Design of blasting in a tunnel in a coastal area near a protected breeding habitat of the Shag (*Phalacrocorax Aristotelis*)

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Abstract

In the framework of a project for a harbour expansion, it was necessary to excavate a tunnel under a cape in which on the rocky coasts there was a Shag colony (*Phalacrocorax Aristotelis*) during some months of the year. The tunnel characteristics (short in length and through very abrasive rock) meant that it was excavated by drilling and blasting, and there was therefore a risk of the blast noise affecting the birds' breeding. For this reason, a study about the air shock wave had to be done in order to ensure that the noise level would be under a reasonable limit. In this paper, the development of a non-complex air wave prediction model, which allowed the determination of the conditions when there was no negative influence, is shown.
Keywords: blasting air wave, tunnelling, environmental impact, Shag.

1 The Shag (*Phalacrocorax Aristotelis*) in Asturias

The Shag in Spain was a game bird until its inclusion in the "Threatened Species Catalogue" in 1980, [1], as a result of the application of the Berna Agreement that established this species as a protected one since 1979. This bird regularly breeds throughout the Bay of Biscay coastal line, where it is estimated to have a growing population of around 2200 couples. In Asturias, northern Spain, the species population had a remarkable fall until the 1980s, where minimum values reached as low as 50 couples [2]. Since then there has been an outstanding recuperation and the number of reproductive couples can be now estimated at around 200, concentrated in several colonies. Among the threats that the species

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can suffer can be included troubles with or the destruction of the nesting places (Álvarez et al. [3]).

In this respect there is a regulation in the Principality of Asturias, the *"Protection Plan of the Shag (Phalacrocorax Aristotelis)"* [4], which objectives are, among others, *"Stablish and apply measures that allow an efficient direct protection of the specie […]. Promote the effective protection of the coast area with presence of breeding colonies of Shag […]"*.To accomplish these objectives several directives and actions are established as *"Establish protection and restricted use areas […], comply with the rules of the existent regulations regarding Environmental Impact Evaluations in any activity done near breeding islands […], control the human activities that change the ecological characteristics of the areas where there are nesting populations of Shag […]"*.

2 The excavation of a tunnel and its environmental impact

In the framework of a large project to extend a seaport, a 400 meter long tunnel had to be drilled just below a cape. This work was very important for the overall planning of the job as it opened a path for the materials transport, so it was needed to start the project as soon as possible. Due to the tunnel characteristics (very short in length) and the rock mass (very abrasive rock) the best method to make the excavation was by drilling and blasting, expecting advances around 100 meters/month. There was record of a nesting colony of the Shag during certain periods of the year (Figures 1 and 2).

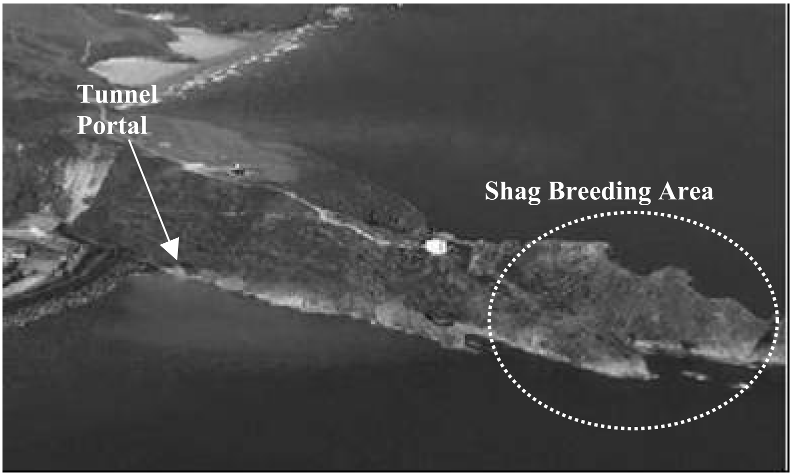

Figure 1: Cliffs location.

As the noise generated by the blasts can put in danger the breeding of these birds, a study had to be done in order to assure that during the breeding season the level of noise in the rocks was below a certain level [5]. As it was not possible to find applicable standards, a maximum sound level of 70 dB was taken. It was the value chosen as a maximum level in a similar problem of blasts done in the Somport Tunnel crossing the Pyrenees between Spain and France, in order to preserve surrounding colonies of *Bearded Vulture* (*Gypaetus Barbatus*), another protected species (López [6]). Nevertheless, it is a very restrictive one as can be inferred from the record of Figure 3 which show the sound level without work interference.

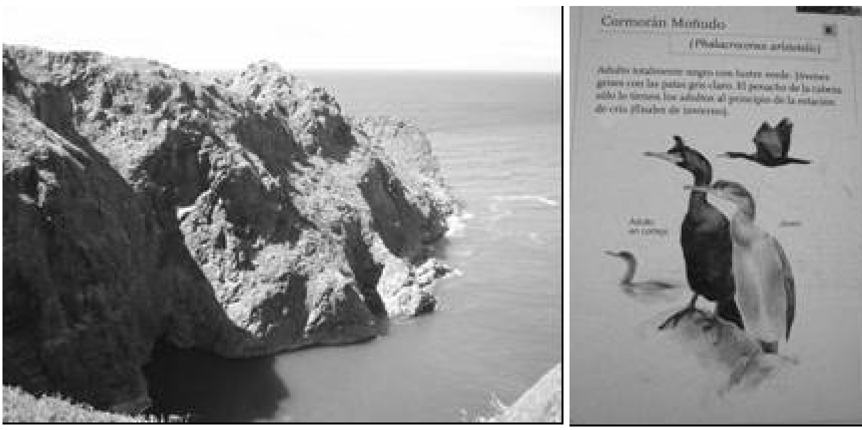

Figure 2: Cliffs and informative panel.

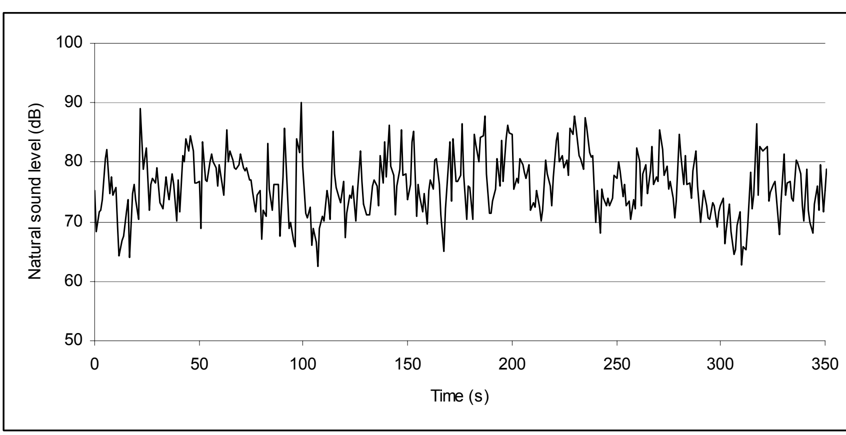

Figure 3: Natural sound level.

It seems reasonable to think that as the tunnel head is advancing the blast noise will get much more attenuated in the tunnel portal, that is, the first blasts will affect the surrounding environment much more than the last ones. The problem was therefore to find at which moment the tunnel excavation had to be started in order to reach an advanced level enough to ensure that the noise level in the tunnel opening was not going to affect the birds' breeding that will take place 250 meters away. We must say that birds have not been apparently affected by the blast noise in the previous seven tunnels done in the area, although this time the tunnel was much closer to their breeding area.

3 Objectives and hypothesis

Although the problem can be solved using more powerful tools (Computational Fluid Dynamics or FEM software applied to Fluid Mechanics) from the environmental impact point of view their use is not so justified as, among several reasons, factors affecting the phenomena in a certain moment have a great component of uncertainty, which means that although those calculation methods are very precise, the results turn out not to be so accurate. We decided to use much less complex calculation methods, taking into consideration the prevalence of the environmental impact effect calculation over the wave transmission physics. In this sense the goal was to develop a prediction method of the aerial wave due to blasts in the tunnels which are not complex, easy to understand and with no need for deep and complex technical knowledge.

Aerial wave effects have been profusely studied in the case of open air blasts and several different prediction models have been developed (the first methods appear in classic references such as as Gustafsson [7]). This is not the situation in the case of blasts inside tunnels, where the published studies (e.g. [8], [9] and [10]) have been focused on the propagation of the aerial wave inside the tunnel but not its propagation towards the tunnel outside. This is the reason for the interest in a model that can predict the aerial wave behaviour outside the tunnel.

In another sense it is also important to work with non-complex models as the environmental impact issues involve technicians from several knowledge fields (such as biologists or government employees, who have to take decisions about environmental impacts) who are not experts in blasting technology.

To achieve this several simplifications must be done, although not very restrictive, of some of the parameters that play a role in the sound level that the aerial wave can reach; the following are assumed:

a) the tunnel will be a maximum of 1000 meter long
b) the tunnel cross sections are between 60 and 90 m^2
c) the operating load (maximum explosive load that detonates per delay) is more or less constant and always less than 10 Kg.
d) the tunnel has a typical lining with steel profiles and shotcrete layer with medium roughness (Figure 4).

Then we can obtain a method where the operating variables are easily extendable and measurable: aerial wave level and distances of the blast from the measuring point, establishing on one side the distance from the blasting face to the tunnel portal and on the other side the distance from the tunnel portal to the measurement point. The method turns out to be a generalization of the aerial wave transmisivity law due to open air blasts, which is simple and useful at the same time.

Figure 4: Portal and tunnel inside.

4 Development of the air wave prediction model

The model taken to calculate the aerial wave propagation in the open air is similar to the ones developed for open air blasts. Assuming that the operating load is more or less constant, the intensity of the aerial wave only depends on the distance as follows:

$$L = L_0 - k \times r \tag{1}$$

where L is the intensity of the sound wave (dB) at a point r meters straight from the tunnel portal and L_0 is the aerial wave intensity exactly in that tunnel opening. In similar experiences in other tunnels it has been observed that in the typical conditions described above (cross sections 60-90 m^2, medium roughness shotcrete lining, charges per delay less than 10 Kg) it can be assumed that L_0 only depends on the distance D (m) from the advancing heading inside the tunnel towards its outside. From the empirical data obtained by the authors from several experiences the following expressions were developed:

$$L_0 = 180 - \frac{D}{5} = 180 - 0.20 \times D \qquad \text{in } 20 \le D \le 125 \text{ m} \tag{2}$$

$$L_0 = 160 - \frac{D}{25} = 160 - 0.04 \times D \qquad \text{in D} \ge 125 \text{ m} \tag{3}$$

Only one parameter has still to be determined in order to completely define the model: k. As the goal is to obtain a non-complex model, the simplest way is to instead of estimating the exact value of the sound wave at one point, to just allow the calculation at that point of a sound level larger than that actually produced. From the empirical data we can define k as:

$$k = 0.25 + \frac{\alpha}{900} \tag{4}$$

where α is the angle (°) between the tunnel axis and the line that links the measurement point and the tunnel opening. Then k is 0.25 in the tunnel direction and 0.35 in the cross direction.

5 Using the prediction model

The use of this prediction model is quite simple in our case. Taking into account that the closest cliff is 250 meters away from the tunnel portal, in cross direction to the tunnel axis, r and k values are 250 m and 0.35 and then $k \times r$ = 87.5. The relationship between the aerial wave L_{250} in the closest cliff and the tunnel advance D can be established as:

$$L_{250} = (180 - 87.5) - 0.20 \times D = 92.5 - 0.20 \times D \qquad \text{while } D \leq 125 \text{ m} \qquad (5)$$

$$L_{250} = (160 - 87.5) - 0.04 \times D = 72.5 - 0.04 \times D \qquad \text{while } D \geq 125 \text{ m} \qquad (6)$$

Figure 5 shows this relationship. Then the sound level will be less than the maximum L_{max}= 70 dB at the closest cliff when the length of the tunnel (or the distance from the blasting point to the tunnel portal) is bigger than 112 m:

$$L_{250} < L_{max} \Rightarrow 92.5 - 0.20 \times D < 70 \Rightarrow D > \frac{92.5 - 70}{0.20} = 112.5 \qquad (7)$$

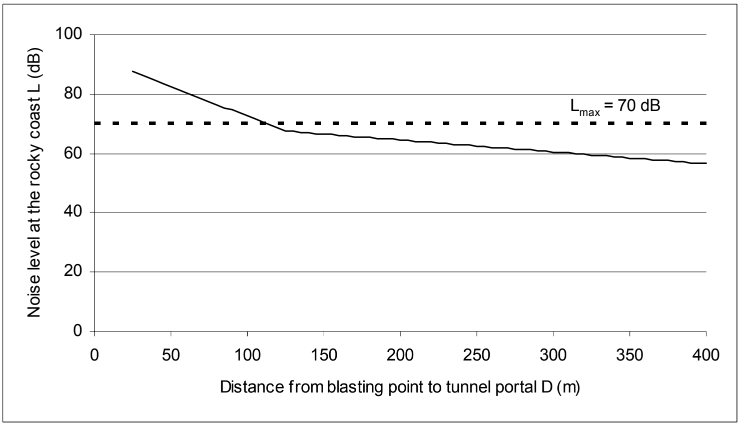

Figure 5: Sound level vs. advance.

Assuming an advance of 100 meters per month and taking into account that in the beginning the advance is smaller than predicted, the tunnel excavation should start two months before the beginning of the breeding period of the *Shag*.

6 Aerial wave measurement during the work

In order to control the environmental impact due to blasts in a tunnel, several aerial waves were measured in different points near the tunnel.

In order to get representative values those measurements were taken in different tunnel advances and at points at different distances and angles in relation to its axis. Table 1 shows the results of the measurement campaign. Figure 6 shows a seismographer-sound level meter installed close to the tunnel opening and a wave sample obtained in one of the blasts. The impact of each one of the partial blasts that constitutes a tunnel blasting procedure (first the central explosive is detonated and then the surrounding ones) can be clearly seen.

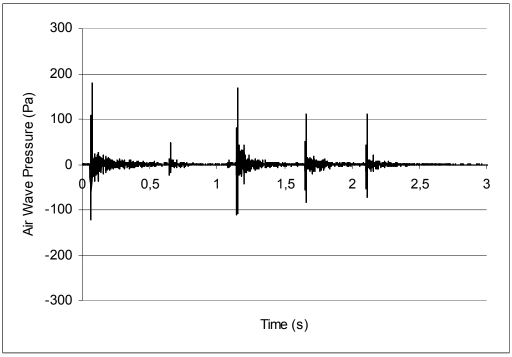

Figure 6: Seismographer-sound level meter.

Table 1: Measurement results.

D (m)	*r (m)*	*α (º)*	*L (dB)*
22	122	90	117
35	135	90	120
125	5	0	141.8
125	15	90	135.5
125	80	30	123.8
190	5	0	141.8
190	50	90	126.1
190	125	0	122.7
355	20	0	138.6
355	50	90	125.5
355	80	30	124.7

7 A comparison between calculated and measured sound level

If the calculated sound intensity values are represented against the measured values (Figure 7) it can be seen that actually this prediction model presented here is not very accurate, and the point cloud appears very dispersed. This is result of the simplifications done, as the model has not taken into account parameters that influence the intensity of the sound wave, mainly the explosive operating load that has been used. In these circumstances the model can only be considered applicable if its results, although not accurate, are always in the safety side, that is, the calculated values are always above the real ones.

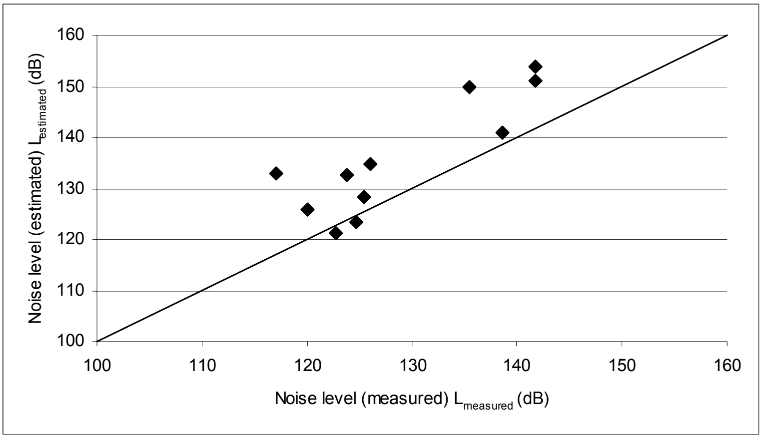

Figure 7: Calculated vs. Measured aerial wave.

This is actually achieved with the model, as the predicted values are always above the measured ones. This can be seen in Figure 7 as almost all representative pairs are over the line $L_{calculated} = L_{measured}$, which means that $L_{calculated} \geq L_{measured}$. The measured values below the calculated ones are only 1 dB apart.

However, this study has been prepared trying to identify with enough advance the initial moment for the tunnel works, and this goal can be easily reached even with the simplifications done and relative inaccuracies obtained.

Nevertheless, it is evident that if the noise problem were more important, e.g. less distance between the tunnel opening and the area to protect, a more complex model must be developed. However, this could have the disadvantage that it should be used by technicians trained in the use of explosives and blast calculations.

8 Conclusions

From the results of this research study the following interesting points can be deducted:
- The aerial wave of the blasts developed in tunnels can have different effects in the surrounding environment, specifically for the birds
- The aerial wave magnitude is bigger in the tunnel direction than in its cross direction
- That magnitude diminishes as the tunnel advances, which is a very positive factor as it allows one to modify the tunnel construction schedule in order to diminish the affection in the critical moments (e.g., in the bird nesting period).
- It is possible to use non-complex aerial wave prediction models in the project phase that allows the estimation of the sound wave variation with the different design factors.

Generally speaking, with good planning this kind of work can be developed with respect to the surrounding environment. In this sense we can be optimistic as the *Shag* continues living in our coasts (Figure 8).

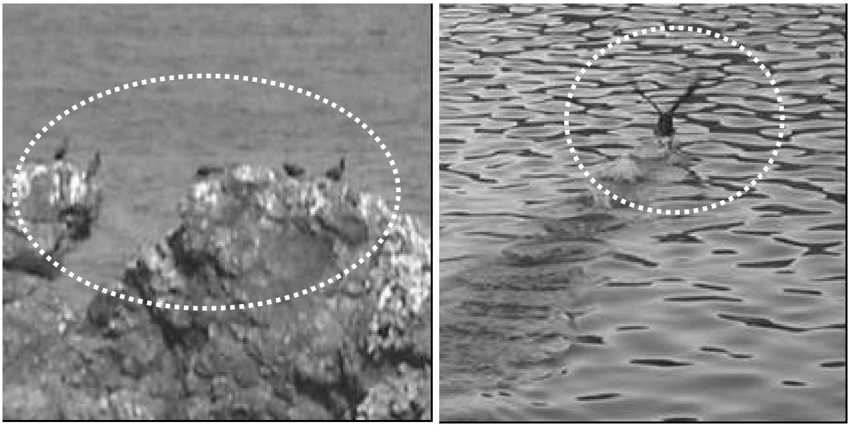

Figure 8: *Shag* near the studied area.

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