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Finite Element Method in Crane Structural Failure Analysis and Rectification

Overviews

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- Introduction of Portek
  a) about Portek
  b) our Experiences
- Introduction
- Application of FEM
  – Crane Repair
  – Crane modification
  – Crane life assessment
- Conclusions
- Q&A Session

History

- Established in 1988
- Turnkey provider of equipment, services and solutions to the global port industry.
- Expanded into port operations in 1999.
- Listed on the Mainboard of Singapore Stock Exchange in 2002.
- Headquartered in Singapore, with offices in locations across Asia, Europe and Africa employing over 1400 employees.

Core Businesses & Competencies

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| Port Operations and Management

| Equipment Engineering

- Equipment sale and leasing
- Mobilization, modification & modernization
- Maintenance, diagnostics & repairs
- Distribution of components and spares

| Port IT Solutions

- Container Terminal Management System
- (CTMS)
- Equipment Maintenance System
- Terminal Planning & Simulation
- Radio Data Terminal System (RDTS)
- Positioning Determining Systems (PDS)
- Optical Character Recognition (OCR)

Terminal Ops & Management

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- Bejaia Mediterranean Terminal, Algeria
- Valletta Gateway Terminals, Malta
- Terminal 009, Jakarta
- Terminal 300, Jakarta
- Port D'Owendo, Libreville, Gabon
- Port Gentil, Gabon
- Banten Multipurpose Terminal, Java

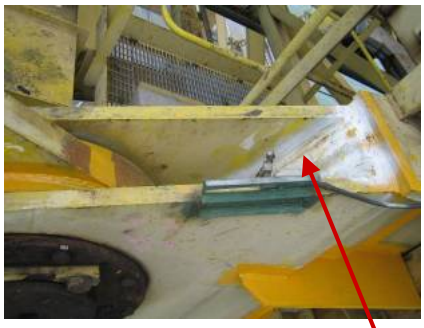
Introduction

Failures of crane structure are becoming more common!

About 1.2m crack found at boom web plate

Introduction

Failures of crane structure are becoming more common!



Crack found at boom-girder hinge

Introduction

Failures of crane structure are becoming more common!

Incident of trolley wheel truck due to crack

Serious wear on trolley rail

Introduction

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Failures of crane structure are becoming more common!

Cracks at girder end

Repair of forestay gusset plate:
ware and cracks

Introduction

Why are crane structure failures becoming more common?

Although modern design software and manufacturing process have helped crane manufacturers to optimize their design, there is still some degree of trial and error in any new crane design.

- Crane sizes have increased significantly. Weight of the crane has increased to 2000 ton versus 800 ton. Outreach of 65m versus 34 m.
- Crane speeds have also increased substantially.
- Crane lift capacity increased from 40 ton to now 65 ton

Introduction

Why are crane structure failures becoming more common? (Continue)

- Most crane designs are based on experiences and data gathered.
  - Static + dynamic factor
  - No enough study on the dynamic characterization of super sized crane
- Crane manufacturing are carried out in countries where labour cost is a lot cheaper, and quality control may not have kept up to standard.
- We are venturing into new territories which only time will tell as to whether the crane structures can withstanding the duties they are designed for.
- Need to determine if manufacturing quality problem or inherent design problem.

Introduction

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What are the common types of crane structure failures?

- Trolley structures
- Boom-girder joints
- Trolley rail
- Crane leg structure
- Gusset plate of forestay
- Main equalizer beam
- Rope sheave supports
- …

Most of the failures caused by fatigue!

Solutions for Crane Failures

Conventional approach of repairing cracks

- gouging out the cracks and filling up with welds is no longer sufficient, and in fact dangerous. Often the root cause of certain cracks may originate from points remote from the cracks
- Due to added design complexity and load, terminals should study and approach each case scientifically and get to the root cause of failure

The Finite Element Method (FEM) should be a standard tool in analyzing the cause of failure, and in recommending proper repair procedures !

What is FEA

Finite Element Analysis (FEA) is a way to simulate loading conditions on a design and determine the design's response to those conditions.

The design is modeled using discrete building blocks called **elements**.

- Each element has exact equations that describe how it responds to a certain load.
- The "sum" of the response of all elements in the model gives the total response of the design.
- The elements have a finite number of unknowns, hence the name **finite elements**.

Why is FEA Needed

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To help finding the root cause of failure

- Computer simulation allows multiple “what-if” scenarios to be tested quickly and effectively.

To help making right decision for the repair at beginning

- Computer simulation allows comparing the different designs **Virtually**.

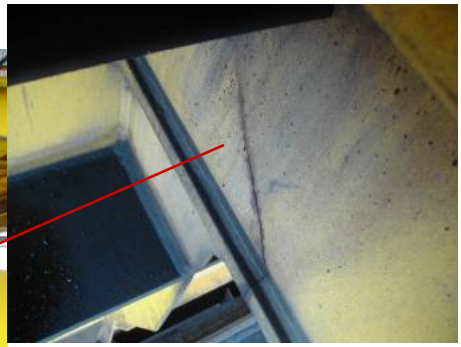
The bottom line:

- Cost savings
- Time savings
- Create more reliable, better-quality designs

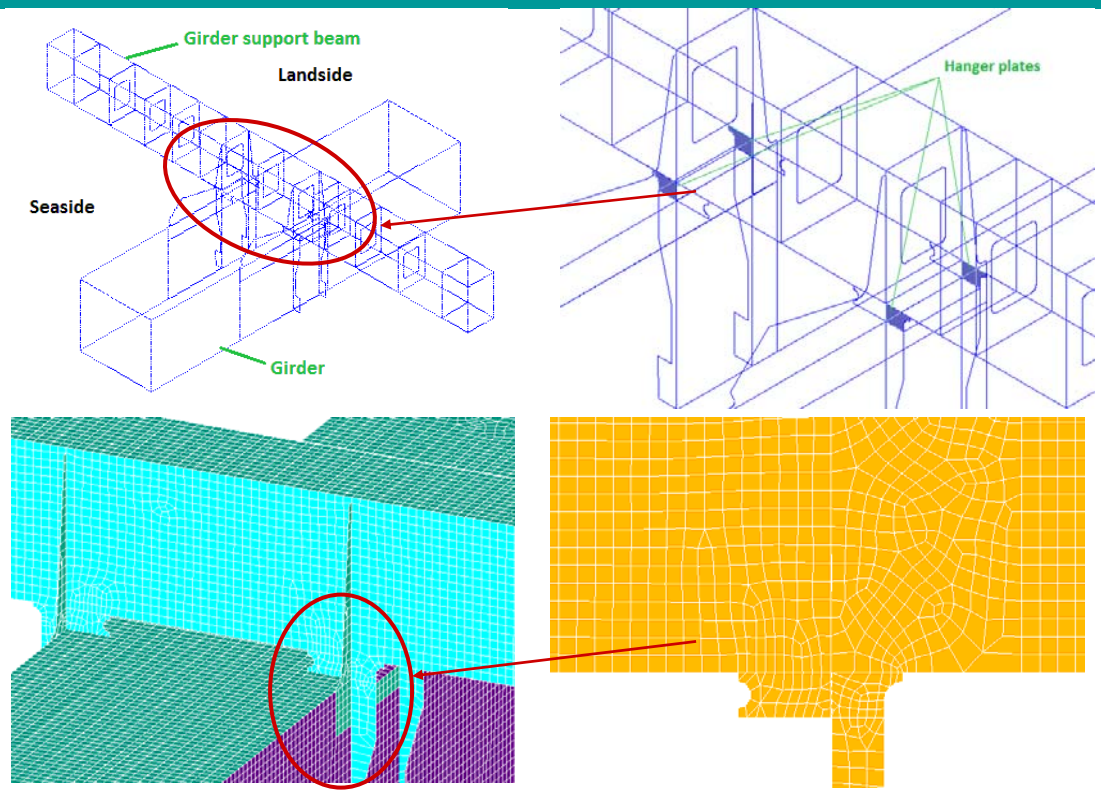
Application of FEM in Portek

1. Transportation
   - Sea fastening design
   - Deck strength
   - Quay strength
2. Crane modification
3. Crane repair
4. Crane life assessment

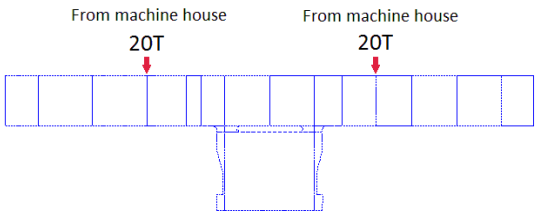
Sample 1: TGSB Crack Repair

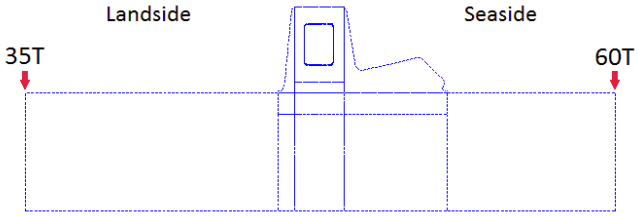


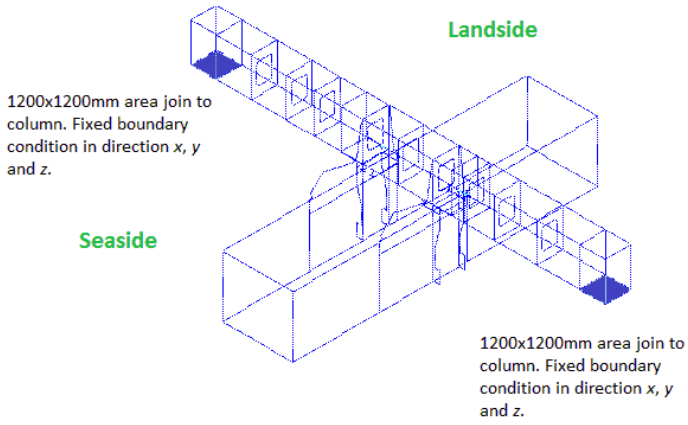
Modeling of the affected areas Using FEM



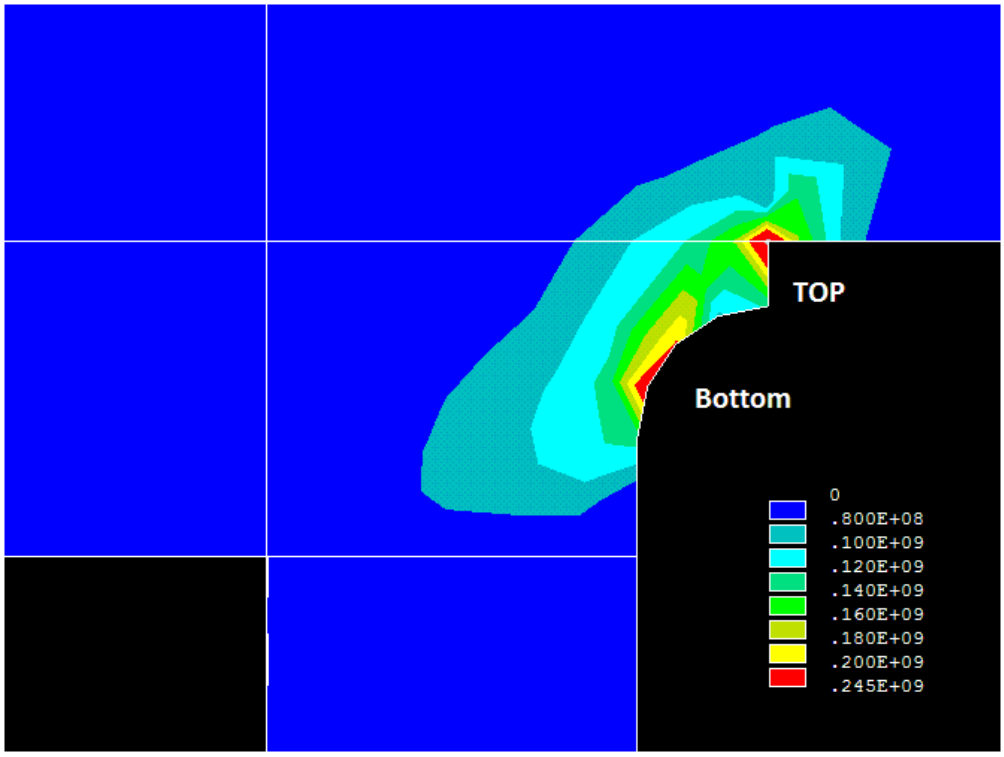
Loading and Boundary Conditions



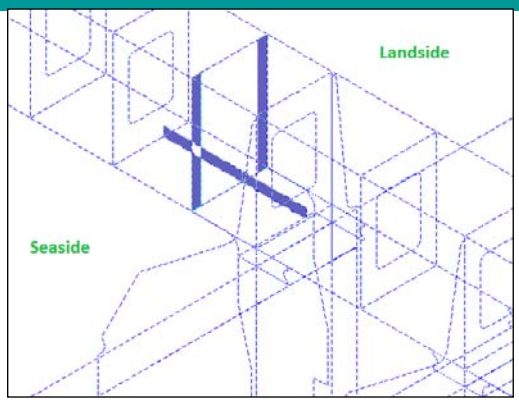


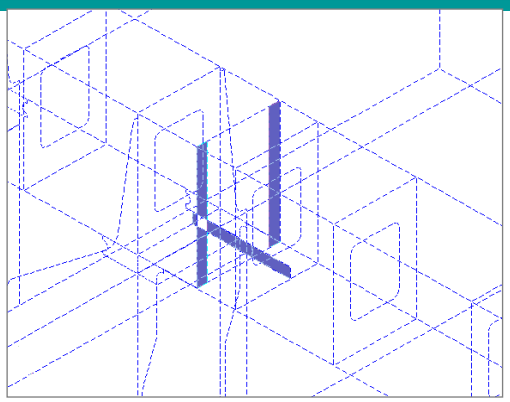


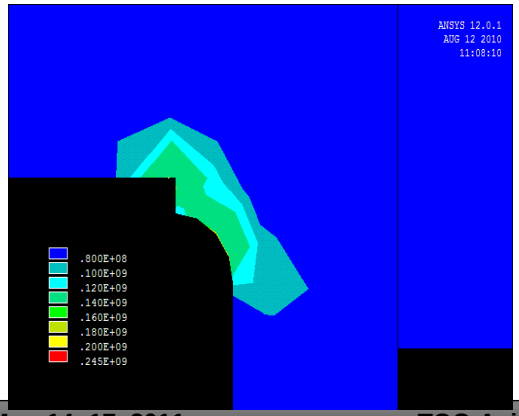
Simulation Results for Original Design

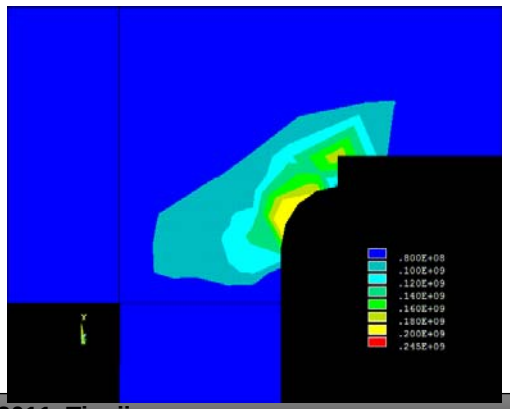


Proposed Solution 1: Internal Reinforcement

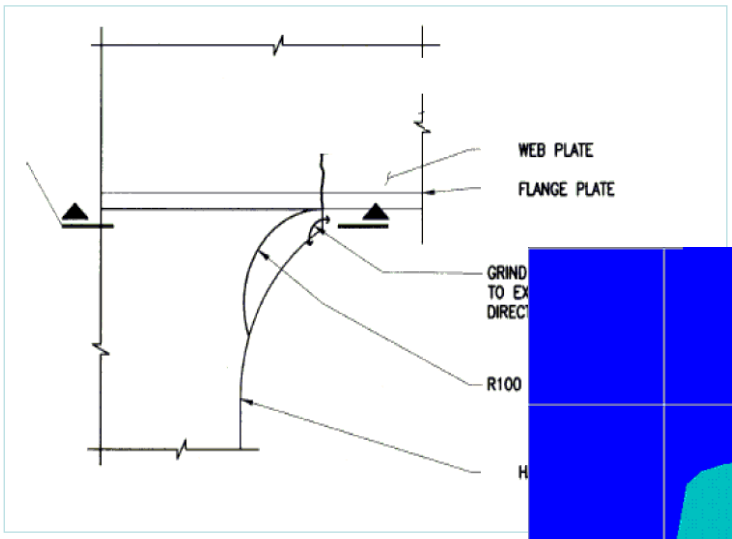




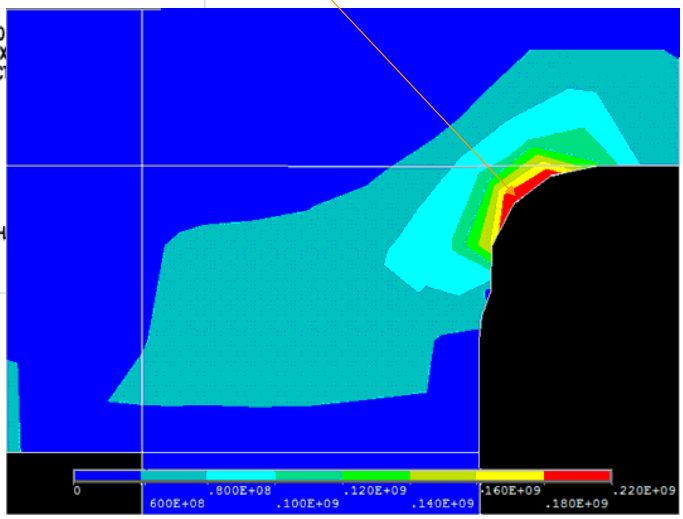




Proposed Solution 2: to Remove Sharp Edges

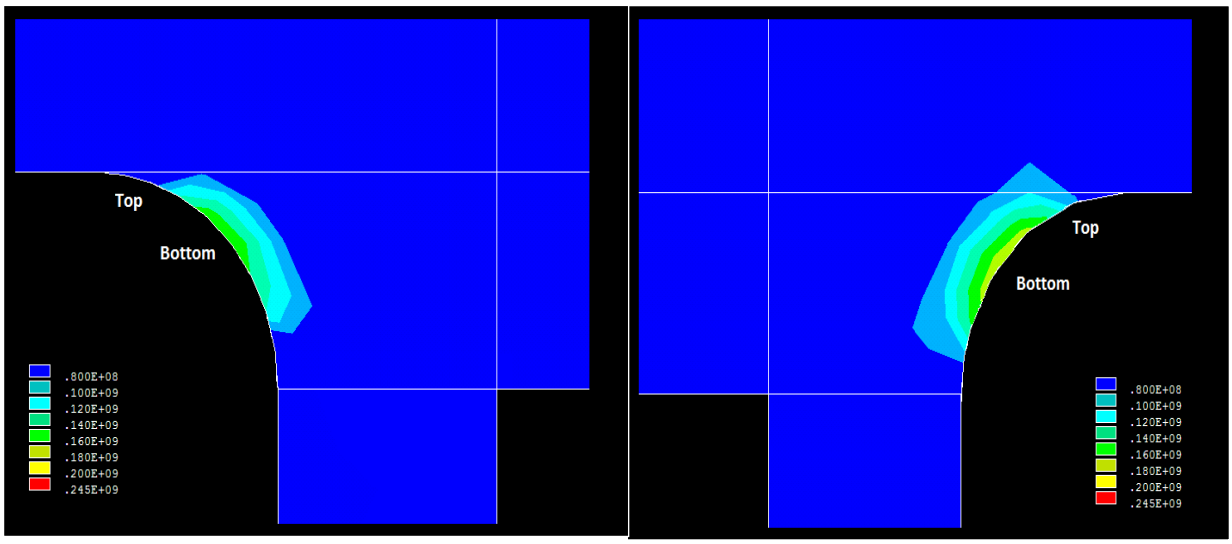


Very High Stress



Improper design caused stress migration!

Proposed Solution 3: Smooth Curve w/o Sharp Edges



Selected Solution Using Finite Element Method!

Interpretation of Results

Maximum stresses found on the hanger plates and stress reduction as compared to the original design

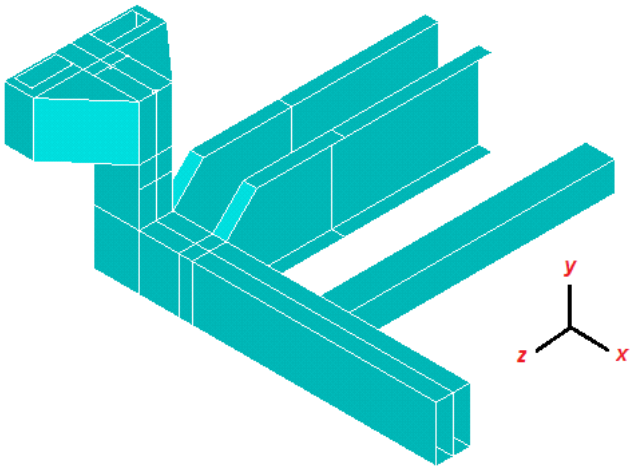
Stresses	Stress value (MPa)	Stress reduction
Landside left top	102	44%
Landside left bottom	132	29%
Landside right top	88	37%
Landside right bottom	98	23%
Seaside left top	125	52%
Seaside left bottom	168	29%
Seaside right top	115	46%
Seaside right bottom	142	15%

Site Execution of Repair

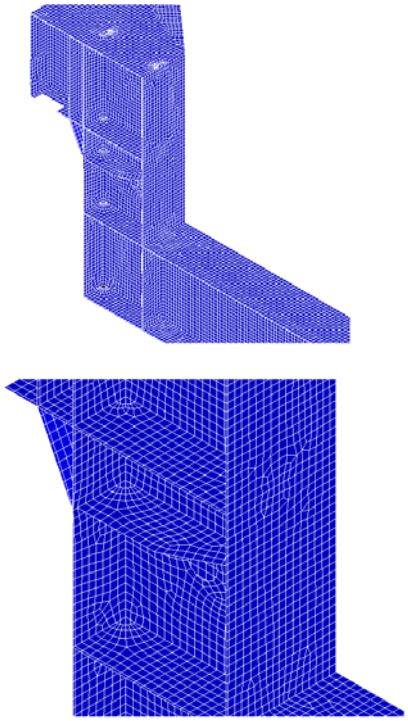
Sample 2: Trolley Structure Recovery and Repair

Trolley Structure Recovery

Investigation of Stress in Trolley Truck

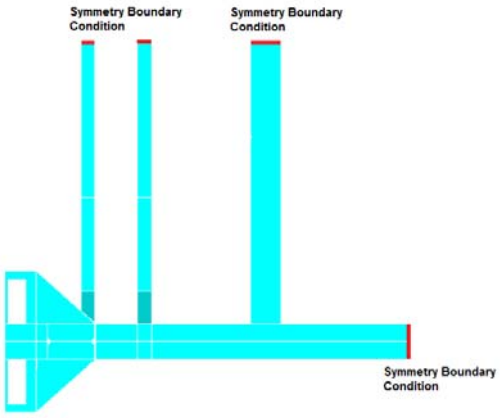


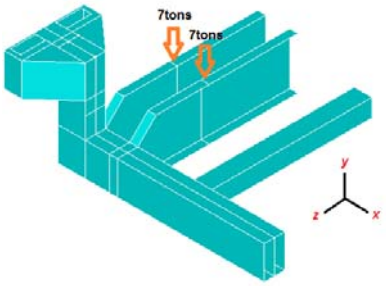
Geometry model
- quarter platform

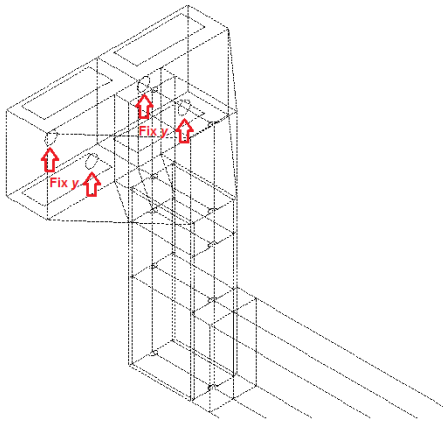


Finite element model

Investigation of Stress in Trolley Truck

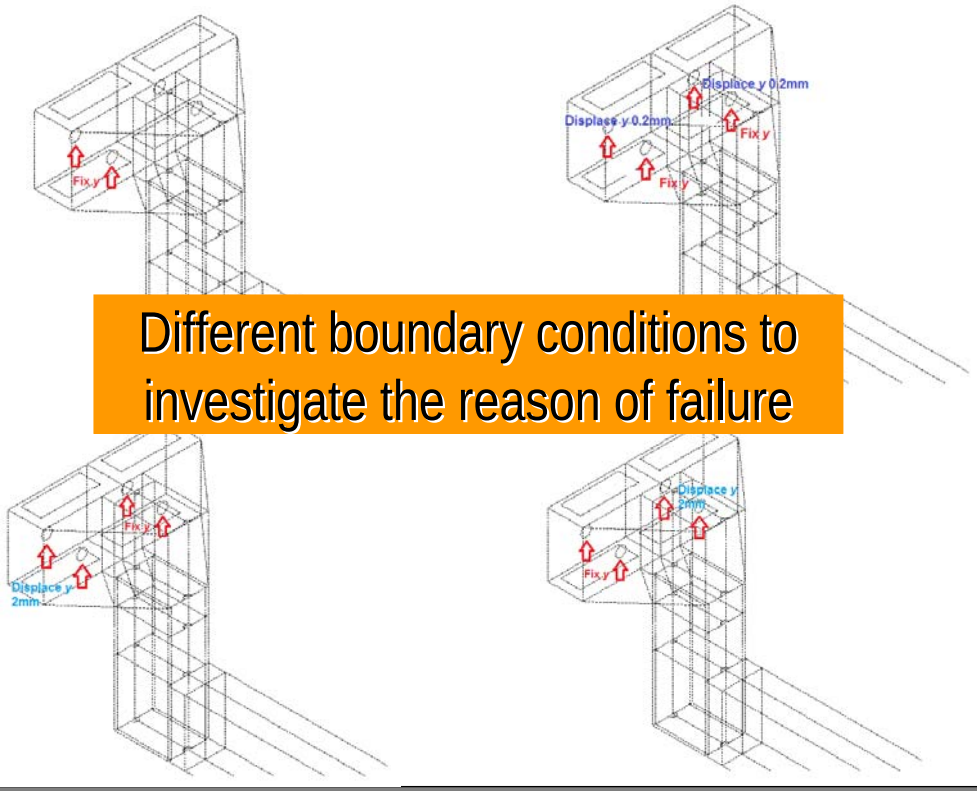






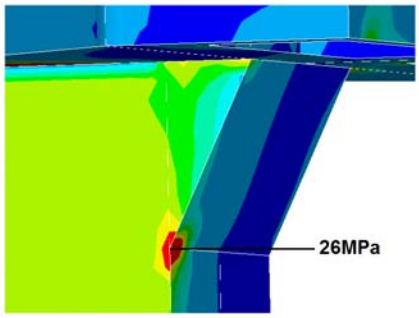
Load and boundary conditions

Investigation of Stress in Trolley Truck

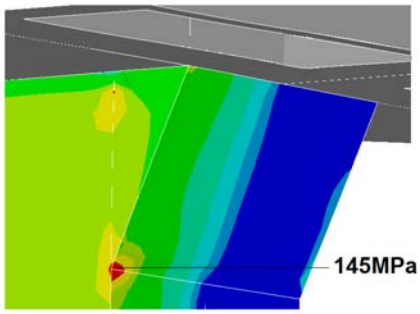


Different boundary conditions to investigate the reason of failure

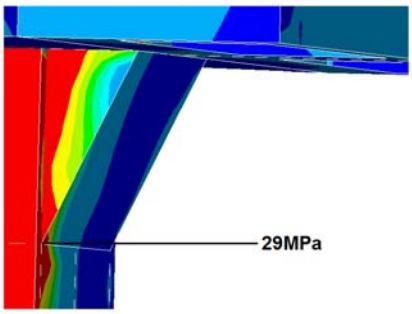
Investigation of Stress in Trolley Truck



structure under uniform constrain



structure under wheel truck bend



One of the proposed modification under uniform constrain--worse

Conclusions:

1. Major cause is the wheel truck bend along the rail direction
2. Boom-girder joint maintenance is very important
3. Trolley truck with equalizer pin is the efficient way to avoid this kind failure

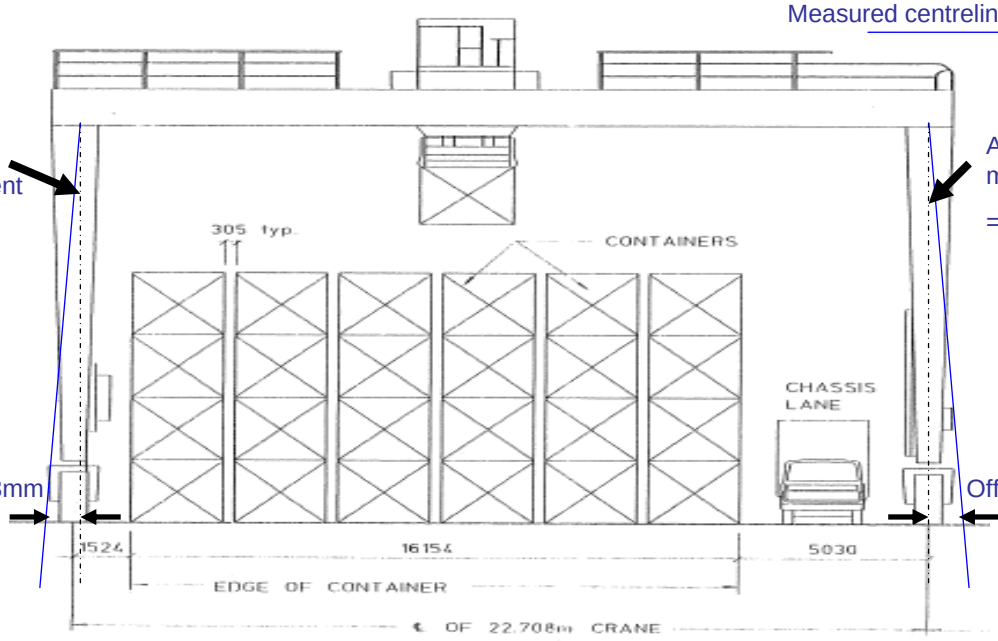
Sample 3: Structure Repair of RTG

Designed centreline of leg

Measured centreline of leg

Angle of misalignment = 0°20'11"

Angle of misalignment = 0°25'30"



Off by 53mm at 0m

Off by 109mm at 0m

Sample 3: Structure Repair of RTG

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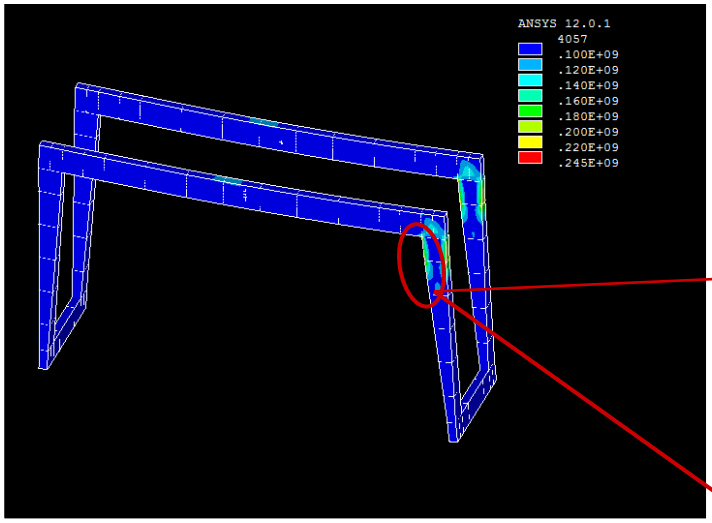
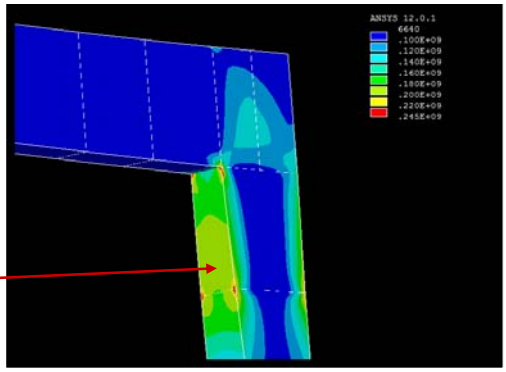
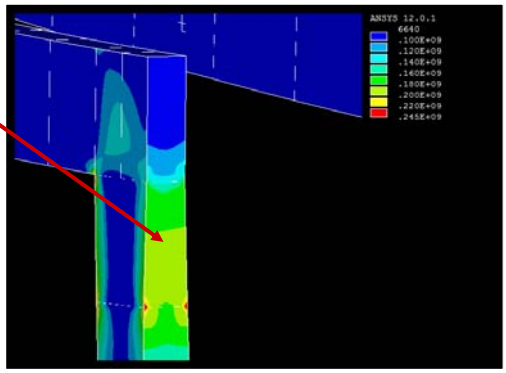
Normal Gantry Tyre Position

Gantry Tyre Position for damaged RTG

Finite Element Analysis

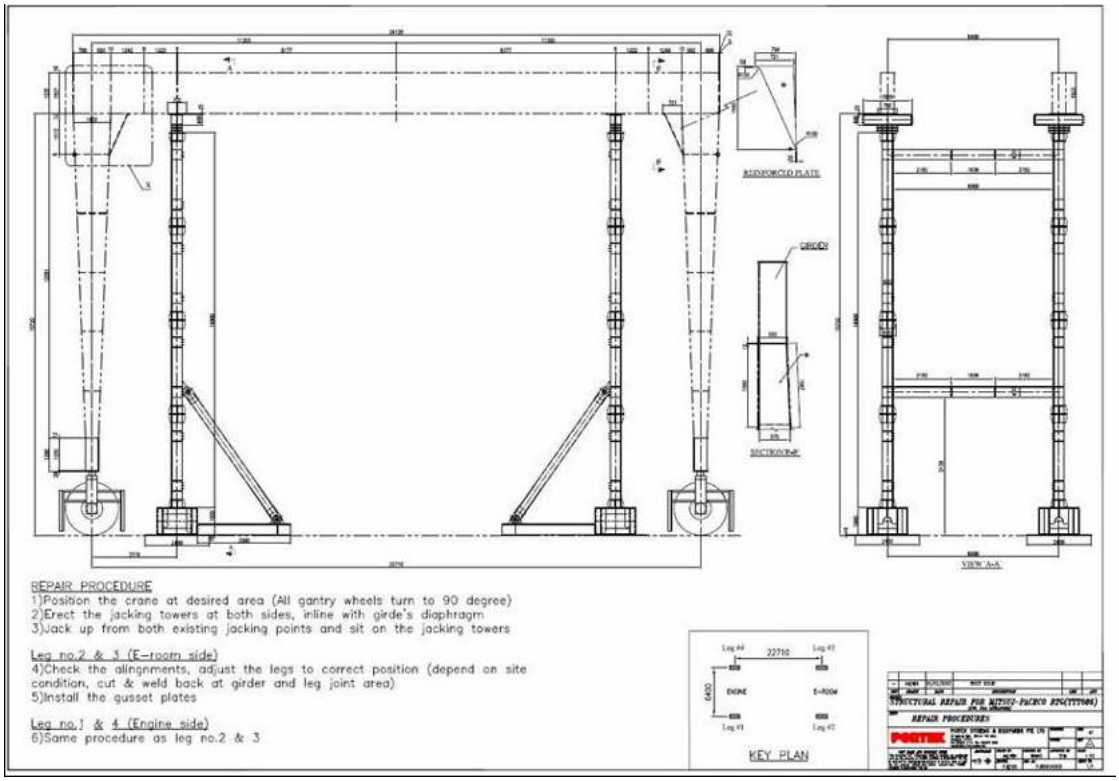




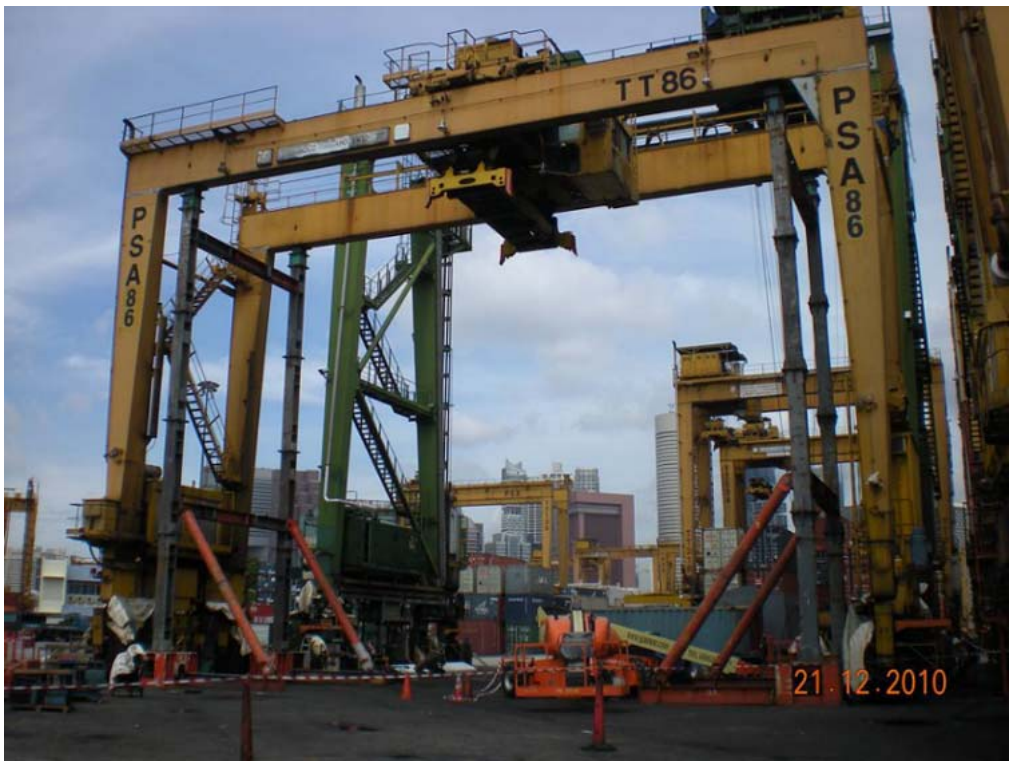


- At least 27ton pulling force to cause this failure
- Plastic deformation occurred at corner
- Conner reinforcement can prevent this failure efficiently

Repair Procedure



Structure Repair



Boom Extension

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Modification required

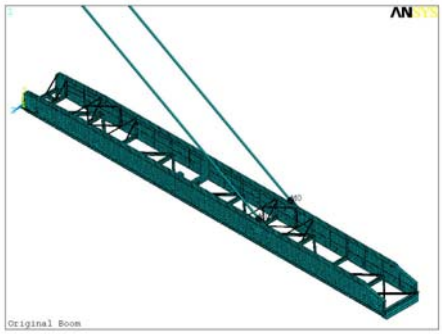
1. Extend boom 4.5 m
2. Expensive to use Floating Crane
3. Design method

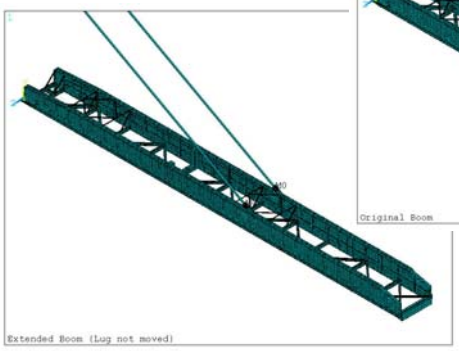
FE Simulation

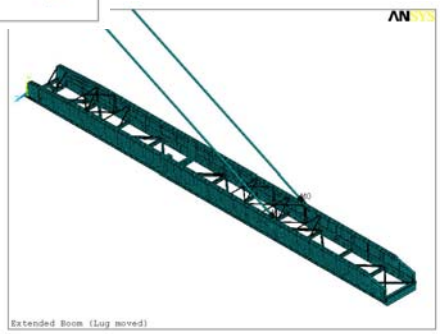
Solver: **ANSYS/Mechanical**

Elements:
- Plate
- Beam
- Bar
- Joint

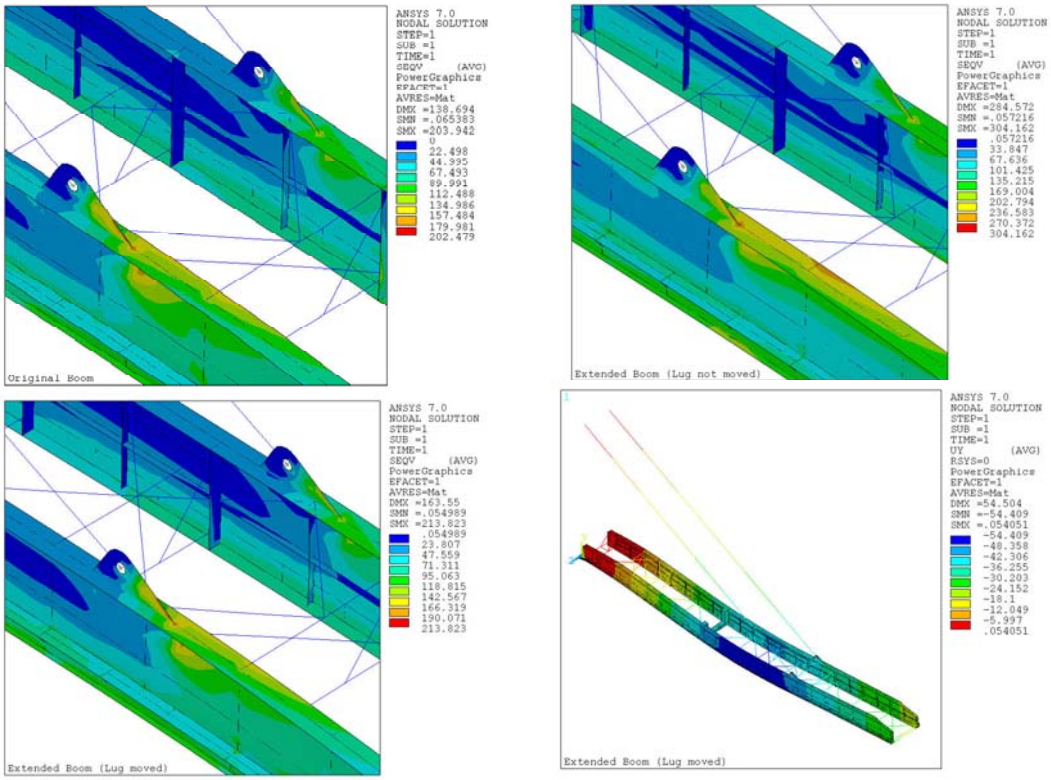
Models:
1. Original boom
2. Extended boom without moving lug
3. Extended boom by moving lug







Simulation results & Comparison



Real World

Height Extension Using Synchronise Jacking System

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Modifications

1. Increase height 5.0 m

2. Strength & stability of jacking tower

3. Design method

FE Simulation

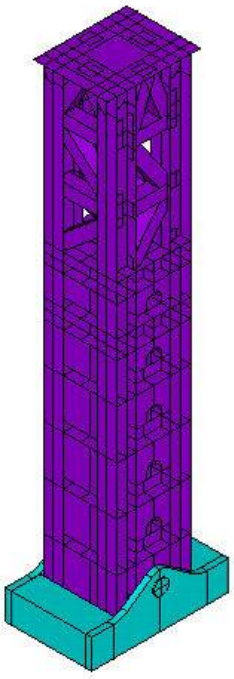
Solver: **LS_DYNA**

Model: Inner tower & Jacking components

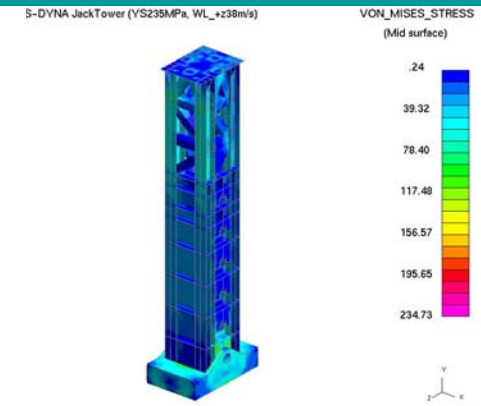
Key point: Multi-surface contact

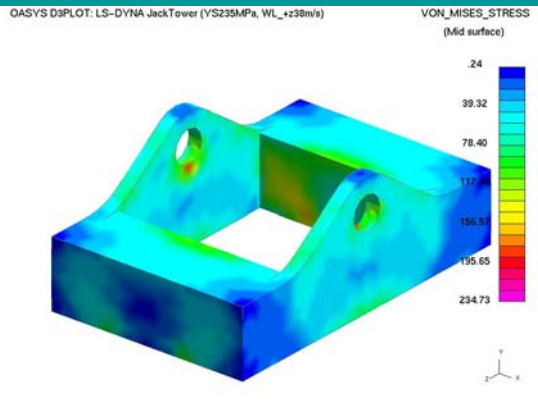
Loads:

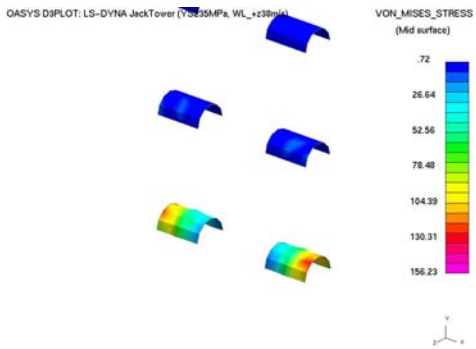
1. Overall crane weight
2. Lateral wind

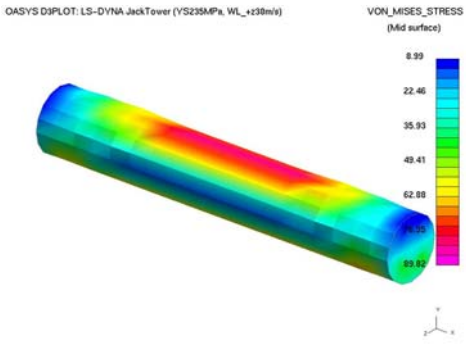


Simulation Results

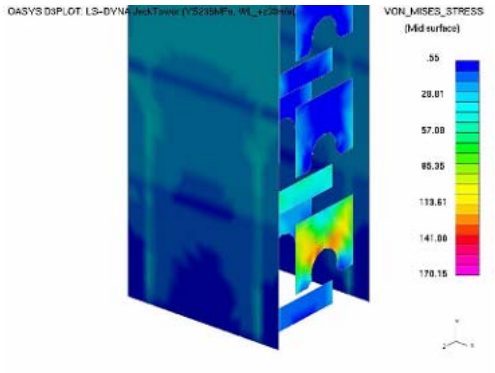


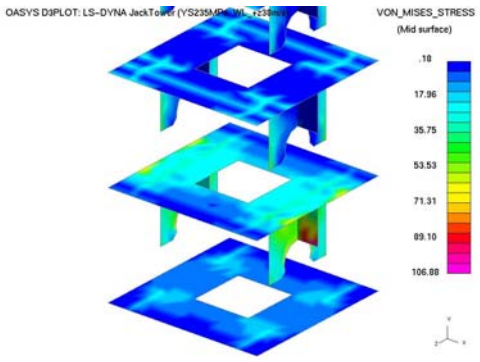


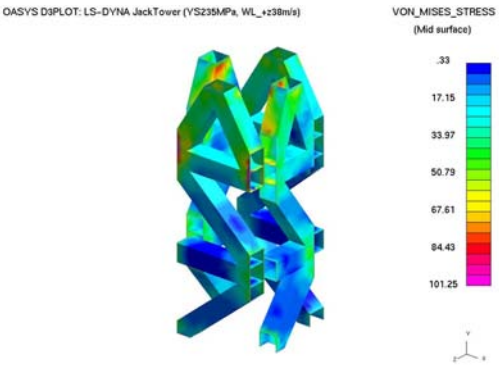


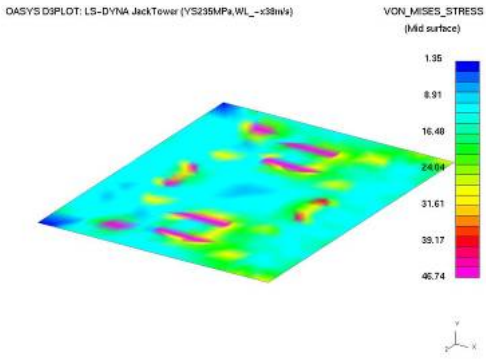


Simulation results









Facing the Real World

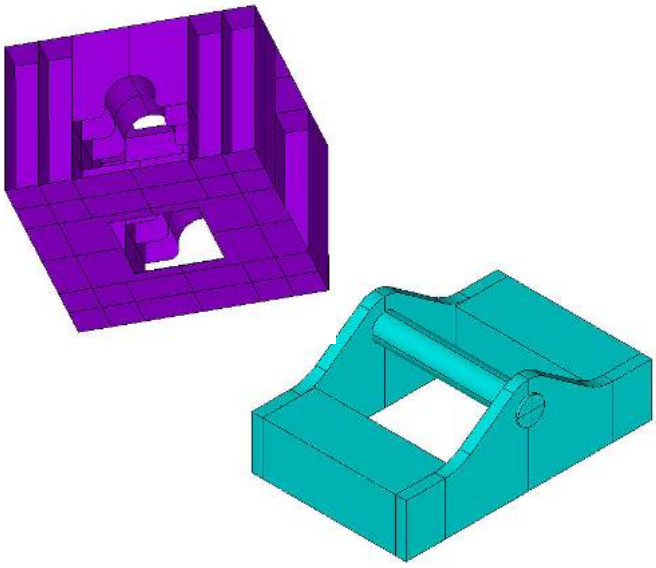
Components to equipment

Jack up 1 m

Jack up 5 m
&
Insert new
leg

Simulation vs. Design

- The jacking procedure is safe despite contact stresses are high;
- The stress on the pin is quite low;
- Local modification of the jacking section is suggested.



Useful Life Assessment

1. Structural Condition Survey

2. Useful Life Estimate Before Inspection

3. Structural Inspection

4. Useful Life Estimate After Inspection

Crane Structural Inspection, Why?

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Many Cranes are at the end of their designed life cycle

Fatigue cracks will occur and can be catastrophic if not repaired

Crack repairs are inexpensive and Cracking can be controlled by proper analysis, design, workmanship, quality control and maintenance

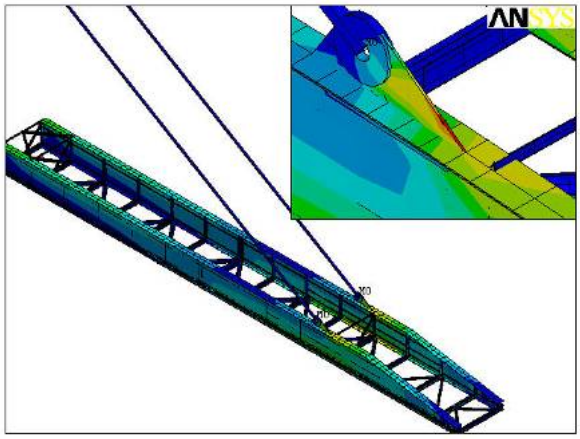
It is prudent to perform structural inspection prior to spending huge amount of money on refurbishment and drive retrofitting

Structural Condition Survey

- Look for:
  - Distress
  - Suspect details
  - Attachments
- Make photo record for the NDT inspection.

Useful Life Estimate Before Inspection

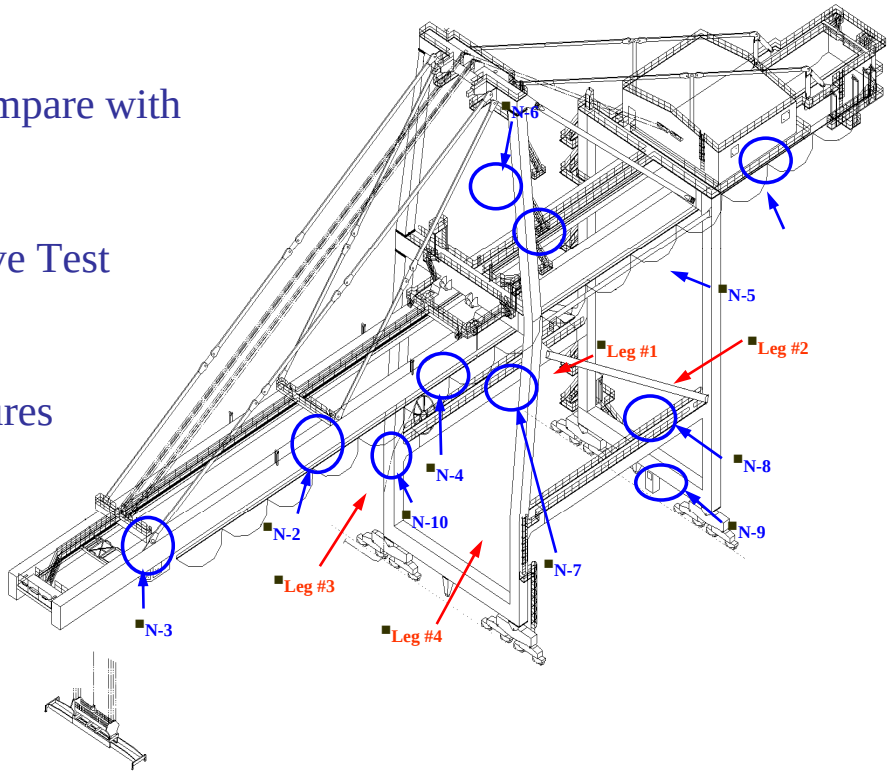
- **Perform finite element analysis**
- **Calculate relative cumulative damage**
- **Estimate remaining useful life**



Forestay failure analysis using ANSYS

Structural Inspection

- Inspect and compare with predictions
- Non-Destructive Test (NDT)
- Repair procedures



Useful Life Estimate After Inspection

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- Review inspection reports
- Identify fatigue cracks
- Compare identified cracks with prediction
- Re-evaluate the reliability and useful life

Conclusions

- Finite Element Analysis is a essential tool for helping us in determining the cause of the problems and recommending the solutions.
- FEM analysis of structural failure should be adopted as standard tool in failure analysis
- With a trained engineer, FEM is quick and easy to deploy.
- With the exponential increase in computing power, FEM is economical to carry out.

Conclusions

- Based on the available of materials, equipment and resources, Portek is able to apply our engineering knowledge to generate innovative solutions (Fast & Economical) to solve the problems.

- Complementing Engineering Knowledge & Practical experiences will provide a practical and long term solutions to an engineering problem

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Thank You !

Q&A