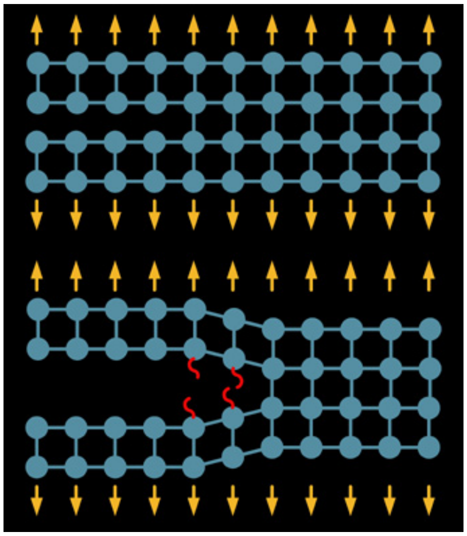
Structural Maintenance of Dockside Container Cranes



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This paper is informational only. Assessments, repairs and maintenance plans should be designed by registered engineers.

STRUCTURAL MAINTENANCE OF DOCKSIDE CONTAINER CRANES

BACKGROUND

Most crane operators have a structural maintenance program to improve the reliability of their cranes. But sometimes, fatigue crack repairs are ill conceived and exacerbate problems. Once fatigue crack growth and brittle fracture are understood, the structural maintenance program discussed below will make sense, and you will be able to make proper judgments about what to do when cracks are detected.

Container crane specifications include this provision:

> STRUCTURAL MAINTENANCE PROGRAM
>
> Periodic structural inspection is required to detect cracks that have developed during the life of the crane.
>
> The Contractor shall submit a Structural Maintenance Program for review. The program shall be based on the principles of fracture mechanics.

The Liftech specification includes two tables relating to structural reliability.

DETAIL	Calculated cumulative damage/ Allowable cumulative damage			
	1.0	0.8	0.6	0.4
W	0.977	0.994	0.999	1.000
G	0.977	0.994	0.999	1.000
F2	0.977	0.992	0.999	1.000
F	0.977	0.993	0.999	1.000
E	0.977	0.991	0.998	1.000
D	0.977	0.993	0.999	1.000
C	0.977	0.993	0.999	1.000
B	0.977	0.994	0.999	1.000
T-X	0.977	0.993	0.999	1.000

Table 1: Fatigue Detail Reliability

	Calculated cumulative damage/ Allowable cumulative damage					
DETAIL	24 YEARS		12 YEARS		6 YEARS	
	NFCM	FCM	NFCM	FCM	NFCM	FCM
B	0.21-0.41	0.19-0.38	0.42-0.69	0.39-0.64	0.70-1.00	0.65-1.00
C	0.18-0.36	0.17-0.33	0.37-0.62	0.34-0.57	0.63-1.00	0.58-1.00
D	0.18-0.35	0.16-0.33	0.36-0.61	0.34-0.56	0.62-1.00	0.57-1.00
E	0.15-0.29	0.13-0.26	0.30-0.50	0.27-0.45	0.51-1.00	0.46-1.00
F	0.17-0.34	0.16-0.31	0.35-0.58	0.32-0.53	0.59-1.00	0.54-1.00
F2	0.16-0.32	0.15-0.29	0.33-0.56	0.30-0.51	0.57-1.00	0.52-1.00
G	0.21-0.41	Not allowed	0.42-0.70	Not allowed	0.71-1.00	Not allowed
W	0.20-0.40	0.19-0.37	0.41-0.69	0.38-0.64	0.70-1.00	0.65-1.00
TUBULAR	0.20-0.35	0.15-0.30	0.36-0.64	0.31-0.50	0.65-1.00	0.51-1.00

Table 2: Inspection Interval Criteria

What is the structural maintenance program and what do these tables mean?

This paper will answer these questions and explain the principles that are used to develop the reliability values and calculate the inspection interval. Finally, three examples of failures and repairs taken from our experience are briefly discussed to help explain how the principles of fracture mechanics are applied in real situations.

The required inspections and the reporting methods in a typical structural maintenance program are self-explanatory and will not be discussed here. If you would like a sample program, please contact Liftech.

THE STRUCTURAL MAINTENANCE PROGRAM

The structural maintenance program is a detailed program developed to increase structural reliability. The program addresses what inspections are required, what is to be inspected and how, how often each detail is to be inspected, how the findings should be reported, and what the repair procedures should be.

Table 1: *Fatigue Detail Reliability* shows the reliability of a particular class of detail in the structure when subjected to the expected or design stress spectrum. The values are calculated based on a statistical analysis of thousands of fatigue tests. This will be addressed later.

Table 2: *Inspection Interval Criteria* provides the data needed to determine the inspection interval for a particular class of detail when subjected to the expected or design stress spectrum.

The inspection interval values are calculated based on the expected cumulative damage and the probable cumulative damage that the detail can withstand, reliably, without failure.

The cumulative damage expected, CDE, is calculated for the expected stress spectrum and number of cycle:

$$CDE = \Sigma\, n_i\, \Delta\sigma^3$$

Where:

ni = the number of applications of the calculated stress range, $\Delta\sigma$.

Note: The power of 3 applies to most details, but not all.

The probable cumulative damage that the detail can withstand, reliably, without failure, K_2, is determined from tests:

$$K_2 = N\, \Delta\sigma^3$$

Where:

N = the number of cycles that the test sample withstood with a reliability of 0.9773, or at two standard deviations above the mean, when subjected to a constant stress range of $\Delta\sigma$.

The probable cumulative damage values vary for each detail because the standard deviation of the test data for each detail varies. See references 3 (BS 5400), 4 (BS 7608), and 6 (Maddox). The values in Table 2 are calculated using the criteria that for fracture critical members, the cumulative damage between inspections should be that which would provide reliability to 0.99999, or 1 failure in 100,000. Fracture critical members are members whose failure would cause a serious collapse.

Engineers have used a number of approaches to determine the inspection interval for cranes. Sometimes an attempt is made to determine the crack growth rate and critical crack size. This method was originally used for Liftech's structural maintenance program. But there are too many variables and the data on fatigue life has too much scatter to produce consistent and practical results.

Liftech has developed a reliability approach using the principles of fracture mechanics that can be applied easily and includes all the important parameters. Those details that are more important and are more likely to fail are inspected more often. The results are practical and appeal to our engineering judgment. The approach has been successfully used for many years on hundreds of cranes.

FRACTURE MECHANICS

Fracture mechanics is the study of material behavior in the presence of a notch. See reference 1 (Anderson).

Ideally Elasto-Plastic Behavior

Tensile Yield Stress

We are all familiar with the properties of ideally elasto-plastic materials. In the absence of a notch, steel is close to being ideally elasto-plastic. When stress is applied, steel follows a linear stress strain path until the "yield stress," σ_{yp}, is reached. Then steel deforms significantly, maintaining the yield stress. This is desirable, since the plastic deformation can be seen and something can be done before a catastrophe occurs.

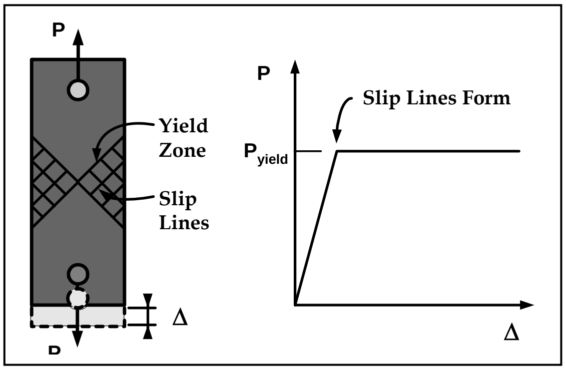


Figure 1: Tensile Yield

The standard tensile test is a uniaxial test where the only stress applied is the axial tension. For crane structures, most details include biaxial stresses and many include triaxial stresses. Under biaxial and triaxial stresses, steel yields at maximum stresses that may be much higher than the tensile yield stress.

Triaxial State of Stress

When steel is subjected to two principal stresses, $\sigma_1$and σ_2, the maximum stress may be slightly higher than the tensile yield stress. When subjected to three principal stresses, σ_1, σ_2, and σ_3, the maximum principal stress may be much higher than the tensile yield stress.

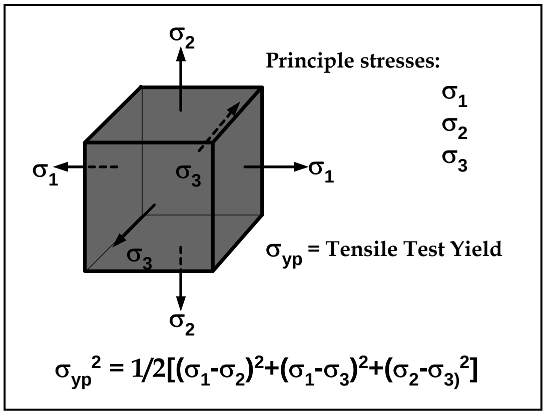


Fig. 2: Triaxial Stresses

Yield Criteria

The best yield criteria for steel is the Hencky-von Mises–Huber maximum distortional energy criteria. This criteria states that yielding occurs when the energy of the non-cubic deformation reaches a limiting value. See reference 2 (Boresi, et al).

A more easily understood yield criteria is the Tresca maximum shear stress criteria. The Tresca criteria states that failure occurs when the maximum shear stress exceeds the shear stress developed in tensile yield specimen. The von Mises criteria is not as intuitive as the Tresca maximum shear stress criteria, but it is slightly more accurate.

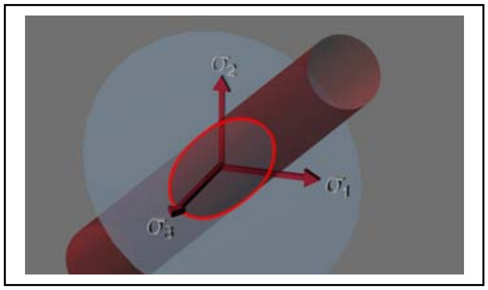


Fig. 3: von Mises Cylinder

Notice that for both the von Mises and the Tresca criteria, the out-of-plane stress, σ_3, increases the apparent strength of the material.

The permissible stress envelope defined by the von Mises criteria is a cylinder with an axis making equal angles with the principal axis. The corresponding envelope of the Tresca criteria is an inscribed regular hexagon. The von Mises cylinder intersects the σ_1 σ_2 plane forming an ellipse. If $\sigma_3 = 0$, this ellipse is the stress envelope for σ_1 and σ_2. If σ_3 is not equal to zero, then the ellipse moves in the positive σ_1 and σ_2 directions and along the line bisecting $\sigma1$ and $\sigma2$. Fig. 5 shows the relocated ellipse for the case when $\sigma_3 = \sigma_{yp}$.

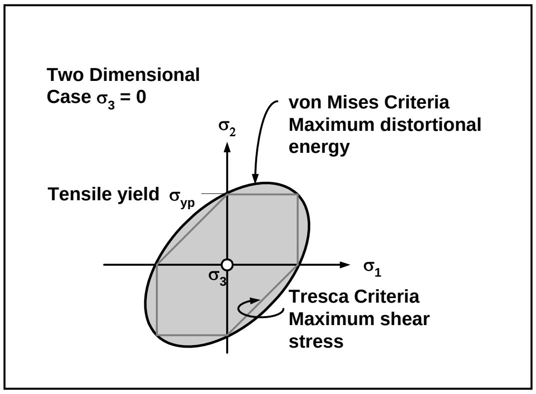


Fig. 4: Biaxial Case

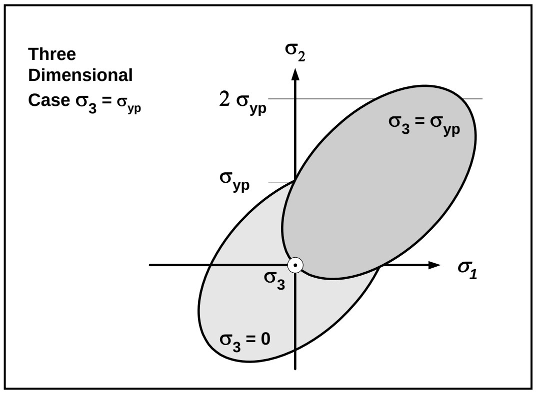


Fig. 5: Triaxial Case

The intermediate stress may be due to a directly applied stress or due to Poison's effect in highly restrained joints or thick plates. In many cases, σ_3 will be as high as σ_{yp} as used in the Fig. 5.

As we will see later, the increased principal stress due to the out-of-plane stress is important when failure initiates from a small discontinuity.

You are probably familiar with the problems in steel frames resulting from the Northridge earthquake. The triaxial stresses at the beam column joint contributed to the cracking. Triaxial stresses are even more important on cranes. The increase in the maximum principal stress due to σ_3 proportionally increases the fatigue crack growth rate and, to make matters worse, decreases the critical crack size.

Ideally Brittle Material

Brittle failure results from cleavage failure. Instead of atoms nicely sliding by one another, deforming yet maintaining strength, the phenomena for brittle failure is quite different. The atoms pull apart until the atomic bonds suddenly fail. When the bonds are broken, all strength is lost. The failure is not nice and occurs without warning.

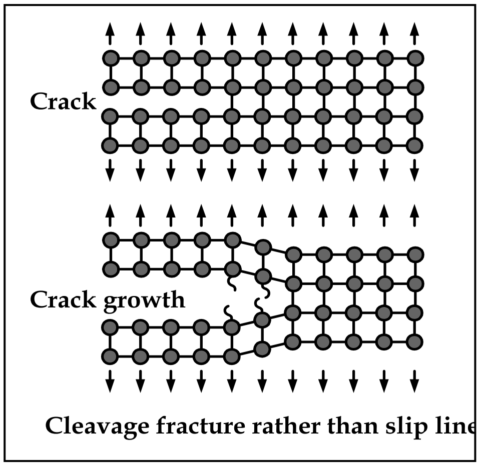


Fig. 6: Cleavage Failure

In all materials, the elastic stress at a crack tip varies inversely with the tip radius. See the Fig. 7. For a notch, the radius at the crack tip is nearly zero and the stresses are extremely high. This causes the atoms at the crack tip to pull apart. This is a cleavage failure. See Fig. 6 and reference 1 (Anderson).

Cleavage failure is indicated by the appearance of the failure surface. Metallurgists can identify brittle fracture under microscopic examination. We can often identify brittle fracture by the nature of the failure surface and the absence of plastic necking.

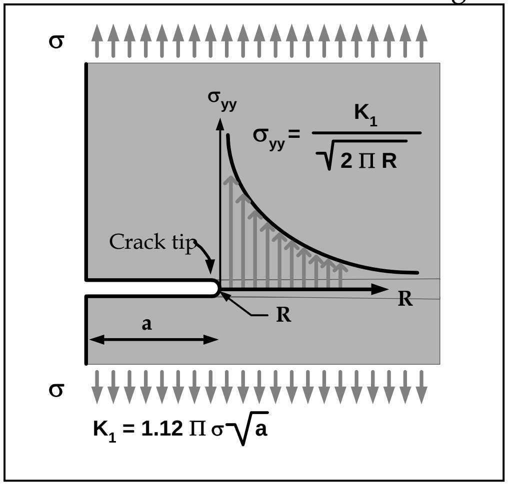


Fig. 7: Stress at a Crack Tip

When the atomic bond breaks, the load deflects and releases energy. This released energy is the demand. The stress intensity is a measure of this energy.

Stress Intensity

As the crack grows, the load deflects and does work. The energy released by the deflecting load is expressed as the stress intensity, K_1. As though the subject is not difficult enough already, the term K_1 used in fracture mechanics is not related to the same term used in reliability. The reliability term means the value one standard deviation above the mean. Also notice the term for fracture toughness, K_{IC}, is not the same as the term for stress intensity,K_1. The 1 and I are different.

As the crack increases in size, the amount of energy released per unit of increased crack area increases. This can be understood by thinking about the deflection of the load. The effect of increasing the size of a large crack is more than the effect of increasing the size of a small crack. The value of K_1 is determined mathematically.

Stress intensity is expressed in ksi√in. These units are awkward and not intuitive. For an engineer, the energy released per unit area, K_1^2 times E, would be more meaningful. The units would then be kip-in/in², a much more easily understood unit. But fracture mechanics uses K_1 ksi√in.

Fracture toughness

The other half of the energy equation is fracture toughness, K_{IC}. Just as K_1 is a measure of the energy released per unit area of crack growth, K_{IC} is a measure of the energy absorbed per unit area of crack growth. All that was said about the units of K_1 can be said about the units of K_{IC}.

The energy absorbed by cleavage is measured by fracture toughness tests or correlated to CVN tests. Fracture toughness measures the work required to tear the atoms apart.

Energy Balance

At first the energy absorbed by breaking the atomic bonds is less than the energy released by the deflecting load. The system is stable. Eventually energy absorbed by breaking atoms per unit area of crack growth equals the energy released by the deflecting load. The crack is in neutral equilibrium. Finally, the crack reaches critical size, and the energy released by the load exceeds the energy absorbed by the breaking atoms. The system is unstable. The unstable crack grows at thousands of feet per second. The member fails suddenly and without warning.

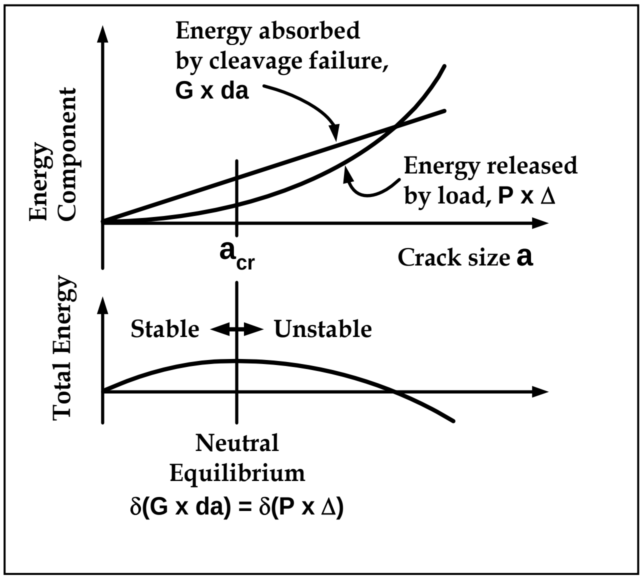


Fig. 8: Brittle Fracture Energy Balance

The stability balance for a crack is analogous to pushing a wheel over a hill. On the uphill side, work is required to raise the wheel. At the top of the hill on level ground, the wheel is in neutral equilibrium. But on the downhill side, energy is released, and the system is unstable. The same is true for the crack.

A crack grows faster and faster as the size increases, until the critical size is reached. Once the critical size is reached the crack becomes unstable, and the member fails suddenly, without warning.

For a given geometry and stress field, tougher materials will tolerate larger cracks. Cracks in tougher materials, therefore, take longer to reach critical size and have a better chance of being detected in the early stages.

Steel Is Not Ideally Elasto-Plastic or Brittle

For steel, a yield zone exists at the crack tip, so the crack growth phenomena for steel is not exactly the same as for an ideally brittle material. But in principle, steel behaves like an ideally plastic material. The fundamental understanding of cracks in ideally brittle material is applicable to steel members containing notches.

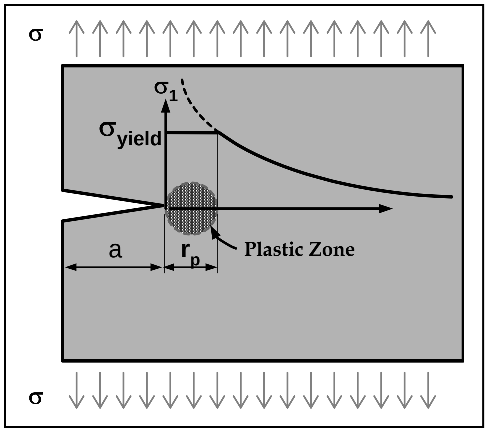


Fig. 9: Plastic Zone at Crack Tip

RELIABILITY

The fatigue strength of steel details is determined from the evaluation of thousands of tests. The tests are performed with different stress ranges, and the number of cycles to failure is found. See Fig. 10. The test data has considerable scatter, so both mean values and the standard deviation are reported.

Test data results along with the standard deviations are given in (3) BS 5400, (4) BS 7608, and (6) Maddox. This data can be used to determine the probability of failure of a given detail subjected to a stress spectrum for a specified number of cycles.

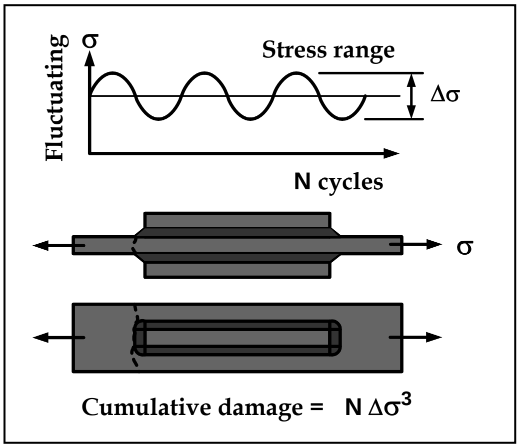


Fig. 10: Typical Fatigue Test

The values in the reliability table are calculated using normal distribution properties and the given mean and standard deviation of the test cumulative damage.

Since the data has considerable scatter and because field conditions are not well known, the results are approximate. But they are consistent with the parameters that affect reliability: detail class, stress spectrum, and the number of cycles. If the stress spectrum and the number of cycles change, the reliability changes accordingly. Although the numbers are approximate, the relative reliabilities are reasonably accurate.

The usually specified reliability for a detail is 0.9773, which is two standard deviations above the mean. This is not very reliable. If the structure was subjected to the design cumulative damage, and the details were working to the allowable limit, one detail in 45 would fail. This would not be acceptable.

For the actual case, the fatigue damage is not as high as the design conditions, and only a few details are working to the limit. Notice from the reliability table that a detail is working to 60% of the limit, the reliability is .999 or more. This is better, but still not very good, if the design conditions are realistic.

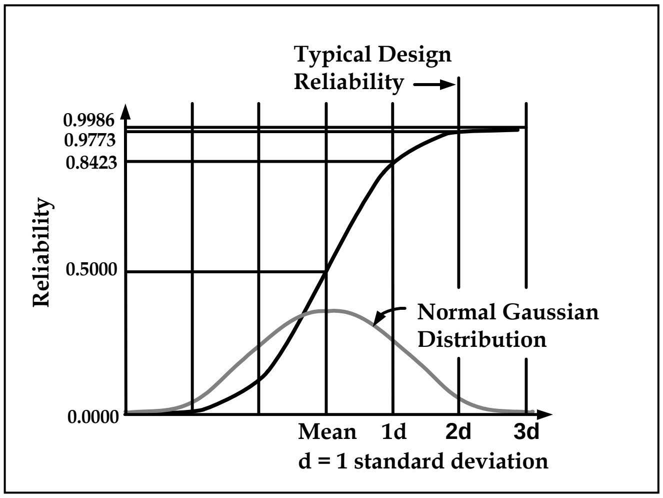


Fig 11: Reliability

In our experience, structures subjected to the design damage develop unacceptable cracks. The reliability of heavily used cranes needs to be improved. This can be done through structural inspection.

The inspection program should be based on engineering analysis, taking into account all the important parameters. The methodology described above will produce a cost effective fracture control plan that will increase the reliability by a factor of thousands.

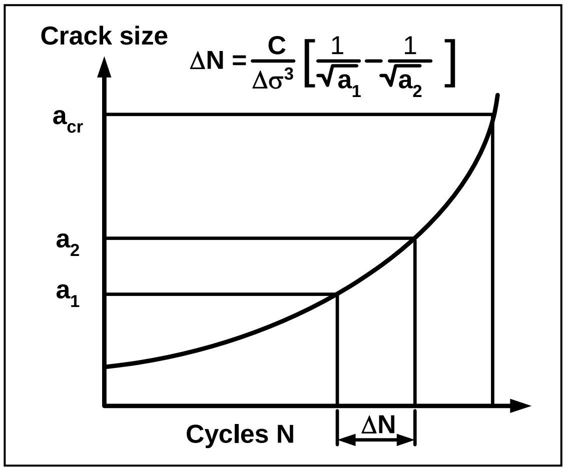


Fig. 12: Fatigue Crack Growth

INSPECTION INTERVAL

Liftech uses a statistical approach to determine the inspection interval. The interval is determined using test data, expected usage, and desired reliability. There are other approaches. In some cases, an approach using the crack growth curve is used. So some mention of crack growth rate is appropriate.

Using fracture mechanics, the number of cycles required, $\triangle N$, for a crack to grow from an initial size, a_1, to a larger size, a_2 ,is calculated. Also using fracture mechanics, the critical crack size, a_{cr} , is calculated. So, in theory, an inspection interval could be determined for the given geometry, material properties, and stress history so cracks would be detected before they reach the critical size. This approach is suitable for airplanes and other machines that have well defined geometry, material properties, and stress history, but it is not suitable for cranes. There are too many unknowns.

We do not know the geometry at the toe of the weld, because no two welds are the same. The allowable stress is determined from numerous fatigue tests. The scatter is so great that the allowable stress is given in terms of Gaussian values, the mean and standard deviation. We do not know the material properties, tensile yield and fracture toughness very well. Only a few samples are taken from a large batch of steel. So the properties for each piece of plate are known only within wide variations. And finally, we do not know the stress history.

Because of the many random variables, we believe the safest and most cost effective approach is the suggested one based on fracture mechanics and statistical analysis.

SOME EXAMPLES OF FAILURES AND REPAIRS

Now that we know the basis of the structural maintenance program and what factors are

Oakland Low Profile Crane

important, we are ready to make inspections. But when a crack is detected, what should be done?

Three cases are presented to guide you. The conditions and repairs were different for each case. But in each case, the failure was repaired following the principles of fracture mechanics discussed above.

Low Profile Cranes

Oakland Hanger Failure

In 1988, during normal operations, a waterside hanger blade failed. A fatigue crack initiated at the toe of the wrap around connecting the gusset plate to the blade. See photos. The fracture surface clearly indicated a fatigue crack that had grown to several inches and resulted in brittle fracture. The brittle fracture was indicated by the crystalline fracture surface and the absence of shear lips.

The crane was designed to stand with one hanger broken, provided the remainder of the structure was intact. Fortunately, no other blades were cracked and the structure was intact. The structure performed so well that the operator didn't notice the major fracture until he finished his shift and could not retract the boom. He noticed that one side of the boom had dropped about six inches, but this didn't concern him.

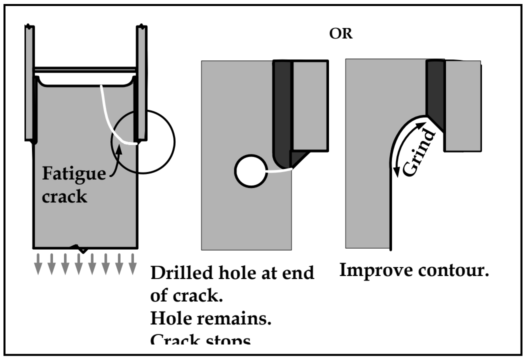


Fig. 13: Hanger Repair

Fracture Surface

Another odd circumstance: The joint had been MT inspected the day of the failure. The inspector inspected the fillet welds on the inside of the gusset but did not inspect the wrap around weld at the outside edge of the blade, since it was difficult to reach. Since he didn't understand the situation, he spent his time inspecting the welds that had little chance of cracking, and did not inspect the small portion of the weld that was most likely to crack. If he understood the subject, he could have spent less time and found the crack. For your guidance, Appendix A shows where fatigue cracks are likely to occur.

The detail at the wrap around weld is not allowed by current standards. A number of details that have been used are likely to crack and should be avoided. Appendix B shows some welds that are not allowed by the Liftech specifications and the proper details. Many of these details have become industry standards.

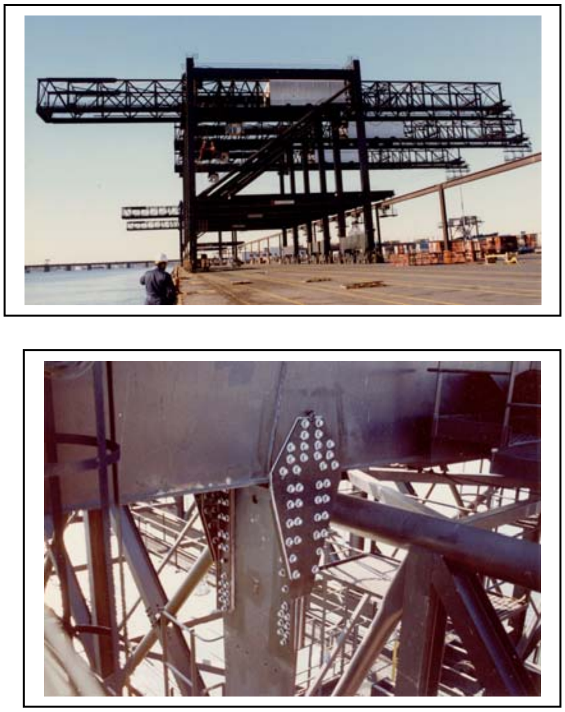
The fractured blade was replaced with an improved detail according to the recommendations in Appendix B. The uncracked blades at the other hangers were modified to improve the contour at the weld. And since we did not know the fracture toughness of the material, reinforcing plates were bolted to the blade and gusset plate as had been done on the Sea-Land low profile cranes in Elizabeth NJ. See photos.

Elizabeth Hanger Repair

In 1975, after a catastrophic fatigue failure caused a low profile boom to collapse and crash onto a ship, the remaining low profiles cranes were carefully inspected. The inspection detected a small fatigue crack at the wrap around weld similar to the detail that failed in Oakland.

Repairs were made. A hole was drilled a short distance beyond the crack and reinforcing plates were bolted to the blade and gusset plate.

The hole acted a crack stopper. Once the crack reached the hole, the stress intensity would be less the fracture toughness and the crack would stop. After about 15 years, the crack did progress to the hole. Since the reinforcing bars covered the sides of the blade, only the end was visible. Now that the crack had reached the hole, it opened enough so the crack was visible at the edge of the blade. This was to be expected and had been predicted. But the operator was concerned that perhaps the crack did not go to the hole and may be progressing across the blade. So the bolted plates were removed for inspection. The hole had progressed to the hole and stopped just as fracture mechanics led us to expect. There are many unknowns about crack growth. But there is one certainty: the crack always grows perpendicular to the principal stress.



Elizabeth Low Profile Crane

Although the hole was an acceptable solution, technically we would have been better to make the hole and then neatly cut the plate to the hole. Then the layman would not have been concerned.

Oakland Low Profile Upper Chord Repair

During routine maintenance inspections, indications were found at the root of the complete penetration butt welds in the upper chord. Attempts were made to repair the welds, but the root at the backing bar could not be brought up to current standards.

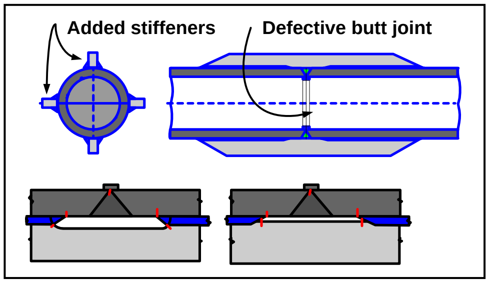


Fig. 14: Upper Chord Repair

The joint is fracture critical, so a reliable solution was needed. We could not risk the uncontrolled growth of a crack initiating at the root, so reinforcing bars of high strength and extremely tough material were welded to the outside of the upper chord. See Fig. 14. These bars reduced the stress at the butt joint, thereby reducing the fatigue crack growth rate. They were designed to carry the full upper chord load, making the welded butt joint redundant.

Notice that the fillet weld on the bars is interrupted at the butt joints. This will prevent a crack extending from the pipe into the bars. With the bars in place, the chance of fracture at the butt joint is reduced. With the repair, the most likely initiation location of fatigue cracks is at the ends of the bars. These ends are inspected regularly in accordance with the port's structural maintenance program.

Oakland Crane Leg Cracks

The conventional A-frame container crane had been raised to service larger ships. See photos next page. New diagonals extending from the portal tie to the leg were added, and a new gusset plate was welded to the leg. During a routine structural maintenance inspection, cracks were found at the discontinuity at the end to gusset plate weld to the leg.

The crack started at the end of a very rough butt weld.

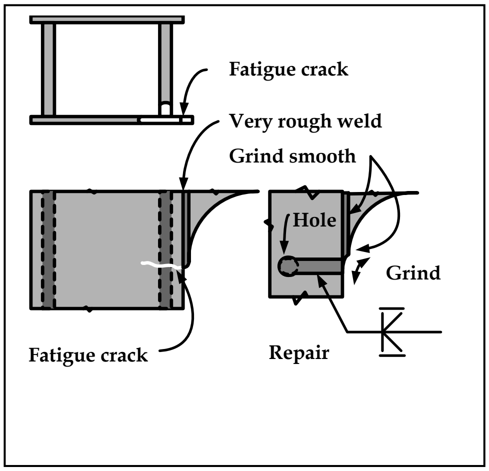
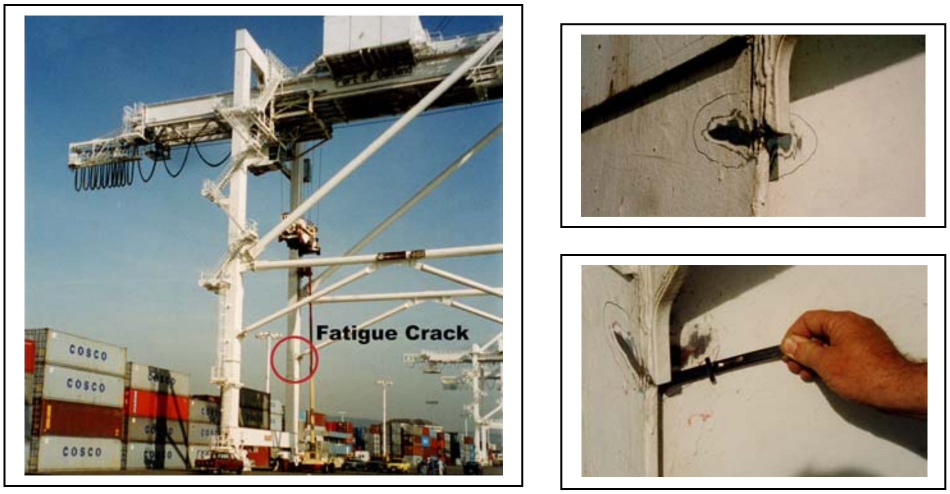


Fig. 15: Leg Repair

The repair was straightforward. A hole was drilled just beyond the end of the crack, and the plates were butt welded with complete joint penetration welds. The rough contours were ground smooth. This repaired the cracks and extended the life of the new detail by a factor of four or more.

This is a good example of proper inspection at the critical locations. The cracks were found and repaired before any serious damage occurred.



Oakland Leg Cracks

One final comment about crack removal. Generally, a hole should be drilled at the end of the crack before the crack is removed by burning. The heat causes the material to expand. The crack has zero clearance, so the heat causes tension at the crack tip and can cause the crack to advance. In one case, a welder caused a crack in a rail support beam to advance 130 feet. He thought he was finding more cracks. Actually the crack that needed removing was only a few inches long. Understanding helps.

CONCLUSION

If we understand the phenomena, we can apply our understanding and put our efforts where they are most effective.

Structural maintenance programs are necessary to maintain highly reliable cranes. If cracks are detected in their early stages, repairs are usually straightforward and economic.

Although life is uncertain we can improve our odds.

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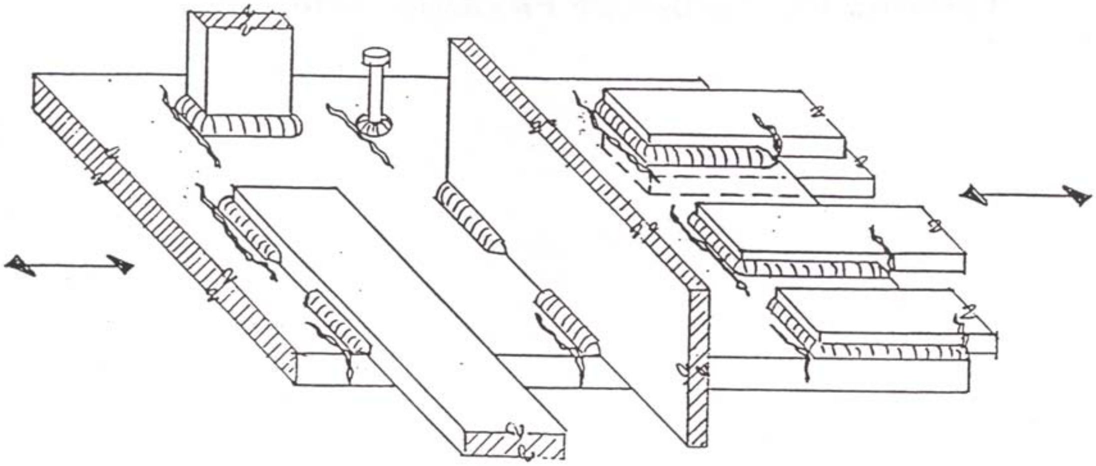
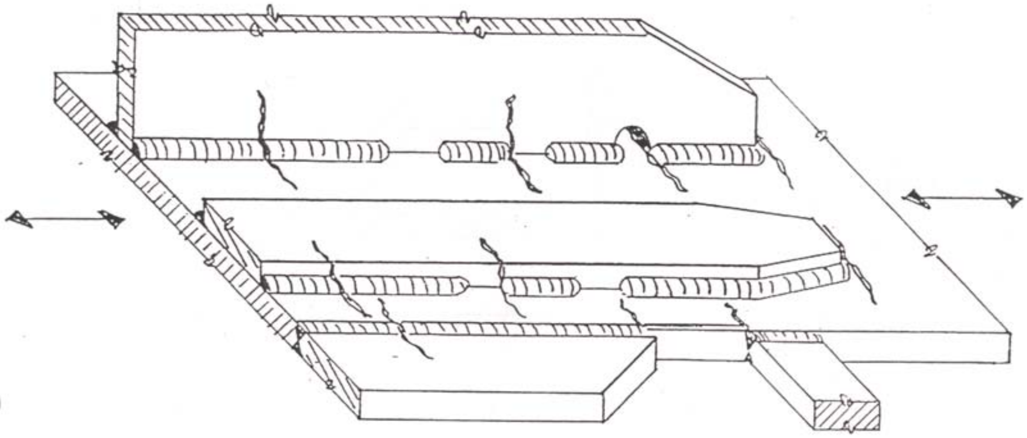
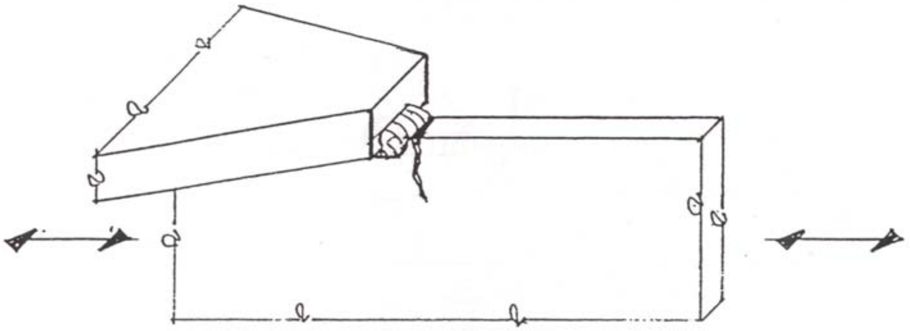
APPENDIX A:

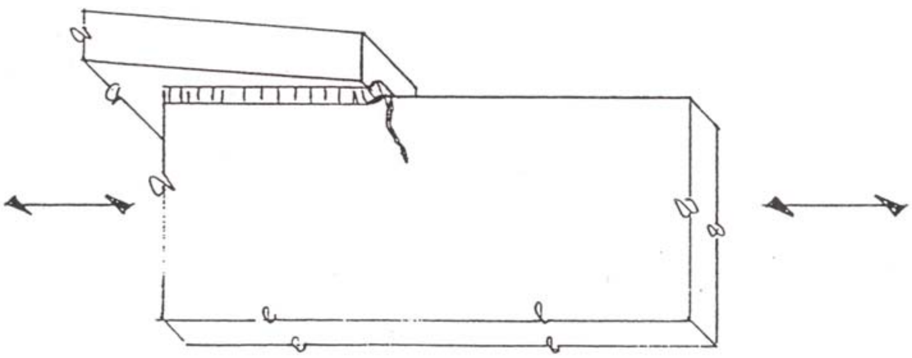
TYPICAL PATTERNS OF FATIGUE CRACKING

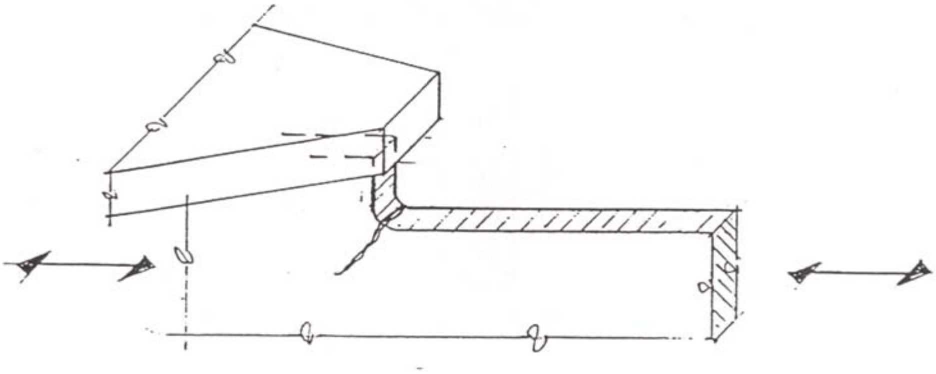
Reference: British Standards Institution. BS 5400: Part 10:1980. *Steel, Concrete and Composite Bridges*. London: BSI.

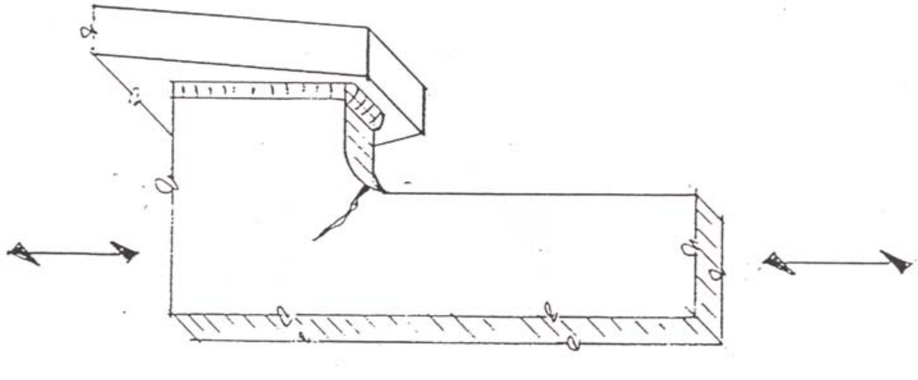


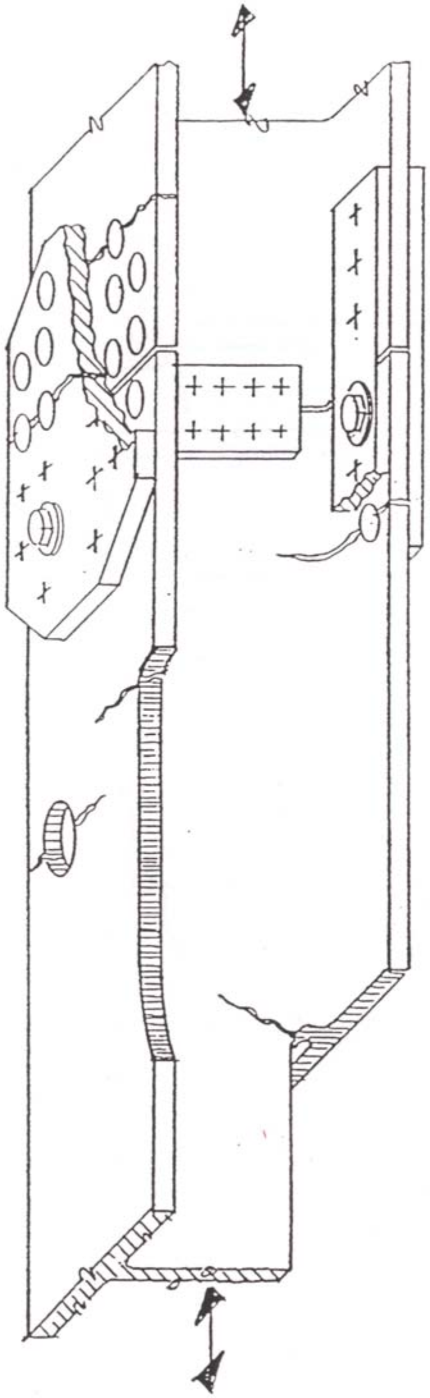










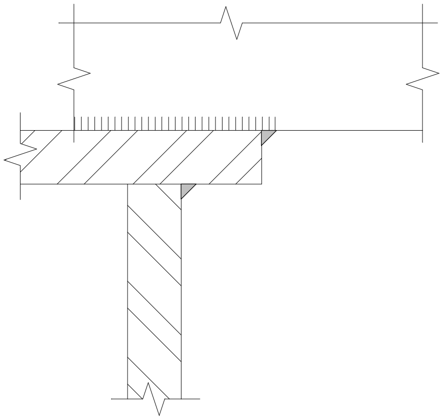

A
A

APPENDIX B:

STRUCTURAL DETAILS

These details have been prepared in accordance with recognized engineering principals and are intended for use only by competent persons who, by education, experience, and expert knowledge, are qualified to understand the limitations of the data.

Structural Details



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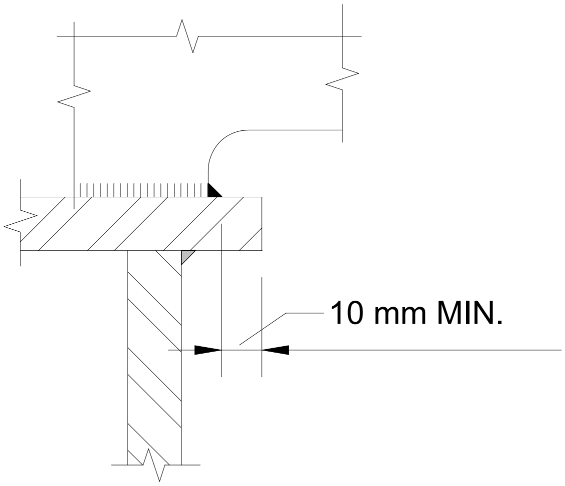

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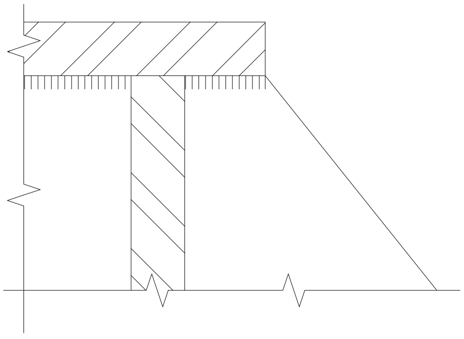

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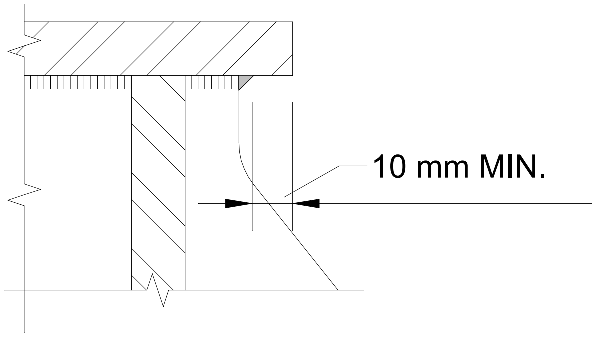

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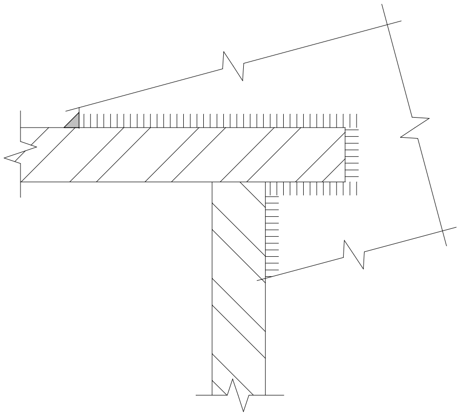

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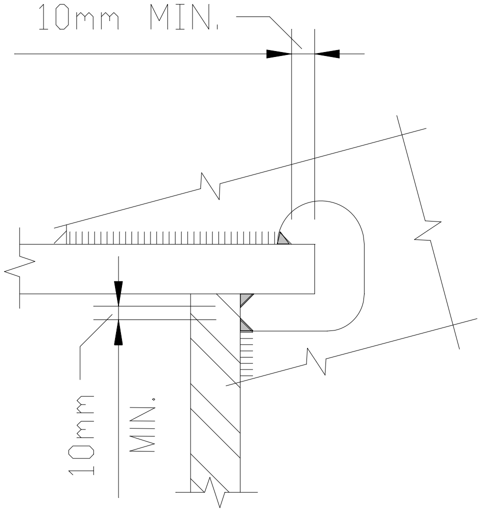

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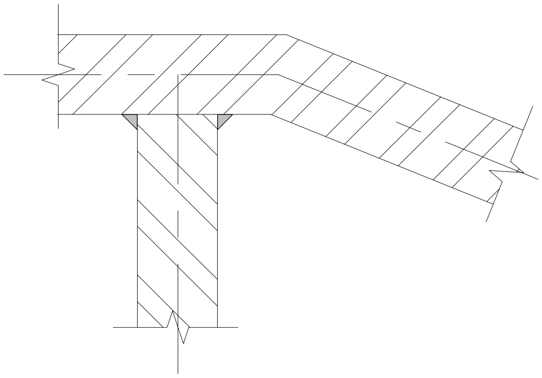

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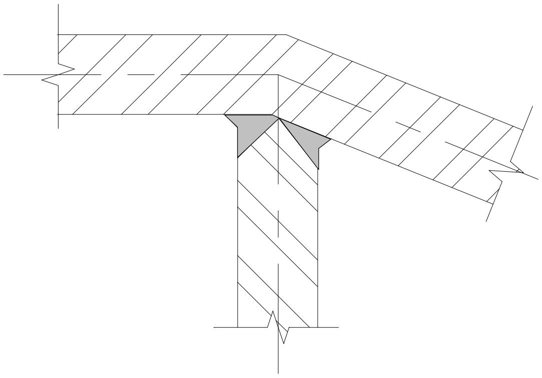

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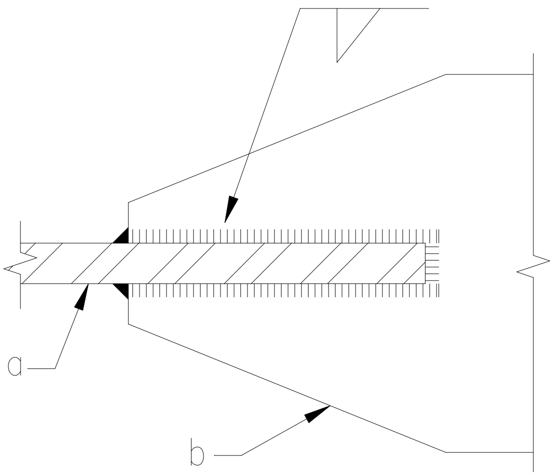

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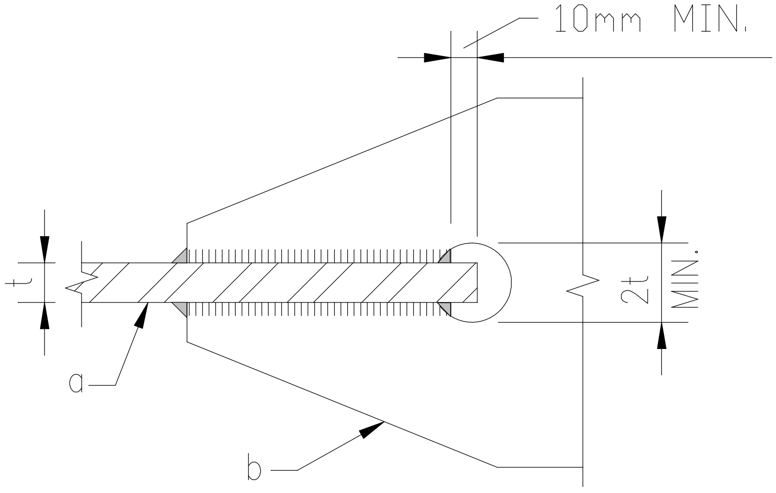

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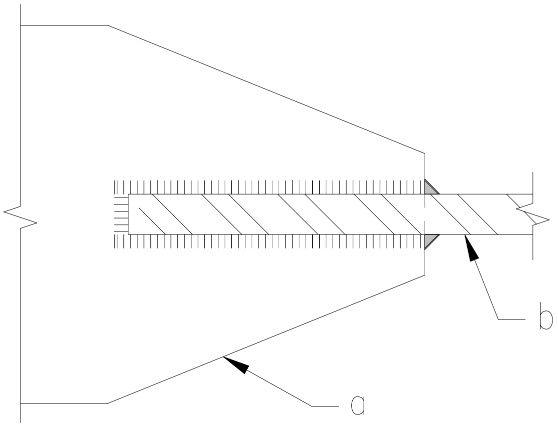

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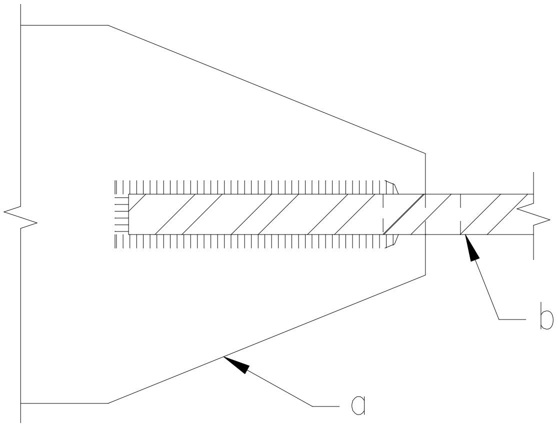

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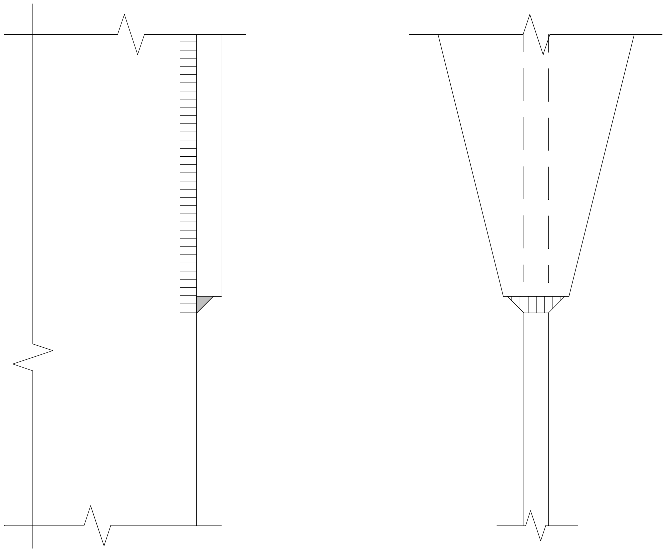

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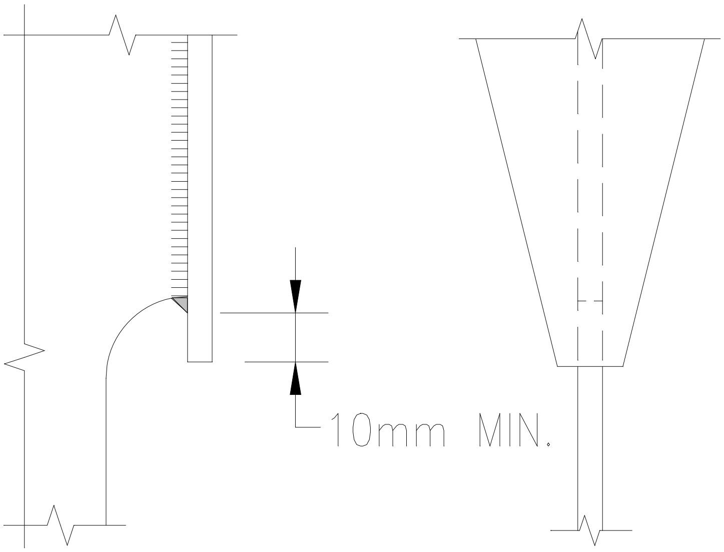
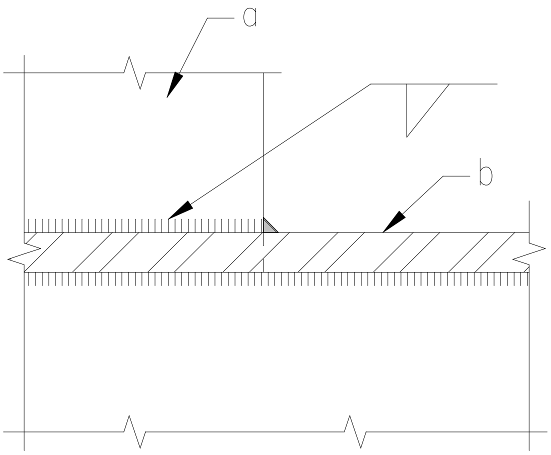


Acceptable

By PWM Approved AB

Structural Details



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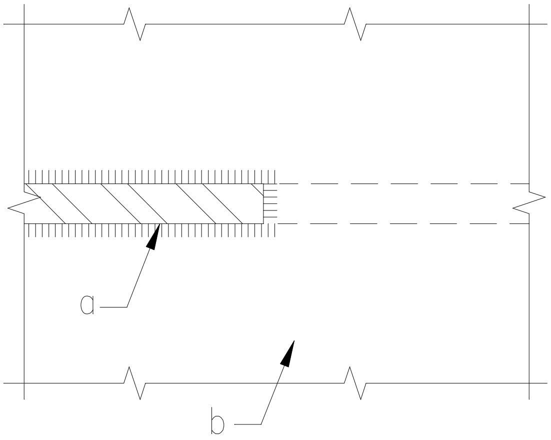

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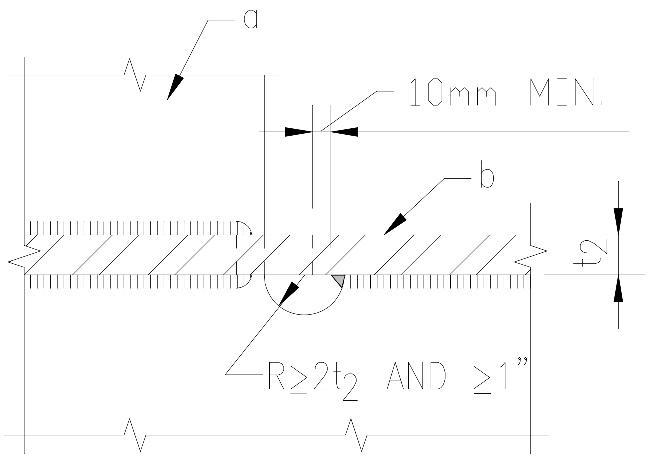

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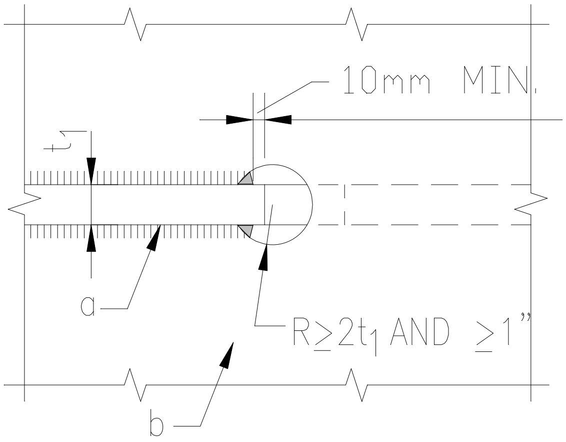
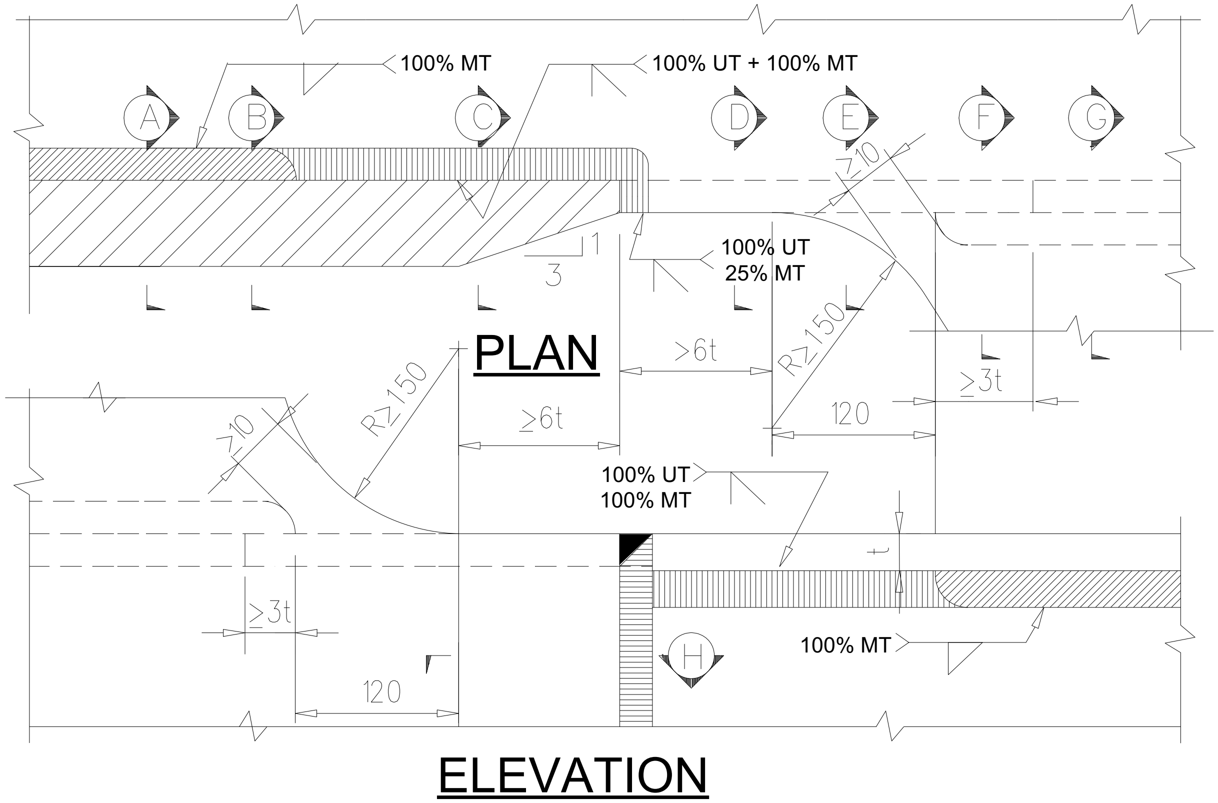


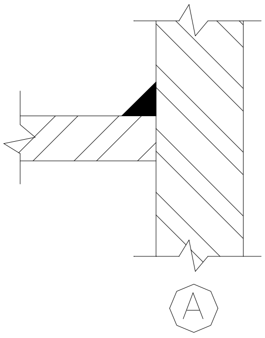
Acceptable

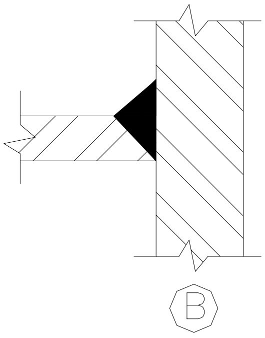
Structural Details

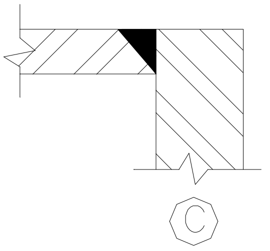
Avoidance of Wraparound Weld Acceptable

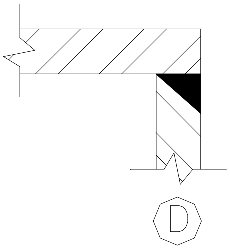
See Sht. 7 for isometric view.

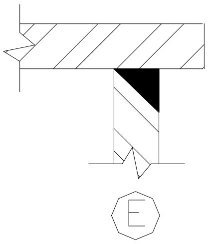


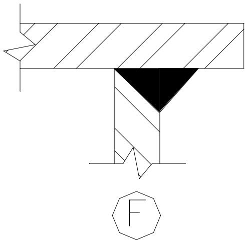


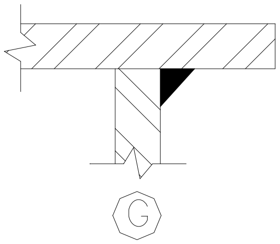


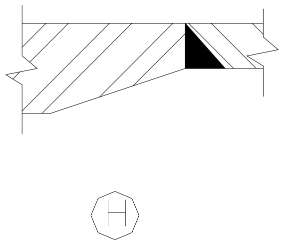












Note: Welds shall conform to the most recent edition of AWS D1.1, including the requirements for cyclically loaded structures.

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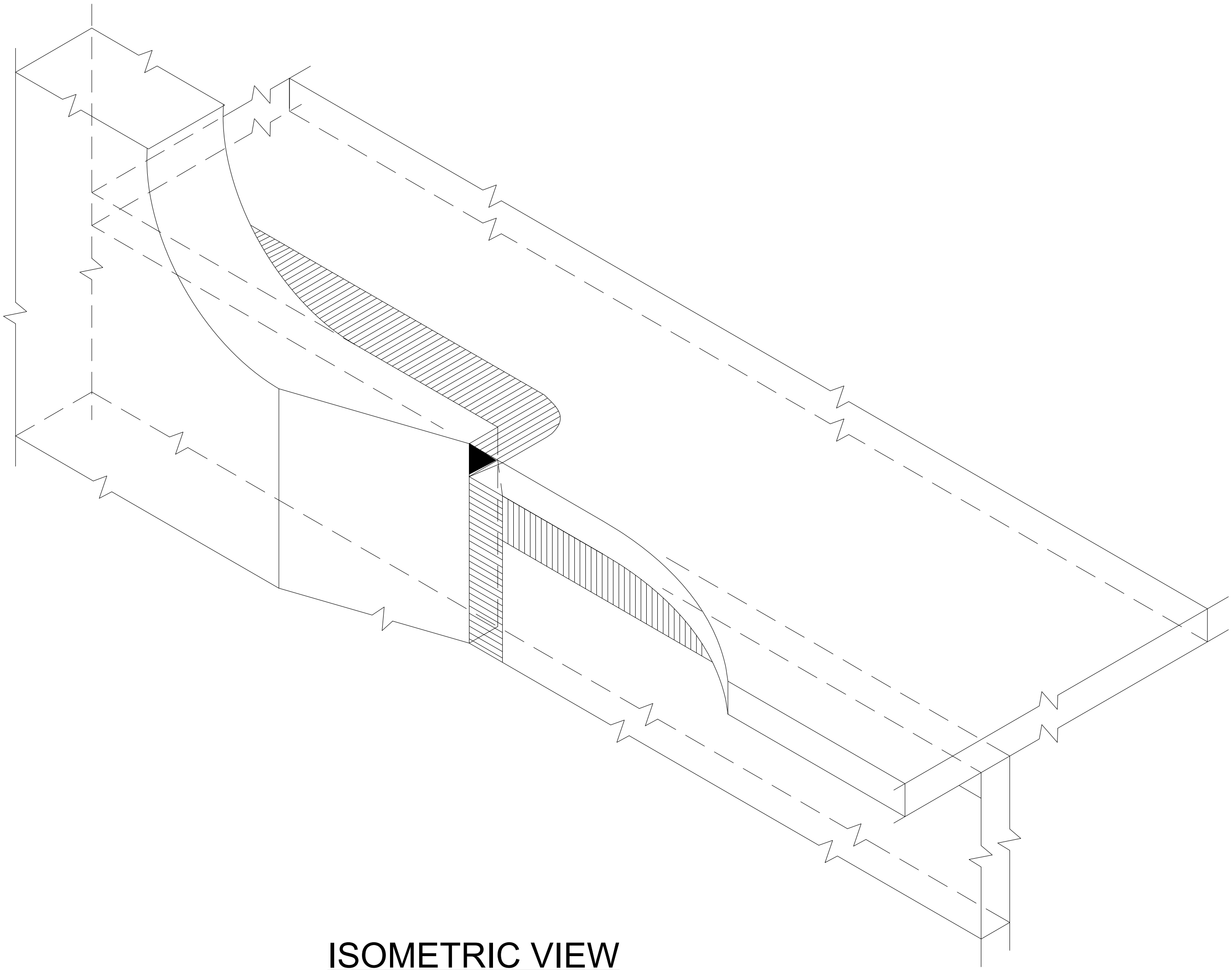
Structural Details

Continued from Sht. 6.

Avoidance of Wraparound Weld
Acceptable



ISOMETRIC VIEW

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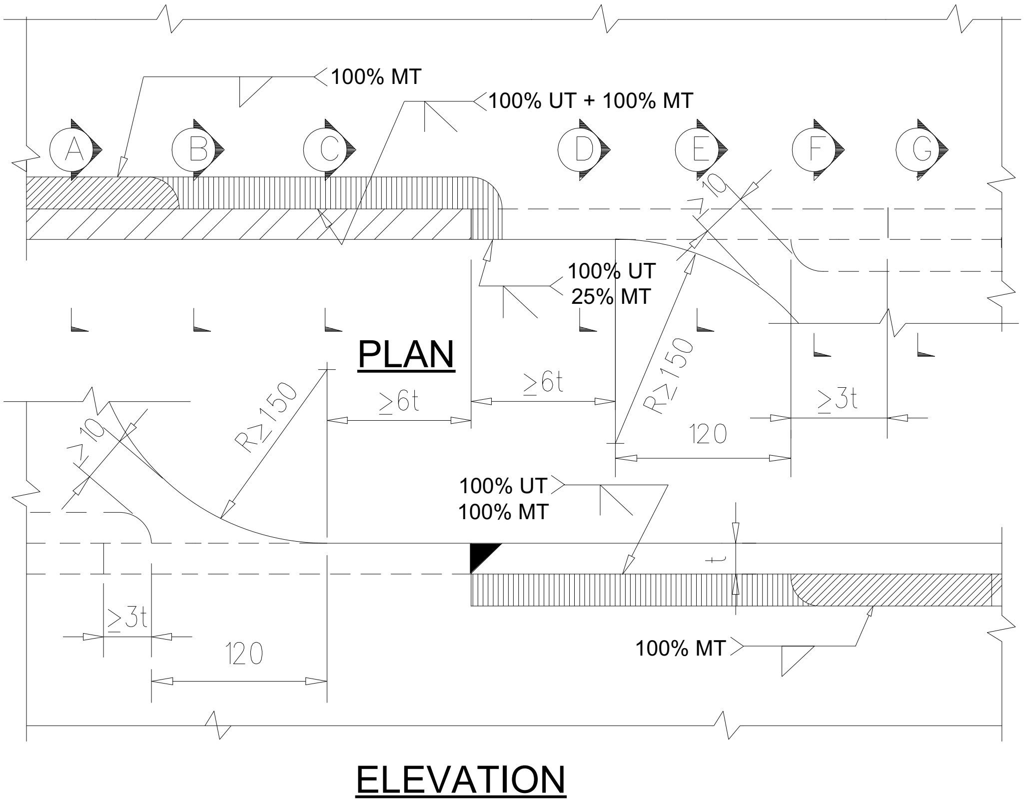
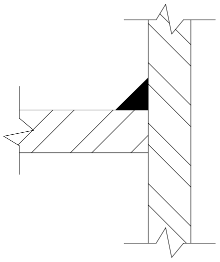
Structural Details

See Sht. 9 for Isometric View

Avoidance of Wraparound Weld Acceptable

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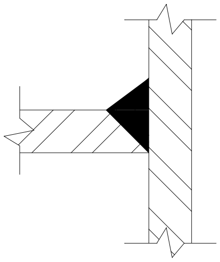
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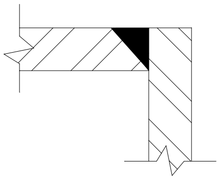
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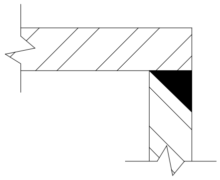
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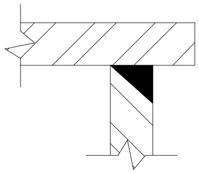
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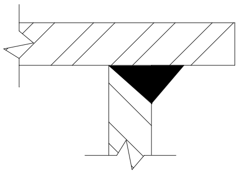
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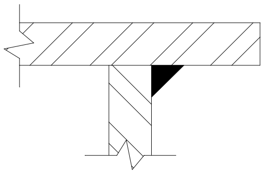
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Note: Welds shall conform to the most recent edition of AWS D1.1, including the requirements for cyclically loaded structures.

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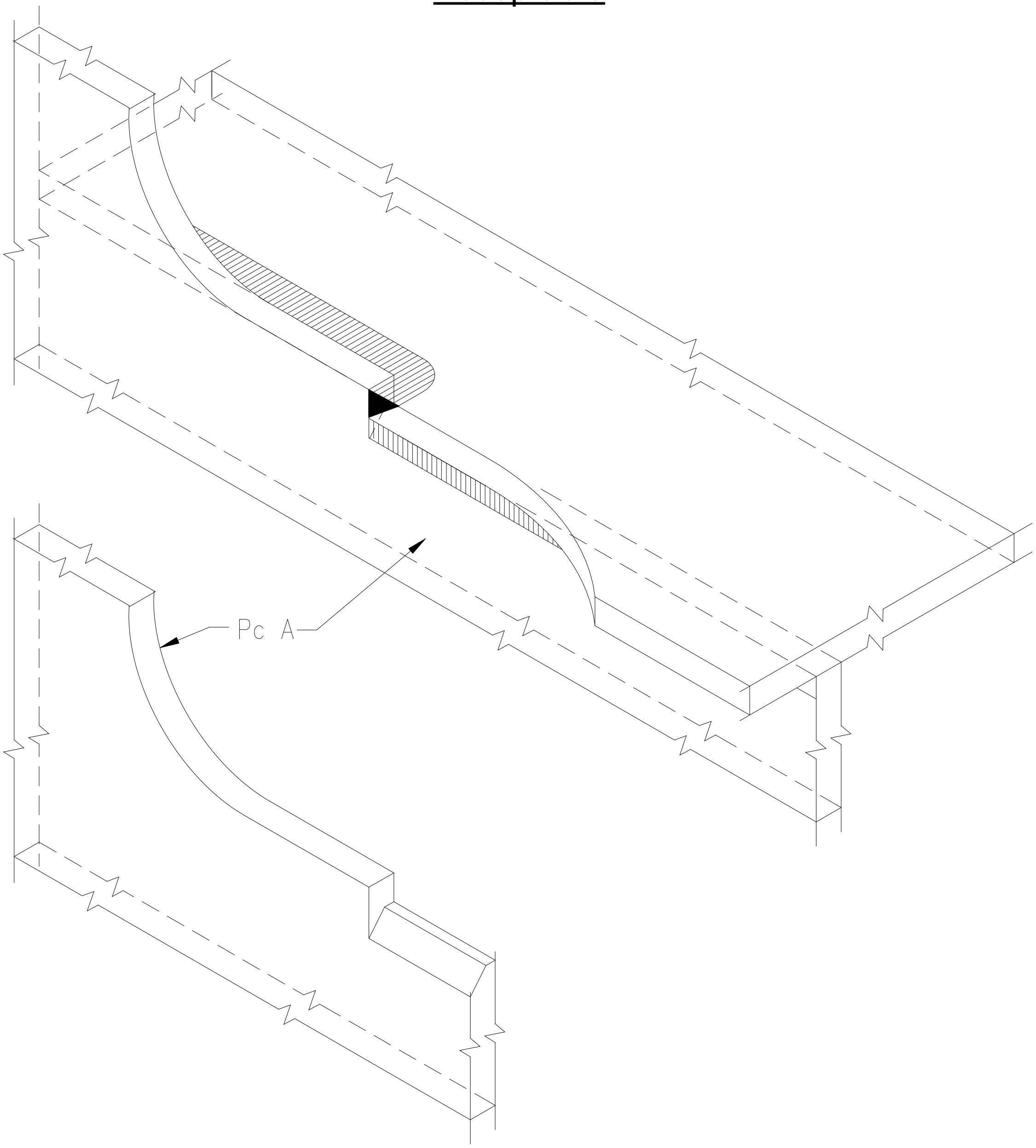
Structural Details

Continued from Sht. 8.

Avoidance of Wraparound Weld
Acceptable

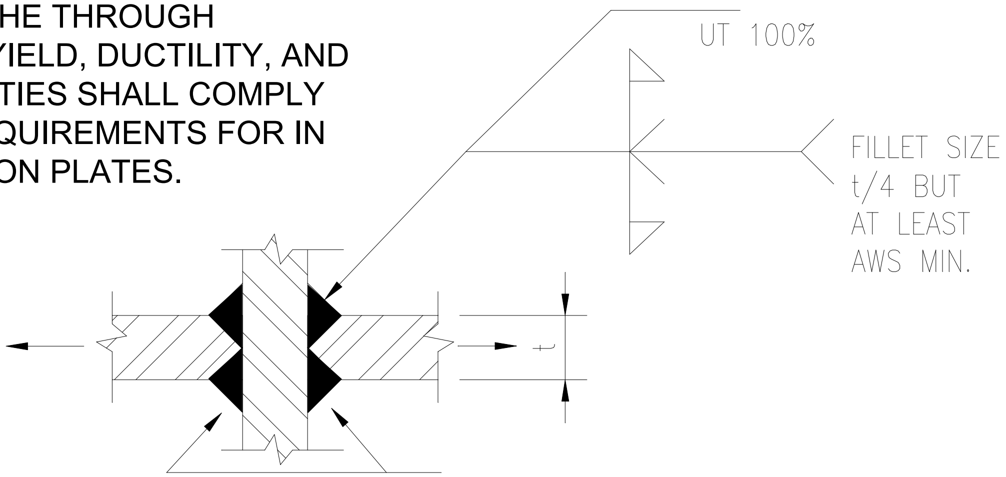


ISOMETRIC VIEW

Cruciform Weld

FOR COMPONENTS
CARRYING CALCULATED
AXIAL STRESS

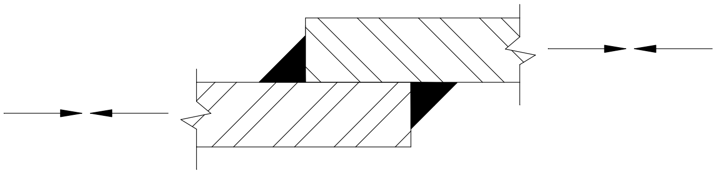
FOR FCMS: THE THROUGH THICKNESS, YIELD, DUCTILITY, AND CVN PROPERTIES SHALL COMPLY WITH THE REQUIREMENTS FOR IN PLANE TENSION PLATES.



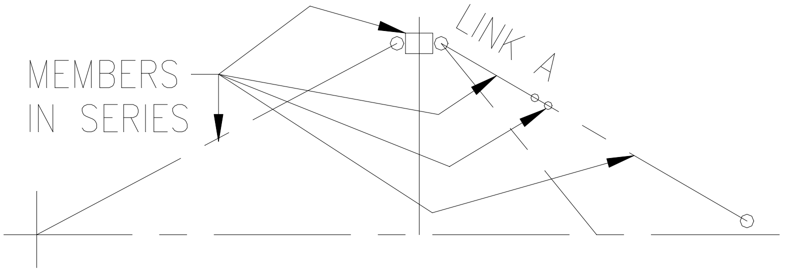
U.T. TO CHECK FOR LAMELLAR TEARS BEFORE WELDING AND 36 HOURS AFTER WELDING.

Eccentric Lap Joints

ECCENTRIC LAP JOINTS
BOLTED OR WELDED
ARE NOT ACCEPTABLE
ON COMPONENTS CARRYING
CALCULATED AXIAL STRESS.



NOT ACCEPTABLE



Structural Details Members in Series

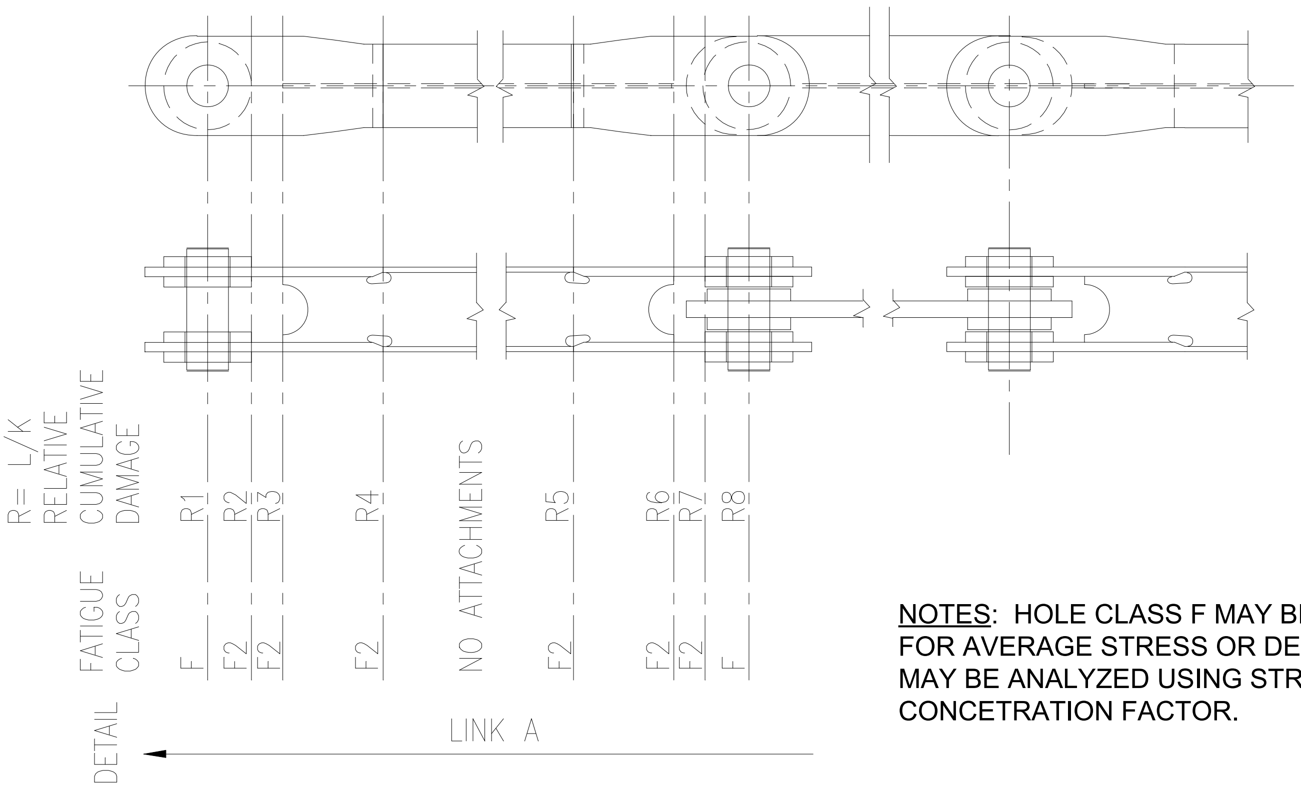
RELIABILITY OF SYSTEM SHALL BE CALCULATED BY DETERMINING THE RELIABILITY “D” OF EACH LINK INCLUDING ALL CONNECTION DETAILS, AND CALCULATING THE RELIABILITY OF THE SYSTEM USING:

$D_{SYSTEM} = D_A \times D_B \times D_C \ldots D_N$

FOR EXAMPLE, THE RELIABILITY OF LINK A IS
$D = D_1 \times D_2 \times D_3 \times D_4 \times D_5 \times D_6 \times D_7 \times D_8$
THE VALUES OF D_i ARE FOUND FROM TABLE FOR EACH R_i.

NOTICE WHEN $R \leq 0.4$, $D = 1$
AND WHEN THE CALCULATED STRESS RANGE IS ≤ 0.74 X ALLOWABLE STRESS RANGE, $R \leq 0.4$.

TYPICAL FORESTAY EXAMPLES



NOTES: HOLE CLASS F MAY BE USED FOR AVERAGE STRESS OR DETAIL MAY BE ANALYZED USING STRESS CONCETRATION FACTOR.