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Development, calibration and validation of a model for the acoustic field generated by a ship in port

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ABSTRACT: The rising concern for environmental pollution effects calls for investigations into the impact of industrial and commercial activities on citizens living and working in the proximity of water cities where ports and ships with their dimensions are a matter of particular concern. In fact, the operation of ships in large ports generates a significant impact on air quality and noise levels of surrounding areas.

Focusing on acoustic issues, the present paper reports a model based on the Ray Tracing technique built and calibrated in order to obtain a tool capable of predicting the acoustic field generated by the operations of the ships. The final aim is to obtain a tool able to investigate continuously the acoustic impact of ships operation in any point around the harbor and the effect of possible countermeasures against noise generation and/or propagation in the area.

1 INTRODUCTION

The World Health Organization has pointed out that, contrary to other environmental stressors, noise exposure is increasing in Europe (WHO 1999, 2009, 2011). As a result, campaigns and studies have been directed towards the analysis and control of main noise sources. However, few research activities have been carried out on environmental noise exposure due to port activities.

During recent years, noise emissions have actually become a key issue for sea ports. On one hand, the raising concern about the effects of noise on health prompted a higher expectation about the ability of rules and regulations of maintaining low noise levels in inhabited zones. On the other hand, the international trend of exploiting waterfront areas in the neighborhoods of harbors has implied a further increase of population in areas that were already densely inhabited since historical times, thus stressing even more the potential impact of port activities. Despite the fact that, so far, no specific requirements have been issued for ports (at the moment included in the broader class of 'industrial plants'), the question of the acoustical impact is going to pose technical, juridical and financial challenges to Port Authorities, also in relation to the concerns brought forward by other Authorities from neighboring areas.

As known, that in a port environment several noise sources may be active, whose presence and significance may vary depending on the type of traffic in the port. Ships are the most significant noise source in ports and possibly those creating the largest impact (Badino et al. 2011, 2012).

The features of ships as noise sources are peculiar and make a proper characterisation quite problematic. Ships, while berthed, run powerful auxiliary engines producing the electric power they need. The noise generated by these engines presents strong components at low-frequencies, making it quite annoying. Low-frequency noise propagates with long wavelength: a proper attenuation requires big, space-consuming silencers onboard the ship and standard countermeasures placed in buildings ashore, like noise walls, soundproof windows and similar are insufficient to mitigate it.

Engines are not the only noise contributors on a ship. For example, in RoPax ships, the ventilation systems of car decks, including fans and compressors, are at least as important noise source as the engines themselves (Viscardi et al. 2017). Air conditioning systems for cabins and ventilation plants for other technical spaces on board (engine, pump rooms and garages, f.i.) are also contributors, as well as cargo handling equipment (grabs, conveyors, ramps for vehicles, etc.). All these noise sources are located in different positions on board, making the ship quite a complex noise source, see e.g. (Badino et al. 2011, 2012), with different emissions while sailing and maneuvering or while berthed: see e.g. (Borelli et al. 2015, 2015b, Viscardi et al. 2017).

Airborne noise emissions at source from seagoing ships are not regulated internationally (Badino 2012b). On the contrary, the International Maritime Organization (IMO) covered since 1981 and more recently revised the requirements about noise levels internal to ships, seen as a threat to occupational health for workers on board, (IMO 1981, 2012).

IMO issued recently, too, recommendations about the limitation of noise emitted into water to protect the marine fauna (IMO 2014).

On the other hand, noise measurements and assessment of the noise situation at the port border are nowadays a compulsory part of the environmental impact assessments of ports (Di Bella and Remigi 2013). In a sense, it could be stated that the noise field within ports falls in a 'grey zone' not very well studied nor regulated. However, such field needs to be investigated also in view of a proper quantification of its effects on the surrounding areas (even if the subject of how to evaluate this impact may also be a matter of discussions, see (Di Bella 2014), (Di Bella et al. 2016).

The paper focuses on acoustic pollution originating from an area of the port of Naples and affecting the surrounding portion of the town. This investigation is a part of a wider impact analysis being carried out by the University of Naples on the port of Naples, taking into account also the effects of chemical pollution in the surrounding area (Battistelli et al. 2011). The paper presents a theoretical/experimental activity carried out in a specific area of the port of Naples and aimed at obtaining a tool able to predict the acoustic impact of the operation of ships in any position around the harbor (a similar investigation for a different case was carried out f.i. in (Badino et al. 2016).

2 AREA OF INVESTIGATION

The port of Naples (Figure 1), featuring an annual traffic capacity of around 25 million tons of cargo, is one of the largest in Italy and in the Mediterranean Sea. The port employs more than 4,800 people providing services to more than 64,000 ships per year. The port is divided into two main areas, distinct for type of traffic and geographical location.

Figure 1. Port of Naples; red circle shows the zone of tests on acoustic impact.

The west end, closer to downtown, is dedicated to passenger traffic and features three sub-areas:

- Molo Beverello, with hydrofoil service connecting the town to the three main islands in the Gulf. Every day hundreds people, (tourists and commuters) embark from this pier;
- Molo Angioino, pier for cruise ships. A large passenger terminal was recently built on it;
- Calata Porta di Massa and Calata Piliero, two more piers used for long range ferry boats.

The east area (much wider) is dedicated to cargo vessels, equipped with several basins and facilities for handling and storage of liquid and dry goods and containers.

The present investigation is focused on different locations of the west end. Notwithstanding the relative wide variety of passenger ships present in this part of the port, the absence of other sources of industrial type or dedicated to cargo handling allow to focus in particular on ship sources.

3 EXPERIMENTAL CAMPAIGN

In order to develop a tool capable to predict the acoustic impact of the incoming ships in the Port of Naples, surveys of the noise actually emitted by ships have been carried out in the area of the Port shown in Figure 1.

Data acquisition regarded the whole evolution of the ship, from entrance in the port area to manoeuvring, access to the mooring point and berthing. As the goal of the measurements in this context is to provide calibration and validation to the model presented later, in this section only the results related to the ship moored will be presented.

The surveyed ship moors in a site close to the Passenger Terminal ('Maritime Station') of the Port of Naples, i.e. the part of the harbour completely dedicated to passengers; in Figure 2 the positions of acoustic sensors are shown together with the mooring point of the ship (corresponding to the white vessel in the Figure).

The investigated ship is a Ro-Ro ferry boat engaged on the route to and from Palermo (Sicily). Like all ships of this type, she features a large garage for the transportation of cars, commercial and industrial self-moving vehicles. In (Borelli et al. 2015) an investigation about noise levels measured on a ship of the same type while sailing and manoeuvring is reported.

In ferries, garages are naturally ventilated during navigation, while forced ventilation is provided

Figure 2. Measuring points in the Port of Naples.

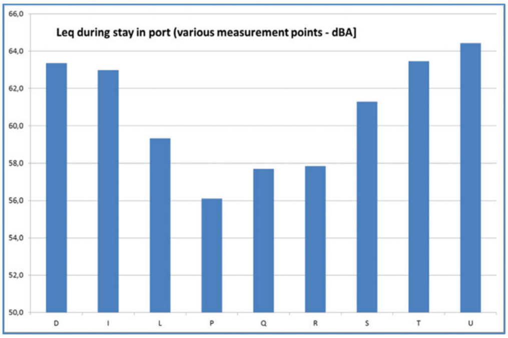

Figure 3. Eq. levels in the measurement points with fans off (Leq Equivalent Continuous Sound Pressure Level—dBA).

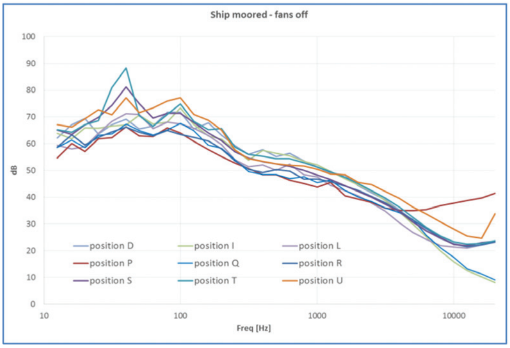

Figure 4. Comparison among spectral levels in different measurement points (fans off—dB).

in port, particularly during the loading/unloading phases (with a massive production of exhaust gas). However, data here presented are related only to time periods when the ship was berthed and fans were off.

During the period of records, no other major external sources of noise were active, and in the position of measurements background noise levels were significantly lower than the main ship source.

The following Figures show the equivalent levels (dBA) of the noise in the various measurement points (Figure 3) and the spectra (dB) of the noise in the same positions (Figure 4).

4 NUMERICAL MODEL

4.1 *Computational approach*

The phenomena related to the propagation of sound waves from a source to a receiver through a given environment are numerous and complex, and different models are available for the simulation, grouped into three main categories:

- statistical methods;
- wave-based methods;
- geometric methods.

Geometric methods are based on the study of wave propagation paths, unlike statistical method and wave-based methods. Statistical methods offer an estimation of parameters such as the sound pressure level or the reverberation time that are based on assumptions limiting the applicability field. Wave-based methods do not solve the wave equations but offer a numerical approximation based on the discretization of the environment in elements and nodes. The waves can be approximated as rays, particles, cones or pyramids without considering the wave propagation equation themselves, but considering only energy assigned (the amplitude) and environmental effects (reflection, refraction, etc..).

The geometric methods, offering an acceptable degree of accuracy for the prediction of different acoustic parameters, are widely used in the virtual acoustic applications. Among the most commonly used geometric methods, is the category of the Ray Tracing models, to which belongs the procedure used in this paper. The sound waves are modeled as rays: every time they encounter a surface are reflected, with consequent decrease of their energy as a function of the sound absorption coefficients of the surfaces. In particular, the point of the first reflection is identified by calculating the intersection of the trajectory with the plans defining the surfaces and selecting the nearest one. If this intersection belongs to a surface, it is the reflection point. After the first reflection, the particle continues according to its new trajectory until the next surface and so on. The reflection can be mirrored or widespread: in the first case, the law of geometric reflection applies, while in the second case a probabilistic distribution of reflected particles is modelled.

The absorption by the surfaces is represented in two ways:

- the energy carried by the particle is reduced of a factor 1-α at every reflection;
- α is used as a probability of absorption.

When the energy of the particle drops below a predetermined threshold or when the particle is absorbed, no contribution form this specific path is considered anymore. The result is collected by counters of surface or counters of predefined volume. When a particle passes through one of these counters, his energy and his drive-time (and possibly the direction of origin) are stored. At the end of the procedure, a histogram is built, in which for each time interval Δt, the energy of all the particles passing through the counter is shown.

The assumptions are the following:

1. validity of the hypotheses of geometric acoustics;
2. specular reflections on the surfaces;
3. the energy is quantized into a finite number of scores particles;
4. sound beams emitted by the source are propagated under the laws of geometrical acoustics and have ideally section infinitesimal and constant;
5. the sound energy divergence corresponds to the divergence of the rays;
6. the rays lose energy due to:
   - absorption of surfaces;
   - air attenuation;
7. in the receiving position the quanta of sound energy are added up.

Sources are characterized by the number of emitted rays by sound power and by direction of each of them. In particular, the power associated with each ray corresponds to the power emitted by the source and the directivity, divided by the total number of rays. Accordingly, it is necessary to generate a large number of rays and use sufficiently large receivers to provide statistically stable results. The generic ray ends when one of the following conditions is verified:

- transported power has reached a predetermined maximum value;
- the order of reflection has reached a predetermined maximum value;
- the length of the ray has reached a predetermined maximum value;
- the travel time has reached a predetermined maximum value.

In this specific application, the Olive Tree Lab-Terrain software has been used (PEMARD 2017). Among the different available computational codes, the new wave-based image-source software uses theoretically accurate 3-dimensional algorithms that agree more closely with measurements than those proposed in ISO Standards 9613-1 and 9613-2 (ISO 1993, 1996). It takes into account reflections from finite impedance surfaces and finite-sized objects, applying Fresnel zone corrections as well as diffractions of unlimited orders from edges. The new software also calculates constructive and destructive interferences that are not possible with simpler algorithms as those included in the ISO Standard 9613-2 (ISO 1996). Full-wave solutions (such as Greens Function-Parabolic Equation), which can also calculate wavelength effects, are usually too computation-intensive for design. The new software is computationally practical for the very large number of sources and sub-sources that are typically modeled during design (PEMARD 2017).

4.2 *Model set-up*

For numerical simulations it is necessary to reproduce the ground, the objects and the buildings of the area under study in order to get the complete scenario in 3D format.

The first step has been realized on the basis of a comprehensive 2D virtual map of the port area of interest, through Google Earth software. After the map has been imported into the software Olive Tree Lab—Terrain, a 3D modeling of the area and of the ship has been created (Figures 5 and 6). As a first approximation, these structures have been modelled as purely reflective objects.

Once the geometrical model has been built, the acoustic source characteristics have been then assigned.

In the specific application, the equivalent noise sources related to the power generation units have been modelled (this reflects the stationary operational condition corresponding to the real data used in the study).

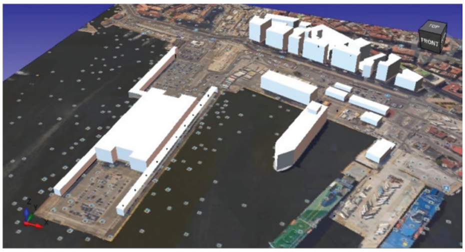

Figure 5. Geometrical model of the area.

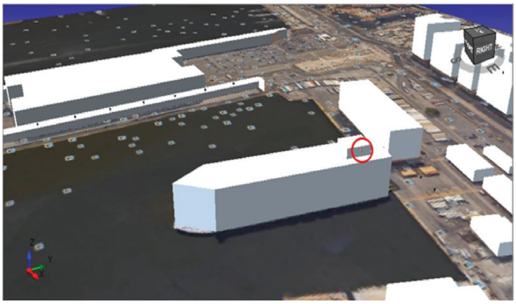

Figure 6. Geometrical model of the area with source location.

Being not available the exact acoustic power and spectral distribution at the source, a sort of reverse engineering approach has been used during the calibration phase of the model (see next chapter 3.3). Once the acoustic sources have been located, and the potential receiving positions identified, the main and secondary noise transmission paths may be computed, including noise attenuation path. The energy transmitted through the various paths, summed to each other will result in a specific noise level at each selected receiving position.

A few locations have been selected for the 'numerical receivers', where predicted levels are to be computed for calibration, refinements and successive validation of the model. These locations include all points with experimental surveys plus a number of other ones, introduced because of interest for further evaluations.

Figure 7 illustrates a representation of some noise paths, while Figure 8 illustrates a typical result for a specific receiver.

4.3 *Model iterative calibration*

As mentioned, the main difficulty of the present work is related to the evaluation of the source peculiarities, because of their location and specific noise emission characteristics.

During this part of the activity, because of unavailability of surveys in the proximity of the single noise sources (mainly the onboard power generator groups) with a characterization in terms of level, spectra and directivity, a reverse engineering approach has been used, implemented through the following steps:

- A single receiver position has been considered as calibration point (point D)
- noise attenuation path between noise source and this receiver has been computed
- the source power has been tuned to fulfil a perfect coincidence between numerical and experimental data at the calibration point.

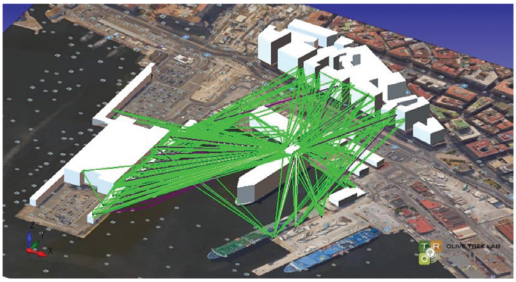

Figure 7. Geometrical model of the area with noise paths.

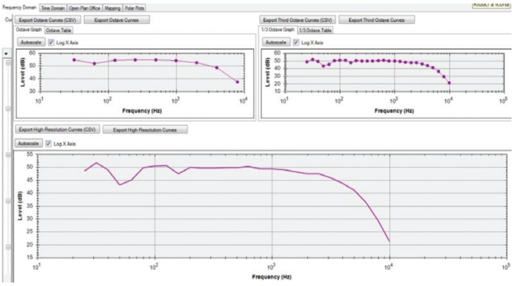

Figure 8. An example of computational results.

Once the noise source is assessed, a validation step needed to be performed.

Numerical and experimental data have been later compared for all the other acoustic receivers, placed in the various positions: close to the cruise terminal, on the opposite side of the dock and to the back of the anchoring station (Figure 2).

Table 1 reports the comparison, receiver by receiver, of numerical and experimental data coming from the calibration carried out in position D. A general comment about the agreement between numerical and experimental data is also reported.

As it can be seen in the table, a general agreement is found, but, while the simulation gives values of the sound pressure coinciding with the experimentally measured values in a couple of points (in addition to the calibration point), other points show differences (in some cases considerable) between predicted and measured values.

The same procedure has been repeated for several source levels or series of distributed monopole sources, in order to identify the value giving the best fitting, but a perfect fit is not possible.

This indicates that the underlying hypothesis of an omnidirectional point source (or a combination of them) is not completely realistic. On the other hand, surveys quite far away from the source like those available in this study are not enough to identify the directivity pattern of a source, which may be enhanced by near field/local screen effects.

Table 1. Comparison of numerical and experimental data.

Point	Experim. value (dB)	Numerical value (dB)	Difference (dB)	Feedback
D	63	63	0	perfect
I	62	60	–2	quite failing
L	60	58	–2	quite failing
S	62	63	+1	satisfactory
T	64	63	–1	satisfactory
U	65	65	0	perfect
V	71	71	0	perfect

5 CONCLUSIONS

A numerical acoustic model of a portion of the Naples harbor has been realized. A comparison between experimentally surveyed data and predicted numerical ones showed a fair agreement. This result may be considered satisfactory, as a precise characterization of the noise source was not available and the entire model has been tuned by the use of a reverse engineering approach.

In order to exploit the potentiality of this type of investigation, however, a proper characterization of the specific noise sources located on board the target ship (in terms of acoustic levels, spectra and directivity) is needed, as well as a further verification of the propagation model in positions farer away from the source.

The effort needed for these additional experimental investigations, already planned for a next phase of the study, is justified, however, in view of deriving a proper model of the first part of the noise propagation path from the ship within the port area. Such model will have the capability of providing a complete picture of the acoustic impact in the surrounding areas and of quantifying the effectiveness of possible counter measures before their implementation.

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