

Predictie van trillingen met behulp van het D11 model

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fundamenteel strategisch onderzoek
op het gebied van duurzame inrichting
van deltegebieden.

Betrokken personen

Bij de totstandkoming van dit rapport waren betrokken:

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Samenvatting

In het kader van Delft Cluster thema 1, 5, 2: "Betrouwbaarheid van trillingspredicties en reducerende maatregelen" zijn trillingsprognoses uitgevoerd voor een aantal locaties. De prognoses zullen met resultaten van trillingsmetingen vergelekt worden. De prognoses zullen met verschillende gereedschappen (variërende van puur empirisch naar numeriek) afgegeven worden.

Dit rapport beschrijft de resultaten van trillingspredicties berekend met het model D11. De prognoses zijn voor zeven locaties uitgevoerd. Voor elke locatie zijn verschillende bronnen gemodelleerd en de gevraagd responsie is berekend.

Met het model D11 is het niet mogelijk expliciet het modelleren van drempels en intrillen/uitrillen van damwanden. De eerste bron is door middel van gelijkwaardige wegoneffenheid gemodelleerd. De tweede is van deze studie uitgezet.

1 Introduction

The objective of the Delft Cluster project “Total Reliability” is to enhance the reliability of vibration prediction. In this framework, Delft Cluster identified seven case studies which are representative of common vibration problems in The Netherlands. The cases are summarized in Table 1.1

Table 1.1 – Summary of the case - studies

#	Case	Place
1	Metro Rotterdam	Rotterdam
2	High Speed Train	Abcoude
3	Speed Ramp	The Hague
4	Speed Ramp	Wester Koggenland
5	ING	Rotterdam
6	NOV	Deventer/Oldenzaal
7	New TNO Bldg.	Delft

For each case, the parties involved in Delft Cluster will perform vibration predictions which will subsequently compared to the results of field tests. The prediction will be performed at two levels, namely first approximation level and expert level. First approximation level indicates a prediction based on the use of *best guess* information. Expert level indicates predictions built on the knowledge of the reliability of the available information.

Further, each case study is analyzed by means of several tools ranging from pure empirical to numerical. Among these, D11 is a semi-empiric model which derives the response in constructions or on ground surface to a given dynamic source. D11 is implemented in the software TP. A detailed description of D11 is given in [1].

This report presents the results of predictions carried out with the model D11 [1] at the first approximation level. In the next chapters, each case is discussed and the results presented. Details are given on the choice of the source characteristics, on the soil profiles used in the modelling, and on the parameters to model the adjoining constructions. In Appendix A, the information provided by Delft Cluster for each case is given, whereas Appendix B shows the output of the software TP. Finally, Appendix C gives information about the sources of vibrations modeled in the current study. Note that driving and extraction of sheet-piles is not considered in this study since D11 does not include models for those activities.

2 Case 1: Metro Rochussenstraat in Rotterdam

2.1 Source of vibrations

Five parameter categories have to be defined to model a train: roughness of the track, railway type, train type, velocity, and position with respect to the target of the modelling (i.e. the construction or the location on the ground surface).

The track may be, in this case, included in the category B (good in terms of roughness) since the underground is relatively young (30 years).

Model D11 includes two sort railway types presenting similar characteristics except for the damping of the ballast and the moment of inertia. Without detailed information, type 2 is chosen for the lower damping associated to the ballast.

Model D11 does not take explicitly into account trains running into tunnels as vibration sources. For case 1, it is assumed that the train runs on the ground surface. Two train models are currently available in TP. The trains are both 72 m long and consist of 4 wagons. The first one exerts on the rail 250 KN per axle, whereas the second one 200 KN. Since metro trains are usually lighter than freight and transportation trains, the second model is chosen.

The velocity of the train is assumed to be 50 km/h (about 14 m/s).

Finally, the origin of the coordinate system is taken on the center of the train, and the angle between x-axis and the railway is zero.

2.2 Soil profile

The soil stratification at the site consists of a compressible formation circa 15 m thick lying on stiffer sand. Neither CPT nor other information is available. The soil profile of choice is "Rotterdam".

2.3 Adjoining construction

The construction can be modeled with the program VRTGEB. Figure 1 shows the site and the input parameters used to model the construction. The distances between source and receiver points are increased by a factor 1.5 to accommodate the larger energy dissipation associated to the embedded source. It has to be noticed that VRTGEB does not model foundation on piles. In Appendix B, the input parameters are given.

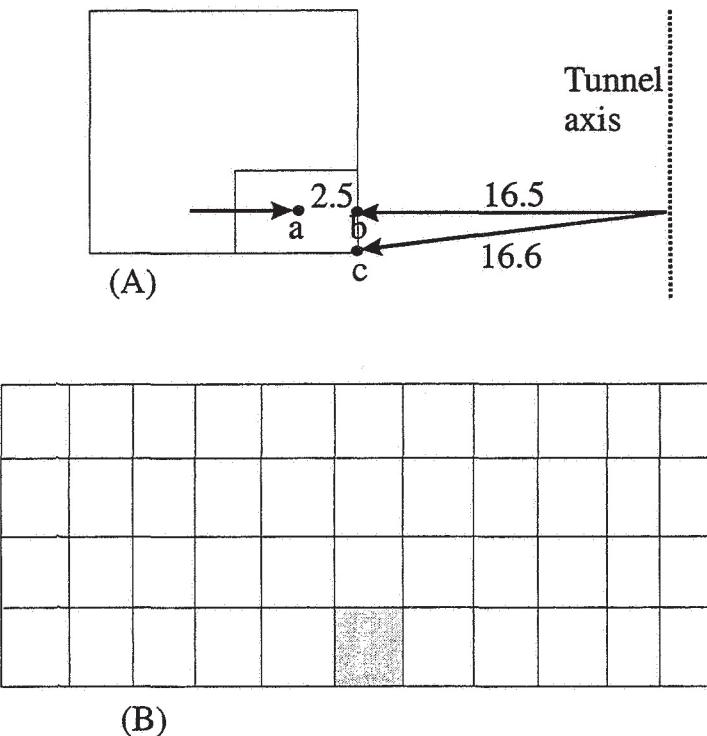


Figure 3.1 – Rochussenstraat in Rotterdam: plan view (A), and cross-section of the building (B).
The apartment objective of this study is shadowed.

2.4 Results

The results of the prediction are given in Table 3.1. The maximal effective velocity is predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

Table 3.1 - $v_{\text{eff,max}}$ in the vertical direction

		$v_{\text{eff,max,ave}}$ [mm/s]	$v_{\text{eff,max,95}}$ [mm/s]
a	At the center of the floor in the living room	3.52	6.75
b	At the center of the windowsill	3.44	6.71
c	At the corner	3.81	7.46

3 Case 2: High Speed Train in Abcoude

3.1 Introduction

From 2004, a new high-speed railway between Amsterdam and Germany will become operational. Some of the railway is founded on compressible geological layers. Vibration predictions have to be carried out at ground surface to investigate how mechanical waves propagate under such geotechnical conditions.

3.2 Source of vibrations

Five parameter categories have to be defined to model a train: roughness of the track, railway type, train type, velocity, and position with respect to the target of the modelling (i.e. ground surface at a given distance).

The track may be, in this case, included in the category A (very good in terms of roughness) since the railway is being built.

Model D11 includes two sort railway types presenting similar characteristics except for the damping of the ballast and the moment of inertia. Without detailed information, type 2 is chosen for the lower damping associated to the ballast.

For the train type, the second model is chosen.

The velocities of the train are 80 km/h (22.2 m/s), 100 km/h (27.8 m/s), and 160 km/h (44.4 m/s).

Finally, the origin of the coordinate system is taken on the center of the train, and the angle between x-axis and the railway is zero.

3.3 Soil profile

The soil stratification at the site consists of a compressible formation about 1 m thick sandwiched between superficial fine/medium sand and deeper pleistocene sand. No information is available on the deeper stratification. Due to the geographic location of the site, the soil profile of choice is "Amsterdam".

3.4 Ground surface

The site is shown in Figure 4.1. The response at ground surface has to be calculated at point 4.

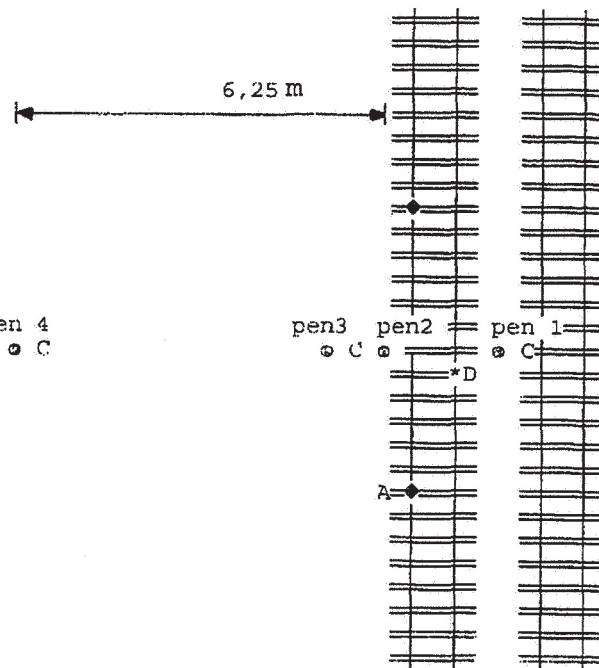


Figure 4.1 – Abcoude: plan view of the site.

3.5 Results

The results of the prediction are given in Table 4.1. The maximal velocity is predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

Table 4.1 - v_{max} in the vertical direction

Train Velocity	$v_{max,ave}$ [mm/s]	$v_{max,95}$ [mm/s]
80 Km/h	4.98	12.78
100 Km/h	4.88	12.59
160 Km/h	6.88	17.06

4 Case 3: Speed Ramp in The Hague

4.1 Introduction

This case concerns a speed ramp placed next a house built in the thirties. The objective is to predict the response of the house on the foundation and on a floor situated at the ground level.

4.2 Source of vibrations

The source of vibration is sand truck having mass equal to 48450 kg and driving at speed of 10 km/h, 20 km/h, 30 km/h, and 40 km/h. The software TP includes 3 standard trucks, namely 2-axle truck, 4-axle truck with trailer, and 4-axle articulated vehicle. A spectrum is associated to each truck. The first spectrum (associated to a 2-axle truck) would be suitable for this case-study. However, the mass of the model is as low as 16000 kg. If the speed of the truck is large enough, only the axles exert the dynamic action on the road, and the total mass of the truck is not of concern. With this assumption the 2-axle truck model can be used in this study.

It seems that a speed ramp cannot be explicitly modeled in TP. The speed ramp of this case – study is shown in Figure 5.1. The wavelength of the speed ramp is 4.8 m. From Figure B.2 in [1], assuming a paved road, w equal to 2 and Ω_0 equal to 1 (see [1] for a detailed explanation), the spectral density of the roughness associated to this wavelength is $9 \times 10^{-6} \text{ m}^3$. According to Table B.1 in [1], a conservative estimation of the roughness quality associated to such spectral density of the roughness is category C –Medium quality. This category is used in this case-study to model the speed ramp.

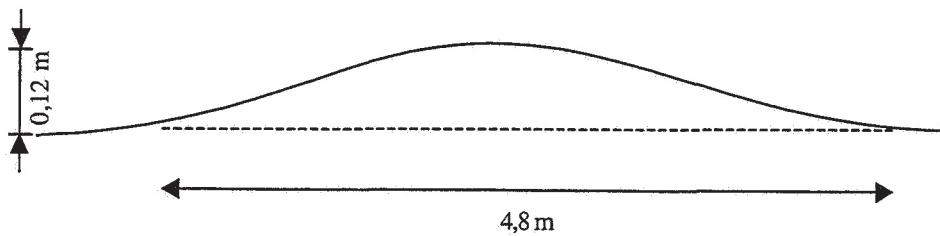


Figure 5.1 – The geometry of the speed ramp

4.3 Soil profile

No information is provided about the soil conditions. However, the site is located in the area of the dune sand. For this reason, the profile Utrecht is used in the modelling.

4.4 Adjoining construction

The construction can be modeled with the program VRTGEB. Figure 5.2 (A) shows the site. Since no information is given on the construction (carrying construction, foundation, etc.), the house is modeled as a single house resting on continuous beams (Figure 5.2 (B)).

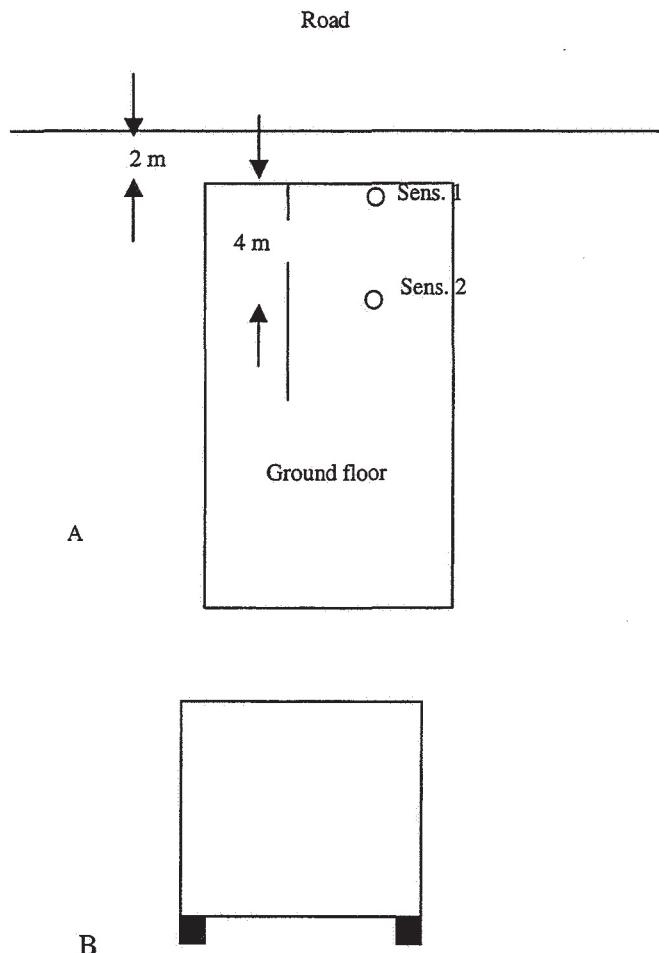


Figure 5.1 –Speed ramp in The Hague: plan view (A), and cross-section of the building (B).

4.5 Results

The results of the prediction are given in Table 4.1. The maximal effective velocity and the maximal velocity are predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

Table 5.1 - $v_{\text{eff,max}}$ v_{max} in the vertical direction

		$v_{\text{max,ave}}$ [mm/s]	$v_{\text{max,95}}$ [mm/s]
1	At the corner	0.20	0.42
		$v_{\text{eff,max,ave}}$ [mm/s]	$v_{\text{eff,max,95}}$ [mm/s]
2	At the center of the floor	0.25	1.00

5 Case 4: Speed Ramp in Wester-Koggenland

5.1 Introduction

This case concerns a speed ramp placed next a house located in Wester-Koggenland. The objective is to predict the response of the house on the foundation and on a floor situated at the ground level.

5.2 Source of vibrations

The source of vibration are a truck having mass equal to 21000 kg and driving at speed of 40 km/h and a bus driving at speed of 40 km/h. The mass of the bus is unknown. The software TP includes 3 standard trucks, namely 2-axle truck, 4-axle truck with trailer, and 4-axle articulated vehicle. A spectrum is associated to each truck. The first spectrum (associated to a 2-axle truck) would be suitable for the bus. The 4-axle truck spectrum is, instead, chosen to model the truck.

It seems that a speed ramp cannot be explicitly modeled in TP. The speed ramp of this case – study is shown in Figure 6.1. The wavelength of the speed ramp is 5.5 m. From Figure B.2 in [1], assuming a paved road, w equal to 2 and Ω_0 equal to 1 (see [1] for a detailed explanation), the spectral density of the roughness associated to this wavelength is $10 \times 10^{-6} \text{ m}^3$. According to Table B.1 in [1], a conservative estimation of the roughness quality associated to such spectral density of the roughness is category C –Medium quality. This category is used in this case-study to model the speed ramp.

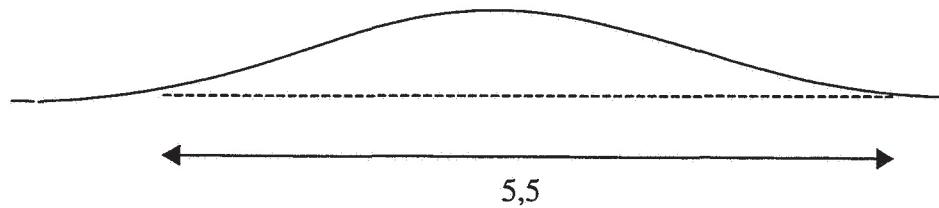


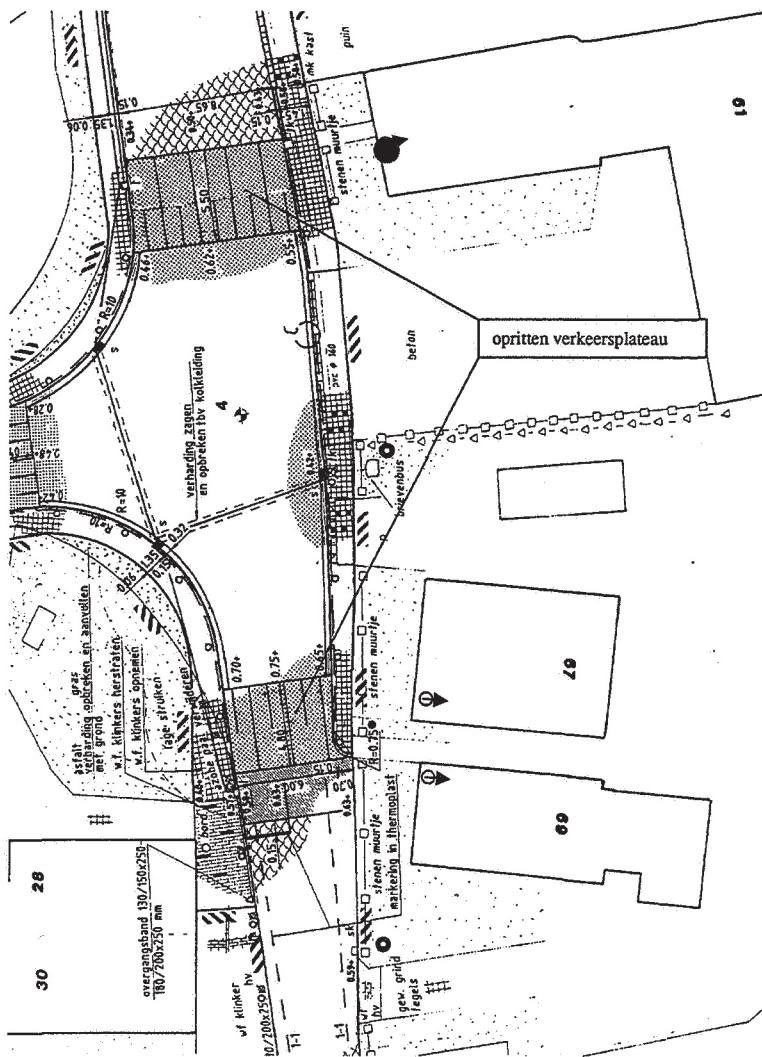
Figure 6.1 – The geometry of the speed ramp

5.3 Soil profile

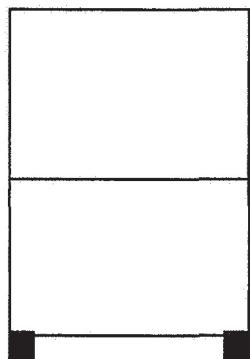
The soil profile used for this case is “Amsterdam” that corresponds quite well to the available CPT of the site (see Appendix A).

5.4 Adjoining construction

The construction can be modeled with the available spectrum Building 1.



A



B

Figure 5.1 –Speed ramp in Wester-Koggenland: plan view (A) (the red spot is the sensor), and cross-section of the building (B).

5.5 Results

The results of the prediction are given in Table 6.1. The maximal effective velocity and the maximal velocity are predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

Table 5.1 - $v_{\text{eff,max}}$ v_{max} in the vertical direction

		50 %	95 %
	bus		
a	v_{max}	0.34	1.27
b	$v_{\text{eff,max}}$	0.54	1.20
	truck		
c	v_{max}	1.49	5.38
d	$v_{\text{eff,max}}$	1.12	3.90

6 Case 5: ING Building in Rotterdam

6.1 Introduction

This case refers to a construction site of the HSL South speed line in Rotterdam. The speed line come close to the calculation center of the ING Bank. Several activities, potential sources of vibration, are planned: pile driving and extraction, sheet-pile driving, and heavy traffic. The objective is to predict the response to pile driving and heavy traffic on the ground surface.

6.2 Source of vibrations

6.2.1 Pile driving

For the driving of the piles, an hammer IHC-S90 is used (see Appendix A). The parameters used in TP to model a sheet-pile driver are Z_{pile} , E_h , β , f_{ov} , n_{golf} , amplired, and X_i, Y_i .

The energy of the hammer is assumed to be equal to 50% of the maximal energy (sse Appendix A).

The impedance of the pile is calculated following equation (1) as 790 kNm/s.

The other input parameters are identical to those used for the sheet-pile driving/extraction.

The input factors to model pile driving are summarized in Table 7.2. A detailed explanation of the physical meaning of the parameters is in [1].

Table 7.2

Parameter	Value
E_h [Nm]	45000
Z_{pile} [kNs/m]	790
β [#]	1
f_{ov} [Hz]	27
n_{golf} [#]	20
Amplired [#]	0.7
X_i, Y_i [m]	0

6.2.2 Heavy traffic

The source of vibration is a 5-axle truck having mass equal to 50000 kg and driving at speed of 30 km/h. The software TP includes 3 standard trucks, namely 2-axle truck, 4-axle truck with trailer, and 4-axle articulated vehicle. A spectrum is associated to each truck. The 4-axle truck spectrum is chosen to model the truck.

A speed ramp cannot be explicitly modeled in TP. The speed ramp of this case – study is shown in Figure 7.1. The wavelength of the speed ramp is 0.695 m. From Figure B.2 in [1], assuming an unpaved road, w equal to 2 and Ω_0 equal to 1 (see [1] for a detailed explanation), the spectral density of the roughness associated to this wavelength is $10 \times 10^{-6} \text{ m}^3$. According to Table B.1 in [1], the roughness quality associated to such spectral density of the roughness is category A – Very Good quality. Since this category is not representative of the irregularity, category C is chosen.

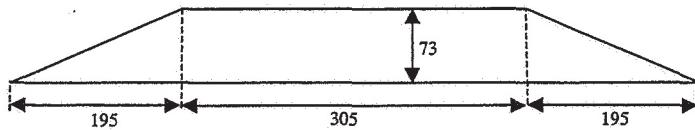


Figure 7.1 – The geometry of the speed ramp. Measures are in mm.

6.3 Soil profile

The soil profile used for this case is “Amsterdam” that corresponds quite well to the available CPT of the site (see Appendix A).

6.4 Ground surface response

This case – study concerns the response of the ground surface at a given distance. The transfer function from the source to the receiver is, therefore, modeled as unity. The points where the response is to be calculated are shown in Figure 7.2. The distance between the speed ramp and sensor 5 is assumed to be equal to 10 m.

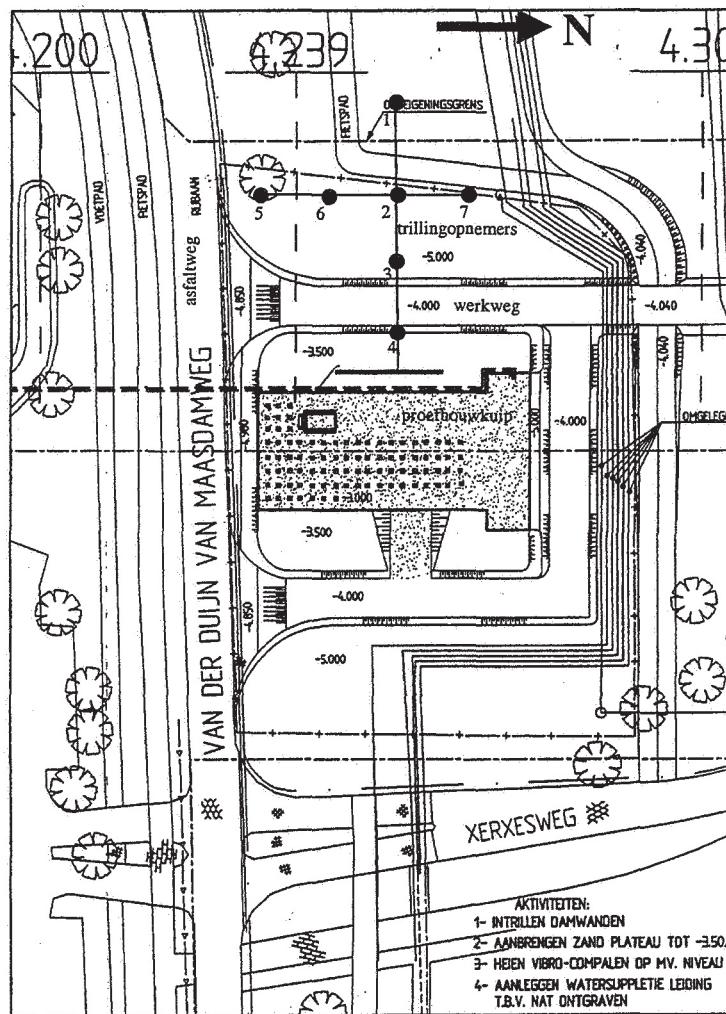


Figure 7.2 – Position of the sensors

6.5 Results

The results of the prediction are given in the following tables. The maximal effective velocity in the vertical direction is predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

6.5.1 Pile driving

			50 %	95 %
c	$v_{eff,max}$	sensor 2 pile 57-55 [mm/s]	3.92	9.07
d	$v_{eff,max}$	sensor 2 pile 57-52 [mm/s]	3.22	7.43

6.5.2 Traffic

			50 %	95 %
e	$v_{eff,max}$	sensor 7 speed ramp [mm/s]	0.18	0.68

7 Case 6: Train transits in East Holland

7.1 Introduction

This case concerns tests carried out in the Eastern part of The Netherlands to study the vibration caused by heavy train traffic. Two are the locations under investigation. For each location, the response to two train transits is to be predicted.

7.2 Source of vibrations

Five parameter categories have to be defined to model a train: roughness of the track, railway type, train type, velocity, and position with respect to the target of the modelling (i.e. ground surface at a given distance).

No information is given on the quality of the track and the Category C (average between good and bad condition) is chosen.

Model D11 includes two sort railway types presenting similar characteristics except for the damping of the ballast and the moment of inertia. Without detailed information, type 2 is chosen for the lower damping associated to the ballast.

For the train type, model 1 is chosen for the freight train whereas model 2 is chosen for the passengers train.

The velocities of the train are 80 km/h (22.2 m/s) for the freight train, and 125 km/h (34.7 m/s) for the passengers train.

Finally, the origin of the coordinate system is taken on the center of the train, and the angle between x-axis and the railway is zero.

7.3 Soil profile

For the first location, the chosen soil profile is Utrecht, whereas for the second location the soil profile of choice is "Amsterdam".

7.4 Ground surface

The sites are shown in Appendix A. For both locations, the response at ground surface has to be calculated at a distance of 25 m from the track.

7.5 Results

The results of the prediction are given in Table 8.1 and Table 8.2. The effective maximal velocity is predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

Table 8.1 - $v_{eff,max}$ in the vertical direction at location 2A

		50 %	95 %
a	ICM [mm/s]	3.06	7.27
b	Freight trein [mm/s]	1.65	3.85

Table 8.2 - $v_{eff,max}$ in the vertical direction at location 4A

		50 %	95 %
c	Passenger train [mm/s]	3.47	8.19
d	Freight trein [mm/s]	3.07	7.41

8 Case 7: TNO new building in Delft

8.1 Introduction

This case refers to a construction site of the new TNO building in Delft. Several activities, potential sources of vibration, are planned, such as sheet-pile driving and extraction, and pile driving. The objective is to predict the response to pile driving in the adjacent building of Fluid Mechanics of TU Delft.

8.2 Source of vibrations

8.2.1 Pile driving

For the driving of the piles, an hammer IHC-S70 is used (see Appendix A). The parameters used in TP to model a sheet-pile driver are Z_{pile} , E_h , β , f_{ov} , n_{golf} , amplired, and X_i, Y_i .

The energy of the hammer is assumed to be equal to 50% of the maximal energy (see Appendix A).

The impedance of the pile is calculated following equation (1) as 790 kNm/s.

The pile frequency is calculated following the equation given in Appendix D in [1].

The other input parameters are identical to those used for the sheet-pile driving/extraction.

The input factors to model pile driving are summarized in Table 8.2. A detailed explanation of the physical meaning of the parameters is in [1].

Table 8.2

Parameter	Value
E_h [Nm]	35000
Z_{pile} [kNs/m]	506
β [#]	1
f_{ov} [Hz]	15
n_{golf} [#]	20
Amplified [#]	0.7
X_i, Y_i [m]	0

8.3 Soil profile

The soil profile used for this case is “Amsterdam” that corresponds quite well to the available CPT of the site (see Appendix A).

8.4 Ground surface response

This case – study concerns the response of the ground floor of the Laboratory of Fluid Mechanics. Due to the characteristics of the construction, the transfer function from the source to the receiver is modeled by using the module Building 3. The point where the response is to be calculated is 26 m from the pile.

8.5 Results

The results of the prediction are given in the following table. The maximal velocity in the vertical direction is predicted at a 50% level (average) and at a 95% level. The calculated spectra are given in Appendix B.

8.5.1 Pile driving

		v_{max} 50 % [mm/s]	v_{max} 95 % [mm/s]
c	v_{max} at 26 m	3.61	8.46

9 Reference

- [1] CUR, (1995). "Prognosemodel trillingshinder", Rapport 95-2.
- [2] Klaver,E.C., (1994). "Onderzoek D11 – Trillingen in bebouwde omgeving – Prototype van een prognosemodel", DHV Rapport G0365 01 001.