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Structural Assessment of Corrosion Damaged Steelwork

Évaluation structurale des dégâts dûs à la corrosion des ouvrages en acier

Tragfähigkeitsbeurteilung korrosionsgeschädigter Stahlbauteile

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SUMMARY

Four severely corroded universal beams were removed from a structural frame, that was undergoing refurbishment, and were load tested to failure in the laboratory. The failure loads were compared with several analytical models including one simulating their as-new condition. They were found to possess surprisingly high residual capacity, prompting a proposal to quantify current visual inspection procedures.

RÉSUMÉ

Quatre poutres sévèrement corrodées extraites d'une structure en cours de rénovation ont été testées jusqu'à la ruine en laboratoire. Les charges ultimes ont été comparées avec plusieurs modèles numériques, dont un simulant leurs nouvelles conditions. Les essais ont montré que les poutres possédaient une capacité résiduelle étonnamment élevée, conduisant à une proposition pour quantifier les procédures d'inspections visuelles courantes.

ZUSAMMENFASSUNG

Von einem Rahmentragwerk, das gerade überholt wurde, wurden vier stark korrodierte, allgemein gebräuchliche Träger entfernt und im Labor bis zum Bruch getestet. Die Bruchlast wurde mit mehreren Berechnungsmodellen verglichen, darunter einem, das den Neuzustand darstellte. Die Tests ergeben eine überraschend hohe Resttragfähigkeit, aufgrund derer ein Vorschlag zur Quantifizierung derzeit verwendeter Inspektionsverfahren ausgearbeitet wurde.

1. INTRODUCTION

In the UK there are literally thousands of exposed steel structures supporting chemical manufacturing plant and refineries. The aggressive atmosphere and exposed location of such plant can result in severe and rapid corrosion. Moreover, in the UK about 25% of steel structures in the chemical industry are more than 50 years old resulting in the need for substantial maintenance and repair which is difficult and costly because of the need to sustain continuous production.

Current practice in the management of inspection and repair of exposed structural steelwork has been described by Gallon [1]. He found that the current inspection and assessment methods, while being safe, were significantly conservative in some instances indicating the need for more realistic appraisal of the capacity of degraded structures.

Similar concerns exist for steel girder bridges. Kayser and Nowak [2] developed a theoretical corrosion damage model for typical short span steel highway bridges. They showed that the governing criteria, which depend on the relative thicknesses of the web and flange, change with time as corrosion progresses. However, the web is generally the most vulnerable element in the long term.

Regular inspection of steel structures in the chemical industry is usually based on visual examination and classification into categories which identify the need for appropriate action [3]. The most severe visual category refers to the presence of serious structural defects and the consequent need for full structural assessment and repair. However, as yet there is no clear relationship between the magnitude of structural defects and the corresponding reduction in capacity. There is an urgent need for this information to avoid the financial penalty of plant closure when the capacity of the supporting steelwork may be adequate.

The objectives of this paper are to compare a corrosion damage model with tests to failure on some severely corroded steel I-beams, and to use the model to help quantify visual inspection.

2. LOAD TESTS ON CORRODED BEAMS

2.1 Specimen beams

Four identical universal beams were recovered from the site of a plant undergoing demolition. The beams formed corner supports for a tank as shown in Fig 1 and were all in severely corroded condition. Detailed measurements of the thicknesses of the webs and flanges were made and are summarised in Table 1.

Table 1 Average measured thicknesses of corroded I-beams (mm)

Element	**As new**	**Beam 1**	**Beam 2**	**Beam 3**	**Beam 4**
Flanges					
Top	10.20	7.25	7.55	6.55	7.94
Bottom	10.20	4.95	5.70	4.52	6.62
Average thickness	10.20	6.10	6.63	5.54	7.28
Thickness loss	nil	4.10	3.57	4.66	2.92
Web					
Average thickness	6.10	4.98	5.38	4.93	5.56
Thickness loss	nil	1.12	0.72	1.17	0.54

It will be noted in Table 1 that the loss of thickness on average was more significant in the flanges than in the webs. However, holes were found in the webs and flanges of two of the beams, one of which is shown in Fig 2.

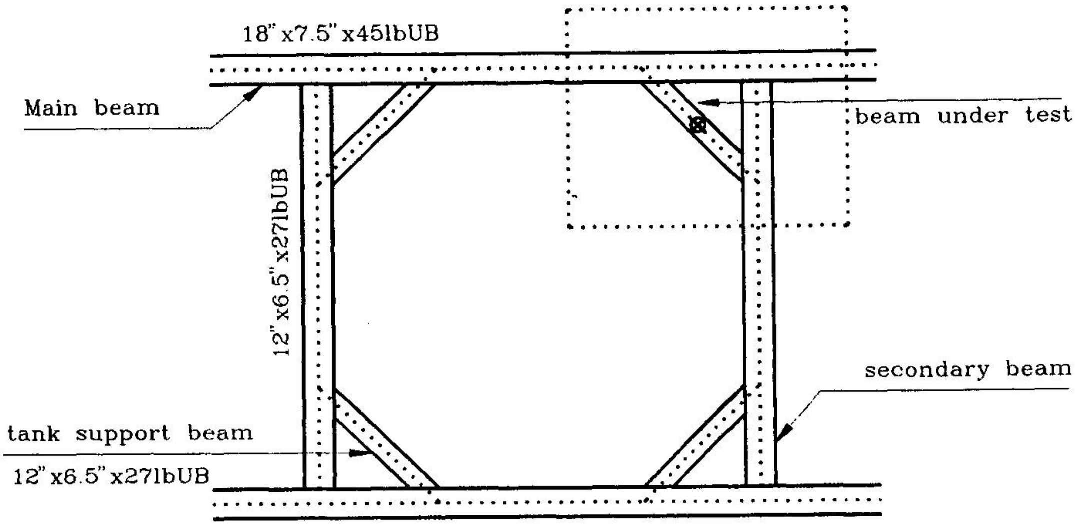


Fig 1 General arrangement of tank support beams

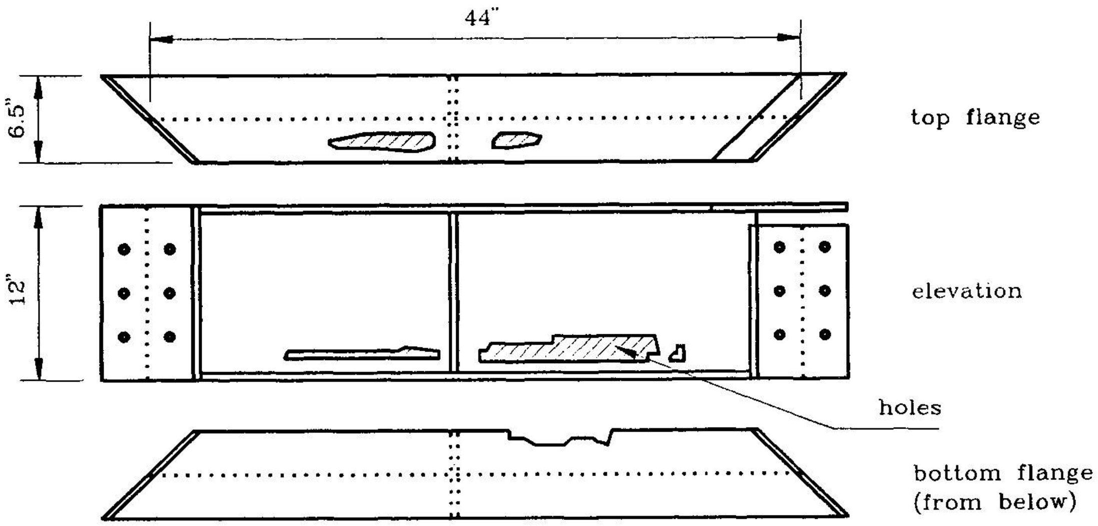


Fig 2 Details of holes in beam No 1

2.2 Load tests to failure

Each beam, when tested, was bolted at its ends to the webs of short lengths of I-beam designed to simulate the support conditions for the steel tank in service (see Fig 1). The assembly was installed in an hydraulic testing machine and the load was applied vertically to the test beam directly over the central stiffener. The load was applied through a ball and slider seating to permit rotation of the cross section of the test beam, as would be the case in service. The vertical deflection of the loaded point was recorded, together with lateral deflections of top and bottom flanges at the same section. This provided information on the onset of lateral torsional buckling and is shown in Fig 3.

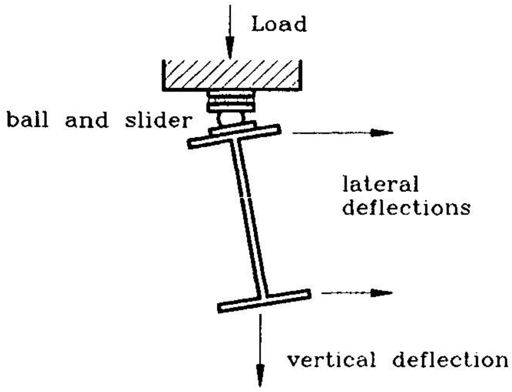


Fig 3 Loading and deflection measurements at central section

The ultimate loads obtained in the tests are given in Table 2. It may be seen that there is a correlation between the condition of each beam and its failure load. The failure loads are compared with the capacity of a new beam calculated using the formulae in the UK code for structural steelwork [4]. Partial safety factors were not used for this purpose. The predominant mode of failure was by lateral torsional buckling originating from the cut-out portion of the top flange.

Table 2 Ultimate loads in the tests compared with calculated as-new capacity

Beam No	Ultimate Load/kN	General condition of beam
1	277.0	Severe loss of material; holes in flanges and lower web
2	318.0	Loss of material all over but no holes
3	287.0	Severe loss of material; holes in flanges and lower web
4	440.0	Loss of material all over but no holes; fairly good condition
all	522.7	Calculated capacity of as-new beam

3. STUDY OF FAILURE MODES OF CORRODED BEAMS

A steel I-beam subjected to bending can fail in the following modes:

a) exceeding moment capacity as determined by the yield strength;
b) lateral torsional buckling;
c) failure of the web in shear;
d) bearing failure of the web under point loads or at the supports.

BS5950 [4] was used for the assessment of the moment capacity, which is mainly dependent on the yield strength of the steel and the flange area of the beam. Lateral torsional buckling was the most important failure mechanism for these beams, but this was largely because of the cut-out in the flange at one end. This is called a "coped beam" and the lateral end restraint is considerably reduced because rotation of the flange in plan is not resisted at the coped end. The method of assessment proposed by Cheng et al [5] was used in this case.

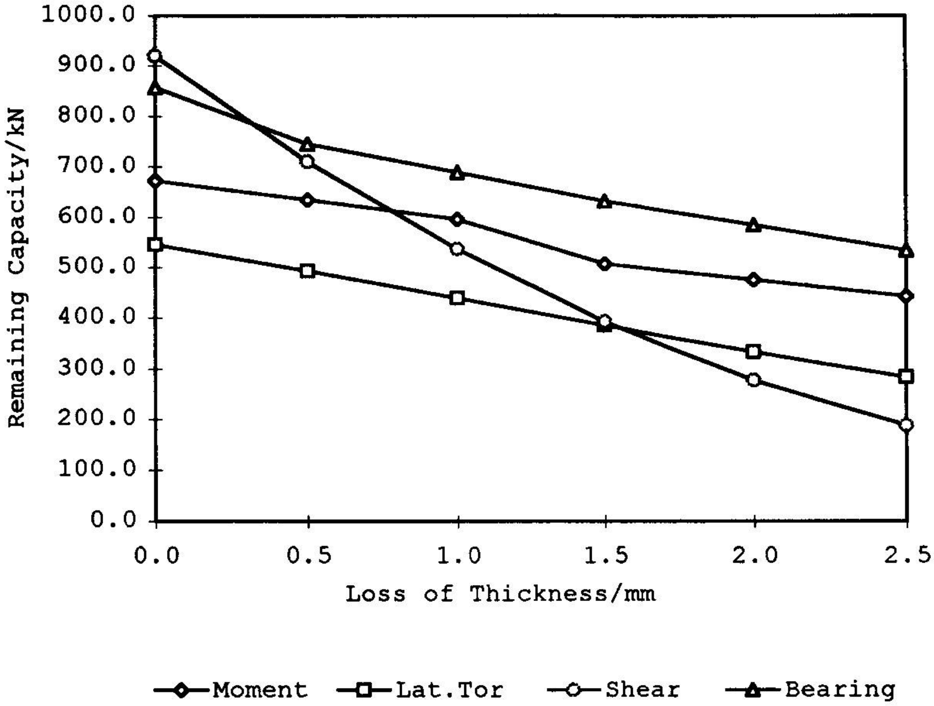
Failure of the web due to shear buckling was the next most significant failure mechanism. The effect of varying web thickness (VWT) was calculated using the formulae in BS5950. The effect of web holes (WH) was assessed by the method of Wang et al [6]. This assumes that plastic deformation occurs near each of the corners of the opening (rectangular openings). A moment-shear interaction curve is identified from which the capacity of a particular load case may be obtained.

While loss of thickness generally reduces the capacity of a loaded beam, it can also change the mode of failure from one mechanism to another depending on the relative thickness loss in the various parts. Three corrosion damage models were therefore analysed, as follows:

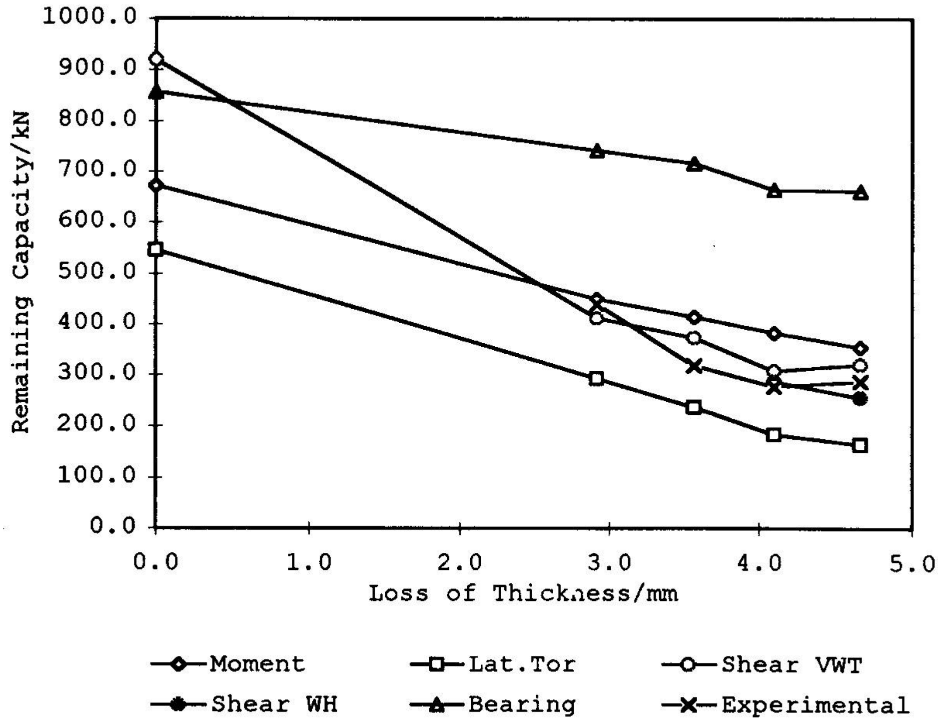
i) the I-beam in its as-new condition;
ii) uniform thickness loss in both flanges and web;

iii) variable thickness loss in flanges and web (the ratio of thickness loss in flange to web was the same as that of the beams tested)

The results are shown in Fig 4.



a) Uniform thickness loss



b) Variable thickness loss

Fig 4 Remaining capacity of corrosion damaged I-beams

4. APPLICATION TO VISUAL INSPECTION

Formal procedures for inspection of structural steelwork already exist in the petro-chemical industry [3]. This involves initial appraisal, preliminary inspection, detailed examination if necessary, and reporting. The preliminary inspection is basically a visual assessment and requires structural elements to be described using defined condition categories, for which subsequent actions are prescribed. Brief descriptions of typical visual categories are as follows:

i) minimal deterioration; no need for immediate action
ii) paint system generally defective, but loss of section estimated visually to be less than about 15%; action required to arrest deterioration
iii) loss of section estimated to be greater than 15%, holes in members, distortion, damaged connections; requirement for further investigation, repair, replacement or removal.

These procedures, properly carried out, provide invaluable assurance that structures for production plant are safe. However, it would be most helpful if visual inspection could be related quantitatively to remaining capacity. It is proposed that the results of the study of failure mechanisms be used as a starting point to achieve this objective. It is evident from Fig 4 that lateral torsional buckling and web shear were the most critical mechanisms. In these cases it was found that if the loss of flange thickness was less than 15% then the remaining capacity was about 75% of the as-new condition. However, more work is required to define a generally acceptable lower bound for a wider range of load cases and configurations. Loss of moment capacity is almost proportional to loss of flange area, so this mechanism is less critical.

The existence of holes in a member is likely to reduce the capacity significantly, although this will depend on the size and location of the holes. At the present time no definitive guidance may be given. However, it should be noted that in this investigation it was found that even the most severely corroded beam possessed more than 50% of its calculated as-new strength.

ACKNOWLEDGEMENTS

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