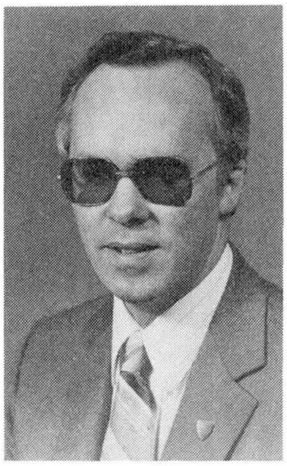
Rehabilitation and Repair of Bridges

Réparation des ponts

Sanierung und Instandstellung von Brücken

Robert A.P. SWEENEY
Regional Engineer
CN Rail
Montreal, PQ, Canada



Dr. Robert Sweeney is the Regional Engineer, Bridges and Structures for CN Rail in Montreal. He has been an active member of a number of technical committees of the American Society of Civil Engineers, the Transportation Research Board and a number of other engineering associations. He has authored or co-authored over twenty technical papers.

SUMMARY
The correct level of maintenance for a bridge structure is a function of its need and the benefit it provides. Structures whose justification for existence is marginal or non-existent or that should not have been built in the first place are not worth maintaining beyond minimum safety levels for their actual use. This paper will illustrate these principles together with a number of repair schemes.

RESUME
Le niveau optimal d'entretien d'un pont dépend de l'utilité de celui-ci et de l'amélioration physique qu'on peut y apporter. Les structures dont l'emplacement et l'existence ne peuvent être justifiés d'un point de vue économique doivent être entretenues au strict minimum qu'exige la sécurité. L'article expliquant ces grands principes est illustré par quelques modèles de réparation.

ZUSAMMENFASSUNG
Der korrekte Stand des Unterhalts für eine Brücke ist eine Funktion ihrer Notwendigkeit und ihres Nutzens. Bauwerke deren Existenzberechtigung marginal oder nicht existent ist oder welche nicht hätten gebaut werden sollen, sollten mit einem absoluten Minimum an Aufwand für die geforderte Sicherheit unterhalten werden. Der Beitrag beschreibt anhand einiger Instandstellungsmodellen diese Prinzipien.

We should view the Maintenance Repair and Rehabilitation of Bridges as a circular process. The first step covered in session one is the "eyes" or inspection phase. The second is the evaluation phase covered in session 2. The third phase is the action phase covered in this session and part of the next. This must be followed by an inspection to ensure the desired results were achieved.

Part of the evaluation and action phases is a determination of how bad the situation really is and what action must be taken. A major ingredient in this is the available or necessary funding which will be more fully covered in the last session. A major problem in this area is that of choosing a proper interest rate for economic decision making. It does not seem right to use interest rates of 20% in deciding whether to paint or not while not including inflation. In profit making companies it does not seem right to declare a profit while due to lack of sufficient maintenance funds the assets of the company are allowed to deteriorate.

If we have been consuming our capital through inadequate maintenance then whatever theory that proports to justify the practice is wrong and not the reality.

Other papers in this session and the results of NCHRP (National Cooperative Highway Research Program) projects 12-20, (1,2) 12-21 (3), 12-15 (4) and other similar studies discuss various repair and rehabilitation schemes. The purpose of this presentation is to serve as an introduction to these and to remind all of the objective of these repair and rehabililtation schemes.

The correct level of maintenance for a bridge structure is a function of its need and the benefit it provides. For all structures a minimum level of safety consistent with the use to which it is actually put is essential. Nevertheless, without being foolhardy, it is sometimes amazing how far materials can be pushed. There are numerous examples of structure that do not meet current standards that are nevertheless quite adequate.

There are many structures that don't meet current geometric standards. Either their clearance or alignment is inadequate.

The solution shown in figure 1 is a lot more economical than building a new bridge. The construction of a new bridge can wait until the traffic warrants it, since the occasional high truck can get across by using a short detour.

It will be a long time before many structures need to be rebuilt to a new alignment as they are infrequently used and are located in areas where excessive speed is not possible.

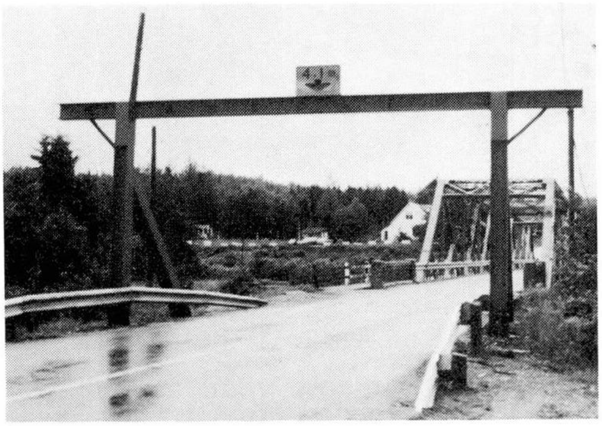


Figure 1 Height Protection

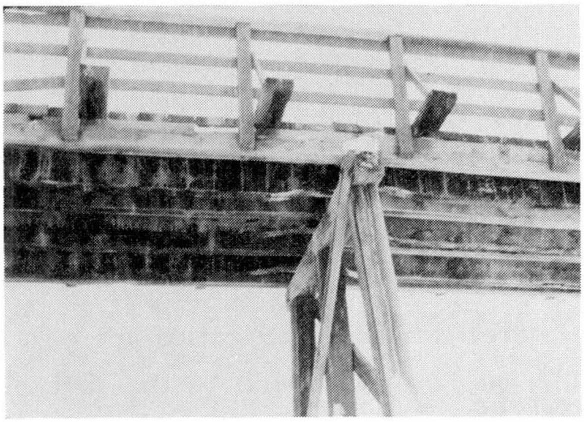


Figure 2 Crushing Timber

The structure shown in Figure 2 shows crushing of the outside stringers and floor beams which are wooden beams. Nevertheless, the center of the structure is used to get one farm tractor across daily. By blocking off the edges, repairs or replacement are avoided.

In the case of another structure, which again serves only one user, as soon as the structure can no longer safely handle his vehicle, it will be closed and a small level crossing will be built at a fraction of the cost. Railway traffic in the area is expected to remain light for some time, so this will not create a safety hazard.

The structure shown in Figure 3 has been carrying mainline railway traffic for three years with the cracks shown. The cracks are monitered annually and if they remain dormant the span won't be replaced for at least another 5 years, at which time they will be replaced for other reasons.

Sometimes the no action solution is the most economical.

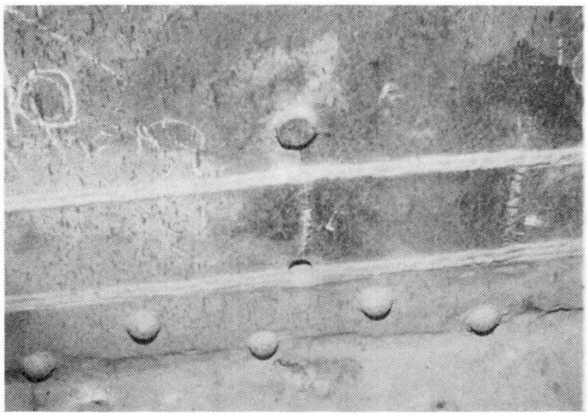


Figure 3 Crack in Girder

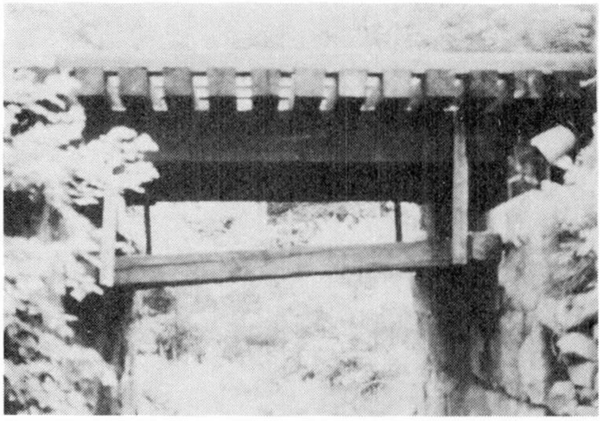


Figure 4 Temporary Support

Structures whose justification for existance is marginal or non-existent or that should not have been built in the first place are not worth maintaining beyond minimum safety levels for their actual use. In fact, if the economic hardship to the users is not too great, breakdown maintenance or closure might be the most viable solution.

Figure 4 shows a structure which has been strengthened sufficiently to last one more winter at which time the railway line is to be closed. Traffic will then be re-routed.

There are other structures which will be kept in service as long as possible with minimum maintenance, as they serve lines which are only profitable as long as maintenance expenditures are kept to a minimum. In one case, because there are 20 structures in similar condition on the line, it would cease to be profitable if full rehabilitation were considered. To do full scale repairs would force us to raise our rates sufficiently to loose the traffic to local trucking companies. This line is a perfect example of a marginal investment which will be kept open until it is no longer safe to do so with minimum maintenance expenditure. In cases where the service is in the public interest, governing authorities pick up all or part of the maintenance costs.

Figure 5 shows a structure over which operations have ceased. This structure became unsafe recently. To rehabilitate it to new condition would cost $7. million dollars, to fix it to last until the next spring ice movement would cost over $400,000. The saving to the railway by using the bridge was of the order of $40,000 before considering any maintenance expenses. I must say that the initial damage to the structure was caused by the action of others who changed the ice conditions. Should the structure be rehabilitated, they will probably be held liable. Nevertheless, we have found another way to adequately serve our customers and are not throwing away money which can be better spent elsewhere.

Figure 5 Moved by ice

One must be very careful with economics. One of our lines, which carriers very little traffic, generates a large profit since the 400 or so cars per year from the line travel 3/4 of our country afterwards generating far more revenue than the maintenance of the line requires. One must always check the theory with reality, especially economic theory.

As resources become scarce, we must be more selective in allocating resources to maintenance. Those structures that are worth having should be maintained to a high standard because it is generally more economical to preserve the asset than to permit it to deteriorate.

The maintenance painting of our large cantilever bridge at Quebec has been kept in our budget in spite of a 50% cut back in funds as it is a worthwhile investment and must be maintained. As long as painting is done regularly, costly sandblasting is not required.

In other areas of the country, the salt spray is so severe that re-painting without sandblasting would be a waste of money.

There are (5) studies which show that preventive maintenance is the least expensive way of maintaining a structure that has full economic justification for existence. The structure shown in Figure 6, built in 1935, is so well maintained that you could almost eat off it, and it has proved over the years to be very inexpensive to maintain. Constrast this with the member shown in Figure 7, built the same year, whose painting has been neglected.

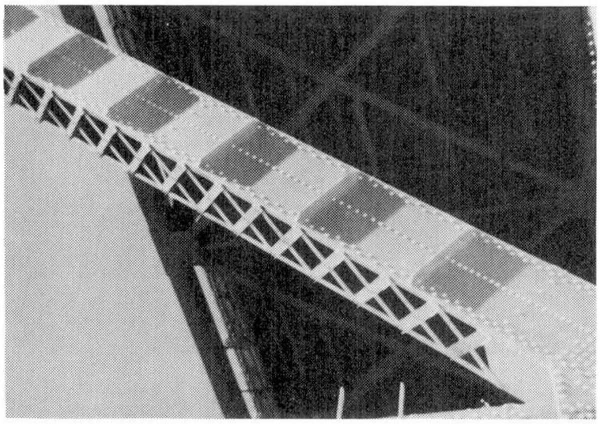


Figure 6 Well painted
(Photo by C. Seim)

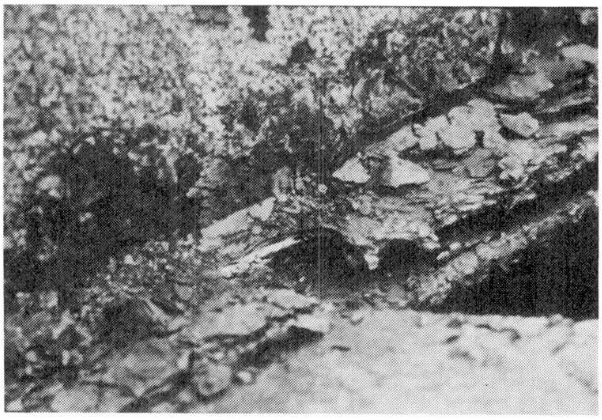


Figure 7 Not painted

In our homes, we all know that it is cheaper to repaint a window frame than to leave it until the wood and perhaps the insulation in the wall has to be replaced, or to replace a few roof tiles before the water and ice enter the walls and cause them to buldge. Yet, when short of funds, the temptation to say that no bridge has ever fallen down because it missed one year's paint exists. The consequences of deferred maintenance come later with a vengeance when an industry or nation can no longer compete because it cannot afford the capital investment to rebuild completely.

Just imagine if all the structure on a railway line were permitted to deteriorate to the level shown in figure 7. Eventually it would be necessary to generate sufficient funds to completely rebuild the whole line. We in North America have lived in a throw away society and this has been applied to most of our industrial plant and many of our bridges, both public and private. Our observations of the consequences show us that this has not been a wise policy.

Nevertheless, if a structure cannot be justified, it is hard, I say impossible, to justify its maintenance. The same is true if only half a structure is justified then maybe only half maintenance is justified?

If safety becomes a problem the alternative of closing the bridge must be considered. Pouring money into structures that are not needed or that can do the job as is, is a terrible waste.

Structurally weak bridges should be maintained to a higher than normal level consistent with their use. The bridge shown in Figure 8, built in 1904 is one of the heaviest travelled and yet weakiest of our main line bridges (6, 7). Because of extremely good preventative maintenance the structure serves us well.

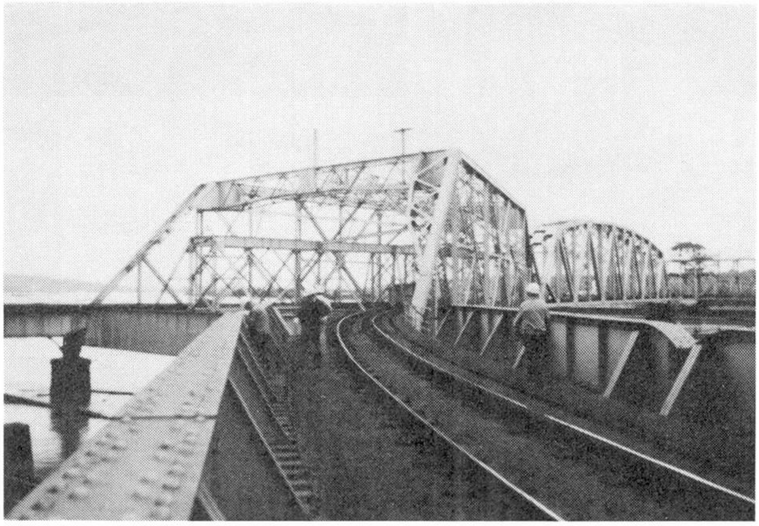


Figure 8 Well maintained

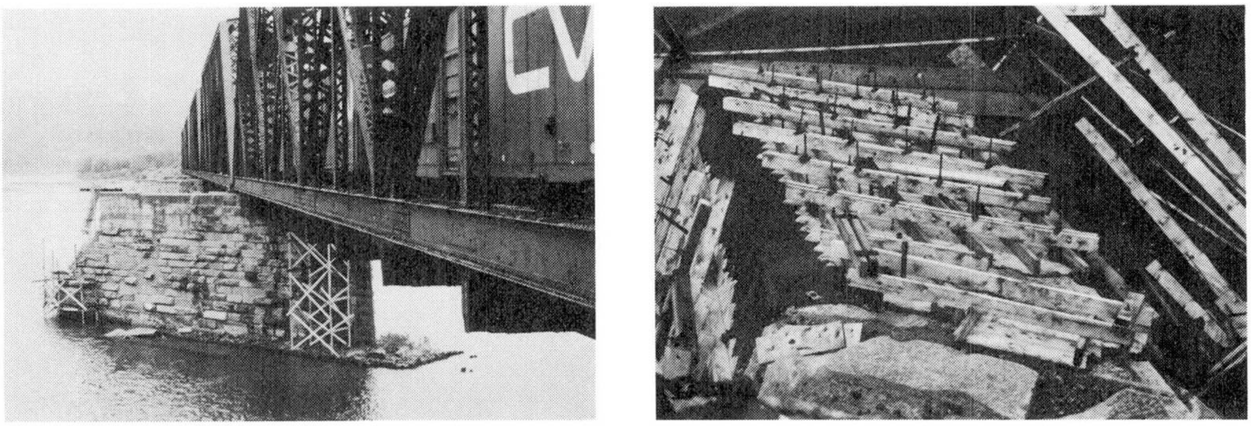
Having questioned whether the maintenance, repair or rehabilitation is in fact appropriate, I would like to illustrate several repair schemes, not covered by others in this session.

Since more than half of all bridge failures are caused by water through flooding, undermining or debris, we might as well start there.

The simple preventative step of keeping stone masonry properly pointed will usually avoid subsequent more costly repairs caused by movement of stones. Once a structure is permitted to loose a stone or two, it becomes costly and technically difficult to repair (Figure 9).

Among the most common techniques are placing bags filled with cement or concrete as a form and either placing tremi concrete or placing aggregate and pumping grout. Larger jobs require extensive forming and reinforcing adequately dowled to the existing structure.

The underpinning, straightening or strengthening of a pier can be quite an undertaking.



A - Overview B - Close-up

Figure 9 Repair to pier

Similar techniques can be applied to concrete piers and abutments.

The maintenance of soil-steel structures can be quite a task if they were improperly installed. Mechanical straightening, followed by qrouting the surrounding soil will usually solve the problem.

The second most prevalent cause of bridge failures is corrosion. Those who maintain reinforced and prestressed concrete structures are learning how difficult it is to adequately handle this problem. Adequate waterproofing protection and confinement of steel is technically and economically quite a challenge as some of the other papers will show. Preventative maintenance is easier said than done.

Because of the disruptions to traffic in replacing defective or non-existent waterproofing, these protects are often delayed until it is too late. Complete deck replacement may be the only feasible solution.

In steel structures, it is very tempting to delay preventative maintenance painting when funds are tight. After all, no structure has ever fallen down because of a one year delay in painting. Those who have watched automobiles rust away know that an adequate paint job at the right time could have saved the vehicle. The same is true of a bridge. A one year delay can allow corrosion to go far enough that is is much more costly and in some environments not possible to stop. In some locations successfully applying a coat of paint is a technical achievement.

When the web of a girder has reached a stage where it can no longer adequately carry the load, then a bolted replacement web Figure 10, is possible. If the corrosion is confined to the web near the stiffener, the stiffener can be removed and a small plate added to the web before replacing the stiffener.

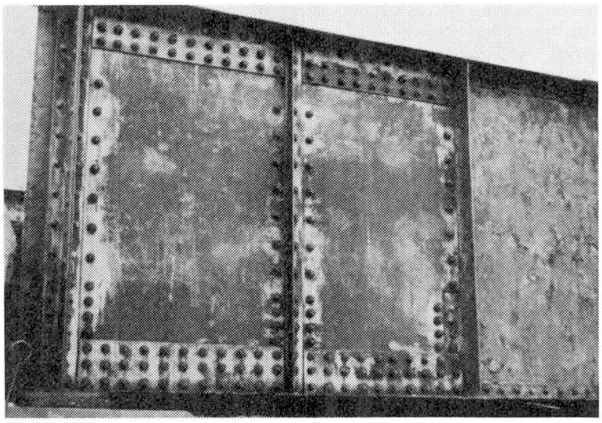


Figure 10 Replacement Web

I must warn against welding these replacements as weld terminations have very low fatigue strength. Cracks initiated in patch plate welds can go into the original web causing a potentially dangerous situation. Welding to a non-welded structure can destroy the inherent component redundancy in the structure (8). In a bolted or riveted girder, a crack in one plate or angle will not propogate to the rest of the member. Join these with a weld and the crack can propogate.

I would recommend the repair shown in Figure 11 to replace the section lost due to corrosion of the web just above the bottom flange. This is a much better solution than the one shown in Figure 3 where the welds cracked.

In the case of yielded, buckled or cracked members, it is possible to splice around the failed part in such a way that all load can be carried by the splice. The repair shown in Figure 12 shows a splice around members that cracked after being exposed to a very severe fire. The extent of locked in residual stresses was of such concern that a significant part of the member was spliced.

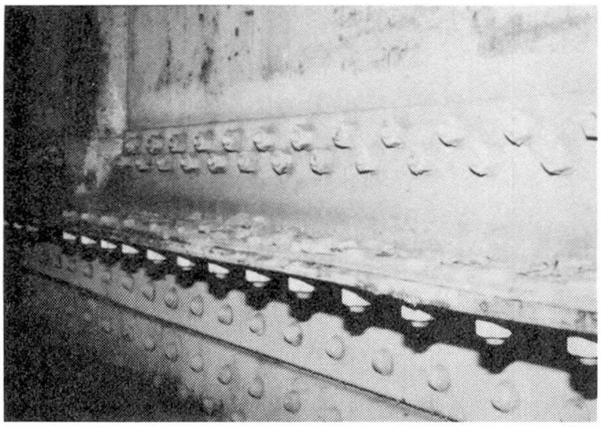


Figure 11 Repair to bottom of web

Figure 12 Member spliced

Care must be taken in the connection of all repair and rehabilitation schemes. The strengthening of a deck truss shown in Figure 13 was not very successful. The staggered welds eventually broke.

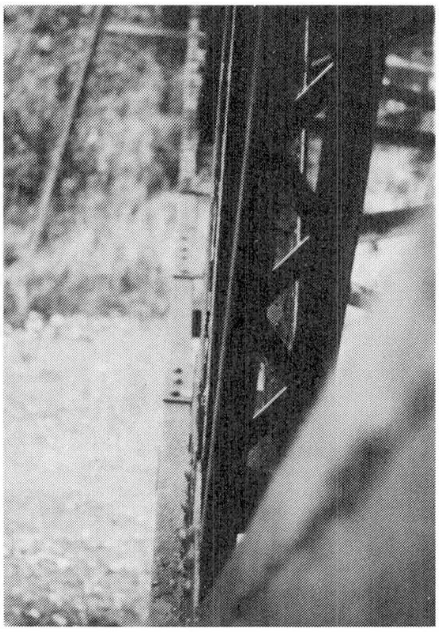


Figure 13 Broken welds

In trusses, when the pins or pinplates wear they can be replaced by larger pins after reaming to make the hole larger. If this is not possible, then a pin joint can sometimes be replaced by gusset plates. In order to minimize future fatigue problems, it is important to be very careful about compatible defections to ensure that the replacement gusset plates equally share all loads (Figure 14). If one plate carries no load, then the doubled stress range in the other could lead to unexpected fatigue problems (6,7).

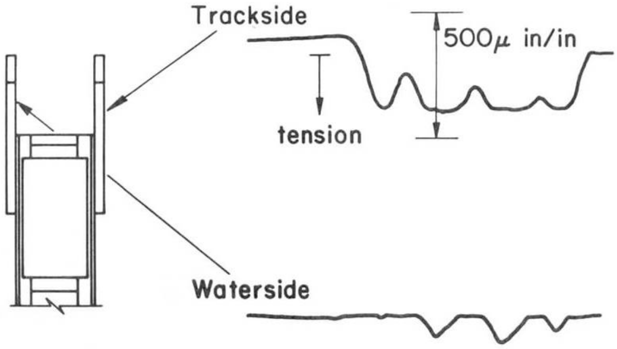


Figure 14 Unequal loading

In older mild steel structures, a differential strain of one thousand of an inch can cause the relief of stress approaching the yield point. Rehabilitation schemes must be planned so that the replacement parts take the load in the way expected. This is not something that can be left to skilled tradesmen. It must be engineered.

Workmanship is just as important when making permanent repairs as in new construction. For example, copes must have proper radii and be ground smooth otherwise cracking may result.

If stiffening is required during jacking, it must be specified or the results could be a bent flange. A timber stiffener jambed betweem the top and bottom flange can often suffice.

Simple preventative measures such as cutting bushes to reduce moisture can retard the corrosion of the base of viaduct towers. Keeping structures clean can allow proper venting which greatly reduces corrosion rates.

During repairs it is a good time to get at the cause and not just the symptom. Mechanically replacing or repairing existing details can be a terrible waste.

In setting up maintenance organizations we must not fall into the trap of replacing in kind but must always check to see if the repair or retrofit should be done, and if so is a repair in kind the most appropriate.

In one of our concrete box girders, water was trapped inside because the small drain got plugged. When the water froze it burst the top slab and heaved the track. A proper retrofit in this case was to make the drain large enough that it could not be so easily blocked.

The crack shown in Figure 15 started where the gusset plate to vertical stiffener weld terminates (10). Many of these cracks were not detected until the crack front had reached the stiffener to web weld. In order to stop the crack from proceeding up or down this weld, holes were drilled. These holes, which were drilled from both sides of the interior stiffener and then from the outside, were quite difficult to do. If the crack is not stopped then a more costly retrofit would be necessary. A permanent repair is shown in Figure 16 (9).

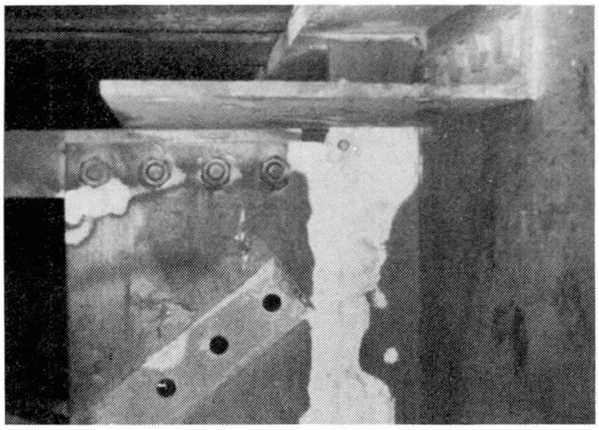


Figure 15 Crack at sharp notch

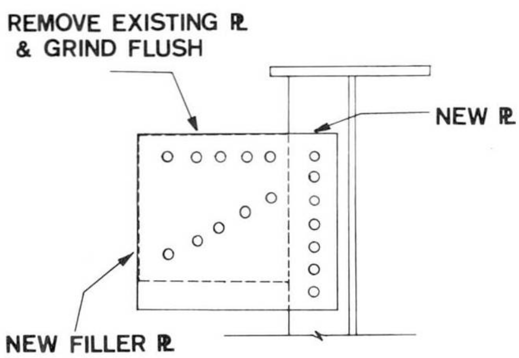


Figure 16 Typical repair

The structure shown in Figure 17 has cracked and been repaired once every ten years when in fact the problem is that there is no where for breaking forces to be dissipated.

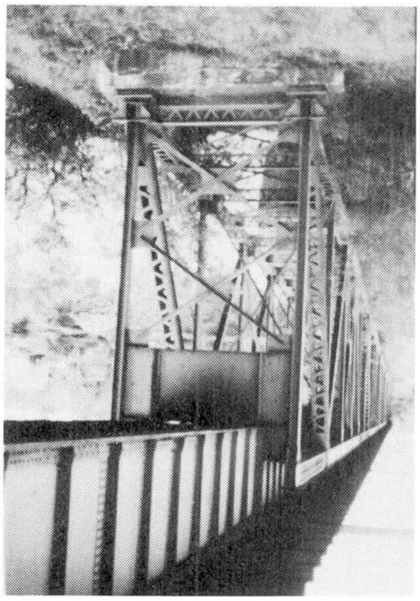


Figure 17 End of deck truss

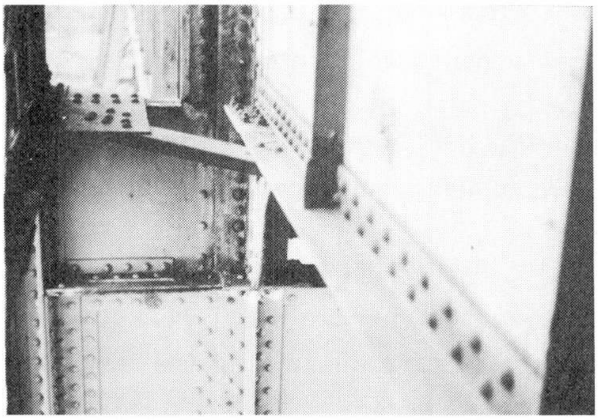


Figure 18 Bracing leads nowhere

The traction bracing ends at the top of the deck truss (Figure 18). Since the end post is relatively flexible, the load is forced to try and go through the deck plate girder. The connection is not designed for this force and movement, so it cracks. Changing the location of traction braking in order to get it directly to the bearings of the truss would permanently solve the problem.

In some older structures, the material was not placed in the most effective position. Deterioration can be permitted in the upper shelf angles of a compound tension flange if calculations confirm the strength of the flange.

Repairs require some thought since structures do not always behave as assumed. Consider the bottom chord in the first panel of a deck truss. In one case although tension was expected the member was in compression. Because the bearings were completely frozen or unable to move, the truss acted like an arch or prestressed truss. Strengthening with say loose cables would not have been effective.

In the event of uncertainty, strain measurements may be necessary.

The next most common cause of bridge failure is fatigue or wear related. Great progress has been made in our understanding of this area in the past decade.

We must be careful to ensure that our repairs will stand the test of time and not be worse than no repair at all. Repairing minor corrosion with welded patch plates with poor fatigue strength is not wise. Repairs should prolong and not shorten the life of the structure.

One technique, we have used, is to peen the ends of shallow cracked welds (Figure 19) to prolong their life. In other cases, replacing poorly installed rivets with high-strength bolts can prolong the life of a connection.

Figure 19 Peening welds

As we come out of the throw away society, there will be plenty of challenges to find successful repair and retrofit methods to difficult cases as the other papers illustrate. In many cases the rehabilitation of a bridge is an extremely difficult technical task limited by many constraints. Nevertheless, the most difficult task will be to convince authorities that the most cost effective route is through a very high level of preventative maintenance for those structures that are worth maintaining.

Maintaining structures to ideal standards, given adequate funds, is relatively easy. The challenge for our profession is that maintenance must not only be safe, cost-effective and environmentally sound, but must also be resource-efficient, technologically appropriate, and socially necessary.

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