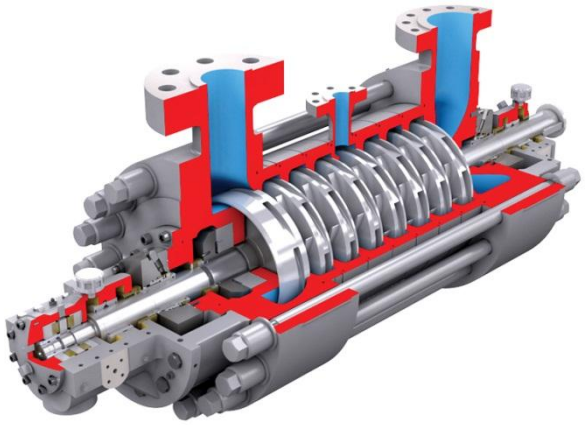
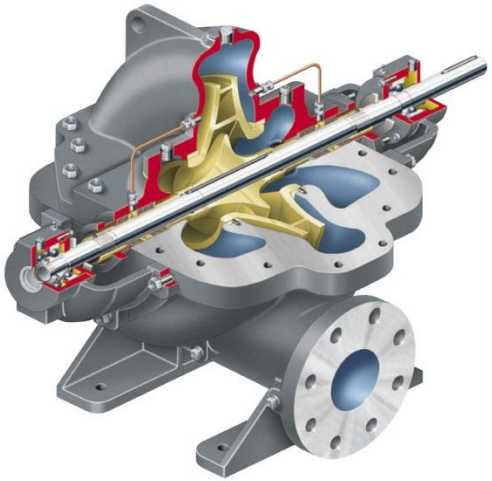
Important Considerations for Pump Modularization Strategies

Beta Machinery Analysis





Presenters

Jordan Grose, P.Eng.	Jordan is a mechanical engineer with a wide range of domestic and international design, field, and monitoring experience with compressors, pumps, and other production machinery. He has specialized skills in vibration, performance, and troubleshooting in onshore and offshore production facilities. Jordan has been with Beta Machinery Analysis for the last 10 years. He was formerly responsible for Beta's Malaysia office in Kuala Lumpur for two and a half years. Jordan currently leads the pump systems department in addressing vibration and reliability issues on reciprocating and centrifugal pumping systems including pulsation, mechanical analysis, structural dynamics, water hammer transient studies, small bore piping analysis and other related design work. He has authored, co-authored, and presented several articles and technical papers, including most recently, *Integrity of Pulsation Dampeners in Liquid Systems*, at the 2012 International Pump Users Conference in Düsseldorf, Germany.
Chris Harper, P.Eng.	For the last 13 years at Beta Machinery Analysis, Chris has developed his expertise in digital acoustic simulation, dynamic finite element analysis of reciprocating compressor packages, and structural analysis for on- and off-shore applications. His field troubleshooting experience includes solving vibration and pulsation problems on reciprocating gas compressors and engines. As a Principal Engineer, Chris has lead research in small bore piping vibration and flow induced vibration. Chris has co-authored numerous technical papers presented at the Gas Machinery Conference, EFRC, and magazines, and is a primary presenter for the GMRC training course "Compressor Station Vibration."

Outline

1. Pump Modularization – General Concept and Motivations
2. Structural Design
    - Static Concerns
    - Dynamic Concerns
    - Foundation Concerns
    - Small Pump Installations
    - Large Pump Installations
3. Other Considerations
    - Piping Design, module edge nozzle load analysis strategies

Pump Modularization

- What is the general concept?
- Installing pumps on steel modules instead of concrete blocks

Pump Modularization

- Why Modularize?
  - Increase Quality
  - Simplify Construction On-site
  - Save Costs

Increased Quality-Lower Cost

- Construction Performed in Shop/Module Yard
  - Better quality control ability
  - Better productivity
  - Conflicting activities affecting more easily managed (e.g. X-ray shooting)
- Construction Site Benefits
  - Reduced # of workers at job-site (easier management)
  - Reduced construction time at site, more parallel activities possible
  - Reduced space conflicts during construction/assembly
  - Reduced need for redundant equipment on-site (e.g. cranes)
  - Reduced overhead and indirect costs

Cost Savings

- The degree to which costs are saved depends on:
  - How remote the site is (i.e. More remote, more savings)
  - Weather
  - # of workers on-site, and whether this # manageable

Feasibility

- There is some trepidation within Alberta Industry to do this.
- The offshore industry has to deal with this everyday, and there are common methods and considerations that make the concept technically feasible

Modularization is Technically Feasible with Proper Design Considerations

Common concerns

- Vibration of rotating equipment
- Machinery alignment
- Poor reliability of machinery
- Vibration transfer to surrounding structure, and equipment

Beta's Experience with This

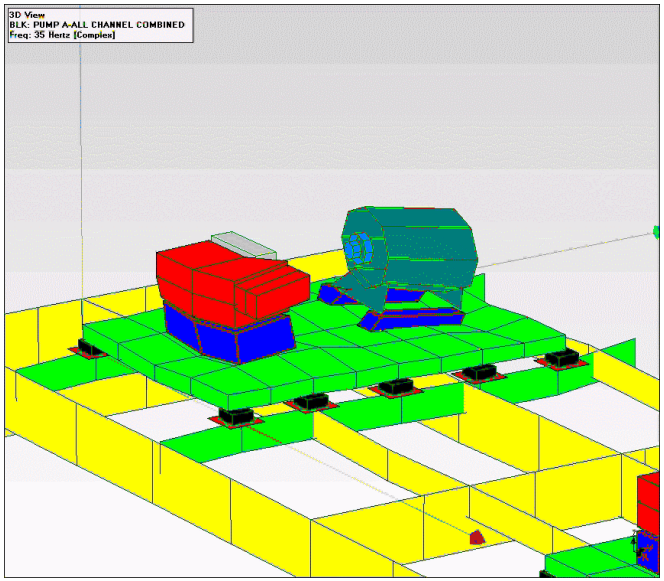
Field Troubleshooting, Design Engineering

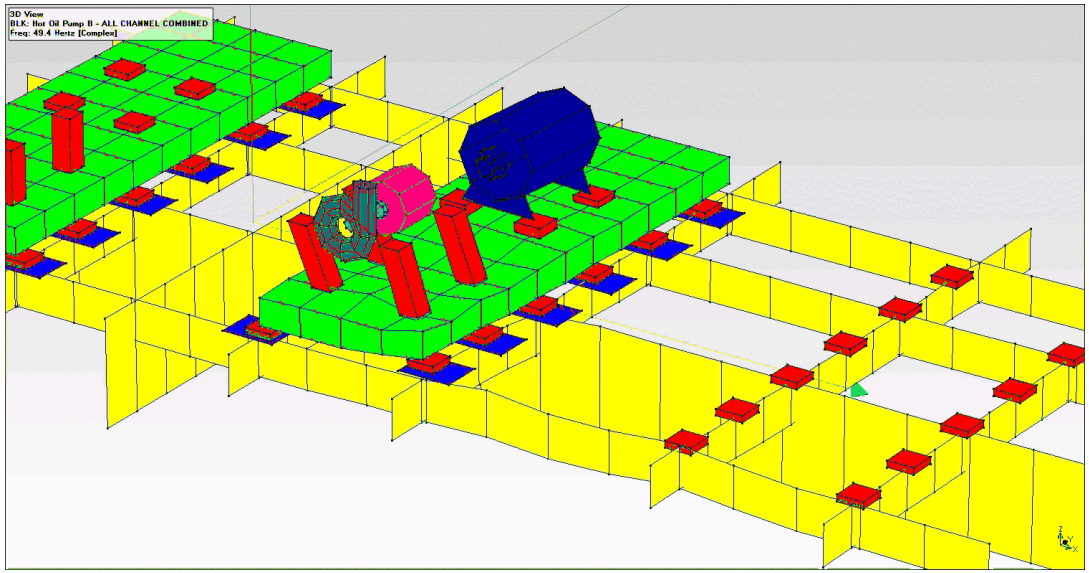
- FPSO Modules

- Offshore Platforms

- Pile mounted machinery

Beta's Experience with This





Glycol Circulation Pumps:

- 110kW, 1500 rpm motor, 294 rpm pump
- Motor, reducing gear box, pump
- 3 double diaphragm plungers
- Offshore application

Hot oil circulation centrifugal pumps:

200kW, 2900 rpm

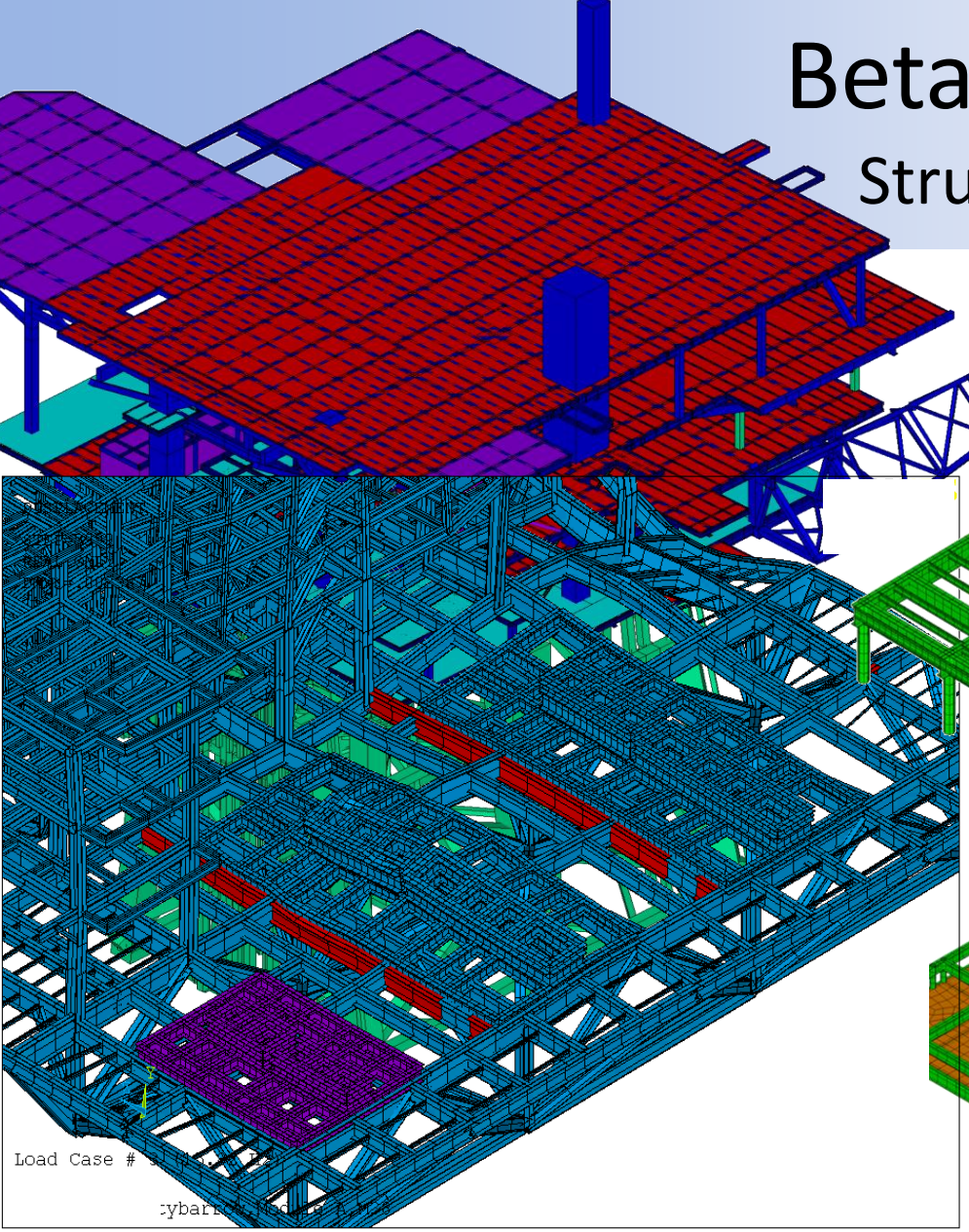
No gear box, direct magnetic coupling drive

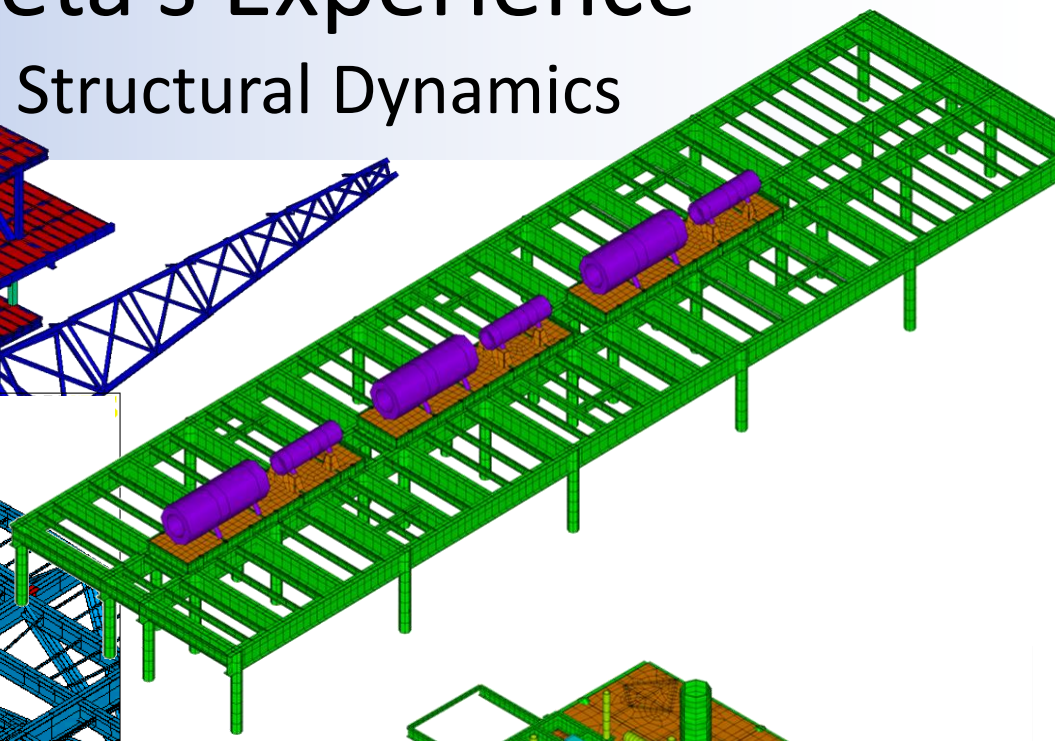
Offshore application

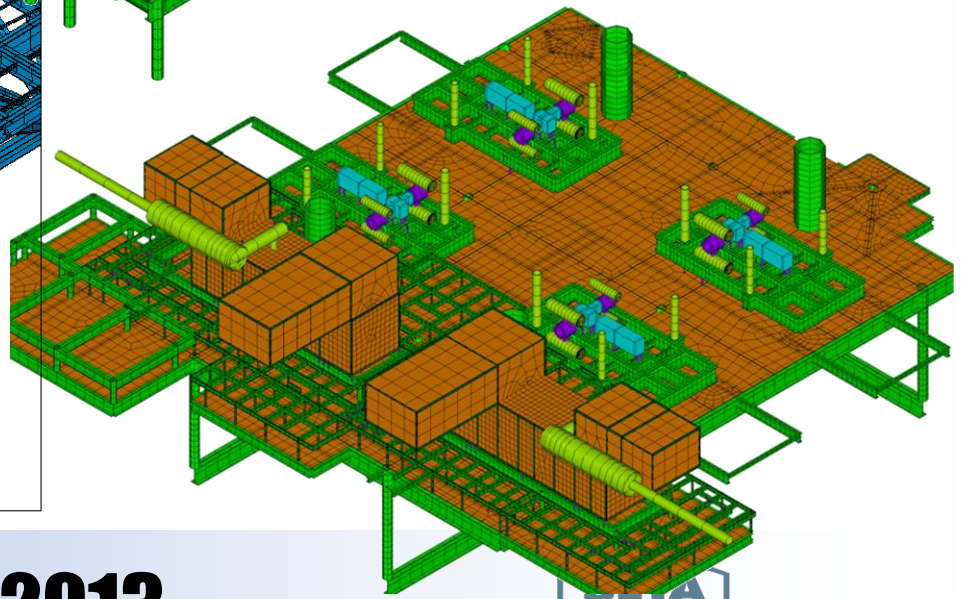
Combined skid support and platform problem

Beta's Experience

Structural Dynamics

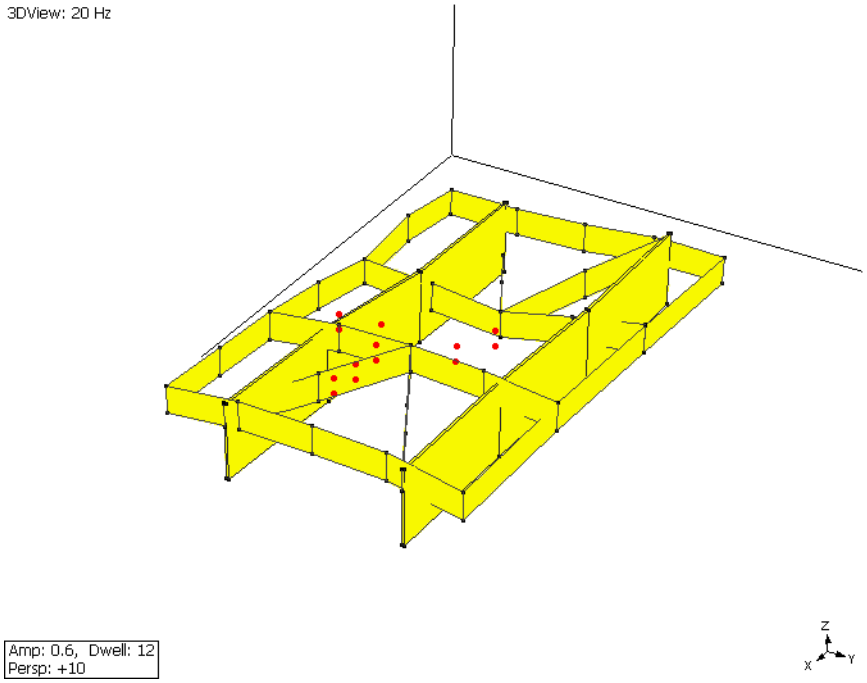




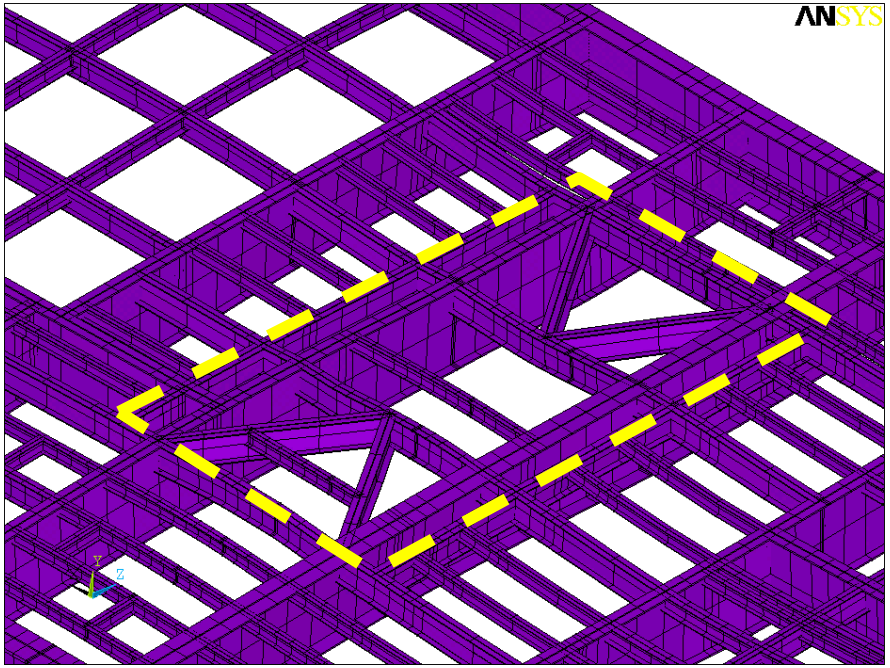


Beta's Experience

Actual Field Data



Detailed Structural Model
(Finite Element Analysis used for Dynamic Analysis)



Modular Design

Important Considerations List

Module Structural Design

- Transportation Size Restrictions
- Static & Quasi-Static Loads
  - Transport
  - Environmental
  - Seismic
- Dynamics
  - Structural Dynamics due to Rotating Machinery
  - Dynamic Forces
  - Dynamic Flexibility
  - Influences on surrounding equipment
  - Limitations of static models used in dynamics
- Foundation
  - Module base stiffness

Piping design

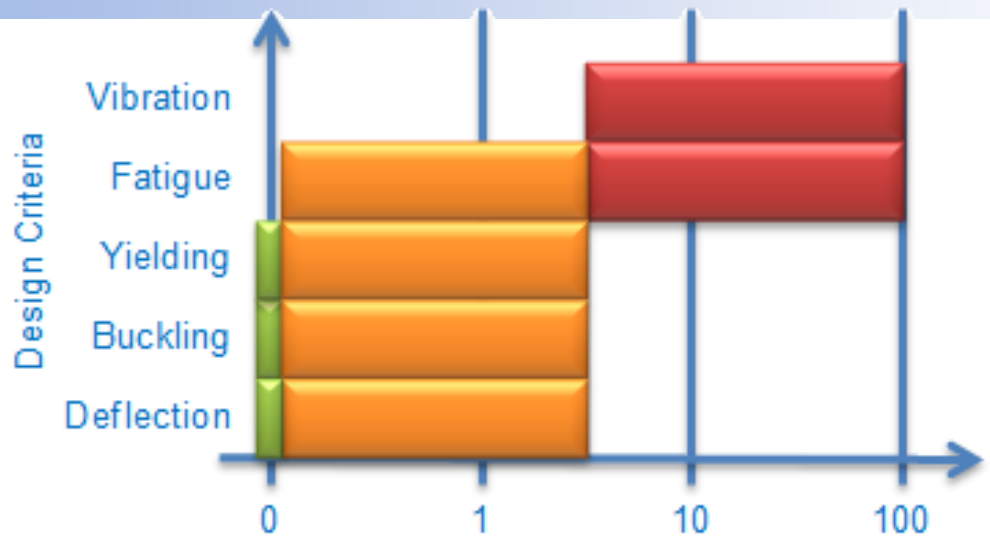
  - Module edge nozzle load analyses
  - Piping vibration on the module

Module Structural Design

Transportation Size Restrictions

- Can we get this on the highway?

Confusion About Static vs. Dynamic Analysis



Static Analysis - Lifting and thermal loads

Quasi-Static Analysis - Loading caused by wave, seismic, etc.

Dynamic Analysis - Equipment and other forces causing resonance

This is NOT a Dynamic Study

Module Structural Design

Static Loads

GOAL – To Prevent Bent Structures

- Typical loads include:

  Lifting, Loadout, Snow, Thermal, Drive Torque
- Analysis done to calculate loads, deflection, buckling, and stress
- Can be done with relatively simple techniques
  - Handbook calculations
  - FE Beam models

Lifting

Loadout

Snow

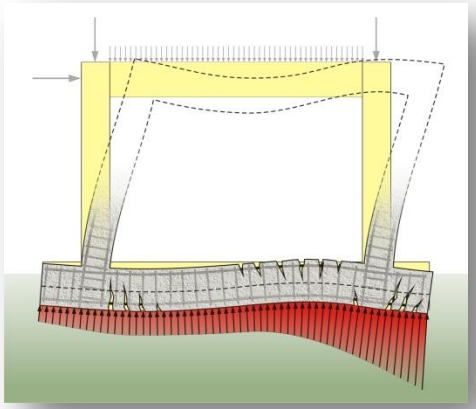
Module Structural Design
Quasi-Static Loads

GOAL – To Prevent Bent and/or Swaying Structures

- Typical loads include:

  Wind, Transit, Blast, Seismic, Wave, and others
- Analysis done to calculate deflection, loads, stress, and fatigue
  - Can use FE Beam models
  - Inertia not considered

Wind



Seismic

Wave

Module Structural Design
Quasi-Static Loads

- Block Foundations do not require Quasi-loads like transportation or Static loads like lifting
- More analysis is required for modular designs

- While structural software packages may have options for dynamic analysis, it can be more complicated than enabling that feature

Module Structural Design

Dynamic Structural Analysis

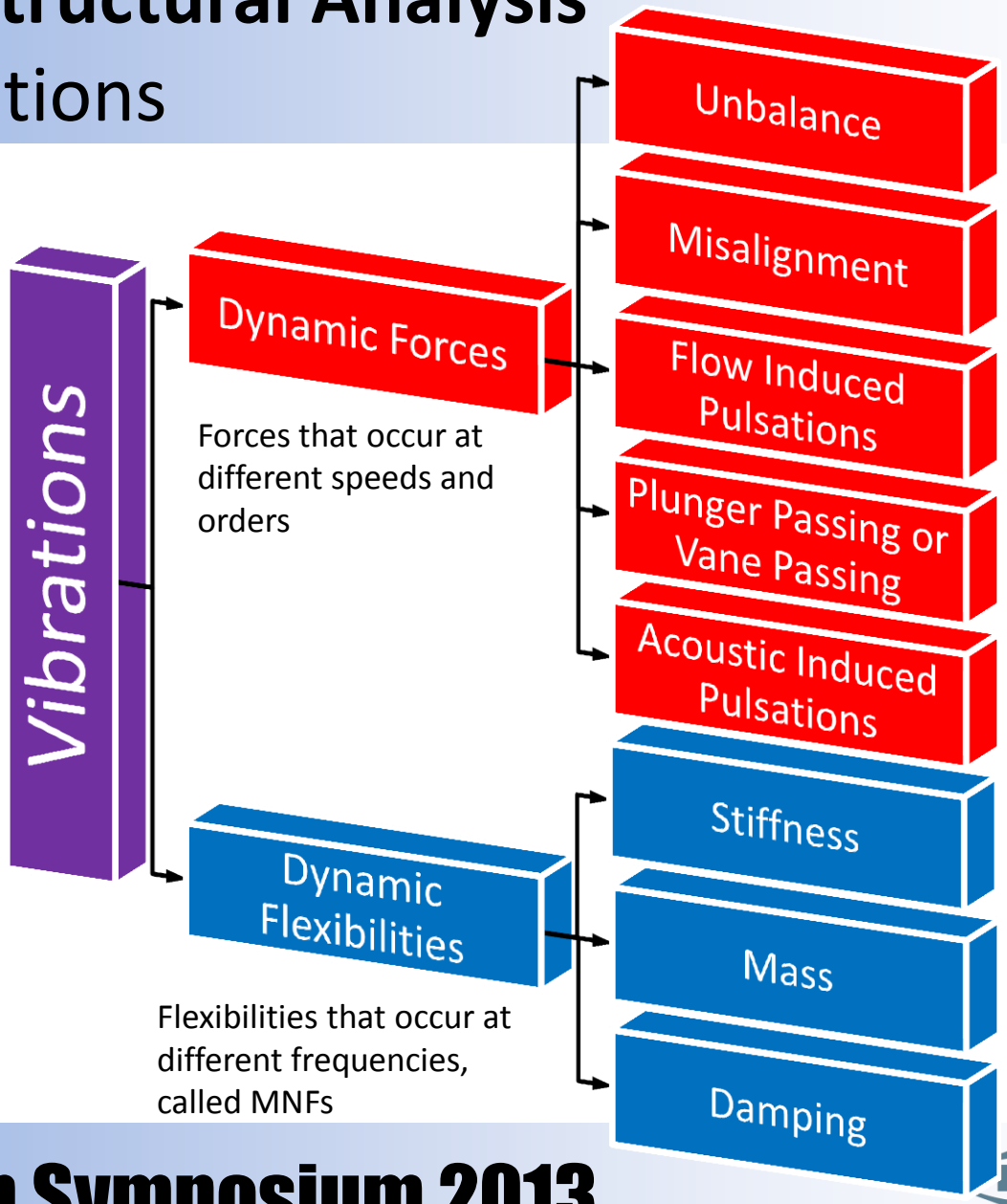
GOAL – To prevent excessively vibrating machinery & structures, prevent fatigue

Considerations

- Much more complicated than with block foundations
- When considering many cycles per second of structural motion, the following aspects must be considered (unlike quasi-static):
  - Structural inertia
  - Dynamic forces
  - Dynamic flexibilities
    - Mechanical natural frequencies (MNFs)
  - Resonance

Dynamic Structural Analysis

Vibrations



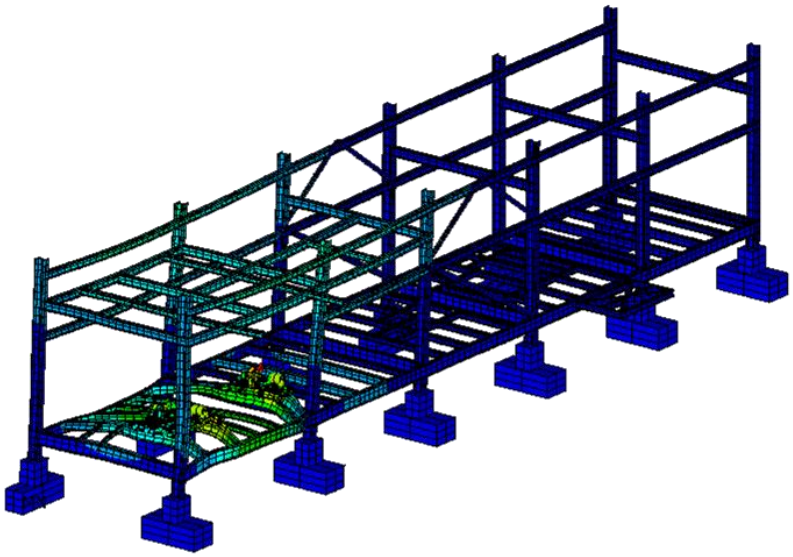
Dynamic Structural Analysis
Dynamic Forces

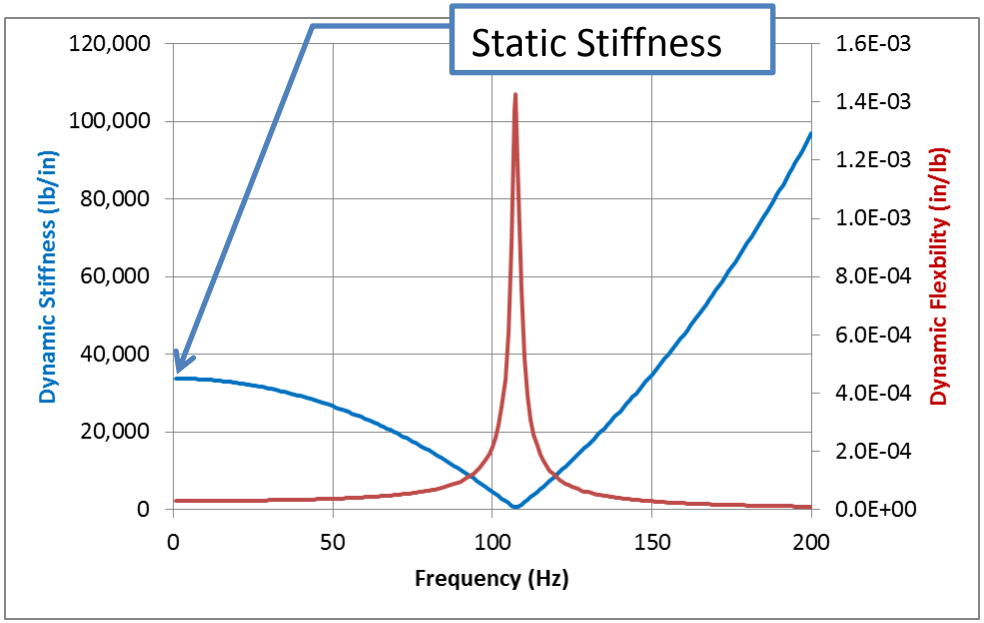
- Centrifugal
  - Rotor unbalanced forces (for motor and pump) calculated with ISO 1940/1 method
- Reciprocating
  - Pump unbalanced forces & moments
  - Fluid end stretch forces (for high pressure ratio cases)
  - Motor unbalanced forces

Dynamic Structural Analysis

Dynamic Flexibility

- Dynamic flexibility increases at the Mechanical Natural Frequency (MNF) – up to 50x static flexibility
- Typical modules will have 40-100 MNFs in the frequencies of concern





Dynamic Structural Analysis

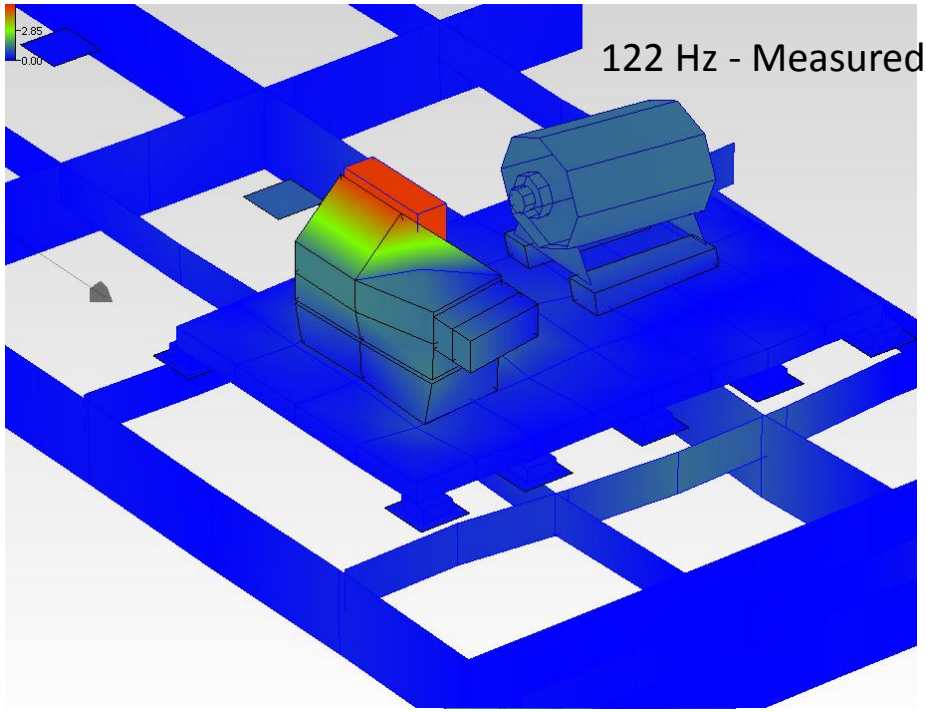
Resonance

- The real problem is resonance (Dynamic Force coinciding at MNF)
- With 50+ MNF's and variable speed machinery, resonance is unavoidable
- Need to conduct a forced response analysis combining dynamic force & dynamic flexibility of the system to calculate vibration
- If vibrations are excessive, modifications of pump skid and/or module structure are required

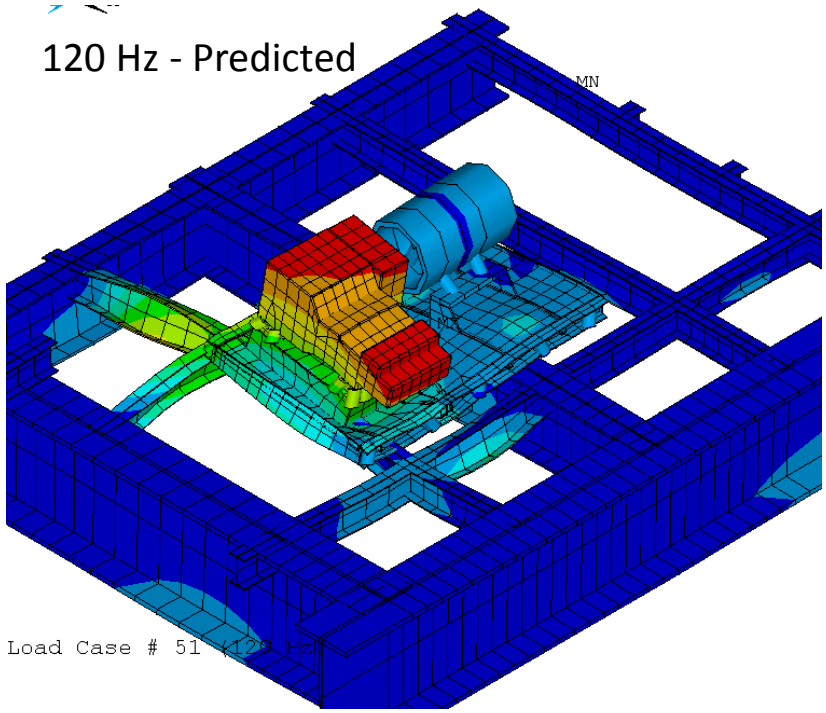
Dynamic Structural Analysis

Field Measured vs. Forced Response

Field Vibration Data (ODS)



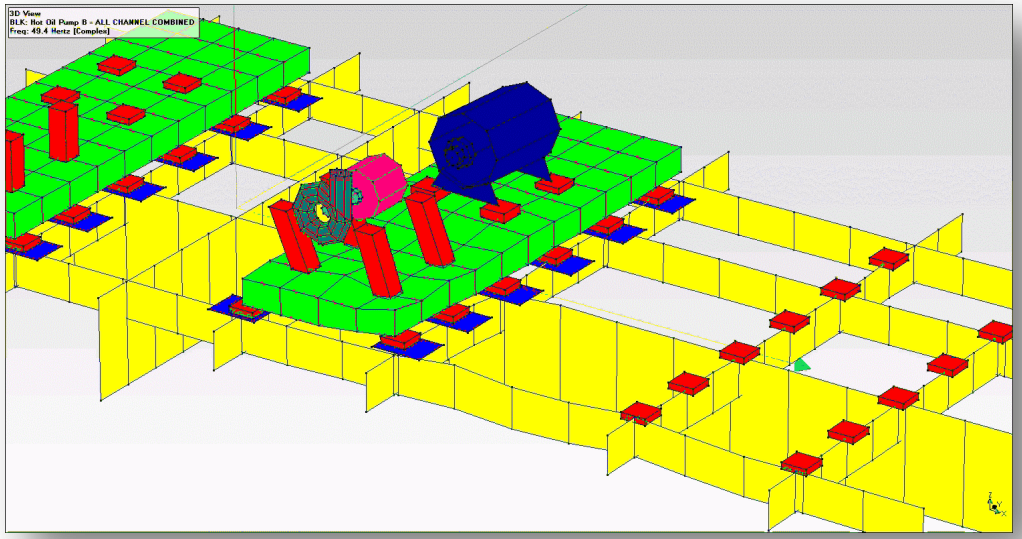
FEA Forced Response



Module Dynamic Structural Design

Baseplate & Structure

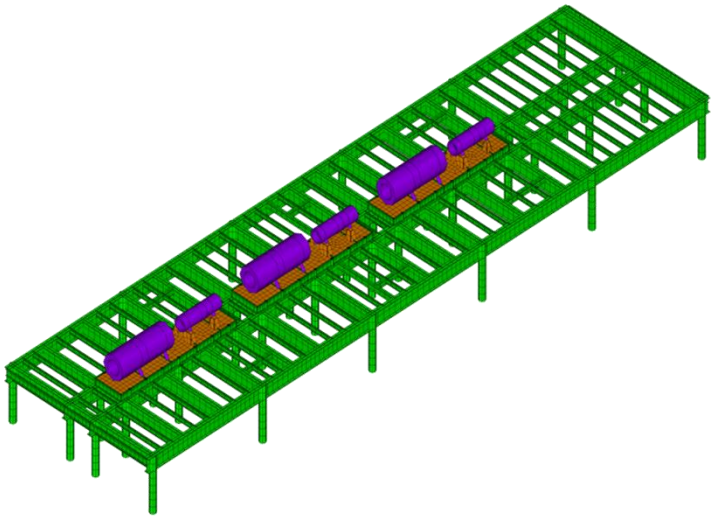
- Baseplate and structure underneath are a system
  - To get accurate results, must analyze together

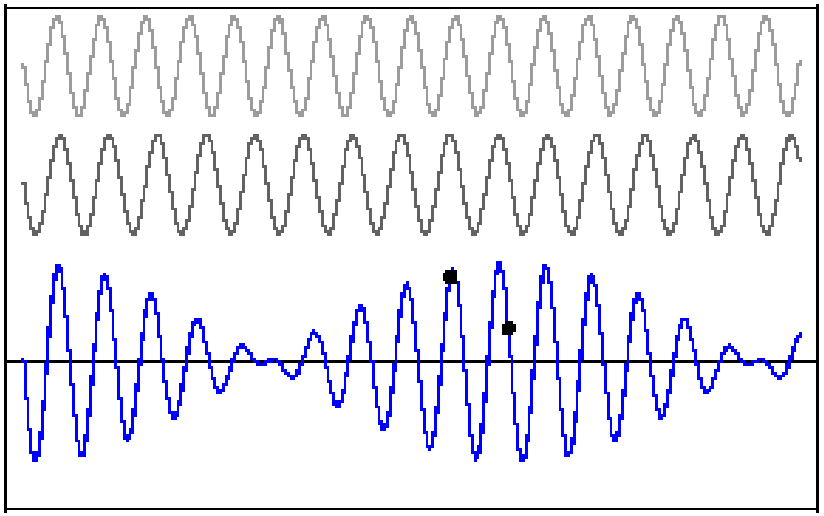


Module Dynamic Structural Design

Influence on Surrounding Equipment

- Multiple baseplates and structure underneath are a system
  - To get accurate results, must analyze together



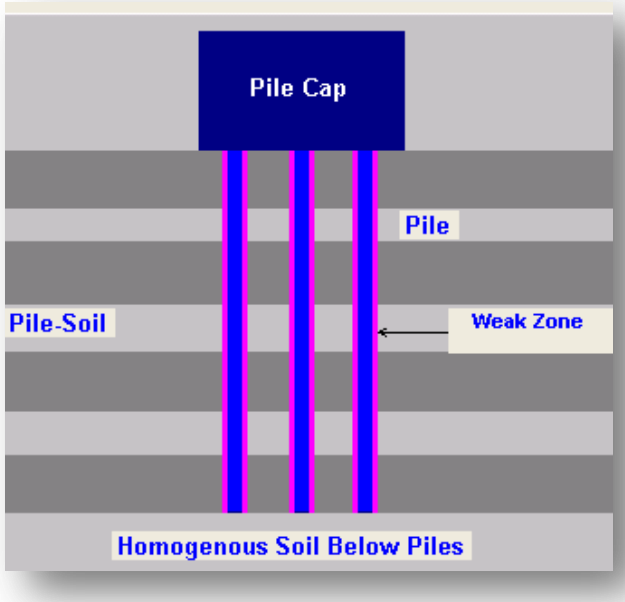


Animation courtesy of Dr. Dan Russell, Kettering University

Module Dynamic Structural Design

Module Footings

- Similar to concrete foundations, an understanding of the foundation stiffness is required
- Must consider:
  - Piles stiffness
  - Concrete pile cap
  - Soil Properties



Small Pump Installations

Dynamic Analysis Rules of Thumb

- Centrifugal pumps < 500 HP, Reciprocating pumps < 50 HP
  - Generally not required
  - A structural review by a dynamics engineer can be done without detailed calculations
  - **HOWEVER**, if the following apply, a Dynamic Structural analysis may still be necessary:
    - Multiple Units on same pancake
    - Critical applications
    - Planned operation significantly off BEP
    - Sensitive Surrounding Equipment

Large Pump Installations

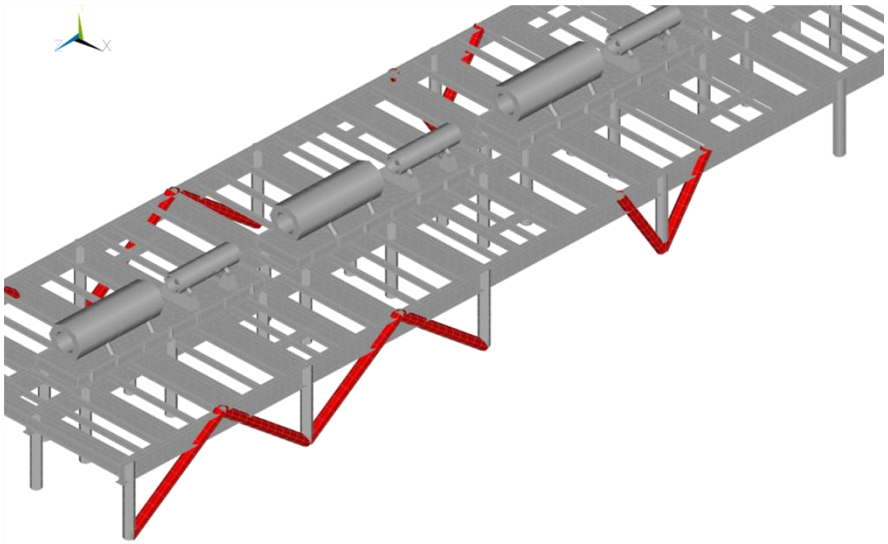
Dynamic Analysis Rules of Thumb

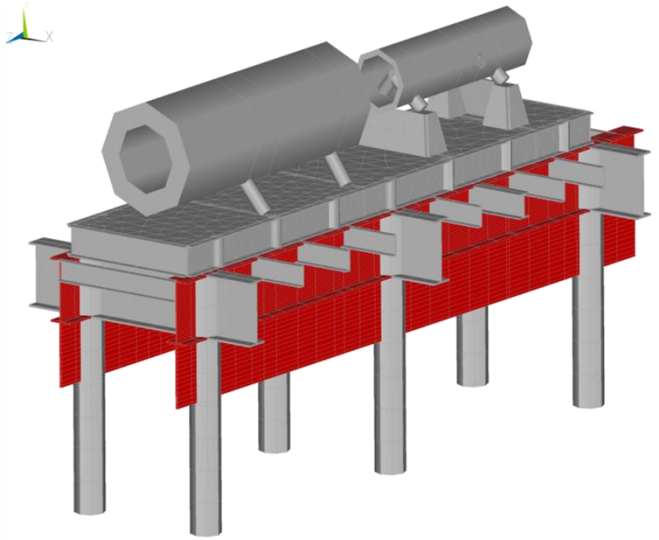
- Centrifugal pumps > 500 HP, Reciprocating pumps > 50 HP
  - Dynamic Structural Analysis should be considered
  - Considerations of the following are needed:
    - Baseplate, Pancake, Support Structure as a system
    - Module footing Flexibilty
    - Multiple units together
    - Rotating Machinery Inherent Forces for all specific operating scenarios

Potential Structural Modifications

Retrofit Example

- Additions of mass/stiffness (grout or concrete)
- More steel in key locations
- More piles in key locations





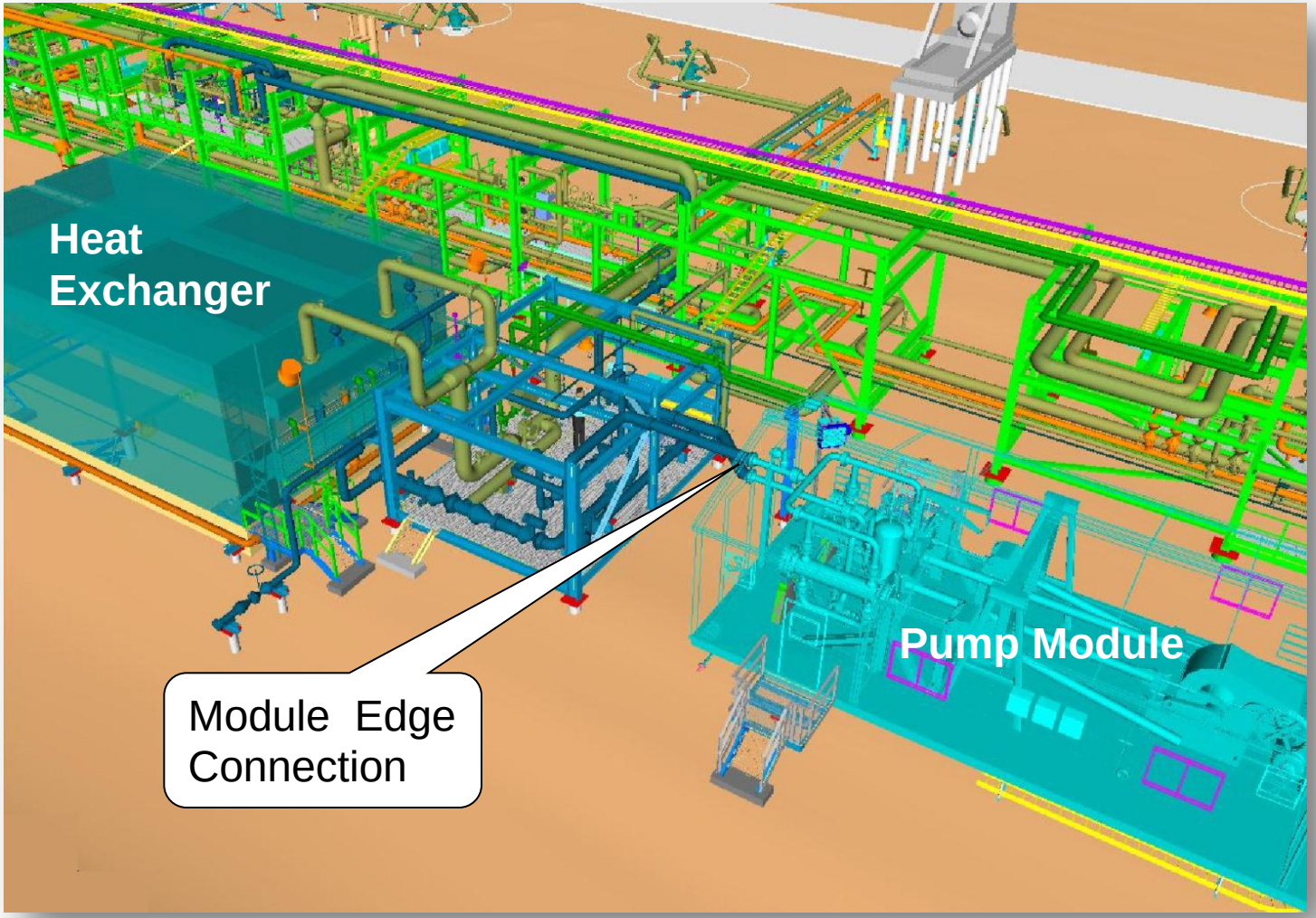
Piping Design

Pipe Stress Concerns

- Module edge pipe connections
  - Common practice is to assume an anchor at the module edge
    - This is generally done if two different companies design adjoining modules (no shared responsibility)
    - Can result in overly-conservative pipe stress design
    - Can be detrimental to vibration design
  - Here is an example

Piping Design

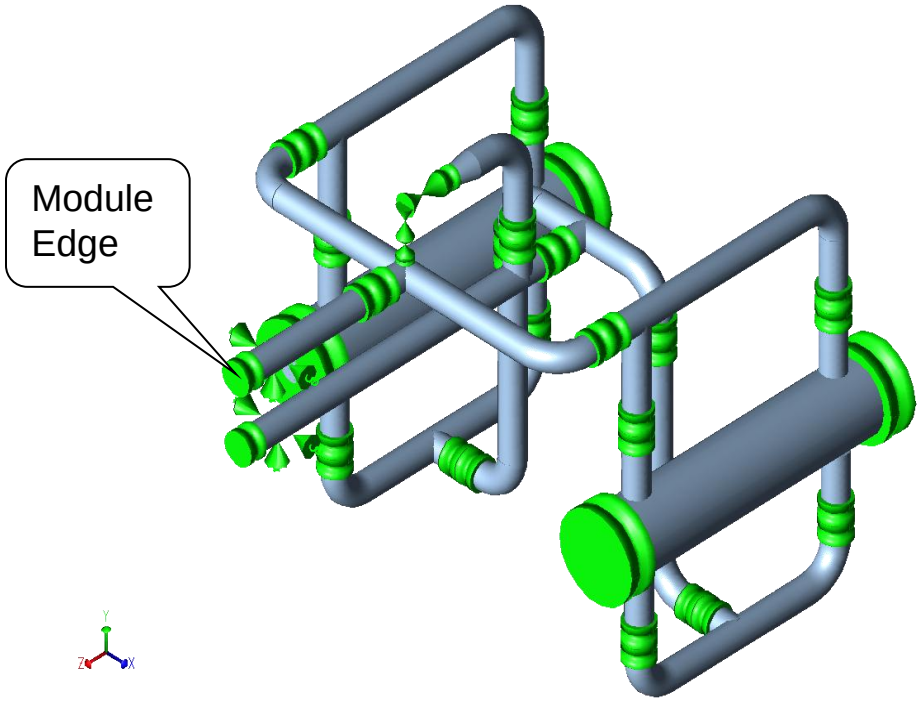
Case Study

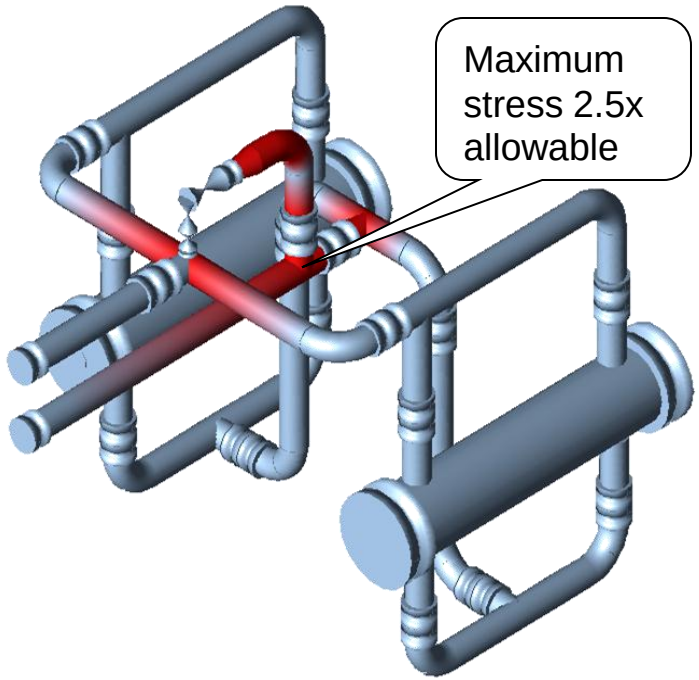


Piping Design

Case Study

- Packager model – anchor at skid edge
- Stress calculated to be 2.5x guideline!
- Big changes required…but unit is about to ship

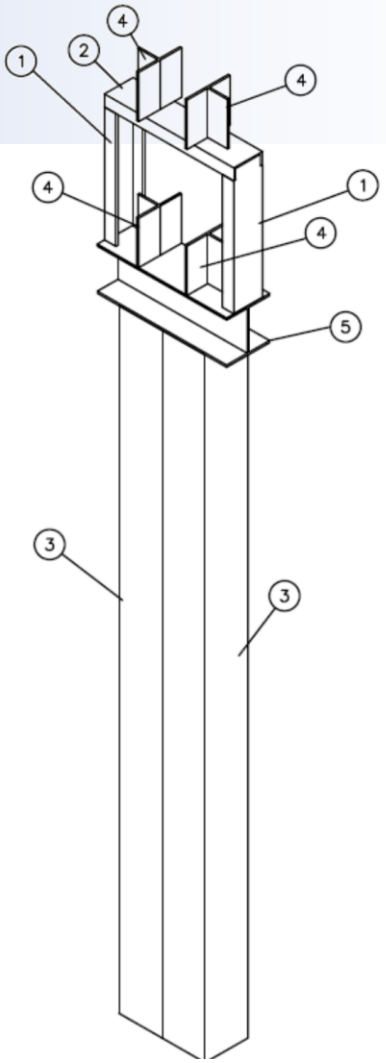




Piping Design

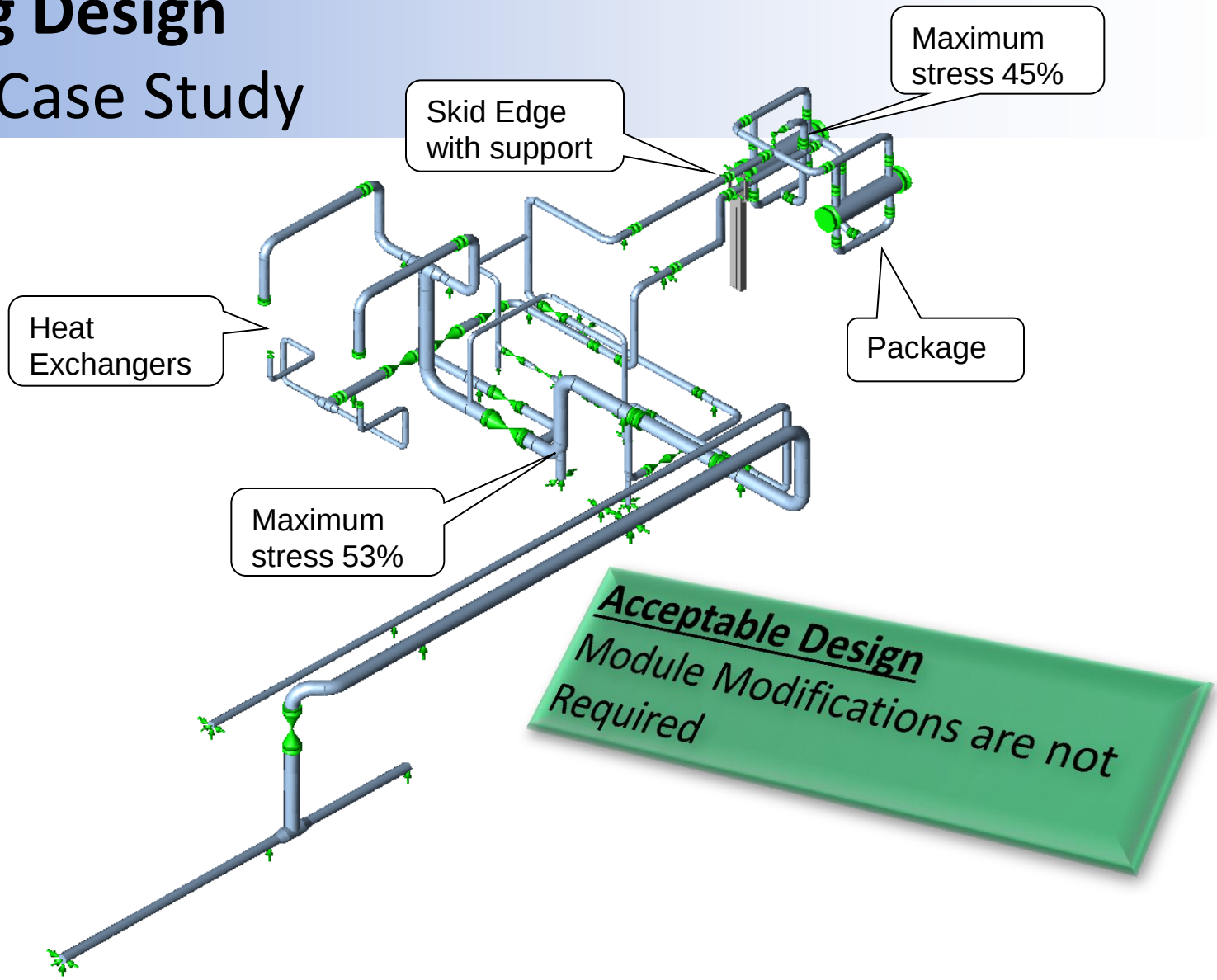
Case Study

- Is Skid Edge Support an Anchor?
- Two, 6”x 6” structural tubes approximately 92” long.



Piping Design

Case Study



Summary

- Pump modularization is feasible with the proper design considerations. Lessons have been learned from the offshore industry.
- Modularized packages have less stiffness and less mass, therefore, more intensive structural design is required
- You can modularize the design but don't modularize the analysis. System analysis must be viewed holistically (ie. OEM scope, EPC scopes must overlap)
- Third party consultants can facilitate this overlap

Acknowledgements

- Chris Gilmour – North West Redwater Partnership
- Kelly Eberle – Beta Machinery Analysis
  - "A recommended approach to piping flexibility studies to avoid compressor system integrity risk", Gas Machinery Conference 2011
- Chris Harper – Beta Machinery Analysis
  - "Optimized Skid Design for Compressor Packages", Gas Machinery Conference 2013