Failed pipe diagonal

Attention to detail

Sooner or later, duty cycle container cranes develop fatigue cracks. Michael A Jordan, Structural Engineer at Liftech Consiultants Inc., explains what is happening to the world's older cranes and what ports must do to deal with the problem

Over time, it is inevitable that container cranes will develop fatigue cracks.The cracks start at minute discontinuities, usually at welded joints. At first, the cracks grow slowly, but as a crack's size increases, the rate of growth increases until it reaches a 'critical size.' It then explodes at the speed of sound. Bang. Failure. This may take months or it may take decades. It all depends on details.

Even though designed to antiquated standards, hundreds of pipe truss booms have performed well. But now, after decades of heavy use, failures occur regularly. That's the bad news. The good news, though, is:

1. the failures are occurring where they are expected;
2. the pipe members are redundant; and
3. the trusses can be repaired very easily if the cracks are detected before they extend through the pipe wall. When the cracks penetrate the wall, the failed sections can be replaced with gusset plates.

What fatigue is

All welds, even if perfectly made and properly inspected, contain small undetectable discontinuities: cracks. Cycles of stress cause yielding at the sharp reentrant corners at the crack boundary. The atoms separate and the crack grows. Increase the stress, undertake more cycles, and larger cracks will lead to an accelerated crack growth.

Eventually the cracks are so large they may be detected by non-destructive testing. Very soon after the cracks are large enough to be found, they reach a critical size, at which the energy released per unit area of crack growth exceeds the energy absorbed by the parting atoms. This is instability. The cracks shoot across the section, causing sudden brittle failure.

The lower the temperature, the lower the energy absorbed. This is why brittle fracture is more likely at low temperatures. The more rapid the loading, the lower the energy absorbed. This is why dynamic loads are more likely to cause brittle failure.

If the failed component causes collapse the component is fracture critical, if not it is not fracture critical.

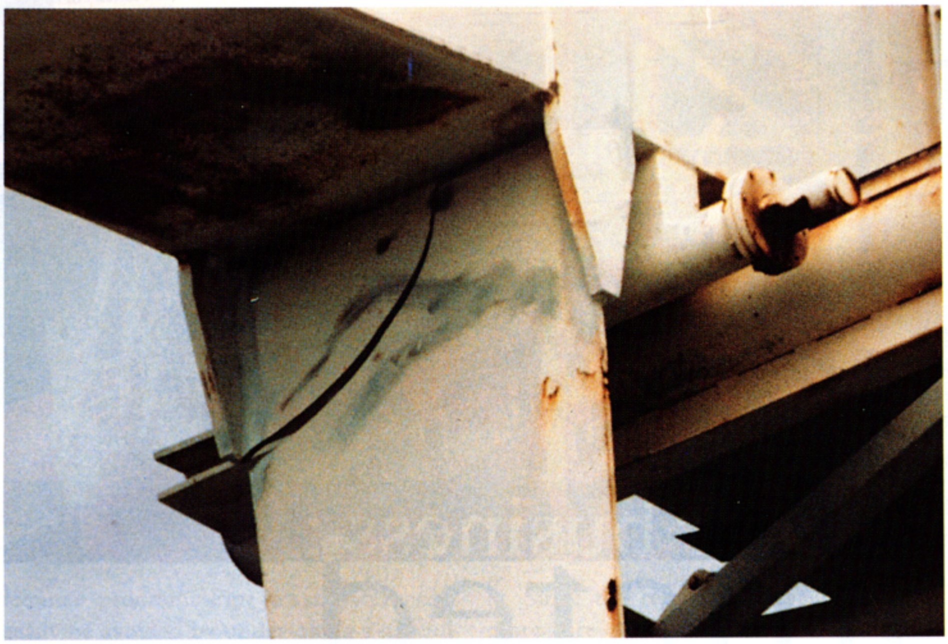
What fatigue is not

Fatigue is not tired steel. The steel that does not crack is as good as new. If the crack is repaired the structure is reborn.

Load tests do not determine fatigue strength. Load test verify static strength at the time of the test, not the fatigue strength. When the crack grows, the strength is reduced and the prior load test is invalid.

Fatigue failure is predictable, but only probabilistically, not deterministically.

Repaired pipe diagonal



Failed Hanger

We can predict the chances of failure but not the certainty of failure.

The probabilistic nature of fatigue is a large part of the problem. What worked in one case may not work in another. Combine this with the length of time that fatigue failure usually takes, ten years or more, and we have myths galore. We hear '*We have done this for years and never had a problem*'. Wait a while. It took me fifteen years to become a believer. Fatigue is real. It happens.

The thousands of fatigue test results, albeit statistically scattered, do predict the behavior of details. Fatigue behaviour is as predictable as the roll of a dice or the flip of a coin. We cannot say which details will fail, or when they will fail, but we can predict the long term performance of many details on real cranes. We can predict which details will last longer and where failure is most likely to occur. Failures occur regularly.

Details, details...

Reliability depends on the details. A proper design can be, and often is, degraded by carelessly adding attachments for hand rails, walkways, and mechanical and electrical equipment. The degradation is, without exception, dramatic.

The expected fatigue life of a welded box beam is two and one half times the expected life of the beam with a fillet welded lapped plate. Bad details can be avoided.

The detail at the 'wrap around' weld on the pictured failed hanger is avoidable and should not be used. Millions of dollars have been lost because of wrap around welds. A simple design change eliminates the problem.

The alternate details shown improve the reliability by a factor of 2.5 or more. They should be used.

Design and build well

Modern codes, such as BS 7608 Code of Practice for Fatigue Design and Assessment of Steel Structures, recommend stress levels for many details.

These stress levels are based on the statistical evaluation of thousands of tests. In most cases, the allowable stresses provide a chance of success of 97.7 percent at the design life.

The design criteria may be made more or less stringent to adjust the reliability. Notice in the table that after the crane has lifted half the number of design lifts, the reliability is 99.9 percent, significantly increased from the design reliability of 97.7 percent. So designing to four million cycles, when two are expected, reduces the chance of failure from 23 in 1000 to 1 in 1000, a significant and relatively inexpensive measure.

Details...and good details

But more important than design criteria is the use of *good* details. The Liftech crane specification shows acceptable and unacceptable details. Use of these details improves the odds.

And even more important than using good details is maintaining the integrity of the design throughout the life of the crane. This starts with the elimination of thoughtless attachments and ends with a carefully thought through periodic main-

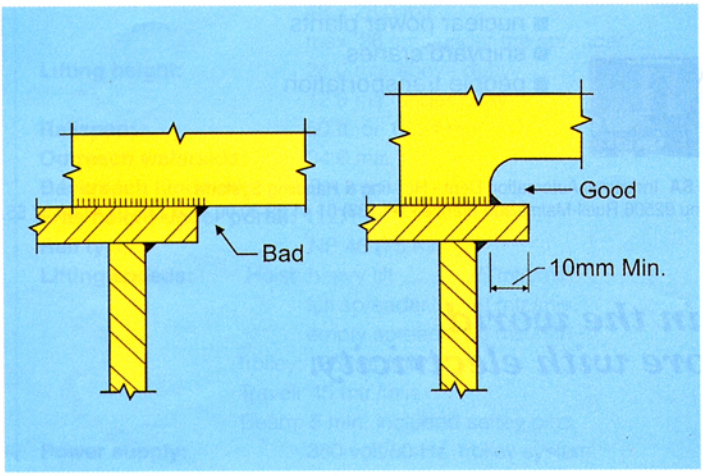


Figure 1: Attachment Detail

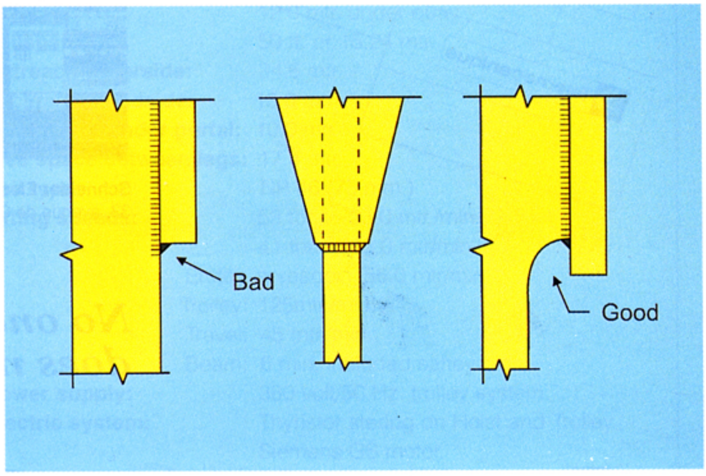


Figure 2: Connection Detail

Chances of success and failure

Actual lifts/ design lifts	Expected success per 1000	Expected failure per 1000
0.50	999	1
0.75	995	5
1.00	977	23
1.50	884	116
2.00	733	267
3.00	426	574

Values based on BS 7608 Class F details designed to recommended allowable stresses

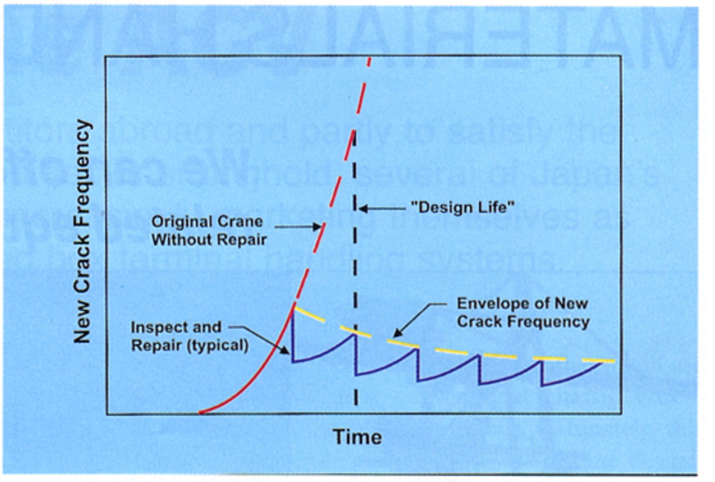


Figure 3: Cracks and Inspection

tenance program. Pipe truss failure can easily be avoided by undertaking a careful structural examination of the crane. We know where to look.

Maintain well

Periodic examination for cracks is one ingredient of a successful maintenance program. Another is proper repair.

If cracks are found and repaired, the structureís life can be extended indefinitely. Since the repairs may be made with more care and inspection than the original, the repaired joint is often better than the original.

Live long...

For one series of cranes that have been routinely inspected and repaired within my experience, the frequency of crack occurrence has actually decreased. In a sense the structure is mellowing as time passes and, in some ways, it may even be said to be 'better than new'.

...and prosper

The threat of fatigue failure is always here. The occurrences are random but follow predictable patterns. You may get lucky or you may get unlucky. Life is uncertain.

But, whilst you never know what might happen, you can do a great deal to improve your odds. ❑