Appendix H2

Groundborne Noise & Vibration Impact Assessment – Tunnel Construction

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ANNEX 1

1 INTRODUCTION

This report provides an assessment of the likely impacts on humans of groundborne noise and vibration resulting from the boring of the Tunnel Boring Machine (TBM) during the construction of the tunnel beneath Sruwaddacon Bay as part of the proposed Corrib Onshore Pipeline development. This document forms Appendix H2 of the EIS.

The onshore pipeline and associated services will be installed within a tunnel approximately 4.9km in length extending from Glengad to Aghoos. The tunnel will be bored, using a TBM, from Aghoos to Glengad. Approximately 4.6km of the tunnel route will be under Sruwaddacon Bay. The proposed construction method is segment lined tunnelling (see Chapter 5 of the EIS).

This report considers available guidance on assessing ground borne noise and vibration from construction activities.

A separate report (Appendix H3 of the EIS) presents the results of predictions of groundborne noise, vibration and resulting sound generated within the waters of Sruwaddacon Bay by the tunnelling activities prepared by Rupert Taylor FIOA.

In this report, the results of the predictions are assessed in terms of their effects on the human population. No significant impacts have been identified. Section 4.1 of this report concludes that the vibration velocity at the nearest residential dwelling will be 0.01 to 0.02mm/s, which is considerably below the threshold of human perception for vibration of around 0.14 mm/s. The predicted ground borne noise level of 9 dB $L_{Amax,S}$ which is well below the significance criterion of 35 dB $L_{Amax,S}$ and would be inaudible within any residential property. No mitigation measures are needed.

This impact assessment was completed by RPS.

2 ASSESSMENT CRITERIA

2.1 NOISE ASSESSMENT CRITERIA

2.1.1 Noise and Vibration from Tunnelling

There is a potential for tunnelling, such as proposed for this project, to generate vibration which will propagate through the ground. In the case of the Corrib Onshore Pipeline project, where approximately 4.6km of the proposed tunnel is under Sruwaddacon Bay, this vibration may also be transmitted to water within the Bay and if so will generate sound within the water body. The nature and extent of the sound levels will vary with the amount of water in the Bay and the location of the tunnelling excavation below ground. Vibration also has the potential to be detectable on the sands in the inter-tidal zone and also may be detectable as groundborne noise or vibration at buildings near to the shore of Sruwaddacon Bay.

2.1.2 Groundborne Noise

The term groundborne noise refers to noise perceived by the sense of hearing that differs from noise in general, insofar as it arrives in the space where it is heard as a result of propagation as vibration (at acoustic frequencies) through the ground or through a structure. For example, vibrating room surfaces cause airborne sound to be radiated and the effect is sometimes referred to as re-radiated noise.

In many respects, the phenomenon merits using the same assessment methods applied to noise in general. However, there are special features that should be taken into account. The first is that, whereas noise in dwellings originating from outside tends primarily to affect one or two façades with the result that the occupant can find lower noise levels in rooms on the other side of the dwelling, groundborne noise tends to be the same in all rooms (albeit with a slight reduction with increasing floor level). The second feature is that night-time groundborne noise may reach the ear without passing through air, i.e. through the bed and pillow, and cause a greater effect than would be expected from airborne noise at a similar level.

The practice adopted in the case of groundborne noise from underground railways has been to use the $L_{Amax,S}$ noise parameter[1]. For dwellings that are not currently affected by groundborne noise, the threshold of significance is typically taken as 35 dB $L_{Amax,S}$.

Large scale construction work, such as tunnelling, can result in the generation of groundborne noise.

2.1.3 Construction Vibration Criteria

Common practice in Ireland has been to use guidance from the following British Standards, BS 6472, which addresses human response to vibration, and BS7385 which deals with the effects of vibration on buildings.

[1] L_{Amax} is the maximum value that the A-weighted sound pressure level reaches during a measurement period. $L_{Amax,\,S}$ or slow is averaged over 1 second. The bandwidth of the frequency response of the ear is usually taken to be from approximately 18 Hz to 18,000 Hz. The auditory system is not equally sensitive throughout this frequency range. This is taken into account when making acoustic measurements by the use of A-weighting, a filter circuit which has a frequency response similar to the human auditory system.

It is noted that there is other relevant, internationally recognised guidance on human response to vibration such as the German Standard 4150. However, the above British Standards are considered to be the most relevant as they also link into BS 5228: Part 2 which specifically deals with vibration from construction works, which is the principle potential vibration effect for this project.

Groundborne vibration from construction sources, such as piling, can be a source of concern for occupants of buildings in the vicinity. The concern can be that the building may suffer some form of cosmetic or structural damage or that ground settlement may arise that could subsequently lead to damage. Research associated with British Standard 7385 (BS 7385-1 and BS 7385-2, *“Evaluation and measurement for vibration in buildings”)* concerned with vibration-induced building damage found that although a large number of case histories were assembled, very few cases of vibration-induced damage were found. However, structural vibration in buildings can be detected by the occupants and this can affect them in many ways; their quality of life can be reduced, as can their working efficiency, although there is little evidence that whole-body vibration directly affects cognitive processes. It should be noted that there is a major difference between the sensitivity of people feeling vibration and the onset of levels of vibration that damage a structure.

- Vibration Dose Value (VDV): The effect of building vibration on people inside buildings is assessed by determining their vibration dose. Present knowledge indicates that this is best evaluated with the VDV, as promoted through BS 6472-1, *“Guide to evaluation of human exposure to vibration in buildings. Part 1: Vibration sources other than blasting”*. VDV defines a relationship that yields a consistent assessment of intermittent, occasional and impulsive vibration, as well as continuous input, and correlates well with subjective response. The way in which people perceive building vibration depends upon various factors, including the vibration frequency and direction. The VDV is given by the fourth root of the integral of the fourth power of the acceleration after it has been frequency weighted.

- Peak Particle Velocity (PPV): Peak particle velocity is defined as ‘the maximum instantaneous velocity of a particle at a point during a given time interval’, and has been found to be the best single descriptor for correlating with case history data on the occurrence of vibration-induced damage.

BS 5228, *”Code of practice for noise and vibration control on construction and open sites,”* is a two part standard which provides guidance, information and procedures on the control of noise and vibration from construction sites. BS 5228 Part 2 covers basic information and recommendations for basic methods of vibration control relating to construction and open sites where work activities/operations generate significant vibration levels. It includes sections on: community relations; vibration and persons on site; neighbourhood nuisance; project supervision; control of vibration; and measurement.

Annex B of BS 5228 Part 2 refers to BS 7385 and BS 6472 for further advice on the assessment of the significance of vibration levels. Annex E refers to TRL (Transport Research Laboratory) Report 429 for further advice on the prediction of vibration levels from some construction sources.

Human beings are known to be very sensitive to vibration, with the threshold of perception being typically in the PPV range of 0.14 mm/s to 0.3 mm/s. Vibrations above these values can disturb, startle, cause annoyance or interfere with work activities.

BS 6472 sets down vibration levels at which minimal adverse comment is likely to be provoked from the occupants of the premises being subjected to vibration. It is not concerned primarily with short-term health hazards or working efficiency. Whilst the assessment of the response to vibration in BS 6472 is based on the VDV and weighted acceleration, for construction it is considered more appropriate to provide guidance in terms of the PPV, since this parameter is likely to be more routinely measured based upon the more usual concern for potential building damage. Furthermore, since many of the empirical vibration predictors yield a result in terms of PPV, it is necessary to understand what the consequences might be of any predicted levels in terms of human perception and disturbance.

Guidance on the human response to vibration from demolition and construction activities that is contained within BS 5228-2 is provided in Table 2.1.

Table 2.1: Human Response to vibration from construction and demolition activities

Vibration Level PPV (mm/s)	Effect
0.14	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration.
0.3	Vibration might be just perceptible in residential environments.
1.0	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents.
10	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

Source: BS 5228-2

The following table also provides guidance on interpreting vibration velocity values by putting them in the context of typical events that people experience. Note that where the "effect" column refers to annoyance, this relates to permanent sources of vibration such as metro and railway lines. It has generally been found that people have a higher tolerance to temporary sources of vibration than permanent. Therefore, the threshold for the likelihood of complaints is higher for construction vibration than, say, vibration from railways.

Table 2.2: Vibration velocities from typical sources and possible effects

RMS Vibration Velocity (mm/s)	Approx Equivalent PPV (mm/s)	Source (at approx 15 m distance)	Effect
2.5*	10*	Blasting for construction project	Threshold of minor cosmetic damage in fragile buildings
1.0	3	Heavy tracked construction plant	
0.8	2.5		Difficulty with tasks such as reading VDU
0.5	1.5	Passenger railway trains – upper range	
0.3	1.0		Residential annoyance, infrequent events (e.g. from a commuter railway line)
0.1	0.3	Passenger railway trains – lower range	Residential annoyance, frequent events (e.g. from a metro system)
0.1	0.3	Bus or truck over bump	
0.03	0.1	Typical bus or truck	

*Values are not direct equivalent but are typical likely values.
RMS: Root Mean Square
Based on US Department of Transportation, *"Transit Noise and Vibration Impact Assessment"*, April 1995

New (TRL Research Report 53) cites research indicating that, *"Peoples tolerance will also be improved provided that the origin of the vibration is known in advance and no damage is done."* New also finds that, *"levels of perception are considerably higher when the vibration is of a transient rather than continuous nature."*

Considering effects upon buildings and structures, BS 7385-2, *"Guide to damage levels from groundborne vibration",* provides guidance on the levels of vibration above which building structures could be damaged. It identifies the factors that influence the vibration response of buildings, and describes the basic procedure for carrying out measurements. It also states that there is a major difference between the sensitivity of people feeling vibration and the onset of levels of vibration that damage structures; and that levels of vibration at which adverse comment from people is likely are below levels of vibration that damage buildings, except at lower frequencies.

Table 2.3 provides the vibration limits contained within BS 7385 Part 2 above which *"cosmetic"* damage could occur. BS 7385 Part 2 suggests that the thresholds for the possibility of *"minor"* and *"major"* damage are at vibration magnitudes that are greater than twice and four times those given in Table 2.3, respectively.

Table 2.3 – Threshold Vibration Values for the Evaluation of Cosmetic Building Damage (BS 7385 Part 2)

Building Classification	Frequency Range of Vibration (Hz)	PPV mm/s	
		Transient Vibration	Continuous Vibration
Unreinforced or light framed structures Residential or light commercial type buildings	4 Hz to 15 Hz	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	7.5 mm/s at 4 Hz increasing to 10 mm/s at 15 Hz
	15 Hz and above	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above	10 mm/s at 15 Hz increasing to 25 mm/s at 40 Hz and above
Reinforced or framed structures Industrial and heavy commercial buildings	4 Hz and above	50	25

Note: the limits refer to vibration measured in the foundations of a building.

The National Roads Authority guidelines identify 2.5 mm/s as the vibration level that may be considered tolerable due to piling works. The potential vibration levels that could be generated by rock breaking works, if required would be expected to be comparable to the level of vibration that may be generated by piling works. The vibration level of 2.5 mm/s is substantially below the guideline values for protection of properties against cosmetic damage. The NRA limits for protection against cosmetic damage are given as a function of vibration frequency, and are:

- 8 mm/s (vibration frequency <10Hz);
- 12.5 mm/s (vibration frequency 10 to 50Hz); and
- 20 mm/s (vibration frequency >50 Hz).

The NRA 2.5 mm/s limit is for piling, which is a continuous activity. This limit provides for protection against the vibration nuisance, and is comfortably within the limits for cosmetic damage.

3 POTENTIAL NOISE AND VIBRATION IMPACT

3.1 GROUNDBORNE NOISE AND VIBRATION FROM TUNNELLING

The proposed tunnel will be constructed using segment lined tunnelling. This is a technique where a tunnel boring machine (TBM) is used to excavate a tunnel, with a concrete lining made up of pre-constructed concrete segments installed as the TBM is advanced. The tunnelling operation will be a continuous 24-hour process and is described in Chapter 5.

Vibration from tunnelling is caused when the TBM's cutting shield rotates whilst being under a constant pressure from hydraulic cylinders that push the TBM forwards. The TBM machine is active for approximately 15 to 20 minutes per hour. The vibration generation will thus also be periodic.

The excavation process will generate forces within the sands, gravel and rock that may propagate as groundborne vibration. These vibrations will travel through the ground as various different waveforms dependent on the nature of the geology surrounding the TBM. The other activities within the main tunnelling cycle are unlikely to generate significant vibration within the ground. A railway will be used within the tunnel during construction for transport of materials and personnel. This may cause very transient vibrations to be generated, particularly when segment wagons pass over rail joints. However, levels of vibration will generally be no higher than those expected from the TBM and would only occur for seconds at any particular location.

There is a potential for groundborne vibration from the tunnel excavation by the TBM to be detected within the sands forming the sea bed within Sruwaddacon Bay. This vibration will also be transmitted to water within the Bay and will generate sound within the water body. The nature and extent of the sound levels will vary with the amount of water in the Bay and the location of the TBM.

Groundborne vibration has the potential to be transmitted to residential and other buildings near to the shore. This vibration may be detectable as "feelable" vibration and groundborne noise re- radiated from the ground via building structures to cause audible sound.

In considering all of the above potential effects it should be considered that:

- The TBM will move at approximately 11m per day and hence effects will be temporary and transient; and

- The excavation process which has the potential to generate vibration typically lasts for approximately 15 - 20 minutes in each hour.

In order to consider the effects of groundborne noise and vibration from tunnelling, modelling has been carried out by Rupert Taylor FIOA using the FINDWAVE model to predict vibration generated by the tunnel excavation. A report describing the nature of the model, input data and assumptions and the results obtained is presented in Appendix H3. The results of the groundborne noise and vibration modelling as they affect human receptors are presented in Section 4 of this report. Appendices J, K and L of the EIS consider the results of the modelling in relation to ecological receptors.

3.2 GROUNDBORNE NOISE AND VIBRATION MODEL

The FINDWAVE model uses input data representing the forces generated by the excavation at the tunnel face and calculates how these propagate through the various layers within the ground to the surface. In the case of the modelling carried out for this project, models have been run at four representative points along the length of the tunnel. At each of these cross-sections, the model has been run with and without a layer of water as the surface layer, thus representing conditions at high water and low water. This has allowed the sound pressure due to the tunnel excavation to be predicted within the Bay with the tide in and vibration to be predicted on the sands with the tide out. Vibration and groundborne noise levels at the nearest residential buildings to the tunnel have also been calculated.

The results of these predictions are presented graphically in Appendix H3 of the Corrib Onshore Pipeline EIS in the following formats;

- Graphs of rms (see below) vibration against distance in the sand/gravel at low water for each axis: vertical vibration, lateral vibration and longitudinal vibration. Results are presented in 1/3 octave bands, 1Hz to 100Hz.

- Graphs of sound pressure in Pascals against distance within the water at high water. Results are presented in 1/3 octave bands, 1Hz to 100Hz.

- A graph of rms vertical vibration on the foreshore against frequency in 1/3 octave bands, 1Hz to 100Hz.

- A graph of groundborne noise representative of the worst case building against frequency in 1/3 octave bands, 10Hz to 100Hz.

Vibration results are presented as root mean square (rms) values in micrometres per second (μm/s). 1 μm/s = 0.001 mm/s.

Ground vibration is often quoted in Peak Particle Velocity (PPV) usually in mm/s. PPV values are typically around 3 times the corresponding rms value although this depends on the nature of the vibration signal.

4 PREDICTED NOISE AND VIBRATION IMPACT

4.1 CONSTRUCTION PHASE

4.1.1 Groundborne Noise and Vibration from Tunnel Construction

The closest residential properties to the tunnelling are located near to the narrowest part of the mouth of Sruwaddacon Bay on the road (L1202) between Pollatomish and Glengad are approximately 240m from the line of the tunnel (such as property BQ07 as shown in Appendix A of the Corrib Onshore Pipeline EIS). These properties are likely to experience the highest levels of vibration from tunnelling. The predicted root mean square (rms) vibration velocity in the ground at a location representative of these dwellings is shown graphically in Annex 1. It can be seen that the highest velocity is predicted in the 16Hz 1/3 octave band and reaches a value of 1.8μm/s. In terms of PPV, taking account of the vibration throughout the 10Hz to 100Hz range, this corresponds to a value in the range 0.01 to 0.02 mm/s. Comparing this value with Table 2.1 indicates that this is a level that is considerably below the threshold of human perception for vibration. With reference to Table 2.2 it is no more than a fifth of the vibration likely to be generated by a bus or truck passing by on a smooth road at a distance of around 15m. It can therefore be seen that there will be no impact as the vibration will not be perceptible.

Taking a rigorous approach, the transmission of ground vibration into the dwellings should also be considered. The magnitude of vibration in the ground is attenuated by the mass-loading of the building when it enters the building via the foundations. Furthermore, the dynamic response of a suspended floor will amplify vibration such that the vibration in the vertical direction is greater in the middle of the floor that at its edges. Both effects are frequency dependent, site specific, and can depend upon the soil properties of the ground, the design and construction of the building and the vibration characteristics of the source. However, the combined dynamic amplification due to both effects is unlikely to increase the vibration levels in the ground by more than 1.5 times. On this basis, the vibration level on suspended floors within houses between Pollatomish and Glengad during the pass-by of the TBM is likely to be significantly less than the threshold of human perception for vibration, confirming there will be no impact.

The corresponding predicted groundborne noise level is 9 dB $L_{Amax,S}$. It can be seen that such a level is well below the significance criterion of 35dB $L_{Amax,S}$ and would be inaudible within any residential property.

5 MITIGATION (REMEDIAL OR REDUCTIVE) MEASURES

No mitigation measures will be required to reduce the effects of vibration or groundborne noise from the tunnelling works.

REFERENCES

British Standards Institution. British Standard 7385: Evaluation and measurement for vibration in buildings. Part 1: Guide for measurement of vibration and evaluation of their effects on buildings. 1990.

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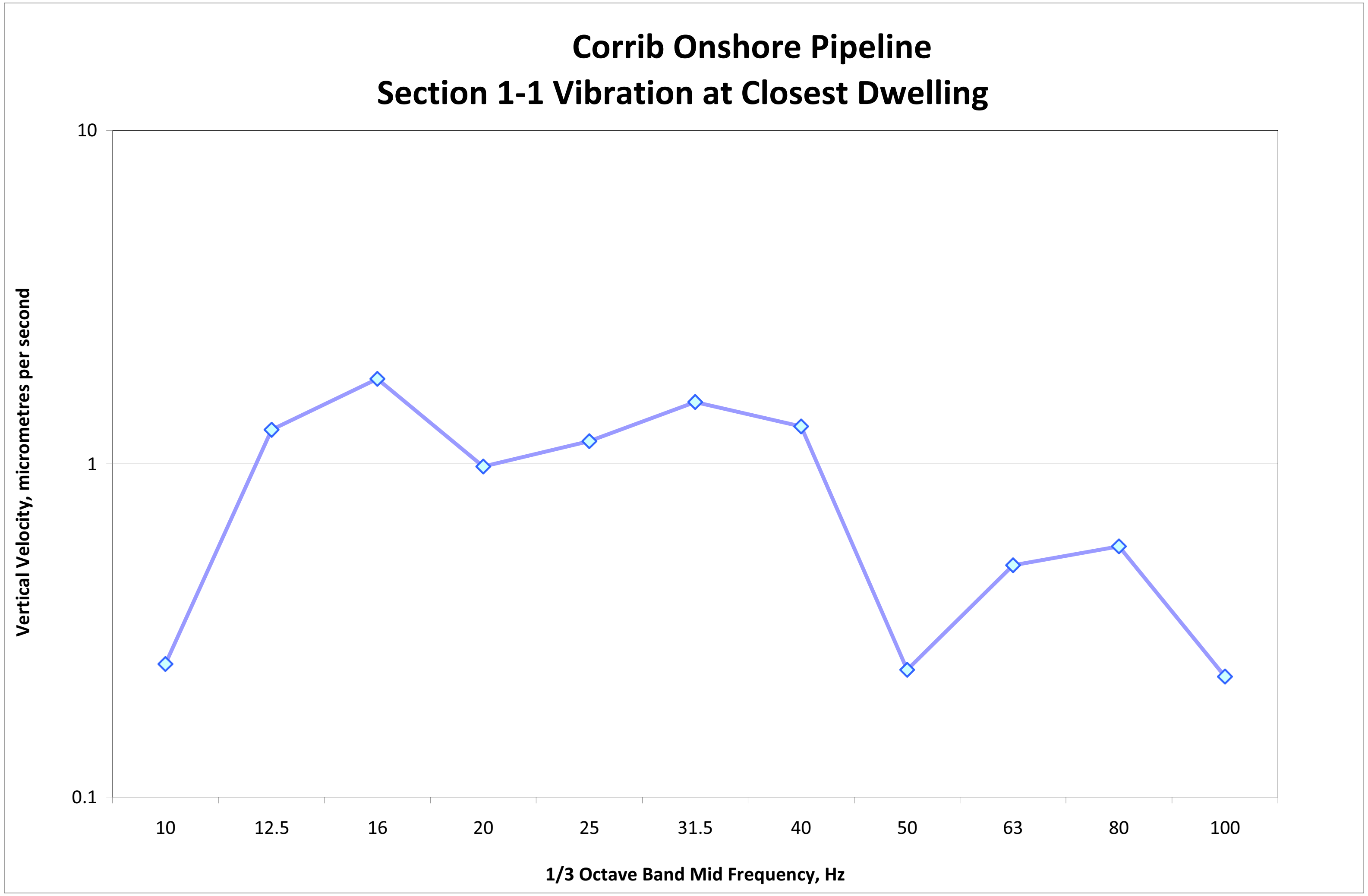
ANNEX 1

PREDICTED VIBRATION AT NEAREST RESIDENTIAL PROPERTY BETWEEN POLLATOMISH AND GLENGAD

Annex 1



Corrib Onshore Pipeline
Section 1-1 Vibration at Closest Dwelling
10
1
0.1
Vertical Velocity, micrometres per second
10
12.5
16
20
25
31.5
40
50
63
80
100
1/3 Octave Band Mid Frequency, Hz