MICHEL TOURNAY

INTERNAL RESISTANCE TO CORROSION IN STEEL HOLLOW SECTIONS

CSFTA

Notice 1059

CIDECT

Rapport final
10 B 78/3

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The following is a full English translation of the original work, published in French under the title:

LA RESISTANCE A LA CORROSION DE
L' INTERIEUR DES PROFILS CREUX EN ACIER

An introductory summary has been added by the Corus Tubes, Corby, U.K. in 2002

SUMMARY

RESISTANCE TO INTERNAL CORROSION IN STEEL HOLLOW SECTIONS

This report covers detailed investigations into internal corrosion in steel structural hollow sections which have seen service in widely differing geographical and environmenta1 locations.

The samples investigated were removed from the following structures.

America	Pittsburg	Trolley bus poles. Urban atmosphere. 40-50 Years service.
	Dayton, Ohio.	Lighting columns. Urban atmosphere. 59 years service.
Britain	Nore Forts	Tubular gangway. Marine atmosphere. 10 years service.
	S.S. Aquitania	Lifeboat davits. Marine atmosphere. 37 years service.
	Chelsea F.C.	Floodlighting tower. Urban atmosphere. 21 years service.
Germany	Wiesental	Transmission towers. Rural atmosphere. 18 years service.
	Hiltrup	Roof trusses. Highly corrosive atmosphere over pickling bath. 10 years service. (Dismantled due to heavy external corrosion).
Japan		Lighting columns. Urban atmosphere. 5-11 years service. (Investigation into location of drain holes at base of columns).
Italy		Lattice braced tower cranes. Urban atmosphere. 10-20 years service. Tubular steel framed buildings. Industrial atmosphere. 25-30 years service.
France	Valenciennes	Outside loading gantry. Industrial atmosphere. 14 years service.
		Sulphate store. Highly corrosive next to pickling plant. 10 years service. (Roof bracings and stair handrails)
		Stores building. Industrial atmosphere. 15 years service.
		Factory building. Industrial atmosphere. 16 years service.

These investigations all show that steel hollow sections which have been sealed by welding or have their ends flattened do not corrode internally. The majority of such samples investigated still had the original mill scale adhering to their inner surfaces. Samples which had holes through the wall of the section (unplugged drilled holes, damaged seam welds, and holes due to external corrosion) all showed some corrosion adjacent to the hole but elsewhere remained unimpaired, revealing only slight internal corrosion. Sections which have been sealed at one end only show internal corrosion adjacent

to the open end but elsewhere are not seriously impaired.
The report also deals with hot dip galvanising of structural hollow sections, including drilling, draining and venting. It touches briefly upon the subject of 'breathing', and the advisability of providing "pressure balancing" holes to obviate ingress of water during inhalation due to temperature changes.
It also refers briefly to concrete filling and moisture venting.

The following companies and organisations referred to in this booklet are now part of the organizations shown:

British Steel Tubes Division and Stewarts & Lloyds are now part of Corus Tubes, Corby, UK

GIE-Cometube and Cometube are now part of Arcelor Tubes, Aubervilliers, France

Mannesmannrohren-Werke are now part of V & M Tubes, Dusseldorf, Germany

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ACKNOWLEDGEMENTS

The author wishes to thank all the organisations which took part in this research work. In particular, he would like to extend his appreciation to the members of the Technical Commission of CIDECT as well as to the experts on corrosion not belonging to CIDECT, who have made it possible to gather the data on which this work is based.

TABLE OF CONTENTS.

1. FOREWARD.

It is perhaps strange that so much energy and not inconsiderable sums of money have been devoted to an investigation to prove that in the case of hollow sections sealed at both ends internal corrosion does not exist.

It should be obvious!

If the research over the years has been haphazard it is simply because no international organisation has taken the initiative to coordinate and analise the available information. It is to fill this gap that CIDECT some years ago asked GIE Cometube to collate the existing information and from it form an authorative understanding of the conclusions to be drawn from existing structures.

This investigation into the simple protection of the interior of hollow sections was carried out by Cometube, who are indebted to the following for financial assistance.

The Federation of Steel Tube Makers (CSFTA).

The International Committee for the Development and Study of Tubular Construction (CIDECT).

This investigation has made possible the reports of the National Test Laboratory (LNE) in Paris.

The purpose of this paper is to present the information which is available world-wide, together with that which has been gained from more recent investigations in France.

2. BACKGROUND.

2.1. Theoretical

Corrosion can only take place if certain elements are present; iron, oxygen and water, in the form of moisture in the air. If a section is hermetically sealed the moisture in the entrapped air will allow only a limited amount of corrosion to take place. As the oxygen is used up oxidation will cease, since the entrapped air cannot be replenished.

2.2. Practical.

On the basis of this theory it seems obvious that the protection of hollow sections is simply a question of air tightness. Thus the general outlines of the investigation are clearly defined; the inspection of structures which have been standing for many years must prove that the normal methods of fabrication are sufficient to prevent internal corrosion.

3. SURVEY OF EXISTING LITERATURE.

It is impossible to list here, even briefly, all the publications which have been issued on this subject and which may have come to our notice. We shall therefore limit ourselves to mentioning some particularly interesting accounts which are based either on very detailed theoretical investigations or refer to significant experiments.

3.1. **Article by G. B. Godfrey from "The Civil Engineer" Journal of May1961** [1].

This article describes the investigation carried out at that time (1961) and mentions particular cases where observations could be made on existing structures, more often than not as a result of fortuitous accidents, such as that which occurred to the footbridge at Le Nore.
Further details on this particular structure is given in the chapter dealing with British experiencies.

3.2 Report by Omer W. Blodgett in the Lincoln Electric Co. Journal of August 1967 [2]

This report investigates the problems presented by the welding of hollow sections used in structures and in particular the protection given to the interior of sections when closed by welding.

On the basis of his own observations and on foreign experience, he reaches the conclusions which we reproduce in full below.

1) Sealed hollow sections require no internal protective coating and may be regarded as essentially immune from corrosive attack.

2) Condensation in a sealed section is impossible, and when found upon inspection is evidence of an opening having developed -possibly a small opening that is drawing surface water in through capilliary action.

3) Adding a "pressure equilibrium hole" at any point in a hollow structure where water cannot enter by gravity will prevent aspiration in an imperfectly sealed system. (If the engineer has qualms about condensation, he might as well put the hole at a low point where it would serve for drainage also - merely to satisfy his peace of mind.')

4) An "open" system should generally be kept as tight as feasible with rubber gaskets used at manholes and such closures positioned so as to avoid water accumulation and the possibility of its entrance by capillarity action or aspiration. A strategically placed pressure equilibrium hole might be advisable. Such Systems should be protected with an interior coating.

5) A ventilated hollow structure should be internally protected and have adequate ventilation holes at each end and in the sides.

6) Bolt and rivet holes should be avoided where-ever possible; they create conditions conducive to water entrance by capillarity action.

In general, good design and good practice should eliminate concern about corrosion in hollow steel sections. The overwhelming mass of evidence, scientific analysis, and European experience suggest that it is - as the Englishman said - more of a "bogey" than a serious engineering problem.

3.3. **Bulletin of the American Iron and Steel Institute, February 1970** [3]

This important study carried out by a working group originating from American Steel Production and Construction Industry is based upon extensive evidence in North America and Europe.

A substantial part of the report is devoted to the theoretical investigation of corrosion. The authors discuss the equations relating to the electro-chemical reaction of oxidation. In addition they give mathematical expressions which make it possible to calculate the thickness loss of metal on the assumption that there is a possibility of partial renewal of the internal air.

We reproduce below, in full, the summary given in that bulletin:

> "An investigation carried out on electricity poles, water tank supports, orthotropic decks of bridges, tubular footbridges for marine applications, davits and welded steel columns

indicates that, contrary to some opinion, the internal surface of closed steel components do not corrode under atmospheric conditions, even if they are not completely sealed. Only slight corrosion occurs since the quantities of oxygen and water contained in the imprisoned air within the component are limited, and the condensation which is necessary for corrosion to occur is very rare. Calculations based on the oxidation reaction, taking into account the surface area, the enclosed volume of air, the relative humidity and the air changes, indicate that the loss of steel thickness due to such corrosion is negligible

Therefore, the use of closed steel sections in bridges and buildings can be considered now that we know there is no fear of loss of strength due to internal oxidation. This principle applies to all closed steel sections, regardless of size, from relatively small tubular structures to large size box sections. The fact that the internal surfaces of closed steel sections do not require painting to prevent corrosion means a substantial reduction in maintenance costs and the elimination of manholes with removable covers, which have been common practice until now. Schwendenan estimates a saving in maintenance costs amounting to as much as 45% in the case of closed box sections for bridges if the painting of the internal surfaces is considered unnecessary."

4 INVESTIGATIONS CARRIED OUT THROUGHOUT THE WORLD

4.1 **American experience**

The observations given hereunder are extracts from the major publication quoted in section 3.3 [3].

4.1.1 Trolley Bus Poles in Pittsburg

Thanks to the cooperation of Mr. C. E. Schauck of the Allegheny County Port Authority, Pennsylvania, it was possible to obtain some samples from poles used to support trolley bus cables in the Pittsburg area. These poles which have been in service for 40/50 years are stepped poles fabricated from three telescoping sizes of tube, the sizes of which are given below. All the sections had the same nominal thickness of 12.7mm.

lower section:	hollow section 219mm dia.	height 5.80m.
middle section:	hollow section 193.7mm dia.	height 2.20m.
upper section:	hollow section 168.3mm dia.	height 2.20m.

In order to establish the loss of steel due to corrosion, the thickness of the wall of the 219mm sections was measured with an audio-gauge, an ultrasonic measuring apparatus using flat crystals. Unfortunately, for the measuring of the wall thickness of the 193.7 mm hollow sections, and the 168.3mm sections, the audio-gauge could not be used owing to the sharper radius of curvature.

Although the upper ends of the columns had been left open to the weather, it was noticable that the corrosion in the 219mm dia. tubes ,which were half a century old, was negligible, as indicated in the following table:

Sample No.	Nominal thickness		Measured thickness		Difference with regard to nominal thickness
	ins	mm	ins	mm	
1	0.500	12.7	0.493	12.32	-1.4%
2	0.500	12.7	0.474	11.8	-5.2%
3	0.500	12.7	0.526	13.2	+ 5.2%
4	0.500	12.7	0.498	12.48	- 0.4%
5	0.500	12.7	0.520	13.0	+ 0.4%
6	0.500	12.7	0.492	12..3	- 1.6%

The origina1 specification allowed for a tolerance of ±12.5% with regard to the nominal thickness. The chemical composition of the 219mm diameter hollow section, taken at random, was 0.8% carbon, 0.58% manganese, 0.10% phosphorous and 0.005% copper. The small copper content did not increase the steel's resistance to corrosion.

The comparative atmospheric corrosion rates for an open hearth steel of similar chemical composition and of a copper open hearth steel have been determined by the A-5 Committee of the ASTM. The Committee found that in Pittsburgh the average number of years required to perforate 22 gauge corrugated iron sheets, with 0.02% copper content, was 1.3 years, whereas that for a 0.21% copper content was 4.8 years. The sample trolley bus pole should probably have had an atmospheric corrosion resistance amounting to ¼ to ⅓ of that of a copper steel and yet the inside surfaces of the post were practically intact after half a century of service. It can therefore reasonably be concluded that the inside surface of tubes placed vertically and not closed shows virtually no corrosion in the atmosphere.
At least 22,000 poles of this type were installed in Pittsburgh. After 40 to 50 years of service, with their upper ends open, some 18,000 are still in use and functioning in good condition. The other posts have been dismantled following the replacement of the majority of the trolley buses by ordinary buses.

4.1.2 Lighting Columns in Dayton, Ohio

Mr. I. G. Holmer, Director of the Department for Municipal Affairs of the Dayton Power and Light Company, Dayton, Ohio, has supplied a sample of lighting column which had been installed in 1905 and removed in 1964. The upper part of the column was curved through 80^{o}. No internal protection had been provided.

The sample had been cut just above the ground level. The chemical composition of the material was as follows: 0.04% carbon, 0.38% manganese, 0.002% phosphorous and less than 0.0005% copper. The section had been cut longitudinally. The internal surface was examined and found to have retained the original mill scale. There was no pitting of the steel which would indicate atmospheric corrosion. The external surface of the column had been repainted periodically. With regard to the internal surface, this had remained intact after 59 years of service. None of the columns in this series, installed at the same time, had been damaged by corrosion.

4.2 **British Experience**

4.2.1.Catwalk at the Nore forts - Thames Estuary.

The following is an extract from a report drafted in 1953 by the Stewarts and Lloyds Research Department, today the British Steel Corporation - Tubes Division [4].

The information given here has intentionally been limited to those paragraphs covering only the subject with which we are concerned, the resistance of hollow sections to internal corrosion.
In 1943 Tubewrights supplied catwalks connecting the forts erected offshore on the Nore. These were fabricated from both seamless and welded CHS in diameters ranging from 33.7.mm to 168.3.mm. At the time of erection, these sections were covered with a first coat of "Drynamels" anti-rust paint. Obviously all the ends of the hollow sections were sealed so that their interiors were not exposed to the marine atmosphere and, naturally, no internal corrosion took place.

Ten years later, the steamship "Baalbek" collided with one of these catwalks in foggy weather. The ship suffered substantial damage and the catwalk was completely destroyed, as can be seen from the photographs. It must however be observed that, in spite of the extent of the damage, there were comparatively few broken hollow sections; the whole structure was deformed in a ductile manner. Subsequent inspection showed that, even where the hollow sections were broken, the rupture was not of a brittle nature.(Figs. 1-6).

Given the doubt often expressed as to the ability of Bessemer steel to stand up to impact and substantial deformation, it was thought useful to collect a few of these damaged hollow sections for a more detailed examination. Many users of tubular structures had expressed some concern as to the possibility of internal corrosion taking place in spite of having ascertained that the sections were properly sealed.

It is difficult to imagine more corrosive conditions than those endured by these catwalks, exposed as they were to moisture, a marine atmosphere, variations in temperature etc. Consequently, this accident presented a unique opportunity to examine the inside of the tubes.

Naturally, only a small part of the catwalk was removed for this examination, the samples being cut out of the main members. These samples suffered further considerable damage while lying on a scrap heap and during transport. The photographs accompanying the report show the state of the components. It must be pointed out that a detailed inspection of the inside of the tubes failed to reveal any deterioration which is not shown on the photographs.

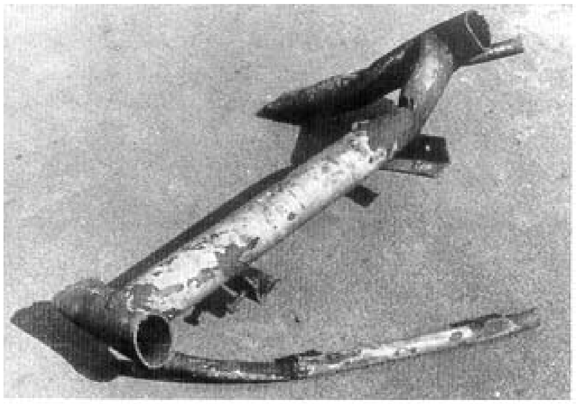


Figure 1: Joint unit with parts of the chords showing severe deformation and rupture at the point of impact.

Figure 2: Detail of the rupture at the point of impact showing the ductile fracture.

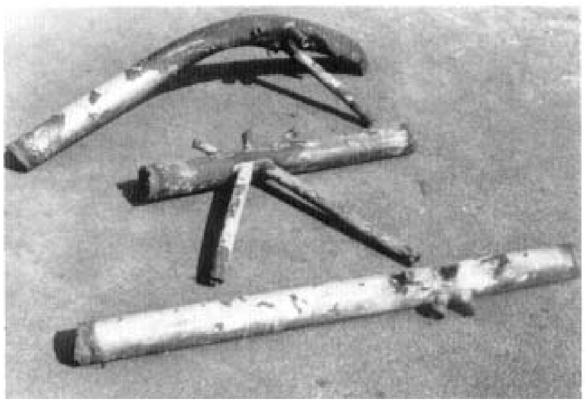


Figure 3: Various parts of the twisted and damaged side chords.

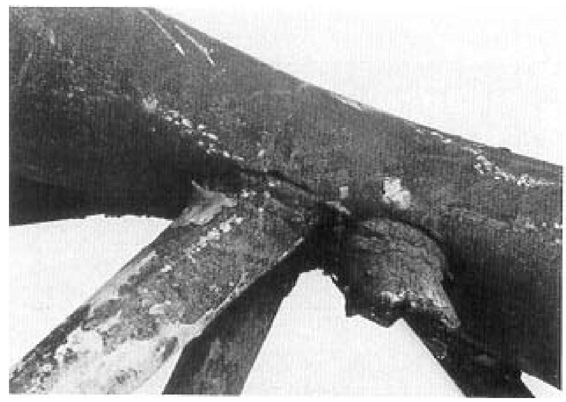


Figure 4: Detail of the upper chord from Fig. 3

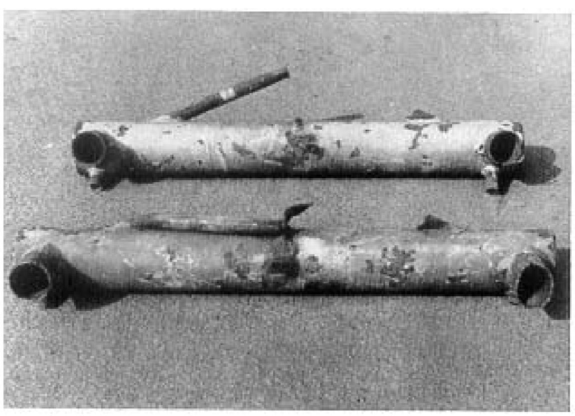


Figure 5: Compressed members with ends still sealed, the ductile bending of the lattice members should be noted.

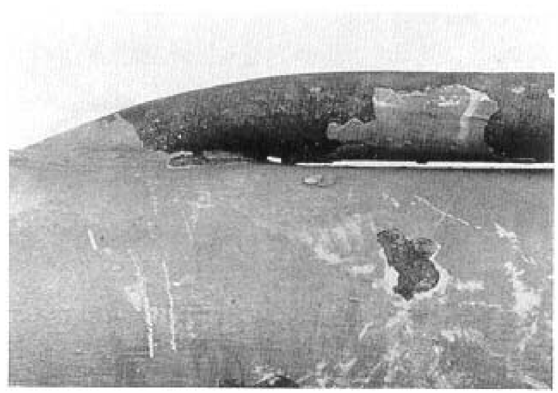


Figure 6: Web member at the bottom of Fig. 5 indicating that the weld has not parted in spite of the large bending force.

1 - <u>State of the external surface</u>

It was rather difficult to check the state of the external surface owing to the extent of damage which had been done to the coat of paint during the accident and, even more, during subsequent handling. However, most of the external surface seemed to have remained in a good condition, and at the spots where the coating had been damaged on the surface, the primary coat had kept its original qualities.

One major case of external corrosion was however observed. This can be seen on the photos, Figs. 7 and 8, where a hole has developed in one of the lattice members. It appears that another component of the framework or even possibly a rope had been in contact with this member causing abrasion which assisted the penetration of moisture, thus intensifying the corrosion. A proper inspection would have made it possible to detect damage of this type.

No variance of corrosion rate between weld and parent metal due to electrolytic action was observed either at the welds or elsewhere. Indeed, providing that the paint coat was properly maintained, this tubular structure could have lasted indefinitely.

2 –State of the internal surface

At the time of the cutting out of the samples and before their arrival at Corby, a large number of hollow sections, previously sealed, had been opened at the ends. The number of components still sealed was nevertheless sufficient to allow for inspection. When these were opened, it was found that the internal surfaces still bore the original mill scale, identical to that which is found when leaving the mill.

The photos showing the internal and external surfaces of these hollow sections illustrate these points quite clearly (Figs. 9 to 12)

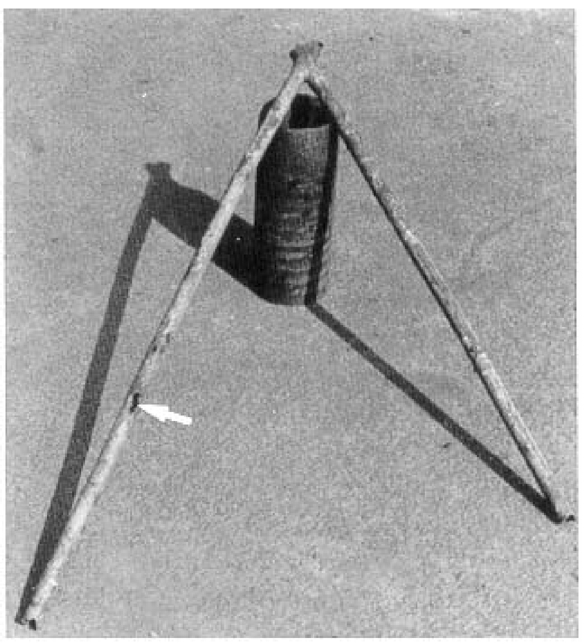


Figure 7: Perforated member, probably the result of rubbing against another part during its working life.

Figure 8: Detail of the corroded openings of the members in fig. 7.

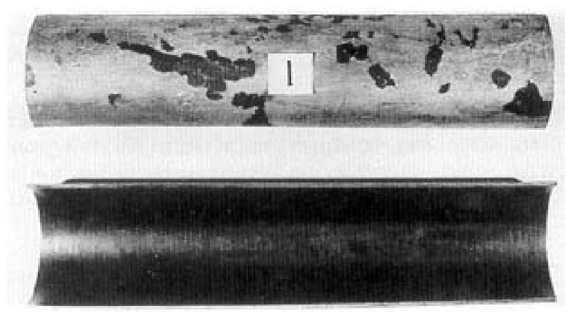


Figure 9: Hollow sections 114.3.mm dia. internal surface: perfectly preserved. External surface paint chipped during handling.

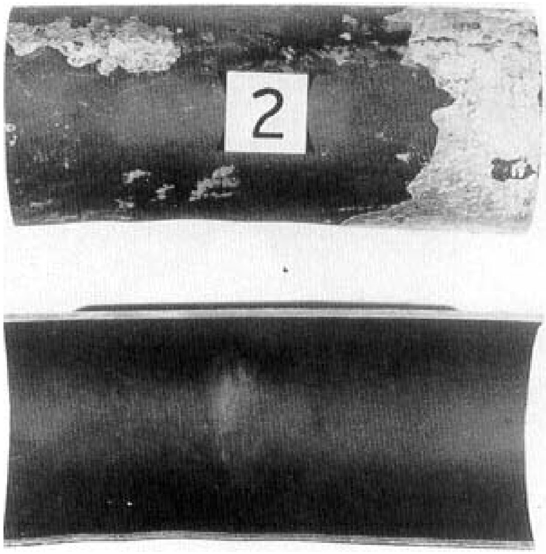


Figure 10: The same part. The traces of pre-welding heating can still be seen intact after 10 years.

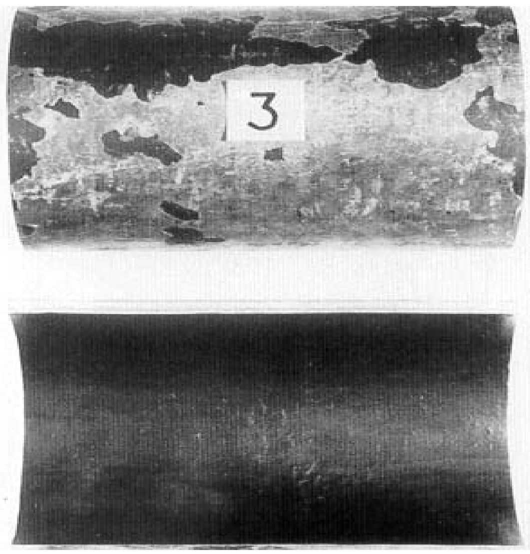


Figure 11: Hollow section 168.3.mm dia internal and external faces

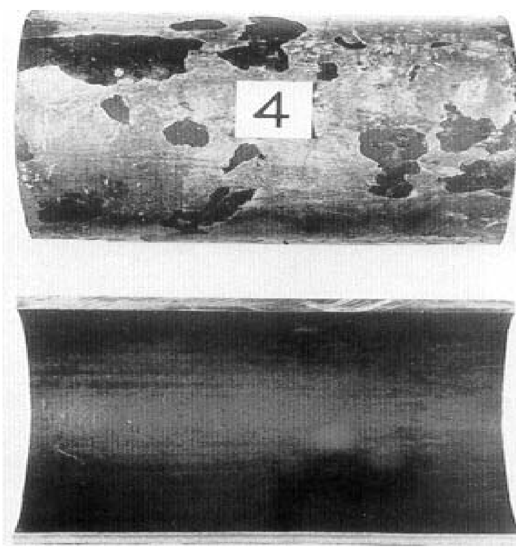


Figure 12: Same component as Fig. 11, the bright appearance of the internal surface should be noted. Some of the origina1 mill-scale adheres to the wall.

Figure 13: Complete S. S. Aquitania davit as delivered for inspection

It is interesting to note, on Figure 10, the indication of the area heated during the welding operation, visible on the internal wall. Nevertheless no deterioration occurred in this region.

4.2.2 Davits from S. S. Aquitania

This is an excerpt from a report of the 6th May 1960 produced by the Corby Works of the Tubes Division of the British Steel Corporation [5].

Two davits, supplied initially by Stewarts & Lloyds, for the liner 'Aquitania" were kindly given to the Research Centre at Corby so that they could be examined in the course of an investigation into the internal corrosion of hollow sections. The davits were installed in "Aquitania" at the time when she was built in 1913 to 1914. The ship was scrapped in 1950. Two davits were than dismantled and used for various demonstrations at Stewarts & Lloyds over several years, until they were finally scrapped at the "Globe Tube Works" in Wednesbury, England.

These davits were then about 37 years old and had been exposed to a marine atmosphere for the greater part of their lives. As can' be seen in the photo (Fig. 13) each davit is made of tube approximately 406 mm diameter and 52 mm thickness, cylindrical at the centre and conical at each end, where the diameter is reduced to about 170 mm. Both ends are sealed by welding, one with a steel ball to carry the lifeboat and the other by means of a circular plug in mild steel. The total length was about 9 meters. One of these davits was cut with the flame cutter so that the interior could be examined.

Figure 14 shows a sample of the cylindrical part, figure 15 a sample of the upper conical part and figure 16 a sample of the lower sealed part.

Unfortunately, bearing in mind the size and the weight of the various components, all the cuts had to be made with a torch and very often the resulting flashes soiled the internal faces that were to be inspected. This is why the photos seem to indicate a somewhat rough surface, whereas in fact there was no internal corrosion whatsoever in the davits inspected. The true appearance of the internal surface is better shown at the centre of the section in Figure 14.

It can be stated in conclusion that, as one would expect no internal corrosion occurred in these davits in spite of their 40 years' service at sea.

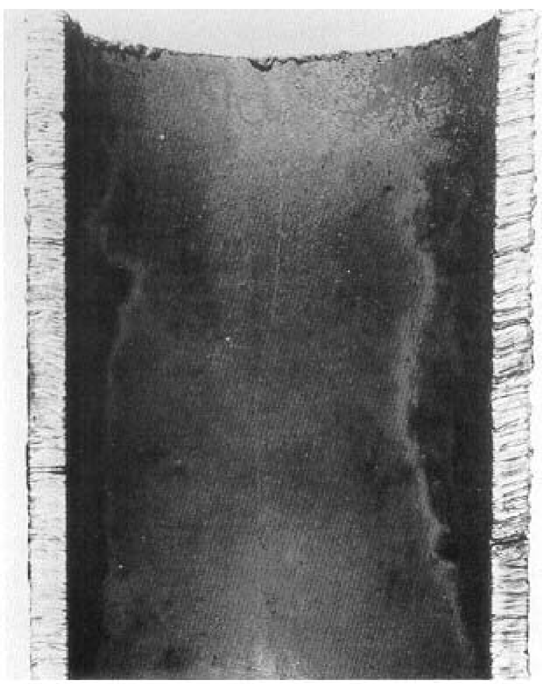


Figure 14: Internal surface of the central section of the davit

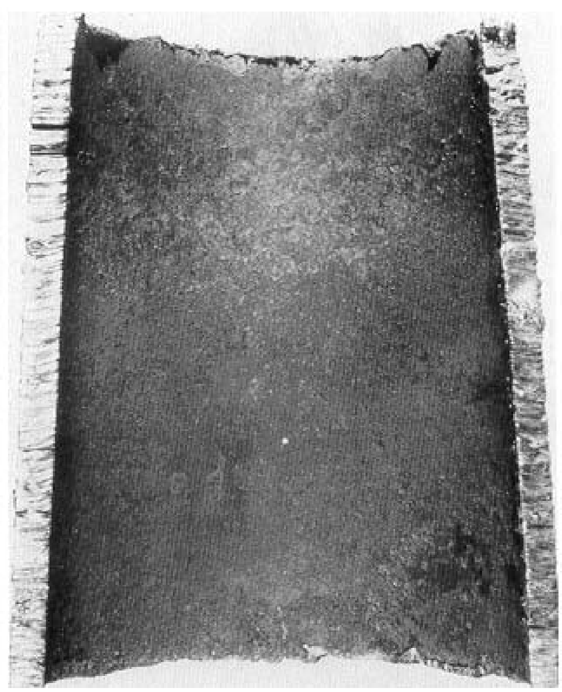


Figure 15: Upper part of the davit post cut open. (note the white spaces and the small spots due to oxyacetylene cutting)

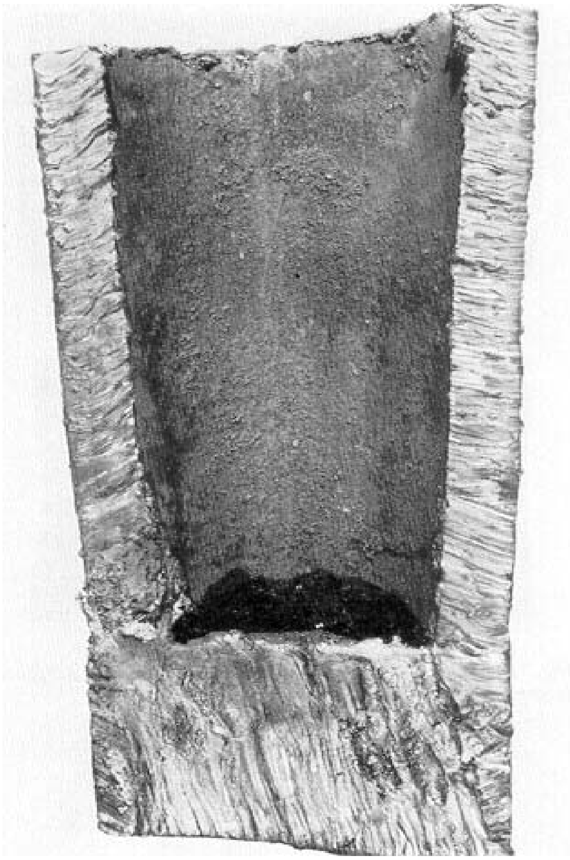


Figure 16: Lower part of the davit post as cut open.
(The white spots are again due to oxyacetylene cutting)

4.2.3 Floodlighting towers at the Chelsea Football Club.

Extract from the journal "Tubular Structures Exposed" of 1977[6]

The Chelsea football Club acquired an international reputation in the mid-sixties when its young team, managed by Tommy Docherty, gained fame both in the European field as well as in the national one. This action on the football field was matched by an impressive record with regard to the improvement of the stadium, and the new stand at Stamford Bridge was among the very first to be built according to the Wheatley proposals for crowd safety. The erection of the new grandstand meant that two of the "Tubewrights" tubular steel floodlighting towers installed in 1954 would be hidden.

In 1975, Tower Structures Marketing informed Dick Williams of the Market Development (SHS) Department that these towers were going to be demolished and steps were quickly taken to obtain sections from the towers in order to examine them. The sections were stored temporarily in the London warehouse of the Tubes Division in Pudding Mill Lane) and were sent by the first available lorry to the Research Centre at Corby for examination.

A case Study on the question of Internal Corrosion in sealed Hollow Sections by Charles Dawson, Tubes Division, British Steel Corporation.

The samples cut from the two Chelsea towers came from the CHS legs, 159.7 mm dia. by 6.3 mm or 4.5 mm thick, and 114.3.mm dia. x 6.3 mm thick. These were closed at the ends by solid flanges which were then bolted together.

The flanges had a diameter of 504.8 mm x 16 mm thick with four BSW bolts 28.6 mm x 80 mm long at a pitch circle diameter of 209.5 mm. The external protection of these components consisted of a zinc coating applied after fabrication, in accordance with British Standard 729.

These towers had, naturally enough, been painted in the Chelsea colour, blue. The upper part of the structure and the portal bases had been fabricated from hollow sections and galvanised plates. The weld seams had subsequently been shot blasted and zinc sprayed. The joints were then covered with a coat of zinc rich paint and the whole unit was finished with an application of aluminised paint.

Examination of the samples collected.

Sample no. 1: 159.7 mm dia. was slit longitudinally in order to reveal the internal face (Figure 17). Very slight signs of internal corrosion were observed, other than surface discolouration, due to the oxygen and the humidity in the imprisoned air. Much of the original mill scale was also visible. The slight rusting which was found at the centre of the sample was recent, having appeared after the tube had been cut open for examination.

Sample no. 2: Also l59.7 mm dia. included an intermediate flange assembly (Figure 18). The conditions of the internal face of the flange, which had been enclosed and hermetically sealed by being welded to the CHS, was still relatively bright, the original marking-off lines being clearly visible. The intermediate flange assembly was dismantled in order to examine the contact faces of the flanges (Figure 19)

Figure 17: Circular hollow section 139.7 mm showing one of the half cylinders cut longitudinally. The slight amount of rust in the middle the tube is recent and has appeared since the tube was cut for inspection.

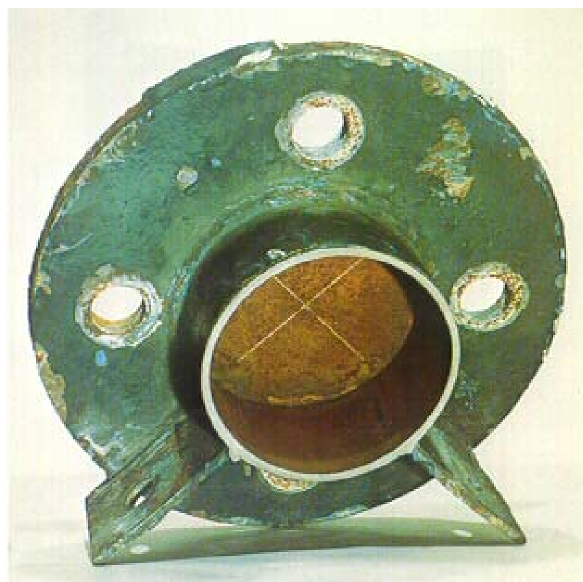


Figure 18: Circular hollow section l39.7 dia. welded to a solid flange showing clean conditions of the internal of faces. The original marking off lines on the flange are still perfectly visible.

On the outside of the flanges a certain amount of corrosion was discovered, but this was, in fact limited to the area which was outside the pitch circle diameter of the bolts and was obviously due to the progressive ingress of rainwater between the flanges over many years of service (Figure 19).

The amount of corrosion that was discovered was not considered sufficient to adversely affect the strength of the joint. The penetration of water in this manner is a problem normal to all structures which use bolted joints exposed to the weather. The effect can, however, be reduced, if particularly critical, by using jointing material that will seal the connection or by applying mastic between the flanges.

Other samples were also examined and these again showed the excellent condition of the interior of the circular hollow sections and the internal faces of the flanges, demonstrating an almost total absence of corrosion.

The fact that these sealed hollow sections show such a high resistance to internal corrosion is not surprising to engineers familiar with this type of construction. Indeed, it is because this is so well established that the clause referring to this problem in BS 449 allows structural members in hollow sections, which are hermetically sealed at the ends, to be thinner than corresponding members in conventional open sections.

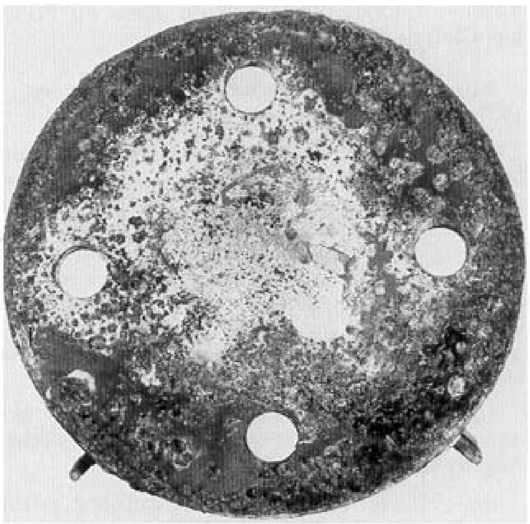


Figure 19: Contact faces of the solid flange after dismantling.

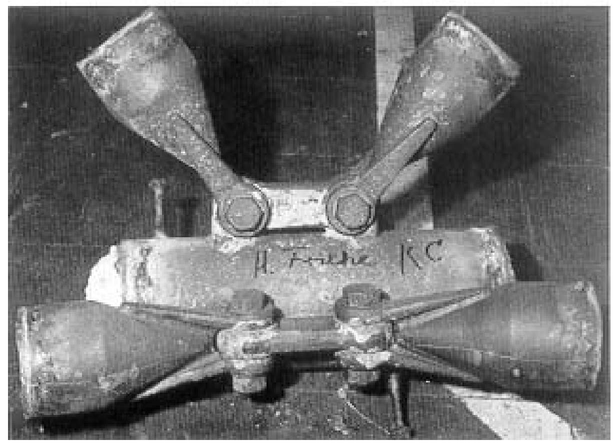


Figure 20: High voltage transmission tower. External view of the cut out joint sample.

4.3. **German Experience**

4.3.1 Verification of the internal condition of tubular members in transmission tower. Report of the Mannesmann Research Institute in Huckingen. December 1974 [7]

Summary: The internal surfaces of four hollow sections originating from a joint in a high voltage transmission tower do not show any corrosion defect after 18 years of service. When the hollow sections are hermetically sealed, their use as a structural element does not present any problems with regard to internal corrosion.

Background: In 1956 the Rath Works of Mannesmannrohren-Werke delivered guyed towers for a 220/380 kw power line from Wiesental (Laufenburg-Kembs) to Badenwerk AG, Karlsruhe. After some 18 years tower No. 13 at Stackingen was withdrawn from service, presumably following some alterations. This made it possible to cut out some samples and to assess the state of the internal surfaces.

Result of the examination: Figure 20 shows the part of the pylon which was supplied by Mannesmannrohren-Werke. This sample had been cut out of a joint situated some 12 m above the ground.

At this joint four tubular bracing members were connected to one of the concrete filled chords. These members were made of seamless hollow sections, hermetically sealed, in steel corresponding to the old grade Marwe 134 a (which now corresponds to steel St.55 of standard DIN 1629). The hollow sections were cut at about 40 cm from the junction with the chord.

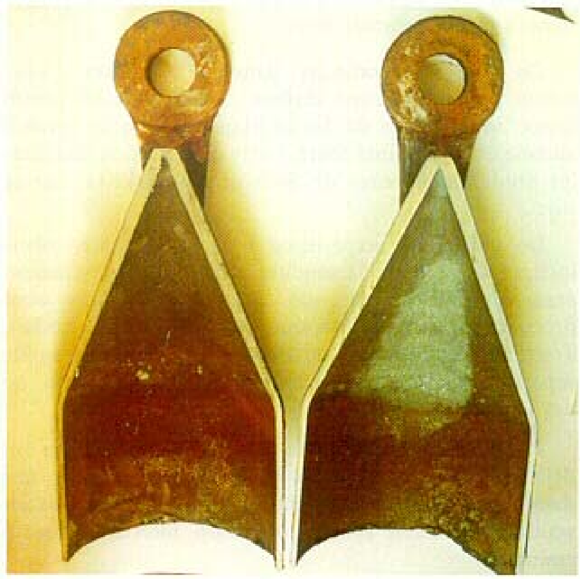


Figure 21: View of the internal faces of the brace component No. 1.

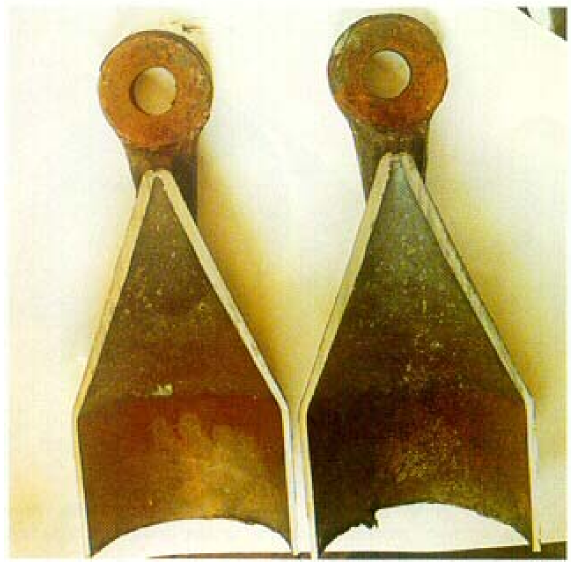


Figure 22: View of the internal faces of the brace component no. 2.

Figure 23: View of the internal faces of the brace component no. 3.

Figure 24: View of the internal faces of the brace component no. 4.

In order to be able to examine the internal surfaces, the four bracing members were detached from the chords and cut longitudinally in half (Figures 21 to 24).

The internal surfaces were perfectly smooth and did not present any sign of corrosion attack. This complete lack of internal corrosion was confirmed by the presence of the mill scale going back to the original rolling of the section, as well as the good preservation of the 'blue' colour due to the heating caused by the welding of the fixing lugs. These observations apply to both the upper and lower ends of the diagonal bracing members.

Conclusions: The observations carried out showed that there is no fear of internal corrosion where hollow sections have been sealed by welding and that they can be used as constructional elements in structures intended for long-term service.

4.3.2 Trusses in hollow sections above pickling baths. Report of the Hoesch Company (1974). Extract from the report by Dr. H. Kotter. [8]

In 1953 a new building was erected for the installation of a pickling plant for precision tubes at the Hoesch Tube Works in Hiltrup in Westphalia.

Symmetrical double slope trusses were made in hollow sections. The framework consisted of a lattice system without any gussets, with sealing welds throughout. A crane rail was suspended from the lower chord. The framework was initially covered with a coat of anti-rust primer.

The pickling plant comprised the following open baths:

1.- Pickling bath with 25% sulphuric acid (H_2SO_4) – temperature 75 ^{0}C.

2.- Hot and cold water washing baths.

3.- Phosphate solution (H_3PO_4) baths at a temperature of 65^0 to 70^0 C with added oxidisers (nitrite and nitrate solutions)

4.- Lubrication baths at a temperature above 90^{0}C.

The fact that the pickling baths were open caused an almost permanent high level of humidity with the formation of vapour. The ventilation openings provided along the roof ridge did not reduce this to any extent. In particular the sulphuric acid carried by water droplets was causing very serious damage to the steelwork. A second coat of paint had to be applied after a short time, the rust having been previously cleaned off by hand. Three years later, a re-paint was necessary, but this time after sanding and the application of an anti-rust primer

In spite of these three painting operations, the corrosion on the external surfaces was so extensive by 1962, i.e. less than 10 years after the erection of the building, that the first deformation became evident and it was found necessary to dismantle the roof structure.

After being dismantled, the trusses were cut up with a flame-cutter into sections of relatively short length and scrapped. It was thus possible to examine the internal surface of the members through the cut ends. (see fig. 25).

Although external corrosion had caused some holes through the wall thickness at certain localised points, no internal corrosion whatsoever was observed. The original mill scale was still clinging partially to the internal surface.

It was thus possible to verify that, under particularly severe conditions of use no internal corrosion takes place in hollow sections providing the sections have been sealed properly. This confirms the previous investigations of Seils and Kranitzky [17] on this subject.

Figure 25: Truss component located over a pickling bath. The external surface shows an advanced state of corrosion, due to the ambient atmosphere, whereas the inside is well preserved, the traces of damage are entirely due to the oxyacetylene cutting operation.

Moreover, this experience demonstrates that, even when the weld seams are not perfectly sealed or small holes have been made in the section, no internal corrosion follows. The most that can be found is a slight trace of superficial rust in the immediate neighbourhood of the holes or the welds which are not airtight. In conclusion, it is therefore possible to confirm that which has already been demonstrated in previous investigations, namely that in the case of welded structures in hollow sections there is no fear of internal corrosion.

4.4 **Japanese Experience**

Enquiry concerning urban lighting columns. Report by the Sumitomo Metal Co. - February 1977 [9]

Structure: This document refers to the investigation carried out on the internal corrosion of lighting columns for public thoroughfares with a high level of traffic (Figure 26).

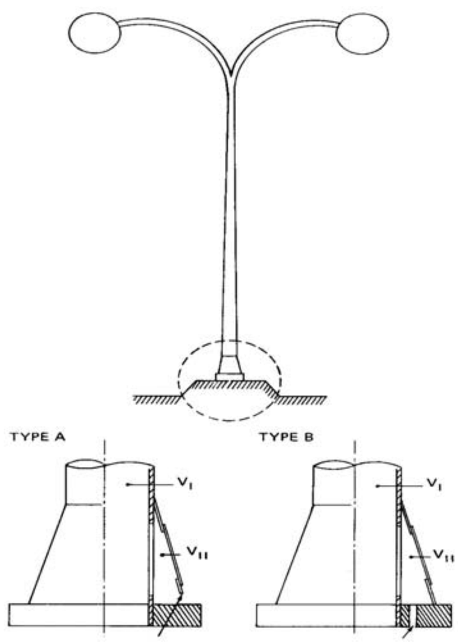


Figure 26 - Urban lamp-post: water drainage hole 10 mm radius for both types
Type A: side hole Type B: base hole

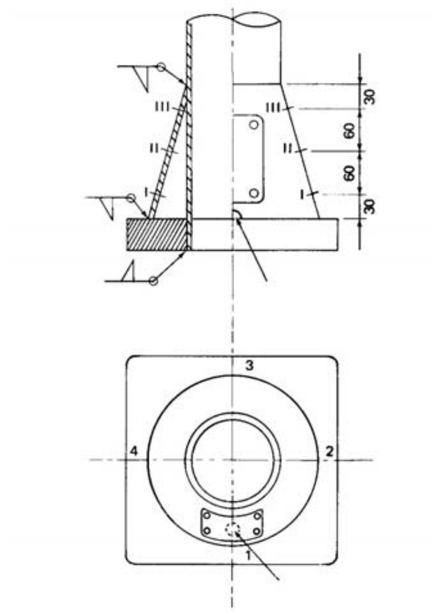


Figure 27 - Column Base

Table 1: Amount of interior corrosion (t mm)

N°(a)	POINTS DE MESURE (b)															Moyenne	Type (c)	Zone (d)	Années (e)
	I					II					III								
	1	2	3	4	Moy.	1	2	3	4	Moy.	1	2	3	4	Moy.				
1	.8	.4	1.0	.2	.6	.5	.0	.2	.1	.2	.2	.0	.0	.0	.1	.3	A	X	6
2	1.8	1.8	.6	.1	1.1	1.1	1.0	.6	.2	.7	.0	.0	.3	.0	.1	.6	A	X	6
3	.5	.0	.7	.5	.4	.0	.1	.7	.7	.4	.0	.0	.3	.2	.1	.3	A	X	6
4	.4	.9	1.3	.6	.8	.6	.1	.7	.9	.6	.0	.0	.3	.8	.3	.6	A	X	6
5	1.2	.7	.7	.6	.8	1.0	1.2	1.0	.4	.9	.1	.0	.2	.2	.1	.6	A	X	6
6	.8	.4	.1	.9	.6	1.9	.1	.2	1.7	1.0	.4	.1	.0	.4	.2	.6	A	X	6
7	1.7	.5	.7	1.0	1.0	.4	.6	.5	.0	.4	.3	.0	.1	.0	.1	.5	A	X	6
8	1.3	.6	.8	.7	.9	.8	.1	.1	.6	.4	.0	.2	.2	.0	.1	.5	A	X	6
9	.7	.9	1.0	1.1	.9	1.0	.7	.8	.6	.8	.6	.2	.3	.2	.3	.7	A	X	6
10	*	.8	.7	.3	(1.3)	.8	.5	1.7	.9	1.0	.7	1.1	.6	.6	.8	(1.0)	A	Y	10
11	*	*	*	*	(3.2)	1.5	.7	.7	1.3	1.1	1.1	1.5	.7	.5	1.0	(1.3)	A	Y	10
12	*	*	*	*	(3.2)	*	*	*	*	(3.2)	.5	.9	1.4	1.6	1.1	(2.5)	A	Y	10
13	.1	.0	.0	.0	.0	.1	.0	.1	.1	.1	.1	.1	.1	.1	.1	.1	A	Y	7
14	1.7	.7	.7	1.3	1.1	.2	1.0	.7	.2	.5	.0	.0	.6	.4	.3	.6	A	Y	7
15	2.0	.0	.7	.3	.8	.1	.1	.4	.1	.2	.1	.0	.1	.0	.1	.3	A	X	5
16	1.1	.0	.6	.1	.5	.1	.0	.1	.1	.1	.1	.0	.1	.0	.1	.2	A	X	5
17	1.7	.1	.1	.0	.5	.0	.4	.1	.0	.1	.1	.2	.1	.1	.1	.2	B	Z	11
18	.2	.1	.1	.2	.2	.0	.0	.2	.1	.1	.0	.1	.2	.1	.1	.1	B	Z	11
19	.0	.0	.0	.0	.0	.1	.1	.1	.0	.1	.1	.1	.1	.0	.1	.1	B	X	11
20	.2	.0	.1	.0	.1	.1	.1	.1	.1	.1	.1	.1	.2	.0	.1	.1	B	X	11
21	.1	.0	.1	.2	.1	.0	.0	.0	.0	.0	.2	.1	.0	.0	.1	.1	B	X	10
22	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	B	Y	7
23	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	B	Y	7

Notes:

(a) No. 1-2 — lighting posts reference number

(b) I, II, II and 1, 2, 3, 4 — measuring point locations, see fig. 27

(c) Types A and B — location of water drainage hole, see figs. 26 and 27

(d) Zone of location — X – industrial, Y – commercial, Z – residential

(e) Annees — years in service

* thickness less than 1 mm, no measurement possible

calculated internal corrosion thickness, t = original thickness (3.2 mm) – remaining thickness

Measurements carried out: The internal corrosion was measured by means of an ultrasonic thickness tester. The measuring points (I, II and III) are shown on Figure 27. There was no internal paint.

Amount of internal corrosion.: The measurements of internal corrosion for those columns examined are given in Table 1.

Result: The relation between t (thickness reduction due to internal corrosion and T (years elapsed since installation) are shown on Figure 28 for two types of water drainage holes.

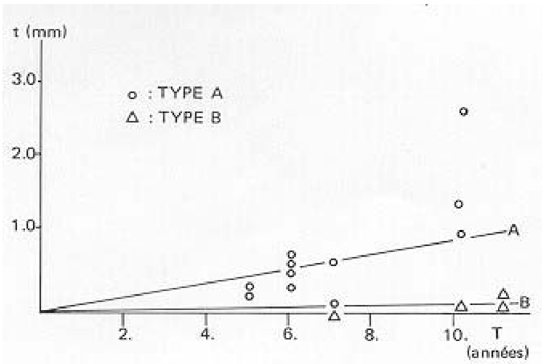


Figure 28: -t/T ratio in relation to the type of drainage hole (years)

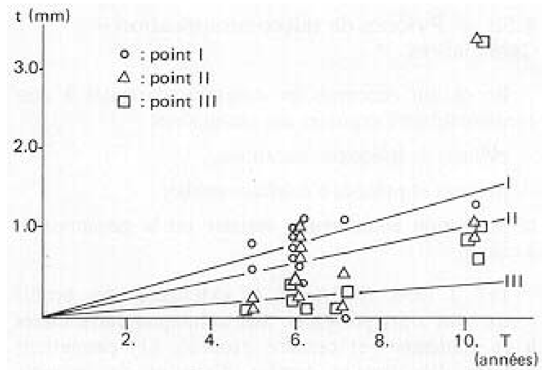


Figure 29: Type A column. t/T ratio in relation to the measuring points(years)

Conclusion: The following results have been obtained at the end of our investigation.

1) The location of the drainage hole is one of the most important factors affecting internal corrosion. Type A posts with a drainage hole on their tapering sides do rust severely, whereas type B posts with a drainage hole on the base plate do not rust.

2) Corrosion is particularly severe at the point where the edge plate is welded to the base plate.

3) There is little relation between corrosion and the nature of the posts' environment.

4.5 **Italian Experience**

Extracts from the report of the 3 March 1977 – ref. SCN/339 by the FIT Ferrotubi Co. of Milan.[10]

4.5.1 Cranes

We have had the opportunity over some thirty years of activity as constructors, particularly when dealing with lattices of tower cranes for building sites, to observe that if the weld had been carried out according to established practice and if consequently, the hollow section was airtight, the interior of that section showed no sign of corrosion even after 10 or 20 years of service. The amount of iron oxide present was not greater than that present at the time of welding or that which had formed as a result of the oxygen remaining inside the hollow section.

4.5.2 Industrial buildings

Some buildings with a tubular framework, belonging to our Company, which were erected 25 or 30 years ago, are due for dismantling. These will enable us to carry out a detailed investigation on this subject, but we have already cut out some samples from a tubular lattice component and we are sending these to CIDECT.

The 3 samples taken from an industrial building had been cut longitudinally and examined (see figure 30). There is no trace of internal corrosion in spite of the age of the structures (more than 10 years) and the conditions of exposure (industrial atmosphere).

Figure 30 - Internal and external appearance of three samples cut from the tubular framework of an industrial building.

4.5.3 Telecommunication masts - Lighting towers

In the case of structures which are continuously exposed to the weather, e.g. telecommunication towers, posts or towers for public lighting, the protection usually adopted is hot dip galvanising. Both external and internal surfaces of the hollow sections are then protected. The techniques particular to this treatment and specific procedures mentioned in (i) allow for the prevention of any subsequent ingress of water and for the provision of drainage to eliminate the danger of ice formation within the structure.

(i) *The Italian author refers here to the provision of holes to facilitate immersion during galvanising and also the provision of 'pressure balancing' holes.*

5 INVESTIGATIONS CARRIED OUT RECENTLY IN FRANCE

5.1 **The investigation carried out at Valenciennes in March 1974**:

This factory situated in the industrial region of the North of France was chosen on account of the numerous possibilities it offered for cutting samples.

Indeed, the high number of hollow section structures more than 10 years old made it possible to find, in the same location, the range of samples which was sought, e.g. members which were hermetically sealed at both ends, members which were partly sealed and members flattened at the ends.

5.1.1 Obtaining the samples: This work commenced on the 28th March 1974 in the presence of Maitre Bettignies who was Legal Officer at Valenciennes. It was Mr. Veaux, Head of the Material and Structure Dept., who represented the National Test Laboratories (LNE). Mr. Tournay, responsible for the Research Dept. at Cometube, was observing the operation for the Chambre Syndicale des Fabricants de Tubes d'Acier (CSFTA).

All the structural components were listed and photographed on the spot by the LNE representatives. They were then sent for examination to the LNE Laboratory, 1 rue Gaston Boissier, in Paris. With the exception of the gantry leg, which was sent as it was to the LNE, all the members were cut out on site.

5.1.2 Description of the structural components which were taken as samples: The choice of members depended essentially on the methods used for joining, which we wanted to test. The final decision regarding the sampling was obviously influenced by the need not to disturb the construction work which was in progress.

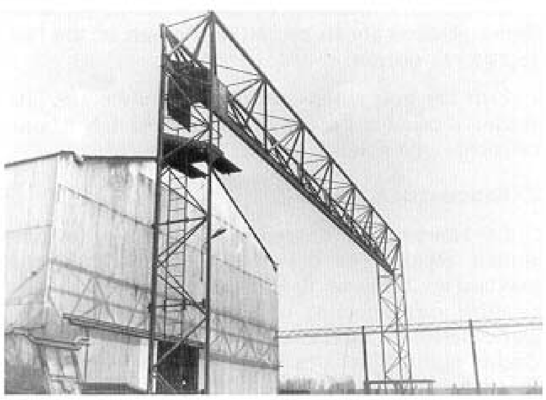


Figure 31: Valenciennes Works -General view of the loading portal before dismantling.

Figure 32 - Cutting out of a sample

The actual units chosen were therefore as follows: 1) external loading gantry, 2) sulphate shed 3) storage shed - eastern extension and 4) factory shed - wind girder.

1) External loading gantry: This gantry (see Fig. 31) had been used for mechanical handling and for loading the structural components fabricated in an adjacent workshop. It had been erected in 1962, and had not been used since 1970, so it was due for dismantling. This is the reason why the highest number of members cut out came from this structure. The working and maintenance conditions for this gantry were those which are commonly encountered in metal workshops of the Valenciennes region, i.e. an industrial atmosphere and severe climatic conditions, being exposed to the weather.

It comprised 2 leg structures 10 m high, and triangular in section, and a horizontal girder of 20 m span. The lower chord, in one section, served as a crane rail.

Samples were cut out from the horizontal girder after it had been dismantled (see Fig. 32). Among these members 1 had 2 fixing holes for electric insulators which had been removed four years previously. The two holes, about 8 mm in diameter and some 50 mm apart, had never been plugged.

One of the gantry legs (see Fig. 33) was of particular interest for the following reasons:

a) it included a service platform which was badly corroded externally

b) the access ladder to this platform made it possible to cut out a large number of samples,

c) one of the three uprights of the leg had suffered an accident several years previously and had remained open over a height of about 1 m.

For these three main reasons it was thought beneficial to send the complete leg unit to the LNE for a detailed investigation.

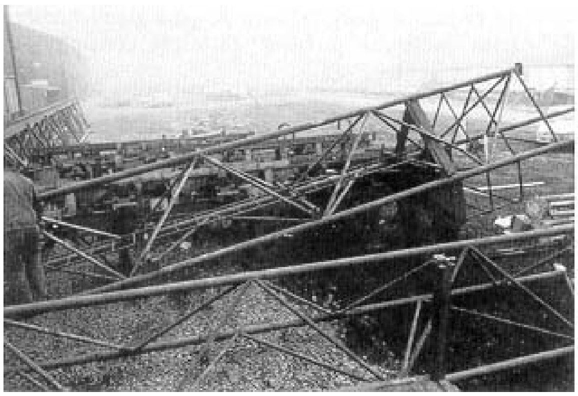


Figure 33: One of the gantry legs comprising the ladder and access platform which was sent as a complete unit to the LNE.

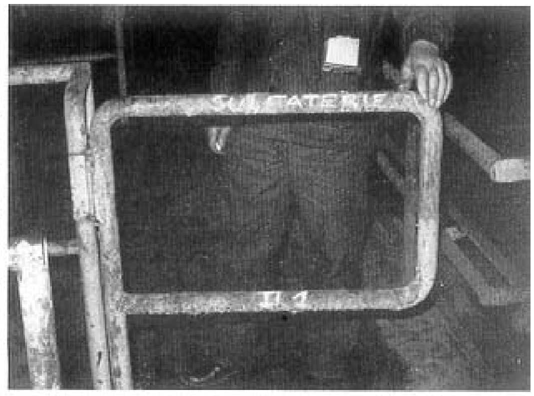


Figure 34: A sample of the railing which had been removed from the sulphate works. Particularly badly corroded externally.

2) Sulphate shed: This relatively small building had been housing the sulphuric acid baths since 1964. It was next to a pickling plant and the whole of the steel framework was situated in a particularly hostile atmosphere owing to the sulphuric acid emanating from the pickling bath operations.

Two samples were taken:

a) the bracing members of the roof structure. These were hollow sections of 34 mm external diameter flattened at both ends and in the centre for bolting purposes

b) the lower rail of the bannister which had been sealed at both ends by welding and whose external appearance showed an advanced stage of corrosion (see Fig. 34)

3) Storage shed - eastern extension: We were dealing here with a building of 20 m span, the upper part of which (trusses and purlins) was a tubular structure. Built in 1961, this building served as a fabrication workshop until 1970. Since that date it has been used as a storage shed. The following samples were selected:

a) From the roof, a lattice purlin comprising an upper chord in hollow sections 45 mm square and a lattice in CHS of a smaller diameter

b) From a stabilising portal frame (see Fig. 35), two units of bolted lattices, which had been dismantled. These had been joined at their flattened ends.

4) Factory shed - gable type wind girder: This building, constructed in 1958, had components which had been exposed to the industrial atmosphere since that date. One sample only was taken, namely a wind girder support (see Fig. 36). This strut was bolted at the top through a welded plate and at the bottom simply by flattening.

Figure 35: Dismantling of two bracing members with flattened ends.

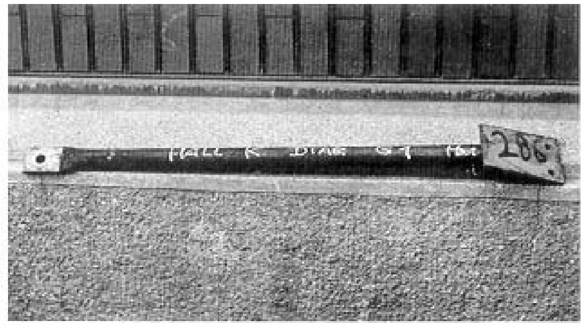


Figure 36: Diagonal member flattened at one end and welded to a plate at the other.

5.1.3 Observations made about the samples: All the observations we were able to make on site, when the samples were being cut, were complemented by careful examination in the LNE laboratory in Paris. 48 of the 100 samples taken were examined.

These 48 samples were made up as follows:

37 members, sealed at the ends, showed an internal surface which had remained intact.

4 members, originally open at the ends, were corroded inside.

7 members, which had either been badly sealed or had suffered damage, had also undergone a change

All these observations are recorded in the very full report of the LNE, which includes, apart from the typescript, photos of the cutting out of the samples, as well as colour photos depicting the comparative state of the internal and external faces of each sample.

This report, Number 403.136, can be consulted either at Cometube or the Chambre Syndicale des Fabricants de Tubes d 'Acier [11].

1) External gantry crane: Without going into a detailed description of each member, descriptions being given in the laboratory report, it is however interesting to underline particular points which have arisen during the course of this investigation.

a) Horizontal girder: 5 diagonal members were taken as samples. All of them were sealed by welding and their internal condition was perfect. Member A31, however, deserves to be dealt with at greater length (see Fig. 37). This member featured 2 holes, for attaching insulators, which had remained open for several years. Corrosion was discovered in the immediate vicinity of the 2 holes, but the corrosion was strictly limited to that area. The internal face of the rest of the member was intact.

b) Leg structure B: This leg structure produced 77 samples, 36 of which were examined. Two details should be commented upon. First of all, this triangular leg structure included three members in circular hollow sections having a diameter of 90 mm. Only one of these three chords exhibited a longitudinal opening over a height of about 1m. The other two chords had remained in perfect condition.

The comparison between these is very easy to make: the open chord was very corroded inside; the

LNE detected a substantial quantity of rust at the bottom of this member and the two undamaged chords retained their original mill scale over a very large area.

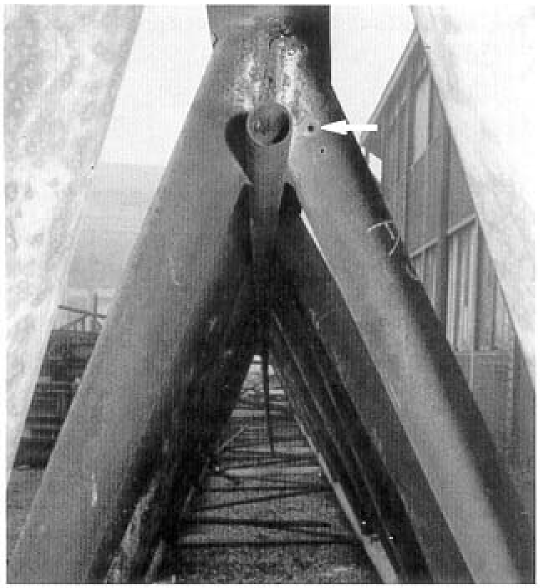


Figure 37: Lower part of the A3 diagonal member showing the two attachment holes (note that the triangular girder is resting upside down)

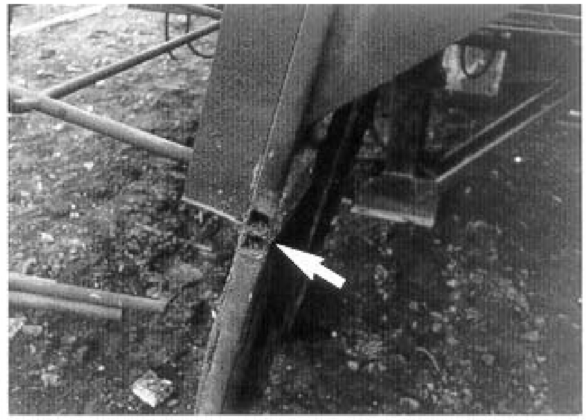


Figure 38: Platform with RHS stiffening. Only the longitudinal members with sealed ends have kept a corrosion-free internal surface.

The ladder of the leg structure was also of great interest; all the rungs in circular hollow sections were welded at both ends and their original internal condition had been preserved. On the other hand, the two uprights of square hollow sections, which had not been sealed at the ends, were in an advanced state of corrosion, both inside and outside.

It is useful to recall that the ladder and the platform were of a temporary nature and had been out of use for more than 4 years; consequently, they had not been painted since being given the original coat of anti-rust paint.

The access platform to the hoist consisted of a chequer plate stiffened by longitudinal and transverse members in RHS (see Fig. 38).

The cross members were open at both ends and their internal faces were in an advanced stage of corrosion. The longitudinal members which were welded at right angles to the transverse ones, and were thus sealed at both ends, had internal faces which remained in an absolutely perfect state. On the whole of this leg structure, 25 of the 36 members, which were examined, were in a perfect condition internally. Of the 11 members which had suffered corrosion, 4 were open at both ends and 7 had deteriorated either at the beginning or during their working life.

2) The sulphate works building: Only a few samples were taken, but all were significant. Indeed, in spite of the particularly corrosive atmosphere (sulphuric acid vapour), the bracing members with flattened ends had been well-preserved internally. A few of the ends had suffered slightly.

The railing sample from the vicinity of an acid bath showed an external surface which was excessively corroded. On the other hand, this member, sealed by welding at both ends, had kept its original internal condition with remains of the mill-scale. The contrast between the two faces of this sample was particularly significant; the sealed interior is protected whatever the external atmosphere.

Figure 39: End of a lattice purlin with a bolt hole through the chord.

3) Storage hall - eastern extension: The lattice purlin included an upper chord member in square RHS sealed at both ends, but drilled through for bolting. The bolt had blocked the hole, apart from clearance, and it is interesting to note that some of the original mill-scale fell from the hole when the bolt was removed. (See Fig 39)

The adjoining diagonal members had flattened ends. These showed slight traces of internal corrosion in the areas where the flattening operation had detached the original mill-scale.

4) Factory hall - wind girder: Here again only the flattened end showed traces of superficial rust due to the flattening operation. Everywhere else the origina1 mill-scale was still to be found in spite of 16 years in an industrial atmosphere.

5.1.4 Conclusions to be drawn from the observations: Our findings are confirmed by the LNE report:

- all the members with sealed ends showed an intact internal surface,
- in the cases we have examined, where the members were flattened at the ends, the sealing was sufficiently well done to prevent internal corrosion, when openings were present, either due to the original design or as a result of an accident, internal corrosion has been noted within the hollow section.

These observations do, of course, fall in line with what we thought at the start, closing the ends of a steel hollow section will ensure that no internal corrosion will take place.

We must, however, comment on this enquiry carried out at Valenciennes. It is noticable that the proportion of severely corroded members appearing in this report is fairly high. This is explained by the fact that, in agreement with the LNE representatives, we deliberately looked for structures which were located in particularly unfavourable situations.

The choice of a portal frame which had been out of service and submitted to weather conditions without maintenance for many years, as well as that of components situated in the corrosive atmosphere of a sulphate works, was dictated by the scientific guidelines agreed for this investigation.

5.2. **Investigations carried out in Dunkirk in July 1975 [12]**: In the case of the earlier sampling carried out at Valenciennes, the hollow sections observed were limited to a diameter of 90 mm, and located in an industrial atmosphere. It remained therefore to complete the investigation by taking samples from components of larger sizes (up to 500 mm diameter) situated by the sea. It was to meet these two requirements that the Vallourec Tubeworks in Dunkirk were chosen for the continuation of the enquiry.

This new phase was financed by the Chambre Syndicale des Fabricants de Tubes d'Acier (CSFTA) and the Comite International pour le Developpement et l'Etude de la Construction Tubulaire

(CIDECT). The sampling and inspection work was followed by Cometube and was carried out by the Laboratoire National d'Essais. The conclusions of these investigations are recorded in the official report of the LNE, No. 507.055 [12].

The full text is reproduced below including the tables of samples and the black and white photos depicted in it. Some of the colour photographs of samples taken in the laboratory have been omitted from this report.

The report itself can be consulted at any of the organisations which participated in the research:

Chambre Syndicale des Fabricants de Tubes d'Acier, 57, Avenue George V, 75008 Paris
G.I.E. Cometube, 102, Rue des Poissonniers, 75018 Paris.
CIDECT, Technical Secretariat, 12 Addiscombe Road, Croydon, CR9 3JH (England)

THE NATIONAL TEST LABORATORIES, PARIS - TEST REPORT No. 507-055/DMS/3/302

5.2.1 Objective

The Laboratoire National d'Essais was to examine the state of the internal surfaces of hollow sections used as steel frame components in sizes greater than 90 mm in diameter. This dimension was the upper limit of the first phase of the enquiry relating to the internal corrosion of hollow sections (see report no. 403.136 dated 22 October 1974), in which hollow sections with open and closed ends are compared.

5.2.2 Sampling cutting conditions

Cometube sent to the Laboratoire National d'Essais samples cut on the 9 July 1975 from old tubular structures at the Vallourec Works, Dunkirk. The sampling was carried out in the presence of the client, an engineer from the Laboratory, Maitre Prevot, the Legal Officer of Dunkirk and a representative of the Vallourec Works at Dunkirk.

All the hollow sections were listed and photographed on site by the Laboratoire National d'Essais (Figures 40 to 52). Flamecutters were used to cut out the samples on site. In the Laboratory, the hollow sections were slit longitudinally by sawing in the plane of the axis, avoiding the line of the seam weld.

Type of samples: Table 2 lists the samples that were cut out. For each of them the following is shown:

- its date of erection and the type of environment
- its size, function and type of assembly
- an identification number given by the Laboratoire National d'Essais, following the sampling programme.

Observation methods used: The hollow sections were examined following the methods established for the previous enquiry, the main comparison being between the appearance of the internal surface of the hollow section in relation to that of the external surface.

5.2.3 Result of visual examination of the samples

Column of Hall III: The hollow section marked "Column D-18-l" was cut from the horizontal bracing of a crane rail stanchion in No. 2. tube mill after more than twelve years in an industrial atmosphere. This stanchion numbered “D-18 row B” is shown on Figures 40 to 41. Figure 42 shows the same stanchion after 800 mm had been cut out from the bracing. The sample is shown in Figure 43. It is a seamless circular hollow section about 168 mm external diameter, sealed at both ends where it is welded to the

Table 2: List and details of samples

General information				Properties of the member								
Location of samples	Type of structure	Date installed	Working environment	Prog. Ref.	Figure number	Usage	Circular or square	Size mm	Member detail	Production location	Position	Protective coating
Hall III Row B D-18	Column supporting building	1962	Inside tube production hall	1	40 to 43	Brace	Circ.	168	Welded sealed tube	Seamless, Aulnoye	Horizontal	Green paint
Hall V	Lifting beam	1965	Stored inside for 5 years	2	44 to 46	Lifting beam	Circ.	500	Ends welded to end plate	Welded, Dunkirk	Horizontal	Not painted
External	Wind girder from Halls I, II or III from 1st phase	1961/2	Dismantled and stored outside for 5 years in industrial atmosphere near sea	3	47 and 48	Chord Brace Brace	Circ. Circ. Circ.	168 76 70	Welded sealed tube Braces welded to chord	Seamless, Aulnoye Welded, Valenciennes	Horizontal Horizontal for 5 years	Green paint Green paint
External	Access catwalk between Halls I & II row B	1961/2		4	49 and 50	Top rail Bot. rail Brace Brace	Circ. Circ. Square Square	70 26 50 50	Open at ends Sealed, welded to rails	Seamless, Aulnoye Seamless, Aulnoye	Horizontal Inclined brace	Anti-rust paint Green paint
External	Single tube, half portal in Hall I	1962	Dismantled and stored outside for 3 years in industrial atmosphere near sea	5	51 and 52	Half portal	Circ.	460	Ends welded to end plate	Welded, Dunkirk	Horizontal	Yellow paint

vertical chords, also of circular sections, taken from stanchion D-18. The external surface, painted green over an anti-rust primer of a red colour, is in good condition.

The internal surface is covered, as is normal, with a thin film of rust which does not affect the integrity of the structure of which the member is a part (Fig .59)

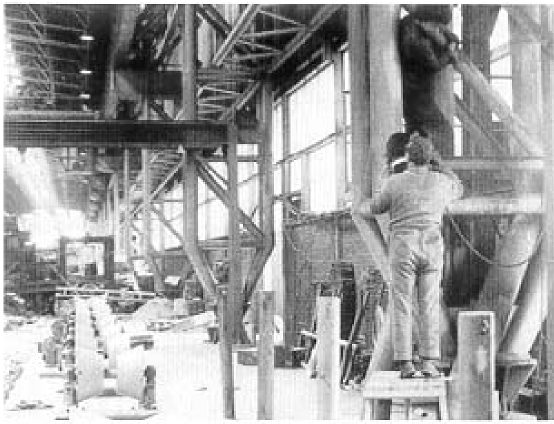


Figure 40: Hall III, Row B. Column D-18 and general view of hall.

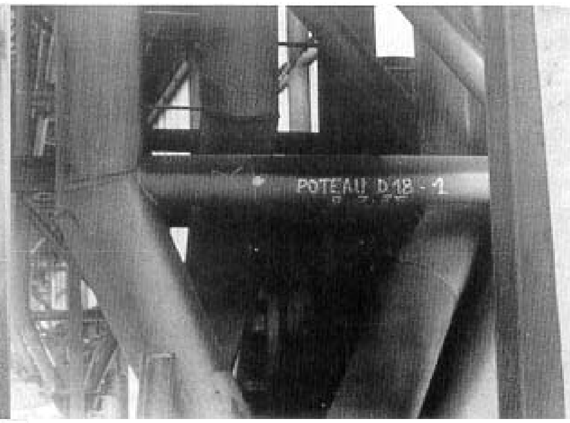


Figure 41: Distance piece 1 in column D-18

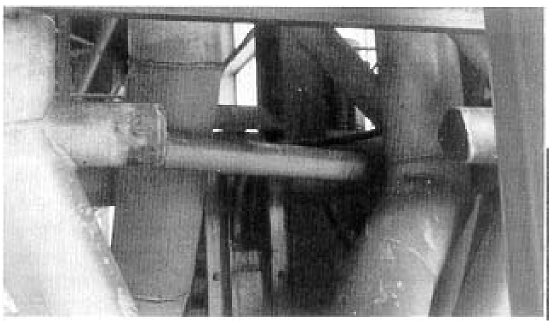


Figure 42: Column D-18 after part of the distance piece has been removed.

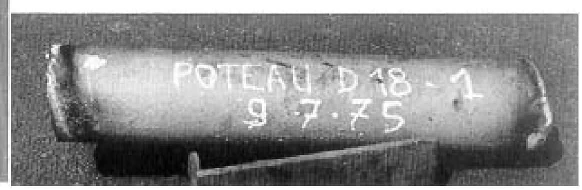


Figure 43: Sample cut from distance piece 1.

Lifting beam of Hall V: Lifting beam 2, which went into service some 10 years ago, has been stored in No. 5 tube fabrication shop for five years, (Fig. 44)

It consists mainly of a circular hollow section welded longitudinally, external diameter about 500 mm by some 6 m long, in a horizontal position with sealing plates at both ends. A sample was cut from one end, approximately 200 mm long (Figs. 45 and 46). The unpainted external surface is uniformly pitted by corrosion. The internal surface, which as is normal, is covered with a superficial film of rust and looks satisfactory (Fig. 60): the marking off lines are still visible on the end plate which still retains the original mill-scale in certain areas *(1)*.

Wind girder 3: This was erected some thirteen years ago in the tube mill, was removed from its initial position five years ago, and has since been stored outside in the open air (Fig. 47) in an atmosphere both industrial and maritime (about 1 km from the North Sea). This girder consists of two tubular chords connected by diagonal bracings in hollow sections. The sample delivered to the Laboratory (Fig. 48) is a 600 mm length cut from the end of one of the chords.

This chord consists of a seamless CHS with an external diameter of 168 mm, positioned horizontally and sealed at both ends by end plates. The sample includes a node point where two diagonal bracings meet the chord. These are continuously welded tubes, measuring about 76 mm and 70 mm in diameter, and have also lain horizontal for at least five years. The latter were sealed at their ends by the chord member to which they were welded.

Figure 44: Hall no. 5, lifting beam 2
- General view.

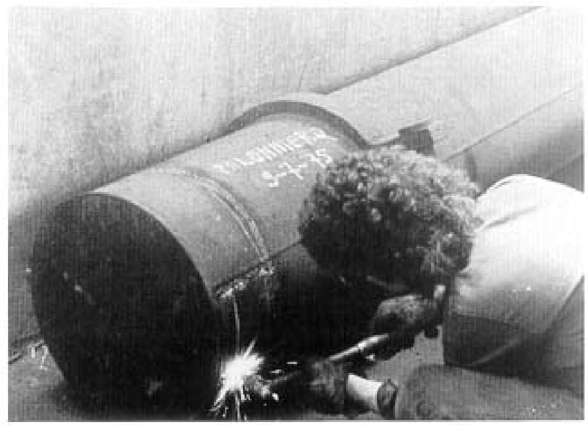


Figure 45: Lifting beam 2 – cutting out of sample

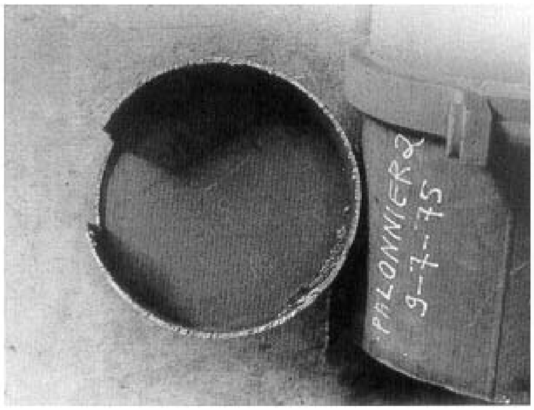
The external surface of the whole structure has been covered with green paint applied over an undercoat of red coloured anti-rust paint, which has flaked, apparently allowing some corrosion to take place.

The internal surface of the chord is covered, as is normal, by a uniform superficial film of rust, which cannot affect the integrity of the structure. The internal surface of both diagonal members remained in a satisfactory condition (original mill-scale and superficial rust) *(1)*.

<u>Gangway No. 4</u>: This was installed thirteen years ago on line B between halls I and II and ran inside these halls. It was dismantled five years ago and has since been stored outside the building (Fig. 49) in an industrial atmosphere and close to the sea.

The sample delivered to the laboratory (Fig. 50) was about 850 mm long, cut from one end of one of the two gangway guardrails. It consisted of a longitudinal rail and secondary rail connected by two diagonal members in hollow section. The rail and secondary rail consisted of two seamless circular hollow sections of 70 mm and 76 mm approximate external diameter respectively, horizontal and open at the ends. The sample includes the node point of the two seamless 50 mm RHS diagonal members, which were sealed at their ends by being welded to the external face either of the rail or of another hollow section; one is laid in a vertical position and its external wall is welded to the external wall of the secondary rail, the other is in a sloping position.

The external face of the two circular hollow sections is covered by an anti-rust paint of a red colour, which has suffered considerably. This surface has been pitted by corrosion. The internal walls of these hollow sections, which were open at the ends, are relatively uniformly affected by corrosion *(1)*.



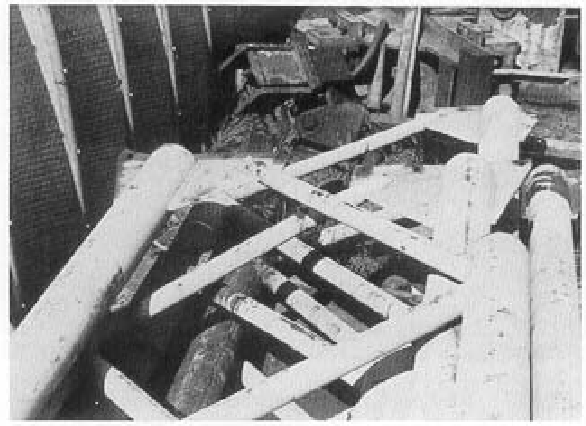


Figure 46: Lifting beam 2. View of the bottom plate at one of the ends.

Figure 47: Wind girder 3 in the store.

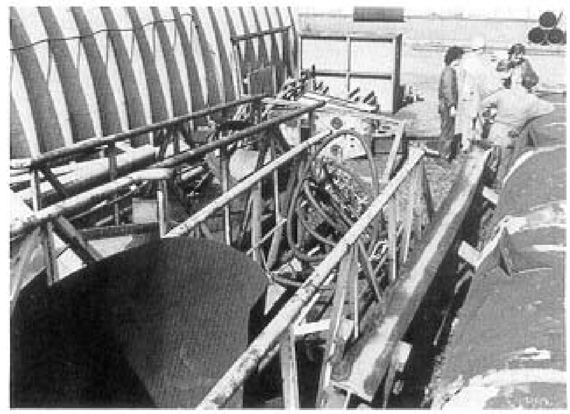


Figure 48: Wind girder 3. Sample removed.

Figure 49: Gangway No. 4. as stored.

The external surfaces of both RHS are painted green over an undercoat of red-coloured anti-rust paint. The surface is corroded where the paint has flaked. On the other hand, the internal surfaces of these sealed hollow sections are in a satisfactory state, i.e. the surface still shows the mill-scale, though there are some traces of corrosion in places *(1)*.

Single tube semi-portal of hall I: The single tube semi-portal No. 5, which was installed in 1962 in hall I, has been stored for three years in the open air, in an industrial atmosphere not far from the sea (Fig. 51) We are dealing here with a longitudinally welded circular hollow section 460 mm in diameter, and some 6 m long, bent in the middle. It was originally in a vertical position but has been lying in a horizontal position for three years. Both ends are sealed, welded to a plate. The laboratory sample (Fig. 52) about 100 mm long, had been cut from one end. The external surface is painted yellow over an undercoat of red anti-rust paint, and has a satisfactory appearance. The internal surface is covered, as normal, with a thin film of rust which cannot affect the quality of the hollow section, or indeed that of the structure *(1)*.

5.2.4 Conclusions

Ten hollow sections have been cut and examined at the Laboratoire National d'Essais including four with an external diameter greater than 90 mm. Of these, eight with sealed ends have remained in a satisfactory condition internally, and unaffected from a structural point of view. The two with open ends show a deterioration of the internal surfaces due to corrosion, which, in their present state, does not appear to endanger the structure.

These hollow sections, some of which have been in service for more than thirteen years, under cover or outside, in industrial or marine atmospheres, show no deterioration to their internal surfaces when their ends have been sealed. This applies to all the sealed samples regardless of structural location and atmospheric environment.

The only hollow sections in which corrosion was observed were the two which had open ends, thus permitted the ingress of moisture.

(Signed) M. Veaux Head of Material & Structure Dept.	(signed) P. Guillaume Director of the Laboratoire National d'Essais.

(1) Editor's note. The corresponding illustration of LNE Report is not reproduced in this document.

Figure 50: Gangway 4 - Cut sample

Figure 51: Hall I: single tube semi-portal. Cutting out of the sample

Figure 52: Single tube semi-portal. Cut sample

5.2.5 Lesson to be learned from the results of this enquiry: The results observed were the same for the first series of samples cut out at Valenciennes for small size components (maximum diameter 90 mm) as for the second series carried out at Dunkirk on components of larger sizes (diameter up to 500mm) There is no possibility of corrosion inside hollow sections when these are sealed at both ends, whatever their size and length of service.

However, we noticed a slight difference in the surface condition of the components between the 1st and 2nd series. In the 1st series (maximum diameter 90 mm), we were always dealing with welded or seamless hollow sections which were hot finished and were therefore covered initially with a coating of mill-scale, which was frequently found when cutting out the samples.

In the 2nd series (maximum diameter 500 mm) we were dealing mostly with cold formed welded hollow sections, i.e. products which left the production line without a coating of mill-scale. This difference in the manufacturing process is the reason for the superficial film of rust found on the Dunkirk samples. This slight rusting occurred during the period between the manufacture of the sections and their incorporation into the fabricated structure.

The presence of uniform superficial coatings of rust as described in the report of the LNE does not affect in any way the conclusions reached as regards the protection afforded the interior of hollow sections. The differences in methods of production affect only the appearance of the interior; i.e. mill-scale or superficial rust.

5.3 General Report Of The Laboratoire National D'Essais, Paris

Following these two investigations carried out in 1974 and 1975, the LNE was asked to write a general report which was handed to CIDECT members as well as the Chambre Syndicale des Fabricants de Tubes d'Acier. Figure 53 reproduces in facsimile the first page of this report No. 601.084-DMS/3-302 dated 19th March 1976 [13], which we reproduce hereunder in full.

We have merely renumbered the photographs (which have been reduced in size) as well as the tables and paragraphs to ensure the continuity within the present work.

LABORATOIRE NATIONAL D'ESSAIS, PARIS:
TEST REPORT No. 601.084 - DMS/3-302.

5.3.1 Aim of the investigation

The "Groupement d'Interet Economique, COMETUBE" acting respectively, as has been stated, for the Chambre Syndicale des Fabricants de Tube d'Acier and the Comite International pour le Developpement et l'Etude de la Construction Tubulaire, has sent to the Laboratoire National d'Essais some samples which were cut out in the presence of the latter from old tubular structures.

The Laboratoire National d'Essais was asked to observe the state of the internal surfaces in steel hollow sections used as components in these structures. The investigation included cutting two series of samples.

The first dealt with hollow sections of less than 90 mm diameter (Report no. 403 136 dated 22 October 1974). The second dealt with hollow sections some of which were larger than 90 mm in diameter (Report no. 507 055 dated 7 October 1975)

5.3.2 Observation method

The cutting out of the tubes was always undertaken in the presence of the client, an engineer of the Laboratoire National d'Essais and a bailiff. The tubes were numbered, then photographed on the site before, during and after the cutting operation. After their arrival at the Laboratoire National d'Essais, some were sawn open longitudinally.

For each sample the following was noted: the location, the type of structure in which it was located, its

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C. N. A. M. - **LABORATOIRE NATIONAL D'ESSAIS**

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PARIS, LE 19 MAR 1976

-o- MC -o-

DUPLICATA

Société C O M E T U B E -
Construction Métallique et Tube d'acier
156, Avenue Parmentier
75010 - P A R I S -

ESSAI N° 601 084
DMS/3-302.

PROCÈS-VERBAL

OBSERVATION DE LA CORROSION INTERNE DE PROFILS CREUX UTILISES
COMME ELEMENTS DE CHARPENTE METALLIQUE

I - But de la demande -

Le Groupement d'Intérêt Economique COMETUBE, agissant respectivement comme il nous l'a précisé pour le compte de la Chambre Syndicale des Fabricants de Tube d'acier et du Comité International pour le Développement et l'Etude de la Construction Tubulaire, a fait parvenir au Laboratoire National d'Essais des échantillons prélevés en présence de ce dernier sur des constructions tubulaires ançiennes.

Il s'agissait pour le Laboratoire National d'Essais de constater l'état des parois internes des profils creux en acier utilisés comme éléments de charpente métallique. Cette enquête a comporté deux campagnes de prélèvements :

. La première concernait des profils creux de dimensions inférieures au rond de 90 mm (Procès-Verbal N° 403 136 en date du 22 Octobre 1974).

. La seconde était relative à des profils creux dont certains étaient de dimensions supérieures au rond de 90 mm (Procès-Verbal N° 507 055 en date du 7 Octobre 1975).

2 - Méthodologie des observations -

Les prélèvements de tubes ont toujours été effectués en présence du demandeur, d'un Ingénieur du Laboratoire National d'Essais et d'un Huissier de Justice. Ces tubes ont été répertoriés, puis photographiés sur chantier avant, pendant et après leur découpage. Après leur réception au Laboratoire National d'Essais, certains d'entre eux ont été ouverts longitudinalement par sciage.

Pour chaque échantillon, on a précisé son lieu de prélèvement et le type de structure dans laquelle il se situait, sa date de mise en service, l'environnement dans lequel il était placé et sa provenance de fabrication.

Le Laboratoire s'interdit de communiquer à des tiers les résultats des essais. Si le demandeur désire les publier avec référence du Laboratoire, il ne peut le faire que par reproduction intégrale du procès-verbal. Toute infraction à cette règle autorise le Laboratoire à publier les résultats complets des essais.

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Figure 53: Facsimile of first page of Laboratoire National d'Essais report no. 601.084 – DMS/3-302

date of installation, the environment in which it was situated and its origin.

For each of the samples, which had been cut longitudinally, a note was made of its geometrical properties, the type of assembly and the position in the structure.

The main comparison between the hollow sections concentrated on the appearance of the internal surface in relation to that of the external surface, depending on whether the tube had or had not been sealed at the ends (assembly by welding or flattening at the ends).

5.33 General conclusions of the enquiry

Of the 110 tubular samples, 58 were examined at the Laboratoire National d'Essais (see table 3)

It was observed, as could be expected, that the 45 hollow sections which showed no alteration inside were those whose ends had been suitably sealed when installed. Some of them had been in place for more than thirteen years in a particularly hostile industrial or marine atmosphere, being:

on the outside of the buildings (Figs 54 and 55),

along side the sea (Fig. 56),

on the inside of the buildings (Fig. 40)*

**Editor's Note: This figure has been taken from Report No. 507.055 (enquiry carried out in Dunkirk in July 1975) [12]*

Table 3: Distribution of the tubes examined according to the state of their internal surface

Type of tube	Series no.	Number of tubes in good condition	Number of tubes in altered state
Column	1	25	11
Tubes larger than 90 mm diameter	2	4	0
Other tubes	1 & 2	16	2
Total	1 & 2	45	13

Among the 13 tubes whose internal surface had been altered by corrosion, 6 were tubes which were open at their extremities. As regards the other 7, on the other hand, the quality of the seal had deteriorated during service.

Figures 57 to 63 represent characteristic examples of the two phases of the enquiry.

Figure 57 shows a circular tube sealed by flattening at the ends; its internal surface has remained in a satisfactory state in spite of the corrosion on the external surface.

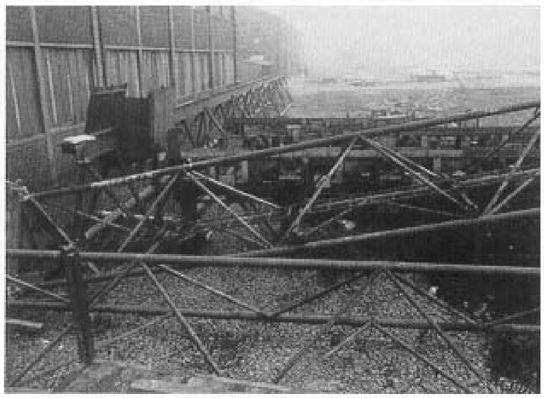


Figure 54: View of lattice column in storing area (first programme)

Figure 55: View of lattice column in storing area(first programme)

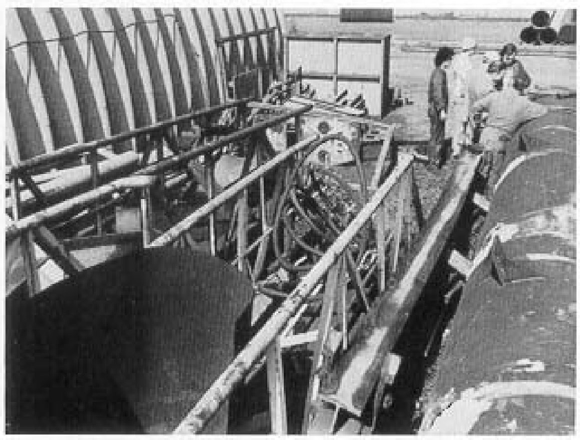


Figure 56: View of the samples in storing area (second programme)

The original mill-scale was found to be virtually intact in the case of a hot-finished RHS whose ends had been sealed (Fig. 58) by being welded at one end and bolted at the other.

Figures 59 and 60 represent two tubes of more than 90 mm diameter; one is a circular seamless tube with its ends welded to the external face of another tube, the other is a circular welded tube whose ends were welded to end plates. In each case, the internal surfaces are covered, as normal, with a thin coating of rust which could not affect the performance of the structure.

The substantial internal deterioration in one of the tubes in Figure 61 is due to the open weld over this part of the section which exposed the interior to the hostile external environment. On the other hand, the other tube in Figure 61, which was properly sealed in the same environment (column of Figs .54 and 55), has a satisfactory inside appearance.

Figures 62 and 63 show the welded junction of open ended tubes (RHS in one case and CHS in the other) and one or two tubes sealed at the ends. The deterioration of the internal surface of the open ended tubes only is due to the ingress of aggressive agents (or simply moisture), which lead to corrosion. This is only possible in the case of tubes which have not been sealed, or where openings have occurred, such as cracks or holes. These conclusions remain valid whatever the location and type of assembly of the hollow sections within the structure, whatever the geometrical properties or the method of manufacture.

Figure 57: Flattened end tube (First inspection programme)

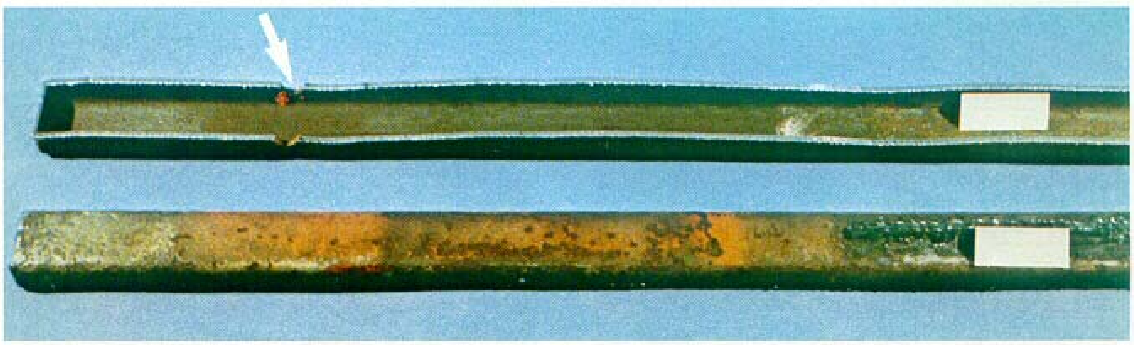


Figure 58: Tube with closed ends, one of which is bolted (First inspection programme)

Figure 59: Tube with ends welded to the wall of another tube(Second inspection programme)

Figure 60: Tube with ends welded to a bottom plate (First inspection programme)

Figure 61: Tube(A) sealed and Tube(B) showing damage going back to original fabrication (First inspection programme)

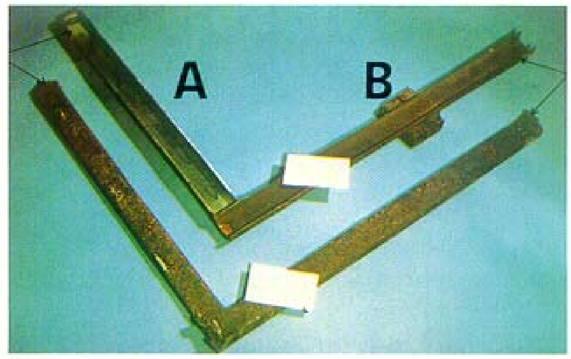


Figure 62: Joint between open Tube (A) and closed Tube(B)

Head of Material
and Structures Dept.
M. Veaux.

Director of the Laboratoire
National d'Essais
J. Clavier.

6 SOME SPECIAL CASES

All the investigations mentioned above are concerned with external structures exposed to the elements, or industrial buildings situated in a particularly corrosive atmosphere. Wherever the investigation has been carried out, the conclusion drawn from it is always the same:

'It is sufficient to seal the ends of hollow sections to avoid internal corrosion'

However, there are other ways of using hollow sections, where the sealing of the ends is not necessary and even, in some cases, strongly inadvisable.

It is impossible to examine, or even merely to mention, every type of structure that can be encountered, and we shall limit ourselves to studying a few of the particular cases which appear to be especially significant,

- steel structures inside heated spaces (normally referred to as "warm structures")
- galvanised structures,
- concrete filled columns.

6.1 **Steel structures in heated interior locations (controlled environment)**:

Examples of steel structures situated in a non-corrosive atmosphere are often encountered, and for these the precautions taken for industrial buildings or exposed frameworks are not applicable. Typical examples are housing blocks, office blocks or commercial premises, hospitals, some schools. To simplify the picture, a distinction can be made between concealed and visible frameworks.

6.1.1 Concealed frameworks: Let us examine the case of the framework of a steel girder placed between the ceiling and the slab in a dwelling block, which is constantly heated (Fig. 64)

As indicated in the figure, the lower chord, which does not extend to the column, is not sealed as part of the structure. With this type of construction, there is generally only a slight possibility of air renewal.

In order to be able to dispense with the usual precautions with regard to the sealing of the ends, it is sufficient to assure oneself that, in normal use, this closed space, which is not ventilated, will meet the following conditions: a relative humidity rate lower than 30% and a temperature equal to or higher than 18^{o}C.

Though these conditions are usually met in dwelling blocks or offices, it is of course the relative humidity rate which is the significant criterion.

In the case of a hidden structure it is also necessary to check that no condensation can occur in the steel structure. Such condensation could for example be due to: a thermal bridge or the running of cold water piping in the enclosed space or even within the lower chord itself.

If these 3 conditions (humidity rate, temperature, lack of condensation) are fulfilled, it is not necessary to hermetically seal the ends of the lower chord. One can then either provide simple stoppers in plastic material, or even leave the ends open, if for example one wishes to run electric or telephone cables through the chord.

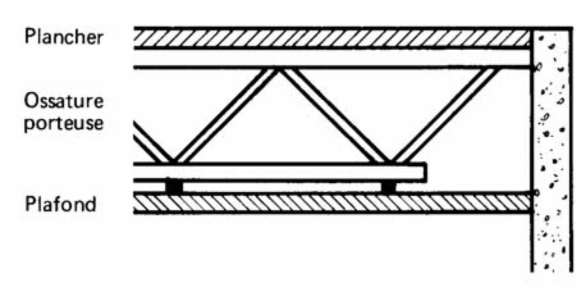
6.1.2 Visible structures: This type of structure can assume a load carrying function, a decorative function or a combination of the two.

We are dealing here, in most cases, with ceiling structures (see Fig. 65) but it is also possible to imagine a facade structure or even an internal staircase.

In contrast to the previous case, there is here a possibility of air renewal, but there is much less fear of condensation, since the whole of the steel structure is situated in the atmosphere of the dwelling or office area.

It is therefore necessary to check that the two above-mentioned conditions are met, namely that the relative humidity rate is less than 30% and the temperature is equal to or higher than 18° C.

If these conditions are satisfied, as in the previous case, it would be possible either to close the ends with simple stoppers of plastic material, or to leave the ends open, with the possibility of using the lower chord as a duct.



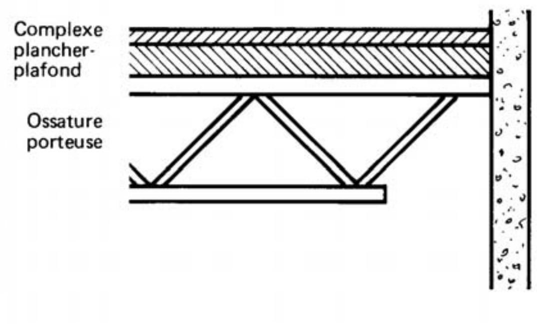


Figure 64: Concealed steel framework situated in a heated space. Framework floor supporting deck and ceiling

Figure 65: Visible steel framework situated in a heated space, framework supporting deck

6.2 **Galvanised structures**

There are two very different ways of using galvanising in steel structures:

1 – galvanising the individual components and then fabricating the units or assemblies

2 – fabricating the units/assemblies and then galvanizing the complete assembly

In the first case, the problems of internal protection are solved since firstly, the internal surfaces are galvanized and secondly, the ends of the members are sealed so no subsequent attack is to be feared.

On the other hand, in the second case, it is necessary to provide openings which make it possible to carry out both the pickling and the rinsing operations and the final galvanizing (see Figure 66)

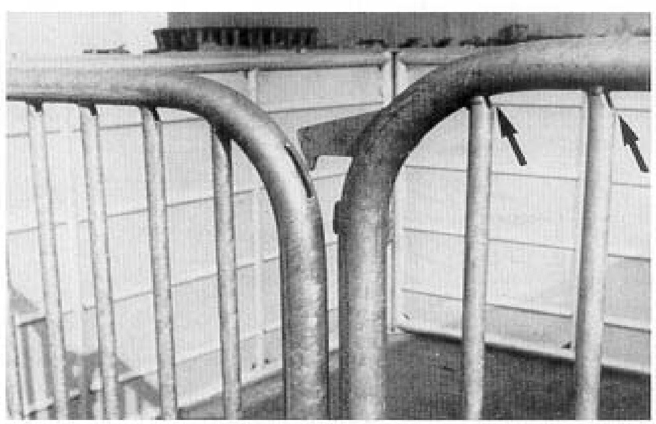


Figure 66: This partition fence in a cattle rearing installation has been galvanized after fabrication. Note the openings at the ends of the vertical infills (arrowed).

It should be remembered that galvanizing consists of dipping the object to be protected in a molten zinc bath at 460° C. This means first of all that the units fabricated in the workshop must be smaller in size than the galvanizing bath. The sizes of these baths vary a great deal and the first concern of the designer will be to make himself familiar with their limitations, so that the assembly can be suitably designed. The next thing to be considered is the other aspect of the operation, dipping.

As we are dealing here with hollow sections, (whether or not they are associated with open sections), we must remember that a member hermetically sealed at both ends would constitute a 'float" which would be quite difficult to immerse. On the other band, and this is the important point, this member could contain (as a result, say of a weld seam that was not completely tight) a certain quantity of pickling acid which could lead to instantaneous vaporisation at the time of dipping in the 460° C zinc bath and the possible bursting of the assembly.

It is therefore essential, in the case of fully welded units, to provide holes at the ends of the members before pickling, rinsing and galvanizing.

Some structural arrangements have been investigated by the professional organisations concerned, and we give in Figures 67 to 70 some technical extracts from the paper "Hot dip galvanising" published by the Syndicat National du Revetement et du Traitement des Metaux (National Federation for Coating and Treatment of Metals) and the French Standard NF A 91-122.

Finally, it should be noted that the drainage and inter-communicating holes should have a cross sectional area not less than 1/5 of the internal cross section of the hollow section.

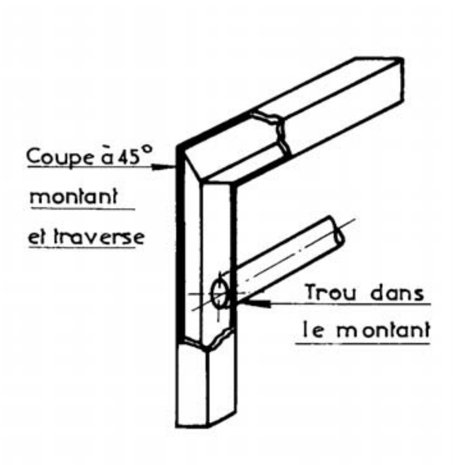


Figure 67: Cut view of a joint allowing the free circulation of zinc between the cross member and the upright. (Upright and cross member cut at 45°. Hole in the upright.)

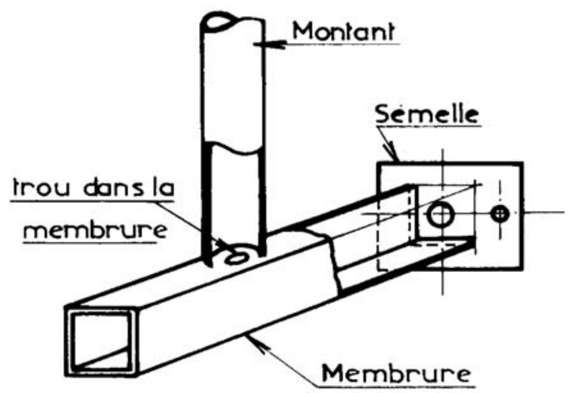
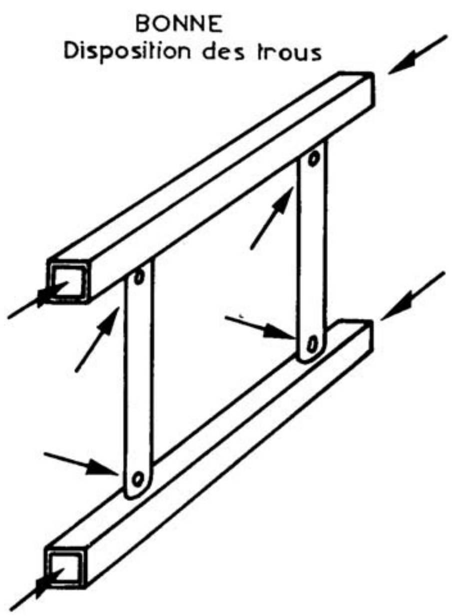


Figure 68: Cut view showing connection between upright and chord. The size of the opening must be at least 1/5 of the area of the member (upright, end plate, chord)



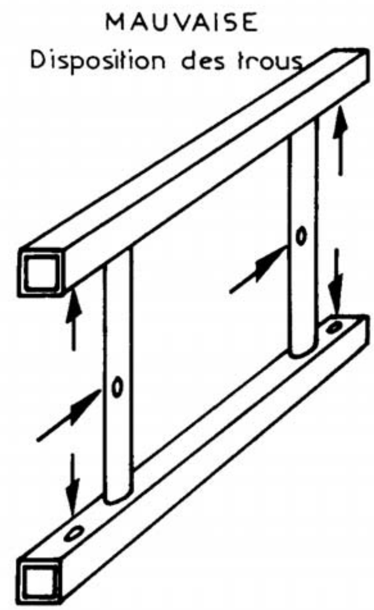


Figure 69: Diagram showing the position of recommended openings for a good circulation of pickling acid and molten zinc. (GOOD location of holes)

Figure 70: Diagram showing an un-recommended arrangement of holes for the circulation of the pickling acid and molten zinc (BAD location of the holes)

6.3 **Concrete filled columns**

In the case of concrete filled columns, some precautions must be taken. They are given in the recommendations to be found in CIDECT Monograph No. 5. (Part 1 of September 1977) [15]. Among these recommendations two concern the present investigation: the preparation of the hollow sections and the preparation of concrete used for filling

More recent information can be found in CIDECT Design Guide No. 5. 1995 [18]

6.3.1 Preparation of the hollow sections: As well as the considerations regarding the maximum allowable length of column (30 times diameter of the side - or 12 m), the recommendations give the following details concerning the holes to be made.

> "Small sized holes are made in the walls of the sections, generally in groups of two (see Fig. 71). These holes are to be provided on each single length, and on each floor in the case of columns for buildings.
>
> They are situated between 100 and 200 mm from the end of each length, but it is necessary to introduce two intermediary holes if the length exceeds 5 m.
>
> These holes are intended to prevent the bursting of the column as a result of the steam pressure generated due to the boiling of the water within the concrete in the case of fire. The diameter of these openings should be between 10 mm or 15 mm for hollow sections of usual construction sizes."

6.3.2 Preparation of concrete for filling: Monograph 5 recommends:

> "The concrete shall be prepared in such a manner as to be sufficiently plastic; the wall effect of small size hollow sections will have to be taken into account, which will mean increasing the proportion of sand and cement. The materials (sand and gravel) must be or good quality and properly washed. The maximum size of the gravel should not exceed one sixth (1/6) of the internal diameter or side of the section.

Any additives likely to cause corrosion of the steel are forbidden, in particular setting accelerators with a calcium chloride base (Cl_2Ca). The addition of plasticisers, which allows a reduction in the volume of the mixing water, is recommended".

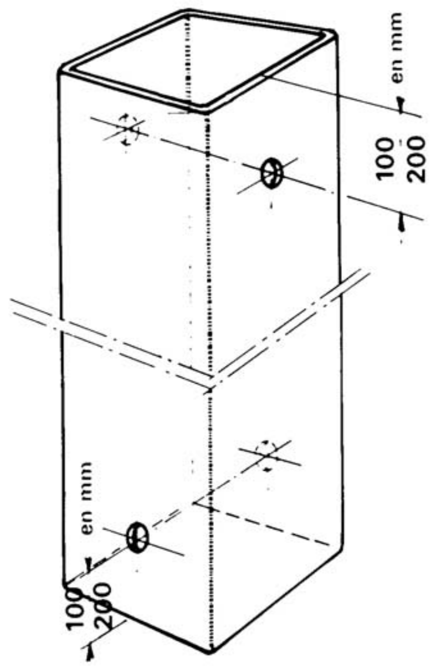


Figure 71: Hole positions in the walls of a concrete filled column.

It can thus be seen that, providing certain elementary precautions are taken with regard to the additives, there is no great fear of corrosion on the internal walls of concrete filled hollow sections.

7 CONCLUSIONS

On the basis of these investigations; originating from very different quarters, there can be no doubt with regard to the protection of the inside of hollow sections.

There is no possibility of internal corrosion in hollow sections, when these are sealed at both ends, whatever the environment in which they are found.

It has also been noticed that in certain structural cases the sealing of the ends of hollow sections could be superfluous (structures situated in heated premises), or even strictly inadvisable (structures galvanised after welding, and concrete filled columns).

Many more examples could have been mentioned; more cases could have been investigated, but we think that the examples chosen here are sufficiently convincing. We hope that this selection has contributed in some measure to a better understanding of the problems of protection of steel structures against corrosion. We are convinced that by keeping to simple rules, when fabricating hollow sections, it will be possible to obtain a protection against corrosion which is both efficient, permanent and nevertheless economical.

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