sections (A,B,C and D). Now the load on the first order road can be calculated by summarising the calculated traffic on the second order roads in the four sections.

5.2. Load determination

In this section the expected load, generated by the construction activities, on the temporary roads is calculated. In section 5.2.1, the basic design of the model is explained, in section 5.2.2 the properties of the possible construction materials used in the model are displayed. How weight calculations can be made is explained in section 5.2.3. The necessary input parameters of the model are discussed in 5.2.4. Finally the use of the safety factor is explained in section 5.2.5

5.2.1. Basic model design

The schematic design of standard buildings, used in the model, is displayed in Figure 43. The model is designed so that two types of buildings can be calculated. The figure represents a house, housing block or apartment building with a pitched roof (left) or a flat roof (right). A house is a single residential space, a block is a building with multiple accommodations under one roof. An apartment building or flat is a building with multiple apartments next an above each other. The model was specifically designed to calculate the weight of a house or block as shown on the left figure, but can also calculate the weight of a multiple story building with many apartments. Due to the assumption that all apartments in a building are equally sized, it is only necessary to enter the number of apartments or houses on the ground level and the number of floors.

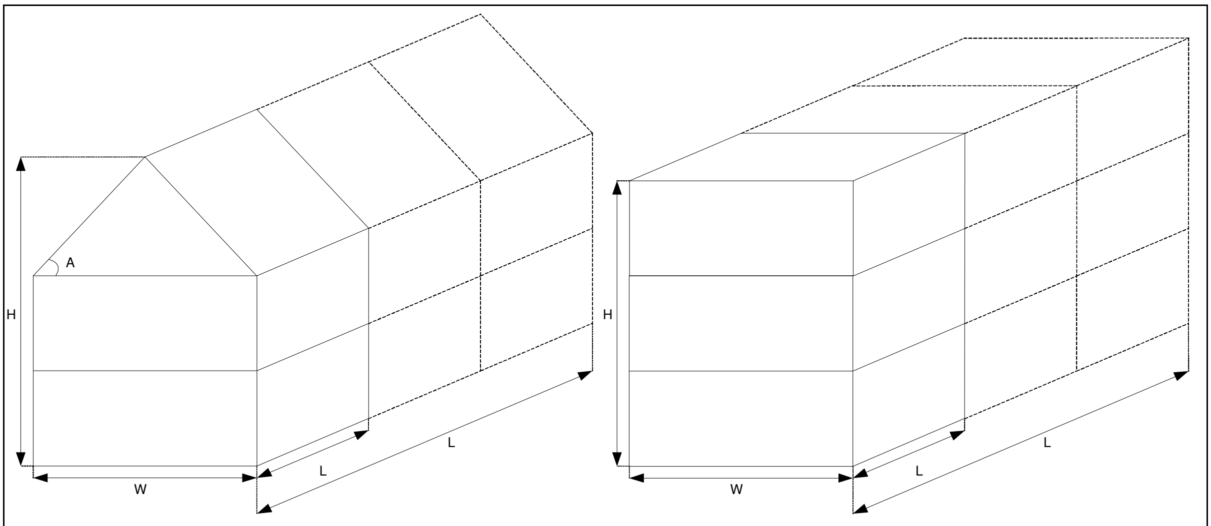
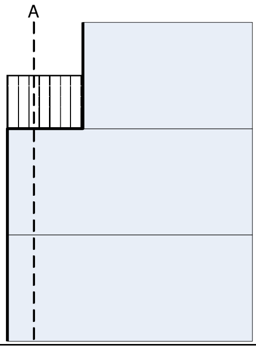
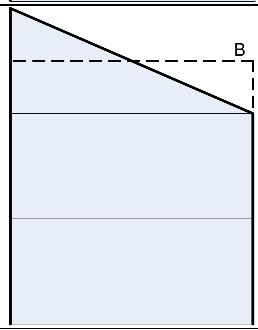
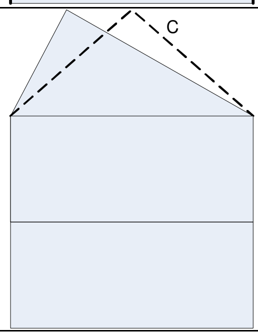


Figure 43: schematic representation of a house (block) and apartment building as used in the model.

In the past, new houses where build similar to the standard houses in Figure 43. Variations were made in dimensions but hardly in the shape of the building. Nowadays houses are designed in many different shapes. To keep the computer model simple, and thereby making it easier to use, the possibly more complex shapes of current houses need to be translated into one of the two possibilities as shown in Figure 43. This has to be done such that the result is a good approximation, in terms of weight. Some examples of how this can be done are provided below in Table 34.

Table 34: examples of approximating houses with standard houses of Figure 43.

Description	Figure
The first example is a three-story house with a balcony on the top floor. This house resembles the right standard house of Figure 43 with a gap on the top floor. This can be easily transformed into the basic house by reducing the building width by 1/3 of the balcony's width, making the whole building a bit smaller. This way the total area of the side wall stays the same. However by doing this the foundation is also made smaller leading to some loss of weight. Using the safety factor can be used to compensate for this loss.	
The second example is a house with a pitched roof however unlike the left standard house in Figure 43.. The easiest way of transforming this house into one of the standard house is to approximate it with the right house of Figure 43. This will result in slightly less roof surface. The safety factor can be used to compensate for this loss.	
The last example shows a house with a pitched roof, however the top of the roof is not in the centre of the building. This can be approximated with the right standard house as shown in the figure to the right. It is recommended that the new wall area be kept the same, leading to the same weight of the load-bearing walls in the new situation. These adjustments will not result in large differences in the calculated weight of the roof The safety factor can be used to compensate for this loss.	

The model calculates the weight of the building by calculating the weight of specific parts of the building. To limit the number of input parameters and to reduce the model's complexity the building has been divided into ten main parts. The following ten parts can be distinguished (see also Figure 44):

Table 35: parts of the building with description.

Part	description
1) Excavation	Before a foundation can be constructed the soil, to be removed. Since it is possible that the soil is transported away over the temporary road, this weight can be included in the model. The option no excavation is also present in the model.
2) Foundation	Under building are the foundation walls situated. There are two possibilities: in case no piles are used, then a concrete plate supports the foundation walls. In case piles are used, a plate is not necessary.
3) Load-bearing wall	The load-bearing walls support the roof and floors. These walls separate buildings from each other.
4) Ground floor	This floor is laid on top of the foundation walls.
5) Level floor(s)	Several level floor(s) present in the building.
6) Interior walls	These walls are placed between the load-bearing walls and behind the exterior wall.

Part	description
7) Exterior walls	The exterior walls are on the outside of the building.
8) Floor cover layer	After the installation of services in the building the cables and tubes are covered with a cover layer.
9) Roof	The building's roof, can be flat or under an angle.
10) Glass percentage	This is the surface percentage of windows and doors in the outside walls of a single house (from the ground floor up to the roof). The weight of glass areas is considerably less then the weight of the inner- and outer-wall combination.

The load-bearing walls, exterior walls, interior walls, ground level floor, level floor(s) and the roof as used in the model are displayed more clearly below in Figure 44.

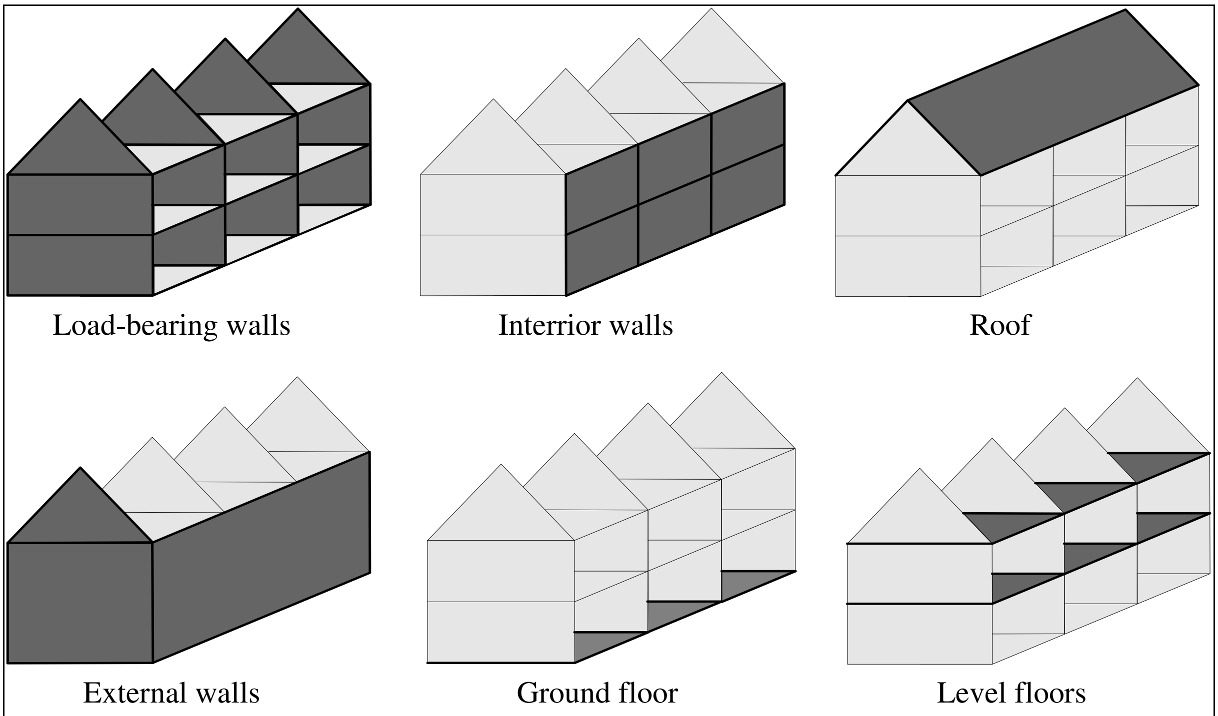


Figure 44: parts of a block.

All buildings need a foundation in order to transfer the load of the building to the ground. Before a foundation can be constructed the location of the foundation first needs to be excavated. There are three possibilities in the model for the excavation of the foundation: stroke, complete or no excavation. Figure 45 shows these possibilities for the excavation. The left figure shows the stroke excavation, only on the place of the foundation the soil has been removed with 0,5 m extra on both sides. The right figure shows the complete excavation where all soil under the houses has been removed to a certain depth with 0,5 m extra around the foundation. The last possibility is that there is no excavation at all. The depth of the excavation is in al cases equal to the height of the foundation walls. This assumption is made to limit the number of input parameters.

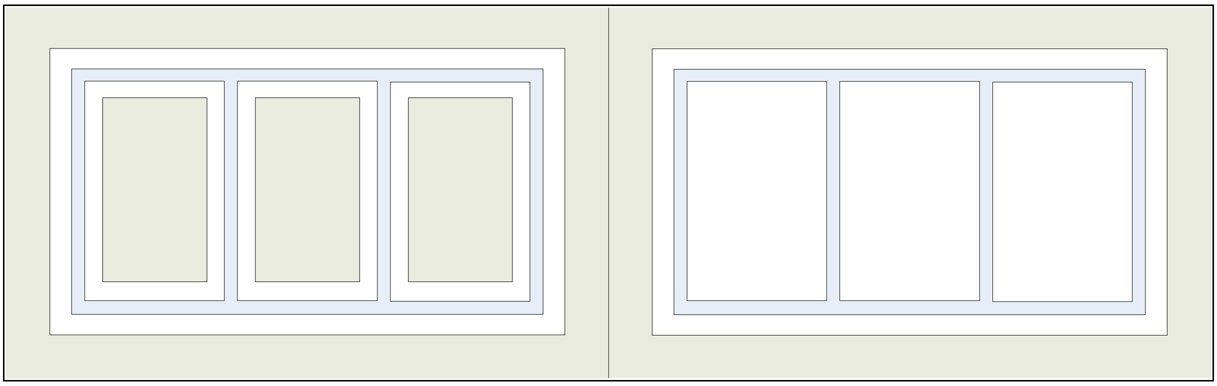


Figure 45: foundation in excavation. Left: stroke, right: complete.

Besides the building itself the model can also be used to calculate some additional load on the temporary road. The following can be calculated in the model

1) *Waterways*. Sometimes it is not possible to dig waterways on the construction site before the construction of the buildings is finished (this happened for example on IJburg).

2) *Garden heightening.* Sometimes gardens have to be heightened after the construction of the building is finished.

3) *Sheds*. These are buildings in gardens mostly used for storage or parking. These buildings are sometimes constructed at the same time as the other buildings.

5.2.2. Materials

The construction materials shown in Table 36 are used in the model. All these materials have their own specific weight. To calculate the weight of the construction material that has to be transported the specific weight is required.

Table 36: specific weight of the materials used in the model.

Material	**Specific weight**	**Dimension**
Concrete (gravel)[11]	2403	kg/m^3
Sand-lime stone[2]	2000	kg/m^3
Clay bricks (common red)[2]	1922	kg/m^3
Concrete brick[2]	2403	kg/m^3
Aerated concrete	1000	kg/m^3
Glass[2]	2579	kg/m^3
Tiles[12]	45	kg/m^2
Prefab wooden roof[13]	55	kg/m^2
Vuren Wood[1]	600	kg/m^3
Asphalt roofing	5	kg/m^2
Possible floor types		
Isolation floor 200 mm[14]	303	kg/m^2
Isolation floor 260 mm[4]	376	kg/m^2

[11] http://www.simetric.co.uk/si_materials.htm

[12] http://www.wienerberger.nl

[13] http://www.unidek.nl

[14] http://www.vbi.nl

Material	Specific weight	Dimension
Isolation floor 320 mm[4]	443	kg/m^2
Channel floor 200 mm[4]	303	kg/m^2
Channel floor 260 mm[4]	376	kg/m^2
Channel floor 320 mm[4]	443	kg/m^2
Apartment floor 200 mm[4]	382	kg/m^2
Apartment floor 260 mm[4]	606	kg/m^2
Apartment floor 320 mm[4]	706	kg/m^2
Possible roof types		
Wood, clay tiles	100	kg/m^2
Wood, roof covering	60	kg/m^2
200mm concrete, roof covering	308	kg/m^2
260mm concrete, roof covering	381	kg/m^2
320mm concrete, roof covering	448	kg/m^2
Possible pile types		
180 mm x 180 mm	78	kg/m
220 mm x 220 mm	116	kg/m
250 mm x 250 mm	150	kg/m
290 mm x 290 mm	202	kg/m

Soil transportation is likely to happen over the temporary roads, thus it is important to know the specific weight of soil on the construction site. In the Netherlands, five main soil types can be distinguished. These are displayed in Table 37.

Table 37: specific weight soil [kg/m^3] (C.R.O.W. 2005)

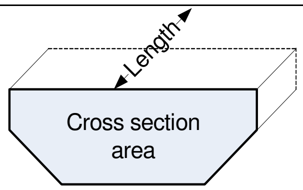
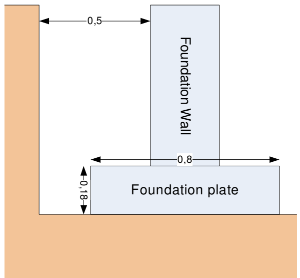
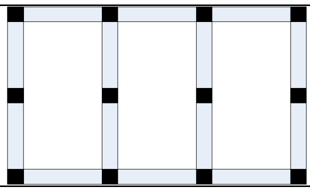
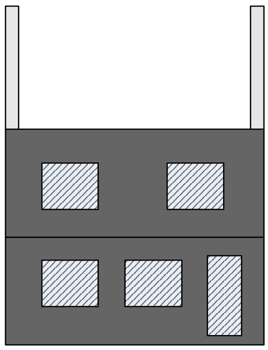
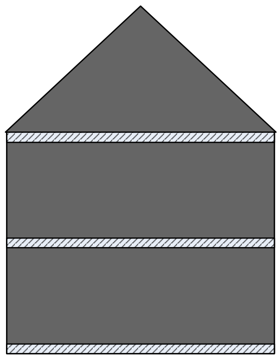
Soil	Specific weight
Sea clay	1500
River clay	1400
Peat	1150
Sand saturated	2000
Sand dry	1800
Garden soil (sand/clay mixture)	1600

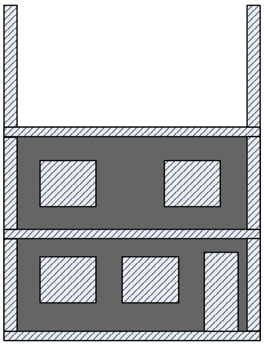
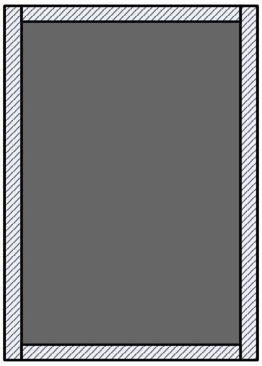
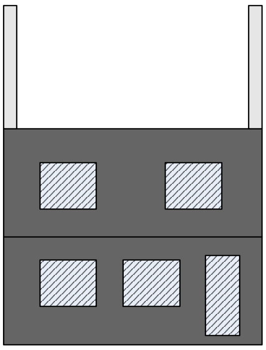
5.2.3. Calculations

The model calculates the weight of a house or a block by adding the weights of the different parts of the building. How these calculations are done is discussed in detail in Table 38. To ensure that the calculated weight is on the safe side, the models' safety factor can be used to compensate for uncertainty in the model. This is elaborated in section 2.5.

Table 38: parts of the building with calculation method (M = mass).

Part	Calculations
1) Foundation excavation	There are two possibilities for the excavation. ♦ Stroke (0,5 m extra on both sides of the foundation walls): M_{1a} = length foundation walls * (thickness + (2*0,5)) * foundation depth * ρ_{soil} ♦ Complete (0,5 m extra around the foundation)

Part	Calculations	
	$M_{1b} =$ (W + 2*0,5) * (L + 2*0,5) * foundation depth * ρ_{soil}	
2) Waterway excavation		M_2 = cross section area * waterway length * ρ_{soil} The cross section area is the blue area in the figure to the left.
3) Garden heightening	M_3 = average garden area per house * number of houses * ρ_{soil} ρ_{soil} = 1600 (mixture clay/sand)	
4) Foundation		If no foundation piles are used than a foundation plate is necessary (typically 0,18 m high and 0,8 m wide) $M_{4a} =$ total length foundation walls * thickness * height foundation * $\rho_{foundation}$ $M_{4b} =$ total length foundation walls * 0,18 * 0,8 * $\rho_{concrete}$
5) Foundation piles		Foundation piles (example pile plan to the left) $M_5 =$ length piles * γ_{pile} * number of piles
6) External wall		$M_6 =$ effective surface * thickness * $\rho_{outer\text{-}wall}$ The grey area in the figure topthe left is the surface of the exterior walls. The surface of the exterior walls does not include the gaps for doors and windows in the building. Therefore hatched surface has to be subtracted.
7) Load-bearing wall		$M_7 =$ effective surface * thickness * $\rho_{load\ bearing\ walls}$ * Number of walls The surface of the load bearing walls is the grey area in the figure to the left. The surface of the load-bearing walls does not include the floor layers in the building. The hatched surface has to be subtracted.

Part	Calculations
8) Interior wall	 $M_8 =$ effective surface * thickness * $\rho_{groundfloor}$ * number of interior walls The grey area in the figure to the left is the surface of the interior walls. The surface of the interior walls does not include the floor layers, load bearing walls and gaps for door's and windows in the building. Therefore the hatched surface has to be subtracted.
9) Ground floor	$M_9 =$ L * W * ground floor thickness * $\rho_{groundfloor}$
10) Level floor	$M_{10} =$ L * W * level floor thickness * $\rho_{levelfloor}$ * (number of floors - 1)
11) Floor cover layer	 $M_{11} =$ effective surface * thickness * $\rho_{cover\text{-}layer}$ * number of houses * number of floors The grey area in the figure to the left is the surface of the floor cover layer. The surface of the interior walls and the load-bearing walls does not include the floor cover layer in the building. Therefor hatched surface has to be subtracted.
12) Glass percentage	 $M_{12} =$ glass percentage * surface front and read building * thickness * ρ_{glass} Glass percentage = glass area / outer wall area * 100%
13) Roof	$M_{13} =$ surface * γ_{roof}
14) Shed	$M_{14} =$ weight shed walls + weight shed floor + weight shed roof
15) Total block weight	$M_{total} = M_1+M_2+_{.....}+M_{14}$
16) Total project weight	$M_{project}$ = total block weight * number of blocks
17) Total project weight including safety factor	$M_{project,incl.\ safety}$ = total project weight * safety factor
A) Transport weight	Transport weight = total project weight including safety factor

Part	Calculations
B) Dead weight trucks	M_{truck} = 0,5291 * Transport weight + 1191 See section 5.3 for explanation.
C) Total transport weight:	Total transport weight = dead weight trucks + transport weight

5.2.4. Input parameters:

The model requires the input parameters as shown in Table 39. In this table each parameter is explained, possible input and the input's dimension is given.

Table 39: input parameters weight calculation model.

Model	Parameter	Possible input	[Dim.]	Description
General	Number of blocks	Value	-	Number of blocks
	Number of houses per block	Value	-	Number of houses in a block. It is only necessary to enter the number of apartments or houses on the ground level.
	Height	Value	m	House or block height
	Width	Value	m	House or block width
	Length	Value	m	House or block length
	Roof angle	Value	degree	Roof angle
	Number of floors	Value	-	Total number of floors (ground + level floors)
	Construction time	Value	months	Specifies the total construction time (working days)
	Safety factor	Value	-	Represents the extra safety on calculations (see also section 5.2.5).
Specific	Soil type	-Sea clay -River clay -Peat -Sand saturated -Sand dry	-	The soil present on the construction site
	Foundation excavation	-Stroke -Complete -None	-	Specifies how the excavation for the foundation is done.
	Excavation depth	Value	m	Specifies the depth of the excavation (this is also the height of the foundation walls).
	Pile type	-none -180x180 -220x220 -250x250 -290x290	-	If a pile foundation is used then the pile type can be selected here.
	Piles per block	Value	-	Specifies the number of piles under a house or block

Model	Parameter	Possible input	[Dim.]	Description
	Pile length	Value	m	Specifies the length of the piles.
	Glass percentage	Value	m^2	Specifies the glass percentage in the front and rear of the building.
	Glass thickness	Value	m	Specifies the glass thickness
	Material foundation walls	-Concrete -Sand-lime stone	-	Specifies the material used for the foundation walls
	Foundation walls thickness	Value	m	Specifies the thickness of the foundation walls
	Material exterior walls	-Clay brick -Concrete wall -Concrete brick -Sand-lime stone	-	Specifies the material used for the exterior walls
	Exterior wall thickness	Value	m	Specifies the exterior wall thickness
	Material load-bearing walls	-Concrete -Sand-lime stone	-	Specifies the material used for the load bearing walls
	Load-bearing wall thickness	Value	m	Specifies the load bearing walls thickness
	Material interior walls	-Sand-lime stones -Concrete -Clay bricks -Concrete bricks -Aerated concrete	-	Specifies the material used for the interior walls
	Interior wall thickness	Value	m	Specifies the interior wall thickness
	Material ground floor	-Isolation floor 200mm -Isolation floor 260mm -Isolation floor 320mm -Concrete, specify thickness	-	Specifies the material used to construct the ground floor. See site VBI[15]
	Ground floor thickness	Value	m	When concrete is chosen as the ground floor material, then the floors' thickness can be entered here.
	Material level floor	-Channel floor 200mm -Channel floor 260mm -Channel floor 320mm -Concrete, specify thickness	-	Specifies the material used to construct the level floor(s). See site VBI[6]
	Level floor thickness	Value	m	When concrete is chosen as level floor material, then the floors' thickness can be entered here.
	Floor cover layer thickness	Value	m	Specifies the thickness of the layer on top of the floor level to cover installations.

[15] http://www.vbi.nl

Model	Parameter	Possible input	[Dim.]	Description
	Material roof	-Wood, clay tiles -Wood, roof covering -200mm concrete, roof covering -260mm concrete, roof covering -320mm concrete, roof covering -Concrete, specify thickness, roof covering	-	Specifies the roof is design. In case a flat roofs is used, VBI plates can be used.
	Roof thickness	Value	m	When concrete is chosen as roof material (only possible with a flat roof), then the roofs' thickness can be entered here.
Optional	Waterways	-No -Yes	-	Set to yes if waterways have to be dug and the soil is transported over the temporary roads.
	Average cross-section area	Value	m^2	Specifies the cross-section area of the waterway.
	Waterway length	Value	m	Specifies the length of the waterway.
	garden heightening	-No -Yes		Set to yes if the gardens of the buildings need to be heightened.
	Average garden area per house	Value	m^2	Specifies the area per house that needs to be heightened.
	Garden heightening	Value	m	Specifies the extra height of ground that is to be added on the garden.
	Shed	-No -Yes, wood -Yes, bricks	-	In case an additional shed is constructed. Specifies whether it is made from wood or from clay bricks.
	Width shed	Value	m	Specifies the width of the shed
	Length shed	Value	m	Specifies the length of the shed
	Height shed	Value	m	Specifies the height of the shed
	Floor	-Concrete -Wood	-	Specifies the floors material. Concrete floor thickness is 150mm, wood floor thickness is 28 mm.

5.2.5. Safety factor

To compensate for inaccuracy in the model the safety factor has been introduced. The safety factor is recommended because of the following three reasons.

- *Additional weight*. Since not every detail of the house is calculated, like installations or separation walls, the actual transport weight might be higher then the model calculates.

- *On site transportation*. Heavy construction vehicles like hoses are used on the construction sites. This also generates additional load on the temporary roads.

- *Simplification of reality*. Modern houses are constructed in many shapes. As explained in section 5.2.1 the buildings have to be transformed in one of the basis buildings. This generates inaccuracy in the calculation.

To compensate for the inaccuracies as explained above the proposed safety factor is 1.3. In this research, pavement calculations are made using computer programs. Traffic load on roads is hard to predict; therefore these programs already have a safety factor. The safety factor in this model is therefore *not* intended to increase the traffic load in order to make a safe pavement design; it is just a way to better approximate the expected traffic load.

5.3. Truck load capacity

In section 5.2 the total transport weight of the construction material for the construct project is calculated. This weight needs to be transported over the temporary roads to the different parts of the construction site by lorries and/or trailer-trucks combinations, as shown in Figure 46. These have a certain loading capacity and dead weight. The maximum allowed gross vehicle weight (GVW) or gross train weight (GTW) on the Dutch roads is 50.000 kg. In this section the abbreviation TW is used for transport weight, DW for the dead weight of the transport vehicles and PW for the total project weight (dead weight and transport weight combined).

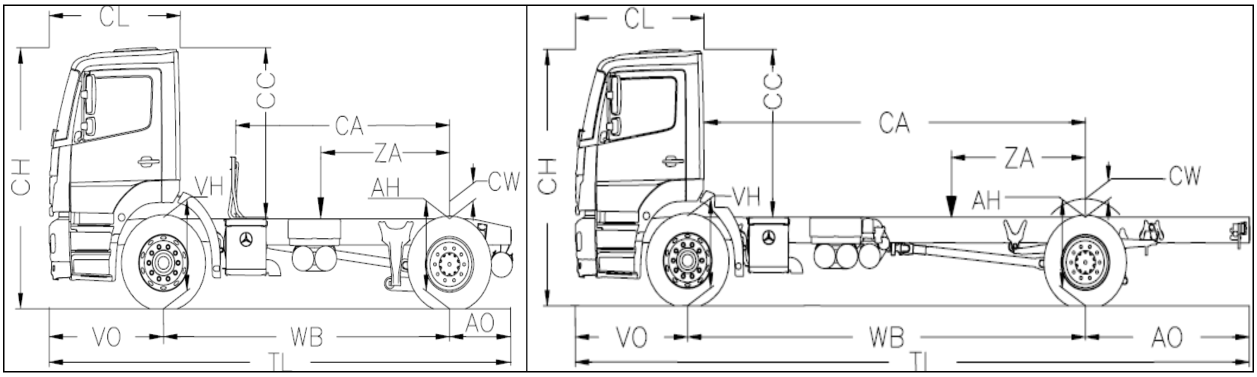


Figure 46: schematic figure of trucks 4x2 (left) and lorries 4x2 (right)

An estimation of the total load on the temporary road during its lifespan is required to design the road. The total load consists of the transport weight of the construction material and the dead weight of the transport trucks. This section deals with the determination of the relation between transport weight and the generated dead weight of the transport trucks. Section 5.3.1 looks if a relation can be found by lorries and in section 5.3.2 for trailer-truck combinations. A general relation, using the data of lorries and truck trailer combinations, is determined in section 5.3.3. Not al trucks are always fully loaded. Therefore a load factor is introduced in section 5.3.4.

5.3.1. Lorries

Lorries are used to transport the somewhat lighter loads and consist of a chassis, as shown right in Figure 46, and a holder to carry the load. Table 40 shows twenty lorries build by MAN and Mercedes. The GVW and the lorries dead weight can be found in the technical details on the web-site of the producer (see footnotes). However, not much details about possible holders is available. Therefore the assumption is made that the dead weight of the holder is 20% of the dead weight of the lorry. With this assumption the total dead weight is calculated for each lorry.

Table 40: lorry specifications [kg]

Type	GVW	DW truck*	DW Holder	Total DW	Load capacity
MAN[16]					
TGL 7 4x2	7.490	3.120	624	3.744	3.746
TGL 8 4x2	7.490	3.230	646	3.876	3.614
TGL 10 4x2	10.000	3.623	725	4.348	5.652
TGL 12 4x2	11.990	3.623	725	4.348	7.642
TGM 15 4x2	15.000	4.707	941	5.648	9.352
TGM 18 4x2	18.600	5.244	1.049	6.293	12.307
TGA 18 4x2	19.000	7.380	1.476	8.856	10.144
TGA 26 6x2	26.500	8.190	1.638	9.828	16.672
TGA 39 8x2	35.000	9.495	1.899	11.394	23.606
Mercedes[17]					
Atego 8	7.490	3.344	669	4.013	3.477
Atego 10	10.500	3.601	720	4.321	6.179
Atego 12	11.990	4.209	848	5.088	6.902
Atego 13	13.500	4.277	855	5.132	8.368
Atego 15	15.000	4.353	871	5.224	9.776
Atego 16	16.000	4.523	905	5.428	10.572
Axor 18	18.600	5.992	1.198	7.190	11.410
Axor 25 lena 6x2	26.500	7.443	1.489	8.931	17.568
Actros 18 L	18.600	6.811	1.362	8.173	10.427
Actros 25 lena 6x2	26.500	8.271	1.654	9.925	16.575
Actros 26 L 6x4	26.500	8.885	1.777	10.662	15.838
* Average weight for several wheel-base lengths.					

When the total dead weight is plotted against the load capacity (as shown in Figure 47) it is visible that there is a relation between the DW and TW. With a correlation factor of R^2 = 0,8392 (the maximum value for a perfect correlation is 1,0) it is likely that there is a correlation between these datasheets. The relation between the total dead weight and load capacity can be calculated using the least square method. This relationship can be used to calculate the generated dead weight of lorries given a certain amount of transport weight. The resulting equation for the dead weight is shown below.

$$DW = 0{,}4325 * TW + 2084 \quad (7)$$

[16] http://www.man-mn.nl/nl/

[17] http://www.mercedes.com/

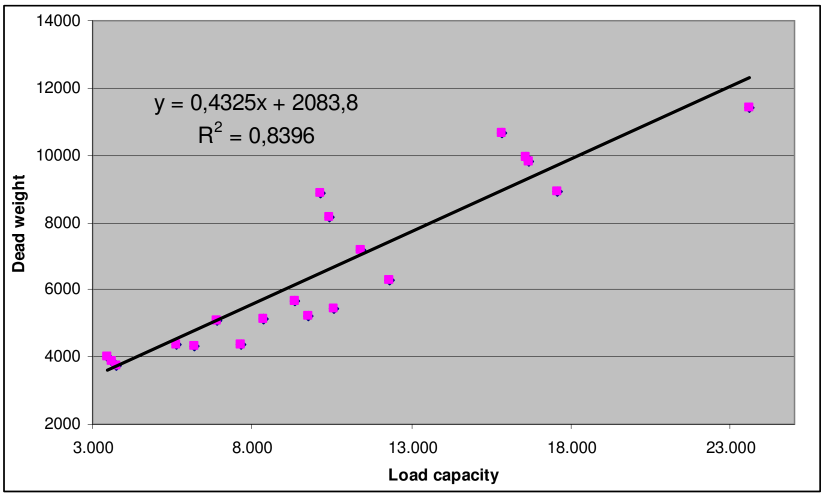


Figure 47: Relation dead weight – load capacity of lorries.

5.3.2. Truck-trailer combination

With a truck-trailer combination, the load capacity of the trailer is representative for the combination since the trailer carries the load. To transport the trailer, a truck is used. Table 33 shows thirteen trucks build by MAN and Mercedes. The GVW and the trucks dead weight can be found in the technical details on the web-site of the producer. The dead weight is necessary to calculate the total dead weight of the truck-trailer combination. The GVW can be used to indicate the tractive power of the truck, which is used later on.

Table 41: trailer truck and dump truck specifications [kg]

Truck type	GVW	DW truck
Mercedes		
Atego 13 LS	13.500	4.215
Axor 18 LS	18.600	5.810
Axor 18 K 4x2	18.600	5.975
Axor 18 AK 4x4	18.600	6.557
Axor 26 K 6x4	26.500	7.763
Actros 25 LS 6x2	26.500	8.080
Axtros 33 S 6x4	26.500	8.750
MAN		
TGA 4x2	19.000	6.903
TGA 4x4	20.500	7.546
TGA 6x2	23.500	7.865
TGA 6x4	28.000	8.818
TGA 6x6	28.000	10.209
TGA 8x8	37.000	12.203

On construction sites many different kind of trailers, mixers or kippers are used. Table 33 provides an overview of some trailer types that can be expected. The GVW and the trailers dead weight can be found in the technical details on the web-site of the producers (see footnotes). However an assumption needs to made about the dead weight of the truck that pulls the trailer. By looking at the differences in dead weight (DW) of the trucks and the difference in GVW of the trailers, the dead weight of the truck can then be estimated with the following formula:

$$DW_{truck} = \left(\frac{GVW_{trailer} - GVW_{min}}{GVW_{max} - GVW_{min}} * \left(DW_{truck,max} - DW_{truck,min} \right) \right) + DW_{truck,min} \tag{8}$$

Now, the total dead weight of the truck-trailer combination can be calculated by adding the trailer weight to the truck weight. The load capacity of the trailer can then be calculated by subtracting the dead weight off the GVW. Table 42 shows the results of these calculations.

Table 42: trailer specifications [kg]

Truck type	GVW	DW trailer	DW Truck	Total DW	Load capacity
Schmitz Cargobull[18]					
S.KI Solid tipper trailer	39.000	6.200	12.203	18.403	32.800
S.CS Light semi-trailer	35.000	5.500	10.589	16.089	29.500
S.CS Universal semi-trailer	39.000	6.285	12.203	18.488	32.715
Meiering Alustar[19]					
MSA 24 C semi-trailer	26.000	5.100	6.958	12.058	20.900
MSA 40 C semi-trailer	40.000	7.500	12.606	20.106	32.500
Liebherr[20]					
HTM 804Truck mixer*	19.200	4.660	4.215	8.875	14.540
HTM 1004 Truck mixer*	24.000	5.050	6.151	11.201	18.950
HTM 1204 Truck mixer*	28.800	5.700	8.088	13.788	23.100
HTM 1504 Truck mixer*	36.000	6.400	10.993	17.393	29.600
Krone[21]					
Profi Liner	39.000	6.250	12.203	18.453	32.750
Mega Liner	39.000	6.900	12.203	19.103	32.100
* GVW calculated					

When the total dead weight is plotted against the load capacity (as shown in Figure 48) it is visible that there is a relation is between the dead weight and the load capacity. With a correlation factor of R^2 = 0,9718 a strong correlation between these datasheets can be found. The relation between the total dead weight and load capacity can be calculated using the least square method. The resulting equation is shown below.

DW = 0,5562 * TW + 672 (9)

[18] http://www.cargobull.com/uk/

[19] http://www.meierling-alustar.de/

[20] http://www.liebherr.com/

[21] http://www.krone.de/

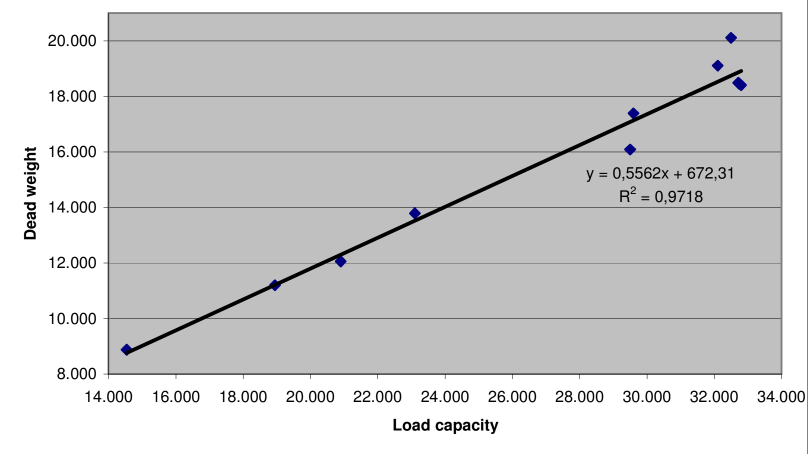


Figure 48: Relation dead weight – load capacity of truck-trailer combinations.

5.3.3. Dead weight – load capacity relation

The separate relations of the dead weight and the load capacity for lorries and truck-trailers can be proven. The results from the lorries and the truck-trailer combinations are combined to see if there is also a connection between these two data sets. This is shown in Figure 49. The optimal regression line trough the points is the black line. Using excel, a strong correlation between these points can be found (R^2 = 0,9657). The equation belonging to this line can be calculated using the least squares method and is shown below.

$$DW = 0{,}5291 * TW + 1191 \quad (10)$$

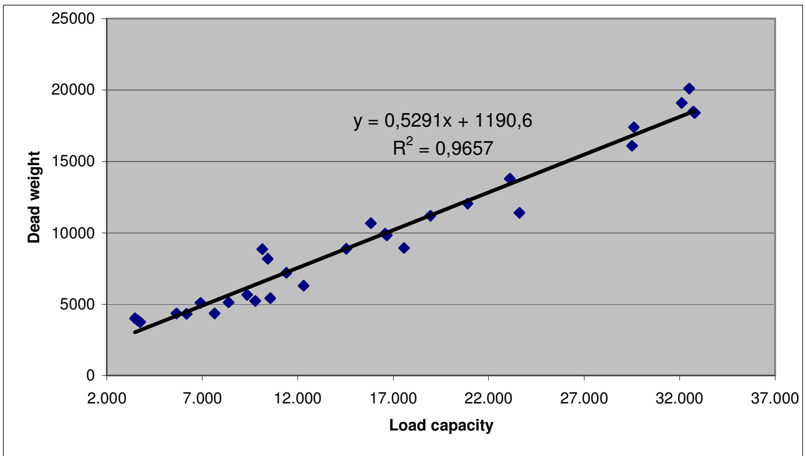


Figure 49: combined data of lorries and truck-trailer combinations.

The relationship between the dead weight and the load capacity can be used to calculate the dead weight generated by a certain transport load. The number 1190,6 in the equation can be easily explained; this is the minimal own weight of a truck before it can transport load. For large values of TW, which is the case for construction projects, this value can be neglected.

5.3.4. Load factor

The found relation is only valid if all trucks are 100% loaded, which is in mostly not the case. If not all trucks are fully loaded than additional trucks will be necessary to transport the material and thus increasing the dead weight of the trucks required transporting the weight. To compensate for this a load factor (LF) is introduced into the model, which is expressed in percentages. This is implemented in the model using a correction factor for the dead weight (C_{LF}) as is displayed in the equation below. By multiplying the found dead weight with this correction factor the actual dead weight of the trucks used can be calculated. The 'corrected' dead weight is called $DW_{corrected}$.

$$C_{LF} = \frac{1}{\left(\frac{LF}{100}\right)} \tag{11}$$

On construction sites trucks are arriving loaded and are leaving unloaded. The assumption made is that the trucks use the same route on the construction site to deliver and to leave, thus every truck is passing twice of the road and thus generation two times dead weight load on the road. The corrected DW equation becomes:

$$DW_{corrected} = 2 * C_{LF} * (0{,}5291 * TW + 1191) \tag{12}$$

To explain how the corrected dead weight of the trucks can be calculated, an example is provided below.

Example 1:
- Total load to be transported: 3.000.000 kg
- Load factor trucks: ± 80%

Calculation
C_{LF} = 1 / (LF / 100) = 1 / (80 / 100) = 1,25
$DW_{corrected}$ = 2 * C_{LF} * (0,5291 * x + 1191) = 2 * 1,25 * (0,5291 * 3.000.000 + 1191)
$DW_{corrected}$ = 3.971.227 kg

5.4. Design load

In the previous sections is discussed how the weight of the construction materials and how much dead weight of the transport trucks this generates to transport can be calculated. The influence of the load factor on the dead weight of the trucks is also researched. The total weight (PW) that will pass over the temporary roads during the construction period of the project can be calculated by summarising these to weights.

$$PW = TW + DW_{corrected} \tag{13}$$

However, the different available design methods do not use the total load on the road in kg as traffic-load input parameter. Therefore this data has to be transformed into more usable values. Many pavement design methods use 100 kN axle loads (N) as input. It is rather easy to transform the calculated load into equivalent 100 kN axle loads by using the following formula:

$$N = \frac{10 * PW}{100.000} \tag{14}$$

This is generally the main design criterion for the lifetime of the road. In the following subsections is described how the calculated traffic load can be implemented in the design programs. Subsection 5.4.1 deals with the asphalt design program ASCON. Other programs are not discussed due tot time constraints.

5.4.1. ASCON

According to VBW-Asfalt (2000) and Ministry of Transport, Public Works and Water Management (RWS, 1998) the load on a road is expressed as the number of equivalent standard axle loads (N_{eq}) of 100 kN with twinned wheels during the road's lifetime. This can be calculated by the following formula:

$$N_{eq} = V * W * VSF_{100} * G * F_r * F_s * F_{nb} * F_v \qquad (15)$$

In which:
N_{eq} = Design load
V = Number of trucks on a workday in a traffic stream
W = Number of workdays in a year
G = Growth factor
VSF_{100} = Correction factor for truck damage factor
F_r = Correction factor for number of driving lanes available for a traffic stream
F_s = Correction factor for lane width
F_{nb} = Correction factor for trucks with wide wheels
F_v = Correction factor for truck driving speed.

Note that the developed model calculates N or V * W * G * VSF_{100}. Because the model calculates the design load for the entire construction period, there is no traffic growth. In this case G can be substituted by the expected lifetime of the road (L). F_r, F_s, F_{nb} and F_v are road specific correction factors (see Table 43). This formula can be simplified to:

$$N = V * W * L * VSF_{100} \qquad (16)$$

ASCON can only calculate N_{eq} itself; a value for N_{eq} cannot be entered. Therefore N needs to split-up into values for V, W, G and VSF_{100}. This is done in Table 43.

Table 43: input computer programs

Required input	Proposed input
Preconditions screen:	
Driving speed (F_v)	The assumption is made that all construction sites are in urban areas making 50 km/h the top speed. However, due to some factors like unclear roads, damage to roads and unfamiliarity of the driver with the delivery location, the average driving speed is expected to be lower. The proposed input for this factor is 30 km/h.
Lane width (F_s)	The lane width of temporary roads is mostly based on the width of permanent roads (5,5 to 6m wide). So the proposed lane width of the road is 3m wide (F_s = 1,00).
Traffic load screen:	
Trucks per day (V)	To calculate the number of trucks per day it is necessary to rewrite formula X. This gives the following result: $\mathrm{N}_{eq} = V * W * L * VSF_{100} \rightarrow V = \frac{N_{eq}}{W * L * VSF_{100}}$ (17) Now the number of trucks per day can be calculated.
Working days a year (W)	This is the number of working days in a year. For the Netherlands this is 270 days a year, which is also the proposed input.
Yearly growth (G)	The model calculated the traffic load during the entire construc-

Required input	Proposed input
	tion period, therefore no growth is expected. The proposed input for this factor is therefore 0%.
Truck damage factor (VSF_{100})	Heavy traffic does more damage then light traffic. Construction traffic is assumed to be heavy traffic. The proposed input for this factor is therefore 2 (see RWS, 1998).
Percentage wide wheels (F_{nd})	This value is expected to stabilise at 40% (see RWS, 1998). This is also the proposed input for this factor.
Number of driving lanes (F_r)	Temporary roads never have more than one lane in each direction. So the proposed input is 1 lane (Fr = 1.00).
Design lifetime (L)	This is the construction period and differs from project to project.

5.5. Traffic load design tables

We can implement the previous sections on standard houses and apartments to compute traffic load design tables. With these tables a quick estimation of the expected traffic load can be obtained which is especially useful in early stages of a construction project. In the development of the design tables it is necessary to make a distinction between houses and apartment buildings, because of the differences in dimensions. Subsection 5.5.1 deals with the creation of a design table for standard houses and subsection 5.5.2 with the creation of a design table for standard apartment buildings. Optional design load tables for sheds and garden heightening are provided in subsection 5.5.3. All design tables are computed with the assumption that the truck load factor of 100%. How design tables can be adjusted for different load capacities is explained in subsection 5.5.4. The total expected traffic load is discussed in 5.5.5.

5.5.1. Standard houses

Two main kinds of houses can be distinguished: free-standing houses and block houses. Blockhouses can then be divided into two categories: end or between houses. A block is made of two end houses and a certain number of between houses. Not al houses have the same amount of floor space. Using Funda[22] houses have been categorised in three categories based on their gross floor space. The three categories are small, medium or large (as displayed in Table 44).

Table 44: house categories

Size	Floor space [M^2]	Average gross floor space [M^2]
Small:	50 – 100	75
Medium:	100 –150	125
Large:	150 – 250	200

Figure 50 shows what is meant by an end and between house or apartment column in a block. Examples of houses en apartments can be found in appendix 5.

[22] http://www.funda.nl

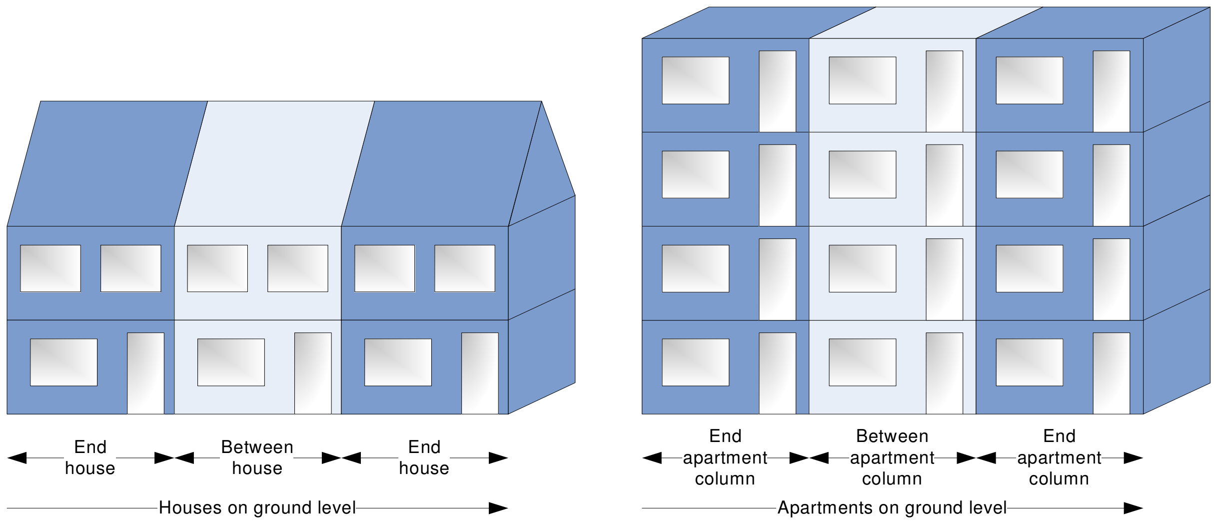


Figure 50: explanation of end and between houses and apartments.

Figure 51 shows the standard designs of the houses that will be used for computation of the traffic load design table. The assumption is made that the standard houses have either a flat roof or a pointed roof (45^o). By combining the three sizes of the standard houses with the two possible roof types, it will generate six standard houses. If we combine this with the fact that there are free-standing, end and between houses we have eighteen different house types.

Construction design.

Now that the dimensions for the standard houses are specified, it is also necessary to specify how these houses are build and what materials will be used. This is done in Table 35.

Table 45: parts of the building with description.

Part	description
1) Excavation	The foundation is stroke excavated in sea clay.
2) Foundation	No piles, thickness foundation walls: 35 cm, 75 cm deep.
3) Load-bearing wall	Lime stone, thickness walls 25 cm
4) Ground floor	VBI isolation floor 200
5) Level floor(s)	VBI channel floor 200
6) Interior walls	Aerated concrete, wall thickness: 8 cm.
7) Exterior walls	Burnt clay bricks, wall thickness 10 cm.
8) Floor cover layer	Concrete, layer thickness 5 cm.
9) Roof	Flat roof: concrete with asphalt roofing. Pointed roof: 45^o, prefab wooden roof with tiles.
10) Glass percentage	35 %
Safety factor	1,3

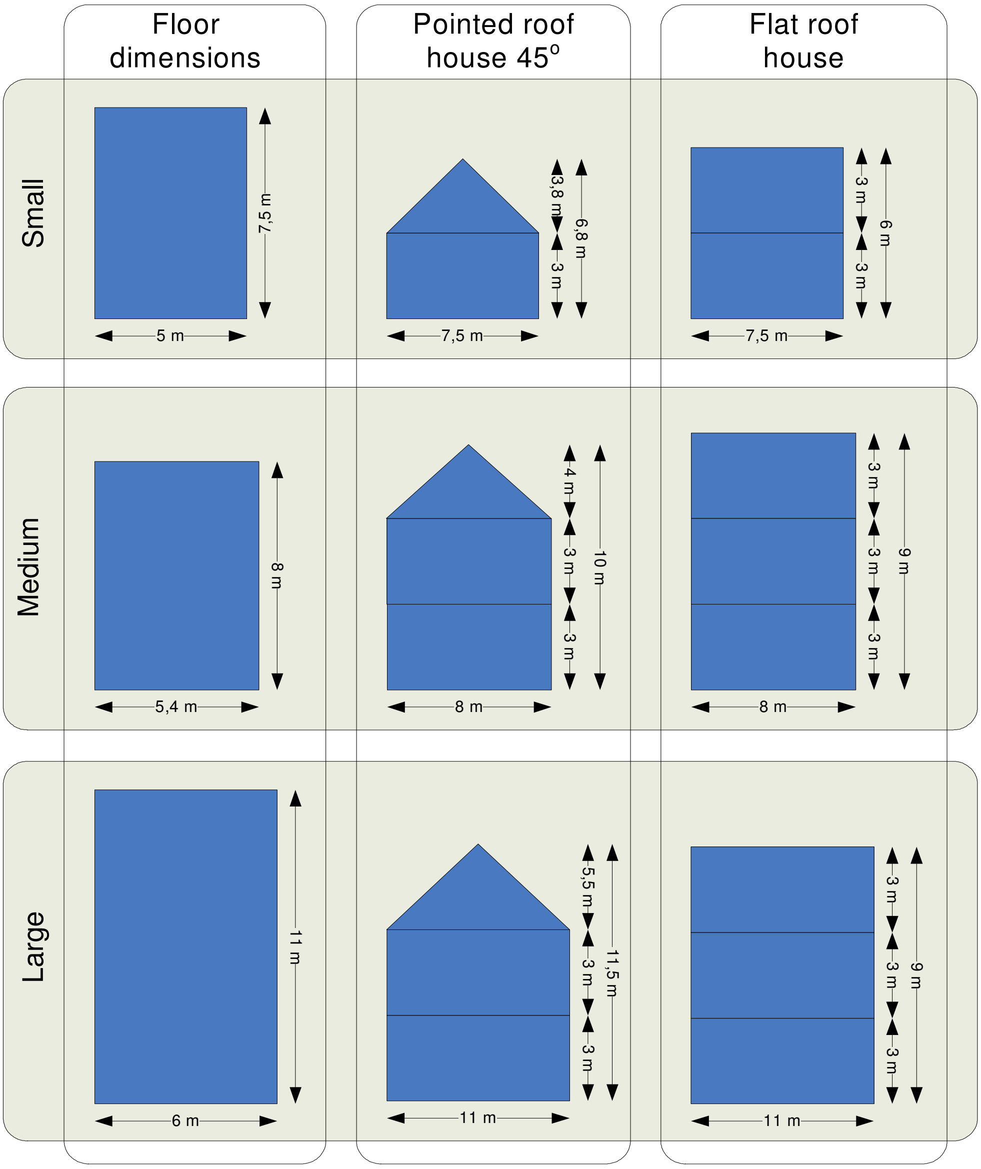


Figure 51: dimensions for the design houses.

Traffic load table

With the dimensions and design of the standard houses and apartments known, the developed computer model can be used to calculate the expected traffic load generated on the temporary road. This is expressed as the number of equivalent 100kN axle loads. Table 46 shows the design loads for each house type, house size and roof type.

Table 46: traffic load determinations, load factor 100%.

Size	Roof type	Free-standing house	Row house	
			End	Between
Small	Flat roof	45	38	30
	Pointed roof (45°)	40	33	27
Medium	Flat roof	63	53	41
	Pointed roof (45°)	57	48	38
Large	Flat roof	87	72	58
	Pointed roof (45°)	82	68	53

To calculate the total traffic load that can be expected due to the construction activities of houses on a project the following formula is necessary.

$$N_{eq;total} = \sum_{n}^{Houses} X_n * H_n \qquad (18)$$

In which:
$N_{eq;total}$ = total expected traffic load on the temporary road in 100 kN equivalent axle loads
n = house type
X_n = number of houses in category n
H_n = expected load for one house in category n

Example 3:
Calculating the main access road.

Project:
- Only one available access road for construction traffic.
- 30 Large, free-standing houses with pointed roof.
- 8 Blocks of row houses with each 6 medium houses with flat roof.

Calculation
Only one access road → all construction traffic over this road.
$N_{eq;total} = X_{large;free\text{-}standing} * H_{large;free\text{-}standing} + * X_{medium;end;flat\ roof} * H_{medium;end;flat\ roof} + X_{medium;between;flat\ roof} * H_{medium;between;flat\ roof}$ = (30 * 82) + (8 * 2 * 53) + (8 * 4 * 41) = 2460 + 848 + 1312 = **4620**

5.5.2. Standard apartments

Apartments can be found in many different sizes. Just like with the standard houses, Funda is used to get an idea about apartment sizes and derive standard apartments to make calculations with. In this research, the classification as shown in Table 47 for apartment sizes is used. The average floor space of each apartment is used to determine dimensions for each category. This is done in Figure 52. The height of each level is assumed to be 3 meter.

Table 47: apartment categories

Size	Floor space [M^2]	Average space [M^2]
Small	< 50	40
Medium:	50 –100	75
large:	100 –150	125
Extra large	> 150	175

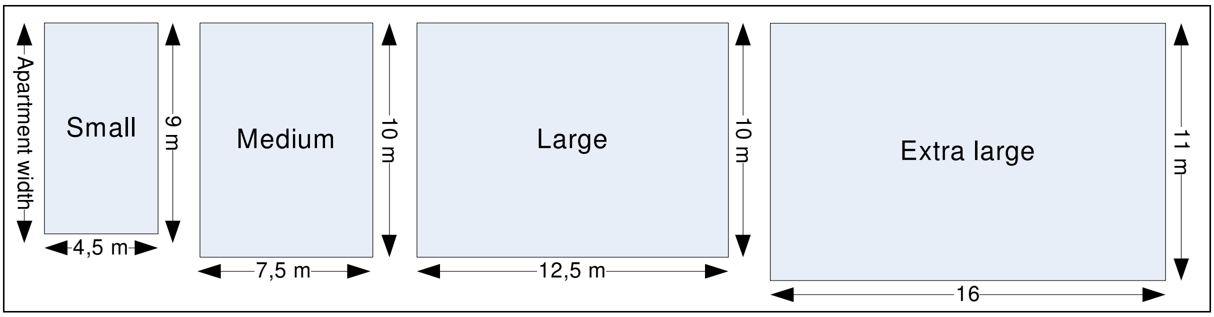


Figure 52: dimensions for the design apartment buildings.

Two kinds of apartments buildings can be distinguished: the apartments on the end (end column) and the apartments between the to end columns (between column). The main difference is that the structural design will lead to a different design load. The two kinds of apartments are shown in Figure 50. The structural design of the standard apartment building, used to calculate the traffic load design table, is displayed in Table 48.

Table 48: parts of the building with description.

Part	description
1) Excavation	The foundation is stroke excavated.
2) Foundation	Pile foundation (2 apartments on ground floor = 25 piles, 3 apartments on ground floor = 35 piles), size: 220x220 mm, 10m deep, thickness foundation walls: 35 cm, height = 0,75m.
3) Load-bearing wall	Prefab concrete, 28 cm thick
4) Ground floor	VBI: Apartment floor 200 (small) VBI: Apartment floor 260 (medium/large) VBI: Apartment floor 320 (extra large)
5) Level floor(s)	VBI: Apartment floor 200 (small) VBI: Apartment floor 260 (medium/large) VBI: Apartment floor 320 (extra large)
6) Interior walls	Aerated concrete, 8cm thick
7) Exterior walls	Burnt clay bricks, wall thickness 10 cm.
8) Floor cover layer	Concrete, 5 cm thick
9) Roof	Concrete 260 mm with roof-covering
10) Glass percentage	45 %
Safety factor	1,3

The results of the calculations with the traffic load model gave the traffic load design table as shown in Table 49. These results show the expected traffic load for a column of the apartment building as shown in Figure 50.

Table 49: traffic load design table for an apartment building.

	Small		Medium		Large		Extra large	
Floors	End	Between	End	Between	End	Between	End	Between
2	51	40	80	65	112	99	154	141
3	66	50	105	86	147	132	206	188
4	80	62	130	107	183	162	258	235
5	95	72	155	129	219	193	309	284
6	109	84	181	148	254	226	361	330
8	138	106	231	191	325	289	465	424
10	168	126	281	234	396	353	568	520
15	240	183	407	339	574	510	827	756
20	313	237	532	447	752	668	1086	992
25	386	291	658	552	930	826	1345	1228

Note: apartment buildings with a different number of storeys can be calculated using interpolation.

This table has to be used with the following formula to calculate the weight of a apartment building.

$$\mathrm{N}_{\text{eq;apartment building}} = 2 * N_{end} + H_{between} * N_{between} \qquad (19)$$

In which:
$N_{eq;total}$ = Total expected traffic load on the temporary road in 100 kN axle's.
N_{end} = Expected load for one end apartment column (see Table 49).
$H_{between}$ = Number of apartment columns between end houses.
$N_{between}$ = Expected load for one column of apartments (see Table 49).

The expected traffic load for the construction of an apartment building can be easily calculated. This is explained in the example below.

Example 4:

Project:
- End Apartment size: 120 m^2
- Between apartment size: 80 m^2
- Building: 7 apartments on ground floor, building is 10 stories high.

Calculation:
Seven apartments on the ground floor → 2 end and 5 between apartment columns
End: 120 m^2 → Large apartment
Between: 80 m^2 → Medium apartment

$N_{eq;total} = 2 * N_{end} + H_{between} * N_{between} = 2 * 396 + 5 * 234 = 792 + 1170 =$ **1962**

5.5.3. Optional load

Some optional activities during construction might cause additional load on the temporary road. Two of these activities are discussed in this subsection. The first is the heightening of the garden with additional soil. Table 50 shows the design load table in case

Table 50: traffic load (N) design table for garden heightening (incl. safety factor).

Extra soil height	Garden size [m^2]								
	5	10	20	40	80	160	320	640	1280
0,05	0,05	0,10	0,21	0,42	0,83	1,66	3,33	6,66	13,31
0,10	0,10	0,21	0,42	0,83	1,66	3,33	6,66	13,31	26,62
0,15	0,16	0,31	0,62	1,25	2,50	4,99	9,98	19,97	39,94
0,20	0,21	0,42	0,83	1,66	3,33	6,66	13,31	26,62	53,25
0,25	0,26	0,52	1,04	2,08	4,16	8,32	16,64	33,28	66,56
0,30	0,31	0,62	1,25	2,50	4,99	9,98	19,97	39,94	79,87

Table 51 shows the extra load generated if a shed, belonging to a house, is constructed.

Table 51: traffic load (N) design table for the construction of a shed.

Wall type:	Floor:	Shed size [m]			
		2 x 2	2x3	3x3	3x4
Wood	Wood	0,06	0,08	0,11	0,13
	Concrete	0,19	0,28	0,41	0,53
Clay bricks	Concrete	0,46	0,62	0,81	1,00

Note: if waterways are present then additional calculations are necessary. These calculations need to be made by hand.

5.5.4. Load factor compensation

The traffic load design tables as shown in Table 46, Table 49, Table 50 and Table 51 are calculated based on the assumption that all trucks are fully loaded (Truck load factor of 100%). The truck load factor is most likely lower then 100% therefore the expected traffic load has to be compensated. To do this we are interested in the effect of the load factor on the traffic load. We can calculate the project weight (PW) traffic load by summarising the transport weight (TW) and the corrected dead weight of the trucks (DW)

$$PW = TW + NW_{corrected} \quad (20)$$

In section 5.3.4 the following formula for $DW_{corrected}$ was determined:

$$NW_{corrected} = 2 * C_{LF} * (0,5291 * TW + 1191) \quad (21)$$

Combining these two equations gives the relation between the transport weight, the load factor and the project weight.

$$PW = TW + 2 * C_{LF} * (0,5291 * TW + 1191) \quad (22)$$

This relation can be used to investigate the influence of the load factor on the total project weight. First the project weight is calculated for different values for the load factor and the transport weight. This is done in the left half of Table 52, in the right half these values are compared to the calculated values with a load factor of 100%. As shown in the table, the influence of the load factor is the same for different values for the transport weight. This outcome is as expected; if transport trucks have lower load capacity then more trucks are necessary to transport the weight of the construction material resulting in more DW and thus to more design load on the road.

Table 52: determination of truck load correction factor

LF	TW → PW calculated				Comparison to load factor 100%			
[%]	100.000	500.000	1.000.000	5.000.000	100.000	500.000	1.000.000	5.000.000
70	254.574	1.259.260	2.515.117	12.561.974	1,22	1,22	1,22	1,22
80	235.253	1.164.353	2.325.728	11.616.728	1,13	1,13	1,13	1,13
90	220.224	1.090.536	2.178.424	10.881.536	1,06	1,06	1,06	1,06
100	208.202	1.031.482	2.060.582	10.293.382	1,00	1,00	1,00	1,00
110	198.365	983.165	1.964.165	9.812.165	0,95	0,95	0,95	0,95
120	190.168	942.902	1.883.818	9.411.152	0,91	0,91	0,91	0,91

This correction factor can now be used to compensate the estimated traffic load, determined using the design tables, for other values of the truck load factor.

Table 53: truck load correction factor.

LF [%]	70	80	90	100	110
Average ($TL_{cor.f.}$)	1,22	1,13	1,06	1,00	0,95

The traffic load design tables can be corrected for a different load factor using the following formula and the $TL_{cor.f.}$ from Table 53.

$$N_{eq;corrected} = TL_{cor.f.} * N_{eq;design\_table} \quad (23)$$

5.5.5. Expected traffic load

The total expected traffic load on the temporary road can be determined by summarising the loads determined in subsections 5.5.1 to 5.5.4 and correcting it with for the truck load factor. The values in the design tables are inclusive the safety factor of 1,3.

$$\mathrm{N}_{\mathrm{eq;total;project}} = TL_{cor.f.} * \left(\sum_{n}^{Houses} X_n * H_n + \sum_{m}^{Aparmtnents} X_m * A_m + \sum_{p}^{Optional} X_p * O_p \right) \tag{24}$$

In which:
$N_{eq;total}$ = Total expected traffic load on the temporary road in 100 kN axle’s.
$TL_{cor.f.}$ = Truck load correction factor
n = House type(s)
m = Apartment type(s)
p = Optional traffic load type(s)
X_n = Number of houses in category n
H_n = Expected traffic load for one house in category n
X_m = Number of apartments in category m
A_m = Expected traffic load for one apartment in category m
X_p = Number of units in optional category p
O_p = Expected traffic load for one unit of optional category p

5.6. Model verification

Since there is no empirical data available about temporary roads it is hard to verify the model presented in this chapter. There are three mayor steps in the model:

- The first step in the model is to calculate the weight of the construction material required for the project. This part of the model can be easily checked with hand made calculations. This part can therefore easily be verified.

- Secondly a relation between the transport weight and the dead weight of transport trucks is determined depending on the weight of the construction material. There is no other research available on this specific topic. There is however data available over the dead weight and loading capacity of trucks on the Dutch roads. However, there is no relation between the data regarding the dead weight and the data regarding the load capacity. Table 54 and Table 55 show the data found in Statline from CBS[23]. Using this data the average dead weight (calculated 8895 kg) and the average load capacity (calculated 9535 kg) can be calculated.

Table 54: number of trucks in the following dead weight range (Statline, 2007).

Range	1000 – 2000	2000 – 3000	3000 – 4000	4000 – 5000	5000 – 6000	6000 – 7000	7000 – 8000	8000 – 9000	9000 – 10000	10000 – 11000	11000 – 12000	12000 – 13000	13000 – 14000	14000 – 15000	15000 – 16000	16000 – 20000	20000 - 25000	25000 - 30000	> 30000
Average	1500	2500	3500	4500	5500	6500	7500	8500	9500	10500	11500	12500	13500	14500	15500	18000	22500	27500	30000
Trucks	117	2484	4228	6502	7226	6051	5859	8318	8133	6485	6075	4212	2783	2014	1697	3146	535	33	19

[23] http://statline.cbs.nl

Table 55: number of trucks in the following load capacity range (Statline, 2007).

Range	1000 – 2000	2000 – 3000	3000 – 4000	4000 – 5000	5000 – 6000	6000 – 7000	7000 – 8000	8000 – 9000	9000 – 10000	10000 – 11000	11000 – 12000	12000 – 13000	13000 – 14000	14000 – 15000	15000 – 16000	16000 – 20000	20000 - 25000	25000 - 30000	> 30000
Average	1500	2500	3500	4500	5500	6500	7500	8500	9500	10500	11500	12500	13500	14500	15500	18000	22500	27500	30000
Trucks	3637	8831	4780	4382	4534	2241	3620	5525	7812	4919	2411	1798	2582	3777	3723	4627	2859	1557	529

By dividing the average dead weight through the average load capacity we can find an alternative relation:

Dead weight = Transport weight * 0,93

This value differs from the previous calculated value (0,53) by 75%, which is rather much. However there is significant doubt if the data can be used as described above. This is mainly because no relation between the dead weight and the allowed load capacity is provided in the datasheet, which can lead to incorrect indications. Therefore the relation provided in section 5.3.3 is assumed to be more accurate.

- Thirdly it is stated that trucks are not always fully loaded, however there is no data available the average load factor of trucks on construction sites. No easy way to verify the load factor was found. Further research on this topic is recommended.

5.7. Summary

This chapter first provides a way to classify temporary roads into three categories. This is done to prevent over- or under-dimensioning of the roads since the traffic load will vary on different roads on the project. Next, this chapter provides a way to estimate the traffic load on a temporary road, based on the project characteristics.

This method is based on the calculation of the total weight of the construction material required to construct the project. Transport trucks transport the construction material to the construction site and generate additional load on the temporary road with their dead weight. Research shows that a relation between the load capacity and the dead weight of transport vehicles can determined. Using this relation an estimation of the dead weight of the transport trucks required transporting the construction material can be found. By summarising the dead weight and the weight of the construction material an estimation for the total load on the temporary road during the construction phase can be found. A load factor is introduced into the model since not all trucks are fully loaded. To compensate for uncertainties in the model a safety factor of 1,3 is applied.

To make the model better practical applicable, a number of standard houses and apartments was developed and applied using the model, to calculate traffic load design tables. Using these traffic load design tables results in a quick estimation of the expected traffic load on a certain temporary road. The output of the traffic load model is in 100 kN axle loadings, which is common in road design.

Progressive scheme

Step 1: Determine the traffic distribution routes and classify the temporary roads into categories (section 5.1.).

Step 2: Determine N_{eq} for each road category using design tables or the computer program (section 5.5).

Step 3: Rewrite N_{eq} into parameters that can be used in the design programs (section 5.4).

6. PAVEMENT

This chapter discusses possible pavement types for temporary roads and the way they can be designed. Temporary roads are indirect project costs, making this an important selection criterion. Therefore this chapter starts with analysing costs involved in the construction of several potential pavement types in section 6.1. This section also discusses the ‘upgrade’ costs for a temporary road to a permanent road. A pavement consists sometimes contains a possible foundation layer. Therefore possible foundation materials are discussed In section 6.2.

Section 6.3 deals with the design of an unpaved road, section 6.4 with the design of prefabricated concrete plate pavements, section 6.5 with the design of asphalt paved roads and section 6.6 with the design of small element pavements. Section 6.7 investigates the effects of the geosynthetic materials in the roads’ body. A summary is provided in section 6.8.

Figure 53: asphalt, small elements, prefabricated concrete plates and unpaved road.

6.1. Pavement costs

Temporary roads on construction projects are an example of indirect costs of a project. These costs have, unlike the direct costs (for example cost for construction material), no direct added value to the project but are unavoidable in order to build it. Thus, these unprofitable costs should be minimised. Therefore, on most projects the pavement type for temporary roads is largely determined by the construction costs of the road or, if the temporary road is combined with the permanent road, the ‘upgrade’ costs.

In this section, pavement costs of five possible pavements are determined: small elements, concrete, prefabricated concrete plates, asphalt and unpaved roads. The foundation layer also belongs to the pavement layer, as described in chapter 3. To determine the construction costs of several pavement types, the GWW-costs books from Reed Business Information (2006) “Foundation layers and small element pavements” and ”Foundation layers and bound pavements” are used. The costs for the embankment material are not included in this research. This is done because all roads need an embankment and embankment material. Therefore these costs are not differentiating. In subsection 6.1.1 the pavement construction costs of temporary road are discussed. The costs required to remove the temporary roads are also investigated. In subsection 6.1.2 the costs for upgrading the temporary road to the permanent road are discussed. In subsection 6.1.3, the combined cost for the temporary roads with the upgrade costs are discussed. Section 6.1.4 deals with the maintenance costs. Conclusions regarding the cost of the combination of the temporary and permanent pavements are made in section 6.1.5.

Note: these costs are based on construction costs design tables provided by Reed Business Information (2006) and only provide an indication of the actual costs. Actual cost might vary in time due to market forces. The total surface of the road will also influence the costs, larger volumes are usually cheaper than small quantities.

6.1.1. Temporary road

Only the costs for the pavement are determined for the different types of temporary. The rest of the road bodies for all road types are assumed to be equals a therefore undifferentiating. To make a comparison between cost calculations are made for a project of 3000 m^2 (this temporary road is 6 meter wide and 500 m long). The total construction and removal costs of the five pavement types are determined in this subsection.

Small element pavement

There are several types of small element pavements available. Material used to create the bricks and the dimensions of the bricks can used to distinguish these types. The bricks can be fabricated from clay and from concrete. Concrete bricks are much cheaper than clay bricks thus only concrete bricks are investigated.

There are three main sizes of bricks available, the Waal, Thick and Cobble format. The cobble format is applied most in the Netherlands because it is cheaper to install. Bricks are paved by hand in herringbone bond. The edge restraint is 130/150x200mm. Table 56 shows the construction costs for the road with a small element pavement. These costs consist of material, delivery and installation costs. The second part of the table shows the removal costs of the pavement.

Table 56: small element pavement cost (GWW-costs, 2006).

What	Dim.	Amount	€	Sand	Foundation 0,20 m	Foundation 0,25 m	Foundation 0,30 m
Shaping sand layer	m^2	3000	0,96	2.880			
bedding sand (0,05m thick)	m^2	3000	1,40	4.200	4.200	4.200	4.200
Foundation (0,20 m mix. granule)	m^2	3000	2,47		7.410		
Foundation (0,25 m mix. granule)	m^2	3000	2,87			8.610	
Foundation (0,30 m mix. granule)	m^2	3000	3,33				9.990
Concrete bricks	m^2	3000	17,75	53.250	53.250	53.250	53.250
Edge restraint	m	1000	13,60	13.600	13.600	13.600	13.600
			Construction costs:	***73.930***	***78.460***	***79.660***	***81.040***
			Construction costs per m^2:	**24,64**	**26,15**	**26,55**	**27,01**
Removing small elements	m^2	3000	2,52	7.560	7.560	7.560	7.560
Removing edge restraint	m	1000	2.81	2.810	2.810	2.810	2.810
Removing foundation 0,20 m	m^2	3000	4,15		12.450		
Removing foundation 0,25 m	m^2	3000	4,80			14.400	
Removing foundation 0,30 m	m^2	3000	5,60				16.800
			Removal costs:	***10.370***	***22.820***	***24.770***	***27.170***
			Total costs:	**84.300**	**101.280**	**104.430**	**108.210**
			Total costs per m^2:	**28,10**	**33,76**	**34,81**	**36,07**

Note: experience tells that after construction is completed around 70% of the bricks can be re-used for the permanent pavement or in the construction of a road on another project. If this is the case the costs of the small element pavement will drop. However, in this comparison the assumption is made that no used bricks are available and afterwards these bricks are either used in the permanent pavement or do not have any remaining value.

Concrete pavement costs

Concrete pavements can be constructed on a sand layer or on a foundation layer. After construction, every five meter transverse joints are sawed in the road prevent cracking due to expansion and shrinkage. To make the roads safer, a texture needs to be applied to the surface of the road.

Table 57 shows the cost for concrete pavements. These costs consist of material, delivery and installation costs. The second part of the table shows the removal costs of the pavement.

Table 57: concrete pavement costs (GWW-costs, 2006).

What	Dim.	Amount	€	Sand	Foundation 0,20 m	Foundation 0,25 m
Shaping sand layer	m^2	3000	0,96	2.880		
Foundation (0,20 m mix. granule)	m^2	3000	2,47		7.410	
Foundation (0,25 m mix. granule)	m^2	3000	2,87			8.610
Concrete (0,25m thick)	m^3	750	108,00	81.000	81.000	81.000
Applying texture on road	m^2	3000	0,14	420	420	420
Sawing transverse joint	m	600	4,13	2.478	2.478	2.478
			Construction costs:	***86.778***	***91.308***	***92.508***
			Construction costs per m^2:	**28,93**	**30,44**	**30,84**
Removing concrete	m	3000	2,55	7.650	7.650	7.650
Removing foundation	m^2	3000	4,15		12.450	
Removing foundation	m^2	3000	4,80			14.400
			Removal costs:	***7.650***	***20.100***	***22.050***
			Total costs:	**94.428**	**111.408**	**114.558**
			Total costs per m^2:	**31,48**	**37,14**	**38,19**

Prefabricated concrete plate costs

These plates can be used as pavement layer. The plates are installed directly on sand and are available in several sizes. Due to the heavy traffic on the temporary roads the thickest plates are used with steel edges to prevent cracking. The dimension of the plates is 2 by 2 meter. Table 58 shows the costs for a prefabricated concrete plate pavement. These costs consist of material, delivery and installation costs. The second part of the table shows the removal costs of the pavement.

Table 58: prefabricated concrete plate pavement costs (GWW-costs, 2006).

What	Dim.	Amount	€	Price
Shaping sand layer	m^2	3000	0,96	2.880
Prefabricated concrete plate	per piece	750	26,10	19.575
			Construction costs:	***22.455***
			Construction costs per m^2:	**7,49**
Removing plates	piece	750	19,60	14.700
			Removal costs:	***14.700***
			Total costs:	**37.155**
			Total costs per m^2:	**12,39**

Note: experience tells that after construction is completed 75% of the plates can be re-used on another construction project. If this is the case the costs of the prefabricated concrete plate pavement will drop. However, in this comparison the assumption is made that no used plates are available and afterwards these plates do not have any remaining value.

Asphalt pavement costs

There are many different types of asphalt available, however not all of them are applicable as top layer on temporary roads. Experience tells that the best asphalt type for temporary roads is STAP 0/22 (crushed stone asphalt concrete, see section 6.5.2), which currently also most used for temporary roads. Asphalt pavements can either be constructed on sand or on a foundation. Table 59 shows the costs for asphalt pavements. These costs consist of material, delivery and installation costs. The second part of the table shows the removal costs of the pavement.

Table 59: asphalt pavement costs (GWW-costs, 2006).

What	Dim.	Amount	€	Sand		Foundation 0,20 m			Foundation 0,25 m		
				7 cm	10cm	5 cm	7 cm	10cm	5 cm	7 cm	10cm
Shaping sand layer	m^2	3000	0,96	2.880	2.880						
0,20m mix. granule (fund.)	m^2	3000	2,47			7.410	7.410	7.410			
0,25 m mix. granule (fund.)	m^2	3000	2,87						8.610	8.610	8.610
STAB 0/22 on sand 5 cm	ton	375	62,95								
STAB 0/22 on sand 7 cm	ton	525	58,50	30.712							
STAB 0/22 on sand 10 cm	ton	750	55,80		41.850						
STAB 0/22 on found. 5 cm	ton	375	61,25			22.968			22.968		
STAB 0/22 on found. 7 cm	ton	525	57,20				30.030			30.030	
STAB 0/22 on found. 10 cm	ton	750	54,95					41.212			41.212
Construction costs:				***33.592***	***44.730***	***30.378***	***37.440***	***48.622***	***31.578***	***38.640***	***49.822***
Construction costs per m^2:				**11,20**	**14,91**	**10,13**	**12,48**	**16,21**	**10,53**	**12,88**	**16,61**
Removing asphalt	ton	375	2,70			1.013			1.013		
Removing asphalt	ton	525	2,70	1.418			1.418			1.418	
Removing asphalt	ton	750	2,70		2.025			2.025			2.025
Removing found. 0,20m	m^2	3000	4,15			12.450	12.450	12.450			
Removing found. 0,25m	m^2	3000	4,80						14.400	14.400	14.400
Removal costs:				***1.418***	***2.025***	***13.463***	***13.868***	***14.475***	***15.413***	***15.818***	***16.425***
Total costs:				**35.010**	**46.755**	**43.841**	**51.308**	**63.097**	**46.991**	**54.458**	**66.247**
Total costs per m^2:				**11,67**	**15,59**	**14,61**	**17,10**	**21,03**	**15,66**	**18,15**	**22,08**

Unpaved road costs

Unpaved roads are constructed of grain material. Since mixed granule is the cheapest grain material available, this is used mostly. Table 60 shows the costs for unpaved roads. These costs consist of material, delivery and installation costs. The second part of the table shows the removal costs of the pavement.

Table 60: unpaved road costs (GWW-costs, 2006).

What	Dim.	Amount	€	Found. 0,20 m	Found. 0,25 m	Found. 0,30 m	Found. 0,35 m	Found. 0,40 m
0,20m mix. granule (fund)	m^2	3000	2,47	7.410				
0,25 m mix. granule (fund)	m^2	3000	2,87		8.610			
0,30 m mix. granule (fund)	m^2	3000	3,33			9.990		
0,35 m mix. granule (fund)	m^2	3000	3,79				11.370	
0,40 m mix. granule (fund)	m^2	3000	4,33					13.990
Construction costs:				***7.410***	***8.610***	***9.990***	***11.370***	***13.990***
Construction costs per m^2:				**2,47**	**2,87**	**3,33**	**3,79**	**4,66**
Removing foundation 0,20m	m^2	3000	4,15	12.450				
Removing foundation 0,25m	m^2	3000	4,80		14.400			
Removing foundation 0,30m	m^2	3000	5,60			16.800		
Removing foundation 0,35m	m^2	3000	6,60				19.800	
Removing foundation 0,40m	m^2	3000	7,10					21.300
Removal costs:				***12.450***	***14.400***	***16.800***	***19.800***	***21.300***
Total costs:				**19.860**	**23.010**	**26.790**	**31.170**	**35.290**
Total costs per m^2:				**6,62**	**7,67**	**8,93**	**10,39**	**11,76**

Conclusion

Looking at the construction costs of the different pavement types discussed above, can see a broad range of costs varying between € 19.860,- and € 114.558,-. As explained above, costs for temporary roads have no direct added value to a project. Therefore the most expensive types of pavement are not applied in a project if not required. Table 61 provides an overview of the construction costs and the costs if the road has to be removed after construction is finished.

Table 61: overview pavement costs for temporary roads.

Pavement type	Construction [€/m^2]	Incl. removal [€/m^2]
Unpaved road	2,47 – 4,66	6,62 – 11,76
Prefab concrete plates	7,49	12,39
Asphalt	11,20 – 16,61	11,67 – 22,08
Small element	24,64 – 27,01	28,10 – 36,07
Concrete	28,93 – 30,84	31,48 – 38,19

The cheapest solution for temporary roads is the unpaved road. However, these roads cannot handle heavy traffic loads (see section 6.3), generate a lot of dust in dry times and dirt in wet times, and require allot of maintenance. For these reasons this type of road cannot always be used. The second cheapest solution is to install prefabricated concrete plates on the road. These plates are however, compared to other pavement types, expensive to remove.

Concrete roads are never used as a pavement for temporary roads, simply because they are too expensive. Another reason it is expensive and time consuming to lay cables and tubes through the roads, which is often necessary in the construction phase. Concrete pavements are therefore not further researched in this research.

In Birons research (2004) it was already clear that small element pavements were no longer used much in 2004, but in 1977 they were used on 67% of the projects. The reason for this drop is most likely also the construction costs. Small element pavements are time consuming to construct and workers are becoming increasingly more expensive. Still, many residential zone's still have a small element paved roads. Also, if 70% of the bricks can be re-used in the permanent pavement or in temporary roads on other project this pavement might still be cost efficient. Next, In subsection 6.1.2, the 'upgrade' costs for a temporary road to a permanent road are determined.

6.1.2. Upgrading a temporary road

Temporary roads are often situated on the same route as the permanent road. On many occasions, parts or the entire temporary road can be re-used for the permanent road. The temporary roads as discussed in subsection 6.1.1 serve as starting point.

There are two options available for pavement in the utilisation phase: asphalt or small elements. For asphalt a two-layer system is chosen. First a layer of STAB 0/22 (this is also used for the temporary roads with an asphalt pavement) is applied followed by a top-layer of DAB 0/16. For the small element pavement the cheapest solution is chosen: concrete bricks (cobble format). The small element pavement requires an edge restraint.

Unpaved road

The muddy top two centimetres of unpaved roads first needs to be removed before they can be used as a foundation for the permanent road. On this foundation layer either asphalt or a small element pavement can be constructed. Table 62 shows the construction costs if an unpaved road is used as base for the permanent road. These costs consist of material, delivery and installation costs.

Table 62: costs necessary to upgrade an unpaved road with permanent pavement (GWW-costs, 2006).

What	Dim.	Amount	€	Small element	Asphalt
Removing top 2 cm	m^2	3000	1,00	3.000	3.000
Bedding sand layer	m^2	3000	0,96	2.880	
Concrete bricks	m^2	3000	17,75	53.250	
Edge restraint	m	1000	13,60	13.600	
Asphalt STAB 0/22 on found, 5 cm	ton	375	55,70		20.887
Asphalt DAB 0/16, 4 cm	ton	300	62,45		18.735
			Construction costs:	**72.730**	**42.622**
			Construction cost per m²:	**24,24**	**14,21**

Note: due to rutting and grading, shaping the thickness of the grain layer might be unequal. For this example the assumption is made that the foundation layer is thick enough after the construction phase is finished. If the foundation becomes too thin, extra granule is required.

Prefabricated concrete plates

Prefabricated concrete plates are installed directly on a sand layer, therefore after removal there is no foundation layer present. Only a sand base is left on which either asphalt or a small element pavement can be constructed, with or without a foundation. Table 63 shows the costs if a small element pavement is constructed and Table 64 if an asphalt pavement is constructed. These costs consist of material, delivery and installation costs.

Table 63: costs necessary to upgrade a small element paved temporary road with permanent pavement (GWW-costs, 2006).

				Small element		
What	**Dim.**	**Amount**	**Price**	**Sand fund.**	**Found. 0,20 m**	**Found. 0,25 m**
Removing plates	piece	750	19,60	14.700	14.700	14.700
bedding sand (0,05m thick)	m^2	3000	1,40		4.200	4.200
Foundation (0,20 m mix. granule)	m^2	3000	2,47		7.410	
Foundation (0,25 m mix. granule)	m^2	3000	2,87			8.610
Concrete bricks	m^2	3000	17,75	53.250	53.250	53.250
Edge restraint	m	1000	13,60	13.600	13.600	13.600
			Construction costs:	**81.550**	**93.160**	**94.360**
			Construction cost per m²:	**27,18**	**31,05**	**31,45**

Table 64: costs necessary to upgrade a prefabricated concrete plate paved temporary with permanent pavement (GWW-costs, 2006).

				Asphalt		
What	**Dim.**	**Amount**	**Price**	**Sand fund.**	**Found. 0,20 m**	**Found. 0,25 m**
Removing plates	piece	750	19,60	14.700	14.700	14.700
Foundation (0,20 m mix. granule)	m^2	3000	2,47		7.410	
Foundation (0,25 m mix. granule)	m^2	3000	2,87			8.610
Asphalt STAB 0/22, 5 cm	ton	375	55,70	20.887	20.887	20.887
Asphalt DAB 0/16, 4 cm	ton	300	62,45	18.735	18.735	18.735
			Construction costs:	**54.322**	**61.732**	**62.932**
			Construction cost per m^2:	**18,11**	**20,58**	**20,98**

Small element

Small element pavements can be easily re-used as permanent pavement. Turning the bricks up-side down during the construction period and re-paving them, with the topside up, for the utilisation phase can do this. Table 65 shows the costs for repaving a small element pavement. These costs consist of material, delivery and installation costs. The assumption is made that 30% of bricks needs to be replaced after the construction stage.

Table 65: costs necessary to upgrade a small element paved temporary road with permanent pavement (GWW-costs, 2006).

What	dim.	Amount	€	Repaving
Breaking up pavement	m^2	3000	0,62	1.860
Breaking up edge restraint	m	1000	2,56	2.560
bedding sand (0,05m thick)	m^2	3000	1,40	4.200
Replacing concrete bricks (30%)	m^2	900	17,75	15.750
Repaving concrete bricks	m^2	3000	8,19	24.570
Replacing edge restraint	m	1000	5.16	5.160
			Construction costs:	**54.100**
			Construction cost per m^2:	**18,03**

Asphalt

Asphalt pavements can easily be upgraded with an extra layer of asphalt (for example with DAB 0/16). A small element pavement is also possible but is rather expensive. Table 66 shows the costs if an asphalt paved temporary road is re-used for the permanent pavement. These costs consist of material, delivery and installation costs.

Table 66: costs necessary to upgrade asphalt paved temporary road with permanent pavement (GWW-costs, 2006).

What	dim.	Amount	€	Asphalt	Small elements
Cleaning asphalt	m^2	3000	0,16	480	
Applying tack coat	100 m^2	30	21,55	646	
Asphalt DAB 0/16, 4 cm	ton	300	62,45	18.735	
Removing asphalt (80mm)	m^2	3000	2.64		7.920
bedding sand (0,05m thick)	m^2	3000	1,40		4.200
Concrete bricks	m^2	3000	17,75		53.250
Edge restraint	m	1000	13,60		13.600
			Construction costs:	**19.861**	**78.970**

What	dim.	Amount	€	Asphalt	Small elements
			Construction cost per m²:	**6,62**	**26,32**

Overview

The cheapest upgrade for a temporary road to a permanent road is an extra asphalt layer on an asphalt paved temporary road. The most expensive upgrade is the construction of a complete new small element pavement with foundation. As expected, repaving a small element pavement is cheaper than installing a new small element pavement. Repaving a small element paved road is still rather expensive compared to installing a completely new small element pavement.

Table 67: overview of pavement upgrade costs.

Permanent pavement	Price [€/m²]
Extra asphalt layer	6,62
New asphalt pavement	24,24 – 31,45
Repaving small element	18,03
New small element pavement	14,21 – 31,45

6.1.3. Combination of temporary road and upgrade costs

In subsection 6.1.1 the construction costs for different temporary road designs were determined and in section 6.1.2 the 'upgrade' costs for temporary roads to a permanent road. Now, the temporary roads can be combined with possible upgrades. When ranked on total construction costs an overview of the most cost efficient combinations is found. This way the total costs for pavement of our example project can be determined and the cheapest solution selected. However, this list can also be generally used for other projects. The result of this calculation is shown in Table 68. Another overview of this table is included in appendix 6.

Table 68: overview combination with permanent pavement.

Construction phase		Utilisation phase	Costs [€/m²]
Unpaved, 0,20 m found.	→	Asphalt 0,9 m STAB/DAB	16,68
Asphalt 0,05 m, 0,20 m found.	→	Asphalt 0,04 DAB	16,75
Unpaved, 0,25 m found.	→	Asphalt 0,9 m STAB/DAB	17,08
Asphalt 0,05 m, 0,25 m found.	→	Asphalt 0,04 DAB	17,15
Unpaved, 0,30 m found	→	Asphalt 0,9 m STAB/DAB	17,54
Asphalt 0,07 m on sand	→	Asphalt 0,04 DAB	17,82
Unpaved, 0,35 m found.	→	Asphalt 0,9 m STAB/DAB	18,00
Unpaved, 0,40 m found.	→	Asphalt 0,9 m STAB/DAB	18,87
Asphalt 0,07 m, 0,20 m found.	→	Asphalt 0,04 DAB	19,10
Asphalt 0,07 m, 0,25 m found.	→	Asphalt 0,04 DAB	19,50
Asphalt 0,10 m on sand	→	Asphalt 0,04 DAB	21,53
Asphalt 0,10 m, 0,20 m found.	→	Asphalt 0,04 DAB	22,83
Asphalt 0,10 m, 0,25 m found.	→	Asphalt 0,04 DAB	23,23
Concrete plates	→	Asphalt 0,9 m STAB/DAB on sand	25,59
Unpaved, 0,20 m found.	→	Small elements	26,71
Unpaved, 0,25 m found.	→	Small elements	27,11
Unpaved, 0,30 m found.	→	Small elements	27,57
Unpaved, 0,35 m found.	→	Small elements	28,03
Concrete plates	→	Asphalt 0,9 m STAB/DAB on 0,20 found.	28,06
Concrete plates	→	Asphalt 0,9 m STAB/DAB on 0,25 found.	28,46
Unpaved, 0,40 m found.	→	Small elements	28,91

Construction phase	Utilisation phase		Costs [€/m^2]
Concrete plates	→	Small elements on sand	34,67
Asphalt 0,05 m, 0,20 m found.	→	Small elements	36,45
Asphalt 0,05 m, 0,25 m found.	→	Small elements	36,85
Asphalt 0,07 m on sand	→	Small elements	37,52
Concrete plates	→	Small elements on 0,20 found.	38,54
Asphalt 0,07 m, 0,20 m found.	→	Small elements	38,80
Concrete plates	→	Small elements on 0,25 found.	38,94
Asphalt 0,07 m, 0,25 m found.	→	Small elements	39,20
Asphalt 0,10 m on sand	→	Small elements	41,23
Asphalt 0,10 m, 0,20 m fund.	→	Small elements	42,53
Small elements on sand	→	Repaving small elements	42,68
Asphalt 0,10 m, 0,25 m fund.	→	Small elements	42,93
Small elements on 0,20 fund.	→	Repaving small elements	44,19
Small elements on 0,25 fund.	→	Repaving small elements	44,59
Small elements on 0,30 fund.	→	Repaving small elements	45,05

It can be concluded that an asphalt pavement in the utilisation phase combined with an unpaved or asphalt paved temporary road is the cheapest solution. The most expensive option is to repave a small element pavement for use as pavement in the utilisation phase. This explains the drop in used of a small element pavement as pavement on temporary roads. Repaving a small element pavement is even more expensive than removing an asphalt layer and installing a new small element pavement. A small element pavement is therefore not recommended as temporary road pavement. If a small element pavement is required in the utilisation phase, the best solution is to combine it with an unpaved temporary road, which is not much more expensive than an asphalt pavement. Concrete plates are cheap to install as pavement for a temporary road, but are not used in the pavement in the utilisation phase, are expensive to remove and do not leave a foundation that can be used for the permanent pavement. Finally it can be noticed that if the permanent road will have an asphalt pavement that is a good solution also to use an asphalt pavement on the temporary road, since this will increase the conditions on the construction site and is not much more expensive.

Sometimes other project requirements can influence the pavement choice. Examples for this can be architectural requirements (the pavement type in the utilisation phase is specified) and residential traffic routing (it is not recommended, and sometimes not allowed, to route residents over an unpaved road).

6.1.4. Maintenance costs

Different pavement types require different amounts of maintenance. Of the temporary road designs unpaved roads require the most maintenance. These roads require grading, shaping, and regular addition of gravel. However is it not easy to predict the maintenance costs for unpaved roads precisely, because maintenance depends largely on the weather. Maintenance is however easy and quickly to perform. A bulldozer can easily carry out shaping and grading as maintenance of a temporary road and only costs about €60 per hour (GWW-costs, 2006). Maintenance should be carried out after a wet period to restore the roads' surface and during dry periods to prevent dust. A couple of hours per maintenance round should be enough for the unpaved roads on a construction site. For the other pavement types the assumption is made that they do not require maintenance during the construction period because they can be designed such that maintenance in not necessary during the construction period. Paved roads are a little more expensive to construct but there are no maintenance costs. Another aspect is that the road often has to be closed if maintenance is required. This is undesirable and hard to express in costs.

Previously in this chapter it was recommended not to use concrete or small element pavements for a temporary road because of their relatively high construction cost. Therefore the maintenance costs were not investigated for these pavements. For the permanent phase no extensive research regarding maintenance cost was performed. However, small element roads require a re-pavement every 10 years and are more sensitive than asphalt paved roads. A correct road design, based on the required lifetime, is assumed to be carried out thereby reducing the chance for maintenance during the lifespan of the road.

6.1.5. Conclusion

The conclusion of section 6.1.1 is that an unpaved road is the cheapest solution if a temporary road is removed after the project is finished. Concrete and small element pavements are nowadays too expensive for used on a temporary road. Asphalt and prefabricated concrete plates are almost equally expensive. However they both have their advantages and disadvantages which are hard to express in value and can differ per project. It is recommended that the pavement choice for the temporary road is not purely based on cost reasons, but also has to meet other preconditions.

Now costs for the temporary road and permanent road can be combined with an estimation of maintenance costs to create an overview. This overview is presented in Table 69. It can be concluded that an asphalt pavement in the utilisation phase is the cheapest solution, however in most residential areas a small element pavement is used as permanent pavement. If a small element pavement is used as permanent pavement, then the best solution is to use an unpaved temporary road because of the difference in construction cost. It should however be noted that an unpaved road cannot be used for residential traffic and cannot handle large amounts of traffic. If an unpaved road is not possible, the best solution is to use a prefabricated concrete plate pavement or asphalt paved road as temporary road. Design aspects for temporary roads are discussed in chapter 3.

Table 69: life-cycle overview different road types.

	Road design		Construction	Maintenance**	
Option.	**Temporary pavement**	**Permanent pavement**	**costs [€/m^2]**	**Temp.**	**Def.**
1	Unpaved	asphalt	16,68 – 18,87	M	N/L
2	Asphalt	asphalt	16,75 – 23,23	N	N/L
3	Prefab concrete plates	asphalt	25,59 – 28,46	N	N/L
4	Unpaved	small elements	26,71 – 28,91	M	L
5	Prefab concrete plates	small elements	34,67 – 38,94	N	L
6	Asphalt	small elements	36,45 – 42,93	N	L

* Costs for the designs as used in section 6.1.1 and 6.1.2. Actual costs and road designs have to be based on the expected traffic load (see chapter 5).

** Assuming a correct road calculation has been made. M = Much, L = Little, N = None. Maintenance of unpaved roads is strongly weather dependent.

The last thing noteworthy is that on some cases a road construction company has connections or discounts for construction materials. This can lead to reduced construction costs as calculated in this chapter and thus to other results for construction costs.

6.2. Foundation

There are numerous materials available for use as a foundation in road building. To make a proper design of a road's foundation a sound knowledge about these materials and their behaviour under different circumstances is necessary. Experience with various unbound and bound base materials has led to the technical specifications that are listed in the RAW Standard Conditions 2005 (C.R.O.W. 2005), currently in use in most pavement construction works in the Netherlands. In this paragraph the different kinds of foundations are discussed. In general terms, the functions of foundation materials are to:

1) Spread the wheel loads in order to reduce its intensity on the underlying sub-grade;
2) Provide a platform for construction equipment used during the building of the road;
3) Provide support for the overlying pavement;
4) Act as drainage layer to remove ingress water away from the pavement.

The choice of a foundation is used in the roads design largely depends on the condition of the sub-grade and the expected traffic load. If a weak sub-grade is present or large traffic loads are expected then a foundation is recommended. Besides the traffic load and the condition of the sub-grade also the availability of materials, technical implementation and environmental aspects a role when determining if a foundation is applied. Foundation materials can be classified in three main categories: unbound, slightly bound and bound foundations.

Unbound materials are mostly applied as temporary road, as work floor or, when large sized granular materials is used, to improve the hydrological regime. Unbound foundation materials only have a slightly higher constructive value than sand. Requirements at unbound foundations at the execution of road building in the Netherlands are discussed in chapter 28.1 of RAW 2005. With slightly bound foundation material is a light-binding agent applied in the unbound material. This results in a higher constructive value of the foundation layer. A bound foundation can is a granular material with one or more added binding agent. Bound foundation materials have a high constructive value. Requirements at bound foundations at the execution of road building in the Netherlands are discussed in chapter 28.2 of RAW 2005.

The main difference between these three categories is the Young's modules (E). With an increasing Young modulus, different failure mechanisms will occur. Especially cracking of the foundation layer is a problem with bound foundations. If a too thin flexible pavement (asphalt) is applied on the foundation, cracks in the foundation will continue in the pavement. Therefore a minimum asphalt thickness is recommended. It is also not recommend applying bound foundation layers in area's where large settlements are likely to occur. This will shorten the lifespan of the road, which is not desired.

For temporary roads, a bound foundation layer can also give problems if cables and tubes need to be laid in the roads' body because these layers are harder and more expensive to restore. Therefore bound foundation layers are not recommended for use in temporary roads and therefore excluded from this research. Unbound foundation materials have only a slightly higher (150 MPa) constructive value than sand (100 MPa), which is also not recommended as foundation layer.

Table 70 provides an overview of the different unbound and slightly bound foundation materials available in the Netherlands (RWS, 1998; Egyed et al., 2006). The construction costs for a 300m thick layer per m^2 is also provided in the table. As can be seen in the table, mixed granule is quite a lot cheaper than other slightly bound foundation materials. Therefore mixed granule is used for unpaved roads and as foundation layer.

Table 70: overview foundation materials with characteristics (RWS, 1998).

Category	Material	constructive value	E [MPa]	γ* [kg/m^3]	€/m^2 layer 300 mm**
Unbound	Brickwork granule	low	150	1.600	2,31
	volcanic rocks	low	150	1.700	10,85
Slightly bound	Mixed granule	average	400	1.850	3,33
	Hydraulic mix granule	average	600	1.850	6,30
	Concrete granule	average	600	2.100	6,33
	Phosphorus slag	average	1.000	2.000	8,51
	Melting furnace slag mixture	average	1.000	2.000	9,42
* After compaction ** GWW-costs (2006)					

It is also interesting to compare the price of sand to the price of foundation materials. Mixed granule is considered a waste product of demolishing buildings, while sand has to be gained making it more expensive (around 8/9 €/m3). Therefore mixed granule is only slightly more expensive than sand, but does provide much better construction characteristics. The application of a mixed granule layer under a pavement will improve the roads' bearing capacity and reduces maintenance. If an asphalt pavement is used, the thickness of asphalt layer can be reduced by the application of a foundation layer, leading to cost reductions.

6.3. Unpaved road design

An unpaved road is a road without a top layer of asphalt, concrete or small elements. A commonly used road on Dutch construction sites is the grain road. Unpaved roads are much cheaper to construct than paved roads, but require more maintenance, especially on weak sub-grades (due to rutting) and if high traffic loads can be expected. Unpaved road require regular addition of granule, grading and shaping in wet times. In dry periods often dust control is necessary. The operation costs increases significantly as traffic load increases or if the stiffness of the sub-grade decreases.

Figure 54: construction of an unpaved road.

6.3.1. Failure mechanisms

The unbounded material of an unpaved road incrementally degrades under repeated load of traffic. Giroud et al. (1981) indicated that progressive deterioration of the base layer occurs through four mechanisms:

1) Lateral displacement of the base layer material resulting from tensile and shear strains at the bottom of the base layer;
2) Contamination of the base layer by fine particles moving upward from sub-grade;
3) Sinking of the base course layer aggregate into sub-grade soil;
4) Breakdown of base layer aggregate due to repeated loading.

These mechanisms all result in damage to the surface of the road. To some degree this damage can be accepted, since the demands at temporary roads are lower than for permanent roads. If to much damage occurs then maintenance is required. Figure 55 shows some examples of damage to unpaved roads.

Figure 55: examples of damage to an unpaved road.

6.3.2. Unpaved road design

Research by Giroud and Noiray (1981) shows that the required thickness of a self-binding (mixed granule) foundation layer during the construction phase can be calculated using the following equation.

$$h_g = \frac{125{,}7 * \log(N_{eq}) + 496{,}52 * \log(P) - 294{,}14 * SP - 2412{,}42}{\left(f_{undr.}\right)^{0,63}} \qquad (25)$$

In which:
h_g = Recommended thickness foundation layer [m]
N_{eq} = Expected traffic load during construction phase
P = Average axle load [N]
SP = Acceptable rutting depth [m]
$f_{undr.}$= Undrained shear strength of sub-grade [Pa]

This equation is valid up to 10.000 axle loads and on cohesive soils. This means the formula cannot be applied to the standard sub-grade profile 4B. However, on sandy sub-grades the chance at damage to unpaved roads is significantly lower than on the other, weak sub-grade profiles. Using this equation and the standard ground profiles, discussed in chapter 4, now the foundation layer thickness for different rutting depths (0,1 and 0,2 meter) and traffic loads (100, 1.000, 10.000 axle loads) can be determined. Rutting depths of 0,1 and 0,2 seem to be much, however this is the total expected rutting after a certain number of 100 kN axle loadings. However, unpaved roads require grading, shaping, and regular addition of gravel. After maintenance the rutting on the surface is removed. Therefore rutting of 0,2 meter is allowed. Table 71 shows the results of these calculations.

Table 71: required thickness of granular layer for standard sub-grade profiles according to Giroud and Noiray (1981).

	N:	100		1.000		10.000	
	Rutting [m]:	0,1	0,2	0,1	0,2	0,1	0,2
Profile	$f_{undr.}$ [kPa]	h_g [m]					
1A	14.500	0,70	0,63	1,00	0,93	1,30	1,23
1B	14.600	0,70	0,63	0,99	0,92	1,29	1,22
2A	24.500	0,50	0,45	0,71	0,66	0,93	0,88
2B	25.000	0,50	0,45	0,71	0,66	0,92	0,87
2C	25.000	0,50	0,45	0,71	0,66	0,92	0,87
3A	14.500	0,49	0,44	0,70	0,65	0,91	0,86
3B	14.600	0,54	0,48	0,77	0,71	1,00	0,94
3C	14.600	0,54	0,49	0,78	0,72	1,01	0,96
3D	40.000	0,37	0,33	0,53	0,49	0,69	0,65
4A	50.000	0,32	0,29	0,46	0,43	0,60	0,56

Figure 56 is a graphical representation of Table 71 and can be used to quickly determine the required foundation thickness if the undrained shear strength of the sub-grade, allowed rutting depth and the traffic load are known. If the undrained shearstrength is unknown the result of a cone penetration tests can be used to calculate the undrained shearstrength with the following equation (ten Hagen & Stam 1997):

$$f_{undr.} = q_c / A \qquad (26)$$

In which
$f_{undr.}$ = Undrained shearstrength [kPa]
q_c = Cone tip resistance [kPa]
A = Soil dependant factor (for normal consolidated soils between 12 and 15).

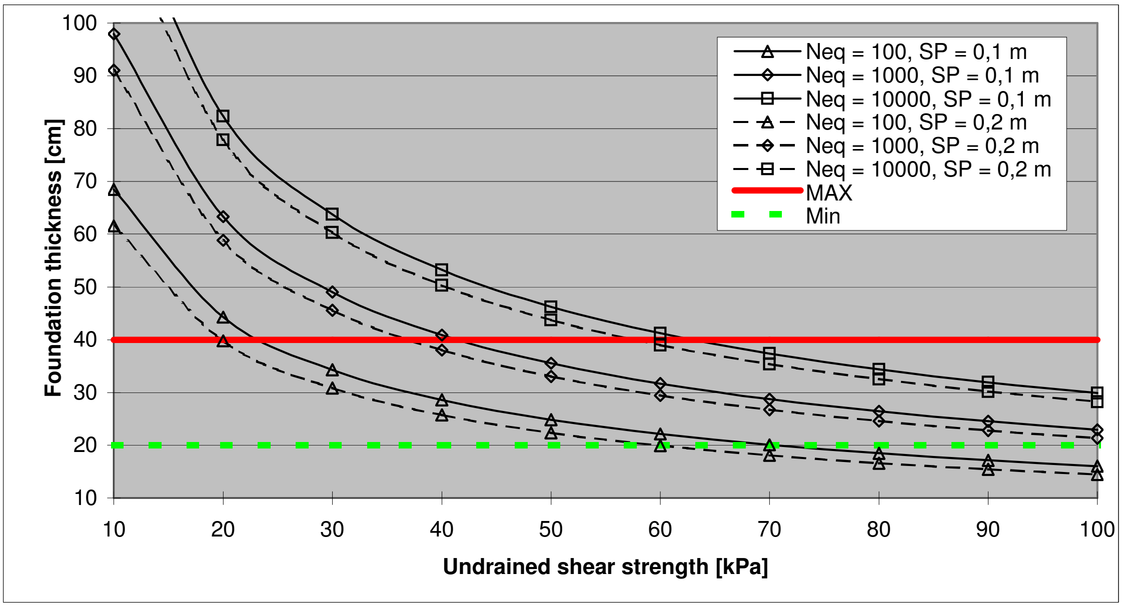


Figure 56: determination of the grain layer thickness (Giroud and Noiray, 1981).

Figure 56 and calculations in Table 71 show that if a very weak sub-grade (standard ground profile 1A-3C) is present on the construction site a very thick grain layer is required. If a very stiff sandy sub-grade is present than an unpaved road can even handle rather heavy traffic loads.

Chapter 2 shows that on the researched project never more than 35 cm of grain material was applied on a temporary road. Also, grain layers thicker than 40 cm need to be constructed in two separate layers, this is more expensive and not desired. Therefore the maximum layer thickness of the grain material is set to 40 cm (MAX), this is also confirmed in VBW-Asfalt (2000).

If, according to Figure 56 a thicker foundation layer is required than 40 cm, then a sand layer is constructed instead. The thickness of a layer foundation material can be converted into an equivalent thickness for another material using the "Method of Equivalent Thickness", developed by Ullidtz (1987), with the following equation.

$$h_e = f_i * h_{sub} \left[\frac{E_{sub}}{E_{base}} \right]^{\frac{1}{3}} \tag{27}$$

In which:
h_e = Equivalent layer thickness [m]
f_i = Correction factor (for two layer system f_i = 0,9)
h_{sub} = Thickness of the original layer that needs to be converted into substitute material [m]
E_{sub} = Modulus of original material [MPa]
E_{base} = Modulus of substitute material [MPa]

On projects with a weak, often consolidation sensitive sub-grade, the site is first made construction ready by adding an extra sand layer. The temporary roads are constructed on this layer which means this sand layer can be used for the roads construction. This layer can be used as a embankment material after compaction. Under other circumstances (high traffic load, weak subgrade) it is possible that an unrealistically thick sand layer is required. In such cases the application of a top pavement layer is required. To clarify how an unpaved road can be calculated this will be illustrated with an example below.

Example: Design of an unpaved road. AANPASSEN !!!

Project:
Mixed granule road (E=400 MPa), maximum grain thickness: 0,35 m, allowed rutting: 0,1 m.
Sub-grade: 2A ($f_{undr.}$ = 24,5 MPa)
N_{eq}: 2.000
The terrain is improved by the addition of 0,7 m sand.
The design height of road is 0,1 m above ground level.

Calculation:
Using equation of Giroud and Noiray we find the required grain layer thickness is 0,73 m.
Thus the grain layer is 0,73 – 0,35 = 0,38 m too thick. We want to replace this by sand.
h_e = 0,9 * 0,38 * $(400/100)^{1/3}$ = 0,54 m sand. The thickness of the road body becomes: 0,54+0,35 = 0,89 m ≈ 0,90 m. This means under the roads an addition 0,9 – (0,7 + 0,1) = 0,1 m sand required is.

6.3.3. Combination with permanent road

Unpaved roads can easily be re-used as foundation for the permanent pavement. Both permanent pavement types can be used in combination with an unpaved road small element pavement or asphalt pavement. These can be calculated as discussed in section 6.6 for small elements and section 6.5 for asphalt pavements. It might be necessary to choose a different design for the unpaved road to be able to meat the requirements of the permanent road. Especially the frost penetration and drainage criteria need to be checked. If an unpaved road is used as a foundation for the permanent road it is important that the muddy top layer (about 2 cm) is removed first.

6.4. Prefabricated concrete plate pavement design

Prefabricated concrete plates are easy to install and to remove, can good resist heavy traffic, requires hardly any maintenance and can be re-used multiple times. The standard size for a prefabricated concrete plate is 2 by 2 meter, and is available in different thickness. Prefabricated plates are available with or without steel edging for extra strength. However, if the steel edging is broken it can cause flat tires. It is recommended to chose plates that can handle axle load up to 200 kN because sometimes trucks are over-loaded and with a steel edging to prevent damage due to pressure of two connection plates. Prefabricated concrete plates are installed using a lift truck with a seam of 5 mm. After placement the seam has to be filled with sand. In the Netherlands the most famous type of prefabricated plates is Stelcon[24], created by De Meteoor B.V.

Figure 57: Stelcon plates.

According to the specifications of Meteoor, Stelcon plates are installed on a 10 cm thick bedding sand layer (specified according to the RAW (2005) standard conditions). The embankment layer has to be well compacted to a depth of 1 meter with a minimum proctor-value of 98% and an average proctor-value of 100%. The crest constant of the embankment layer has to be at least 0,06 N/mm3 (= CBR15 ≈ 150 MPa). This value corresponds with an unbound foundation material.

There is however a problem with the specifications of Meteoor. An unbound foundation layer is almost impermeable. This will lead to accumulation in the embankment layer, which will cause damage to the road because of ‘pumping’ under the plates. A better solution, which is mostly used when concrete plates are used as or in temporary roads, is a sand embankment. This is possible because calculations by Meteoor have a long design lifetime, while the lifetime of a temporary road is much shorter. A sand embankment is a good alternative for temporary roads with a prefabricated concrete plate pavement because of its good permeability. The sand layer thickness has to be substantial, so it will have the characteristics of a sand sub-grade. On places with a high ground water table extra drainage might be required. If a weak sub-grade is present then an improved sub-grade layer is required.

Prefabricated concrete plates are not only applicable as pavement but also as protection for underlying cables and tubes or as reinforcement in unpaved roads. Cables and tubes under the prefabricated concrete plates are easy accessible.

[24] http://www.stelcon.nl

Unpaved roads cannot handle torsion forces applied by the wheels of the trucks in corners and connections to existing infrastructure. This will quickly lead to damage on the unpaved road surface. Prefabricated concrete plates can handle these forces very good. Applying these plates in corners and on connections to existing infrastructure can increase the lifespan of the unpaved roads.

Concrete plates can also be used for the protection of underlying lead-up services. Concrete plates are easily removed and installed again to lay lead-up services under the road. This can result in a temporary road partly paved with concrete plates and partly with another pavement material or unpaved. This practise is applied on Floriande and Duyfrak. Figure 58 shows an example of this practise. A strip of bricks was to prevent the asphalt to stick to the concrete plates. Concrete plates can also be used to widen a small existing road.

Figure 58: combination of concrete plate and asphalt pavement as temporary road on Duyfrak.

6.4.1. Combination with permanent road

After the construction project is finished the prefabricated concrete plates are removed. After removal the embankment under the plates is left. Requirements at the embankment material are set rather high. Therefore after removal of the plates a good and thick embankment sand layer is left. This can be re-used for the permanent road. No foundation layer is used under these plates. This means that a temporary road of concrete plates can be easily combined with the permanent road. It should be checked if the frost penetration and drainage criteria are met.

6.5. Asphalt pavement design

Asphalt has been widely used since 1920-1930, though in ancient times asphalt was already used for road building. The viscous nature of the bitumen binder allows asphalt pavements to sustain significant plastic deformation without significant damage to the pavement. Most asphalt pavements are built on a granular foundation but it is also possible to construct an asphalt pavement directly on sand. In areas with very weak sub-grade, such as clay or peat, a thick granular foundation or stabilisation of the sub-grade might be required. A road with an asphalt top layer and a bound or unbound base are also called flexible pavements.

Figure 59: construction of an asphalt pavement.

For use of asphalt as a pavement layer on temporary roads, experience and calculations show that only a thin layer (5 to 10 cm) of asphalt is required (see chapter 2), depending on the sub-grade and traffic load. In section 6.1 was determined that asphalt paved temporary roads are only slightly more expensive than unpaved roads but still much cheaper than a small element pavements. Asphalt pavements however can handle more and heavier traffic, are easy to re-used in the permanent road and are much better weather resistant than unpaved roads, thus requiring less maintenance. Thin asphalt layers defined as asphalt layers with a maximum thickness of 80 mm. Because of the thin asphalt layers these roads rely heavily on the bearing capacity of the foundation and sub-grade. C.R.O.W. (2002) researched the application of thin asphalt pavement and developed a design method. However, this method is rather elaborate, extensive asphalt pavement knowledge is required and is therefore difficult to use. However this method does provide insight in several design aspects involved in the design of thin asphalt pavements. An easier to use program is CARE, developed by the Dutch Public Works and Water Management office.

The first subsection (6.5.1) starts with the discussing of the main failure mechanisms of asphalt paved road. In the next subsection (6.5.2) the different available asphalt mixtures and their applications are discussed. Then, in subsection 6.5.3 is explained how thin asphalt pavements can be calculated in CARE. The allowed structural damage to an asphalt paved road might vary from the permanent road. This is discussed in subsection 6.5.4. How an asphalt paved temporary road can be combined with the permanent road is discussed in subsection 6.5.5.

6.5.1. Failure mechanisms

VBW-Asphalt (2000) concludes that there are two failure criteria are leading for asphalt roads with an unbound foundation: horizontal stretch at the bottom of the asphalt layer and vertical strain on the upper side of the sub-grade or the embankment. C.R.O.W. (2002) acknowledge these two failure mechanisms for this asphalt layers. Figure 60 shows some examples of damage to an asphalt pavement.

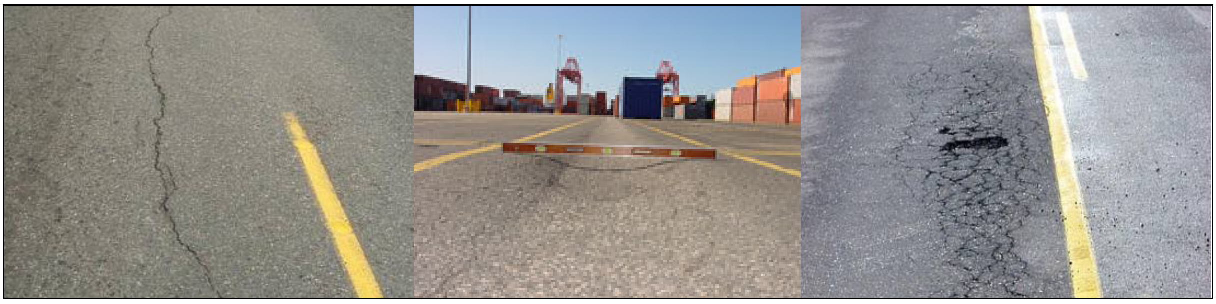


Figure 60: damage to asphalt pavements, left: cracking, middle: rutting, right: hole (structural damage).

Horizontal stretch is dependant on the number of axle loading that has passed over the road. Each pass will cause a small deformation in at the bottom of the asphalt layer and does more damage to the road. Once the asphalt specific critical number has been reached, damage will start to occur on the top of the road. This will result in cracks in the roads' surface and a decreased bearing capacity of the asphalt layer. When much damage occurs to the roads' surface this will lead to holes in the road. How much damage occurs is dependent on the thickness of the asphalt layer and the extent of the traffic load on the road. The damage to the roads surface is expressed in the structural damage factor (see section 6.5.4).

Heavy load on the road will cause vertical strain forces on the upper side of the sub-grade or embankment. In these layers are not designed properly displacements will occur in these layers. Deformations in the foundation and/or embankment material or in the sub-grade will cause rutting in the roads' surface, which should be prevented.

Asphalt pavements are good resistant against frost damage (see chapter 7). Only when often frequently frost thaw cycles occur, some mechanical damage to asphalt may occur. Minimising the hollow spaces in the asphalt layer, to prevent water from entering can reduce this. The stitching properties of the minerals used and the thickness of the hydrocarbon film on the grain are also of importance.

6.5.2. Asphalt types

The mineral skeleton and the fill material for the hollow spaces can be used to make a distinction between the compositions of different asphalt mixtures. Depending on the type of asphalt the mineral skeleton is made of crushed rocks, grain material or a combination of sand with grain material (VBW-asphalt, 2000). The fill material is either mortar (hydrocarbon + filler) or mastic (hydrocarbon + filler + sand). These mixtures can be underfilled, filled or overfilled depending on the remaining hollow spaces in the skeleton. Overfilled mixtures are better frost resistant because there are no hollow spaces where water can accumulate in the skeleton. Underfilled mixtures are good permeability for water. The mineral takes care of force transmission in underfilled mixtures skeleton. In overfilled mixtures there is no longer a mineral skeleton present, the mastic has to take care of force transmission. Overfilled mixtures have more chance of rutting then underfilled mixtures.

Filled mixtures combine the good force transmission characteristics of the underfilled mixtures with the frost resistance of the overfilled mixtures. This is done by adding just enough mastic of mortar to prevent water from accumulating in the asphalt but not enough to remove the positive effects of bearing force of the mineral skeleton. Hollow spaces in filled asphalt mixtures do not have a mutual connection. Most common type of mixture is the asphalt concrete mixture, based on the concrete principle: continues grading of the mineral skeleton (thus, as little as possible hollow spaces). This will lead to more contact points in the mineral skeleton, and thus to a lower contact pressure between points preventing crushing of the skeleton and improving stability. This way, a minimal amount of relatively expensive fill material is required. Table 72 displays the most common types of filled asphalt mixtures used in the Netherlands and the rest of the world. Not all of the above mixtures are suitable for the pavement of a temporary road. Hot-mix gravel is meant for underlying or top layers and is known to have relatively low bearing capacity (the shape of the gravel is resulting in only little shear force) and is thus sensitive to permanent displacements or rutting. This makes hot mix asphalt not well suited for temporary road pavements. Crushed-stone asphalt concrete is also meant for underlying layers but due to the crushed stone aggregate it is much better able to handle heavy traffic loads than hot-mix gravel asphalt. Open-textured asphalt concrete is applied as interlayer in an asphalt pavement. On temporary roads an interlayer is not required. Close-textured asphalt concrete is meant for top layers. The 0/8 mixture is mostly applied on roads with relatively little heavy traffic, like residential area’s. On roads with more heavy traffic the 0/11 or 0/16 mixture is mostly applied. The pervious-coated macadam mixture is also a top-layer mixture with many good characteristics like road safety (good permeable) and noise reduction and is known for high resistance for displacements. However, pervious-coated macadam but can poorly resist torsion forces, which are likely to occur on temporary roads. Lastly, stone mastic asphalt is a top layer mixture as well, its very durable but also very expensive due to it specific composition.

The best choice for the asphalt pavement on temporary roads is therefore the crushed-stone asphalt concrete mixture. Especially the 0/22 mixture, with large crushed-rocks is good suited for application on a temporary road. This mixture can also be applied in relatively thick layers. If it is possible to apply the asphalt pavement in one time this is preferred because it is cheaper. If the temporary road is re-used as permanent road, the best mixture is the close-textured asphalt concrete mixture is the best choice.

Table 72 asphalt types (RWS, 1998; VBW-asphalt 2000)

Asphalt mixture	Type	Applicable as			Recommended layer thickness	Costs per ton [€]
		Top	Inter	Under		
hot-mix gravel (GAB)	0/16 type 1	Y	Y	Y	40 mm	45,00
	0/16 type 2	Y	Y	Y	40 mm	45,00
	0/32	N	Y	Y	60 mm	44,75
crushed-stone asphalt concrete (STAB)	0/16	Y	Y	Y	40 mm	44,85
	0/22	N	Y	Y	60 mm	45,15
open-textured asphalt concrete (OAB)	0/11	N	Y	N	30 mm	47,70
	0/16 type 2	N	Y	N	40 mm	45,90
	0/16 type 3	Y	Y	N	40 mm	49,00
	0/22	N	Y	N	60 mm	46,35
close-textured asphalt concrete (DAB)	0/8	Y	N	N	20 mm	52,70
	0/11	Y	N	N	30 mm	51,85
	0/16	Y	N	N	40 mm	51,69
pervious-coated macadam (ZOAB)	0/11	Y	N	N	30 mm	48,50
	0/16	Y	N	N	50 mm	48,40
stone mastic asphalt (SMA)	0/6	Y	N	N	25 mm	62,50
	0/8	Y	N	N	25 mm	58,90
	0/11 type 1	Y	N	N	40 mm	58,45
	0/11 type 2	Y	N	N	40 mm	58,55

6.5.3. CARE

CARE stands for 'Computer Applications for Road Engineering', and is developed by the Highway and Hydraulic Engineering Department of the Ministry of Transport, Public Works and Water Management (1998, 2006). The CARE methodology exists out of five modules, which can be used for support and advice activities in road construction. ASCON is the design module of CARE, but there is also a stand-alone ASCON module available with only limited options compared to module present in CARE. For this research the CARE program is used, but also ASCON can be used. In this subsection is explained how temporary roads can be calculated using ASCON or CARE and what the differences are between those two. Figure 61 shows the operation diagram of the pavement design module from CARE.

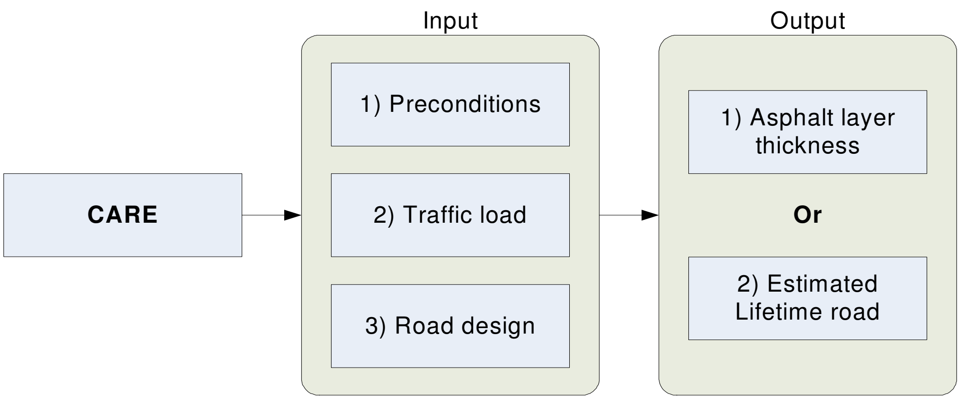


Figure 61: CARE diagram for the design module.

Input

To make calculations CARE needs certain input. Three categories of input can be distinguished in CARE as shown in Figure 61: preconditions, traffic load and the roads' design. In the precondition some general characteristics of the road can be entered like the lane width, reliability of the road, driving speed, the leading design criterion, etc. Parameters regarding the expected traffic load need to be determined for each road. How the traffic load can be determined is discussed in chapter 5. The last input category is roads' design, which is discussed later.

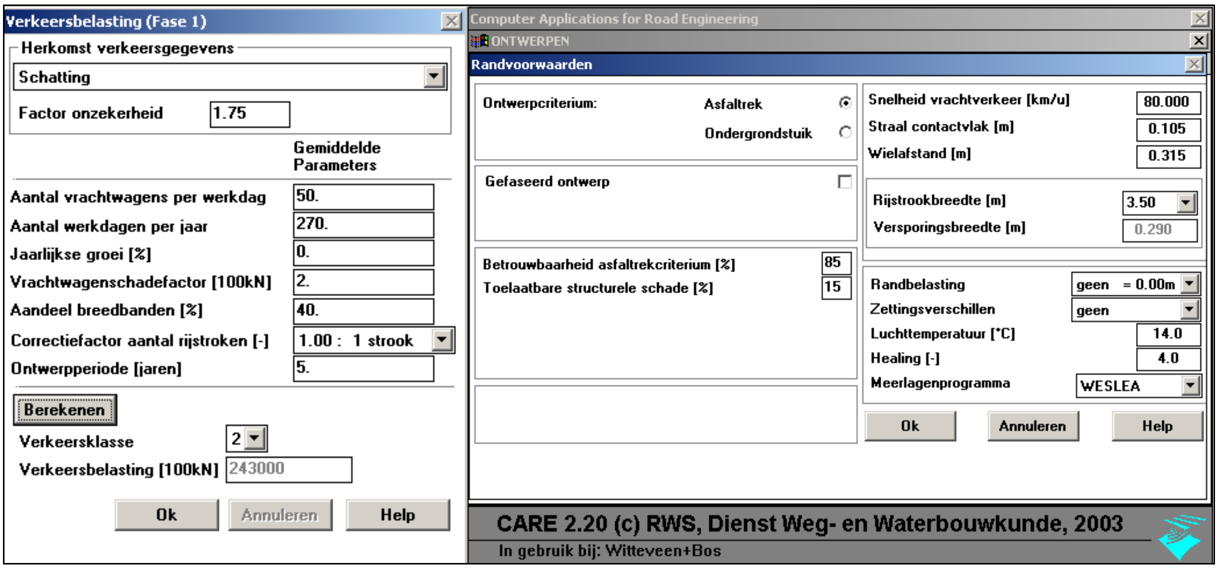


Figure 62: left traffic load screen and right preconditions screen of CARE.

All the input parameters regarding the preconditions and traffic load are shown in

Table 73. In this table is also explained how these parameters can be filled in for asphalt paved temporary roads. Only the parameters, which are used in or relevant for this research, are discussed.

Table 73: inputs required in CARE

Section/Input	Possible input	Description
Preconditions		
- Design criteria	♦ Horizontal stretch ♦ vertical strain	Specifies which on which design criteria the road is being designed. Chose Horizontal stretch for temporary roads.
- Phased design	♦ Yes ♦ No	Specifies if the road is constructed in phases. This is mainly based on the expected settlements, but can also be used to combine the temporary road with the permanent road.
- Reliability horizontal stretch	Value [%]	Specifies the required reliability of the horizontal stretch. For lower order roads, like temporary roads and road in urban areas this is 70 %.
- Reliability vertical strain	Value [%]	Specifies the required reliability of the vertical strain. For lower order roads, like temporary roads and road in urban areas this is 70 %.
- Acceptable structural damage	Value [%]	This is the maximum allowed structural damage at the end of the roads lifetime (see section 6.5.4).
- Speed freight traffic	Value [km/h]	Specifies the driving speed of the freight traffic.

Section/Input	Possible input	Description
		The speed on the temporary roads is dependent on the road type and the current state of the road.
- Driving lane width	♦ 3,50 m ♦ 3,25 m ♦ 3,00 m	Specifies the lane width of the temporary road. Most temporary roads are based on the perma-nent road width. In most residential area's this is 5,5 or 6 m. Thus, the driving lane is 3 m wide.
- Edge load	♦ none = 0,00 m ♦ little = 0,01 m ♦ much = 0,02 m	Specifies the amount of edge load that is to be expected. On roads where the distance between the roads' edge and the rut is smaller than 0,7 m, the horizontal stretch will be larger then on road with a wider pavement.
- Consolidation differences	♦ none ♦ limited ♦ much	Specifies the expected difference in settlements of the sub-grade. New construction sites are always made construction ready so expected settlements are none or limited for most construction sites (see chapter 4)
Traffic load		
Uncertainty factor	Value	Specifies the uncertainty in the available data re-garding traffic load. This also provides a safety factor in the calculations. In this research 1.75 is used, determined by the public works and water management office.
Freight trucks per day	Value	Specifies the number of freight trucks that can be expected on the temporary roads (see chapter 5).
Number of working days per year	Value [days]	Specifies the number of working days in a year. For construction projects this is 270.
Yearly traffic growth	Value [%]	Specifies the expected yearly traffic growth. Since the developed model calculated the traffic for the entire lifespan, no growth is expected (0%).
Truck damage factor	Value [100kN]	Specifies the truck damage factor (see chapter 5). This factor is 2 for heavy freight traffic, since this is the most likely traffic class on the temporary roads.
Number of wide wheels	Value [%]	Specifies the percentage wide wheels. It is ex-pected that this value stabilise at 40 %. The as-sumption is made that this is also the case for temporary roads.
Number of driving lanes	♦ 1,00: 1 lane ♦ 0,95: 2 lanes ♦ 0,90: >2 lanes	Specifies the number of driving lanes on a road per driving direction. This is always 1 lane for tem-porary roads.
Design lifetime	Value [Year]	Specifies the design lifetime of the road. For tem-porary roads this is the construction time of the project.

A description of how the third type of input, the road design, should be entered in CARE cannot be summarised in a table. Calculating thin asphalt layers in CARE is an iterative process and in-volves changing the asphalt and foundation layer thickness. Figure 63 shows the road design in-put window of CARE. A road construction is split up in the asphalt pavement, foundation and sub-grade.

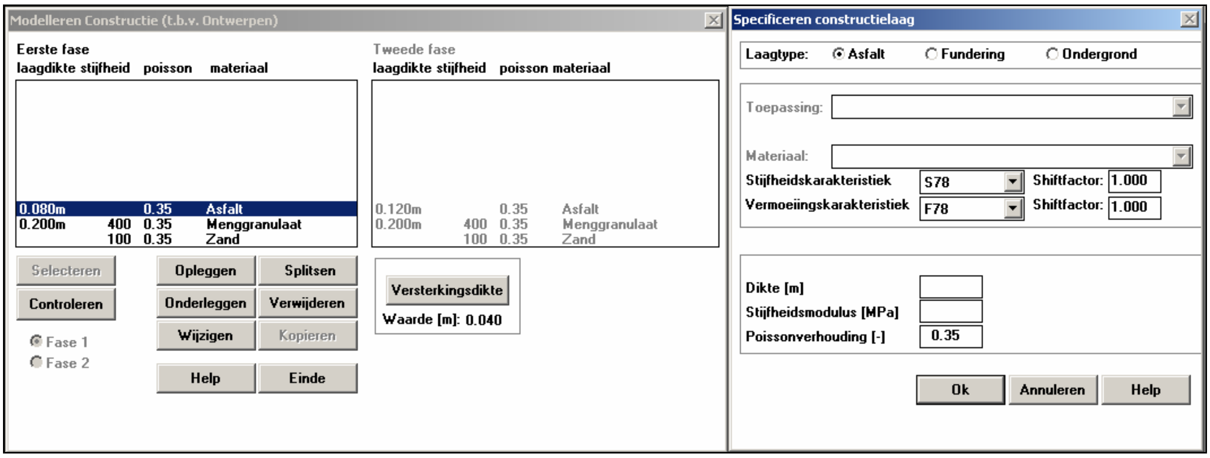


Figure 63: road design section CARE.

If the besides the foundation material an embankment material like sand is used, this can be entered in the model by adding an additional foundation layer and adjusting the Youngs modulus for this layer to 100 MPa. For the sub-grade the standard ground profiles, as discussed in chapter 4, can be used. To do this, the Youngs modulus provided by CARE has to be adjusted.

Table 73 shows the Youngs modulus for the standard ground profiles. The Youngs modules will increase if the terrain is upgraded with an additional sand layer first.

Table 74: Youngs modules for standard ground profiles according to C.R.O.W. (2005)

Profile	Youngs modules [MPa]	Upgraded modules [MPa]	Profile	Youngs modules [MPa]	Upgraded Youngs modules [MPa]
1A	20	80	3A	20	80
1B	20	80	3B	20	80
2A	20	80	3C	20	80
2B	20	80	3D	50	80
2C	20	80	4A	75	100
			4B	100	100

Output

The design module of CARE can be used for the structural design of new asphalt pavements, constructed in one or two phases. Calculations can be made in two different ways as shown in Figure 61. The first method is to only specify the sub-grade and, if present, the foundation and let CARE calculate the asphalt layer thickness. This only works with asphalt layers thicker then 10 cm. Most temporary roads do not require such a thick asphalt layer, thus this option cannot be used to calculate the asphalt layer thickness for a temporary road with a asphalt layer thinner than 10 cm. The second method is to specify the preconditions, traffic load and the roads' global design and let CARE calculates the roads' lifespan. This can then be compared to required lifespan of the road. By adjusting the foundation of asphalt layer thickness the desired lifetime can be found in an iterative process. This is illustrated with the following design example.

Example: Design of asphalt pavement.
Temporary road will be 5,5m wide.

Project:
Sub-grade: profile 2B (20 MPa)
Trucks per day = 20 (30 km/h, VSF_{100}=2)

Required lifetime = 3 years
Reliability horizontal stretch = 70%

Calculation
Calculations with CARE show that asphalt on a sand embankment is not possible.
A road with 0,35 cm sand, 0,25 cm mixed granule and 0,07 cm asphalt is can handle the load and has a expected lifetime of 3.1 years if 15% structural damage is allowed. However, a temporary road with 15% structural damage is as good as new. Therefore we investigate the influence of the structural damage factor in subsection 6.5.4.

6.5.4. Structural damage

To make calculations regarding the estimated lifespan it is first necessary to define when a road is at the end of its lifetime. In CARE this is done with the structural damage factor. This factor can be explained as the maximum allowed crack-initiation (damage) to the road. This is the length of crack initiation occurring on the road as a percentage of the total length. The bureau of Public Works and Water Management (RWS, 2006) utilises 15% crack initiation as design criteria the roads' life span. With only 15% structural damage, it is possible to 'regenerate' the road with an extra asphalt layer to extent the roads' lifetime.

Figure 64: 100% structural damage.

When 15% structural damage occurs, this does not mean that the road is no longer usable as a temporary road, since the requirements set for this type of roads are lower. When 90-100% structural damage occurs, the asphalt pavement is completely destroyed as shown in Figure 64. In the stand alone version of ASCON this factor is set by default to 15% and cannot be adjusted. CARE does provide the option to adjust the structural damage factor. To be able to use this factor in ASCON, the influence of this factor on the expected lifetime for the road is researched. For six different roads the calculation was made to see how the structural damage factor influences the roads lifespan.

Table 75 shows the different road designs. Table 76 shows the life span for different values for the structural damage factor.

Table 75: road designs

Layer	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6
Asphalt	7 cm	7 cm	8 cm	8 cm	8 cm	8 cm
Mixed granule	25 cm	20 cm	25 cm	20 cm	none	none
Embankment	Sand	Sand	Sand	Sand	Sand	Sand
Traffic load	50	50	100	100	30	30
Lane width	3 m	3 m	3,5 m	3,5 m	3 m	3,5 m
Driving speed	30 km/h	30 km/h	20 km/h	20 km/h	30 km/h	50 km/h

Table 76: life span for different roads with different amount of allowed structural damage

Structural damage	Lifetime					
	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6
15 %	3,5	2,8	2,7	2,2	0,6	0,8
20 %	4,1	3,4	3,2	2,6	0,7	1,0
30 %	5,4	4,4	4,2	3,4	0,9	1,3
40 %	6,9	5,6	5,3	4,3	1,2	1,6
50 %	8,5	6,9	6,6	5,3	1,5	2,0
60 %	10,6	8,6	8,2	6,7	1,9	2,5
70 %	13,4	10,9	10,3	8,4	2,3	3,2
80 %	17,7	14,4	13,6	11,1	3,1	4,2
90 %	25,9	21,0	19,9	16,2	4,5	6,2

To find the relation between the roads lifetime and the structural damage, the ratio in which the lifetime increases compared to the lifetime at 15% is calculated. The results are shown in Table 77.

Table 77: structural damage factor's compared.

Ratio	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6	Average
15-15	1,0	1,0	1,0	1,0	1,0	1,0	**1,0**
20-15	1,2	1,2	1,2	1,2	1,2	1,3	**1,2**
30-15	1,5	1,6	1,6	1,5	1,5	1,6	**1,6**
40-15	2,0	2,0	2,0	2,0	2,0	2,0	**2,0**
50-15	2,4	2,5	2,4	2,4	2,5	2,5	**2,5**
60-15	3,0	3,1	3,0	3,0	3,2	3,1	**3,1**
70-15	3,8	3,9	3,8	3,8	3,8	4,0	**3,9**
80-15	5,1	5,1	5,0	5,0	5,2	5,3	**5,1**
90-15	7,4	7,5	7,4	7,4	7,5	7,8	**7,5**

In Table 77 it is apparent that the ratio for each structural damage factor is almost the same. The average values for the ratios are calculated in the last column. To see if there is a relation present in the ratios these values are plotted in Figure 65.

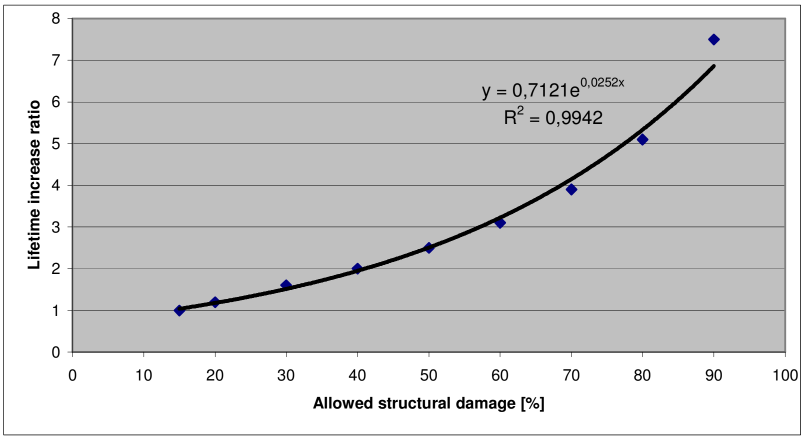


Figure 65: ratio of increasing lifetime at different structural damage percentages.

The values seem to increase exponentially. With help of excel the formula shown in Figure 65 can be derived. Excel calculates also the correlation between the values. For the calculated average values of the ratio the correlation appears to be 0,99. This is nearly a perfect fit, since a perfect correlation has the value 1.

Example (): Design asphalt paved with 80% structural damage.

Project (same as previous example):
Sub-grade: profile 2B (20 MPa)
Trucks per day = 20 (30 km/h, VSF_{100}=2)
Required lifetime = 3 years
Reliability horizontal stretch = 70%
Allowed structural damage 80%

Calculation
Calculations with CARE show that an asphalt pavement on a sand embankment is possible: 10 cm asphalt on 50 cm sand and would be a solution. When a 20 cm thick foundation layer is applied then a 5 cm thick asphalt layer is sufficient and no embankment sand layer is required for structural reasons (this might be required, ever recommended for drainage purposes). If we look at the construction cost in Table 59 we can see that the second solution is the cheapest one.

6.5.5. Combination with permanent road

Asphalt paved temporary roads can be easily combined with the permanent road in the utilisation phase. This can be accomplished by adding an extra layer of asphalt on the road or by the removal of the asphalt layer and the construction of a small element pavement. Since the expected traffic load in residential areas low is in the utilisation phase makes the addition of a thin (about 4 cm) extra asphalt layer on top of the temporary road sufficient. Calculations can be made in CARE using the phased construction option. The temporary road design (phase 1 in CARE) should be calculated with a maximum structural damage factor of 15%. This is the maximum allowed structural damage at which a road can be upgraded.

Most the roads in residential areas have a small element pavement. As shown in section 6.1 it is cheaper to remove the asphalt layer and construct a new small element pavement than repaving a temporary road with a small element. After the removal of the asphalt layer a bedding sand layer can be constructed on which the small element pavement can be installed. How this layer can be designed is discussed in the next section.

6.6. Small element pavement design

In section 6.1.1 the costs for several pavement types were discussed and it is concluded that a small element pavement is too expensive for use as temporary road. Therefore it is not discussed how a small element pavement can be designed as temporary road pavement. It is discussed how a small element pavement on the permanent road can be calculated and/or combined with the permanent road. Since most roads in residential areas have a small element pavement it is likely that if a temporary road is combined with the permanent road that it will have a small element pavement. First, a short introduction to small element pavements is provided.

Figure 66: small element pavements in the utilisation phase.

Pavements constructed with small elements consist out of a top layer of small precast elements, also called bricks. Bricks can be lifted and re-installed rather easily therefore providing easy accesses to the substructure and the underground infrastructure unlike concrete and asphalt pavements. Figure 67 shows a typical structure for a road paved with small elements. The edge restraint has to lock up the bedding layer and the small element top layer to resist the horizontal stresses applied to the pavement by traffic. The required edge restraint is dependent to the load applied by the traffic. The edge restraint needs to be supported at the backside by a well-compacted verge or footway. To achieve a maximum load spreading for the small element pavement it is important that the joints between the small elements are very narrow (2 to 3 mm) and filled with sand. In this light concrete blocks are favourable above burnt clay bricks because narrower joints can be realised due to the smaller dimensional tolerances.

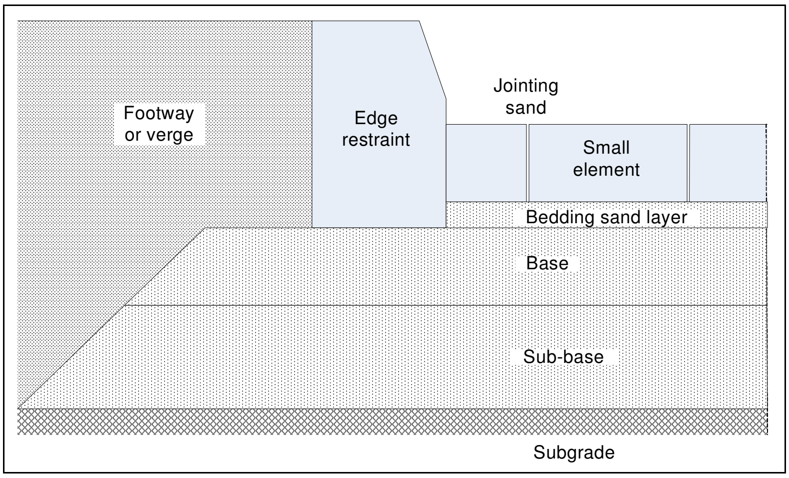


Figure 67: small elements pavement

Between the edge restraints and on the base a thin layer of bedding sand is applied to eliminate the unevenness of the base or sub-base. Because the bedding layer is directly under the elements pavement the material used has to be very stable. Typical thickness of the bedding layer is between 30 and 70 mm (C.R.O.W. 1991). Special types of sand are available for use in the bedding layer. The RAW (2005) specify the requirement for sand used in the bedding layer. The thickness of the Base and Sub-base are dependent on the design of the road surface, the frost penetration depth, the traffic loadings, the bearing capacity of the sub-grade and the materials used. Foundations and foundation materials are discussed in detail in section 6.2.

There are many different laying patterns available for concrete and bunt clay blocks. Figure 68 presents an overview of the most important laying patterns: stretcher bond, herringbone bond and basket weave. Laying patterns influence the structural behaviour and the creep (horizontal displacements in the traffic direction) of the element due to traffic loadings. The herringbone bond is better suited to resist traffic loading then the stretcher bond and basket weave. Better interlock between blocks can also be realised by shaping the blocks for better interlock. In the Netherlands mostly the herring bone pattern is applied. Different laying patterns can also be used for functional reasons like traffic guidance and parking lots. Different functions can also be pointed out by using different block colours.

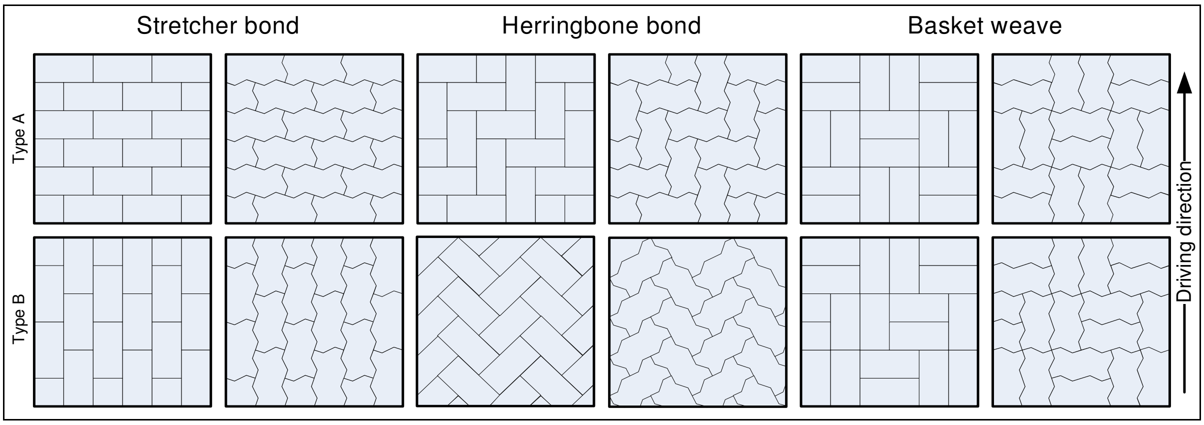


Figure 68: most important types of laying pattern for element pavements

In the Netherlands burnt clay bricks are made from river-clay. Burnt clay bricks are very durable and resistant against frost/thaw-action just like concrete bricks. The manufacturing process of burnt clay bricks requires a lot of energy, which makes them much more expensive then the concrete paving elements. Concrete paving blocks or tiles are made in specialised plants with a high production rate. Concrete paving blocks can be made in different sizes and dimensions. With concrete blocks its also possible to create better interlock between blocks to improve the load capacity. However on weak soils or foundations these stones act the same as the normal rectangular blocks. Quality demands at concrete blocks are specified in the NEN-EN 1338 and concrete clay burnt bricks in NEN-EN 1344. Research by C.R.O.W. (1991) shows that most roads the preferable block thickness is 80 mm. Blocks with more thickness are only necessary when a extremely high concentrated, impact or torsion load can be expected. Three sizes of bricks can be distinguished: Waal, thick and cobble format. The cobble format is applied most.

Table 78: minimal dimensions of burned clay bricks in the Netherlands (RAW, 2005)

Dimension	Waal format	Thick format	Cobble format
Length	195	195	195
Width	48	64	92
height	85	85	78

6.6.1. KMW 1.1

In 2005, C.R.O.W. published the successor of publication 42, “design method for concrete block pavements” (1991), the small element pavement design program ‘BESCON 1.0’. With this program the design for small element pavements can be calculated. However, the program is rather elaborate and therefore quite complex. In 2005/2006 C.R.O.W. developed the ‘choice model road constructions’ (abbreviation KMW) for the Dutch situation. In this program the results of calculations made with BESCON, are implemented. KMW also utilises the standard sub-grade profiles as described in chapter 4. This program is much easier to use and suits the needs for this research better. However, detailed calculations are required for the permanent design. The basic assumptions for small element pavements in KMW are:

- Proper edge restraint;
- Sufficient drainage;
- Sufficient element thickness to prevent cracks;
- Minimal joints, filled with sand.

Details regarding the traffic load on a residential street are required when a temporary road is combined with the permanent road. For the development of the KMW 1.1 (2005) an elaborate study was performed into traffic loads on residential roads. Table 79 shows the traffic data used in BESCON and KMW 1.1 with the loads that can be expected on residential roads that are either light or heavy loaded. On these residential roads there is no public transport is present. If this is the case then additional calculations are required.

Table 79: traffic load on residential road per week (KMW 1.1, 2006).

Type	Light	Heavy
Car	500	1000
Light lorry, single wheels	9	12
Light lorry, twinned wheels	6	8
Bus	0	0
Total	**515**	**1.020**
Per day	**74**	**145**
Percentage heavy traffic	**3 %**	**2 %**

Now road design calculations can be made using KMW 1.1. The results are shown in Figure 69. The following input data is used in KMW 1.1:

- Design lifespan: 20 years.
- Repaving frequency: 10 years.
- Road type: residential road on ground level, two driving directions.
- Driving speed: 30 km/h.
- Yearly growth: 0 %.
- Foundation (if necessary): mixed granule, no reinforcement.
- Sub-grade: Weak clay or peat (20 MPa), stiff clay (50 MPa) or sand (100MPa).
- Location: Central Holland, Utrecht.

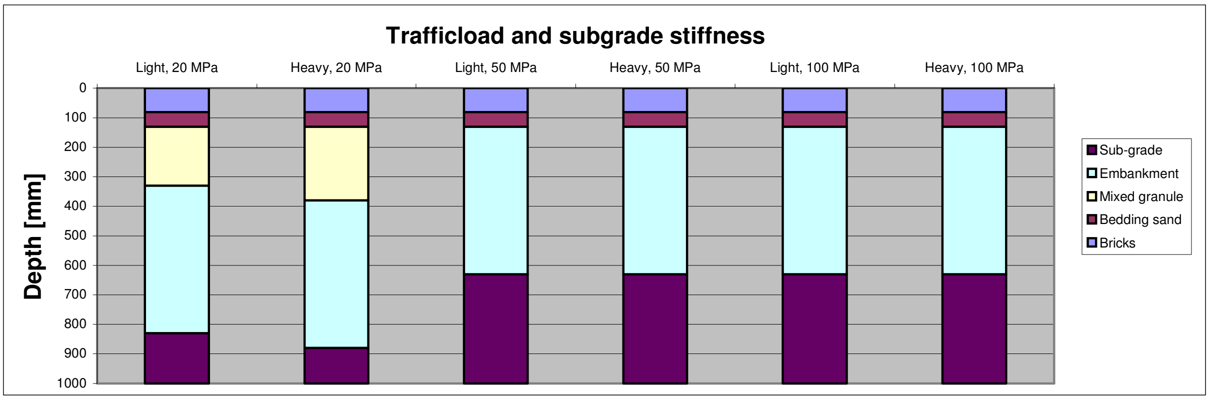


Figure 69: small element pavement designs according to KMW (C.R.O.W. 2006).

Small element pavements on a weak sub-grade (standard ground profiles 1A to 3C) require a foundation layer. However, this layer is relatively thin, compared to the required temporary road designs with often a much higher load. In areas with stiff clay as sub-grade or with good sub-grades (standard ground profiles 3C to 4C), no foundation layer is necessary. If the sub-grade is upgraded first, no foundation is necessary either. Installation of the small element pavement can be done directly on the sand embankment layer. The sand embankment layer is required because of the frost penetration depth (see chapter 7). The depth of the embankment layer has to be at least as deep as the frost penetration depth, preferably a bit deeper (around 10 cm). This makes the permanent situation most likely the selection criterion for the embankment thickness. So there are two design requirements for a temporary road when it is going to be used as permanent road.

1) Roads need to have a body thickness of at least the frost penetration depth.
2) On weak soils, the foundation layer thickness has to be at least as thick as in Figure 69.

RAW standard conditions (2005) specify that a small element pavement has to be installed at least under an incline of 1:50, with a maximum of 1:25, see Figure 70.

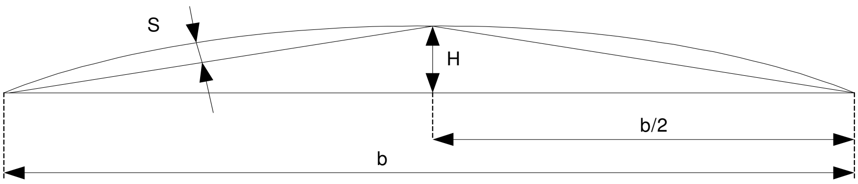


Figure 70: cross-section element road

H = (incline) * b/2 (28)
S = H / 8 (29)

6.7. GeoSynthetic materials

A road construction can only stay even when the maximum load capacity of the sub-grade is not reached. Good load spreading in the road is necessary to prevent the road from showing displacements or other forms of damage. On weak soils this often results in extra thick foundation and/or embankment layers. Geotextiles are permeable fabrics, which have the ability to separate, filter, reinforce, protect, or drain and can be used to improve the road characteristics. Figure 71 shows some examples of geotextiles and gives an impression of how the geotextile works in road construction. Geosynthetic material is a collective term for many different materials: from thick but waterproof foils to persistent, wide-meshed geogrids. All synthetic materials used in civil- and environmental-engineering.

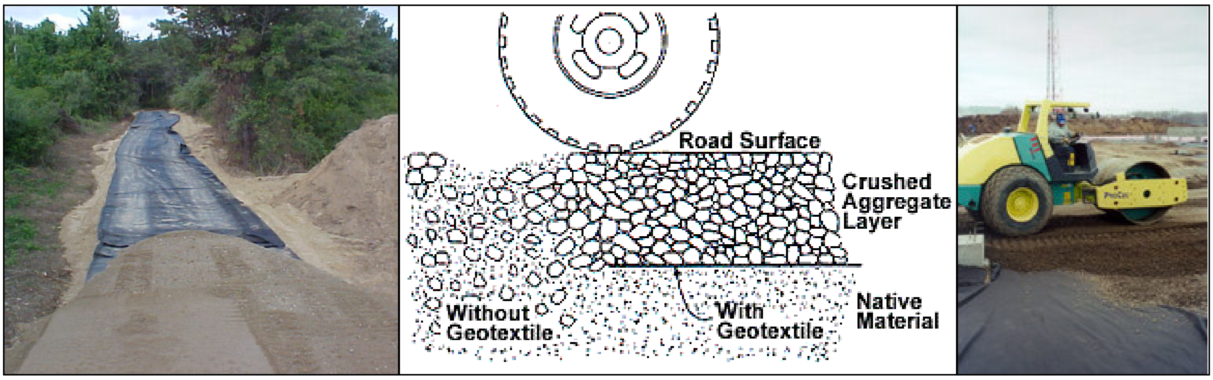


Figure 71: geotextile

Geotextiles can have three main functions in road design. Firstly they can act as a separation layer, which can be used to prevent 'mixture' of two neighbouring layers. Secondly the geotextile can act as a filtration layer, preventing uncontrolled infiltration of small particles from the layers above. Preventing small soil particles from enter the underlying layer will increase the roads drainage capabilities. Finally, the geotextile can be used as a reinforcement layer, by utilising the elastic capabilities of the geotextile to prevent displacements in the road. This can also help with even load distribution in the road, leading to a thinner road construction. This is mainly used in areas with low bearing capacity soils to reduce displacements in the road. So in general geotextiles can be used to increase the roads drainage capacity, increasing the roads load capacity, reducing the road thickness and perhaps reducing the construction costs.

The way a geotextile is used it dependent of the roads' design. Three main types of roads can be distinguished: Paved road, temporary unpaved roads, and unpaved roads. A distinction needs to be made between the construction stage and the utilisation stage. During construction, a temporarily higher load will be applied to the road and therefore to the geotextile. Once a road is paved this load will be more evenly distributed. On temporarily unpaved and unpaved roads this load will stay higher for a longer time. The advantages of geotextile are however mainly noticeable in the construction stage of the paved road or in unpaved roads. Geotextiles are therefore currently mainly used in roads that stay unpaved for longer times or forever. Research performed by C.R.O.W. (2002) on the application of geosynthetic materials is currently applied in road design. Results of this research are utilised in this research.

6.7.1. Types and applications

C.R.O.W. (2002) distinguishes four types of geosynthetic material based on the way they are fabricated or on the used material. The first two go under the name of geotextile. The Dutch organisation for geosynthetic material[25] distinguishes even more types.

[25] http://www.ngo.nl/

Table 80: types of geosynthetic materials.

What	Description	Function
1 Membranes.	Fabrics fixed together using a special production method. Membranes usually possess little strength and can show large deformations and are therefore mainly used for separation and filtration functions.	Separation Filtration
2 Fabrics.	Fabrics are made of strings or tapes that are ordered according to strict structures. In fabrics connections can move separately, making shear forces the main force transition, but only when large deformations occur.	Separation Enforcement
3 Geogrids.	Geogrids are like wire netting, characterised by an open structure. There are two kinds: Woven geogrids and fixed mauled. The difference is that fixed mauled geogrids act as enforcement even by small deformations and woven geogrids can only act as enforcement with large deformations.	Enforcement
4 Geo-composites.	Geo-composites can be made of a combination of membanes, frabics or geogrids or can be a combination of	Separation Enforcement

Figure 72 shows examples for membranes, fabrics and geogrids.

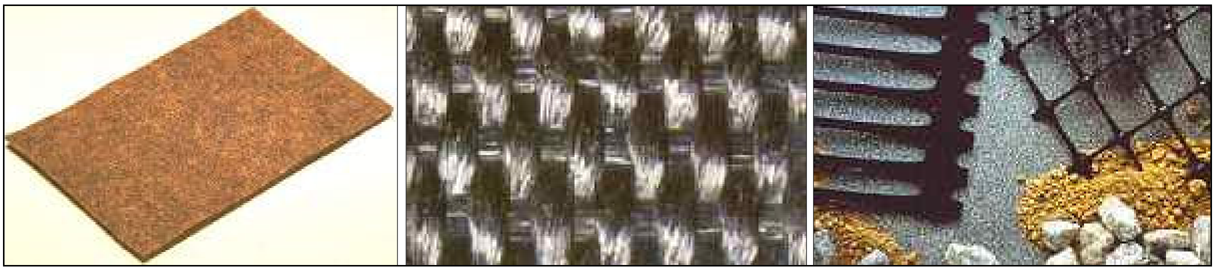


Figure 72: membranes (left), fabrics (middle) and geogrids (right)

6.7.2. Effects

The effects of geosynthetic materials on the roads' behaviour are dependent of numerous factors, making it difficult to predict. In some cases the effect of geosynthetic materials is substantial, in others there is no effect at all. Most effects of geosynthetic materials are expressed in a layer reduction or a lifetime improvement factor. The effects of geosynthetic materials in correlation with the sub-grade and road design are displayed in

Table 81.

Table 81: qualitative consideration effects of reinforcement by geosynthetic materials (C.R.O.W. 2002)

Effects reinforcements	**Sub-grade class**								
	Weak (<30 MPa)			**Average (30 < MPa < 80)**			**Strong (>80 MPa)**		
	P	**TU**	**U**	**P**	**TU**	**U**	**P**	**TU**	**U**
Reduction of embankment depth. - Effect up to 50%.	+	+	+	O	-	-	-	-	-
Reduction of improved sub-grade layer. - Effect up to 50%.	+	+	+	O	-	-	-	-	-
Reduction of sub-grade disturbance during construction. - Makes constructions of thin embankments possible.	+	+	+	O	O	O	-	-	-
Reinforced embankment to reduce thickness. - Reduction up to 250 mm, typical value: 75 mm.	+	+	+	O	O	O	-	-	-
Reinforced foundation to reduce thickness. - Reduction up to 150 mm, typical value: 75 mm.	O	+	+	+	O	O	O	O	O
Reinforced embankment to improve lifetime. - Improvement factor between 1 and 3,8.	O	+	+	O	-	-	O	-	-
Reinforced foundation to improve lifetime. - Improvement factor between 1 and 10.	+	+	+	+	-	-	O	-	-
Improved reliability of the road. - Better response to excess load.	+	+	+	+	+	+	+	+	+

P: Paved road, TU: Temporary Unpaved road, U: Unpaved road.

+: Positive effect, o: Sometimes positive, -: No effect.

Reinforced foundations have several important advantages above traditional foundations. The modulus of elasticity in shear of traditional foundations tends to decrease in time due to loss of particles in the sub-grade and an increase in moisture content. Geosynthetic materials can prevent this from happening due to the separation and filter function. They also allow the use of more open foundation and embankment materials, leading to a improved drainage function under the road. Even geosynthetic materials have several advantages it is sometimes not applied. In situations where enough, high quality, embankment material is available is a geosynthetic material not attractive because of cost reasons.

Research by Berg Christopher and Perking (2000) confirms these effects, and make the distinction to the function of the effects of geosynthetic material:

1) Reducing the intensity of stress on the sub-grade (function: separation).
2) Preventing sub-grade fines from pumping into the base (function: filtration).
3) Preventing contamination of the base materials allowing more open-graded, free-draining aggregates to be considered in the design (function: filtration).
4) Reducing the depth of excavation required for the removal of unsuitable sub-grade materials (function: separation and reinforcement).
5) Reducing the thickness of aggregate required to stabilise the sub-grade (function: separation and reinforcement).
6) Minimising disturbance of the sub-grade during construction (function: separation and reinforcement).
7) Assisting the increase in sub-grade strength over time (function: filtration).
8) Minimising the differential settlement of the roadway, which helps maintain pavement integrity and uniformity (function: reinforcement).
9) Minimising maintenance and extending the life of the pavement (functions: all).

6.7.3. Design method

It is hard to predict the effects of geosynthetic materials on the roads' behaviour. Therefore there is not an unambiguous design method available. The method developed by C.R.O.W. (2002) is generally accepted in the Netherlands. Research shows that the calculation of geosynthetic materials can be split into two main functions: reinforcement and separation. Not all geosynthetic materials can be used as reinforcement for the road body. Table 82 shows the suitability of geosynthetic materials as reinforcement for different types of road and different types of sub-grades.

Table 82: suitability of geotextiles in different types of roads (C.R.O.W. 2002).

Design criteria			Geotextile type					
Road type	Underground	Total thickness foundation (mm)	Geotextile (GT)		Geogrid (GG)		GG-GT composite	
			Non-woven	Woven	Extruded	Woven	open graded foundation	well graded foundation
P	<30 MPa	150-300 >300	+ +	+ +	+ o	❑ o	+ o	- -
	30< MPa <80	150-300 >300	- -	o -	+ o	❑ ❑	+ +	- -
	>80 MPa	150-300 >300	- -	- -	o -	❑ -	❑ -	- -
TU	<30 MPa	150-300 >300	+ +	+ +	+ o	+ o	+ o	- -
	30< MPa <80	150-300 >300	- -	o -	o o	o ❑	- -	- -
	>80 MPa	150-300 >300	- -	- -	- -	- -	- -	- -
U	<30 MPa	150-300 >300	+ +	+ +	+ o	+ o	+ o	- -
	30< MPa <80	150-300 >300	- -	+ o	+ o	o ❑	+ o	- -
	>80 MPa	150-300 >300	- -	- -	- -	- -	- -	- -

P: Paved road, TU: Temporary Unpaved road, U: Unpaved road.
+: Applicable, o: Sometimes applicable, -: Not applicable, ❑: Not enough information

If a geosynthetic material can be applied, the effects can be expressed in the Foundation Reduction Factor. There are three requirements set for the foundation reduction factor:

1) The maximum value of the foundation reduction factor is 0,5.
2) The maximum foundation reduction is 150 mm
3) The layer thickness of the reinforced foundation is al least 150 mm.

Figure 73 can be used to select the geosynthetic material and determine the foundation reduction factor. When the roads' foundation is multiplied with the foundation reduction factor and all three above described requirements are met, the new foundation thickness for the temporary road can be determined.

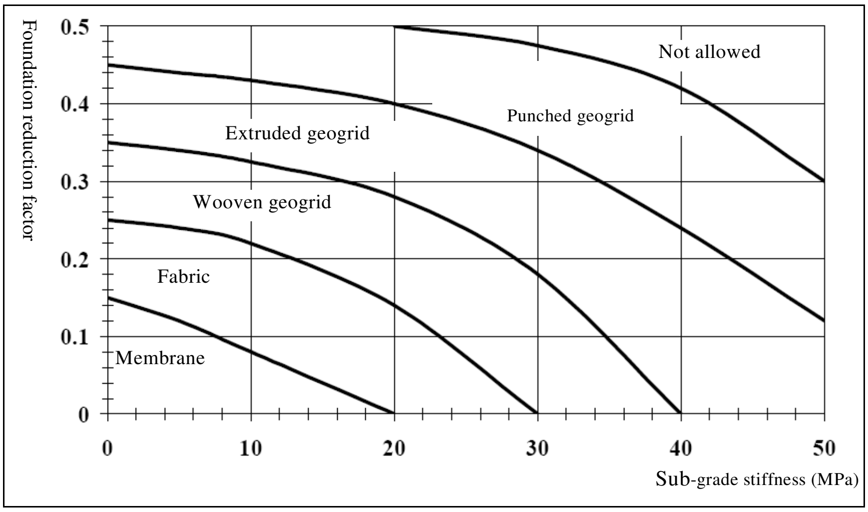


Figure 73: foundation reduction factor (C.R.O.W. 2002).

There are also design programs available to design a road with geotextile. Examples are EnkaRoad from Colbond geo synthetics[26] and Mstab from Geo-Delft[27]. In 2004 the NGO inventoried the available geosynthetic design programs. The report can be found on their website.

6.7.4. Costs

The costs for geotextiles can be estimated at €1,50 per m^2. This corresponds with a mixed granule layer with a thickness of 135 mm. This is within the set limit for the maximum reduction of 120 mm. Therefore it can be cost neutral to construct a geotextile layer under the foundation layer. However, geotextiles are also used to increase a road drainage capacity therefore it has additional positive effects.

6.8. Summary

In chapter 3 it is decided that the construction costs would be the main selection criteria for the pavement choice of the temporary road after other preconditions are met. Therefore this chapter started with the global determination of the pavement cost. This resulted in conclusion that unpaved roads are the cheapest solution, followed by the asphalt and concrete plate paved roads and the exclusion of concrete and small element pavements as temporary road pavement. Next, the ‘upgrade’ costs for a temporary road to a permanent road are researched. The conclusion is that it is always more expensive to upgrade a temporary road with a small element pavement than with an asphalt pavement. However, in residential area’s it is still highly likely that a small element pavement is constructed as permanent pavement.

Research shows that mixed granule the best foundation material for use in a temporary road or as top layer in an unpaved road. The three pavement types and the way pavements can be designed is discussed next. In the utilisation phase it is assumed that there are two main pavement types in residential areas: small element and asphalt. How design calculations can be made for these two pavement types is discussed in section 6.5 (asphalt) and 6.6 (small elements). The temporary road pavement choise model is presented in Figure 74.

[26] http://www.colbond-geosynthetics.com/

[27] http://www.delftgeosystems.nl/

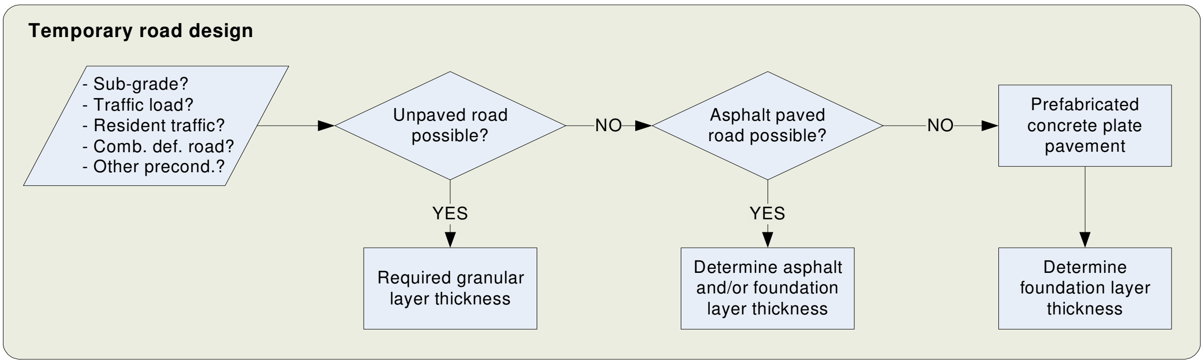


Figure 74: Design scheme temporary road pavement.

The effects and use of geosynthetic materials in temporary roads are also discussed. It can be concluded that geosynthetic materials are cost efficient and show much promise for use in temporary roads. This is especially the case in unpaved roads or in areas with weak sub-grades. The following progressive scheme is based on the construction costs after the preconditions are met and can be used for pavement design of temporary roads.

Progressive scheme:

Step 1: Determine the optimal pavement design specific for the project using Figure 74.

Step 2: Determine the effects of geosynthetic materials.

7. WATERMANAGEMENT.

About half of the Netherlands is only 1 meter above sea level, and much of it is actually below sea level. A substantial part of the Netherlands, for example, all of the province of Flevoland and large parts of Holland, have been reclaimed from the sea and lay below sea level, making water-management on construction sites important. Biron (2004) and SBR (2007) also underline the importance of water management in their research. If not enough attention is paid to water management, significant water logging on the construction site can occur. Most water logging on construction sites in the Netherlands is due to the combination of low permeability soils and inadequate drainage system for the road.

Figure 75: water logging on construction sites.

Temporary roads are also often exposed to water logging on construction sites. Not all types of roads can resist water equally, resulting in to varieties of damage to the road. In the worst case this can lead to the destruction of the road. Temporary roads can not only experience damage resulting from water logging, they can also cause it. There are two main causes for this:

1) A badly constructed embankment sometimes in combination with a road surface above ground level can cause the road to start acting as a dike, especially if it is constructed in a low permeability soil. This makes it impossible for water to get past the temporary road off the construction site. This will flood the surroundings causing much hindrance to construction activities and is undesired.

2) When the road surface is below the ground level then water will stay on the road and the road will start acting as a waterway. Especially roads made of mixed granule, which have low water resistance, will be destroyed if water stays on the road to long.

In this chapter is discussed how water logging on temporary roads as well as on construction sites can be (partly) solved or minimised by optimising drainage in the temporary road. Section 7.1 starts with the discussion the ground water table. Then, in section 7.2, is discussed how much rain can be expected in the Netherlands. The drainage head set for construction and utilisation phase is required before drainage calculations can be made. This is done in section 7.3.

The height of the fake water level in embankments, resulting from rainfall, is discussed in section 7.2. How calculations can be made for horizontal drainage systems is discussed in section 7.5. The frost penetration criterion is discussed in section 7.6. This chapter ends with a summary and progressive scheme in section 7.7.

7.1. Ground water

Rain or surface water penetrates the soil till it reached an impervious layer. Above this layer the soil is saturated. The depth of this fully saturated soil layer under ground layer is called the ground water level. Large parts of the Netherlands are known to have a high ground water table. The influence of a high ground water table on the bearing capacity of the road is discussed in this section.

A high ground water table has two main negative influences on a road. Firstly it can fill the embankment of the road with water which will result in a significant decrease in bearing capacity of the road. This is because the hollow spaces in a saturated soil are filled with water, resulting in a lower contact pressure between the mineral skeleton and thus to a lower bearing capacity. If the embankment is not well compacted this will further decrease the bearing capacity when it is soaked. Secondly, frost/thaw cycles can cause damage to the road in several ways. This main damage mechanism behind this is the expansion of water when it changes from a liquid to a solid state. This mechanism is further elaborated in section 7.6.

Figure 76: left: drinking water area, middle: high ground water table, right: possible result of consolidation.

The Netherlands has one of the highest construction densities in the world. Especially in the western parts of the Netherlands this means that the locations with ‘relatively’ good construction sub-grades are already taken leaving the parts with a bad construction sub-grade for new construction/expansion. In these area’s, usually having a high ground water table, lowering of the ground water table is often not an option. Reasons for this can be the gaining of drinking water, dehydration of the surroundings, settlements due to consolidation sensitive soils or oxidation in peat layers and damage to wooden foundation piles. The question therefore becomes what ground water level is still acceptable for the construction of roads.

7.2. Design showers

Data regarding design showers is required before drainage calculations can be made. A distinction can be made between short-duration showers and long-duration showers. Table 83 shows the amount of rain during short-duration showers and Table 84 during long-duration showers.

Table 83: short-duration showers in mm/m^2 in the Netherlands (C.R.O.W. 2002)

Duration [s]	Occurrence, once every X year			
	1	2	5	10
300	3,8	7	9	10
600	5,5	11	13	15
1.200	7,0	14	17	20
1.800	7,5	16	20	23
3.600	8,1	19	23	27

Table 84: long-duration showers in mm/m^2 in the Netherlands (KNMI, 2004)

Occurrence	Hours				Days			
	4	8	12	24	2	4	8	9
10x a year	9	12	13	15	19	-	-	-
5x a year	12	15	17	21	26	33	43	45
2x a year	16	20	23	28	35	45	61	64
1x a year	21	24	27	33	41	52	71	75
1x in 2 year	25	29	32	39	48	60	81	86
1x in 5 year	31	36	40	47	58	71	94	99
1x in 10 year	36	41	46	54	65	80	103	109
1x in 20 year	41	47	52	61	73	89	113	118
1x in 25 year	43	49	54	63	75	91	115	121
1x in 50 year	49	56	61	71	84	100	124	130

7.3. Required drainage heads

Data regarding the required drainage heads on construction sites and during the utilisation phase is also required before drainage calculations can be made. Table 85 shows indications for the required drainage head on projects according to SBR (2007).

Table 85: indications for drainage heads (SBR, 2007)

Construction phase		Utilisation phase	
What	Drainage head [m]	What	Drainage head [m]
Buildings	0,6-0,7	Houses with crawl space	0,7
Service cables/tubes	0,5-0,6	Cables and tubes	0,6-1,0
Primary roads	1,0	Primary roads	1,0
Secondary roads	0,7	Secondary roads	0,7
Parking spaces/squares	0,4	Gardens/parks	0,5
Accessibility site	0,5-0,7		

7.4. Fake water level

If a road is constructed in a sub-grade with low permeability and water cannot drain in the sub-grade and not to the sides of the road. This will cause the embankment to fill with water, which is called the 'fake water level'. Most of the drainage calculations for a road are focussed on the determination of the fake water level. This is because a soaked embankment and/or foundation will significantly reduce the roads capability to resist traffic load. Therefore the 'fake' ground water level in the roads' body has to be determined. It is recommended for permanent roads that the embankment is never completely soaked. The height of the fake water level in the embankment can be calculated with the following equation (only valid for short-term showers):

$$\Delta z = \frac{q-k}{f_b} * \Delta t \qquad (30)$$

In which:

Δz = height fake water level [m]

q = Amount of rain per m^2 (see Table 83) [mm]

k = Permeability of sub-grade (see chapter 4) [m/s]

f_b = Retention factor (embankment sand f_b = 0,02 or approximation $f_b = 30 * \sqrt{k}$) [-]

Δt = Duration of shower (see Table 83) [s]

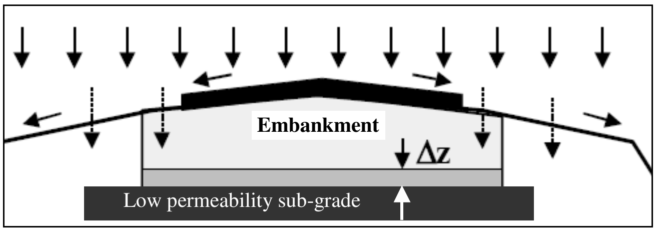


Figure 77: fake water level in road embankment

For temporary roads, it is not a problem that sometimes the embankment is filled with water since the desired lifetime is only short and some damage to the road is acceptable. However, if the temporary road is combined with the permanent road, which has much higher demands, then it is important that sufficient drainage is installed under or near the road. When the temporary and permanent roads are combined then it is necessary that drainage required for the permanent road is already constructed in the temporary road. Some results of calculations regarding the fake water table for the eleven standard ground profiles are shown in Table 86. Calculations are made with an occurrence of one time per year with short-duration showers. For profile 1A to 3D the shower with the duration of 3.600 seconds is leading for the fake water table. For profile 4A this is the shower with the duration of 1.200 or 1.800 seconds is leading. Only ground profile 4B (sand) does not require drainage at all, since the sub-grade is permeable enough to drain the road itself.

Table 86: fake water table height [m] for short duration showers with a chance of occurrence: 1x per year.

Ground profile	k [m/s]	Duration [s]				
		300	600	1.200	1.800	3.600
1A/B	1,00E-08	0,19	0,27	0,35	0,37	***0,40***
2A/B/C	5,00E-08	0,19	0,27	0,35	0,37	***0,40***
3A/B/C	5,00E-09	0,19	0,27	0,35	0,37	***0,40***
3D	1,00E-07	0,19	0,27	0,34	0,37	***0,39***
4A	1,00E-06	0,18	0,25	*0,29*	***0,29***	0,23
4B	5,00E-05	0,00	0,00	0,00	0,00	0,00

7.5. Drainage

Drainage systems can be used to prevent water logging on construction sites. The installation of drainage under the temporary roads to prevent a soaked embankment can also be used to prevent water logging on the construction sites. In this section is discussed how horizontal drainage can be designed in subsection 7.5.1 and where drains can be installed in the roads body in subsection 7.5.2.

7.5.1. Horizontal drainage systems

Horizontal drainage is used to lower the groundwater table. Figure 78 shows an example of how drains can be applied. The top illustration shows the situation if only drains are applied under the road. The bottom illustration shows a more optimal situation in which an extra drain is installed between the two roads. The required drainage heads during construction and utilisation phase are already discussed in section 7.3 discussed. It can be interesting to install the drainage tubes in the construction ready phase to improve the construction site conditions. It is important to note that the drainage heads for the construction phase are sometimes lower than in the utilisation phase. The construction depth of the drains for should be based on the drainage head in the utilisation phase when the temporary is combined with the permanent road. The most important drainage heads are shown in the figure. H_1 is the drainage head under the buildings (during utilisation a drainage head of 0,7 metre is required) and H_2 is the drainage head under garden (during utilisation a drainage head of 0,5 metre is required.

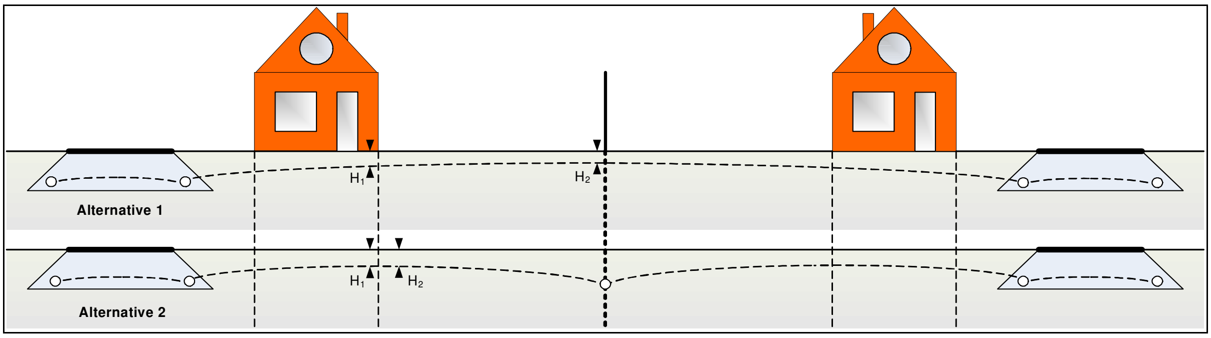


Figure 78: drainage tubes in residential area.

The distance between drains can be calculated using the Hooghoudt equation (Segeren 1984). The Hooghoudt equation is preferably used if the top layer has a higher permeability then the underlying0 layer.

$$L^2 = \frac{8 * K_2 * d * h + 4 * K_1 * h^2}{q} \tag{31}$$

With:

$$h = \frac{D}{1 + \frac{8 * D}{\pi * L} * \ln\left(\frac{D}{\pi * r_0}\right)} \tag{32}$$

L = Distance between parallel drains [m]
K_1 = Permeability of the layer above the drain depth [m/day]
K_2 = Permeability of the layer below the drain depth [m/day]
d = Thickness of the equivalent layer [m]
m = Curving of the water table [m]
q = Specific discharge [m/day]
D = Layer thickness below drains [m]
r_0 = Diameter drain [m]

Calculating the drain distance is an iterative process. The standard sub-grade profiles as developed by C.R.O.W. (2006) can be used for the permeability of the sub-grade. These values are shown in Table 23. There is however real doubt about the correctness of values for the permeability provided by C.R.O.W. It looks like they are chosen far the safe side (thus lower permeability which will lead to smaller drain distances). The values as suggested by C.R.O.W. are most likely based on a virgin terrain with undisturbed compressed layers. Drainage calculations are usually made with higher values. It is proposed to use other values for the permeability as shown in Table 23. For these profiles is assumed that the whole layer is homogeneous, that the influence depth of the drainage system is the thickness of the top layer, as described by C.R.O.W., and that $K_1 = K_2$. It is recommended performing field tests to find the proper value for the permeability on construction sites.

Table 87: permeability for the standard sub-grade profiles determined by C.R.O.W. (2006).

Profile	Layer thickness [m]	K (C.R.O.W.) [10^{-8} m/s]	K [m/day]	
			C.R.O.W.	Suggested
1A	5	1	0,0086	0,05 – 0,1
1B	10	1	0,0086	0,05 – 0,1
2A	6	5	0,0432	0,2 – 0,5
2B	11	5	0,0432	0,2 – 0,5
2C	16	5	0,0432	0,2 – 0,5
3A	9	0,5	0,0043	0,2 – 0,5
3B	12	0,5	0,0043	0,2 – 0,5
3C	15	0,5	0,0043	0,2 – 0,5
3D	3	10	0,0864	1,0 – 2,0
4A	3	100	0,8640	1,0 – 2,0
4B	3	5000	43,2000	10,0 – 20,0

For the required discharge the values provided by Segeren (1984) can be used. During the construction phase calculations have to made with 10 mm/day. Because more terrain will have a pavement (and thus additional drainage systems) during utilisation calculations can be made with a discharge of 5 mm/day. It is also recommended installing the drainage system in the utilisation phase, with calculations based on 10 mm/day. This will lead to better construction site conditions. It is not recommended to make calculations with the values for design showers provided in Table 84 because water will be temporarily stored in the sub-grade leading to a lower discharge.

How drainage systems can be calculated is explained in the example below. This example also shows that there might be a problem with the values of the permeability of the sub-grades provided by C.R.O.W.

Example

Sub-grade 2A: K_1 = K2 = 0,2 m/day
Discharge = 0,01 m/day
r0 = 0,08 m
Design depth drains:1,5 m → D = 6,0 – 1,5 = 4,5 m
Required drainage head = 0,7 m → h = 0,8

Calculation with C.R.O.W. values:
Iteration 1: assume L = 3 m → d = 0,37 → L = 4,63 → Difference: 54 % → Not good
Iteration 2: assume L = 4,63 m → d = 0,55 → L = 5,13 → Difference: 11 % → Not good
Iteration 3: assume L = 5,13 m → d = 0,60 → L = 5,27 → Difference: 3 % → Good

Calculation with suggested values
Iteration 1: assume L = 10 m → d = 1,05 → L = 13,60 → Difference: 36 % → Not good
Iteration 2: assume L = 13,60 m → d = 1,31 → L = 14,80 → Difference: 9 % → Not good
Iteration 3: assume L = 14,80 m → d = 1,39 → L = 15,14 → Difference: 2 % → Good

This means that horizontal drains should be installed every 5,2 m according to C.R.O.W. data, which is rather close, or every 15m when using the new, suggested values.

7.5.2. Location drainage in road

There are two main locations for drainage tubes under a road: on both sides of the road or under the centre of the road. When the drainage tubes are installed on both sides then water will flow directly into the drainage tubes. The tubes are also easier accessible in case the tubes get clogged. However there are two tubes installed which is on some cases unnecessary. In case there is only one drainage tube is required it can also be installed under the centre of the road. In case the drain gets clogged it is hard to access it. The bottom right illustration in Figure 79 shows that the drain can also be installed next to the sewer. In most cases this is a temporary solution to keep the trenching dry. After the trench is filled with sand, the permanent drain is installed.

Drainage tubes can be installed on different depths in the road body. If the drain is installed deeper this will result in larger distances between two parallel drains and thus to cost reductions. Installing drains below the ground water table is not recommended unless the drains can dispose their water on waterways with a lower water table. Figure 79 shows the possible locations for drainage tubes under a road.

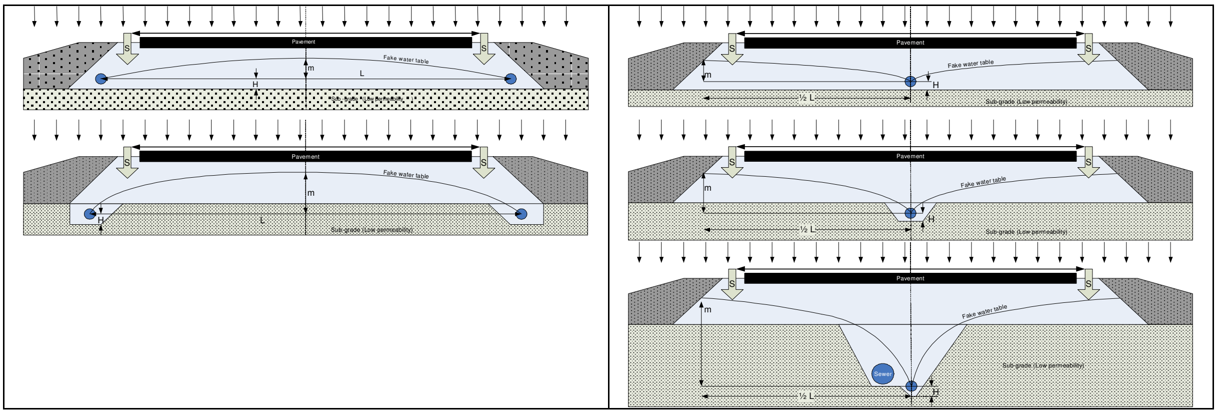


Figure 79: possible locations for drainage tubes under a road.

7.6. Frost

Water can not only cause damage to a road in its liquid state, damage can also occur when groundwater freezes due to low temperatures in the winter. Frost can have three types of negative effects on road constructions (Molenaar (2000), Van der Velden (1999)):

1) The upper layer freezes to pieces because water expands when it freezes. When the residual water stays in hollow spaces of the upper layer and it does not have enough space to expand it will ‘push’ the upper layer to pieces. This problem mainly occurs in asphalt or concrete pavements or bound foundations. It hardly does any damage to a pavement when this only occurs in the foundation of the road.

2) Heave damage. This means that the total pavement structure is pushed upward through the accumulation of water in the form of ice lenses that grow at the freezing plane in the sub-grade. If heave occurs uniformly in the road then heave will not cause much damage, the degree of compaction (density) of the road’s body and the sub-grade however is lowered. This results in a slightly lower bearing capacity.

3) Thaw damage is the worst kind of damage due to frost. When thawing begins, ice melts primarily from the top down, resulting in an impermeable frozen soil layer in the roads’ body. Melted water is then trapped between the pavement structure and the impermeable soil layer,

leading to a very low bearing capacity layer where traffic easily can cause structural damage to the road.

The frost penetration depth and the probability of occurring are necessary to properly design a road. Several climate zones can be distinguished, each having a different frost penetration depth. Historical research by C.R.O.W. (2002) shows that the Netherlands can be split in three zones as shown in Table 88. The probability of occurring is once in the 10 years. This is in accordance with lower class roads where slight damage to the road is not critical.

Table 88: frost penetration depth (C.R.O.W. 2002).

Zone	1x per 10 years
Coast	0,5
South and west	0,5 – 0,6
Middle and north-east	0,6 – 0,7

Now the minimum drainage head required preventing frost damage from occurring can be calculated with the following formula:

$$z_{pav} - z_{gwt} > h_{fpd} + h_c \qquad (33)$$

In which:

z_{pav} = Height of pavement in the centre of the road compared to NAP (m)
z_{gwt} = Height of the ground water table compared to NAP (m)
h_{fpd} = Frost penetration depth (m) (see Table 88)
h_c = Capillary rise height (m) (see Table 89)

Table 89: capillary rise height (C.R.O.W. 2005).

Soil type	Average grain size (d50, µm)	Capillary rise height (m)
Grit	2000-6000	0-0,05
Sand	600-2000 200-600 100-200 60-100	0,03-0,1 0,1-0,2 0,1-0,3 0,3-1,0
Silt	20-60 6-20 2-6	1-3 3-10 >10
Clay	<2	>>10

As can be seen in Table 89, the capillary rises in grit and sand with larger grain size is not much. The capillary rise height in silt and clay however, is very large. Soil can therefore be classified as frost-susceptible if particles of 20 µm. and larger are present. Therefore the RAW standard conditions (2005) limits the used of small particles in the roads' embankment. Sand lesser than 1m below the pavement is not allowed to have more then 15% mineral particles smaller then 63 µm. If there is between 10 and 15% mineral particles smaller then 63 µm, then the maximum number of allowed particles smaller then 20 µm is 3%.

Several measures can be taken to prevent or limit frost penetration in the soil according to C.R.O.W. (2002), Molenaar (2000):

1) Lowering and control of the ground water table.
2) Replacing frost-susceptible soils/material for frost-unsusceptible material.
3) Ditches next to the road to allow melt water to flow away.
4) Raising the level of the road surface relative to the groundwater table by increasing the thickness of the frost-unsusceptible material.
5) For cohesive soils: increasing the degree of compaction r stabilisation with lime and/or cement
6) For granular (non-cohesive) material: stabilisation with cement or bitumen.

7.7. Summary

The importance of watermanagement on construction sites and in residential area's is discussed in this chapter. It is shown that the installation of drainage tubes during the construction phase will lead to better conditions on the construction site and also to better quality temporary roads. The embankment of temporary roads is well suited for drainage tubes. This chapter provides a method how the necessary drainage can be calculated when the standard sub-grade profiles are used. It is also recommend to installing drains on both sides of the road. This way they are better accessible in case clogging occurs and will ensure a continuously dry embankment.

In this chapter the importance of the frost penetration criterion for (permanent) roads is discussed. When the temporary road is to be combined with the permanent road, the frost penetration criterion is also a requirement for the temporary road. This chapter can be summarised in the following progressive scheme:

Progressive scheme

Step 1: Determine sub-grade profile and ground water table level (Chapter 4)

Step 2: Determine the required drainage head (Table 85) and compare it to the water table level. When the depth of the water table is than the required drainage head, then drainage is required. If no drainage is required: go to step 4.

Step 3: Determine the drain distance using the Hooghoudt equation.

Step 4: When the temporary road is combined with the permanent road: check the frost penetration depth and see if the temporary road design meets this requirement.

8. FLOW-CHART DESIGN MODEL

The results of this research, as discussed in chapter 2 to 7, are combined in this chapter into a temporary road design model. The developed flow-chart of the developed model is displayed in Figure 80. A good temporary road design can be made by following the flow-chart.

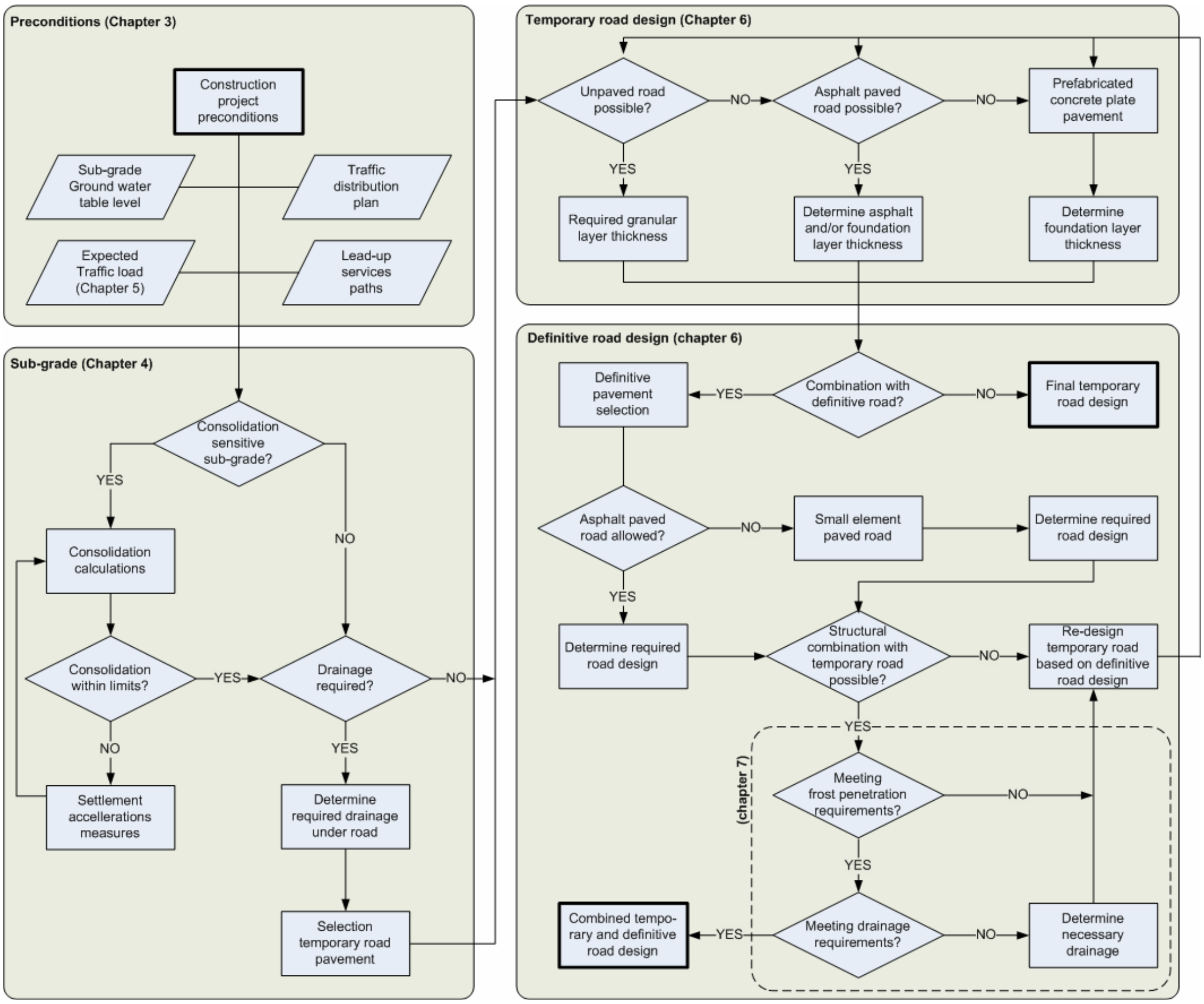


Figure 80: the developed temporary road design model.

The model consists of four main parts that will be discussed in the next sections: preconditions (section 8.1), sub-grade (section 8.2), temporary road design (section 8.3) and permanent road design (section 8.4). In each section a part of the model is explained and references are made to important sections in the previous chapters of this report. This chapter is not a summary, but can be seen as the result of the previous chapters. A more elaborate explanation and a progressive scheme of the model can be found in the scientific article. A short summary of this chapter can be found in section 8.5.

8.1. Part 1: preconditions

The first part of the model is about the determination of preconditions and design aspects required later on in the model. This part deals with the determination of the following project characteristics:

♦ *Project location and layout*. The layout of the construction project will largely determine the location of the temporary roads on the project and the way construction (and resident) traffic will be distributed on the project. It will also show the dimensions of the buildings, which is required to determine the estimated traffic load on the construction site.
♦ *Traffic distribution plan*. This is way the traffic is routed over the construction site. It largely determines the load each temporary road will receive and whether or not residential traffic will can be expected on the temporary roads. Because the requirements at temporary roads with residential traffic are higher it is important to determine these routes. Therefore it is recommended in section 5.1 to classify the temporary roads into categories.
♦ *Expected traffic load*. Each road, based on its location, will have a certain traffic load. We can estimate this load by on all temporary roads. See for more details chapter 5.
♦ *Sub-grade characteristics* and *ground water table*. The sub-grade characteristics determine the way the sub-grade will act when a certain load is applied to it. These characteristics largely determine the method that will be used to make the site construction ready. The ground water table determines if drainage is necessary. See for more details chapter 4.
♦ *Lead-up services path.* The lead-up services are constructed under or next to the road. The moment of constructing these services can influence the temporary road design. See for more details chapter 3.

Recommendations:
♦ When possible it is recommended that lead-up services are installed before the temporary roads are constructed
♦ Waterways and excavations for buildings should be, if possible, excavated before the temporary roads are constructed.

8.2. Part 2: sub-grade

In the second part of the model the behaviour of the sub-grade is discussed.

♦ The first step is to determine if the sub-grade is consolidation sensitive. If this is the case then consolidation calculations are necessary. Construction can only commence when the remaining settlements are within the allowed limit. How consolidation calculations can be made is discussed in section 4.4. Settlement acceleration measures might be required when the expected settlement period is to long.
♦ Drainage under the roads is necessary when the ground water table or the curving of the ground water table is higher than the minimum required drainage head (see section 7.3) during the construction of utilisation phase. How drainage calculations can be made is discussed in section 7.5.

Recommendations

- If drainage is required on the construction site or only required in the utilisation phase it is recommended to install the drainage system in the construction ready stage. This will increase the conditions on the construction site.
- Install drainage on both sides in the roads' embankment. This makes the tubes better accessible in case clogging occurs.
- There is significant doubt about the correctness of the consolidation calculations made by C.R.O.W. (2006). Therefore it is recommended to perform field tests and more detailed calculations.

8.3. Part 3: temporary road design

After the preconditions are met, the temporary road type selection is based on the construction costs as determined in section 6.1.

- The first, and cheapest solution, is the unpaved road. This road is however not always possible on construction sites. The main reasons not to use unpaved roads are weak sub-grades and the presence of residential traffic on the temporary road. How temporary roads can be designed is discussed in section 6.3
- When a unpaved road is not possible an asphalt paved road is the best solution.
- prefabricated concrete plates

Recommendations:

- Mixed granule is recommended as foundation or unpaved road material.
- Design the temporary road above ground level and ensure a good permeable embankment, eventually with horizontal drainage in the road.
- Design unpaved roads at least 20 cm thick with a maximum of 40 cm. Keep in mind that the road will loose around 5 centimetre thickness due to dust and flushing away by water.
- Asphalt roads are more expensive but do not require maintenance and provide better conditions on the construction site.
- On lower order roads a minimum width of 4,5m is recommended (to allow a truck and a car to pass by each other). On higher category roads with more traffic, a minimum of 5,5m width is recommended (to allow two trucks to pass by each other).
- Create enough parking spaces to prevent parking on the roads.
- Prefabricated plates can be used to protect underlying services and to reinforce corners and connections to other roads in unpaved roads.

8.4. Part 4: permanent road design.

In the fourth part of the flow-chart deals with the combined design of the temporary road with the permanent road. This results in an additional set of requirements, which might require redesigning the temporary road.

- The first step is to select the permanent pavement. For the permanent pavement, two pavement types are used by far the most: small element and asphalt. In section 6.1 is determined that it is cheaper to upgrade a temporary road with an asphalt pavement then with a small element pavement. After the decision for the permanent road pavement is made, design calculations can be made.
- When the permanent road is combined with the temporary road, this generates an additional set of requirements for the temporary road. The design of the temporary road has to be checked if it is possible to combine the permanent pavement with the temporary pavement.

- The first check is to compare the structural designs of the two roads in terms of layer thickness. When combined, the layer thickness of the temporary road has to meet the minimum requirements of the permanent road. If this is not the case the temporary road design should be adjusted to meet these demands
- The second check is to see if the frost penetration requirement is met. If this is not the case, the thickness of the embankment layer should be increase to meet this demand. The frost penetration depth is discussed in section 7.6.
- The last check is to see if the drainage requirements set for the utilisation phase of the project are met. If this is not the case then a new drainage design is required.

Recommendations:
- An integral approach for the temporary and permanent road can lead to costs reductions and better conditions on the construction site.
- When the temporary and permanent roads are combined, the width of the temporary road should be at least the width of the permanent road.
- Design the temporary road in such a way that its design also meets the requirements set for the permanent road.
- If calculations show that no drainage is required in the construction phase, but drainage is required in the definite phase then this new design should be installed in the construction ready phase.

8.5. Summary

This chapter provides a flow-chart for the developed design model. This model can be used to create a good temporary road design. In this chapter references are made to sections that contain the information which is required at certain points in the model. The four parts that can be distinguished are based on several chapters in this report.

9. CASE STUDY: DUYFRAK

To see how the model works the project Duyfrak – Valkenburg is analysed as case study. The current situation is discussed in section 2.4. Figure 81 shows zone 1 on Duyfrak and the five parts that can be distinguished.

Figure 81: the five parts in zone 1 on Duyfrak.

9.1. Sub-grade

Duyfrak, the new district of Valkenburg, is located in the western parts of the Netherlands next to the old Rijn. The sub-grade category, based on Figure 82, is therefore Riverclay.

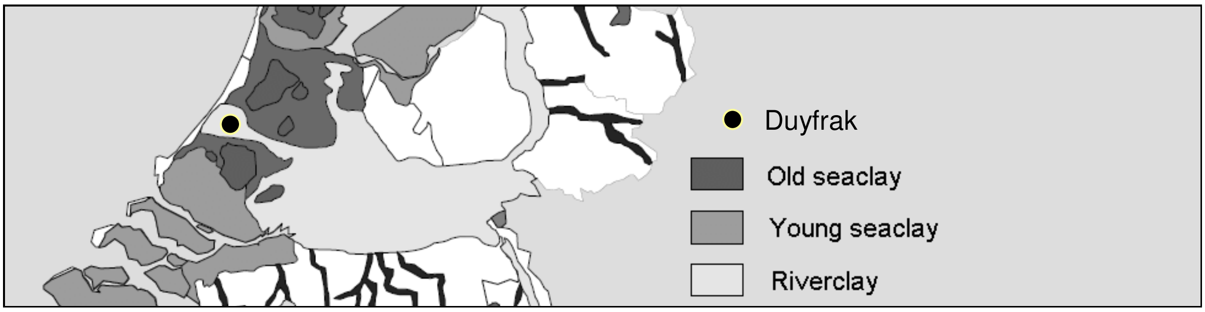


Figure 82: location Duyfrak.

The standard sub-grade profiles are used to make a quick estimation of the sub-grade characteristics. Standard profile 3A fits best when comparing the performed sub-grade analysis (subsection 2.4.2) on Duyfrak to the standard ground profiles (section 4.1). The data of the field tests on Duyfrak can be found in section 2.4.2 and the standard sub-grade profiles can be found in section 4.1. The sub-grade characteristics of profile 3A are shown in Table 32.

Table 90: summary soil characteristics.

E_{used} [MPa]	$\Phi'_{e;d}$ [°]	t_e [m]	$f_{undr.}$ [kPa]	k [10^{-8} m/s]
20	17,2	6,5	25,5	0,5

The integral heightening method was used make zone 1 construction ready. This means a layer of sand was applied on the site. The total settlement that can be expected, according to C.R.O.W. (2006), is 1,10 metre. This is significantly more than calculations based on the field testing data. In chapter 4 is already discussed that there is significant doubt about the correctness of the calculations performed by C.R.O.W. Therefore is assumed that the calculations performed by Witteveen+Bos to be better, which are based on cone penetration tests and sub-grade analysis. The allowed remaining settlement is 0,1 metre. The site is therefore construction ready after three months. The results of calculations by Witteveen+Bos are shown in Table 91. After consolidation the new ground level should be 0,7 metre above the old sub-grade. This means that a layer of 0,7 + 0,23 = 0,93 m sand is applied on the construction site.

Table 91: result settlement calculation [m].

Test location	1	2
Total heightening terrain	0,70	0,70
Total settlements in 30 years	0,23	0,21
Settlements after 3 months	0,13	0,15
Remaining settlements after 3 months	0,10	0,06
Settlements after 6 months	0,17	0,18
Remaining settlements after 6 months	0,06	0,03

The ground water table on Duyfrak is –0,55 NAP and the future ground level is at +0,4 NAP, resulting in a ground water table depth of 0,95m. This is more than the minimum required drainage heads during constructions. However, the storage capacity of the sub-grade is insignificant and the allowed fake water level in the sands is only 0,95 – 0,7 = 0,25 m. Calculations in section 7.4 show that the fake water level in sand can reach 0,4 m during short duration showers. This means that drainage is required. Installing drainage will also improve the general conditions on the construction site.

9.2. Drainage calculation

Drainage calculations are made according to section 7.5. The drains are just under on the ground water table depth on 1 metre deep. Above the drains will be a thick sand layer due to the integral heightening method. To calculate the required drainage we use the following input parameters:

- Sub-grade above drains: sand → K_1 = 2 m/day
- Sub-grade below drains: profile 3A: K_2 = 0,2 m/day
- Discharge = 0,01 m/day
- r0 = 0,08 m
- Design depth drains: 1 m → D = 9,0 – 1 = 8 m
- Required drainage head = 0,7 m → h = 1 – 0,7 = 0,3 m

Iteration 1: assume L = 10,00 m → d = 0,99 → L = 22,01 m → Difference: 120 % → Not good
Iteration 2: assume L = 22,01 m → d = 1,90 → L = 30,35 m → Difference: 38 % → Not good
Iteration 3: assume L = 30,35 m → d = 2,41 → L = 34,10 m → Difference: 12 % → Not good
Iteration 4: assume L = 34,10 m → d = 2,61 → L = 35,48 m → Difference: 4 % → Good

Thus the parallel drain distance is 35 metre. This means that part 2 is sufficient drained by the drains under the roads. Part 1, 3, 4 and 5 will require an additional drain in the centre of the part. In the original plans, drainage tubes were calculated every 7 m. However, these calculations were based on the permeability of the sub-grade and not on the added sand layer due to the integral heightening method.

9.3. Traffic load estimation

There is a preference for combining the temporary road with the permanent road on Duyfrak. The following preconditions exist by the selection of the pavement for the temporary and permanent road.

- It is not possible to separate the construction traffic from the residential traffic on the roads. Therefore an unpaved road is not possible.
- In the permanent phase a pavement with high permeability should be installed.
- The lead-up services are installed after the temporary roads are constructed.

Traffic routing

First, the roads are classified into three categories in order to properly design the temporary roads. Duyfrak consist of six zones that are connected by one main road. This is the first category road on Duyfrak. The main road on zone one is a secondary category road. The temporary roads between the houses are third category roads. The design of Duyfrak is based on 30 % private construction. Therefore not all houses are delivered simultaneously, thus no unpaved roads are possible.

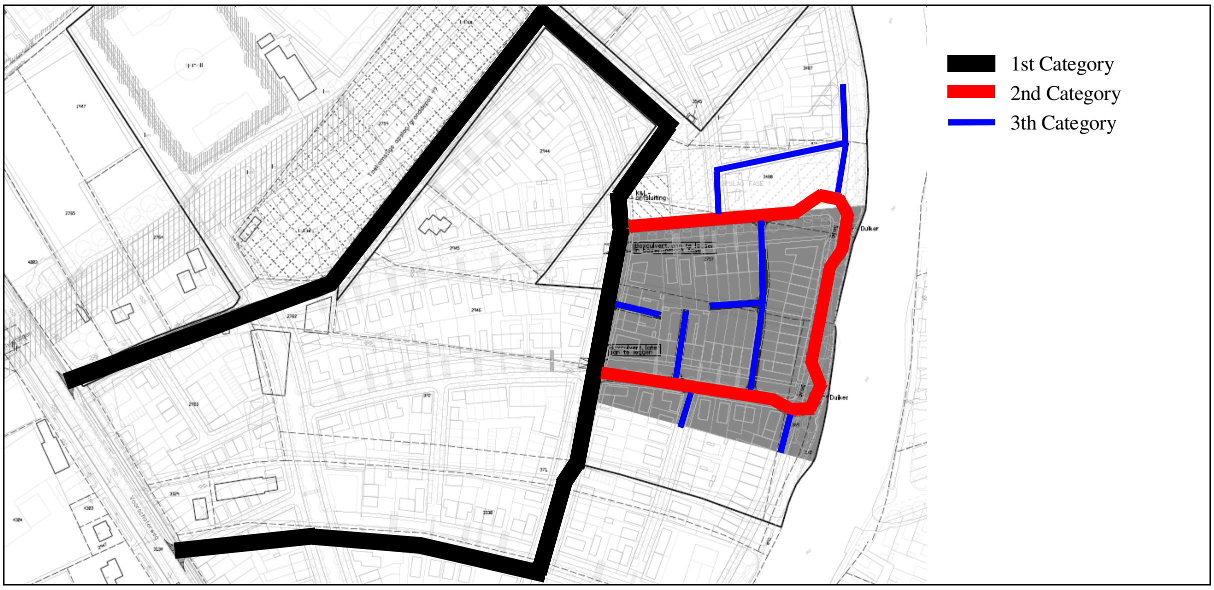


Figure 83: temporary road on Duyfrak, zone 1.

9.3.1. Traffic load

It is hard to predict the estimated traffic load on the first category road since there are is no exact data available about the sizes of the houses on the other zones of Duyfrak. However, it is known that there will be in total about 800 houses. The number of houses and the estimated traffic load on the second category road in zone 1 can be determined. Then, the estimated traffic load on the first category road can be determined using linear interpolation. Table 92 displays the estimated traffic load generated in zone 1. Construction activities are expected to last 24 months on zone one.

Table 92: traffic load per part on zone 1.

Part	Buildings	Amount	Traffic load	Total
1	Free standing, Large, pointed roof	1	82	
	Row houses, Large, pointed roof	(9)		
	- End houses,	4	272	
	- Between houses	5	265	
	Sheds 6 m^2 brick wall.	10	7	
	Garden heightening	1.510 m^2	94	**720**
2	Apartments 6 floors, pointed roof	(25)		
	- End column, large	2	508	
	- Between column, large	3	678	
	Garden heightening	1.281 m^2	80	**1.266**
3	Free standing, Large	10	820	
	Row houses, Large, pointed roof	(24)		
	- End houses,	8	544	
	- Between houses	16	848	
	Sheds 6 m^2 brick wall.	34	21	
	Garden heightening	5.942 m^2	370	**2.603**
4	Free standing, Large, pointed roof	4	328	
	Row houses, Large, pointed roof	(12)		
	- End houses	4	272	
	- Between houses	8	424	
	Sheds 6 m^2 brick wall.	16	10	
	Garden heightening	1.918 m^2	120	**1.154**
5	Free standing, Large, pointed roof	8	656	
	Row houses, Large, pointed roof	(10)		
	- End houses,	4	272	
	- Between houses	6	318	
	Sheds 6 m^2 brick wall.	18	11	
	Garden heightening	2.413 m^2	150	**1.407**
O	Waterway 1: 156m long, 8m wide, 1,2m deep		383	
O	Waterway 2: 153m long, 8m wide, 1,2m deep		375	**758**
	Total number of houses zone 1:	(103)	*Total load:*	**7.908**

9.4. Pavement design

The temporary road is to be combined with the permanent road, with the precondition that a good permeable small element road is used as permanent road. If a mixed granule layer is used in the temporary road, this has to be removed before the permanent pavement can be. Because a layer of sand is applied on the construction site there the frost penetration depth will not reach the ground water table in the permanent phase, thus no extra sand layer is required:

$z_{pav} - z_{gwt} > h_{fpd} + h_c \rightarrow 0{,}95 > 0{,}5 + 0{,}3 = 0{,}8$ metre

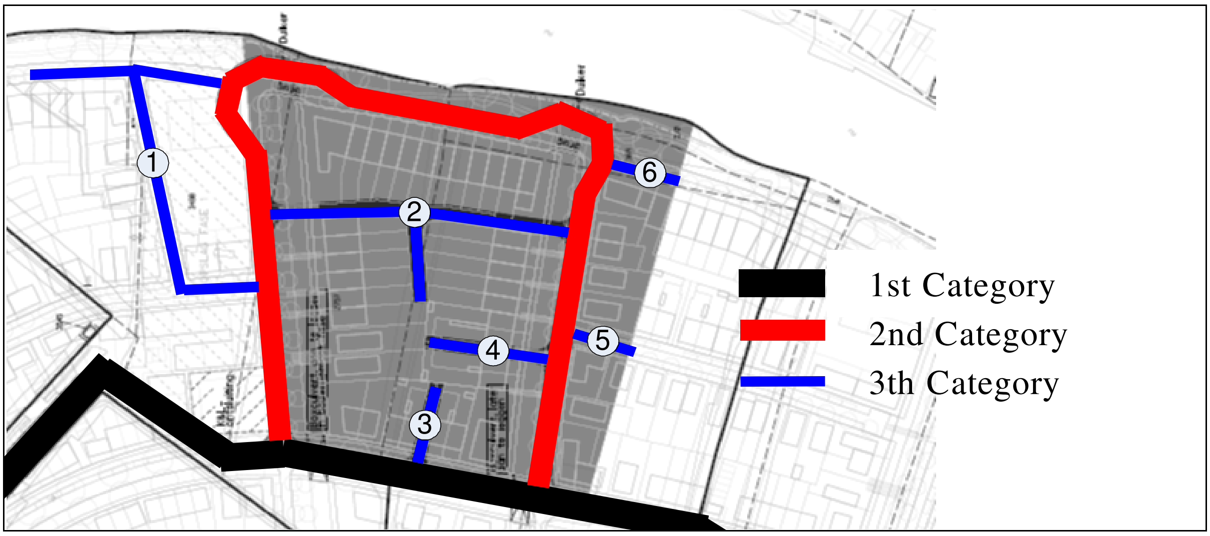


Figure 84: temporary roads on Duyfrak (numbering third category roads).

Subsection 9.4.1 deals with the design of the third category roads, subsection 9.4.2 with the design of the second category road and subsection 9.4.3 with the design of the first category road. Maintenance is discussed in subsection 9.4.4.

Third category

There are six temporary roads in the third category on Duyfrak as can be seen in Figure 84. The expected traffic load on each road can be found in Table 93. An unpaved road is not possible due to the possibility of residential traffic. This leaves an asphalt or prefabricated concrete plate pavement as options for the temporary roads. The temporary roads in the third category are assumed to be 5,5 metre wide.

Table 93: unpaved road design.

Road	Traffic (Figure 81)	N	N/day
1	Part 1 + ½ part 2	1.353	2,51 (≈3)
2	¾ part 3	1.900	3,51 (≈4)
3	¼ part 3	650	1,20 (≈2)
4	¼ part 3	650	1,20 (≈2)
5	½ part 5	704	1,30 (≈2)
6	½ part 4 + ½ part 5	1.280	2,37 (≈3)

Calculations with CARE show that 0,07 m asphalt on sand is an option for the temporary road in with the highest expected traffic load (road 2) when 50% structural damage is accepted to the road at the end of the construction period. The expected lifetime for this design is 2,1 years. The design with 0,05 m asphalt on 0,20 m mixed granule is also an option, however this is more expensive that asphalt on sand. When the construction and removal costs of the asphalt layer (€11,67) and concrete plates (€12,39) are compared, it can be seen that asphalt is the preferred choice. STAP 0/22 will be used for the asphalt layer. A similar trade-off can be made for the other roads. Resulting in asphalt layer thickness of 0,06 m for road 3, 4 and 5 and 0,07 m for road 1 and 6. Since there is only a small difference in layer thickness, all roads can be constructed 0,07 m thick.

Because an asphalt pavement is used and the sand layer can easily support the road, there is no added value for geosynthetic materials in the road body.

Second category

In Table 32 is calculated that the total expected traffic load (N_{total}) to construct zone 1 is 7908. Based on the construction time of two years (540 workdays) the traffic load per day becomes 14,6 (≈15) trucks per day. This is the design traffic load for the road in the secondary category. Because residential traffic can be expected on this road makes an unpaved road impossible.

The main lead-up services are installed under this road. Therefore wide strip of concrete plates is constructed in the pavement, to protect the underlying cables and tubes. These plates can be easily constructed on top of the sand layer since it is already almost 1 metre thick. In chapter 6 was already determined that the costs for a prefabricated plate road or asphalt paved road are more or less equal when the removal costs are involved. There is however a high risk that these plates will move and create spaces between plates and ridges due to unequal settlement. Therefore it is not recommended to completely construct the roads where also residential traffic can be expected with prefabricated concrete plates. The temporary road will be 5,5 m wide, which means the other 3,5 m will be an asphalt pavement.

Two alternatives are studied for the asphalt strip: asphalt on sand and asphalt with a mixed granule foundation. The minimum asphalt layer thickness for STAB 0/22 on a foundation is 0,05 m and when directly applied on sand this becomes 0,06 m. The allowed structural damage is set to 50%, since the asphalt layer is not re-used for the permanent road. Because residential traffic is present on this road, it is not recommended to further heighten this factor. Calculations are made with CARE. The results are shown in Figure 85 and Figure 86.

Figure 85: alternative 1, asphalt pavement with foundation.

	Depth* [m]	**Description.**
	0,00 – 0,05	Asphalt
	0,05 – 0,25	Mixed granule
	0,25 - 0,93	Sand (E=100 MPa)
	0,93 - …	Natural sub-grade: weak-clay (E=20 MPa)
* Below ground level [m]		

Figure 86: alternative 2, asphalt pavement on sand.

	Depth [m]	**Description.**
	0,00 – 0,10	Asphalt
	0,10 - 0,93	Sand (E=100MPa)
	0,93 - …	Natural sub-grade: weak-clay (E=20 MPa)

The estimated lifespan of the first alternative (asphalt pavement with foundation) is 5,5 years, which is significantly more than the estimated construction time of 2 years → good possible temporary road design. The estimated lifespan of the second alternative is only 2.4 years, which is sufficient but is significantly shorter than the first alternative. In the original plan a 0,8m thick asphalt pavement on sand is used. According to these calculations this might be insufficient.

When the construction costs are involved it can be seen that the second alternative is more expensive (€15,59 for alternative 2 to €14,61 for alternative 1) than the first due to the thicker expensive asphalt layer. Therefore the first alternative is the best one. Also, the choice was made to excavate the waterways after the temporary roads are constructed. This will cause significant damage the road due to the heavy machinery (thus with a higher truck damage factor) making the first alternative the preferred choice.

First category

The estimated traffic load on the second category road, generated by 103 houses was estimated to be 7.908. In total around 800 houses will be build during five years (Duyfrak is expected to be finished in 2012). Now an estimation of the traffic load on the first category road can be made:

$$N_{total} = \frac{7.908}{103} * 800 = 61.421$$

This is resulting in an average of 45,5 (≈46) trucks per day during five years. A currently existing road is re-used as primary temporary road. This road is only 4,5 m wide and thus too small to allow two trucks passing each other. Therefore this road has to be widened. There are two options available: asphalt or concrete plates. However the required asphalt pavement (0,085m asphalt on 0,25m mixed granule) is significantly more expensive than concrete plates. Therefore a concrete plate pavement is used to widen the road.

Maintenance

For the asphalt paved roads only minimum damage can be expected. If holes form in the pavement they should be repaired.

9.5. Construction costs

Now the construction costs for the pavement in zone one can be calculated and compared to the original plans of section 2.4. This is done in Table 94.

Table 94: estimation of the construction costs for the temporary road.

Road category	Description	Construction costs*	Amount [m^2]	Total costs [€]
3	0,07m asphalt on sand	11,67 €/m^2	3.176	37.064
2	♦ Concrete plates ♦ 0,05m asphalt on 0,2m mixed granule	12,39 €/m^2 14,61 €/m^2	869 1.304	10.767 19.051
1	Concrete plates on sand	12,39 €/m^2	**	**
		Total:	5.349 m^2	66.882
* Inclusive removal cost because of the permanent road. Costs based on GWW-costs (2006) ** Unknown.				

In the current plans, all the temporary roads as shown in Figure 84 have asphalt pavement (0,08m) on sand. The construction costs for this pavement are €12,66 m^2. The total costs for the temporary roads becomes 5349 m^2 * 12,66 €/m^2 = € 67.718,-. However, the design of the temporary roads in the second category in the original plan is thinner and might be insufficient. Still the 'new' design is € 1.000,- cheaper than the original plan (-1,2 %).

9.6. Summary

In this case study the project Duyfrak is analysed. The standard ground profiles were used to determine the sub-grade behaviour. The sub-grade selected was profile 3A. Next the traffic load model was applied to Duyfrak. Calculations showed that the current road design might be insufficient to sustain the construction activities. Other roads are over designed leading to unnecessary costs.

10. CONCLUSIONS

Up to now, temporary road design is mostly based on experience and assumptions instead of sound research. This study provides a good start in the development of a temporary road design model. Such a model can help to save costs and can be used as standard method to develop high quality temporary roads, thereby improving the general conditions on the construction site.

As a first step the current situation has be analyzed. This led to the following conclusions:

1) Mostly the following three types of temporary roads are applied in the Netherlands: unpaved, asphalt paved and prefabricated plate paved roads. Small elements are hardly applied anymore because of the high construction costs. Prefabricated concrete plates are mainly used to reinforce corners and connections to higher order roads. They are also used to protect lead-up services under the road.
2) There are three possible points in time to construct lead-up services: before construction of the temporary road, after construction of the temporary road and during the thirteen weeks phase before the houses are delivered. The best moment to install the lead-up services is before the temporary roads are constructed as it is expensive to reopen paved roads and restore them to the old situation.
3) Separating residential traffic from construction traffic is recommended when possible. This will increase the safety for the residents and reduce temporary road costs.
4) When residential traffic is expected on a temporary road, the requirements set for this road are the same as for a public road.
5) Parking should be prevented on temporary roads. Therefore enough parking spaces should be created on the construction site.

Next, it was investigated whether the sub-grade profiles as developed by C.R.O.W. (2006) could be applied to the temporary road design model:

6) There is significant doubt about the correctness of the standard sub-grade profiles and their corresponding soil parameters. Some improvements are made in this research, however further research is required to increase the reliability of these profiles.
7) Standard sub-grade profiles will help to quickly gain insight into possible sub-grade behaviour on the construction site.

A model to estimate the traffic load has been build based on the project characteristics:

8) Temporary roads can be classified into three categories based on their expected traffic load.
9) Research has shown that project characteristics are well suited to predict expected traffic load on temporary roads.
10) The developed model does require verification/validation.

Current pavement design methods have been integrated into the temporary road design model:

11) It should be decided in an early stage whether the permanent road is combined with the temporary road. This can lead to cost reductions, better temporary roads and improved quality of the construction site.
12) Currently available pavement design methods are well investigated and can be used in temporary road design.
13) When drainage is required in the utilisation phase, this should be installed in the construction ready stage. This will lead to better conditions on the construction site.

The developed model was applied to the construction site Duvfrak as case study:

14) According to the road design model temporary roads on Duyfrak are not designed efficiently; some roads are to weak will probably fail while others are overdimensioned and could have been constructed in a cheaper way.

While this explanatory report provides important background information, the main results and instructions on how to use the temporary road design model are presented concisely in Harms (2007). Even though the developed model can already be used to construct temporary roads it does require further verification. Some suggestions for future research are included in section 10.1.

10.1. Suggestions for future research

The following suggestions could be investigated in future research:

- This research was limited to standard sub-grade profiles, as developed by C.R.O.W. (2006) that are characteristic for sub-grade in the Netherlands. The use of standard ground profiles to quickly estimate a temporary road design is promising. However, during the performed research, significant doubts about the correctness of the corresponding parameters raise. Control calculations showed large differences when compared with the NEN 6740 parameters or other more commonly used values, leading to unreliable results. Therefore it is recommend to further investigate these standard sub-grade profiles and to improve their characteristics.

- Ten Cate[28] is developing artificial textiles with flexible fibreglass tissues, which detect moister and damage/deformation by monitoring changes in spectrums. This type of system could easily be installed under temporary roads and could stay a long time to monitor changes due to intense traffic on temporary roads. Usually these textiles are used to strengthen the underground/pavement and to reduce deformations.

- The developed model for traffic load on temporary roads can be verified using traffic counters and classification equipment. The results can then be compared to the results of the developed model. This way the model can be further calibrated and improved for better traffic intensity estimations. There is also no data available about the load factor of transport trucks on construction sites. Eventually, the model can also be extended to non-residential construction sites.

- Besides the pavement types studied in this research there are other, innovative pavement methods in development. A good example for this is the use of lime to stabilise the natural sub-grade. The application of steel and rubber plates as temporary roads was also not investigated

- The project Duyfrak in Valkenburg is used as case study. At the time this report was written, the project is made construction ready and the temporary roads are constructed. From this case study was concluded that not all roads are designed strong enough. Therefore it is interesting to check the condition of the temporary roads after construction is finished. This can also be used to validate the model.

[28] http://www.tencate-nicolon.com/

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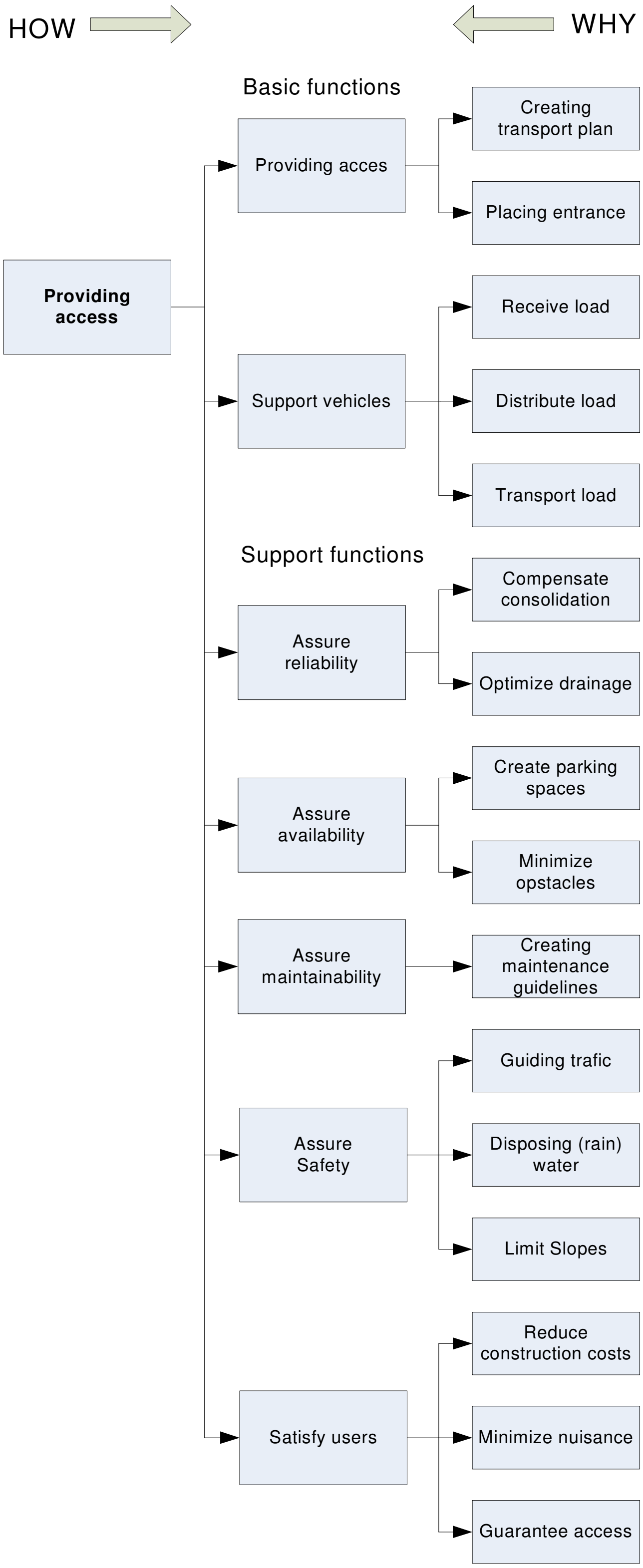
Appendixes

Appendix 1: Fast diagram



Appendix 2: Locations of lead-up services in residential areas in the Netherlands.

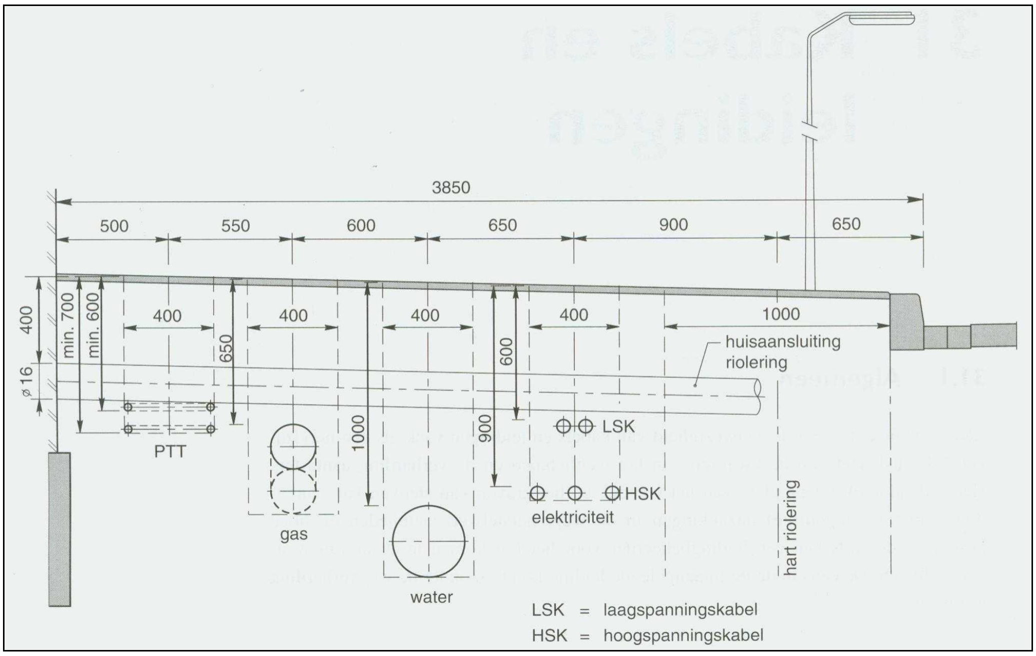


Figure 87: location of lead-up services in residential areas on one side of the road (NEN 1739).

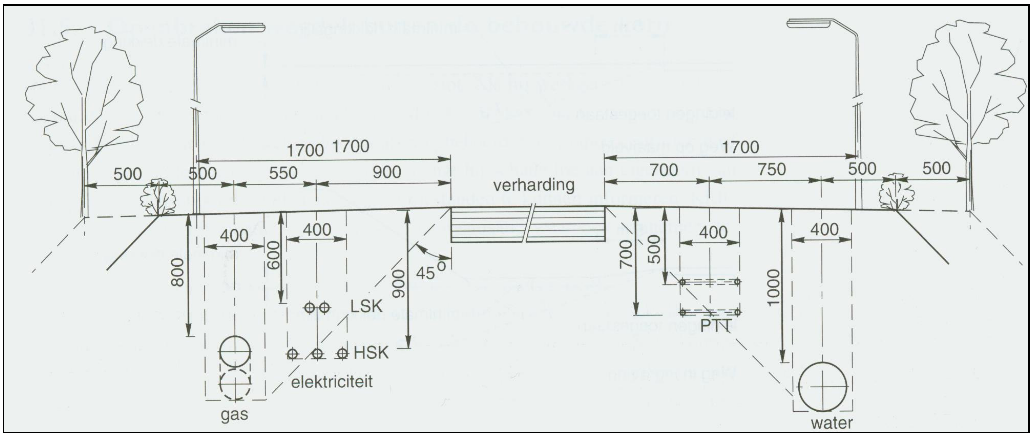


Figure 88: location of lead-up services in residential areas on both sides of the road (NEN 1739).

Appendix 3: Calculation of the internal friction angle and undrained shear strength

Parametres

B_{ef}	5,50	5,50	5,50	5,50	5,50	5,50	5,50	5,50	5,50	5,50	5,50
$\Phi'_{e;d;start}$	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00
t_e	11,50	11,50	11,50	11,50	11,50	11,50	11,50	11,50	11,50	11,50	11,50

Later thickness according to C.R.O.W. (2006) standard profiles

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	1,00	1,00	5,00	10,00	15,00	1,00	1,00	1,00			
Peat	4,00	9,00	1,00	1,00	1,00	1,00	3,00	5,00			
Very organic clay						2,00	3,00	4,00			
Organic silty clay						2,00	3,50	5,00			
Clayey Peat						1,00	0,50	0,00			
Silty clay						2,00	1,00	0,00			
Silty sandy clay									3,00		
Sandy loam										3,00	
low compacted sand											3,00
Well compacted sand	infinity										
Total	5,00	10,00	6,00	11,00	16,00	9,00	12,00	15,00	3,00	3,00	3,00

Iteration 1: Layer thickness untill $f_{e;start}$

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	1,00	1,00	5,00	10,00	11,50	1,00	1,00	1,00			
Peat	4,00	9,00	1,00	1,00		1,00	3,00	5,00			
Very organic clay						2,00	3,00	4,00			
Organic silty clay						2,00	3,50	1,50			
Clayey Peat						1,00	0,50				
Silty clay						2,00	0,50				
Silty sandy clay									3,00		
Sandy loam										3,00	
low compacted sand											3,00
Well compacted sand	6,50	1,50	5,50	0,50		2,50			8,50	8,50	8,50
Total	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**	**11,50**

Iteration 1: $\Phi'_{i;d}$ taken from NEN 6740 table 1

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00			
Peat	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00			
Very organic clay						15,00	15,00	15,00			
Organic silty clay						17,50	17,50	17,50			
Clayey Peat						15,00	15,00	15,00			
Silty clay						22,50	22,50	22,50			
Silty sandy clay									22,50		
Sandy loam										27,50	
low compacted sand											30,00
Well compacted sand	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00	35,00

Iteration 1: X_i

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	11,00	11,00	9,00	6,50	5,75	11,00	11,00	11,00			
Peat	8,50	6,00	6,00	1,00		10,00	9,00	8,00			
Very organic clay						8,50	6,00	3,50			
Organic silty clay						6,50	2,75	0,75			
Clayey Peat						5,00	3,25				
Silty clay						3,50	0,25				
Silty sandy clay									10,00		
Sandy loam										10,00	
low compacted sand											10,00
Well compacted sand	3,25	0,75	2,75	0,25		1,25			4,25	4,25	4,25

$\Phi'_{e;d}$ Iteration 1	**21,39**	**15,34**	**19,57**	**15,04**	**15,00**	**17,23**	**15,37**	**15,04**	**29,33**	**31,60**	**32,73**
New f_e	7,50	6,06	7,05	5,99	5,98	6,49	6,06	5,99	9,70	10,39	10,75
Difference [%]	34,79	47,34	38,74	47,92	47,99	43,60	47,28	47,91	15,67	9,65	6,55

Iteration 2: layer thickness untill f_e

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	1,00	1,00	5,00	5,99	5,98	1,00	1,00	1,00			
Peat	4,00	5,06	1,00			1,00	3,00	5,00			
Very organic clay						2,00	2,06				
Organic silty clay						2,00					
Clayey Peat						0,49					
Silty clay											
Silty sandy clay									3,00		
Sandy loam										3,00	
low compacted sand											3,00
Well compacted sand	2,50		1,05						6,70	7,39	7,75
Total	**7,50**	**6,06**	**7,05**	**5,99**	**5,98**	**6,49**	**6,06**	**6,00**	**9,70**	**10,39**	**10,75**

Iteration 2: X_i

Profile	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	4B
Organic clay	7,00	5,56	4,55	2,99	2,99	5,99	5,56	5,49			
Peat	4,50	2,53	1,55			4,99	3,56	2,49			
Very organic clay						3,49	1,03				
Organic silty clay						1,49					
Clayey Peat						0,24					
Silty clay											
Silty sandy clay									8,20		
Sandy loam										8,89	
low compacted sand											9,25
Well compacted sand	1,25		0,52						3,35	3,70	3,87

$\Phi'_{e;d}$ (Iteration 2)	**17,22**	**15,00**	**15,44**	**15,00**	**15,00**	**15,35**	**15,00**	**15,00**	**28,46**	**31,29**	**32,60**
New fe	6,48	5,98	6,08	5,98	5,98	6,06	5,98	5,98	9,44	10,30	10,70
Difference [%]	13,54	1,24	13,72	0,14	0,00	6,57	1,35	0,16	2,65	0,91	0,39

Iteration 3: layer thickness untill fe

Profile	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
Organic clay	1,00	1,00	5,00	5,98	5,98	1,00	1,00	1,00			
Peat	4,00	4,98	1,00			1,00	3,00	5,00			
Very organic clay						2,00	1,98				
Organic silty clay						2,00					
Clayey Peat						0,06					
Silty clay											
Silty sandy clay									3,00		
Sandy loam										3,00	
low compacted sand											3,00
Well compacted sand	1,48		0,08						6,44	7,30	7,70
Total	**6,48**	**5,98**	**6,08**	**5,98**	**5,98**	**6,06**	**5,98**	**6,00**	**9,44**	**10,30**	**10,70**

Iteration 3: X_i

Profile	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
Organic clay	5,98	5,48	3,58	2,99	2,99	5,56	5,48	5,48			
Peat	3,48	2,49	0,58			4,56	3,48	2,48			
Very organic clay						3,06	0,99				
Organic silty clay						1,06					
Clayey Peat						0,03					
Silty clay											
Silty sandy clay									7,94		
Sandy loam										8,80	
low compacted sand											9,20
Well compacted sand	0,74		0,04						3,22	3,65	3,85

$\Phi'_{e;d}$ Iteration 3	**16,05**	**15,00**	**15,00**	**15,00**	**15,00**	**15,29**	**15,00**	**15,00**	**28,32**	**31,27**	**32,59**
New fe	6,21	5,98	5,98	5,98	5,98	6,04	5,98	5,98	9,40	10,29	10,70
Difference [%]	4,15	0,00	1,59	0,00	0,00	0,24	0,00	0,00	0,45	0,08	0,02

Difference within 5 % → END

Determiniation representative $C_{e;d}$

$C_{i;d}$ taken from NEN 6740 table 1

Profile	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**
Organic clay	25	25	25	25	25	25	25	25	25	25	25
Peat	10	10	20			20	20	20			
Very organic clay						25	25	25			
Organic silty clay						40					
Clayey Peat						20					
Silty clay						25					
Silty sandy clay									40		
Sandy loam										50	
low compacted sand	Does not have $c_{i;d}$										
Well compacted sand	Does not have $c_{i;d}$										

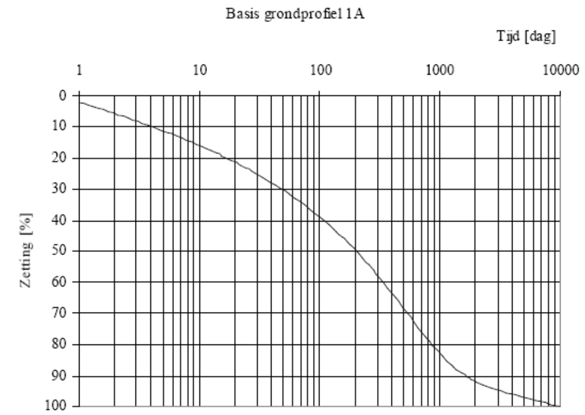
$C_{e;d}$	**14,51**	**14,60**	**24,84**	**25,00**	**25,00**	**25,49**	**22,08**	**21,53**	**40,00**	**50,00**	**-**

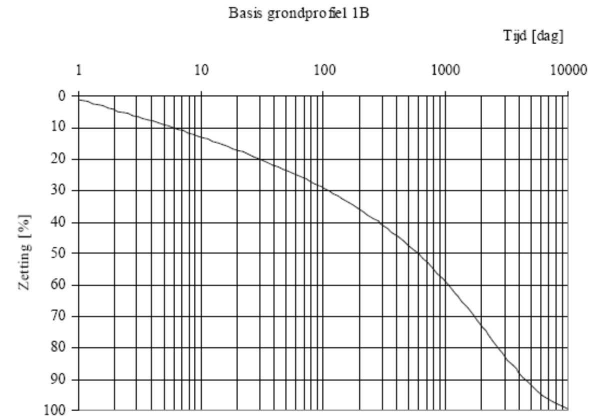
Appendix 4: Displacement design graphs

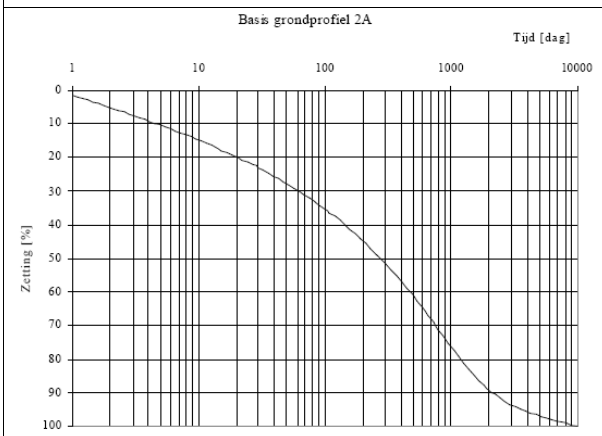
Displacement design graphs (C.R.O.W., 2006)

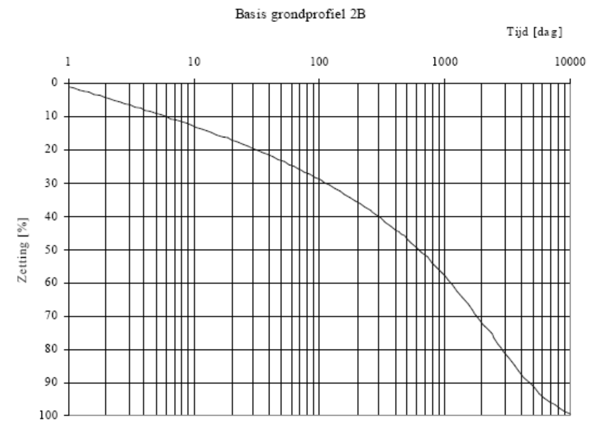
- X axis: Time [day]
- Y axis: Settlement [%]

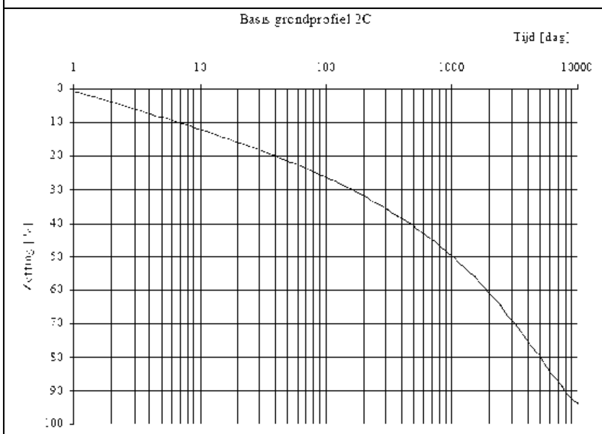
A. Normal

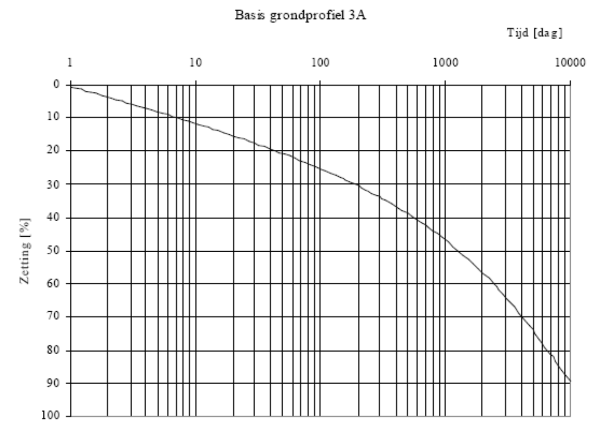


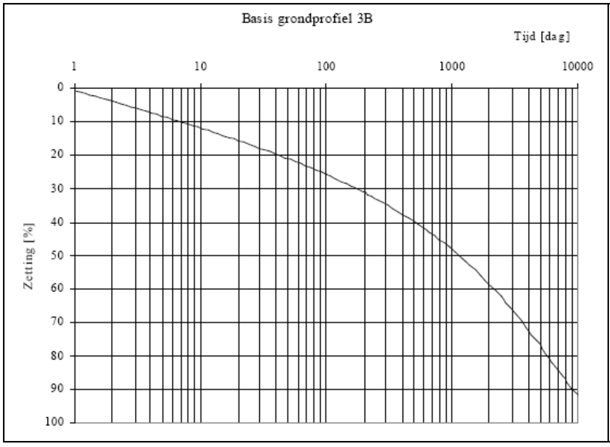


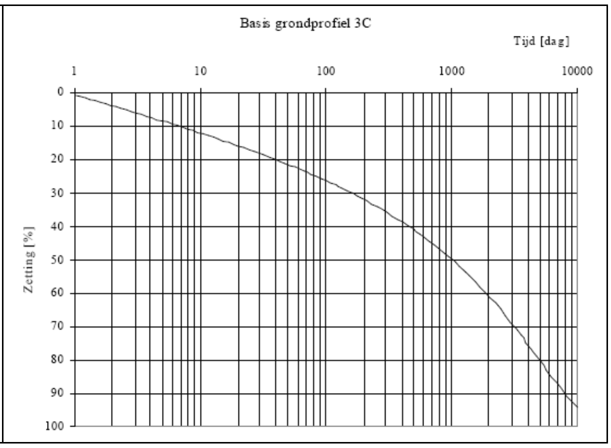




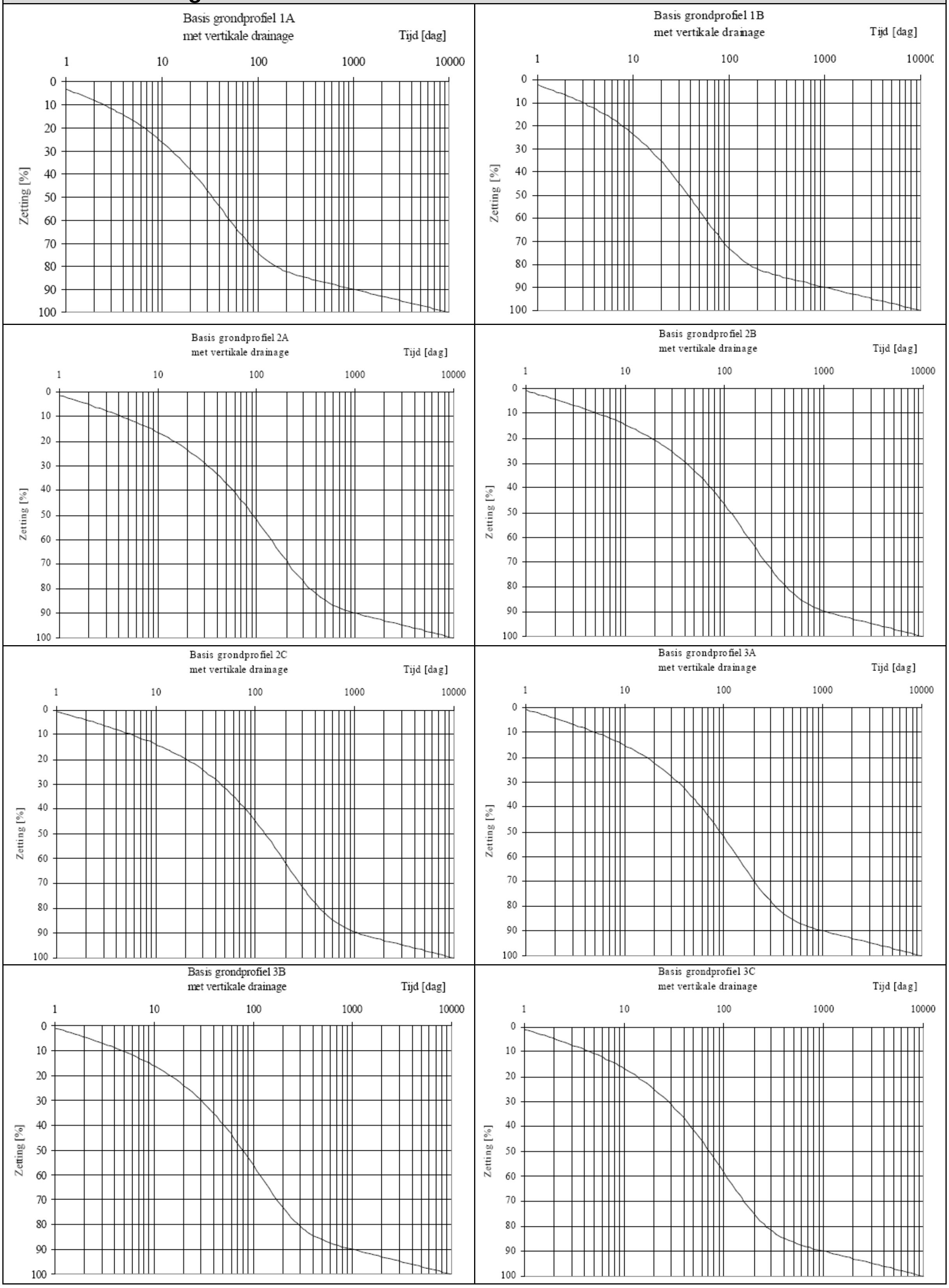




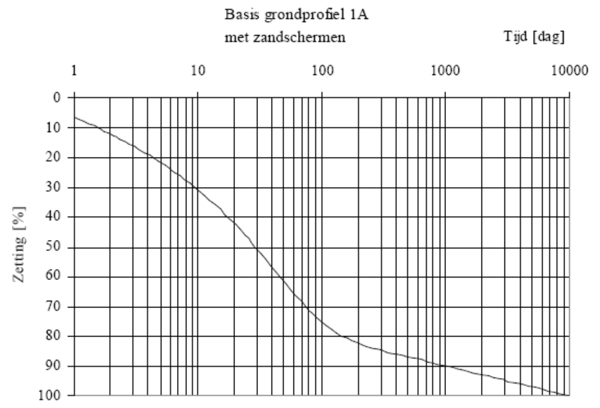

Basis grondprofiel 3B
Tijd [dag]
1
10
100
1000
10000
Zetting [%]
0
10
20
30
40
50
60
70
80
90
100

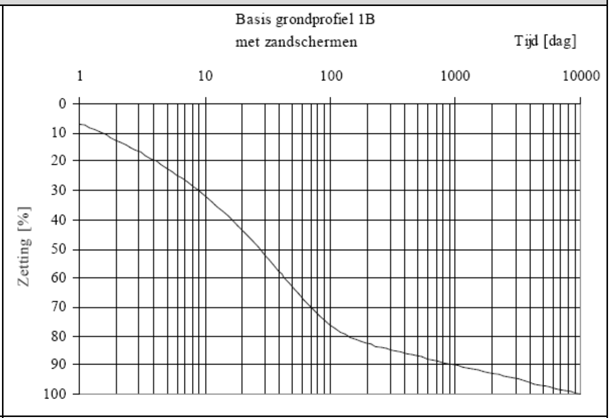

Basis grondprofiel 3C
Tijd [dag]
1
10
100
1000
10000
Zetting [%]
0
10
20
30
40
50
60
70
80
90
100

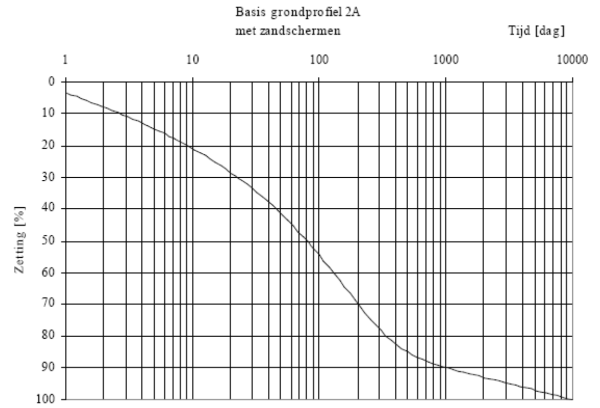
B. Vertical drainage

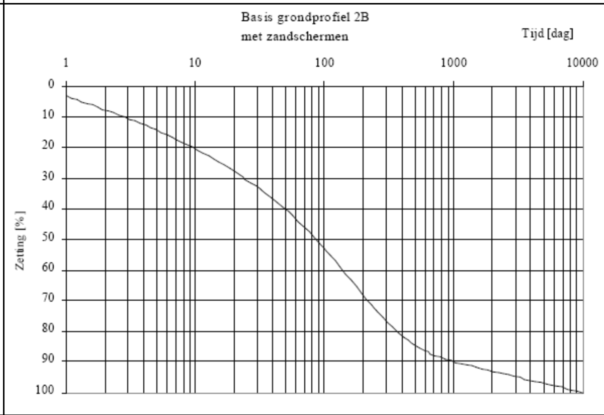


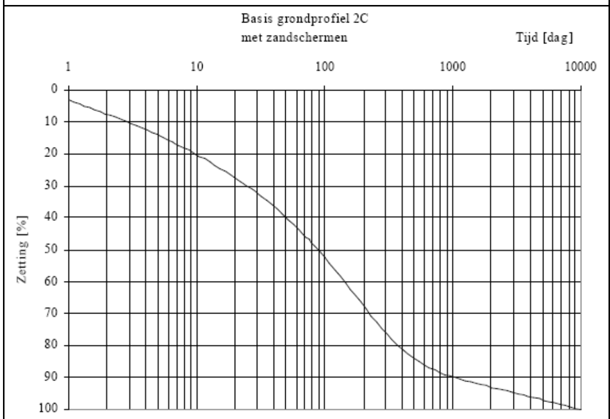
C. Sand screens

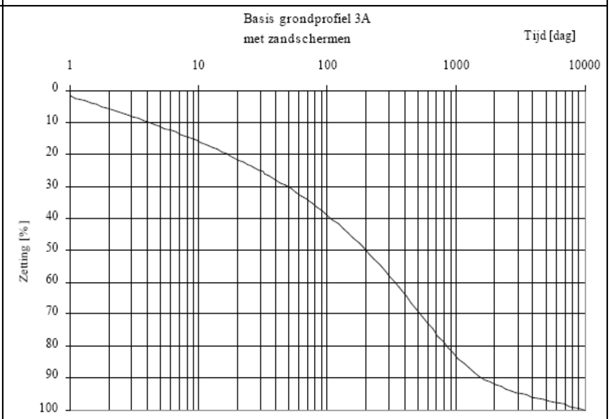


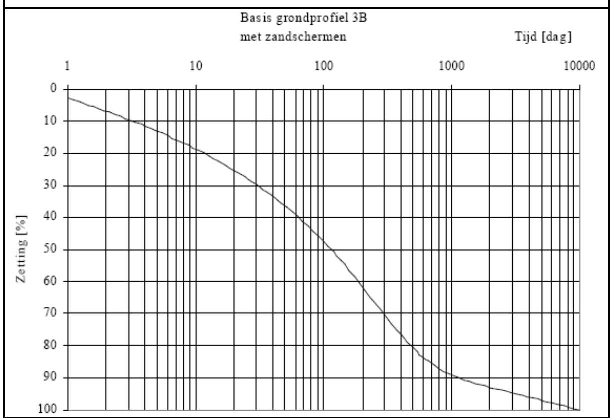


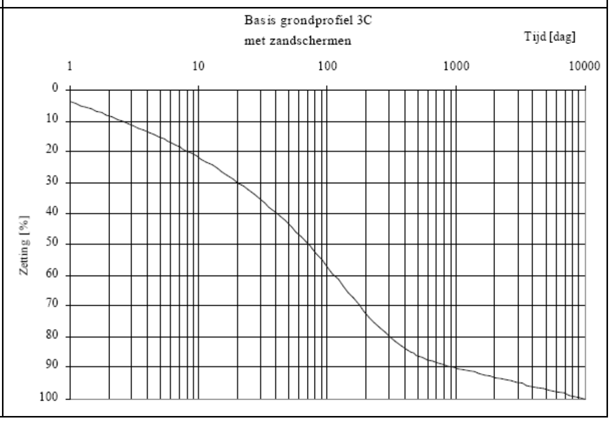












Appendix 5: examples

Houses

Type: free-standing		
 Amsterdam: Zuiderakerweg 78 House size: 210 m^2	 Utrecht: Prins Bernhardlaan 61 House size: 155 m^2	 Groningen: Gregoriusstraat 55 House size: 120 m^2
Type: block		
 Amsterdam: Pradolaan 11 House size: 180 m^2	 Utrecht: Joseph Haydnlaan 115 House size: 135 m^2	 Groningen: Briljantstraat 151 House size: 110 m^2

Apartments

Small (50-75 m^2)		
 Amsterdam: Burgem. Roellstr. 20 Apartment size: 70 M^2	 Utrecht: Kapteynlaan 93 Apartment size: 70 M^2	 Groningen Apartment size: 65 M^2
 Amsterdam: Giessenburg 4 Apartment: size 85 M^2	 Utrecht: Rhodosdreef 50 Apartment size 80 M^2	 Groningen: Muntinglaan 13 Apartment size 90 M^2

Appendix 6: Upgrade costs

Construction phase	Price [€/m^2]	Utilisation phase	Price [€/m^2]	Total costs [€/m2]
Unpaved, 0,20 m found.	2,47	Small elements	24,24	**26,71**
		Asphalt 0,9 m STAB/DAB	14,21	**16,68**
Unpaved, 0,25 m found.	2,87	Small elements	24,24	**27,11**
		Asphalt 0,9 m STAB/DAB	14,21	**17,08**
Unpaved, 0,30 m found.	3,33	Small elements	24,24	**27,57**
		Asphalt 0,9 m STAB/DAB	14,21	**17,54**
Unpaved, 0,35 m found.	3,79	Small elements	24,24	**28,03**
		Asphalt 0,9 m STAB/DAB	14,21	**18,00**
Unpaved, 0,40 m found.	4,66	Small elements	24,24	**28,91**
		Asphalt 0,9 m STAB/DAB	14,21	**18,87**
Concrete plates	7,49	Small elements on sand	27,18	**34,67**
		Small elements on 0,20 found.	31,05	**38,54**
		Small elements on 0,25 found.	31,45	**38,94**
		Asphalt 0,9 m STAB/DAB on sand	18,11	**25,59**
		Asphalt 0,9 m STAB/DAB on 0,20 found.	20,58	**28,06**
		Asphalt 0,9 m STAB/DAB on 0,25 found.	20,98	**28,46**
Asphalt 0,07 m on sand	11,20	Asphalt 0,4 m DAB	6,62	**17,82**
		Small elements	26,32	**37,52**
Asphalt 0,10 m on sand	14,91	Asphalt 0,4 m DAB	6,62	**21,53**
		Small elements	26,32	**41,23**
Asphalt 0,05 m, 0,20 m found.	10,13	Asphalt 0,4 m DAB	6,62	**16,75**
		Small elements	26,32	**36,45**
Asphalt 0,07 m, 0,20 m found.	12,48	Asphalt 0,4 m DAB	6,62	**19,10**
		Small elements	26,32	**38,80**
Asphalt 0,10 m, 0,20 m found.	16,21	Asphalt 0,4 m DAB	6,62	**22,83**
		Small elements	26,32	**42,53**
Asphalt 0,05 m, 0,25 m found.	10,53	Asphalt 0,4 m DAB	6,62	**17,15**
		Small elements	26,32	**36,85**
Asphalt 0,07 m, 0,25 m found.	12,88	Asphalt 0,4 m DAB	6,62	**19,50**
		Small elements	26,32	**39,20**
Asphalt 0,10 m, 0,25 m found.	16,61	Asphalt 0,4 m DAB	6,62	**23,23**
		Small elements	26,32	**42,93**
Small elements on sand	24,64	Repaving small elements	18,03	**42,68**
Small elements on 0,20 found.	26,15	Repaving small elements	18,03	**44,19**
Small elements on 0,25 found.	26,55	Repaving small elements	18,03	**44,59**
Small elements on 0,30 found.	27,01	Repaving small elements	18,03	**45,05**