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Remaining Strength of Bridges in Rotterdam
Capacité restante des ponts à Rotterdam
Resttragfähigkeit von Brücken in Rotterdam

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SUMMARY
In the City of Rotterdam there are over 600 bridges. Decisions concerning maintenance are only possible on a responsible basis if the remaining strength of the structures is taken into account. This is illustrated by some case studies.

RÉSUMÉ
La Ville de Rotterdam compte plus de 600 ponts. Pour prendre des décisions relatives à leur entretien, il est nécessaire de prendre en compte la capacité restante des constructions. Quelques exemples illustrent cette situation.

ZUSAMMENFASSUNG
In der Stadt Rotterdam stehen über 600 Brücken. Um Entscheidungen über ihre Unterhaltung zu treffen ist es notwendig, mit der Resttragfähigkeit der Konstruktionen zu rechnen. An einigen Beispielen wird dies weiter erläutert.

1. INTRODUCTION

The Public Works Service of the City of Rotterdam is responsible for the maintenance of more than 700 bridges with a total value far exceeding 10^9 Ecu. Lifetime varies from new to over a century. The spans vary from some meters to over 270 m. Nearly every type of construction is present.
It is quite clear that, with such a diversity of structures, it can be expected that a considerable number is not confirming to present day design standards. Remaining strength of these structures is of vital importance in decisions concerning maintenance or replacement.
In this paper selection criteria, remaining strength assessment and some selected cases will be dealt with.

2 SELECTION OF STRUCTURES

2.1 Selection criteria

Selection of structures can not be done on the base of an elaborate structural analysis. The intention of the selection is to decide which structures have a high priority. Because it is out of question to base the selection on a thorough analysis good engineering judgement is the only tool available. But of course there are some criteria which can be helpful in this respect: age of the structure, damage reports, maintenance reports, absence of drawings and/ or calculations, changed loading conditions, settlements, problems with similar structures.
Age is, of course, the most important criterium, but damage and maintenance-reports are also quite useful in this respect.

3 ASSESSMENT PROCEDURE

3.1 Introduction

The procedure for the assessment and, as pointed out in the introduction, the loading and finally the risk involved is in nearly all cases the same.

3.2 Procedure

After the decision to evaluate a certain structure the following procedure is applied:

a Retrieval of archival material
This involves the material in the technical and administrative archives, historical archives of the municipality, old engineering handbooks, historical descriptions of the City, whatever may be useful.
In a number of cases drawings as well as design calculation are absent, because the original ones were destroyed during the war.

b Review of drawings and design calculations
In this stage the reliability of drawings and calculations is established. Drawings are compared with the real structure; calculations are checked, especially with respect to modelling and loading.

c Drawings

Depending on the situation drawings should be updated, or, if necessary, completely renewed. This should be based on a recent survey. Under no circumstances it is allowed that any serious work is done before this step is completed.

d Updating design calculations
If the reliability of the existing calculation is not enough it should be updated, or even completely renewed. This can be a quite laborious operation. After this phase it is possible to make conclusions on the static strength of the structure and to perform the fatigue analysis.

e Fatigue life assessment.
Based on the updated calculations and combined with loading spectra derived from recent traffic counts, and, in the case of movable bridges, bridge operation records, the life of the structure is determined.

f Test loading
In a lot of cases the structural system leaves a lot of questions with respect to the reliability of the modelling. In these cases test loads can be conducted.

g Inspection
After static and fatigue analysis detailed directions for the inspection of the structure are given. These can involve searching for cracks in members or welds, corrosion, loose bolts or rivets, specific locations and so on.

h Final conclusions
Based on the finding of the foregoing steps the real state of the structure is determined . In this conclusion static strength and fatigue life are the main items.

i Recommendations.
Depending on the findings actions are recommended; these can be:

Strengthening of the structure
Intensive periodical inspection of critical parts
Partly or complete renewal

4 CRITERIA

Relating remaining strength of a structure to a fixed value in a standard is, to my opinion, not giving any answer to the question how safe or dangerous it is, because strength as well as loading are both stochastic in nature. Risk is the only criterium which has any value for taking decisions. The level of risk that is acceptable depends on a lot of circumstances.
Most important point is the question how serious the collapse really is. Is it a complete collapse of the structure or is it merely regarded by the public as a minor nuisance comparable to a pothole in a road-surface.
So minor damage is accepted by us in a lot of cases provided it is detected within a reasonable time.
Another important point in the possibility of inspection. If it is possible to detect damage just in time we can accept a greater risk.

It is quite clear that in the case of a total collapse of the structure higher levels of safety are

required.
In all these cases a lot of commonsense should be in our judgement. After all if we are predicting problems there is a chance of a near miss. And the smaller safety-margin the greater the chance.
That is the reason that we use recent observations and measured intensity of the actual traffic on the bridge. BS 5400:prt 10 is extremely useful because, in this respect, the level of safety can be varied.

5 CASES

5.1 Bridge with hot-rolled beams and oversized cut-outs.

This fixed bridge which is of a very simple structural concept of parallel INP380 , 0.79 m' c.t.c, with a span of 5.83 m' covered with wooden shelfs.

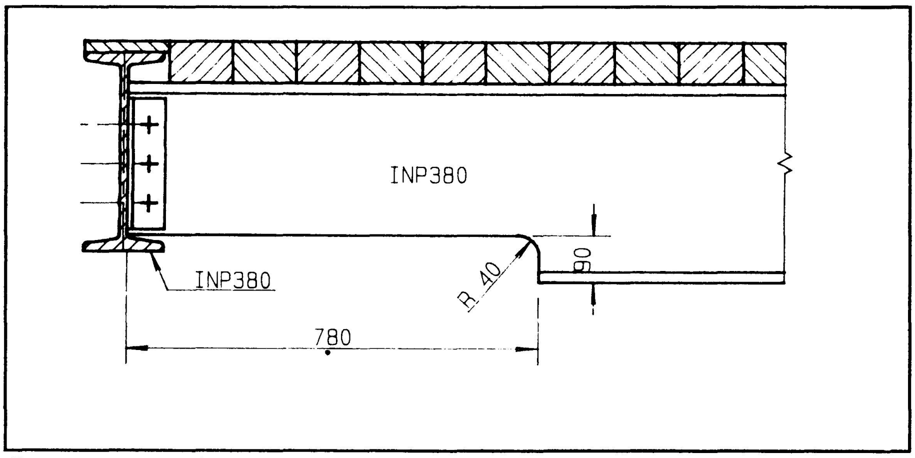

figure 1 Oversized cut-out near support

5.1.1 Selection
The structure was selected because the drawing gave rise to questions with respect to details.

5.1.2 Existing documents

Historical research revealed that the bridge, originally, was a movable bridge. Between 1940 and 1945 it was converted to a fixed structure using the original beams. On the only available drawing a cut-out near one of the abutments showed up. No dimensions were available. In the stress-calculations no reference was made to this detail.

5.1.3 Strength assessment
The analysis of the bridge was preceded by a measurement of the cut out. At the same time the corner of the cut-out was inspected by dye-penetrant; no cracks were found.
On behalf of the existing design calculation it could be concluded that the bridge could be rated as Class 45 which is regarded as quite sufficient in the occurring situation.
A detailed analysis revealed that the cut-out gave a reduction of the classification to 22; if the stress-concentration around the corner was taken into account the classification was further reduced to 15; equivalent to a wheel-load of 12.5 kN. The collapse load, with plasticising crossection occurred at a wheel-load of 69 kN (without impact) that explained why there was no collapse.

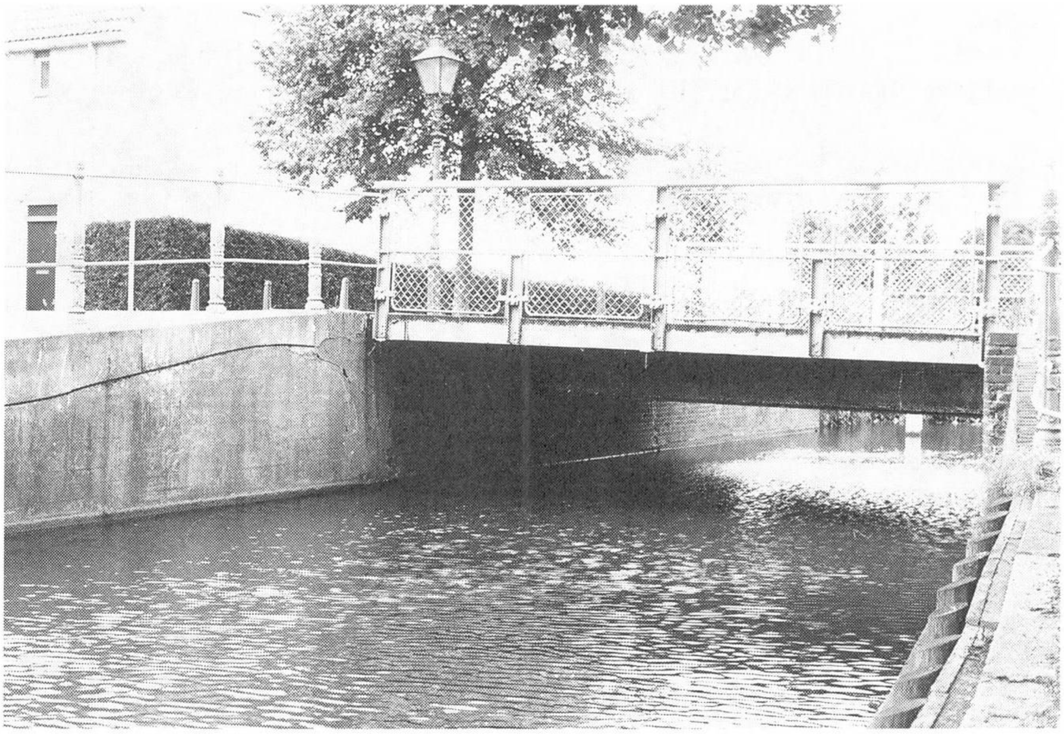

Photo 1 bridge

Recently we analyzed the detail by finite elements. The results didn't differ much from the former calculations by hand.

5.1.4 Recommendations
On account of the result of the analysis a strengthening of the detail was proposed.

5.2 Modelling faults

Modelling faults of the structural system of bridges have been quite numerous in the past. The calculations on their own are quite accurate, but the underlying structural system or loadings are apt to a number of anomalies.
In movable bridges this is quite notable. Especially the modelling of loads is apt to a lot of mistakes; often the fact that opening of the bridge completely changes the loading conditions was completely ignored.
The bridge, of the type pictured in photo 3 and 4 is a specific example of this fact. In closed situation the beam coupling the axles of the balance is a double plate-girder. But after opening this beam is a Vierendeel-truss with high shear-force resulting a high variation of bending-stresses (140 N/mm^2) which was confirmed by means of strain measurements.

5.3 Load testing of cantilevers

In most of the bridges in our city cantilevers are supporting the sidewalks, so loading is only by pedestrians and cyclists.

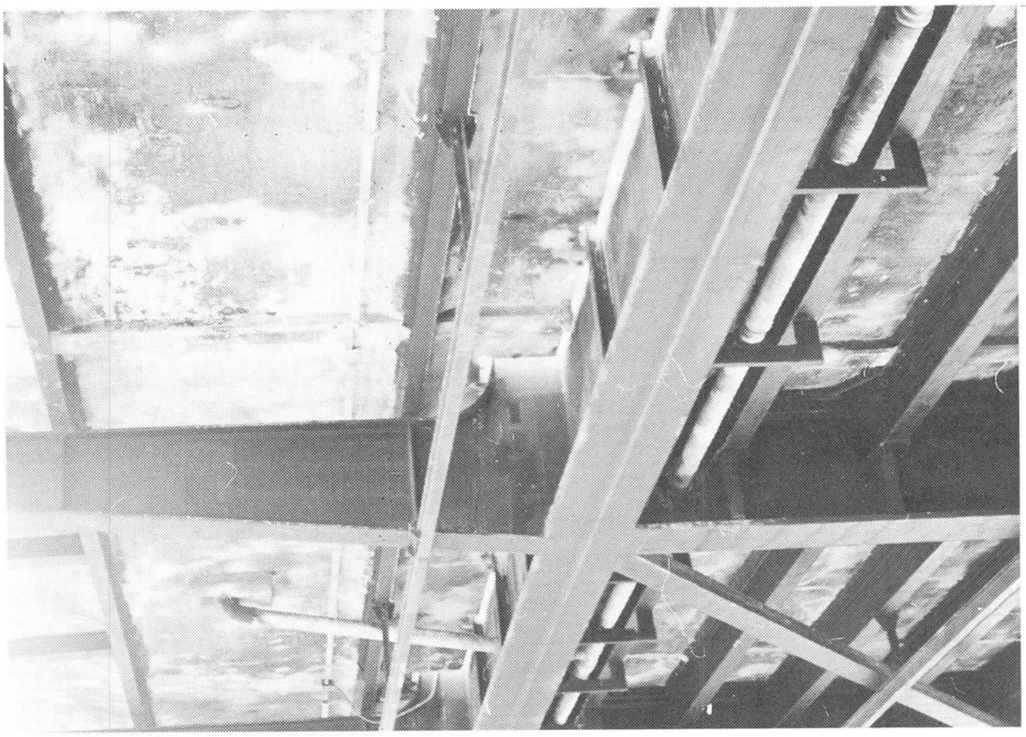

Photo 2 construction of cantilevers

Compared to the loadings specified in the standards real loadings are much lower.
In this case the probability of a high loading on the sidewalks is much higher because the bridge is in the route to the most important football stadium of the city.

The bridge has two spans and serves as an overpass of a railway. The structural system is a double stiffened arch connected by crossbeams with a reinforced concrete deck.
Build in the late thirties, this was the first all welded larger bridge in the Netherlands.
Details were strongly related to riveted construction. In this respect the strength of the cantilever was doubted.

Theoretical analysis revealed that the strength was less than the standards required.
But the reliability of this analysis was questionable. So we decided to test the loading capacity by test loading. During the test deformations as well as strains were recorded.
The testload was applied by means of a loaded truck.
The results were that the safe load was over 50 % higher than the theoretical calculated load.
Plastic deformations were not observed.

5.4 Strain measurements

Strain measurement in stead of analysis

One of the main problems with the analytical stress analysis is that the modelling must confirm to the real structure. In a lot of cases the modelling of more or less loose bolts and rivets, eccentricities, stress-concentrations are quite unreliable or extremely labour consuming.
In these cases the structure itself is the best model we have.

Photo 3 movable bridge

Strain-measurements are quite a good answer to this problem, provided that the restrictions of the method (existing stresses can not be measured by applied strain gages) are not a problem.
In this case the structure is a movable bridge. the problem was the stress-variation resulting from the opening and closing of the bridge. The structure is of a type which is completely balanced; balancing is accomplished by a counterweight supported on a beam above the bridge deck. Eccentricities, stress-concentrations, protruding axles, and so on play an important role in the distribution of the stresses. This is an ideal case for strain gages. The only equipment used were straingages, measuring equipment, electrical wire, a mobile scaffolding an some small hand tools.

The strain measured indicated that the structure was nearly at the end of its life . Subsequent inspection did not reveal any cracks but some doubts existed in this respect because not all parts were good visible.
So it was recommended to strengthen the structure.
To my opinion strain measurements are a neglected tool in the field. In a lot of causes it can be much more economical than extensive analytical approaches. In this case it took only 2 days; the cost that was about 15 % of an analytical approach.

5.5 Ship collisions

Collision of ships to a structure are always a potential danger to most bridge-structures.
Questions of remaining strength may deal with danger of immediate collapse,
the allowance of traffic, the urgency of repairs and so on.

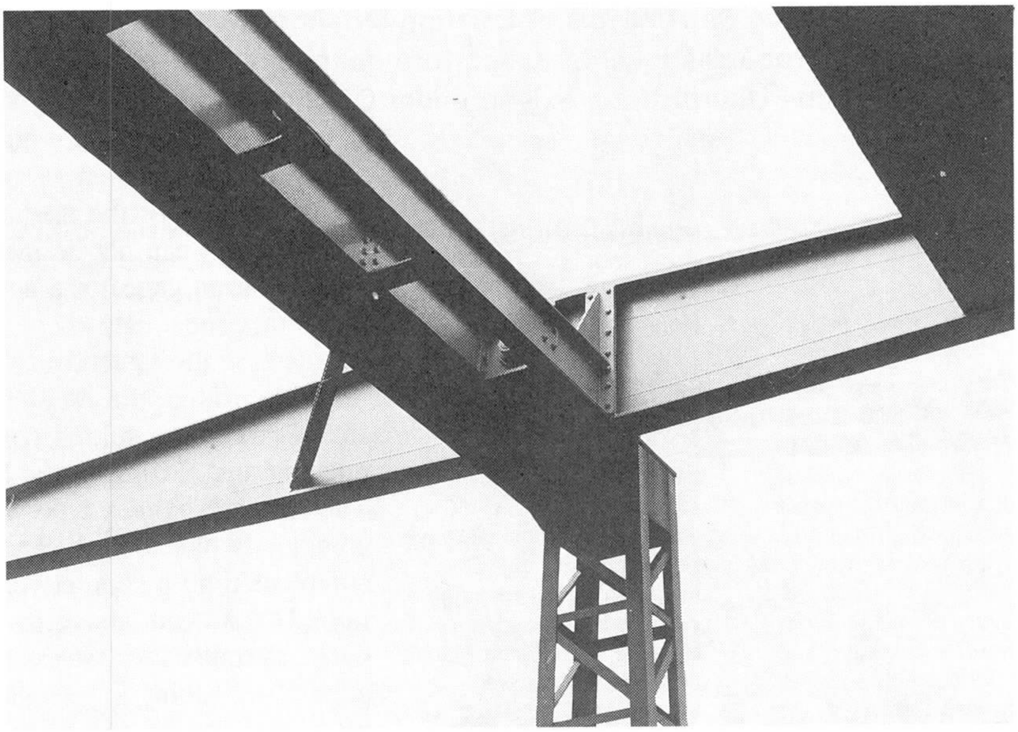

Photo 4 detail of movable bridge

6. CONCLUSIONS

Experience in the past 25 years has learned us that it is possible to make decisions with regard to maintenance or replacement of structures. Remaining strength is of vital importance in this process. It should be based on the risk which is involved in the decision we are making. The risk, but also the cost must be acceptable to the community.

In all our decisions we must seek for the balance between economic and human factors. There is always an opportunity, but a small one, that we are to optimistic. The chance that we are to pessimistic is much greater. It is our responsibility, as engineers, to find the right equilibrium. If there is never any near miss, than the authorities and the public will regard our advices as theoretical, and unpractical.