# Evaluation of Noise in Sensitive Living Quarters aboard Floating Offshore Oil & Gas Facilities Using the SEA Method

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**Summary**

Floating offshore oil & gas facilities are noisy places where employees are expected to live and work for extended periods of time. For health and safety reasons, as well as quality of life, the employee's living quarters should allow for a much needed respite from the high mechanical noise levels associated with continuous daily operations. A detailed design analysis of the vibro-acoustic noise levels can be conducted at any given facility which will help to reduce the stress of continual exposure to high noise levels, as well as to prevent hearing loss or other potential health issues. The Statistical Energy Analysis (SEA) method represents a "high frequency" modeling technology for evaluating vibro-acoustic behavior over a broad range of frequencies. In application to offshore oil & gas facilities, this form of robust mathematical analysis is proven to be effective for evaluating noise over the entire audible frequency range. SEA is an effective tool for modeling multiple complex mechanical sources within multi-level structures to root out and mitigate problematic vibro-acoustic energy pathways. Specifically, this paper is presented to discuss the structural-acoustic propagation method associated with multiple sources using the SEA model to predict the vibro-acoustic propagation impacts at sensitive worker's living quarters. In this case study, the SEA model is used to predict the structural-borne noise levels within living areas to evaluate potential design changes for improved quality of life conditions.

# 1. Introduction

All over the world offshore oil and natural gas fields are being discovered and developed for production. Depending upon the depth of the natural resource within the ocean an offshore platform facility may either be fixed or floating to accommodate the recovery production of the oil or natural gas reserves. No matter the type of the production facility the workers spend extended periods of time working, recreating and sleeping on-board these typically large floating platforms. This arrangement presents a potential for the workers to be exposed to high vibro-acoustic noise levels generated by the operations of mechanical equipment used in the recovery process. Typically, an air-borne noise evaluation will be thoroughly evaluated during the platform design phase to resolve any and all forms of worker noise exposure. However, another type of annoyance is prevalent among these floating communities in the form of noise propagating through the structure (structural-borne noise) from heavy processing machinery. This type of vibro-acoustic energy can reach areas typically not impacted by air-borne noise; such as the worker's living quarters, recreational areas, and control rooms. This paper presents the structural-acoustic propagation method associated with multiple mechanical sources using the SEA model to competently predict these specific vibro-acoustic propagation impacts at identified sensitive worker's areas during the project design phase.

# 2. Overview of Typical Platform Layout

Typical offshore oil platforms include multiple facilities for storage, processing, and worker living spaces. These facilities include the following.

- Process Facilities
- Utility and Miscellaneous Facilities
- Hull
- Marine Systems Facilities
- Storage and Off-loading Facilities
- Living Quarters, Recreation Areas and Buildings

The majority of the noise producing equipment is associated with the processing facilities. Typical mechanical equipment includes the following: large turbines; compressors; pumps; thrusters; and high Pressure Piping. These noise sources have the potential to generate high vibro-acoustic noise levels in excess of 100 dBA, which can excite the supporting structure.

The living quarters provide a place for workers to rest and recreate. They typical consist of employee cabins, mess room, recreation rooms, and control rooms. The cabin areas are designed to provide the workers with a quiet area for sleeping purposes. These are usually stacked cabins with the mess rooms and recreation rooms on the lower levels to create a longer distance for noise to travel. The living quarter's structure typically accommodates large HVAC units and backup generators. Furthermore, these mechanical units are designed to be hard-mounted directly to the supporting structure.

# 3. Applied Noise Criteria

The noise criterion regulating offshore oil and natural gas facilities varies depending upon where it is being developed and the companies responsible for the development. However, the maximum allowable noise levels provided in Table 1 are generally considered acceptable for a typical offshore facility.

Table 1. Living Quarters Typical Allowable Maximum Noise Level Criteria in dB(A)

| Area | Sound Pressure Level dB(A) |
|---|---|
| Mess Rooms | 55 |
| Cabins | 40 |
| Recreation Rooms | 50 |
| Control Room | 45 |
| Workshops | 70 |
| Meeting Rooms | 45 |
| Offices | 45 |

# 4. SEA Model Review

Statistical Energy Analysis (SEA) is an analysis method for predicting the response of vibro-acoustic systems to acoustical or vibrational sources. It is particularly suited for analysis of large complex systems over a wide frequency range. In large complex models there are a great number of waves that propagate throughout the system; there are a large number of reflections and wave interactions in such a system. These waves build up reflections and can be represented as natural frequencies with a mode shape. Uniquely predicting each of the mode shapes in a system such as an offshore oil platform facility over the typical audio frequency range is not a practical. SEA treats these modes as groups of similar modes. The system is broken into many subsystems that are a statistical grouping of modes. All of the detailed interactions are not modeled but are combined into a statistical group where the interactions of the modal groups are modeled. This is done in a rigorous analytical process which is well documented (see Lyon or Fahy in the references). The main equation in SEA is conservation of energy. In a steady-state analysis, the power input will be equal to the power dissipated. Each subsystem (modal group) is assumed to have local modes which act to store, dissipate and transmit energy. By developing detailed models of how energy is shared between different kinds of structures (beams, plates, cavities, etc) and connections (point, line, and area), the distribution of energy through a model can be found.

In this case, the model of the oil platform has about 1200 subsystems with 80 billion modes that are resonant below 8000 Hz. At any frequency above 1 or 2 Hz, there are plenty of modes for the statistical approach to provide an adequate model.

## 5. SEA Model Review

The SEA model developed for the purpose of this paper is based on previous project experience. The model incorporated the high noise levels typically generated within the dominant equipment sections of the floating platform and is used as a worst-case analysis for calculating vibro-acoustic structural-borne noise propagation and predicting resultant noise levels within the sensitive receptor areas of the living quarters. The SEA model of the oil platform is shown in Figure 1.

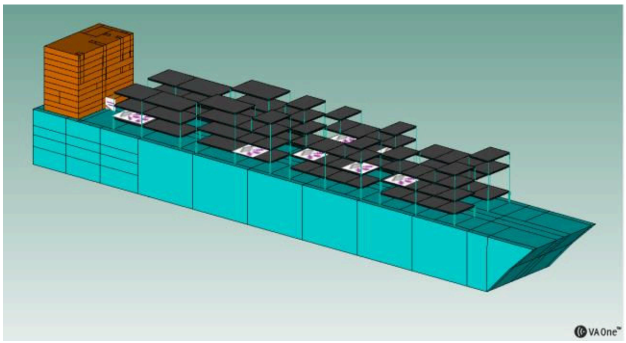


**Figure 1.** SEA model showing the structural components of the oil platform. Some of the sources are visible where a direct acoustic pressure load is applied to the structure at the equipment location.

### 5.1 SEA Model Review

The model incorporated azimuth thrusters, generators and large pumps within a multilevel hull, large turbines and compressors located on level 1 and 2 exterior process decks, and large HVAC units on levels one through six levels of the living quarter's structure. All mechanical sources were originally designed to be hard-mounted directly to the supporting structure. These connections are known to provide a direct path for structural-borne noise and will transmit through the supporting structure and into the living quarters. The model input of mechanical equipment noise emission levels, equipment location, equipment quantity, and mounting information are summarized in Table 2 below.

Table 2. Mechanical Equipment Noise Emission Data

| Location | Equipment Type | Quantity | Connection Point | Sound Power (dB) |
|---|---|---|---|---|
| Hull | Azimuth Thrusters | 2 | Mounted to Floor Deck | 115 |
| Hull | Pump (Engine | 2 | Mounted to Floor Deck | 110 |
| Hull | Generator Engine | 1 | Mounted to Floor Deck | 110 |
| Hull | Gas Turbine Generators | 4 | Mounted to Floor Deck | 110 |
| Process Deck | Compressors | 6 | Mounted to Floor Deck | 103 |
| Living Quarters | HVAC Units | 6 | Mounted to Floor | 76.5 |

Additionally, to accommodate the noise model design layout, it was assumed that the 11-story living quarters area comprised the following elements: Levels 1 and 2 consist of maintenance areas; Levels 3, 4, and 5 consist of control rooms, mess rooms and offices; and Levels 7 on up consist of worker's cabins. The walls of the hull and living quarter areas were assumed to be 1-inch thick steel. It was also assumed that all mechanical equipment was originally designed to be hard-mounted to the supporting structure.

## 6. Calculated Results

The vibro-acoustics structural-borne impact results were calculated at 3rd level control rooms, 4th level Mess room, 6th level office spaces, and cabins from the 7th level to the 11th level. Table 3 provides the calculated results as well as the applied noise criteria. Figure 2 provides a contour plot of the overall sound pressure levels (dBA) in the various rooms of the structure and Figure 3 provides a contour plot of the RMS velocity responses in the panels of the structure.

**Table 3. Predicted Structural-borne Noise Impact Levels and Applied Criteria**

| Room | Floor Level | Maximum Noise Level Criteria (dB(A)) | Structural-borne Noise Impacts (dB(A)) |
|---|---|---|---|
| Control Room 1 | 3 | 40.0 | 42.0 |
| Control Room 2 | 3 | 40.0 | 41.6 |
| Mess Room | 4 | 55.0 | 37.5 |
| Office | 6 | 45.0 | 36.9 |
| Starboard Side Cabin | 7 | 40.0 | 29.4 |
| Port Side Cabin | 8 | 40.0 | 27.2 |
| Central Cabin | 8 | 40.0 | 25.7 |
| Port Side Cabin | 9 | 40.0 | 24.4 |
| Central Cabin | 9 | 40.0 | 23.2 |
| Central Cabin | 9 | 40.0 | 21.8 |
| Port Side Cabin | 10 | 40.0 | 21.9 |
| Central Cabin | 10 | 40.0 | 20.9 |
| Central Cabin | 10 | 40.0 | 19.7 |
| Port Side Cabin | 11 | 40.0 | 20.3 |
| Central Cabin | 11 | 40.0 | 19.4 |

The structural-borne noise levels range from 41.6 dB(A) to 42.0 dB(A) within the control room areas. These noise levels were shown to exceed the established noise criteria of 40.0 dB(A). Structural-borne mitigation measures were determined to be necessary in order to reduce noise impacts to below the noise criteria.

The predicted structural-borne noise levels within the Mess Room was 37.5 dB(A). The structural-borne noise levels within the office area was 36.9 dB(A). These noise levels, within both of these areas, are below the project required noise criteria. Finally, the predicted structural-borne noise levels within the cabin areas range from 19.4 dB(A) to 29.4 dB(A). The project noise criteria for cabin areas allows noise levels up to 40 dB(A). These areas were determined to be below the project required noise criteria.

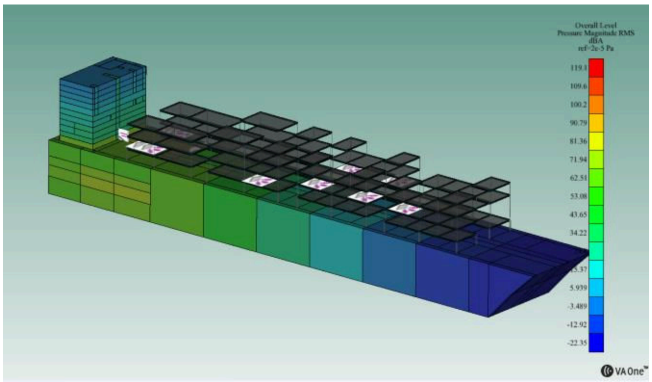


**Figure 2.** SEA model showing the overall A-weighted sound pressure levels in the rooms and chambers of the oil platform.

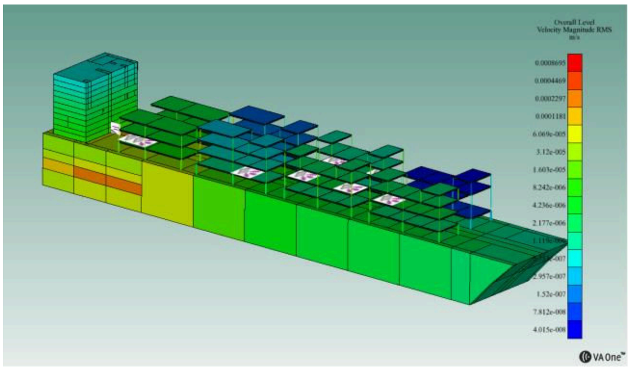


**Figure 3.** SEA model showing the RMS velocities of the structural components of the oil platform.

## 7. Design Recommendation

Structural-borne noise levels are shown to exceed the noise criteria within the sensitive control room areas. The primary sources of structural-borne noise include the azimuth thrusters, generators, and large pumps located within the hull area as well as large turbines located on the Process Decks. The large HVAC units located within the first 6 levels of the living quarters are also shown to contribute to the noise impact threshold exceedance.

To reduce the structure-borne noise, it was determined that the supporting assembly of the azimuth thrusters incorporates stiffeners to the equipment support structure. Stiffening the supporting structure will result in a less efficient path for structural-borne noise to propagate. A stiffened structure will help attenuate noise transmission and reduce impacts to the noise sensitive areas.

Large turbines, generators, and large pumps are a primary source of structure-borne noise as well. This equipment is typically proposed to be hard-mounted directly to the floor deck. This results in a direct connection for noise to transmit. It was further determined that all turbines, generators, and large pumps should be isolated from the floor deck eliminating the direct path for structural-borne noise. Spring isolators were considered and incorporated into the design to reduce these overall structural-borne noise impacts.

Finally, the HVAC units located within the living quarters are also typically hard-mounted directly to the support structure. This type of equipment mount allows for a direct path of structural-borne noise to transmit to the noise sensitive areas within the first 6 floors of the living quarters area, as well as a secondary path through the cabin walls located on the 7$^{th}$ floor and up. Therefore, it was deemed necessary that the HVAC units should be isolated using spring isolators. This form of mechanical vibratory isolation is shown to reduce the direct path for structural-borne noise and reduce the noise levels in these defined sensitive areas.

## 8. Conclusion

The result of this paper found the SEA model to be an effective tool in evaluating complex, multi-dimensional structural-borne noise impacts to sensitive receptor locations. The desktop development of the model was a very efficient tool and allowed for input of multiple mechanical noise sources as well as multiple sensitive receptors. Furthermore, the model assisted in defining the contributing noise sources at each receptor, which effectively helped to identify and mitigate the problematic vibro-acoustic energy pathways.

The results of the SEA model showed structural-borne noise level exceeding the noise criteria at the 3$^{rd}$ level control rooms. Since the model calculates the contribution for each source at each receptor, the problematic sources were efficiently identified. The 3-dimensional model output was used to identify vibro-acoustic propagation pathways yielding to a combination of structural stiffening and spring isolators recommendations to be incorporated into the analysis for achieving an effective reduction structural-borne noise to below the established criteria.

As expected, the noise levels dissipated through the living quarter's structure and were well below the noise criteria. The propagation paths were clearly identified and include elevator and stairway shafts. It was further noted, as a result of using the SEA noise modeling software, that when designing an offshore floating platform facility the living quarters area should be located as far as possible from any significant mechanical noise sources.

Overall, the SEA model was shown to be an efficient and effective tool when modeling offshore platforms. Many offshore facilities contain significant noise producing mechanical equipment attached complex structures. In this case, using SEA provided an efficient way to evaluate the structural-borne noise impacts at sensitive receptor areas and identify mitigation measures to reduce problematic vibro-acoustic energy pathways.

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