International

Cement review

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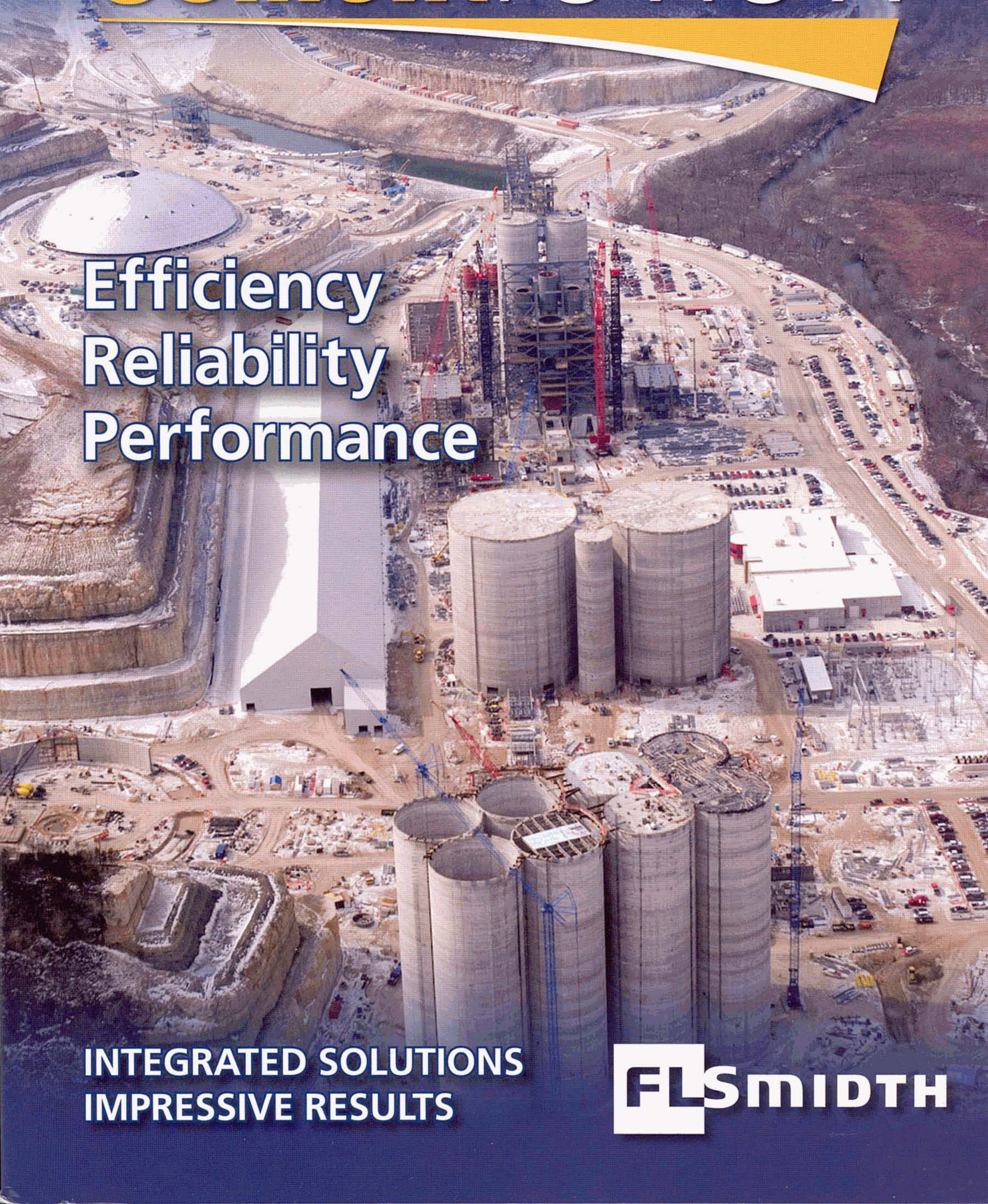

Ball mill maintenance

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Cement plant operators often have to make decisions about repair or replacement of older equipment. Older equipment, that is suffering from wear-out and other end-of-life problems, is often replaced. However, equipment that is suffering from an isolated design or operational problem, but is otherwise serviceable, is usually repaired. With proper engineering analysis and evaluation, it is possible to make cost-effective decisions about repairing older equipment even when replacement seems to be the better choice at first.

Cement plants utilise large ball mills to crush the raw materials and other bulk materials, such as clinker into a powder. A ball mill is a large cylindrical tube partially filled with steel balls. The ends of the steel cylinder are attached to trunnions that are supported on journal bearings. As the ball mill rotates, the steel balls in the cylinder rise up on the mill's inside surface and eventually tumble down to the bottom. The raw material is fed into the ball mill at the ends and the steel balls impacting together eventually grind the material into a powder, which is collected through slots at the centre of the mill. The mill is driven by a pinion gear, which engages with a ring gear, or girth gear, around one end of the mill (see Figure 4).

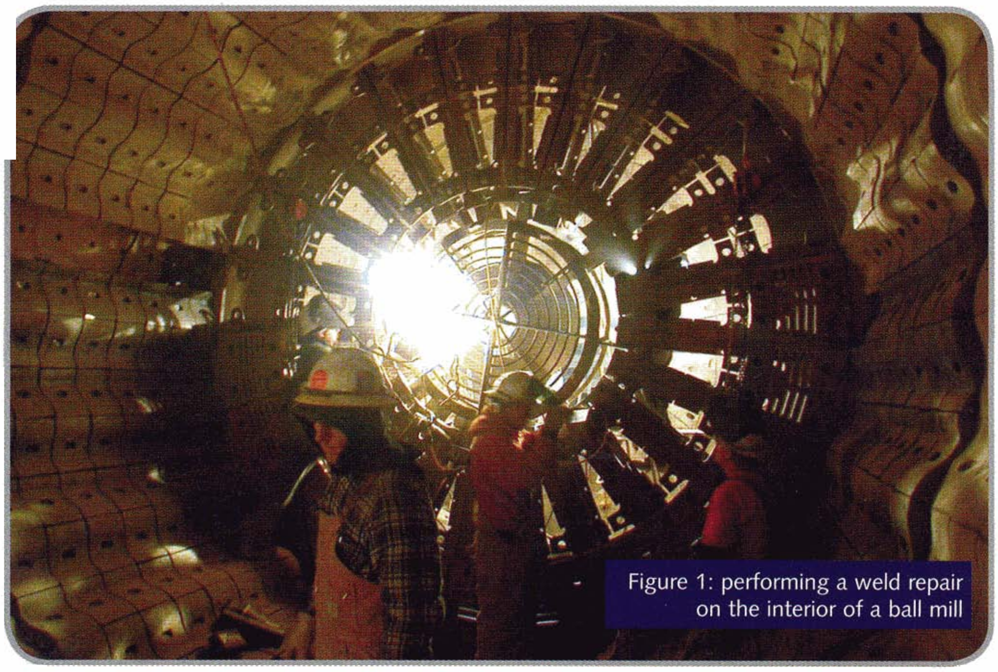


Figure 1: performing a weld repair on the interior of a ball mill

Figure 2: one of the cracked trunnions

Cracked trunnions

A medium-sized cement plant in California had a problem with cracks in two of its raw mills. The raw mills are approximately Ø5m x 16m long. Both have been in continuous operation since 1978 and both were developing cracks in the trunnions.

Due to the local construction economy, this particular plant can sell all of its around-the-clock cement output. In fact, some of the contracts even require this plant to supply cement from other sources in the event of production problems. This demand for cement makes both scheduled down-time and unanticipated failures a serious financial problem.

Options

The cracks in the trunnions were discovered during routine preventative maintenance. The cracks were monitored for a couple of years until their length became a concern. The cracks appeared to start at, and follow along, a series of holes in the trunnion that are used to secure the liner plates (see Figure 2).

The operator had several options for dealing with the cracks:

1. replace the mills with a new mills
2. perform weld-repairs in-place on the trunnions to extend the service life
3. obtain replacement trunnions.

The first option is obviously the most costly both in terms of capital expenditure and lost revenue due to down-time. However, the advantage of this option is reduced operating costs and perhaps greater product output over the life of the new mills. The repair option is only a temporary solution because it is virtually impossible to anneal the material and reduce the heat-affected-zone when the trunnion is welded in-place. The final option, to replace the trunnions with new ones is attractive as long as the trunnions can be manufactured locally at a reasonable cost.

Any decision about these options is driven by knowledge of the failure mode and the constraints on cost and time. If the cracks started because of a design problem then repair or replacement of the trunnions is not sufficient. If the cracks are caused by a change in operating conditions that places the mill outside its original design envelope, then new trunnions will also fail.

The constraints also need to be considered. In this case, the original trunnions were made out of ASTM A148-60-90 cast steel 30 years ago. In investigating sources for new trunnions, the only option was to have them made in Germany because foundries in the USA could no longer cast an item of that size at a reasonable cost and within the time constraints. In order to consider casting the trunnions out of a different material such as EN-GJS-500-7U cast iron, which could be locally manufactured, the original design parameters need to be understood.

Methods and tools

To evaluate the best option. Principia were hired by the plant operator to analyse the stresses created in the trunnions during normal operation to determine if they were being overloaded and to help define the specifications for new trunnions. To complete this work, engineers needed to understand:

1. material properties of the trunnions
2. geometry of the ball mill
3. loads created on the trunnions during operation.

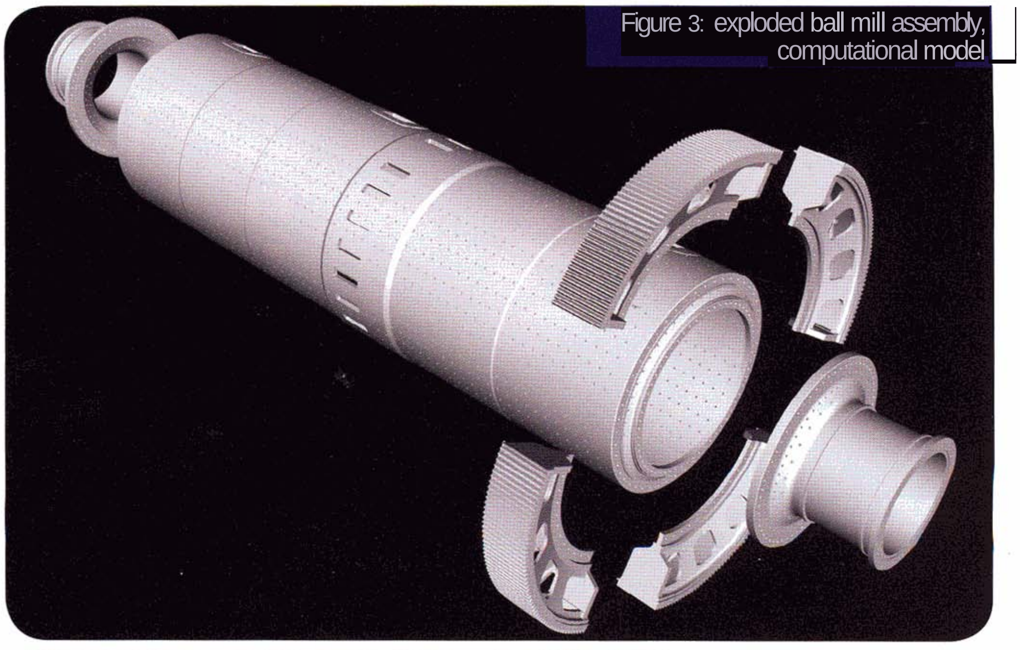


Figure 3: exploded ball mill assembly, computational model

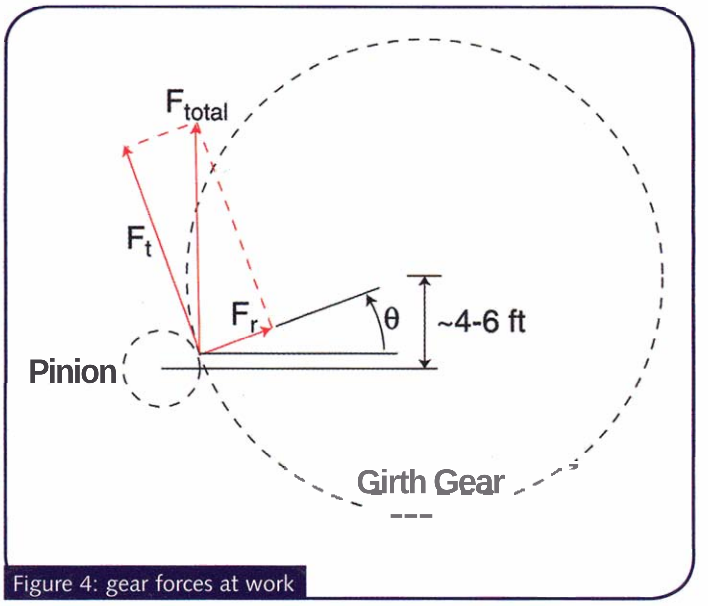


Figure 4: gear forces at work

The original design calculations were not available so Principia had to reverse-engineer most of the design (see Figures 3, 5 and 6). This is a common issue when analysing legacy or obsolete equipment.

To get the geometry of the mill, a solid model was made from both the installation drawings and from measurement of the existing mills. Engineers estimated the material properties of the original cast steel by taking samples of the steel and performing chemical tests in addition to tensile tests on coupons.

The most difficult part of any stress analysis is in estimating the operational, or real world, loads applied to the part.

Figure 5: computational model of trunnion – front view

Figure 6. computational model of trunnion, rear view

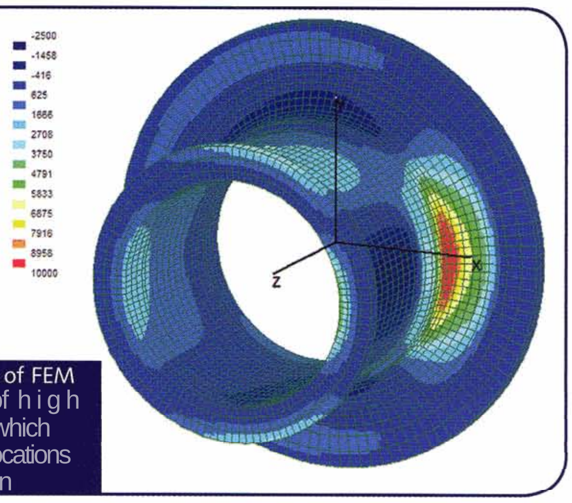


Figure 7: results of FEM showing areas of high principal stress which correspond to locations of crack initiation

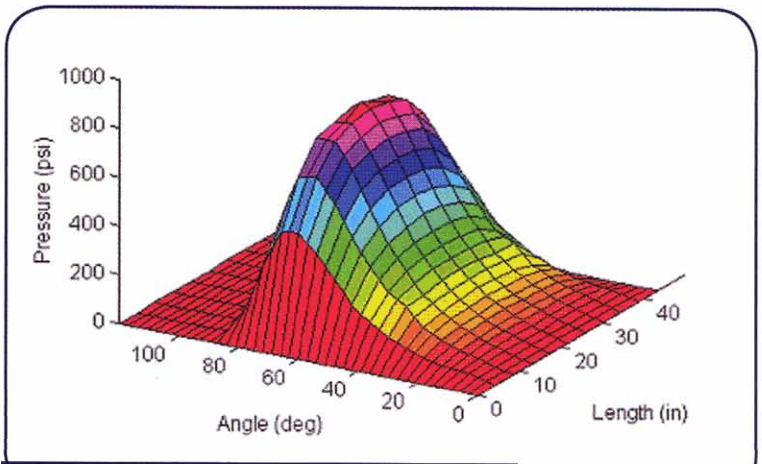
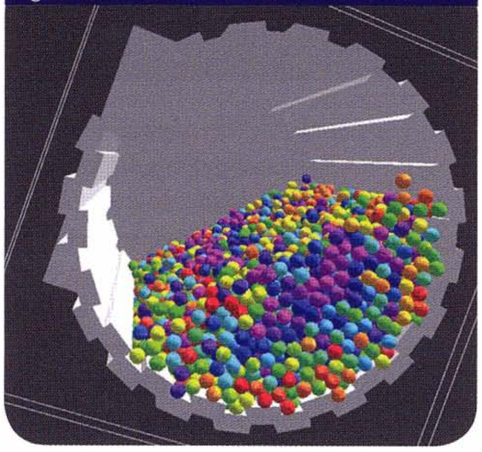


Figure 8: journal bearing 3D pressure distribution

Figure 9: discrete elemental model of ball mill



In this case, the loads imparted on the supporting trunnions resulted from three main components:

1. the static load or weight of the mill
2. the dynamic loads imparted during rotation of the ball mill, and
3. the gear interaction loads.

In addition, to assessing the magnitude of the loads Principia also needed to determine the distribution of these loads on the trunnions (sees Figure 7 and 8). Engineers calculated the weight of the ball mill by using the original installation drawings of the ball mill to create a full three-dimensional model of the entire mill (see Figure 3). This computer-generated model was given appropriate material properties to determine the weight and intertias of the ball mill. This was then added to an estimate of the weight of the steel balls and clinker. The end result was a total weight of over 800t supported by the two trunnions. Principia used standard bearing theory to determine the distribution of this load on the trunnions.

To calculate the additional forces generated during mill operation, Principia used Discrete Element Modelling (DEM) DEM (see Figures 9 and 10), a relatively new tool that has come into use as computer processing power has increased. DEM calculates the forces created by the interaction of many individual particles. which in this case are steel balls moving inside the rotating cylinder.

This type of computational model is also used in the cement industry to model flows in conveyors. A simulation of the mill was made with 11,600 steel balls to determine the forces generated at the trunnions.

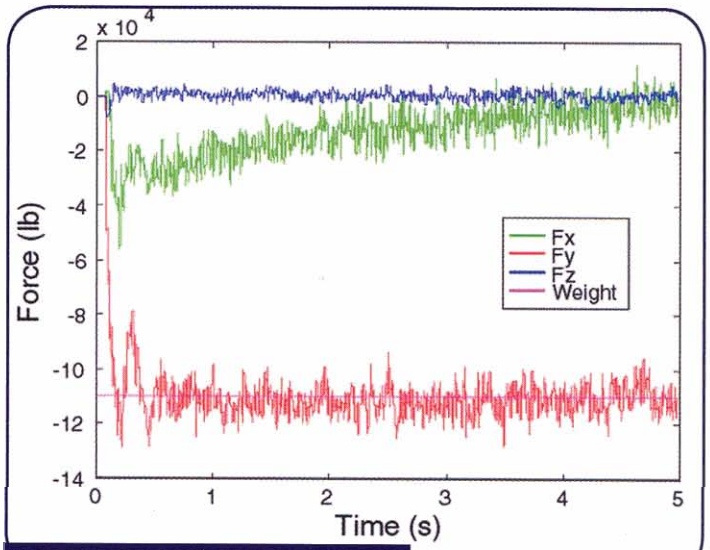


Figure 10: results of DEM simulation

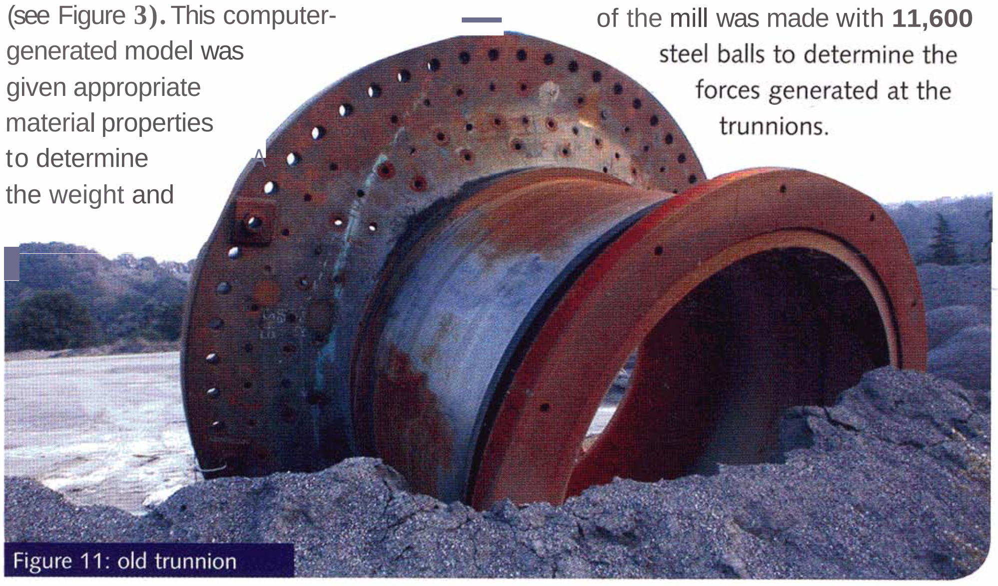


Figure 11: old trunnion

The gear interaction loads were calculated using the geometry of the gears and the torque applied to the drive gear. In this case, the resulting gear force actually lowered the load on the drive side trunnion.

After determining all the loading conditions Principia completed a Finite Element Model (FEM) of the trunnion using this loading as a boundary condition to determine the stresses imparted during operation.

Results

Principia used the results of the FEM to make decisions about the options available to the operator. It was found that substituting cast iron for cast steel was not a viable option without redesigning the trunnion. This meant that the operator would eventually have to replace the trunnions with new ones made of the same material or get a new mill. Based on the costs and timing of the various options, the best time/cost option was to first do an emergency weld-repair now and then have replacement trunnions manufactured overseas from cast steel.