Liftech
LIFTECH CONSULTANTS INC.

CRANE DESIGN CRITERIA BASED ON LIMITED EXPERIENCE

INTRODUCTION

Occasionally, Liftech is asked to rely on historic performance of an existing design for determining acceptable reliability. This is problematic since the acceptable risk of failure for most cranes is extremely small, and a few successes do not indicate that the risk is acceptable or in conformance with normal industry standards.

RELIABILITY

The chance of failure of a long-lived, heavily used crane must be extremely small. The structure must be reliable. Liftech's structural maintenance program uses a reliability of 0.99999, or a one in 100,000 chance of catastrophic collapse due to a single joint failure. This is consistent with the industry standards. Although at first glance a chance of one in 100,000 seems very reliable, it is not since there are many critical joints.

ACCEPTABLE RISK

It is important to understand the concept of acceptable risk.

Determining acceptable risk is difficult. To do so, one must have knowledge, experience, and judgment.

One who has not considered this issue before may think, "I want no risk of failure." Unfortunately, there is always some risk of failure. The question is how much risk is acceptable? The following discussion may explain the problem of basing criteria on the performance of a limited number of cranes operated for much less time than the "design life."

Although unexpected events occur rarely, they do occur—that is what "unexpected" means. We have been involved with thousands of ship-to-shore cranes. We often investigate failures. Some are due to fatigue damage. Some fatigue failures are catastrophic. Fortunately, most failures have not involved personal injuries, only significant financial loss. The risks are real.

So how much risk is acceptable? The following discussion may help the responsible person decide.

DESIGN PHILOSOPHY

A pioneer in determining acceptable risk, T. R. Gurney, discussed design philosophy in the 1968 edition of his classic text *Fatigue of Welded Structures*. Gurney addressed the design of structures subject to large numbers of applications of variable loads.

From the text:

> "The first difficulty is to decide what one is trying to achieve in terms of life. If the designer, who has not had to consider the question in detail before, is asked what life he requires from his structure, he will almost invariably reply that he wants infinite life with no fatigue cracking, regardless of what the structure may be. In the past, even though detailed design to prevent fatigue was not common, infinite life was in fact often achieved, at least for the economic working life of the structure. The reason for this was that the static design of structures involved the application of large safety factors and the use of approximate design methods, which resulted both in the use of pessimistic design stresses and in the overestimation of the applied stresses.
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> However, design stresses have steadily increased and the use of more sophisticated design methods means that, nowadays, design stresses tend actually to exist in structures in service. This, taken in conjunction with the fact that structures are now more intensively utilized, is the reason why fatigue has become a problem. In this new situation the only way that a designer can ensure infinite life is to use working stresses below the fatigue limit-i.e. the stress at which cracks will not propagate-of the joints in his structure. As has already been said this implies the use of very low working stresses. However, if any stresses are greater than that, then it must be accepted that failure will eventually occur and the life will be finite.
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> The designer is therefore in a dilemma. Is he-to keep the stresses very low, inevitably at the expense of a heavy structure, and try to obtain infinite life, or is he to accept a finite life? And if he does accept a finite life, on what basis is he then to choose his design stress?
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> Much of the thinking on this subject has originated in the aircraft industry where weight savings is of particular importance. There the problem is somewhat more critical than that usually encountered in the field of general engineering because human life is at stake and it is necessary to reduce to a negligible level the risk of catastrophic failure. In many cases human life will not be endangered if failure occurs in a welded structure in the general engineering field, but nevertheless the economic consequences may be severe. It is therefore of interest to consider the two design philosophies which were developed by aircraft engineers. They have come to be known as the 'safe-life' and 'fail-safe' concepts of structural design."

INDUSTRY PRACTICE

The container crane industry, and in particular the British Standard, BS 7608 Annex A, considers two design approaches: "Damage Tolerant Design" (Gurney's 'fail-safe') and "Safe-Life Design." The stress levels allowed by BS 7608 and the Liftech specification are based on damage tolerant design. From BS 7608: "Damage tolerant design should ensure that when fatigue cracking occurs in service the remaining structure can sustain the maximum working load without failure until the damage is detected."

This goal is achieved by limiting the allowable fatigue damage and periodically inspecting the structure so cracks are detected before failure occurs. The allowable fatigue damage is determined by statistically analyzing thousands of fatigue test results. The results on similar welded details vary considerably. Therefore, there must be a large number of results for statistical analysis to be meaningful. If for some reason only a few tests have been performed, the allowable stress must be much less than the failure stress indicated from the test results.

Design Based on Limited Data

BS 7608 allows criteria to be based on a limited number of tests. The following table from BS 7608 indicates how the design fatigue life and allowable stress is calculated for various numbers of test specimens.

The geometric mean life obtained from the effective number of specimens is divided by the fatigue test factor, F, to determine the design fatigue life.

The test value is divided by the Fatigue test factor, F.

BS 7608 Table E.1 Fatigue test factor F.		
Effective number of specimens	**Fatigue test factor, F**	**Stress safety factor, S, for typical welds**[1]
1	5	1.7
2	4.2	1.6
3	3.9	1.6
4	3.75	1.6
10	3.5	1.5
Note 1: Liftech added this column to BS 7608 Table E.1; $S = \sqrt[3]{F}$		

Notice that F is asymptotically approaching 3 and that S is approaching 1.5. So, even with a large number of tests, the design fatigue stress is only two-thirds of the test result value. Clearly, reliance on limited experience from ten samples is not a satisfactory basis for determining allowable values. A significant safety factor is still required.

What is the message from the table? If an experience involves, say, four cranes, subjected to the design life history, i.e., number of cycles and magnitude of loads defined in the design criteria, then the design life of another crane should not exceed 27% of the average life of the specimens.

For the reasons discussed, a few successful results for a limited number of cranes, operating for a fraction of the design life, do not reasonably prove that the risk of failure is acceptable.

If data is not available for a very large number of cranes operating for a considerable amount of time and loaded to the design loads, the engineer should not use a limited sample to establish design criteria. The risk would be too high.

The engineer should use, as a minimum, established industry standards.

USING LACK OF FAILURE AS CRITERIA

Using "lack of failure" to determine criteria is not sound. We call this approach the Challenger approach. The Space Shuttle Challenger exploded because the O-rings became brittle at low temperatures. The shuttle had been successfully launched before at temperatures below the design temperature, but not as low as on the fatal day.

Managers based their decision to launch on the "lack of failure" criteria: if failure did not occur at temperatures below the design temperature, it would not occur at even lower temperatures. For the record: the engineers advised that the launch should not be attempted.

Using "lack of failure" as criteria to allow more and more risk will eventually result in failure.

In our practice we are occasionally subjected to this faulty reasoning. We have more examples. We hope this discussion is enough to make the point.

CONCLUSION

It is not sufficient to base design criteria on limited experience. A structure near failure may not show distress. The risk of depending on limited experience is not acceptable.

The acceptable risk of failure must be based on engineering analysis and normal industry standards.

REFERENCES

T. R. Gurney, *Fatigue of Welded Structures*. Cambridge, England: Cambridge University Press, 1968.

British Standards Institution, BS 7608:1993, *Code of Practice for Fatigue Design and Assessment of Steel Structures*. London: BSI, 1993.