Experience in noise protection measures for railways constructions in Russia and Italy

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Abstract

This article describes methods to calculate and assess of the acoustic conditions during the railways construction. It gives information about sizes of the acoustic discomfort zones along construction sites for various technological units. Noise performances of construction machinery and equipment used in Russia and Italy is also given. The list and a brief description of the major noise mitigation measures used in practice in Russia and Italy are finally presented.

Key words: noise, construction, railways, noise protection.

Опыт проектирования шумозащитных мероприятий при строительстве железных дорог в России и Италии

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Аннотация

В статье описаны методы расчета и прогнозирования акустической обстановки при строительстве железных дорог, представлены сведения о размерах зон акустического дискомфорта вдоль строительных площадок для различных технологических звеньев. Приведены шумовые характеристики строительных машин и оборудования, применяемых в России и Италии. Представлен перечень и дано краткое описание основных шумозащитных мероприятий, практикуемых в России и Италии.

Ключевые слова: *шум, строительство, железные дороги, шумозащитные мероприятия.*

Introduction

Railway is a source of increased physical impact on the environment and adjacent residential areas, not only during its operation, but also at construction stage. Thus, development of noise mitigation measures during railway construction works is a necessary condition of maintaining favorable acoustic environment and compliance with sanitary norms.

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Given the specific character of railway construction, associated with the multistage technology and object length, the development of noise mitigation measures must be fulfilled individually for each site and confirmed by acoustic calculations separately for each technological unit.

1. Analysis of railway construction technological schemes and noise emissions by construction machinery

The first task necessary to assess the influence of railway construction on the environment is the identification of the most noisy technological units according to the construction organizational schemes. A railway construction cludes two major work packages: the subgrade construction and the track bed construction.The subgrade construction is executed by successive parts of work and includes:

a) thestrengthening of the subgrade foundation with the use of pile-driving rigs, drilling rigs, truck cranes, drop-side trucks, etc.;

b) the subgrade construction itself: foundation soil replacement, filling draining soil and a protective layer deposition, ground levelling and compaction, slopes layout, preparation of subgrade for track bed laying). These above works require the use of excavators, dozers and dozers with rippers, dumpers, rollers on pneumatic tires, vibration rollers, flusher trucks, graders, slope trimming machines, etc.

The track bed may be constructed with or without ballast bed layer. The noisiest construction machines used in construction of a ballast bed in various technological units are: track cranes, railway cranes, sleeper tamping machines, shunting locomotives, compressors, electric ballasting machines, lining-tamping-straightening machines, hopper-batchers, track welding machines, rail welding trains, etc.

The noisiest machines used in construction of ballastless track in different technological units are: concrete pavers, motormixers, autoconcrete pumps, truck cranes, slab laying machines, drop-side trucks, asphalt spreaders, motor tar sprayers, dumpers, rollers, road milling cutters, rail laying machines, track welding machine, rail welding trains, etc.

Information about noise performance of the machinery involved in subgrade and track bed construction was collected (see Table 1) and analyzed for evaluating the acoustic environment on the areas adjacent to the construction sites. The main noise sources during construction works are engines, hydraulic systems and working bodies of the construction machinery.

Table 1 – Construction machinery noise performance

No.	Type of construction machinery	Russian measurements [1-8]		Italian measurements [13]		
		Equivalent sound level, dBA	**Maximum sound level, dBA**	**Mean measured sound power level (dBA)**	**Dimension of the machine sample**	**Mean Sound pressure level (r = 7.5 m)**
1	Excavator (bucket capacity 1.25 m^3)	71	76	97,6	665	72,1
		r_0= 7,5 м [1]				
2	Bulldozer	76	82	105,3	69	79,8
		r_0= 7,5 м [1]				
3	Bulldozer with ripper	76	82	105,3	69	79,8
		r_0= 7,5 м [1]				
4	Motor grader	74	76	103,6	9	78,1
		r_0= 7,5 м [2]				
5	Slope trimming	82	85	-	-	-

No.	Type of construction machinery	Russian measurements [1-8]		Italian measurements [13]		
		Equivalent sound level, dBA	**Maximum sound level, dBA**	**Mean measured sound power level (dBA)**	**Dimension of the machine sample**	**Mean Sound pressure level (r = 7.5 m)**
	machine	r_0= 7,5 м [2]				
6	Pneumatic roller (11 t)	65	70	-	-	-
		r_0= 7,5 м [1]				
7	Vibration roller	70	75	104,3	764	78,8
		r_0= 7,5 м [1]				
8	Asphalt spreader	77	78	-	-	-
		r_0= 7,5 м [2]				
9	Compressor (capacity 5 m^3/min)	80	82	93,8	615	68,3
		r_0= 1,0 м [1]				
10	Motor tar sprayer (7500 l)	72	78	-	-	-
		r_0= 7,5 м [3]				
11	Road milling cutter	64,3	74,5	108,4	31	82,8
		r_0=30 м [4]				
12	Conveying and spraying machines for concrete	-		101,4	117	75,9
13	Rail laying machine	63	78	-	-	-
		r_0=25 [1, 5]				
		69	72			
		r_0=7,5 [1, 5]				
		total level				
		65,2	78			
		r_0=25				
14	Track welding machine	63	78	-	-	-
		r_0=25 [5, 2]				
		73	74			
		r_0=7,5 [5, 2]				
		total level				
		67,2	78			
		r_0=25				
15	Rail welding train	63	78	-	-	-
		r_0=25 [5, 2]				
		73	74			
		r_0=7,5 [5, 2]				
		total level				
		67,2	78			
		r_0=25				
16	Electric ballasting machine	63	78	-	-	-
		r_0=25 [5]				
17	Lining-tamping-straightening machine	63	78	-	-	-
		r_0=25 [5, 1]				

No.	Type of construction machinery	Russian measurements [1-8]		Italian measurements [13]		
		Equivalent sound level, dBA	**Maximum sound level, dBA**	**Mean measured sound power level (dBA)**	**Dimension of the machine sample**	**Mean Sound pressure level (r = 7.5 m)**
		62	68			
		r_0=7,5 [5, 1]				
		total level				
		63,5	78			
		r_0=25				
18	Track crane	74	78	102,2	210	76,7
		r_0= 7,5 м [6]				
19	Railway crane	74	78	-	-	-
		r_0= 7,5 м [6]				
20	Pile driving rig (Piling equipment)	87	91	128,1	15	102,6
		r_0= 7,5 м [2]				
21	Drilling rig	66	68	107,7	202	82,2
		r_0= 30 м [7]				
22	Drop-side truck (weight carrying capacity 15 t)	74	77	-	-	-
		r_0= 7,5 м [8]				
23	Truck mixer	76	78	104,8	96	79,3
		r_0= 7,5 м [2]				
24	Dump truck (Dumper)	63	68	105,2	295	79,7
		r_0= 7,5 м [1]				
25	Concrete paver (Paver-finiscers)	77	78	104,9	79	79,4
		r_0= 7,5 м [2]				
26	Sleeper tamping machine	77	80	-	-	-
		r_0= 7,5 м [2]				
27	Shunting locomotives	63	78	-	-	-
		r_0= 25 м [5]				
28	High pressure flushers vehicles (Flusher truck)	72	78	98	17	72,5
		r_0= 7,5 м [3]				
29	Slab laying machines	77	78	-	-	-
		r_0= 7,5 м [2]				
30	Hopper-batcher	69	72	-	-	-
		r_0= 7,5 м [1, 5]				
		63	78			
		r_0= 25 м [1, 5]				
		total level				
		65	78			
		r_0= 25 м				

The construction of extended objects is done by divisions.

To evaluate noise during railway construction, it is proposed to allocate plots of lands having an extension of about 3 km, where all construction machinery and equipment involved in the works in different technological units alternately execute the work.

2. Calculation method for determination of the acoustic discomfort zone

2.1. Calculation of the maximum sound level

In Russia the determination of the sound levels in reference points is performed in accordance with Construction rules and regulations (SNiP) 23-03-2003 'Noise Protection' [10], SP 51.13330-2011 'Noise protection. Updated edition of SNiP 23-03-2003' [11].

Sound pressure level at a distance r from a line source of intermittent noise is defined according to the commonly known formula:

$$L = L_A - 15\lg\frac{r}{r_0} - \frac{\beta_a \cdot r}{1000} + 10\lg n \text{, dBA} \quad (1)$$

where L_A is the sound pressure level from the passage of a single piece of equipment, dBA (according to the reference data, measurement protocols of noise level from working equipment at construction site - Table 1), dBA;

r - is the distance from the noise source to the calculation point, m;

β_a - is the sound attenuation in the atmosphere, dB/km (accepted parameter value for a frequency of 1000 Hz in the calculations of sound levels is 6 dB);

r_0 - is the reference distance from the noise source to the noise measurement point, m;

n - is the number of noise sources operating simultaneously within the estimated time, pieces.

To determine the sound level from a point source of intermittent noise the parameter $15\lg\frac{r}{r_0}$ in formula (1) is replaced by $20\lg\frac{r}{r_0}$.

Total sound pressure level in the calculation point from all noise sources is determined by the energy summation of the i-th noise source sound pressure levels calculated according to formula (1).

The sound level in the room is determined by the sound insulation of the standard window fill and is assumed to be 15 dBA (ΔL_{window}=10 dB according to Table 31 of the SNiP II-12-77 [9] and formula 17 of the SNiP 23-03-2003 [10]).

Additionally, green zones $\Delta L_{A\,green}$ are considered when determining the sound levels in calculation points taking into account their reduction with distance, which is important when railways go through the green areas. According to [9], the sound level reduction by dense strips of greenery with the width of over 100 m is equal to 8 dB.

2.2. Calculation of the equivalent sound pressure level

The equivalent sound pressure level of the intermittent noise source is determined by the commonly known formula according to SNiP 23-03-2003 [10], SP 51.13330-2011[11]:

$$L_{экв} = 10 \times \lg\left(\frac{1}{T} \times \sum \tau_j 10^{0,1 \times L_j}\right) \quad (2)$$

where: $L_{экв}$ is the equivalent sound level, dBA;

T is the total time of noise exposure, T=960 min (for day time period – 16 hours);

τ_j is the exposure time during the considered period, min;

L_j is the exposure level over the time T, dBA.

The calculation of equivalent sound levels in reference points, taking into account attenuation of sound on the ground, is carried out according to the formulas similar to the formulas to determine the maximum sound levels presented in section 2.1.

2.3. Determination of the acoustic discomfort zone

The acoustic discomfort zone is determined separately for maximum and equivalent sound levels based on the noise performance of equipment and machinery (Table 1), their operation time and mode, the number of construction and road machinery units working concurrently on the division or construction site and sanitary standards effective on the territory of the state.

In Russia the permissible noise levels are regulated by the Sanitary norms' SN 2.2.4/2.1.8.562-96 'Noise at workplaces, in residential and public buildings and residential areas'[12]. . Thus, on the territories adjacent to houses equivalent sound levels shall not exceed 55 dBA, maximum sound level is 70 dBA in the daytime (from 7.00 to 23.00), in the night time (from 23.00 to 7.00) they are 45 and 60 dB respectively [Table 3, 12]. In the living rooms of the apartments the equivalent and maximum sound levels should not exceed 40 and 55 dBA respectively in the daytime and 30 and 45 dB in the night time.

For calculations according to the formulas presented in sections 2.1-2.2 with the initial noise performance of the machinery described in Table. 1, in subgrade construction depending on the technological unit, the sanitary break area for residential areas varies from 50 to 95 m, subject to a 'discharged' mode, when building machines with high noise performance do not work at the same time. For the equivalent sound level area of the sanitary gap will be 115-250 m for different technological units.

In case of the ballastless track bed construction with the same conditions, the sanitary gap zone in regards to the maximum sound level is 50 to 110 m, and in case of the ballast track bed construction it is from 50 to 125 m. In regards to the equivalent sound level, the sanitary gap zone is determined in the range of 220-250 m.

The sanitary gap zone in regards to the maximum sound level can be reduced by introducing an equivalent machinery operation schedule by limiting continuous operation time and its proportional allocation throughout the working day. Thus, for most technological units in the subgrade and track bed construction, the zone of acoustic discomfort in regards to the equivalent sound level will be about 250 m. It should be noted that the size of the sanitary zone of the gap determines the distance at which regulatory sound levels are achieved for areas immediately adjacent to residential buildings. In case if not residential buildings are regulated, but objects with stricter requirements in terms of the sanitary norms (e.g. hospitals, health resorts, recreation areas, children's camps, etc.) the sanitary gap zone can reach 730 m (to ensure standards of 45 dBA) and more. Of course, in this case, in conditions of constrained residential development, it is required to develop quality and highly effective noise mitigation measures.

It is also necessary to take into consideration that all the above mentioned sizes of the sanitary gap zones are determined for the daytime, provided that construction operations at night are prohibited (from 23.00 to 7.00). At the same time, a number of operations on the construction site are carried out around the clock. For example, any construction site and construction camp require round-the-clock electricity supply for lighting of construction sites, security, etc. In case of absence of technical possibility of connection to regular networks, mobile diesel-generator sets operating around the clock are installed. Assessment of their noise impact depending on their power and quantity should be made not only for the daytime, but for the night time as well. The results of calculations of the sanitary gap zone from the diesel-generator power station at night should also be considered when determining the final sanitary gap zone from the construction site in general.

Moreover, individual calculations for each area should also account for background noise levels in specific areas.

After determining the size of the sanitary gap zone and the list of regulated objects, it is necessary to define the required reduction of the equivalent and maximum sound levels in calculation points based on condition that total noise levels exceed maximum permissible levels.

3. Noise mitigation measures in railway construction in the Russian experience

During the construction operations on railway tracks the following measures can be applied as noise mitigation measures depending on the desired reduction:

– Installation of mobile noise barriers (performed during the construction site preparation);

– Installation of soundproof glazing (performed during the construction site preparation);

– Using construction equipment with minimum noise performance;

– Performing construction operations producing a high level of noise only in the period from 9.00 to 18.00, when most residents are at their workplaces;

– Banning work at night (from 23.00 till 7.00), at weekends and on holidays;

– Acoustically justified arrangement of machinery on a construction site at the largest possible distance from the residential buildings and maximum use of natural barriers, dispersal of construction equipment;

– Using diesel generator sets of sound insulating bonneted design;

– Performing construction work according to the schedule of the construction equipment operation;

– Preventive maintenance of the machinery;

– Improving the quality of access and internal roads;

– Speed limit for construction equipment and vehicles at the construction site;

– Limiting the time of construction equipment operation;

– Parking of construction equipment only with the shutdown engine.

4. Noise mitigation measures in railway maintenance in the Italian experience

In this paragraph some methods and procedures for noise control of railways maintenance sites are shown, with particular regard to the Guidelines drafted by RFI [14], the Italian National Railways Company in 2007, providing to acousticians and administration an assessment tool that can be flexibly applied to most of the acoustic scenarios representing the ordinary and extraordinary maintenance of the railway lines.

In the drawing of the Guidelines [14] that involved RFI and Vie en.ro.se. Ingegneria, a procedure was defined to evaluate the contribution of environmental noise produced by maintenance activities of railway lines in a simple and rapid way. Using this method, it is easy to determine the level of overrun of established limits and the maximum allowed time of annoying activities.

The onsite activities for the maintenance of railway lines determine an acoustic impact of particular complexity in all areas including residential and sensitive (school, hospitals) buildings. They are carried out mainly in the night time period and are characterized by the use of particularly noisy equipment and machineries.

The Guidelines have been conceived for assisting maintenance companies and their acoustic consultants in the assessment of the acoustic impact of their activities and for the preparation and management of related authorization requests as provided by Italian Framework law on noise pollution [15] and other specific decrees for Railway Noise. Scenarios has been considered as point sources moving along the railway line and, consequently, models of rail noise propagation from construction area to annoyed receivers have been derived by the ISO 9613-2 algorithms [16].

In synthesis the proposed methodology addresses systematically the theme of noise produced by railway maintenance sites: starting from a series of emission scenarios, analyzed separately, including the most important site activities, it comes to the definition of produced and propagated noise values adaptable to the most diverse input scenarios and therefore usable in a wide variety of application contexts.

The procedure is articulated in four steps:

1) **Sources:** acoustic characterization of the machinery and emission scenarios;
2) **Models in free field:** modeling of single sources and emission scenarios in free field;
3) **Models in Standard scenarios:** adaptation to input scenarios;
4) **Documentation:** preparation of documents for authorizations, derogations, protocols.

Initially, 10 standard emission scenarios, representing 10 possible types of machining carried out in railway maintenance sites, and the sources that are part of it, are considered. In the method each source can be considered either individually or as part of a system characterized by precise specifications in terms of usage and contemporaneity of the working noisy elements that are part of it.

Data on the quantitative and qualitative characteristics of acoustic emissions are collected or measured for each machine subject to study, using as far as possible, existing databases. The sound power values to be associated with each source and each type of scenario are determined and source emission data sheets (single or complex machinery scenarios) are defined, reporting free field emission sonograms, time-of-use and contemporaneity defined as standard. Of course, in applying the datasheets data it is necessary to verify the consistency of the real timing compared with the standard timings. If such compatibility is not verified, corrective factors can be applied according to an adaptation algorithm that is attached to the Guidelines [14].

So it is possible to determine the impact in facade of all the receivers building present in the scenario. Where limits are not respected, the authorization request must be made in derogation of such limits.

However, a number of possible mitigation measures should be foreseen and attached to the description in the technical documentation attached to the request.

CALCOLO DELLA POTENZA SONORA EMESSA								
DENOMINAZIONE DEL MACCHINARIO CAMPIONE:	FORATRICE ROTAIE (GX30 HONDA) GEA							
TIPO DI LAVORAZIONE:	FORATURA ROTAIA							
TIPOLOGIA DELLA SORGENTE:	PUNTIFORME							
POTENZA SONORA								
COMPOSIZIONE IN FREQUENZA [dB]								GLOBALE [dB(A)]
63	125	250	500	1000	2000	4000	8000	103,8
88,8	96,2	92,9	96,8	96,3	98,4	97,7	90,7	
CURVE ISOFONICHE DI EMISSIONE								

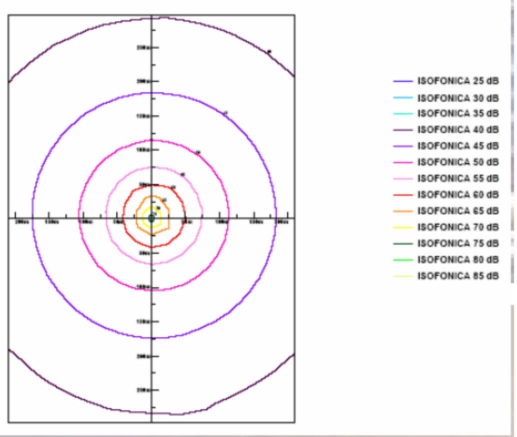

Fig. 1. Track railing drill sound power datasheet and map of equal sound pressure curves calculated in free field conditions

In a special attachment to the Guidelines [14] the main mitigation works that can be included in the noise propagation scenarios are described, they can act to reduce the emission level at the source or to interrupt the propagation paths towards the receptors. Interventions like mobile barriers, are estimated considering versatility of installation, resistance to weather, possibility of washing, and especially adaptability to multiple and complex source configurations. The interposition along the main propagation paths of these shielding barriers will ensure at the moment of the source activity the general reduction of noise from the site.

In addition to the technical measures, indications for behavioral, organizational and procedural measures related to the acoustic optimization of the site's chronogram and the optimization of the most impacting or relatively significant single contributions in complex scenarios.

Through the modeling of the yard and the surrounding areas with an appropriate simulation software, adapting the standard propagation method [16] with the characteristic elements of the maintenance activities, the real in-field scenarios are reproduced. The need to report the full assessment for the whole day or whole night reference time periods makes necessary to consider not only the emissions of every single noisy device in absolute terms but also how and how long the use of each machine in the succession of machining will last. It is therefore necessary to accurately define the timing of the various operations for each different work phase, in a specific acoustic chronoprogram of the works.

Fig. 2. Railroad switch demolition and rebuilding activity in a real in-field scenario

In Table 2 an example of a chronoprogram referred to the maintenance activity is shown.

Table 2 – Chronoprogram of railroad switch demolition and rebuilding activity in a real scenario

Machinery model	Emission Coding	Number of machinery	WORKING HOURS				Usage factor in the noisiest half hour (%)
			1	2	3	4	
Loader	**SC - M05**	**2/1**					50
Drilling	**SC - M10**	**2**					5
Wicker	**SC - M12**	**2**					5
Manual wrench	**SC - M13**	**1**					5
Generator set	**SC - M19**	**2**					100
Rail cutter	**SC - M21**	**2**					5
Mechanical machine	**SC - M22 A**	**1**					80
Heating machine	**SC - M22 B**	**1**					20
Binda	**SC - M23**	**4**					100
Crawler excavators	**SC - M25**	**1**					100

Finally, it is possible to generate sound maps relating to noise introduced into the environment from each activity, represented by its standard emission scenario, on the in-field real scenario in the considered reference time period, considering the different noise sources. As for all other complex sources there is no universal scheme for effective noise control and each type of machine requires its own approach to noise reduction [17], but the proposed method consider and optimize the efficiency of yard measures like barriers, starting from the emission noise maps of the complex scenarios associated at repetitive maintenance activities. These maps allow the user (railway company or its sub contractor responsible of maintenance) to locate a system of 3d acoustic curves in the territory around the construction site which can be used to define a safety offset range, based on noise limits that cannot be exceeded. Therefore, through this simple and reliable procedure it is possible to determine the quantity and quality of the noise levels, higher than the limits, to which impacted receptors are subjected and, consequently, to provide the site with appropriate mitigations and/or to define the request of a derogation to the competent local administration, based on noise limits that are appropriated for both the noise produced, by the specific works in their specific working times respectively, and the respect of the rights (in terms of health and quiet) of citizens living around [18]. An example of this map is shown in Fig. 3.

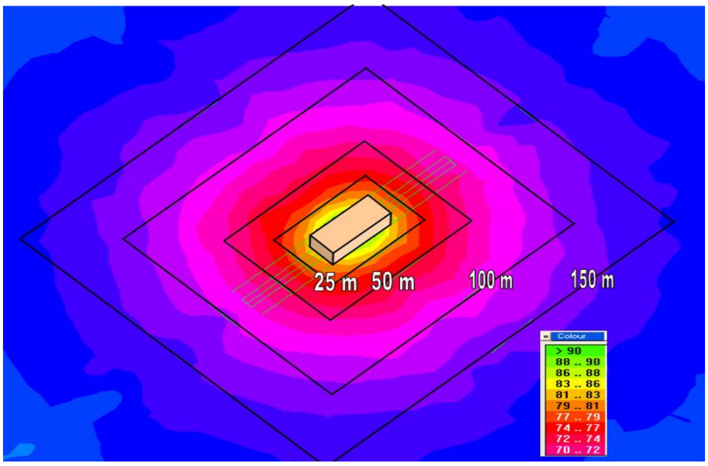

Fig. 3. Map of railroad switch demolition and rebuilding activity

The map is referred to a height of 5-meter-over ground plan and to the repetitive activity of railroad switch demolition and rebuilding: it can be seen that a range of bands spaced at different distance intervals (25, 50, 100 and 150 m) are shown on the map, representing the variations in sound pressure when the distance changes.

Conclusions

Construction sites can be considered as critical areas referring to the noise pollution; they indeed can be very close to urban environments and involve many noisy sources. The intensive development of these transport infrastructures worldwide makes extremely important to assure acoustic safety to the population living in the adjacent areas. Construction machinery and activities, according to noise performances given in the article, obtained in Russia and Italy in particular, are sources of high sound levels requiring the implementation of effective noise mitigation measures both technical and organizational, such as installation of noise barriers, soundproof glazing, limitation of machinery operation time, division and dispersal of the noisy processes. However, there are no common approaches to regulate the noise impact generated by railways construction sites. Therefore, the implementation of the noise mitigation measures specified at the 'project' stage is often neglected and very high noise levels and annoyance are often observed in the adjacent residential areas, resulting in an increasing number of complaints received by the city administrations. To solve these problems it is recommended to develop universal methods and algorithms to face the problem and define the mitigation actions that are needed to assure safe conditions and the respect of the given noise limits. In this perspective the cooperation among specialists from different countries, particularly from Russia and Italy, where some common input for possible joint research have been already drafted, seems very promising.

References

1. Noise survey form No. 1423 of 07.09.2010 (Federal State Healthcare Institution ‘Center of hygiene and epidemiology in St. Petersburg’, St. Petersburg)
2. Noise survey form No. 01-sh of 14.07.2006 (LLC ‘Research and development center ‘Ecology’, Saint-Petersburg)
3. Noise survey form for the noise on the construction site from the operating equipment No. 9 of 09.04.2009 (LLC ‘Institute of applied ecology and hygiene’, Saint-Petersburg)
4. Noise survey form No. 57/2005 of 03.05.2005 (JSC ‘Design and technology Institute’, Saint-Petersburg)
5. National State Standard GOST R 50951-96 ‘External noise from mainline and shunting locomotives. Regulations and methods of measurement’
6. Noise survey form for the noise on the construction site from the operating equipment No. 133/6 of 05.09.2006 (LLC ‘Eco Test’, Saint-Petersburg)
7. Noise survey form No. 123-2/2006 of 28.04.2006 (JSC ‘Design and Technology Institute’, Saint-Petersburg)
8. Noise survey form No. 147-sh of 04.10.2011 (LLC ‘Institute of acoustic designs’, Saint-Petersburg)
9. Construction rules and regulations (SNiP) 2-12-77 ‘Construction rules and regulations. Noise mitigation’
10. SNiP 23-03-2003 ‘Noise mitigation’
11. SP 51.13330-2011 ‘Noise mitigation. Updated edition of SNiP 23-03-2003’
12. SN 2.2.4/2.1.8.562-96 ‘Noise at workplaces, in residential and public buildings and residential areas’
13. M. Dittrich, E. Carletti, G. Spellerberg, Dittrich, M. (TNO), Spellerberg, G. (TÜV Nord), Carletti, E., Pedrielli, F. (IMAMOTER), ‘ODELIA - Study on the suitability of the current scope and limit values of Directive 2000/14/EC relating to the noise emission in the environment by equipment for use outdoors’, Final report. Delft, 2016, http://ec.europa.eu/DocsRoom/documents/18281/attachments/1/translations/en/renditions/native
14. A. Pezzati, M. Lincesso, S. Luzzi, B. Chirici, "Le linee guida di RFI - Impatto acustico dei cantieri ferroviari per trazione elettrica e lavori di armamento”, Ingegneria Ferroviaria n.5/08, May 2008, in Italian
15. Legge 447 del 26/10/1995 “Framework Law on noise pollution” , Ministry of the Environment http://www.minambiente.it/sites/default/files/legge_26_10_95_447.pdf , in Italian
16. ISO Standard 9613-2 Acoustics -- Attenuation of sound during propagation outdoors - Part 2: General method of calculation, 1996
17. N. Ivanov, N. Tyurina, Construction machines: noise control problem and novel approach to low-noise construction machines, Proceedings of 34° AIA National Congress, 2007.
18. S. Luzzi, L. Barbieri, R. Bellomini, ‘Methods and procedures for noise control in railway construction and maintenance sites’, Proceedings of 35° AIA National Congress, 2008., in Italian