Saimaa University of Applied Sciences
Technology, Lappeenranta
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RR-PILING TO RUSSIAN NORMS AND NOISE BARRIER FOUNDATIONS

Bachelor’s Thesis 2010

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ABSTRACT

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RR piling to Russian norms and noise barrier foundations, 43 pages, 4 appendixes
Saimaa University of Applied Sciences, Lappeenranta
Degree Programme in Civil and Construction Engineering
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RR-piles are steel piles, which are assembled from parts on the construction site. A noise barrier cassette is a noise screen made of steel and polyester wool. The whole construction is assembled from rolled H-section columns and cassettes, attached to H-section flanges with bolts through drilled holes. The columns are connected to the top of the RR-piles.

The objective of the study is to make the application of this construction easier in Russia. Nowadays this construction is very seldom used in Russia, but if it can be ensured that all design and calculation methods are suitable to SNiP and GOST norms, this construction can be easier promoted into the Russian market.

The method was to find all Russian norms needed for calculations and to calculate pile and column structures according to them. Also for having the basic view it was useful to interview engineers and managers from Ruukki and lecturers from Saimaa UAS and SPSUACE.

Keywords: Ruukki; RR-pile; noise barrier NBC-95; Eurocodes; SNiP; GOST

TERMINOLOGY, SYMBOLS AND ABBREVIATIONS

1st limit state – in the calculations of structures according to Russian norms this is the name of a calculation method by bearing capacity (cross sections of elements are selected according to bearing capacity).

2nd limit state – this is the name of a calculation method by the movements of structures in Russian norms.

GOST – Russian State Standard. These standards were made for all products in the USSR, nowadays a lot of them are still used, but sometimes non-obligatory and/or replaced/supplemented by Enterprises Standards.

SP – Summary of Rules. These are the standards for construction engineering, each one has an identification number in the system of standards and their own name.

SPSUACE – Saint-Petersburg State University of Architecture and Civil Engineering (the home university of the thesis author).

SNiP – Construction Norms and Regulations. These are standards for construction engineering, each one has an identification number in the system of standards and their own name.

Soil characteristics from table 3.5:

φ – angle of internal friction

γ – density

c – adhesion

γ_s – density of solid parts of soil

W – water content

W_L – liquid limit

W_p – plastic limit

k_f – coefficient of filtration

E – modulus of deformation

I_L – index of fluidity

γ_d – density of dry soil (soil skeleton)

n – porosity

e – voids ratio (coefficient of porosity)

γ_{sb} – density of soil with account of water weighing

1 INTRODUCTION

In the introduction the main purpose of the study, sources of information and time schedule of implementation are described.

1.1 Basis for the research

This study was made for Rautaruukki Corporation and the Saimaa University of Applied Sciences. The supervisor was Veli-Matti Uotinen, technical manager from the Ruukki Construction, Infrastructure construction.

RR-piles are steel piles, which are assembled from parts: a rock shoe or a bottom plate in the bottom part, the selection between them depends on the type of soil; internal or external splices for connections if the pile is assembled from parts; and a bearing plate on the top of the pile.

A noise barrier cassette is a noise screen made of steel and polyester wool. The whole construction is assembled from rolled H-section columns and cassettes, attached to H-section flanges with bolts through drilled holes. Columns are connected to the top of the RR-piles.

1.2 Objectives

The main aim of this study is to make the application of this construction easier in Russia. Nowadays delivery of these cassettes to Russia is just beginning, but if it can be proven that all design and calculation methods are suitable to the SNiP and GOST norms, this construction can be faster promoted into the Russian market.

1.3 Implementation of the research

09.02.2010 - start meeting.
15.02.2010 - excursion to the Kouvola Myllykallio noise barrier construction site.
15.02.2010 - 01.03.2010 - discovering all norms, regulations and literature needed for work.

01.03.2010 - approx. 31.03.2010 - writing the first version of the thesis report and sending this to Veli-Matti Uotinen, Tero Liutu and Matti Hakulinen for corrections.

31.03.2010 - 30.04.2010 - correcting all mistakes.

31.04.2010 - 06.05.2010 - final check and preparing for presentations.

2 NOISE BARRIER BASED ON A SINGLE STEEL PIPE PILE FOUNDATION

In this chapter all elements of Ruukki's noise barrier structure are described in general without calculations.

2.1 Structure of the Ruukki noise barrier system

Mainly the structure of this system consists of four parts:

- RR-piles
- Foundations
- Columns and plinth elements
- Noise barrier cassettes

RR-piles are steel pipe piles. Foundations of the Ruukki noise barrier system usually consist of single steel pipe piles and connection plates through which columns are connected. Columns and plinth structures are usually made of steel S355J2 and have zinc layer thickness 80 – 100 microns (micrometres). Noise barrier cassettes have dimensions of 2500-5000 x 520 x 95 mm, they consist of steel lists, connectors and absorbing wool layer.

Here is a schematic picture for better understanding of the whole structure:

Figure 2.1 The basic structure of Ruukki's noise barrier structure (a misprint in illustration: NBC-95 instead of NBC-10)

2.2 RR-piles

RR-piles are impact-driven steel pipe piles used for bearing the whole upper structure. The arrangement of these piles is shown on figure 2.2:

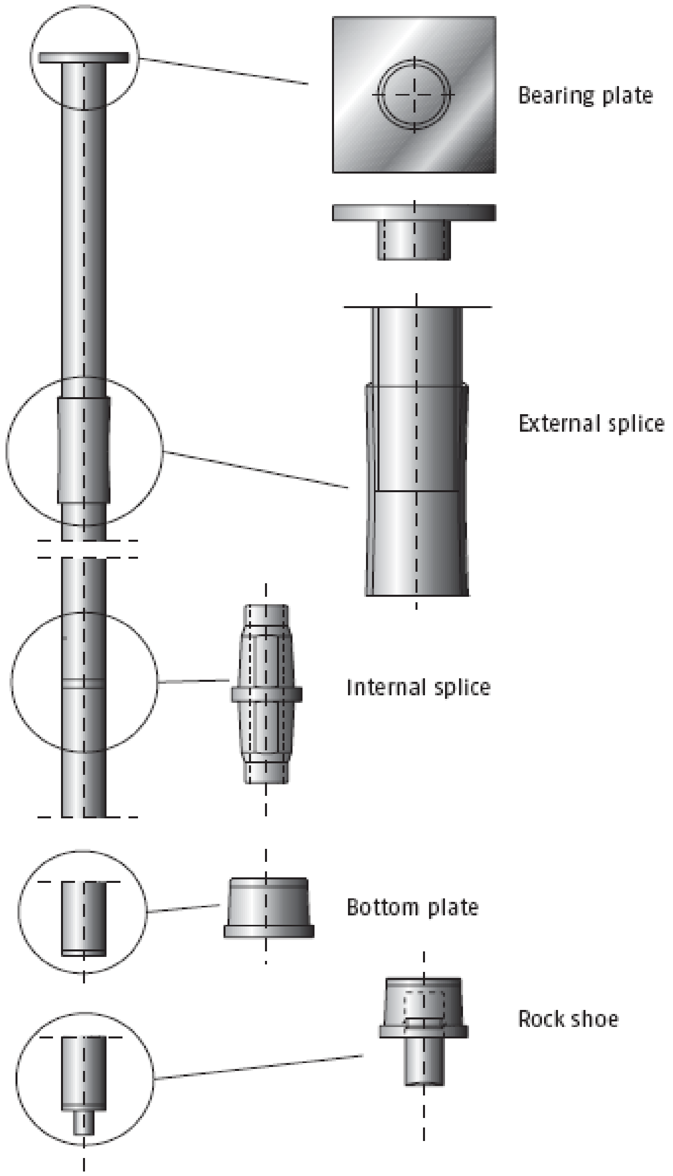


Figure 2.2 Structure of RR-pile sizes RR75 - RR220

The simplest pile which can be made is just the pipe with a bearing plate. If needed by a project, the bottom plate or rock shoe can be added for better footing. Also for making longer piles from standard length elements external or internal splices can be used.

RR-piles have requirements for piling classes. Piling class selection depends on how demanding the structure is. The requirements for RR-piling construction site are shown in the table 2.1:

Table 2.1 Requirements for RR-piles according to PPO-2007

Piling class III	Piling class II	Piling class I B
Easy projects	Demanding projects	Very demanding projects
Lightweight and basic buildings and constructions, not intended for permanent habitation.	Lightweight and basic residential buildings and constructions.	Bridges, hydraulic structures, industrial structures and other corresponding engineering structures; Structures subject to dynamic or otherwise exceptional loads such as significant horizontal loads, bending or heavy vertical loads, or special requirements.
Sites with easy soil conditions.	Sites with easy soil conditions.	Large or complicated structures and buildings located in areas of organic or fine grained soils; Sites where rock is overlaid only by organic or fine-grained soils; Structures incorporating piles driven through thick fill.

To build foundations on these piles we need to make ground investigations. These investigations help us to know the stability of soil, groundwater level, etc. Normally the piling class with noise barrier foundations is II. Also piling class IB is used when the soil conditions are more complicated and/or the height of the noise barrier is higher than 3 - 4 m, or the structure is somehow deviating from normal.

RR-pile materials and details:

Steel grades:

RR-piles sizes RR75 – RR220 are made of S440J2H steel, which has yield strength 440 MPa. The technical characteristics of piles conform to EN 10219 standard except the straightness, which is 1,25/1000 and the length tolerance, which is ±50 mm.

Sections and accessories:
The diameter of RR-piles vary from 76,1 mm (RR75) to 219,1 mm (RR220). The wall thickness varies from 6,3 mm to 12,5 mm. The standard stock lengths of manufactured piles are 6 or 12 metres. Also, when the project specifies length, other lengths can be manufactured, e.g. 1; 1,2; 1,5; 2; 3; 4 metres.

Splices manufactured by Ruukki are used with RR piles. The splices are connected to the pile shaft by friction, no welding on site is needed. The tip of the pile is protected by a bottom plate or a rock shoe. The bottom plate is more common, and it is usually determined by investigations if a rock shoe is required.

Rautaruukki also produces larger diameter piles, longitudinally welded RR270 – RR320 and spirally welded RR400 – RR1200. The most common piles for noise barrier foundations are RR270 – RR500. Normally for RR270 – RR400 piles steel S355J2H is used, because there is not any effect of higher strength steels on pile movements and inclinations.

2.3 Foundations

Foundations of Ruukki's noise barrier system consist usually of single steel pipe piles on which the columns are connected through a connection plate. Piles can be installed by driving, drilling, or vibration.

The dimensioning requirements usually are:
- structures must not be damaged and the failure of soil must not be occured when design loads are multiplied by 1,5
- movement of the upper end of the pile must be less than 20 mm in cohesive soils and 30 mm in non-cohesive soils
- horizontal deflections are within required: column deflection caused by wind load or ploughing load must be < L/150 (L – height of column); overall deflection

of the noise barrier caused by pile inclination, movement of upper end of pile and column deflection must be < L/75 (L – height of noise barrier)

The installation of driven RR-piles can be made by using various equipment as drop hammers, hydraulic hammers, accelerated hydraulic hammers, pneumatic and hydraulic rams or vibrators. They can be easily attached to, for example, track-guided excavators. Side-grip based vibrators have proven to be practical when the installation takes place on electric railways.

In the design of piles, soil corrosion is factored in by over-dimensioning pile wall thickness. Also the welding seams between the connection plate and steel piles are over-dimensioned. According to Eurocode 3, part 5, loss in material thickness because of corrosion is from 0,6 mm to 3,25 mm in 50 years, depending on the type of soil. It is important to note that the values for the corrosion of 5 and 25 years and others are extrapolated in the Eurocode.

In Finland there are two authorities which have a different approach to the corrosion aspect concerning noise barrier foundations:

1. Former Road Administration (Tiehallinto), from 1 January 2010 Finnish Transport Agency, Road Deparment:

- design life 50 years
- corrosion values according to EN 1993-5 on the external surface of the pile
- internal surface: corrosion is 0 mm, when the pile is closed from both ends, and 0.1mm, if the pile is open-ended (but at the head of the pile there is a welded connection plate) (TIEH 2100062-09).

2. Former Railway Administration (RHK), from 1 January 2010 Finnish Transport Agency, Rail Department:

- design life for foundations 100 years, other structures 50 years
- corrosion when the pile is closed from both ends or inside is concreted 2mm, when pile is open-ended overall corrosion is 4mm (i.e. 2mm inside the pile!) (RHK B11).

2.4 Columns and plinth elements

Connection between a column and pile is made in the following way:
The base plate with threaded holes for bolts is welded on the pile top. Welding takes place under shelter to ensure the quality of the welding. This process is shown in figure 2.3:

Figure 2.3 Installation of base plate by welding

Mounting bolts with nuts are fitted to the base plate. The foundation bolts are aligned and levelled in order to guarantee tight enough tolerances for the column installation. Columns are hoisted on their position and bolts and nuts are tightened. In special cases the space between the base plate and the bottom plate of the column can be grouted, for example to ensure a longer life span.

Steel and covering:
Column and plinth structures are always hot dip galvanized according to standard EN ISO 1461. The steel grade used in these structures is usually S355J2 with the silicon content of 0.15…0.25 %. With such a steel the typical thickness of a zinc layer is at minimum 80…100 μm (micrometres) depending on thickness and dipping time. Another possibility is to use steel with the low

silicon content (P+Si ≤ 0,04 %), which gives a thinner zinc layer but a more shiny surface.

Figure 2.4 Views of the structure

Long-term durability of zinc layers:

According to corrosion tests in Finland, zinc corrodes as shown on the diagram:

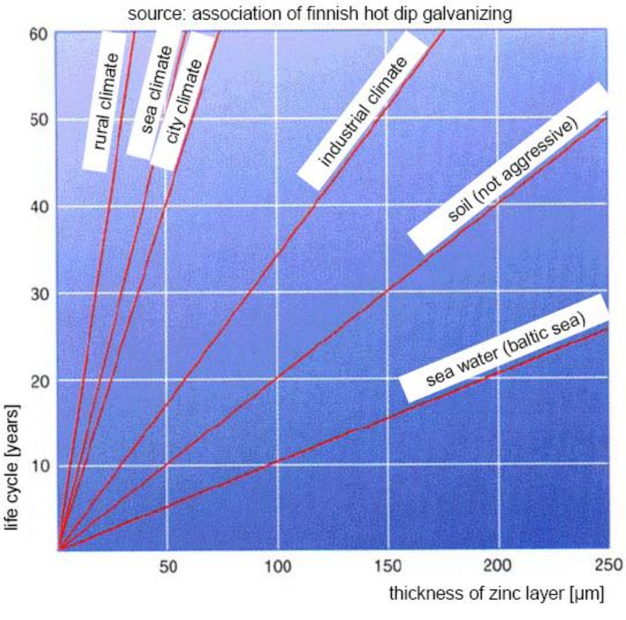
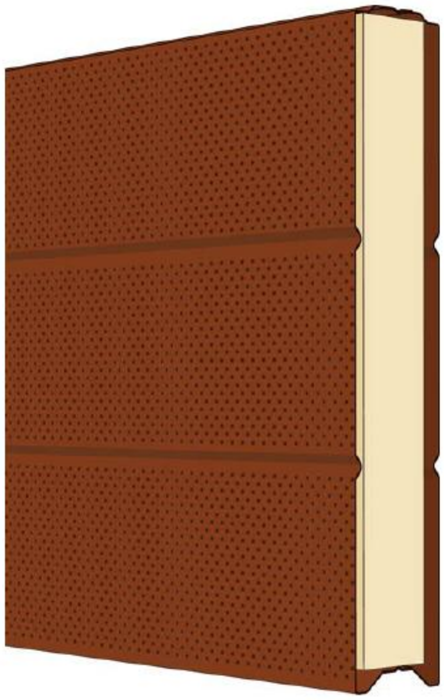


Figure 2.5 Zinc layer corrosion

Here we can see for example, that a 250-micrometer zinc layer will stay for 25 years in the Baltic sea water until completely destroyed.

2.5 Noise barrier cassettes

NBC-95 is the latest model of the cassette made by Ruukki, the scheme of the structure is presented here:



Dimensions:		
Effective height		520 mm
Width		95 mm
Length		3,0 ... 5,0 m
Weight		about 26 kg/m²
Cassette structure:		
Perforated front sheet[1)]		1,2 mm
Back sheet		1,2 mm
End connector		2,0 mm
Absorbing polyester wool		90 mm
Materials:		
Coil coated steel		S280GD+Z275 (DX51D+Z275)
Polyester wool		15 kg/m³
Coatings:		
Coil coated steel		
- zinc layer	275 g/m²	~20 µm
- PVDF/PVDF HB		~27/40 µm
- Colours	according to colour chart	
galvanized steel275 g/m²		~20 µm

1) Aperture ratio 30% with hole diameter 4 mm.

Figure 2.6 Structure of a NBC-95 noise barrier cassette

According to the information given on the right, we can say that maximum span between columns is 5 meters and the weight of one span structure with the height of 3 metres is 3m x 5m x 26 kg/m^2 = 390 kg. The combination of the zinc layer and PVDF/PVDF HB will give a high corrosion resistance.

3 DESIGN OF NOISE BARRIER FOUNDATIONS AND COLUMNS ACCORDING TO EUROCODES AND RUSSIAN NORMS

In this chapter the design of the pile and column structure is described. It should be taken into consideration that the calculations in Finnish method were taken from the brochures by Rautaruukki and from Veli-Matti Uotinen`s methodology of calculation, which are both based on RHK B11 and TIEH 2100062-09, however the calculations are made for KA-10 noise barrier cassettes, which are not produced now, but replaced by NBC-95 cassettes. Comparing them, we can see that the vertical load from the new cassette is lower because of the weight: 26 kg/m^2 instead of 35 kg/m^2. Of course this will not affect stability, so the calculations in the Finnish way are given with the methodology by Ruukki, but calculations by Russian norms are made for new NBC-95 cassettes.

3.1 Basic principles of design

The design of these structures in Finland is based on the following documents:

EN 1997-1 Eurocode 7: Geotechnical design, Part 1: General Rules

EN 1993-5 Eurocode 3: Design of steel structures – Part 5: Piling

EN 1991-1-1 Eurocode 1: Actions on structures – Part 1-1: General actions – Densities, self-weight and imposed loads

EN 1991-1-4 Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions

EN 10219-2:1997 Cold formed welded structural sections of non-alloy and fine grain steels. Tolerances, dimensions and sectional properties

RHK B11, Rautateiden meluesteet (Noise barriers of railways)

TIEH 2100062-09 Tien meluesteiden suunnittelu, luonnos 9.122009 (Designing of road noise barriers, draft for trial use 9.12.2009)

In Russia the following documents for designing noise barrier structures are used:

SNiP 2.01.07-85 (2003) Loads and actions (Нагрузки и воздействия)

SNiP 23-03-2003 Sound protection (Защита от шума)

SNiP 2.02.03-85 (1995, corrected 2003) Pile foundations (Свайные фундаменты)

SNiP 2.02.01-83 (2000) Foundations of structures (Основания зданий и сооружений)

SP 50-102-2003 Design and construction of pile foundations (Проектирование и устройство свайных фундаментов)

SNiP 2.03.11-85 Protection of structures corrosion (Защита строительных конструкций от коррозии)

Of course, if it is needed, we can also use clear and more detailed information guidelines where the process of design and calculations is written more consistently, not like a list of requirements in SNiP. The book by Dalmatov B.I. is one of this guides.

Shortly, the basic principle of design is the order of actions:

external load calculation;

transferring from external to internal loads;

selecting the type of main structure parts from the range of products, according to the internal loads factor;

selecting joint details (bolts, welding, etc.) according to internal loads in the joint.

3.2 Loads

Loads are taken into account in different ways in Eurocodes and in SNiPs. Further in the text the methodology of taking different loads into account will be realised.

3.2.1 Wind load

Finnish method:

If specific calculations according to EN 1991-1-4 General actions: Wind load, is not made, wind load of 1.0 kN/m^2 is used in calculations. For noise barriers on bridges the wind load is 1,6 kN/m^2.

Russian method:

According to SNiP "Loads and actions", normative average wind load w_m on this structure on height z is calculated by formula:

$$w_m = \gamma_f \cdot w_0 \cdot k \cdot c \qquad (3.1)$$

where:

γ_f – safety coefficient for the wind load (this type of coefficients to converse from normative loads to calculation loads are used), for wind this value is 1,4.

w_0 – normative value of the wind load (taken from table of SNiP according to the wind zone of Russia)

Table 3.1 Wind zones of USSR according to SNiP Loads and actions

Wind zones of USSR (taken from the map 3 of obligatory application 5)	Ia	I	II	III	IV	V	VI	VII
w_0, kPa	0,17	0,23	0,30	0,38	0,48	0,60	0,73	0,85

k – coefficient, taking into account the change of wind pressure with height

Table 3.2 Coefficient k selection by SNiP Loads and actions

Height z, m	Coefficient k for types of locality (situation)*		
	A	B	C
≤ 5	0,75	0,5	0,4
10	1,0	0,65	0,4
20	1,25	0,85	0,55
40	1,5	1,1	0,8
60	1,7	1,3	1,0
80	1,85	1,45	1,15
100	2,0	1,6	1,25
150	2,25	1,9	1,55
200	2,45	2,1	1,8
250	2,65	2,3	2,0
300	2,75	2,5	2,2
350	2,75	2,75	2,35
≥ 480	2,75	2,75	2,75

*A — open coastlines of sea, lakes and water storage ponds; deserts, steppes (prairies), forest-steppes, tundra;

B — city territories, forests and other places, uniformly covered with barriers, height more than 10 m;

C — city districts with buildings, height more than 25 m.

c – aerodynamic coefficient, which depends on the scheme of the structure and the surface (windward or lee (downwind)). For our structure, according to obliging attachment 4 of SNiP Loads and actions, these values are +0,8 for the windward side and -0,6 for lee side.

3.2.2 Ploughing load

Finnish method: a dynamic load from snow clearance according to EN 1794-1:2003 (annex E) depends on snow ploughing beside the noise barrier and/or what is the distance from the clearance area to the noise barrier. These loads can be understood from the following schemes:

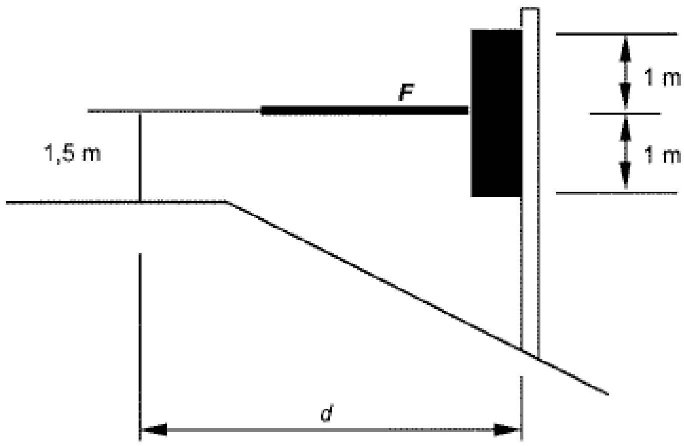
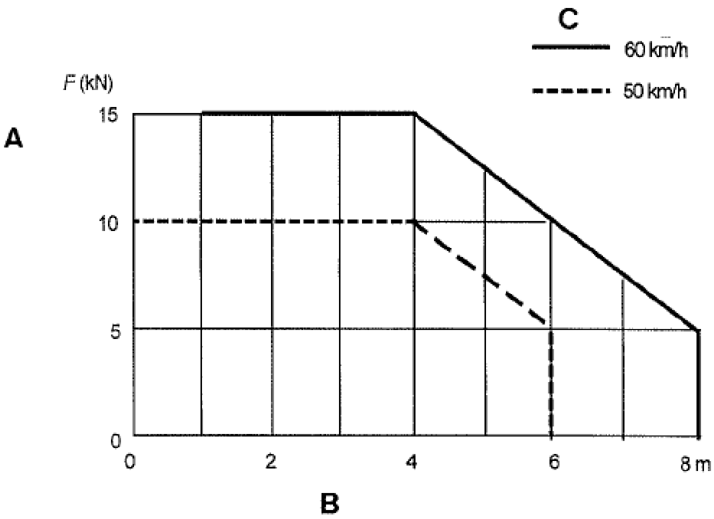


Figure 3.1 The effect of height on the dynamic load from snow clearance



Key
A Dynamic load on 2m × 2m
B Distance *d* from edge of ploughed surface
C Ploughing speed

Figure 3.2 The magnitude of the dynamic load from snow clearance

For example, the dynamic load from a 50 km/h ploughing speed with distance 2 m from the edge of the ploughed surface causes that the load will be 10 kN for 2x2 m area (or 2,5 kN/m^2).

Russian method: not reviewed in SNiP.

3.2.3 Vertical load

Finnish method: a vertical load is the summary load of the self-weight of the column, plinth elements and noise barrier cassettes.

Russian method: the normative value of the load is known from the factory certificates for structures, from standards, graphics or from known volumes and densities. For the converse from the normative to calculation load we need to use coefficient γ_f = 1,05 for steel structures (taken from table 1 of SNiP Loads and actions). If soil load has to be taken into account, coefficient γ_f = 1,1 for natural soils and γ_f = 1,15 for fill is used.

3.3 Design requirements

Table 3.3 Design requirements for columns and piles

Parameter	Finnish norms	Russian norms
Deflection of column	Road noise barriers (TIEH 2100062-09 standard): $e<h/100$ when $h<3m$ e=30mm, when h=3.0…4.5m $e<h/150$, when $h>4.5m$ where e – deflection, h – height Railroad noise barriers (RHK B11): $e_1<L/150$ $e_2<(2{,}2 \cdot K_p \cdot \gamma \cdot d)/N_h$ $e_3<L_1/75$ $e_3<50$ mm	According to SNiP “Loads and actions”, for one-level constructions with level height ≤ 6 m, deflection must be $<h_s/150$, where h_s is the height from the top of a foundation to the top of a column. Foundation inclination is taken into account.

	see figure 3.3	
Overall deflection of column	Same as deflection values	< $h_s/150$, as in upper cell (inclination is taken into account).
Bearing capacity of pile	Must be sufficient against vertical loads	The same as in the Finnish way, but the calculation of bearing capacity is different.

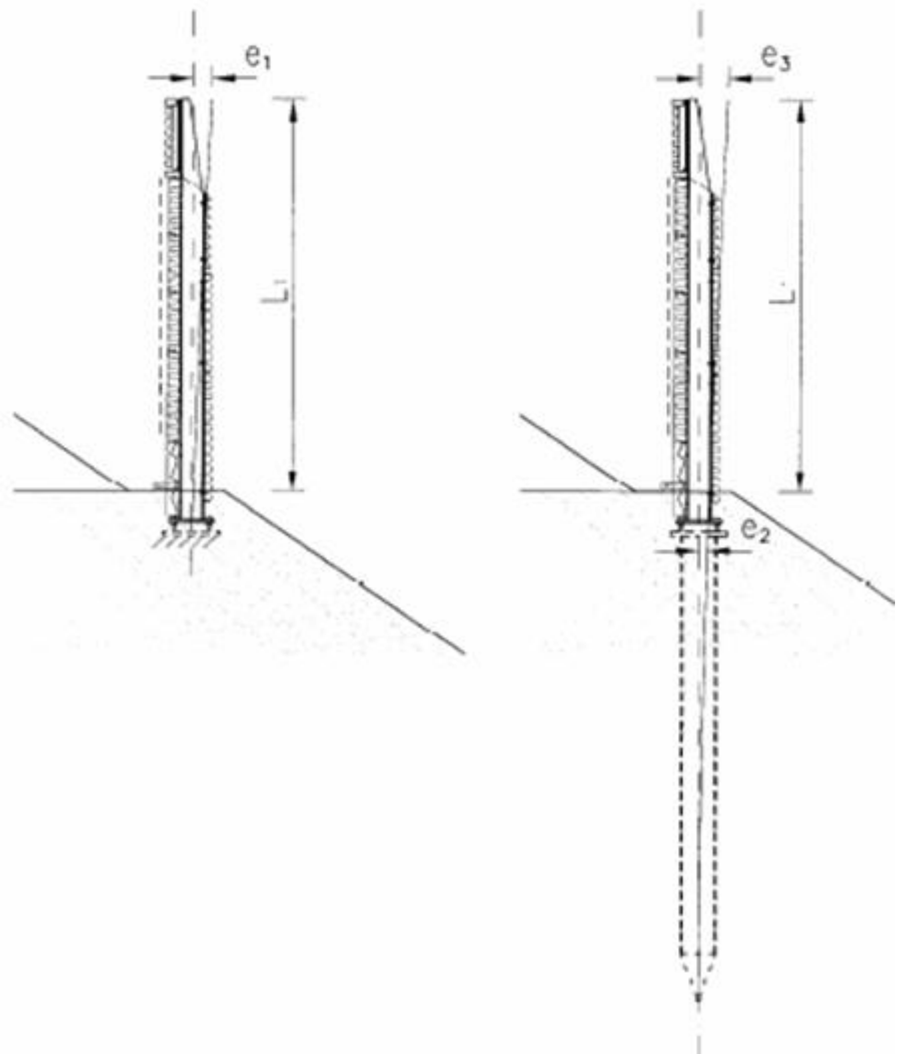


Figure 3.3 Meanings of L_1, e_1, e_2, e_3 values

3.4 Geotechnical design

Here is the methodology of pile calculations according to Eurocodes, SPs and SNiPs with examples of calculations by both methods.

3.4.1 Design principle of horizontally and/or vertically loaded pile according to Eurocodes

First all basic data needed for calculations is collected:

1) Height of the noise barrier
2) Slope angle (if the barrier is situated in a slope)
3) Horizontal load:
- wind load, according to EN 1994-1-4, if specific calculations are not made, 1 kN/m^2 is used in calculations
- dynamic load from snow clearance according to EN 1794-1:2003 (annex E) depend on snow ploughing beside the noise barrier and/or what is the distance from the clearance area to the noise barrier
4) Vertical load is the summary load of:
- noise barrier cassette and plinth, kg/m^2
- column, kg/m
- base plate
- connection plate
- base bolts, screws, accessories etc.
5) Soil conditions
- unit weight [kN/m^3],
- friction angle [°]
- undrained shear strength [kN/m^2],
- deformation parameters (e.g. modulus “m” and modulus exponent ”β”)

The ground water level is discovered and measured by soil investigations: if soil conditions are homogenous along the noise barrier, approximately one soil sounding / geotechnical drilling / soil sampling is needed for every 30…60 meters. When soil conditions are non-homogenous along the noise barrier, a ground survey should be made up to 5 - 10 meter spacing. The survey point density greatly depends on expected soil conditions.

Pile calculations:

Bearing capacity of a pile:

Vertical loads are calculated as dead loads of noise barrier materials. The geotechnical bearing capacity of the pile is calculated according to soil parameters and pile dimensions. Noise barrier steel piles are usually designed as friction piles (shaft resistance). Vertical loads are typically very small because the weight of a noise barrier cassette is only appr. 26 kg/m^2 , so typical values for dead loads for piles are between 3 - 14 kN (from h=2m L=2.0m … to h=4m L=5m noise barriers). Calculations are made according to Eurocodes as ultimate limit state analyses or alternatively by using characteristics values and an overall safety factor (F>2.2 …2.5)

An example of a calculation for height of barrier 3000 mm, space between columns 4000 mm and soil characteristics from table 3.4 is presented here:
The chosen pile is RR320/8 and the pile length is 4500 mm. Piles are open-ended. It is assumed that no plugging is occurring in the pile, so the internal shaft resistance is assumed to be half of the external shaft resistance. The shaft area of pile is A_s = 1.014 m^2 /m (1.52 m^2 when ½ internal shaft area is included) and resistance f_s = 30 kPa in the crushed slag layer, 15 kPa in the silt/sand layer.

Table 3.4 Soil layers, example characteristics

Soil layer	f_s [kPa]*	$R_{s,cal}$ [h x A_s x f_s) [kN]**
0.5m crushed slag, ø = 38°	30	22.8
4 m silt / sand ø = 32°	15	91.2

* shaft resistance

** bearing capacity

$R_{s,cal}$ = 114 kN

Vertical dead load per pile is appr. 5.5 kN

- * noise barrier cassette and plinth 35 kg/m^2 420 kg
- * IPE 180 column 18.8 kg/m 56.4 kg
- * base plate 350 x 350 x 30 28.8 kg
- * connection plate 400 x 400 x 30 37.7 kg
- * base bolts, screws, accessories etc. 20 kg

In summary: 560 - 570 kg, 5.5 kN

Overall safety factor F is approximately 20.

Moment capacity of pile:

$$M = W \cdot \sigma > 1.5 \cdot H_R \cdot e \qquad (3.2)$$

where

M = moment capacity of pile

W = section modulus of pile, loss of material thickness due corrosion (corrosion allowance) must be taken into account

σ = yield strength of steel

H_R = horizontal resultant force

e = arm of force

Arm of force can be assumed in calculations to be 0.2 m longer than in the calculation of moment capacity of the column. 0.2 m is “a safer-side distance” from the upper end of the pile to the base plate of the column. If column, pile and soil can be modelled by a computer program, the moment affecting the pile can be achieved more precisely.

An example of a calculation for barrier height 3000 mm and space between columns 4000 mm is presented here:

With corrosion allowance 2mm, the cross-section parameters of RR323/8 piles are:

W = 456 cm^3

EI = 15310 kNm^4

Maximum moment effect on pile is with 1.5 x 12 kN = 18 kN, the horizontal load is according to Geo-Calc results 35.6 kNm.

Moment capacity of pile is M = 456 cm^3 x 355 MPa = 161.9 kNm > 35.6 kNm.

Deflection and inclination of piles: horizontal displacements of piles are calculated by computer programs which model soil layers with the horizontal modulus of a subgrade reaction. The interaction between the soil and pile is taken into account with supporting springs. If the noise barrier is situated in a slope, spring values of the upper layers has to be reduced (when the slope is 1:1.5, the spring value should be max. 50 % of a horizontally even place). It is notable that topmost soil layers (choice of fill material, depth of fill and compaction of fill) have a great significance spring values and thus to the pile deflection. Programs (for instance Geo-Calc) give the pile head movement and from displacement results it is possible to calculate the inclination of the pile in the soil surface. When determining pile characteristics (values based on outside diameter and wall thickness), the corrosion allowance has to be take into consideration. 2 mm / 50 years for open-ended piles is used if it is assumed that soil corrosion conditions are not aggressive. Other corrosion allowances can be determined according to EN 1993-5.

Here is an example of calculations:

The deflection and inclination of a pile is calculated with the Geo-Calc geotechnical program. A horizontal load of 12 kN is affecting 1.5m above soil surface. Results from the calculation are presented in the following pictures:

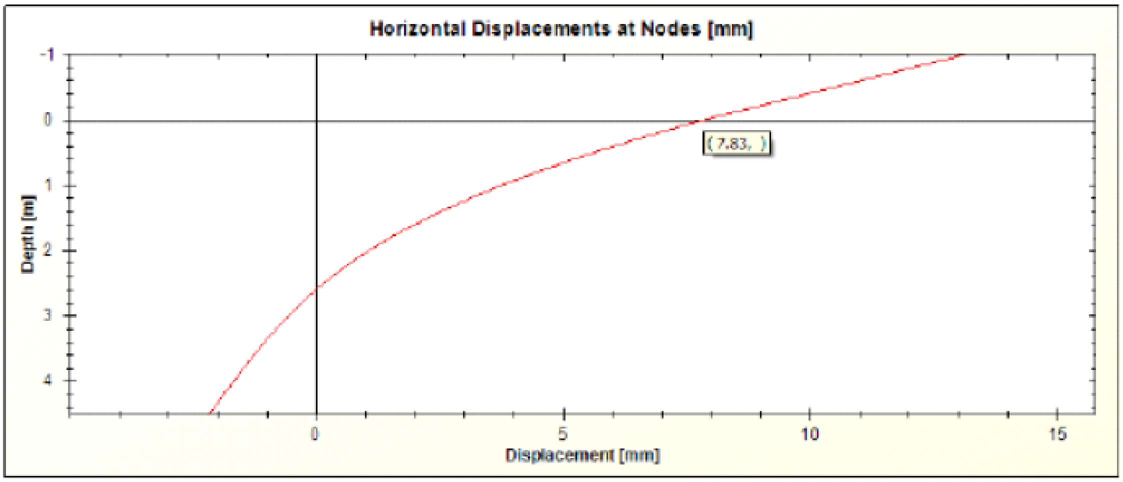


Figure 3.4 Horizontal displacement diagram from Geo-Calc application

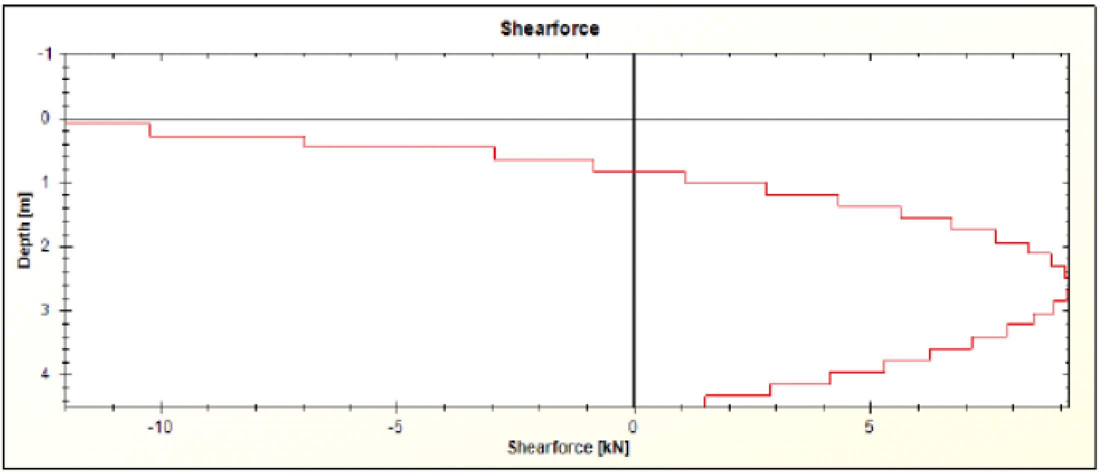


Figure 3.5 Shear force diagram from Geo-Calc application

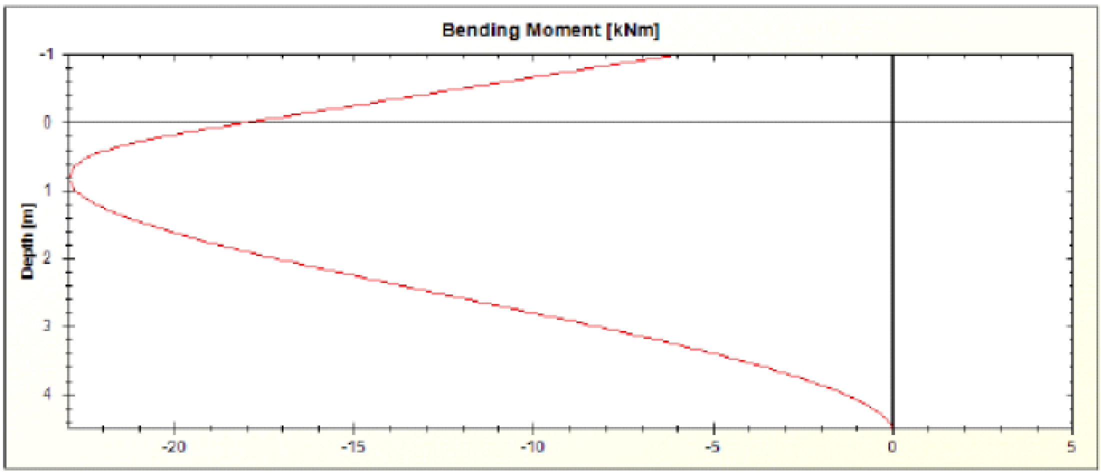


Figure 3.6 Bending moment diagram from Geo-Calc application

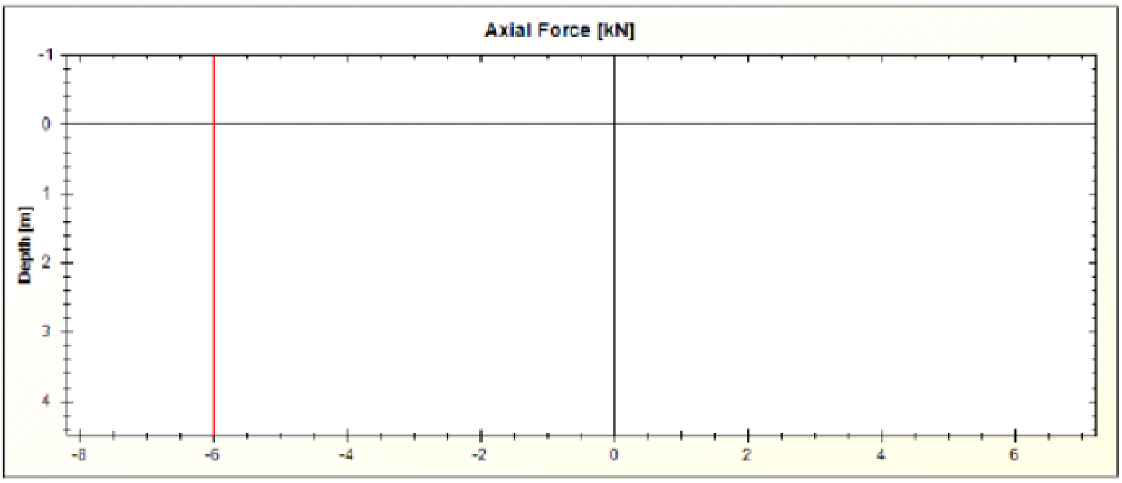


Figure 3.7 Axial Force diagram from Geo-Calc application

The deflection of the pile in the soil surface is 7.83 mm

The inclination of the pile in the soil surface is 0.005375

3.4.2 Design principle of horizontally and/or vertically loaded pile according to Russian norms

First all basic data for calculations is collected:

1) Height of a noise barrier
2) Slope angle (if barrier is situated in slope)
3) Horizontal load:
- wind load, according to SNiP "Loads and actions"
4) Vertical load is the summary load of:
- noise barrier cassette and plinth, kg/m^2

- column, kg/m
- base plate
- connection plate
- base bolts, screws, accessories etc.

5) Soil conditions

- unit weight [kN/m^3],
- friction angle [°]
- undrained shear strength [kN/m^2],
- additional characteristics

The ground water level is discovered and measured by soil investigations.

Next, we need to do calculations for 2 types of limit states:

1) First limit state:

- structural bearing capacity / geotechnical bearing capacity, smaller value is taken into calculations;
- stability of a pile against horizontal load.

2) Second limit state:

- settlements;
- irregularity of settlements;
- movements of piles, caused by horizontal load and moment.

Calculations are done in the certain sequence of actions. A specific sample is given here. Of course it’s not a real project, but it can give a basic view of completing this project in Russia.

Basic data:

Height of a noise barrier 3000 mm

Slope: no slope

Space between columns 5000 mm

Soil conditions: 0,5 m fill layer (sandy loam with construction litter); 0,5 – 3,5 m sandy loam; 3,5 m and lower – heavy loam

Table 3.5 Example of soil characteristics from SNiP 2.02.01-83 Foundations of structures

Name of the soil	Fill (sandy loam)	Sandy loam	Heavy loam
Height, m	0,5	0,5 – 3,5	3,5 and lower
φ, °	-	17	20
γ , kN/m^3	-	15,5	18,3
c , kPa		4	30
γ_s , kN/m^3		26,4	26,5
W		0,29	0,15
W_L		0,31	0,24
W_p		0,25	0,11
k_f , sm/sec		1,1 · 10-5	2,3 · 10-6
E , kPa		8000	22000
Additional characteristics*			
I_L		0,67	0,31
γ_d		12,0	15,9
n		0,55	0,4
e		1,2	0,7
γ_{sb}		2,5	4,9

*formulas for calculating the additional characteristics are taken from Dalmatov B.I., basic characteristics are taken from SPSUACE library methodology.

Loads:

Wind load:

$w_m = \gamma_f \cdot w_0 \cdot k \cdot c = 1{,}4 \cdot 0{,}3$ kPa $\cdot\, 0{,}5 \cdot (0{,}8+0{,}6) = 0{,}294$ kPa $= 0{,}3$ kN/m^2

to have the load, uniformly distributed to column, this value needs to be multiplied by the space between columns:

$w_1 = 0{,}3$ kN/m$^2 \cdot 5$ m $= 1{,}5$ kN/m

to have the moment on the top of the foundation, the following formula has to be used:

$$w_2 = \frac{q \cdot z^2}{2} = \frac{1{,}5 \cdot 3^2}{2} = 6{,}75\ \text{kNm} \qquad (3.3)$$

Table 3.6 Vertical load

Name of the load	Normative load, kg	Coefficient γ_f*	Calculation load, kg
Noise barrier cassette and plinth 26 kg/m^2	390	1,1	429
IPE 180 column 18.8 kg/m	56,4	1,1	62,04
Base plate 350 x 350 x 30	28,8	1,1	31,68
Connection plate 400 x 400 x 30	37,7	1,1	41,47
Base bolts, screws, accessories etc.	20	1,1	22
		Summary load	586 kg

*if the self-weight load is more than 50% of the total load, coefficient 1,1 is used

Calculations: in the SP 50-102-2003 there is the non-obligatory Application D, which tells about the way of pile calculations. According to this application, the calculation of piles under the joint action of the vertical, horizontal force and bending moment, must be made using the scheme shown on figure 3.5 and the following explanations. Important to mention that according to SNiP Steel structures, paragraph 1.2, it is restricted to increase the cross-section size for higher corrosion resistance. Corrosion resistance is achieved only by using all methodology of corrosion protection, described in SNiPs about corrosion. Also to mention: according to methodology book to SNiP (Reinforcement of steel structures design), if cross-section area decreases more than 25% or the rest thickness of cross-section is less than 5 mm, it is needed to multiply R_y on coefficient γ_f (which depends on the aggressiveness of the environment and has values from 0,95 to 0,85).

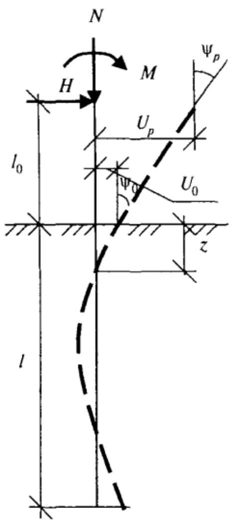


Figure 3.8 Scheme of loaded pile

a) Calculation of pile deformations by formulas:

$$U_p \leq U_u \qquad (3.4)$$

$$\psi_p \leq \psi_u \qquad (3.5)$$

where:

U_p и ψ_p — calculation values of horizontal movement of pile head (m) and angle of rotation (rad), calculated by method of Application D, chapter D4;

U_u и ψ_u — limit values of horizontal movement of pile head (m) and angle of rotation (rad), set by the assignment for the design and calculations of the structure.

b) Calculations of the stability of soil, surrounding pile, is made according to chapter D6 of Application D.

c) Calculations of pile cross-sections by first and second limit states against the joint action of compressive strength, bending moment and shear force is made according to sections 7.1 – 7.2 of SP 50-102-2003 and the calculation values of the forces N_z, M_z, Q_z are made by chapter D7 of Application D.

My objective is to make equations in the Mathcad application for calculating deformations, soil stability and strength of soil and material.

The results for pile RR220/12,5 with 6 m length are:

Stability of soil – does not exceed the limit value

Geotechnical bearing capacity – does not exceed the limit value

Structural bearing capacity – does not exceed the limit value

Horizontal movement of pile head = 3 mm

Inclination = 0,0025 rad = 0,14 °

3.5 Structural design

In this part the design of all structures above the earth surface, column and base bolts, are described. Calculations of columns by Russian norms are done by the SCAD program, which allows to select European steel rolled sections.

3.5.1 Design principle of horizontally and/or vertically loaded column according to Eurocodes

Deflection of column:

$$f = \frac{ql^4}{8EI} \qquad (3.6)$$

where

f = deflection of upper end of column

q = uniformly distributed load

l = height of noise column

EI = bending stiffness of column

Here is an example of calculations for 3000 mm barrier height and 4000 mm distance between columns. Possible column profile IPE 180; EI = 2772 kNm^4

$$f = \frac{4 * 1,0 \frac{kN}{m^2} * 3,0m^4}{8 * 2772kNm^4} = 14,61\ mm$$, allowable value is L/150 = 20 mm

The moment capacity of the column:

$$M = W \cdot s > 1.5 \cdot H_R \cdot e \qquad (3.7)$$

where

M = moment capacity of column

W = section modulus of column

s = yield strength of steel

H_R = horizontal resultant force

e = arm of force

An example of calculations:

$M = W \cdot s > 1.5 \cdot H_R \cdot e$

$H_R = 1.0\ kN/m^2 \times 3m \times 4m = 12\ kN$

$e = 1.5\ m$

$M = 1.5 \times 12kN \times 1.5m = 27\ kNm$

$W = 146\ cm^3$ (IPE 180)

$M = 146\ cm^3 * 355\ MPa = 51.8\ kNm > 27\ kNm$

The overall deflection of a column:

The overall deflection of a column is a sum of the deflection of a column, deflection of a pile head and influence of the pile inclination on the column. The principal scheme for better understanding of all deflections is given in figure 3.6:

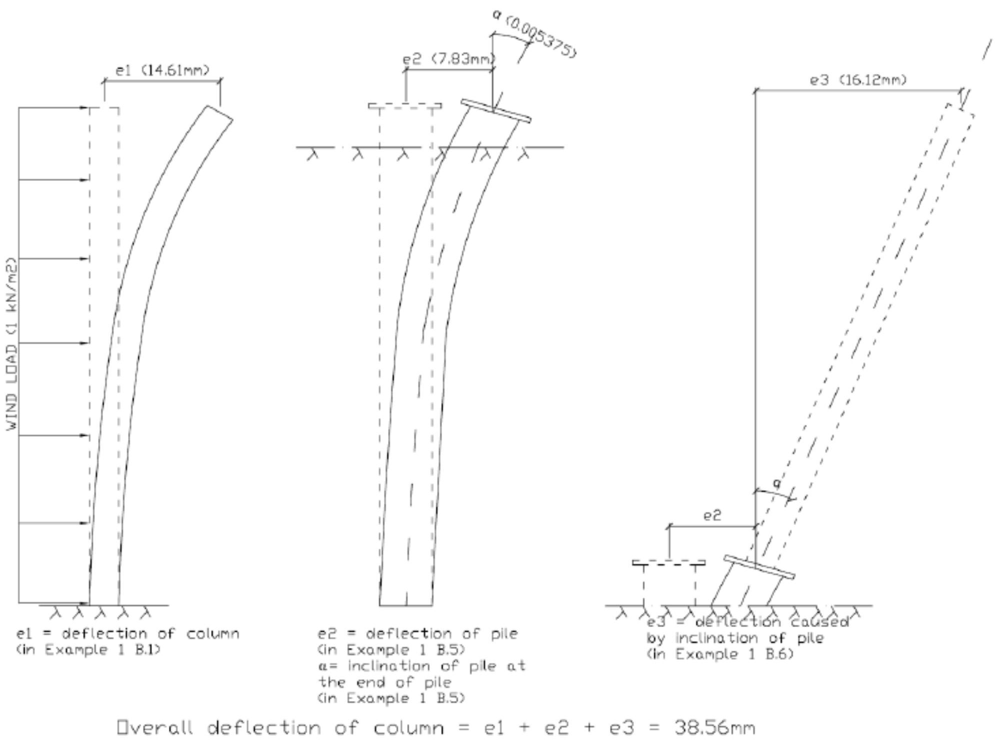


Figure 3.9 Overall deflection of column

An example of calculations:

Deflection of column 14.61 mm

Deflection of pile 7.83 mm

Deflection caused by inclination of pile 3000 mm x 0.005375 = 16.12 mm

Overall deflection of column = 38.56 mm < L/75 (40mm).

3.5.2 Design principle of horizontally and/or vertically loaded column according to Russian norms

The main Russian normative document used for the design and calculations of steel columns SNiP II-23-81* (1990) “Steel structures”. Basic data is already written in the part about pile calculation of this report. Next, columns under the vertical and horizontal force will be calculated. The most common program for this calculation in Russia is SCAD. The scheme of the structure is quite simple, and this program allows to insert the IPE 180 profile characteristics.

The end result of calculations in SCAD:

Deflection of the column top: 5,5 mm

Maximum forces in the foundation level of column:

N = 5,9 kN

Q = 4,5 kN

M = 6,8 kN·m

The file with calculations and charts is attached to the report. As written before, the maximum deflection of a column must be < l/150 = 20 mm, so the deflection 5,5 mm is normal according to Russian norms. The overall deflection is the summary of the pile deflection and column deflection and it is 5,5 + 3 + 3000·sin(0,14˚) = 15,8 mm, that is also less than 20 mm.

3.5.3 Structural design of a pile

Basic design principles are discussed before, in the part “RR-piles”. In noise barriers pile sizes smaller than RR220/10 are very seldom used, but on the other hand pile diameters RR270 (273.0mm), RR320 (323.9mm) and RR400

(406.4mm) with the wall thickness of 8 or 10 mm (also possible RR220/8) are typical pile sizes for noise barriers. Here is the table of the most commonly used cross-sections:

Table 3.7 Dimensions and sectional properties of RR piles, mostly used in noise barrier structures

A = Cross-section area
A_u = External surface area
A_b = Pile base area

Z = Pile impedance
I = Moment of inertia
W_{el} = Section modulus

Cross-sectional values reduced by corrosion allowances of 1.2 mm and 2.0 mm.

D [mm]	t [mm]	M [kg/m]	A [mm^2]	A_u [m^2/m]	A_b [mm^2]	W_{el} [cm^3]	I [cm^4]	EI [kNm^2]	Z [kNs/m]	$A_{1,2}$ [mm^2]	$A_{2,0}$ [cm^4]	$I_{1,2}$ [cm^4]	$I_{2,0}$ [cm^4]	$EI_{1,2}$ [kNm^2]	$EI_{2,0}$ [kNm^2]
219.1	10.0	51.6	6569	0.69	37703	328.5	3598.4	7557	266.7	5748	5205	3110.9	2794.7	6533	5869
219.1	12.5	63.7	8113	0.69	37703	396.6	4344.6	9124	329.4	7292	6749	3857.0	3540.9	8100	7436
273.0	6.3	41.4	5279	0.86	58535	344.0	4695.8	9861	214.3	4254	3576	3749.6	3132.6	7874	6579
273.0	10.0	64.9	8262	0.86	58535	524.1	7154.1	15024	335.5	7238	6560	6207.9	5590.9	13037	11741
273.0	12.5	80.3	10230	0.86	58535	637.2	8697.4	18265	415.3	9205	8527	7751.2	7134.2	16278	14982
323.9	10.0	77.4	9861	1.02	82397	750.7	12158.3	25533	400.4	8645	7839	10574.7	9538.5	22207	20031
323.9	12.5	96.0	12229	1.02	82397	916.7	14846.5	31178	496.5	11012	10206	13262.9	12226.7	27852	25676
406.4	10.0	97.8	12453	1.28	129717	1204.5	24475.8	51399	505.6	10926	9912	21340.7	19281.4	44816	40491
406.4	12.5	121.4	15468	1.28	129717	1477.9	30030.7	63064	628.1	13941	12928	26895.6	24836.3	56481	52156

From table 3.7 we can choose some basic data needed for calculations, such as EI, A, W according to the chosen cross-section.

3.5.4 Structural design of a column

A column is the European profile IPE 180 or a larger size. There is no need to use smaller than IPE 140 size of columns because it will bring the difficulty in mounting the noise barrier panels. To attach the noise barrier panels holes for bolts with certain dimensions are made in the flanges. The verticality of the column and the needed position are achieved by regulating the mounting base bolts.

3.5.5 Corrosion

According to brochures from Ruukki, based on Eurocodes, some investigations have been made in Europe for 5 and 25 years of steel piles service. Other values (for 50, 75, 100 years) were extrapolated. Table 3.8 is taken from the brochure:

Table 3.8 Corrosion allowances (mm) according to EN 1993-5 Eurocode 3: Design of Steel Structures – Part 5: Piling

Soil conditions	Required design working life [year]				
	5	25	50	75	100
Undisturbed natural soils (sand, silt, clay, schist, ...)	0.00	0.30	0.60	0.90	1.20
Polluted natural soils and industrial sites	0.15	0.75	1.50	2.25	3.00
Aggressive natural soils (swamp, marsh, peat, ...)	0.20	1.00	1.75	2.50	3.25
Non-compacted non-aggressive fills (clay, schist, sand, silt, ...)	0.18	0.70	1.20	1.70	2.20
Non-compacted aggressive fills (ashes, slag, ...)	0.50	2.00	3.25	4.50	5.75

- Corrosion rates in compacted fills are lower than those in non-compacted ones. In compacted fills the figures in the table should be divided by two.
- The values given are only for guidance. Local conditions should be considered and suitable values that take into account local conditions should be given in the National Annex.
- The values corresponding given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.

Atmospheric corrosion in 100 years:
– 1 mm in normal atmosphere – 2 mm in marine conditions

In Russia corrosion allowances are regulated by SNiP 2.03.11-85 Corrosion protection of structures. The main principle of taking corrosion into account is to find the degree of environment aggressiveness according to table 28 of SNiP and then to find out what is said about the requirements next to the table (which constructions are allowed and which are not).

The degree of environment aggressiveness depends on:

- Middle year temperature;
- Characteristics of ground water (pH, concentrations of sulfates and chlorides);
- If the pile contacts ground water or not (upper or lower than the ground water level);
- Zone of humidity;
- Unit electrical resistance of the soil.

There are three degrees: low-, middle- and high-aggressive. The best way to find out the degree of environment aggressiveness is to make soil investigations, but as for Saint-Petersburg in general – most common are middle and high-aggressive soils. The methods of the measurements of electrical soil characteristics are described in GOST 9.602-89 Unified system of corrosion and ageing protection. Underground structures. General requirements for corrosion protection.

In normal, non-aggressive soils, corrosion rate is 0,1 mm/year. But if soils are aggressive, this value can increase to 1-2 mm/year and it can be unpredictable.

3.5.6 Dimensioning of connection plates and base bolts

Base plate 350x350x30 has been taken in my example of calculations, so I will calculate this plate with the bending beam of height 30 mm and width 350 mm according to part 5 of SNiP II-23-81 (1990) Steel structures by the following formula:

$$\frac{\mathbf{M}}{\mathbf{W}} \leq \mathbf{R_y} \gamma_c \qquad (3.8)$$

where:

M – bending moment, 6,75 kNm

W – moment of cross-section resistance,

$$W = I/r_{max} = (b \cdot h^3) / (12 \cdot r_{max}) \qquad (3.9)$$

$= (0,35 \cdot 0,03^3) / (12 \cdot 0,015) = 0,00005\ m^3$

R_y – yield strength of steel, 355 MPa

γ_c – coefficient of service circumstances, 1

$\frac{6750}{0,00005} < 355000000$, $\quad 135000000 < 355000000$

So, we can see that this plate is much more durable than required. It is more economical to use a 20 mm thick plate:

$W = (b \cdot h^2)/6 = (0,35 \cdot 0,0004)/6 = 0,0000233$

$$\frac{6750}{0,0000233} = 289699570 < 355000000$$

Base bolts are, for example, d = 16 mm. According to SNiP "Steel structures", they are calculated against tension in the following way:

The tensile force for 2 bolts in our case is 6,75 kNm / (0,35 – (0,03+0,008)·2) = 24,6 kN, so for one bolt it is 12,3 kN. Also, 7,35 kN of the vertical load is applied for all 4 bolts. So, in summary for one bolt we have the following loads:

tensile force 12,3 kN (from moment 6,75 kNm)

compression force 1,84 kN (from 7,35 kN vertical load)

shearing force: 1,13 kN (from 4,5 kN horizontal load)

Combining all these loads it can be detected that the maximum tension for one bolt is 12,3 – 1,84 = 10,5 kN; the maximum compression is 12,3 + 1,84 = 14,2 kN and the maximum shearing force is 1,13 kN. Maximum allowed forces, which can be applied by the bolt are calculated by the following formulas:

shear force:

$$N_b = R_{bs}\,\gamma_b\,A_{ns} \qquad (3.10)$$

compression:

$$N_b = R_{bp}\,\gamma_b\,d\,\sum t \qquad (3.11)$$

tension:

$$N_b = R_{bt}\,A_{bn} \qquad (3.12)$$

Abbreviations used in formulas:

R_{bs}, R_{bp}, R_{bt} – calculation resistances of bolt connections;

d – outer diameter of bolt;

$A = \frac{\pi d^2}{4}$ – calculation area of bolt cross section;

A_{bn} – netto area of bolt cross-section; for bolts with metric thread value A_{bn} needs to be taken from addition 1 to GOST 22356–77*;

$\sum t$ – minimum summary thickness of elements, pressured in one direction;

n_s – number of calculation shears of one bolt;

γ_b – coefficient of working conditions, need to be taken from table 35* of SNiP Steel structures.

R = 355 MPa = 355000000 N/m^2 = 355 N/mm^2

γ_b = 0,75

d = 16 mm

A = 201 mm^2

n_s = 2

Σt = 60 mm (two plates 30 mm each)

$$N_{bs} = 355 \cdot 0{,}75 \cdot 201 \cdot 2 = 107\ kN > 1{,}13\ kN,\ OK$$

$$N_{bc} = 355 \cdot 0{,}75 \cdot 16 \cdot 60 = 256\ kN > 14{,}2\ kN,\ OK$$

$$N_{bt} = 355 \cdot 157 = 55{,}7\ kN > 10{,}5\ kN,\ OK$$

3.6 Comparison between Eurocodes and Russian norms

Of course, laws of physics work in the same way in all cases. But conditions and ways of thinking may differ in different countries. For example, natural conditions such as snow, wind, chemical aggressiveness of air and soils are different from place to place. This causes the changes in coefficients of working conditions and, sometimes, changes in physical laws used in calculations. One example of how the ways of thinking influence structural design and calculations is that in Europe and in the USA an engineer can just make certain sequence of actions to calculate a certain type of structure and almost all structures are described in normative documents, and the Russian system is a little more complicated to understand, and not so unified for all actions. There are basic principles and some types of structures described, but not all. Formulas and ways of calculations are more complicated in SNiP.

To provide more exact comparison of the values the following table has been drafted (all characteristics given in the table are for noise barriers example calculations):

Table 3.9 Comparison of basic differences in norms

Characteristic	**Finland**	**Russia**
Wind load	1,0 kN/m^2 (1,6 if barrier on bridge)	0,3 kN/m^2
Vertical load	Self-weight	Self-weight, multiplied by coefficient 1,1
Piling class (class of responsibility in	II (demanding projects) or IB (very demanding projects)	II (normal level) or I (higher level)

Russian norms)		
Column deflection required	For 3 metres high barrier: -along the traffic road e≤30mm** -along the railroad e≤L/75 or e≤50mm (smaller value is taken into account)***	L/150 for all cases
Noise barrier example calculations		
	Finland (3m height x 4m length)	Russia (3m height x 5m length)
Moment	35,6 kNm	6,8 kNm
Soil	1) Upper soil layer 0 - 0.5 m: compacted gravel or crushed slag; friction angle φ=38º, γ=19.5 kN/m^3, m=600, β=0.5 2) Soil beneath 0.5m to depth of 25 m: loose sand or silty sand, friction angle φ=32º, γ=18 kN/m^3, m=125, β=0.5 Ground water table is assumed to be 0.5m below soil surface	1) Upper soil layer 0,5 - 3,5 m: sandy loam φ = 17°, γ = 15,5 kN/m^3 2) Soil beneath 3,5 m: heavy loam φ = 20°, γ = 18,3 kN/m^3 Ground water level is 0,5 m from the top of upper soil layer.
Vertical force	5,5 kN	5,9 kN
Horizontal force	18 kN	4,5 kN
Pile	**RR 323/8 (corrosion allowance 2 mm per 50 years in not aggressive soil)**	**RR 219/12,5 (without corrosion allowance, not needed)**
Moment capacity	161,9 kNm	140,8 kNm
Bearing capacity	114 kN****	114,5 kN****
Deflection	7,83 mm	3 mm
Inclination	0,005375	0,0025
Column	**IPE 180**	**IPE 180**
Deflection	14,61 mm	5,5 mm
Moment capacity	51,8 kNm	51,8 kNm
Overall deflection	38,56 mm	15,8 mm

* II – for structures of unified typical construction, I – for structures, collapse of which can cause economical, social or ecological problems (GOST 27751-88 (2003))

** TIEH 2100062-09

*** RHK B11

**** coincidence is random, because soils and pile sizes in calculations were different

As we can see from table 3.9 the differences in general are: as follows in Russian norms the wind load is approximately 3x lower than in the Finnish ones and the overall deflection of the column is approximately 2,5x lower in Russian calculations than in the Finnish ones. So, in Russia we have a smaller wind load and stricter requirements for the column deflection (L/150 instead of L/75). As a result for the Finnish wind load Finnish deflection requirements are met and for the Russian wind load Russian deflection requirements are met.

Another difference that was discovered is steel economy. This tradition comes from the late USSR time, the 1970-80s. As a result of this policy as many structures as possible were made of concrete, and SNiPs have been written in that way. For example, in this study the formulas for calculations of steel pipe RR-piles have been taken from SP “Design and construction of pile foundations”, which describes mostly concrete piles. In Russia steel piles such as the described RR-piles are used mostly in Far North areas where it is impossible to transport concrete but possible to transport steel pipes, which have less weight and it is no need to count the temperature’s influence on concrete consolidation. In Eurocodes steel economy means that more new technologies and new steels are used, which mean smaller cross-sections for beams, columns, etc., but it does not mean that concrete is used instead of steel.

4 CASE STUDY

This part describes some real cases of the implementation of these noise barrier structures in Russia (Saint-Petersburg) and in Finland (Kouvola). Some general recommendations for promotion are given.

4.1 Noise barriers in Saint-Petersburg

Above in the text calculations and design of Ruukki's system on Saint-Petersburg soil has been described. It is not a real case, but the situation will be mostly the same in the whole North-West region of Russia. This means that mainly, from the view of Russian construction norms, Ruukki can use this system at least in the North-West region of Russia. Also it can be concluded that soils are more stable in central and southern regions so it will be also possible to use this system. Problems will not be in calculations and design, but in economic questions.

For better understanding the costs we should calculate are in table 4.1. For comparison, 2 graphs are drafted – one with the structural parts used in Finland by Ruukki (with their prices in Russia) and one with structural parts which can be used in Russia instead of delivering parts from Finland. Calculations will be made for one pile + column + span of cassettes NBC-95:

Table 4.1 Prices of parts for noise barrier foundation

Name of part	Finnish		Russian	
	Type	**Price**	**Type**	**Price**
Column 3 m length	IPE 180	460 €	18Б2	1460 rub = 38 €
Pile 6 m length	RR 220/12,5	385 €	D219x14	14270 rub = 370 €
5 x NBC-95 cassettes	NBC-95	1350 €	NBC-95	1350 €
1 x plinth element (600x4000)	Profiled steel	325 €	Profiled steel	2382 rub = 61,7 €

4.2 Kouvola Myllykallio project

Theoretically this project can be analysed if we know the wind zone and soils. SNiP Loads and actions map of wind zones has been made only for Russia and some CIS countries, but not made for Finland. Also the methods of soil testing are special according to GOSTs, not the same as in Eurocodes.

Nevertheless, Kouvola is not situated near the sea coastline, so winds are weaker there than in the example of calculations of Saint-Petersburg. So, with confidence, after the calculations of IPE 180 columns and RR 220/12,5 piles for the Saint-Petersburg conditions we can conclude that all the structures with IPE200 profile column and RR 323/10 pile can be applied in Kouvola according to Russian norms.

5 CONCLUSIONS

To be short, it can be deciphered that this structure complies with SNiPs, GOSTs and SP norms. But it certainly will have economic problems – in Russia it is cheaper to buy already used steel pipes or just make concrete foundations for these noise barriers. Nevertheless, Ruukki has a way to promote this structure in Russia – the main part is NBC-95 cassette, which has quite good sound protection characteristics, and it does not matter which structure is made for them – Russian profile columns and used piles / concrete footings, Russian bolts, profiled steel and base plates or Finnish or European imported parts to Russia. It is suitable to use cheaper supporting structures for NBC-95 cassettes.

6 FIGURES

7 TABLES

8 REFERENCES

Dalmatov B.I., Design of foundations and underground structures, 2006 (ISBN 5-93093-008-2)

Examples of foundation design calculations (brochure by Ruukki)

Foundation structures (brochure by Ruukki)

GOST 22356–77* High strength bolts and nuts and washes. General specifications

GOST 27751-88 (2003) Reliability of the constructions and the foundations

GOST 9.602-89 Unified system of corrosion and ageing protection. Underground structures. General requirements for corrosion protection

Noise barriers product specification (brochure by Ruukki)

Pienpaalutusohje PPO-2007, RIL 230-2007 Finnish micropile manual (in Finnish only)

Reinforcement of steel structures design (metodics for SNiP II-23-81*)

RHK B11 Rautateiden meluesteet (noise barriers of railways)

RR piling manual (brochure by Ruukki)

Ruukki's noise barrier system (brochure by Ruukki)

Splicing of steel piles by welding (brochure by Ruukki)

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