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ANTI-NOISE BARRIERS FOR TRAMS AND TRAINS IN URBAN ENVIRONMENT.

RESULTS OF A MEASUREMENT CAMPAIGN AT ATHENS TRAM NETWORK

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Abstract

Athens Tram has performed during last years an extended Noise & Vibration Abatement Program including both airborne & ground borne noise & vibration levels calculations. The relevant N&V studies suggested the implementation of various anti noise/vibration mitigation measures. The performed calculations & modeling within this study for the design of the Tram's network suggested that in some urban areas the use of adequate noise barriers in order to achieve both improvement of the acoustic environment and aesthetic integration of the relevant construction to the urban environment. The results of the relevant theoretical & measurement's investigations revealed that the two noise barriers tested in Tram's Athens network are very promising towards an effective rehabilitation of the urban acoustic environment.

INTRODUCTION – TYPE OF NOISE BARRIERS

In the framework of the Athens Tram extended Noise & Vibration Abatement & Monitoring Program[1]and towards an effective rehabilitation of the urban acoustic environment, both a medium height transparent barrier and a low height absorbing barrier were installed and tested in situ, in order to evaluate the noise attenuation that can be achieved for the protection of adjacent sensitive land uses. The tested barrier types evaluated in the measurement campaign - organized and executed within the Qcity EU program framework (Quiet City Transport)[2] - are described in detail below :

1. A reflective transparent barrier of a max. height of approx. 1,5 metres (+ 20cm protective border in the lower level) and a length of 60m, in a suitable distance (of approx. 3,0m from the external rail of the tramway) in an “inox” steel structure encasing transparent “ALTUGLAS EX SRD” sheets of 20mm width. All relevant technical specs of these transparent sheets are presented in the Annex 3 hereafter. The medium noise barrier was installed in a typical urban area of the OPERATING network at Glyfada Athens in order to evaluate the relevant noise attenuation characteristics in real commercial operation conditions at A constant sped of approx. 20 Km/h .
2. An approx 44m length, low height (approx 32 cm) absorbing noise barrier from ZBlock (Sweden), in a min. distance of approx. 7cm from the Tram “gabarit” (according to Athens Tram relevant dimensioning in platform areas) This prototype low absorbing barrier was installed in Athens Tram Depot in order to evaluate the relevant insertion loss at various speed conditions (from 10 up to 40 Km/h). The same vehicle (no 10015) was used during all measurements.

MEASUREMENTS SETUP

For both sites / barrier types two distinct measurement setups were executed involving measurements “WITH” & “WITHOUT” the barrier according to the EN ISO 3095:2005(E) and the provisions of the recent 2002/49/CE directive introducing a height for noise recording purposes of H = 4 m (+/- 0.2). The measured campaign was designed especially to obtain reproducible and comparable measurement results of levels and spectra of noise emitted by tramway vehicles operating on rails or fixed track, in Athens Tram network. For the present campaign a frequency analysis was also executed, made at least in one third octave bands according to EN ISO 266: at least from 31,5 Hz to 8 kHz. ensuring that the lower frequency limit is chosen to ensure that the product of the lowest bandwidth and signal duration exceeds unity. For this campaign a frequency range from 20 Hz to 20 KHz was introduced.

The instrumentation system, including the microphones, cables and recording devices was in accordance with the requirements for a type 1 instrument specified in EN 61672-1. Both Harmonie & Symphonie Noise recording instrumentation (01dB – France) were used ensuring two sets of 4 synchronized micros & 2 synchronized micros (for add. Locations in Tram depot site all with suitable windscreens. The microphones had an essentially flat frequency response in a free sound field. The 1/3 octave band filters met the requirements of class 1 according to EN 61260. Before and after each series of measurements a sound calibrator meeting the requirements of class 1 according to EN 60942 was applied to the microphone(s) for verifying the calibration of the entire measuring system. The compliance of the instrumentation system with the requirements of EN 61672-1 and EN 61672-2 was recently verified

The necessary conditions were ensured for each test site very closely to the standard with some slight deviations from the standard test conditions for type tests especially regarding the impossibility of ensuring the distance of 25m for the case of the Medium transparent barrier site (due to dense urban development) fact that obliged us to introduced a distance of 15m instead. Furthermore a microphone height of 4m was also introduced on both sites according to 2002/49/CE directive. In the case of the low height barrier test site add. Micro locations were introduced in order to evaluate more aspects of the screening and diffusion effect. Both the test sites ensures free sound propagation with a ground essentially flat (with a max level variation from 0 m to -0,20 m, relative to the top of rail).

The Athens Tram vehicles measured in both sites was in its normal operating conditions and especially for the test site of the medium transparent barrier (constant speed of 20 Km/h condition), and all vehicle's wheels have already run in normal conditions at least 1 000 km on track with normal traffic. During all measurements, the doors and windows of the vehicle were kept closed, and all auxiliary equipment on the test vehicles that normally operates during the run was in action. Both relevant microphone setups are presented in tables 1 & 2 below (for the two distinct barriers sites respectively).

Table 1- Medium height reflective transparent barrier

MICROPHONE LOCATION 4 channel HARMONIE system	Hor. Dist.	Height	Description
Ch. 1	1,0	1,2	Reference point (Hor. Distance from external rail)
Ch. 2	7,5	1,2	ISO 3095/2005
Ch. 3	15,0	1,2	Closest building line
Ch. 4	15,0	4,0	2002/49/EU

Figure 1 : Medium Height Transparent Reflective Noise Barrier test site

Table 2- low height absorbing barrier

MICROPHONE LOCATION 4 channel HARMONIE system	Hor. Dist.	Height	Description
Ch. 1 (H1)	**3,75**	**0,6**	Reference point
Ch. 2 (H2)	**7,50**	**1,2**	ISO 3095/2005
Ch. 3 (H3)	**10,00**	**1,2**	NORDIC Prediction Model
Ch. 4 (H4)	**10,00**	**4,0**	2002/49/EU

MICROPHONE LOCATION 2 channel SYMPHONIE system	Hor. Dist.	Height	Description
Ch. 1 (S1)	**1,0**	**1,2**	Reference point (Hor. Distance from external rail)
Ch. 2 (S2)	**25,0**	**1,2**	ISO 3095/2005

"without barrier"

"with barrier"

Figure 2 : General view of the low height absorbing Barrier test site at Athens Tram Depot for both "with"& "without barrier" setups

RESULTS

- Transparent Barrier Test Site at Diadohou Pavlou Str. - Glyfada Greece

A total of 8 independent tram pass byes were recorded and analyzed in these test site according to the setup described above at a constant speed of 20 Km/h. The main results for both descriptors Leq (tram passage) and Lmax are presented in the Table 3 and the relevant graphs in figures 3 & 4. In order to evaluate the noise attenuation in various measurement locations, separate calculations were made in both tests and the relevant attenuation was established for channels 2 & 3 @ 7,5 & 15,0 m distances and 1,20 m relevant height, from the reference point (Ch1) placed in a distance of 1,0m from the external rail (between the track and the barrier alignment). The results in dB(A) are presented hereafter in Table 3.

Table 3- Medium height reflective transparent barrier

Simultaneous recordings		Average Leq	Average Lmax	Stdev Leq	Stdev Lmax
Ch.1 @ 1,0m	*"without" barrier*	74,8	84,3	4,1	3,1
Ch.2 @ 7,5m		68,8	77,1	4,1	3,3
Ch.3 @15,0m		67,6	73,7	3,6	2,7
Ch.4 @ 15,0m		65,8	71,8	3,5	2,7
diff.	@ 7,5 m without barrier	**6,0**	**7,2**	**0,4**	**1,3**
	@ 15 m without barrier	**7,1**	**10,6**	**0,7**	**1,6**

Simultaneous recordings		Average Leq	Average Lmax	Stdev Leq	Stdev Lmax
Ch.1 @ 1,0m	*"with" barrier*	78,3	86,9	3,1	2,8
Ch.2 @ 7,5m		62,2	68,4	2,7	2,6
Ch.3 @15,0m		61,2	66,9	2,3	2,2
Ch.4 @ 15,0m		61,9	66,7	2,0	2,2
diff.	@ 7,5 m with barrier	**16,1**	**18,5**	**0,7**	**1,6**
	@ 15 m with barrier	**17,1**	**20,1**	**0,9**	**1,3**

COMPARISON of "with" barrier vs "without" barrier tests	Average Leq	Average Lmax		Stdev Leq	Stdev Lmax
Insertion loss @ 7,5 m & @ 15 m with noise barrier	**10,2**	**11,4**	±	**0,4**	**0,3**
	9,9	**9,4**	±	**0,2**	**-0,3**

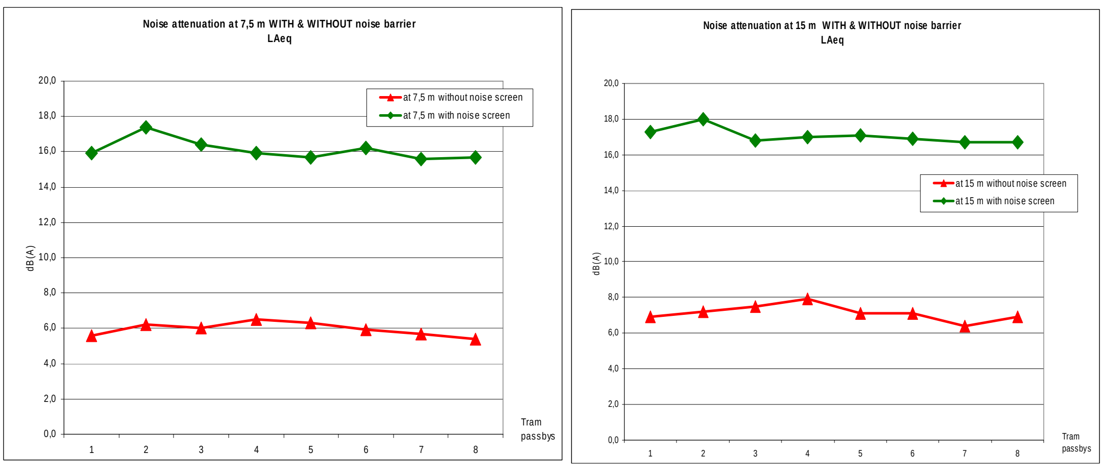
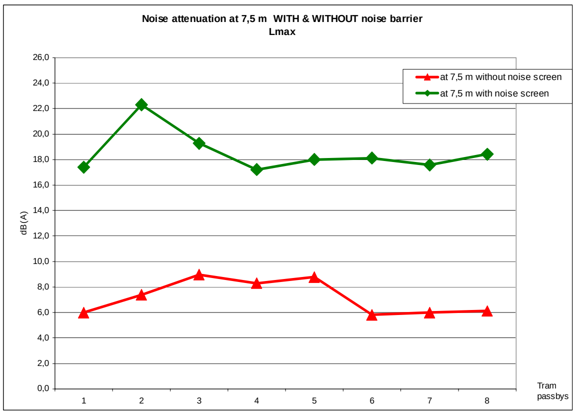


Figure 3 - LAeq index attenuation at 7,5 m & 15,0m WITH & WITHOUT noise barrier



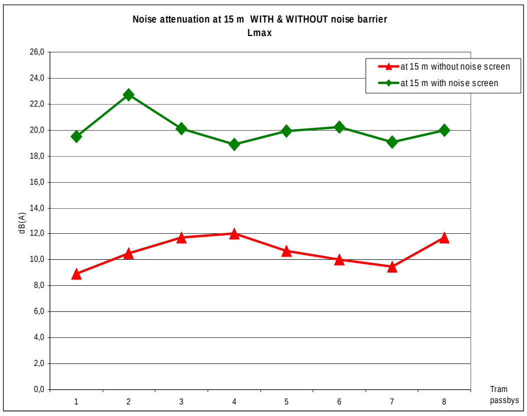


Figure 4 - LAmax index attenuation at 7,5 m & 15,0m WITH & WITHOUT noise barrier

- Low height absorbing barrier test Site at Athens Tram Depot - Hellinikon Greece

A total of 2X12=24 tram pass byes of the same vehicle (10015) were recorded and analyzed in this test site according to the setup described above for various speeds i.e 10,20,30 & 37 to 40 Km/h (3 pass bys per speed and per test). The results for both descriptors Leq (tram passage) and Lmax are presented in the Tables 4 & 5 and relevant graphs in figure 5 hereafter. The differences of average Lmax values between all points vs the reference point S1 were calculated for each speed level and for both “with” & “without barrier” tests. By this approach and given to the fact that reference point S1 reflects for both tests the source emission with no distance interference, the results of table 4 reflects the noise attenuation at all measurement locations including both source absorption/screening effect and distance attenuation. By abstracting the attenuation values of “with barrier” test from the relative values of the “without barrier” test, the insertion loss of the barrier it self is then calculated. This approach has the advantage of normalizing the source strength of the tram (see relevant negative point in approach 1 above) to account for effects from deviations in speed etc., but has also the possible drawback of underestimating the insertion loss (IL) of the barrier due to duct attenuation effects.

Table 4 - Average Lmax attenuation for low height absorbing barrier per measurement point vs reference point S1 for both “Without” & “With Barrier” tests including distance effect

Attenuation from S1 reference point to all measurement points	Vehicle Speed (Km/h) for “Without” – “With” barrier” tests							
	10 Km/h Without barrier	**20 Km/h Without barrier**	**30 Km/h Without barrier**	**37-40 Km/h Without barrier**	**10 Km/h With barrier**	**20 Km/h With barrier**	**30 Km/h With barrier**	**37-40 Km/h With barrier**
S1-H1	4,5	0,5	3,6	2,6	11,7	13,0	10,1	9,3
S1-H2	9,0	6,6	9,3	8,0	16,4	17,2	12,3	14,0
S1-H3	12,1	8,7	10,4	10,5	18,8	18,1	15,3	15,1
S1-H4	13,2	10,7	12,3	11,8	17,9	18,9	15,4	17,3
S1-S2	17,1	14,4	16,2	15,2	22,0	22,8	16,6	19,3

Table 5 - Lmax index average insertion loss for low height absorbing barrier per measurement point for "Without" & "With Barrier" tests

Measurement point	Vehicle Speed (Km/h)				Averages & st.deviation for all speeds	
	10 Km/h	20 Km/h	30 Km/h	37-40 Km/h		
H1 (d=3,75 H=0,6)	7,2	12,5	6,5	6,6	**8,2**	2,9
H2 (d=7,5 H=1,2)	7,4	10,6	3,0	6,1	**6,8**	3,2
H3 (d=10 H=1,2)	6,7	9,3	4,9	4,6	**6,4**	2,2
H4 (d=10 H=4,0)	4,6	8,2	3,0	5,5	**5,3**	2,2
S2 (d=25 H=1,2)	4,9	8,4	0,5	4,1	**4,5**	3,3
Average H2/H3/H4 points/all speeds					**6,2**	**2,5**

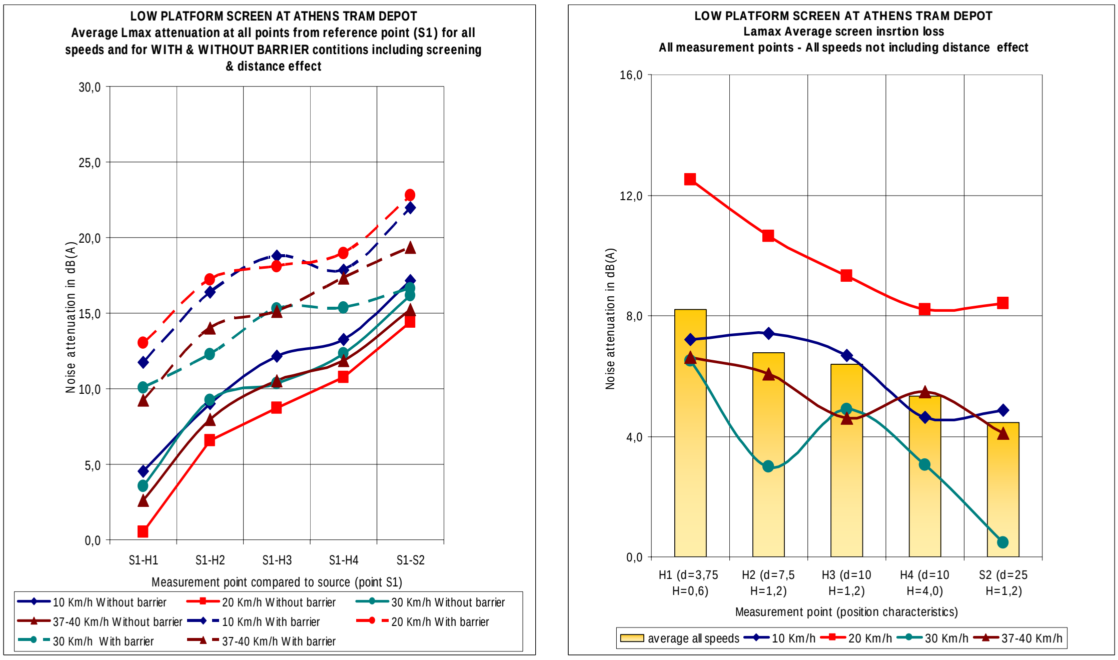


Figure 5 - LAmax results for the low height absorbing barrier at Athens Tram Depot

CONCLUSIONS

Based on the above results, the following remarks & conclusions regarding the achieved noise attenuation that can be achieved from Low & Medium height barriers for trams and trains are concluded :

1. The Medium Height Transparent Reflective noise barrier in an "inox" steel structure encasing transparent ALTUGLAS EX SRD sheets of 20mm width is a highly aesthetic mitigation measure that can be easily incorporated in the urban tissue and can ensure an average insertion loss of approx 9 - 10 dB(A) ± 0,3 dB(A) both for Leq & Lmax indices taking

in to account possible minor back reflection effects. It is clear that the reflective barrier needs to be placed in a considerable distance (approx. 2 or 3m from the external rail of the network) in order to eliminate undesirable reflection effects in the noise source therefore its use is reduced by space limitations if any

2. The Low Height Absorbing noise barrier (at platform level) can ensure also an important insertion loss both on noise source & screening effect due to his absorbing capabilities. It was establish that an average insertion loss up to 6.2 ± 2,5 dB(A) for a speed range from 10 up to 40 Km/h is ensured by the use of this type of low absorbing barrier. However the tested prototype needs to be upgraded on the aesthetical level in order to facilitate the integration in the urban context and not creating adverse population reactions. Furthermore as per the medium height transparent barrier above their implementation will block passage through the track corridor therefore their use needs to be incorporated in the global urban design of the selected site

REFERENCES

[1] C. Vogiatzis & N.Eliou, *Research Program "Athens Tram's Noise & vibration Monitoring Program from train operation*, (University of Thessaly, Faculty of Civil Engineers, February 2006)

[2] "Quiet City Transport (Akronym : QCITY)" - EU Project FP6-516420, Contract No TIP4-CT-2005-516420, 2005