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Troubleshooting and rectifying structural mechanics problems – applied mechanics in industry

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Abstract: This paper outlines the general process of troubleshooting and rectifying unexpected structural mechanics problems in industrial plant and infrastructure. Typically the process includes the combination and correlation of site measurements (strain, vibration), and computational simulations (finite element analysis, computational fluid dynamics) to identify root cause sources and guide re-design and rectification means. Details of typical site installations are outlined, including mining machinery, gas pipelines, railway lines, manufacturing plant and ships. Four case studies are included, ranging from resin manufacturing tubular agitators suffering vortex induced resonance, ore grinding mills needing better access manhole design, mine dump trucks, and ship shafting issues.

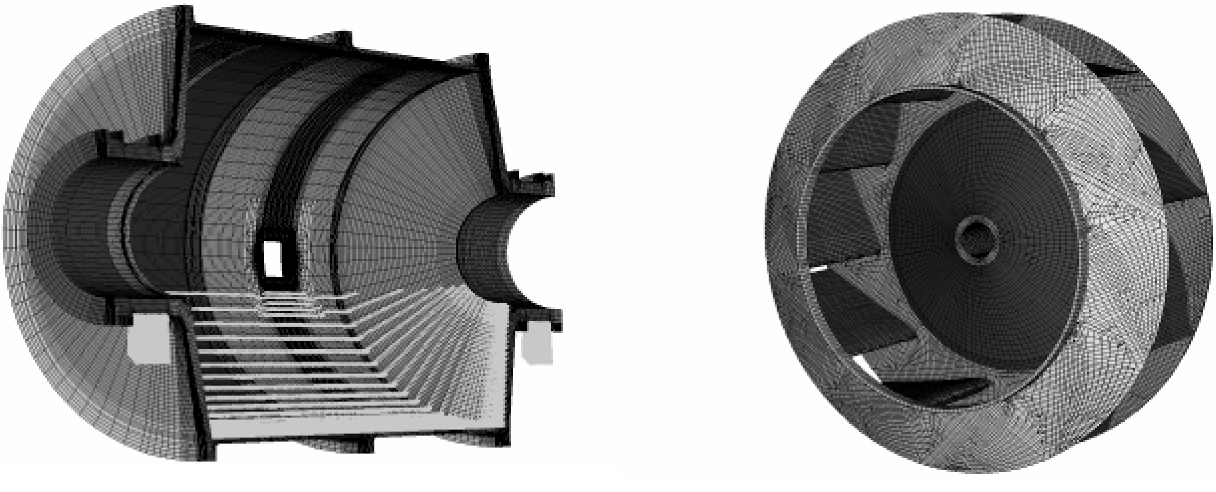
Keywords: troubleshooting, rectifying, structural mechanics, site measurements, computational simulations, correlations, root cause sources, re-design.

1 Introduction

The application of computational and experimental structural mechanics to the design validation and optimisation of industrial machinery is obviously now widespread across most industry spheres.

Manufacturers are increasingly applying finite element methods to confirm steady state and transient stress states, and at times are confirming these simulations with in-situ strain gauging of the prototype plant item. Usually the result is a product which gets to market faster, is more optimised with respect to structural scantlings and manufacturing methods, and has increased reliability.

Figures 1 and 2 show typical finite element simulations, of ore grinding mills used in gold and copper mineral processing plants, and centrifugal fans used across all industry spheres including power generation, steel and sugar mills, mine ventilation and process situations.



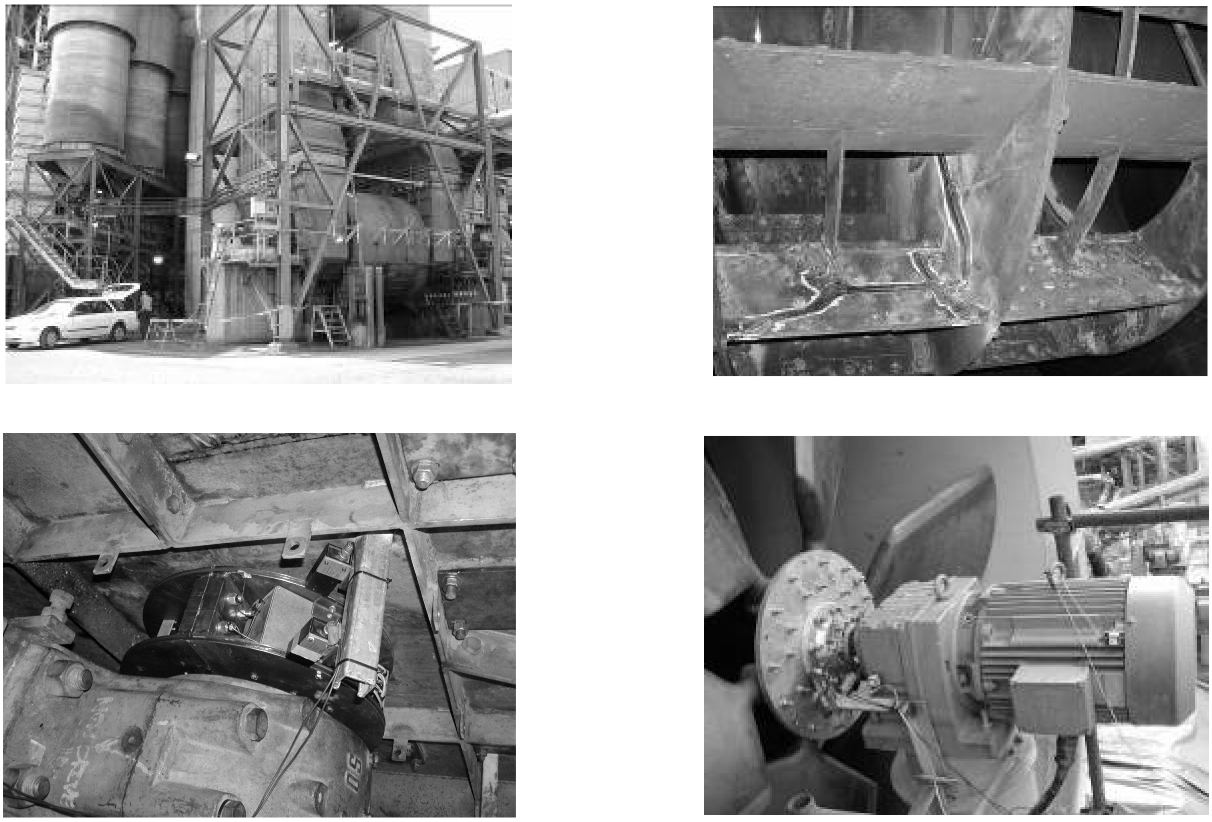
Figures 1, 2 Typical finite element simulations of ore grinding mills and centrifugal fans

In most situations the result of appropriate design, design detailing (particularly at welded joints under fatigue loadings), and fabrication including post-weld improvements, is a machine which has suitable integrity and reliability, and provides good service as long as maintenance actions are not pushed aside by production priorities.

When in-service problems do occur, it is necessary to determine the underlying cause, so that rectifications can be designed which will reliably overcome or eliminate the problems. The alternative is a series of trail-and-error partial fixes which may well result in greater total downtime and even more extensive damage. The troubleshooting technique used will vary depending on the plant item and the nature of the problem, but typically will involve a combination of field measurements of strain, vibration and other parameters, with high level analysis. Sometimes analytical techniques alone may suffice to identify the problem source, but in other cases measurement can rapidly reveal unexpected dynamics or deflections due to phenomena not originally thought to be significant. The combination of the two approaches typically provides much greater certainty in the diagnosis, and leads naturally to the design of rectifications. The next section of this paper outlines typical site installations, and the final section summarises case studies of design rectifications completed across a range of industries.

2 Site Installations

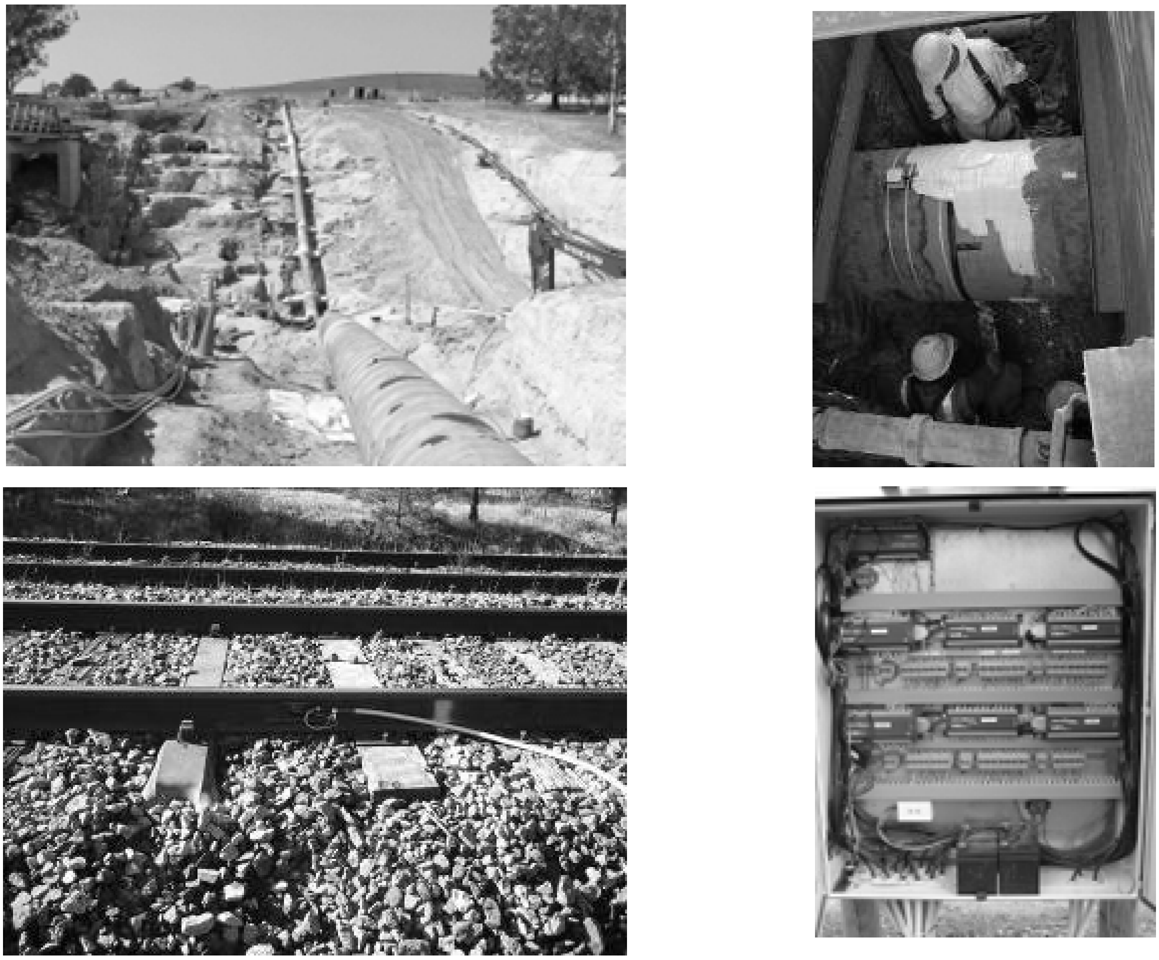
Figures 3 to 6 show typical site strain monitoring installations needing radio telemetry systems, on rotating machinery such as fans, mills, ship shafts. Obviously suitable shutdown planning is needed to allow access to hotspot areas of the impeller or mill shell, to install full three element rosette gauges typically of 5mm gauge length. For fans spot welded stainless steel shim must be used to secure cabling which leads to the multiplexed radio telemetry units affixed to the shafting.



Figures 3 – 6. Typical installations – sugar mill and cooling tower fans

Figures 7 to 10 show typical installations on fixed plant such as gas pipelines and railway tracks, required to trend stress changes caused by longwall mining subsidence and guide mitigating actions. For these installations monitoring is set up by means of automatic data transfer over a mobile network.

The planning and effort required for these installations obviously varies considerably depending on the situation, including the longevity required. For a typical fan or mill project normally up to a dozen rosette gauges and the telemetry system are installed by a two-person team over the course of a two-day shutdown. For large infrastructure projects such as pipelines and bridges, two or three such teams are usually formed, so that installation times do not stretch out.



Figures 7 – 10. Typical installations – gas pipelines, railway tracks

3 Some Case Studies

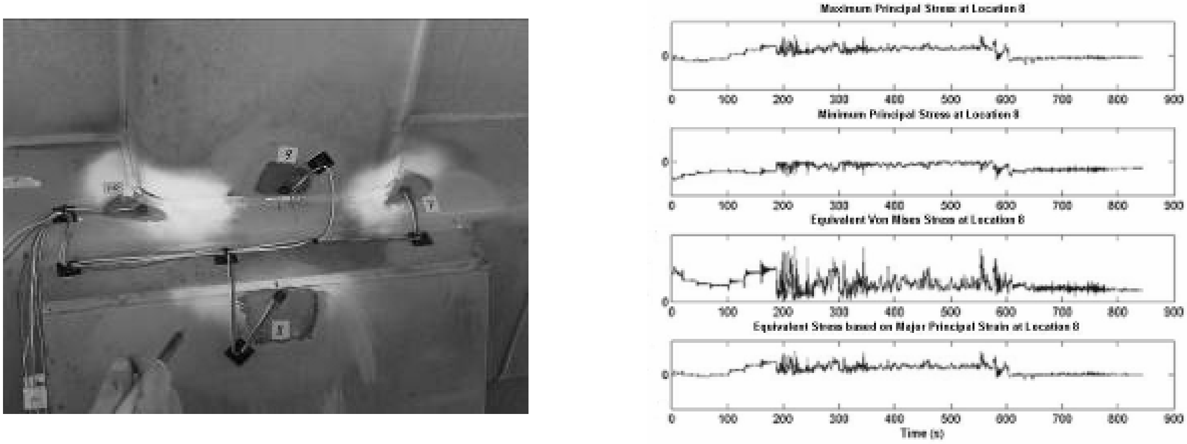
3.1 Dump Truck Trays

Dump truck trays in open cut mines are under increasing pressure to reduce weight yet maintain a suitable level of structural integrity. The operating conditions are severe, with not only impact loadings from shovel fills to be withstood, but also the dynamics created by the dump to pile and the transit road which, depending on the site, can induce significant fatigue loadings.

At one site fatigue cracking on the front wall and bulk deformation of the floor and transverse ribs was observed on a number of 200 tonne capacity dump truck bodies. The damage was thought to have been caused by a combination of operational factors (overloading, rock impacts, tray setup, etc.) as well as issues with the tray design.

Strain gauge measurements (Figures 11, 12) were conducted during normal operations. The resulting data was post processed using rainflow counting to determine the fatigue damage accumulated by the tray in a normal day's operation. This data was used in correlations with finite element simulations of the tray geometry, which allowed local area re-design.

Another situation required a more global approach - Figure 13 shows a finite element mesh of a tray re-design including optimised structural connectivity of the whole monocoque tray arrangement including the intensive longitudinal sill beam / transverse rib joints, the pivot areas, the sidewalls and perimeter, and the canopy. In both cases very significant life extensions have occurred.



Figures 11, 12 Strain gauge installations and recordings – dump truck tray

Figure 13 Dump truck tray simulation

Figures 14, 15 Mill manhole cracking, re-design

3.2 Ore Grinding Mills

The typical 15rpm ball (Figure 1) or SAG mill used in mineral processing plants is a very robust unit giving good service in a difficult fatigue environment. Some mills have achieved service lives approaching 40 years, albeit with suitable "half-life" refurbishments and good maintenance practices.

Manholes are a typical source of fatigue problems, as typically shown in Figure 14 where the shell opening cut-outs have a tight corner radius, and this is further exacerbated by a low fatigue resistance fillet welded and square cornered up-stand type perimeter with flange and a bolt-on cover. Figure 15 shows the rectification using a full penetration butt-welded insert type manhole, with a clamped in cover. This type of manhole has been devised for several mills in Australasia.

3.3 Ship shafting

The normal ship shafting measurements are torque and torsional vibration via strain gauge based telemetry units and encoders, during commissioning trials of new or modified vessels. Most shafting systems designed to classification society rules have suitable design margins to avoid operational issues. Figure 16 shows an exception, wherein the shaft whirl mode of a tanker was excited when the vessel operated in the ballast condition in moderate following seas.

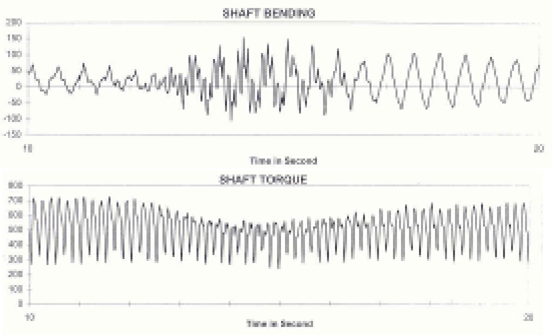


Figure 16 Ship shaft bending and torsional loadings during whirl excitations

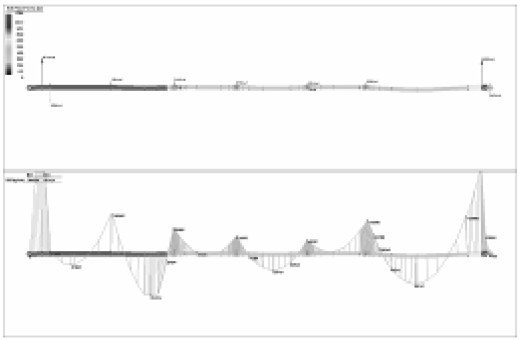


Figure 17 Influence coefficient model for the intermediate shaft alignment process

Long intermediate shafting runs are aligned using the influence coefficient technique – a combination of computational analysis (Figure 17) and strain measurements, where the effect of unit misalignments at each bearing is indicated by shaft bending moments through the whole shafting string. The output of strain gauging at locations adjacent to the bearings, recording the strain changes during a full revolution, is used in conjunction with the matrix of coefficients to derive the vertical and lateral misalignment states.

Unscheduled grounding incidents can lead to bent shafting. Depending on the severity, cold straightening processes can be used. Figure 18 shows a simulation of a propeller shaft stress state during a grounding impact. The resultant deformation was rectified by the judicious application of an 830kN transverse loading onto the end of a steel dummy propeller hub bolted to the shaft flange to provide slightly more than the grounding force and moment at the flange, in the opposite direction. The force required was determined by suitable nonlinear analysis, involving the initial and correction load cases. Vessel downtime was minimised.

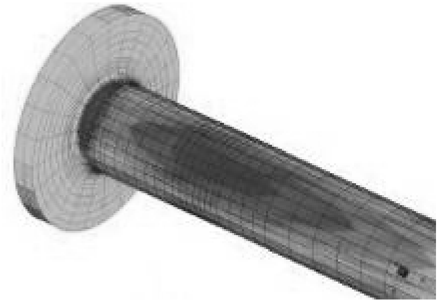


Figure 18 Shaft grounding analysis

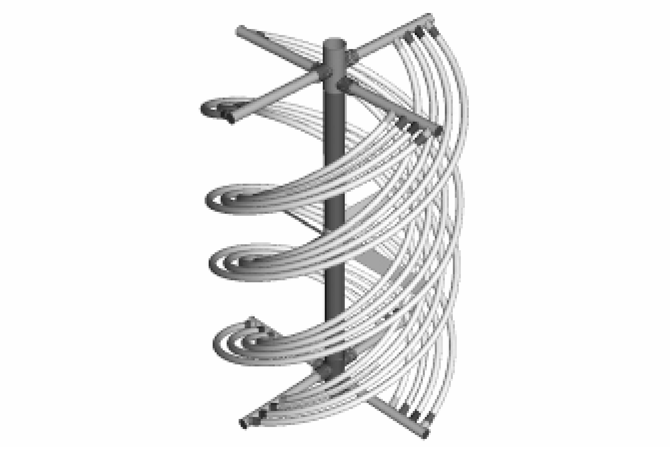
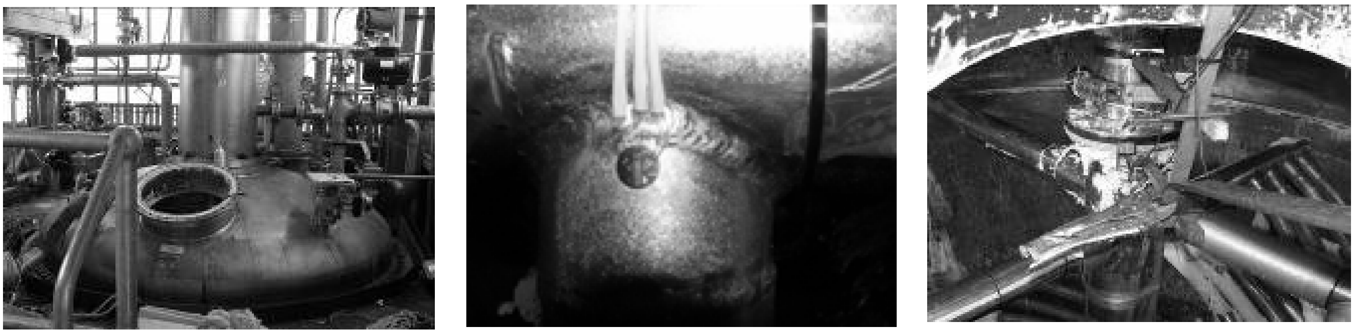


Figure 19 Tubular agitator

3.4 Tubular Agitator

Figure 19 shows a 1.9m diameter x 2.8m high tubular ribbon blender used for low shear agitation, which mixes resin in the vessel shown in Figure 20. Continued fatigue cracking at the junction of the outer helical tubes to the main arms required in-situ strain gauging to diagnose the specific root cause source of the damage.

Figures 21 and 22 show a strain gauge attached to a joint, and the very difficult instrumentation installation inside the vessel.



Figures 20 to 22 Top of the agitator vessel, strain gauge at a tube junction, telemetry instrumentation

The recordings during the complete speed range of the mixer (20-45rpm), indicated high 12.4Hz alternating strains at around 41rpm. Correlations of normal modes analysis and computational fluid dynamics indicated vortex shedding resonant excitation of the 5th natural frequency mode of the rotor. Figure 23 shows the vertical deformation contour plot of this mode, characterised by an out-of-phase oscillation of the top and bottom main arms which inherently created high alternating stress at the helical flight to arm joints. Rectification assessments led to the addition of vertical tubes (Figure 24), which stiffened the rotor that has operated successfully since.

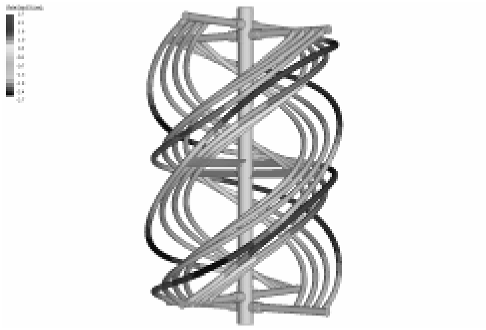


Figure 23 Exaggerated scale plot of 5th mode

Figure 24 Rectification with vertical tubes

4 Conclusion

This paper has outlined some applications of the combination of computational structural mechanics and field measurements in diagnosing and troubleshooting operational issues with specific industrial plant. Our experience is that manufacturers are increasingly using suitable design analysis simulations to improve the robustness and reliability of machine components. In the cases where operational problems do occur, the appropriate use and correlation of in-situ measurements and finite element modelling, including root cause source diagnostics, will lead to the formulation of suitable design rectification actions. In many cases the production teams gain an insight into the difficulties their environment can cause, and go forward with a more forgiving operational attitude which benefits all concerned.

5 Acknowledgments

The authors would like to acknowledge permissions from operational sites and manufacturers to use the case studies included in this paper.