FPSO & Offshore Platforms: Recommendations for Structural and Skid Dynamic Analysis

Background

Reciprocating compressors are a significant source of vibratory forces and can cause high vibrations and resonance on platforms and FPSOs. These high vibrations can result in costly and premature machine failures as well as safety concerns to on-site operators.

Beta Machinery Analysis (Beta) is a global leader in conducting dynamic analysis for compressors, skids and structures, Based on more than 40 years experience, we have outlined the requirements for Structure and Skid analysis. Two types of studies are generally required:

Structural dynamic analysis for Bunduq Platform (Abu Dhabi) including 5 large compressor packages (20,000 HP)

- **Dynamic design analysis** (e.g., response to reciprocating compressor loads, engine loads and pulsation induced forces). Dynamic analysis should include both the compressor skid and platform deck.
- **Quasi-static analysis** (e.g., module lifts, transportation, ship motion, wind loads, blast conditions, storm conditions, and damage conditions).

BHP Billiton Stybarrow FPSO

Topside Dynamic Structural Analysis (FPSO, Platforms)

Description

The goal of this analysis is to evaluate the response of the skid and the topside structure to the equipment dynamic loads and provide recommendations to ensure vibration is below guidelines. The following activities should be included:

Example: Beta's dynamic analysis avoided resonance on topside module (from 3 compressor packages)

- Forces generated by reciprocating compressors create vibrations on the deck structure. Dynamic structural analysis is required to avoid resonance and ensure vibration is under guidelines for all planned operating conditions.
- The platform or FPSO deck stiffness and mass at the skid mounting location has to be considered.
- Design of equipment mounting to deck (e.g., 3 point systems).
- Multi-unit analysis – when multiple skids or packages are connected together.
- Calculate pipe stress and displacements for evaluation against industry guidelines. Design assumptions between pipe flexibility studies (thermal analysis) and dynamic mechanical analysis need careful coordinating to avoid conflicting results. Differing assumptions for stiffness of pipe supports and clamps is a common problem that is difficult to resolve.
- Evaluate all computer model mesh sizes to ensure accuracy of the dynamic analysis.
- Recommend modifications to the structural design.

Study Requirements

The analysis will include evaluation of a finite element model of the skid and topside/platform structure. The model will be primarily a beam element representation of the compressor skid and structure. Shell elements will be used for plate structures and may be used in some specific cases for skid beams.

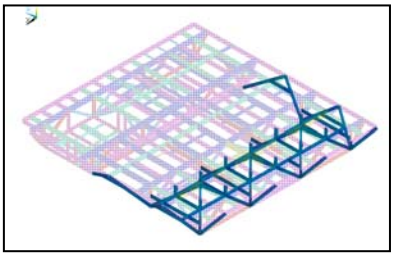
The dynamic loads will include unbalanced forces and moments in the reciprocating compressor, compressor crosshead guide forces, compressor gas rod load forces, pulsation induced forces in key piping and vessels, and unbalanced forces in the motor or engine. The analysis will include simulation at the first and second orders of compressor run speed as dynamic loads are the highest at these frequencies. Vibration will be calculated on the structure, compressor skid, and major components mounted on the compressor skid. The calculated vibration will be compared to industry guidelines. Modifications will be evaluated where necessary to reduce vibrations to acceptable levels.

FPSO design for two, 3500 HP compressor units constructed in Malta

The model will include a representative stiffness for the ship deck/platform and web frame at the structure's stabbing points. The calculation of the ship deck stiffness at each stabbing point is not part of the scope but can be included as an optional analysis.

Information Required for Skid and Structure Analysis

- Weights and Center of Gravity of all equipment
- Compressor skid drawing and platform/topside steel drawings with details
- Unbalanced forces and couples for all installed equipment on platform/topside
- Design loads for the lifting analysis
- Design loads for environmental cases
- Normal liquid levels in vessels
- Ship hull, web frame, and stabbing point fabrication drawings
- Mounting details



Recommendations for improved structural design

Recommended Cost Reduction Opportunity

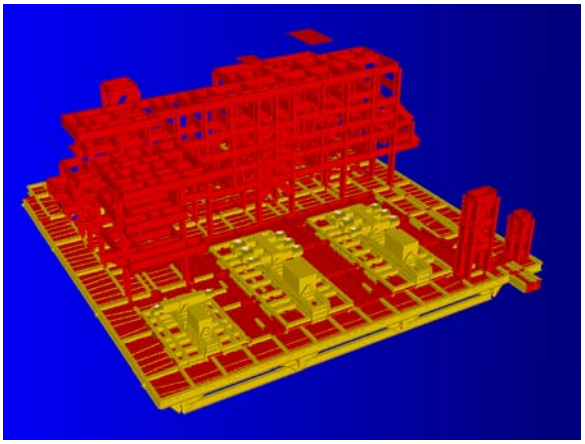
The engineering consultant supplies the platform/deck computer model (STAAD or SACS) to the vibration consultant. This *significantly reduces* amount of work and costs for the dynamic analysis.

Summary (Dynamic Structural Analysis)

The true dynamic characteristics can only be accurately simulated by including the dynamic characteristics of the skid and its support structure.

Our early input on the deck design can be key to avoiding design changes and schedule delays. Please provide preliminary or conceptual drawings of the proposed compressor skid design and deck structure design before detailed engineering or material ordering has been completed.

A report issued at the conclusion of the analysis includes recommendations for the skid and/or skid support structure design and a summary of the applied loads and results (calculated mode shapes, mechanical natural frequencies and vibration amplitudes).



Beta converts your STAAD or SAACs model to our dynamic analysis software. Note the three compressor models (yellow) included in the model

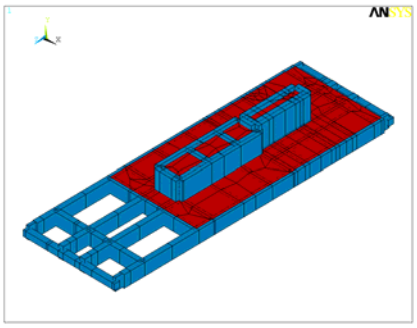
Beta Advantages

- Cost effective and accurate recommendations – compared to alternate approaches
- Validation of modeling techniques with field measurements
- Strong partnering culture to ensure win-win in project execution
- Field staff to support onsite commissioning or testing.

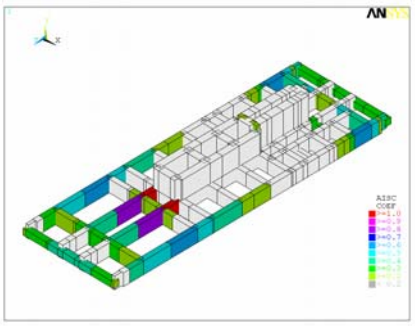
Skid Analysis

Description

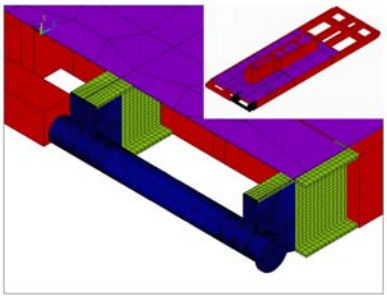
- Ensure safe lifting, transportation and operation
- Applies to skid mounted equipment (reciprocating and centrifugal compressors and pumps, process equipment, engine-generator packages)
- Compliance of skid design with international standards (ABS, API, AISC)
- Optimize skid design to minimize cost, material, weight and construction costs
- Evaluate skid design based upon
  - o Lifting loads
  - o Transportation and hold-down requirements
  - o Environmental loads such as wind, seismic, motion and/or inclination of skid in FPSO or offshore applications
  - o Dynamic loading
- Spreader bar and shackle design
- Anchor bolt loading
- Detailed finite element analysis of compressor skid for evaluation of localized skid flexibility, gusset and equipment mounting design



1. Skid Model used for Lifting Analysis



2. Skid Requires Redesign to meet Lifting Loads. Red Areas indicate beams exceed AISC Code



3. Skid model with detailed drawbar model to evaluate new standard skid design

Quasi-Static Analysis of Skids and Process Equipment
Beta considers the analysis of wind and ship motion loads to be a quasi-static analysis. This analysis evaluates the skid response and major process equipment mounting details (skirt and base plate for vertical vessels, legs for horizontal equipment) due to loading from wind and ship motion (such as pitch, roll, and heave). These loads are applied to the skid finite element model as static forces and/or accelerations.

Different combinations of the loading are considered to determine a worst case scenario. The stresses in the skid members are compared to the AISC allowables. The skid connection point loads due to the environmental loading are calculated. Detailed design of the connection points is outside of the scope of this analysis, however, typical connection configurations can be recommended.

For skids that are mounted next to each other (and connected together) the analysis is performed on the combined skid module.

The effect of FPSO hog and sag on the skid can be included in this analysis.

Skid deflections due to lifting are evaluated based on industry standards or customer specifications. The skid lifting lugs are appropriately sized and the centre of gravity calculated. A report is issued at the conclusion of the analysis that includes recommendations for the skid design (beam specifications) and a summary of the applied loading and calculated results.

<u>Detailed Skid Analysis (Option)</u>

This analysis evaluates the localized flexing of the skid members due to dynamic loads from the machinery mounted on the skid. This analysis involves creating and analyzing a detailed plate and brick finite element model of the skid, compressor frame and other significant components. Machinery loads and acoustical loads are applied to calculate the deflection of the system and determine modification that will ensure the response is within industry standard guidelines.

Spreader Bar Analysis (Option)

This analysis includes design and evaluation of spreader bar, slings and shackles for lifting the skid. The analysis is conducted after the Skid Design Review and Lifting Analysis has been completed. A report is issued at the conclusion of the analysis that includes recommendations for the lifting apparatus design, a summary of the applied loading, and calculated spreader bar stresses and sling loads.

Skid Design, Mechanical Model, Thermal Analysis and Commissioning

Beta Advantages

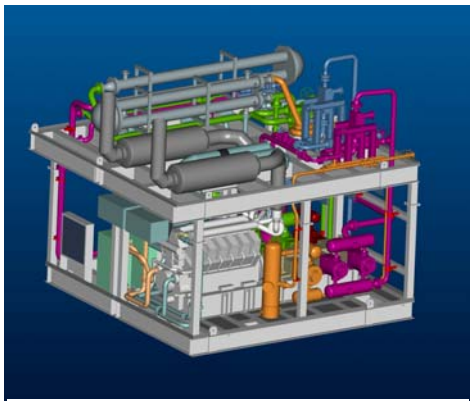
- Comprehensive modeling of all aspects of the package design
- Fast and cost effective approach
- 40 years of field experience to draw upon for recommended practical skid designs

DNV Requirements for Structural and Skid Analysis

Any additional reporting or analysis required by DNV will be done at hourly rates. At this point we are unable to anticipate what is required.

Other Beta Services

Beta works closely with the packager/customer to avoid vibration problems on the compressor package (including piping). Our Beta Design Study can include all of these important design elements:



Integrated Design Study including Pulsation, Mechanical, Thermal, Skid and Structural Analysis (courtesy of Chevron, Mustang)

- **Pulsation and Mechanical Vibration Studies**: These studies are based on API 618 requirements for reciprocating compressor packages.
- **Torsional Vibration Analysis**: Analysis of shafts, couplings, and gears to evaluate torsional natural frequencies, vibration, and stresses.
- **Thermal (Piping Flexibility) Analysis**: Evaluate the stress due to thermal cycles, weight, and static pressure in the piping as per B31.3 or other requirements. Recommendations are provided and include supports, clamp designs, etc.
- **Foundation, Structural, Skid Analysis**: Dynamic analysis to support the compressor application

Structural Design for FPSO

Field Start-up and Troubleshooting: Onsite visit to assess the actual vibration, pulsations and other factors and ensure vibrations meet guideline.

Remote monitoring service for rotating and reciprocating assets. Ideal for FPSO/Platform facilities where condition based maintenance and machine performance is required to avoid production losses.

For application support, please contact us (www.BetaMachinery.com).