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MONITORING OF WEATHERING STEEL STRUCTURES – THE INDUCTION ULTRASONIC THICKNESS TESTER

by

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ABSTRACT

Long term corrosion tests carried out in the UK have shown that weathering steels continue to corrode at a finite rate. It is therefore necessary to use thicker steel and to monitor the corrosion. A novel ultrasonic instrument to measure residual steel thickness has been assessed. This measures steel thickness through a rust layer, requires no couplant to transmit the ultrasound into the steel and gives only the steel thickness not the thickness of the steel plus a layer of rust. This instrument provides a suitable method of measuring the residual steel thickness on weathering steel structures where corrosion has been generally uniform. However, the instrument can give no information on localised roughness or pitting of the underlying steel surface and it would seem worthwhile to include test specimens in any monitoring scheme so that the surface condition of the steel can be assessed.

1. INTRODUCTION

Long term corrosion tests carried out in the UK have shown that Cor-Ten B weathering steel continues to corrode at a finite rate[1]. Hence a structure in weathering steel should incorporate an additional steel thickness to allow for corrosion and some form of corrosion monitoring should be carried out to ensure that the corrosion rate is acceptable.

Corrosion rates for research purposes were determined from the weight loss of small test specimens after the removal of corrosion products in acid containing inhibitors and this method can be used as a monitoring technique. Specimens are exposed at various points on a structure where they then corrode in a similar fashion to the structure itself. Specimens are periodically removed, chemically derusted and loss in thickness due to corrosion calculated. There are, however, obvious limitations to this technique as a method of corrosion monitoring. A considerable number of specimens would be required to comprehensively cover the different degrees of sheltering and steel orientation possible on a particular structure, all to be monitored over a long time period. The method would also not be of use where localised areas of unexpected corrosion were encountered. Clearly a method enabling direct measurement of residual steel thickness to be made at any point on a structure is desirable.

Ultrasonic techniques seem to offer a direct method of measuring steel thickness but the adherent rust layer of varying thickness present on the steel surface leads to problems with standard ultrasonic thickness gauges. A couplant must be used to transmit the ultrasound from the probe through the rust and into the steel and, more important, the thickness measured includes some contribution from the rust layer. Estimates of steel thickness can be obtained by a process of scraping away the rust, measuring the apparent thickness and then subtracting an estimate of the remaining adherent rust thickness. Such procedures are tedious and the results of dubious value. However, the Unit Inspection Section of the British Steel Corporation (BSC) have now developed a novel ultrasonic gauge which measures residual steel thickness through the rust. It requires no couplant and gives only the steel thickness not the steel plus a layer of rust. This instrument is known as the EMA1 induction ultrasonic thickness tester and is manufactured under licence by Wells Krautkramer. BSC carried out some laboratory work and this showed that the instrument could accurately measure steel thickness but indicated that there was a limit to the thickness of rust that could be tolerated. As rust thickness increases, there should be no change in thickness readings but the signal strength will be reduced, eventually becoming too low to give any readings.

TRRL carried out a laboratory assessment of this instrument and this report gives an evaluation of operating difficulties and the accuracy of measurements carried out on rusted samples of Cor-Ten B weathering steel, the measurements being checked by destructive testing of the samples.

2. OPERATING PROCEDURE

The EMA1 consists of three parts – a control and power unit (EMAC1), a transducer, the probe itself (EMAT1), and an ultrasonic instrument type USM2. This combined equipment is quite heavy and bulky and two people are required to operate it. Thickness is measured by inducing high frequency eddy currents into the steel surface in the presence of a magnetic field. The eddy currents and magnetic field interact with the material to produce an ultrasonic shear wave normal to the surface of the material. Ultrasonic pulses reflected from the other surface are detected by the reverse process and displayed on the oscilloscope screen of the USM2. From the time interval between echoes, the material thickness may be obtained after suitable calibration of the instrument. As this method does not necessitate contact between the probe and test material, it is suitable for measuring the residual steel thickness of structures covered by a layer of rust. The instrument is calibrated to give a direct reading of thickness by adjusting the timebase of the echo pattern from a sample of standard thickness. The thickness scale goes from zero to 10 mm where the zero can be adjusted to a value appropriate to the thickness of the material to be measured, eg with the zero set at 20 mm, thicknesses between 20 mm and 30 mm can be measured. The instrument is first calibrated on a standard 10 mm thick sample to which an ultrasonic probe is permanently attached. This is used to give an echo pattern at 5 mm intervals on the oscilloscope screen of the USM2. The USM2 is then connected to the EMAC1 control unit and the EMAT1 transducer. The probe (the EMAT1 transducer) is then placed on the 10 mm standard and the operator pulses the probe. This should give an echo corresponding to a thickness of 10 mm if the setting up procedure has been carried out correctly. The display only persists for two seconds so two or three pulses are usually necessary for an accurate reading to be taken. The transducer incorporates powerful magnets and these can affect the display on the oscilloscope screen. It is important not to use the probe within about one metre of the oscilloscope screen as inaccurate readings could result. In practice, a range of standard thickness samples is used. The probe is placed on a suitable standard and the oscilloscope trace offset so that the echo from the standard appears at the midpoint on the scale. This allows measurements within ± 5 mm of the chosen standard to be made. The effective measurement area of the probe is a circle of 20 mm diameter.

The initial calibration of the instrument is critical and it is important that an operator be very familiar with the instrument for reliable results to be obtained. This is not an instrument that can be used after a few minutes instruction!

3. LABORATORY EVALUATION

3.1 *Measurements on rusted samples of Cor-Ten B*

The accuracy of the instrument was assessed by using it to measure the residual steel thickness of I beam samples of weathering steel which had been exposed under simulated bridge decks for five years at the following test sites:–

Tinsley (Yorks) – an industrial area of Sheffield adjacent to Tinsley viaduct (M1).

Crowthorne (Berks) – a rural area.

Thorney Island (Sussex) – a marine area in Chichester harbour.

Two samples were available from each test site, one of which had been exposed in a position corresponding to a fascia girder, the other in a position corresponding to a sheltered girder. Measurements were taken on the bottom flange of each specimen.

A grid was marked out on each flange (Figure 1) and measurements of total thickness including rust were taken along levels A and D using a micrometer (the diameter of the micrometer jaw was 6 mm). Measurements were then taken using the EMA probe at all levels. To assess variations introduced by the setting up and measurement procedures, three independent sets of measurements were taken with a gap of at least two days between each set. The instrument was recalibrated on each occasion. After the ultrasonic measurements, the flange sections were cut from the I beams then split into two sections between levels B and C. Each piece was then chemically derusted using Clarke's solution and the thickness measured at each position using a micrometer. Again three independent sets of readings were taken. There was no difficulty experienced in the EMA ultrasonic measurements on the Tinsley and Crowthorne specimens, but the specimens from Thorney Island, the marine site, were covered in quite brittle adherent outer layers of rust. These had to be chipped off using a palette knife before any readings could be obtained.

3.2 *Effect of pitting*

This was investigated by taking measurements on an artificially pitted surface. Pitting was simulated by drilling groups of holes of a given diameter to a depth of 2 mm in a grit blasted steel surface of previously measured thickness. The pit diameters were 1 mm, 2 mm, 3 mm and 6 mm. The area of each group of pits was sufficient to cover the effective measurement area of the EMA probe (a circle of 20 mm diameter).

4. RESULTS

4.1 *Measurements on the samples of Cor-Ten B*

The thickness measurements obtained with the micrometer and EMA probe on each specimen are shown in Tables 1 to 6. The average differences between the micrometer and EMA probe for each specimen are summarised in Table 7. There was generally good agreement amongst the three sets of readings taken with the EMA probe at a particular specimen position showing that consistent results can be obtained.

With the Tinsley and Crowthorne specimens, there was good agreement between the results obtained with the EMA probe on the rusted samples and with the micrometer on the samples after derusting. The average difference (see Table 7) was never more than 0.1 mm and the maximum difference at any one point was 0.21 mm (Crowthorne fascia, position C1 – Table 3). The agreement with the specimens from Thorney Island, the marine site, was less good. Results from the fascia specimen (Table 5) showed reasonable agreement except for one position, C6. Here the difference was 0.47 mm. However, on examination of the specimen, it was found that this position corresponded to an area of localised corrosion, a valley in the general surface plane. This was wide enough to allow the 6 mm diameter jaw of the micrometer to enter but was obviously not detected in the larger measurement area of the EMA probe.

The results on the Thorney Island sheltered specimens (Table 6) showed much worse agreement. On average the micrometer gave readings higher by 0.24 mm (Table 7). The surface of this sheltered specimen was, however, very rough and pitted and this could obviously affect the results obtained. On a rough surface, the size of the jaws of a micrometer becomes an important factor as has already been demonstrated.

4.2 *Effect of simulated pitting*

When the EMA probe was used over the areas of simulated pitting, there was no change in the thickness reading, the only effect being some reduction in signal strength. Clearly, the instrument does not detect pitting of the type simulated.

5. DISCUSSION

The EMA induction ultrasonic thickness tester adequately measured the residual steel thickness on the industrial and rural specimens. However, at the marine site where corrosion led to a rough and pitted surface it was not clear just what the EMA probe was measuring. From the simulated pitting experiments, the instrument does not detect minimum thickness but from the Thorney Island sheltered specimen results neither does it measure maximum thickness. It would seem that the particular state of roughness and pitting present in the surface could influence the reading given. However, this should not be a major drawback as, on the basis of exposure tests carried out so far, pitting occurs under sheltered conditions subject to high chloride levels and weathering steels would not be recommended for use in such environments.

There are various ways in which this instrument could be made easier to operate. At present, the connection from the probe to the control unit is heavy, shielded cable as the instrument was developed for high temperature use. This is unnecessary for its present application and much lighter cable could be employed. The USM2 is a general purpose ultrasonic instrument and if it were adapted specifically for use in the EMA instrument much of the critical initial calibration could be eliminated. It should also be possible to produce a longer duration screen display than the present two seconds thereby making readings easier to take. It might also be possible to develop a digital display.

The induction ultrasonic probe has now been used in measurements on some Cor-Ten B bridges and problems only occurred when thick, tenacious rust layers were present. These rust layers reduced the signal strength and no reading could be taken until some of the rust had been removed by scraping. As these were the first measurements taken, nothing could be said about corrosion rates. In fact, because of the measurement limits of the instrument and the relatively slow corrosion of weathering steels, this instrument could only be used to measure rates of corrosion over very long periods. However, the immediate concern at a particular time is the thickness of steel remaining at any point on a structure. The induction ultrasonic probe provides a suitable means of measuring this thickness provided that the corrosion has been generally uniform. As the instrument itself can provide no information on the state of the underlying steel surface it would seem worthwhile that some test specimens be included in monitoring schemes so that localised roughness or pitting can be assessed.

6. CONCLUSIONS

1. The EMA1 ultrasonic probe provides a suitable method of monitoring weathering steel structures where corrosion has been generally uniform.

2. Corrosion monitoring schemes should incorporate test specimens so that localised roughness or pitting can be assessed.

7. ACKNOWLEDGEMENTS

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Dr M B Kilcullen, British Steel Corporation, made available the EMA1 probe for the TRRL assessment.

8. REFERENCE

1. McKENZIE, M. The corrosion performance of weathering steel in highway bridges. *Department of the Environment Department of Transport, TRRL Report* LR 857. Crowthorne, 1978 (Transport and Road Research Laboratory).

TABLE 1

Thickness measurements: Tinsley fascia

Position		Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
			(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A	1	9.84	9.4	9.4	9.4	9.4	9.48	9.50	9.51	9.50	+0.10	0.34
	2	10.00	9.4	9.5	9.5	9.5	9.49	9.50	9.51	9.50	+0.00	0.50
	3	9.85	9.4	9.5	9.4	9.4	9.50	9.51	9.53	9.51	+0.11	0.34
	4	9.82	9.4	9.4	9.5	9.5	9.48	9.49	9.51	9.49	–0.01	0.33
	5	9.81	9.4	9.4	9.5	9.4	9.47	9.47	9.48	9.47	+0.07	0.34
	6	9.85	9.4	9.5	9.5	9.5	9.50	9.50	9.51	9.50	+0.00	0.35
B	1		9.3	9.3	9.3	9.3	9.37	9.36	9.37	9.37	+0.07	
	2		9.3	9.3	9.4	9.3	9.39	9.39	9.41	9.40	+0.10	
	3		9.4	9.4	9.4	9.4	9.38	9.39	9.40	9.39	–0.01	
	4		9.4	9.5	9.5	9.5	9.44	9.44	9.45	9.44	–0.06	
	5		9.4	9.5	9.5	9.5	9.40	9.40	9.43	9.41	–0.09	
	6		9.4	9.4	9.4	9.4	9.41	9.37	9.40	9.39	–0.01	
C	1		9.3	9.3	9.4	9.3	9.42	9.41	9.43	9.42	+0.12	
	2		9.2	9.3	9.3	9.3	9.35	9.32	9.36	9.34	+0.04	
	3		9.3	9.3	9.4	9.3	9.38	9.36	9.36	9.37	+0.07	
	4		9.3	9.3	9.4	9.3	9.40	9.38	9.39	9.39	+0.09	
	5		9.3	9.3	9.4	9.3	9.37	9.35	9.37	9.36	+0.06	
	6		9.3	9.3	9.4	9.3	9.36	9.36	9.38	9.37	+0.07	
D	1	9.57	9.1	9.1	9.2	9.1	9.29	9.20	9.21	9.23	+0.13	0.34
	2	9.61	9.1	9.1	9.2	9.1	9.28	9.20	9.24	9.24	+0.14	0.37
	3	9.58	9.1	9.1	9.2	9.1	9.22	9.21	9.25	9.23	+0.13	0.35
	4	9.55	9.1	9.1	9.2	9.1	9.17	9.17	9.19	9.18	+0.08	0.37
	5	9.61	9.1	9.1	9.2	9.1	9.15	9.23	9.23	9.20	+0.10	0.41
	6	9.50	9.1	9.1	9.2	9.1	9.18	9.17	9.19	9.18	+0.08	0.32
									MEAN		0.06	0.36

TABLE 2

Thickness measurements: Tinsley sheltered

Position		Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
			(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A	1	9.56	9.3	9.2	9.3	9.3	9.36	9.30	9.35	9.34	+0.04	0.22
	2	9.55	9.3	9.3	9.3	9.3	9.36	9.34	9.37	9.36	+0.06	0.19
	3	9.51	9.3	9.3	9.3	9.3	9.34	9.30	9.36	9.33	+0.03	0.18
	4	9.50	9.3	9.2	9.3	9.3	9.31	9.30	9.32	9.31	+0.01	0.19
	5	9.54	9.3	9.3	9.3	9.3	9.37	9.32	9.37	9.35	+0.05	0.19
	6	9.54	9.3	9.3	9.3	9.3	9.35	9.33	9.35	9.34	+0.04	0.20
	7	9.59	9.3	9.3	9.3	9.3	9.37	9.35	9.38	9.37	+0.07	0.22
	8	9.52	9.2	9.3	9.3	9.3	9.36	9.31	9.34	9.34	+0.04	0.18
B	1		9.3	9.2	9.3	9.3	9.31	9.32	9.32	9.32	+0.02	
	2		9.3	9.3	9.3	9.3	9.35	9.36	9.36	9.36	+0.06	
	3		9.3	9.2	9.3	9.3	9.31	9.32	9.33	9.32	+0.02	
	4		9.3	9.3	9.3	9.3	9.39	9.33	9.33	9.33	+0.03	
	5		9.3	9.2	9.3	9.3	9.31	9.32	9.33	9.32	+0.02	
	6		9.3	9.3	9.3	9.3	9.39	9.35	9.40	9.38	+0.08	
	7		9.3	9.2	9.3	9.3	9.34	9.30	9.35	9.33	+0.03	
	8		9.2	9.2	9.2	9.2	9.28	9.27	9.29	9.28	+0.08	
C	1		9.2	9.3	9.3	9.3	9.37	9.38	9.39	9.38	+0.08	
	2		9.2	9.3	9.3	9.3	9.39	9.36	9.38	9.38	+0.08	
	3		9.3	9.3	9.3	9.3	9.36	9.35	9.38	9.36	+0.06	
	4		9.3	9.3	9.3	9.3	9.38	9.37	9.38	9.38	+0.08	
	5		9.2	9.3	9.3	9.3	9.35	9.36	9.36	9.36	+0.06	
	6		9.2	9.3	9.3	9.3	9.35	9.31	9.35	9.34	+0.04	
	7		9.2	9.3	9.3	9.3	9.34	9.34	9.35	9.34	+0.04	
	8		9.2	9.3	9.2	9.2	9.35	9.32	9.35	9.34	+0.14	
D	1	9.38	9.1	9.2	9.1	9.1	9.18	9.15	9.15	9.16	+0.06	0.22
	2	9.39	9.1	9.1	9.1	9.1	9.18	9.16	9.19	9.18	+0.08	0.21
	3	9.37	9.1	9.1	9.1	9.1	9.18	9.13	9.18	9.16	+0.06	0.21
	4	9.32	9.1	9.1	9.1	9.1	9.15	9.13	9.15	9.14	+0.04	0.18
	5	9.34	9.0	9.1	9.1	9.1	9.16	9.13	9.15	9.15	+0.05	0.19
	6	9.30	9.0	9.1	9.1	9.1	9.14	9.12	9.15	9.14	+0.04	0.16
	7	9.30	9.0	9.1	9.1	9.1	9.13	9.09	9.12	9.11	+0.01	0.19
	8	9.32	9.0	9.0	9.1	9.0	9.15	9.13	9.15	9.14	+0.14	0.18
										MEAN	0.05	0.19

TABLE 3

Thickness measurements: Crowthorne fascia

Position		Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
			(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A	1	9.77	9.3	9.3	9.3	9.3	9.35	9.35	9.36	9.35	+0.05	0.42
	2	9.75	9.3	9.3	9.3	9.3	9.33	9.30	9.35	9.33	+0.03	0.42
	3	9.70	9.2	9.3	9.3	9.3	9.31	9.29	9.32	9.31	+0.01	0.39
	4	9.68	9.2	9.3	9.3	9.3	9.31	9.30	9.32	9.31	+0.01	0.37
	5	9.76	9.3	9.3	9.3	9.3	9.36	9.35	9.37	9.36	+0.06	0.40
	6	9.71	9.3	9.3	9.3	9.3	9.34	9.33	9.35	9.34	+0.04	0.37
B	1		9.5	9.5	9.5	9.5	9.61	9.60	9.61	9.61	+0.11	
	2		9.5	9.5	9.5	9.5	9.60	9.60	9.63	9.61	+0.11	
	3		9.5	9.5	9.5	9.5	9.60	9.59	9.61	9.60	+0.10	
	4		9.5	9.6	9.6	9.6	9.63	9.59	9.63	9.62	+0.02	
	5		9.5	9.5	9.5	9.5	9.60	9.61	9.60	9.60	+0.10	
	6		9.5	9.5	9.5	9.5	9.58	9.57	9.59	9.58	+0.08	
C	1		9.3	9.3	9.4	9.3	9.51	9.51	9.50	9.51	+0.21	
	2		9.3	9.3	9.4	9.3	9.48	9.48	9.48	9.48	+0.18	
	3		9.3	9.3	9.4	9.3	9.45	9.47	9.47	9.46	+0.16	
	4		9.4	9.4	9.4	9.4	9.54	9.54	9.56	9.55	+0.11	
	5		9.3	9.3	9.3	9.3	9.47	9.47	9.49	9.48	+0.18	
	6		9.3	9.3	9.4	9.3	9.45	9.49	9.51	9.48	+0.18	
D	1	9.73	9.2	9.1	9.2	9.2	9.30	9.29	9.31	9.30	+0.10	0.43
	2	9.68	9.2	9.2	9.2	9.2	9.31	9.28	9.30	9.30	+0.10	0.38
	3	9.74	9.2	9.1	9.2	9.2	9.29	9.27	9.30	9.29	+0.09	0.45
	4	9.76	9.2	9.2	9.2	9.2	9.34	9.28	9.28	9.30	+0.10	0.46
	5	9.75	9.2	9.2	9.2	9.2	9.28	9.29	9.31	9.29	+0.09	0.46
	6	9.59	9.2	9.1	9.2	9.2	9.27	9.24	9.28	9.26	+0.06	0.33
									MEAN		0.10	0.41

TABLE 4

Thickness measurements: Crowthorne sheltered

Position	Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
		(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A 1	9.81	9.4	9.4	9.4	9.4	9.46	9.43	9.48	9.46	+0.06	0.35
2	9.78	9.4	9.4	9.4	9.4	9.47	9.45	9.49	9.47	+0.07	0.31
3	9.78	9.4	9.4	9.4	9.4	9.48	9.47	9.50	9.48	+0.08	0.30
4	9.75	9.4	9.3	9.4	9.4	9.46	9.41	9.47	9.45	+0.05	0.30
5	9.80	9.4	9.4	9.4	9.4	9.46	9.42	9.50	9.46	+0.06	0.34
6	9.81	9.4	9.4	9.4	9.4	9.48	9.46	9.49	9.48	+0.08	0.33
7	9.85	9.4	9.3	9.4	9.4	9.45	9.44	9.49	9.46	+0.06	0.39
8	9.81	9.4	9.4	9.4	9.4	9.46	9.46	9.50	9.47	+0.07	0.34
B 1		9.5	9.6	9.5	9.5	9.64	9.62	9.66	9.64	+0.14	
2		9.5	9.5	9.5	9.5	9.62	9.62	9.63	9.62	+0.12	
3		9.5	9.5	9.6	9.5	9.68	9.66	9.68	9.67	+0.17	
4		9.5	9.5	9.5	9.5	9.67	9.65	9.69	9.67	+0.17	
5		9.5	9.6	9.5	9.5	9.66	9.62	9.65	9.64	+0.14	
6		9.5	9.5	9.5	9.5	9.65	9.65	9.66	9.66	+0.16	
7		9.5	9.5	9.5	9.5	9.66	9.66	9.65	9.66	+0.16	
8		9.5	9.5	9.5	9.5	9.67	9.66	9.67	9.67	+0.17	
C 1		9.5	9.5	9.5	9.5	9.64	9.61	9.65	9.63	+0.13	
2		9.6	9.6	9.5	9.6	9.67	9.63	9.67	9.66	+0.06	
3		9.6	9.6	9.5	9.6	9.65	9.63	9.66	9.65	+0.05	
4		9.6	9.6	9.5	9.6	9.65	9.63	9.67	9.65	+0.05	
5		9.5	9.5	9.5	9.5	9.65	9.63	9.66	9.65	+0.15	
6		9.6	9.6	9.5	9.6	9.68	9.65	9.66	9.66	+0.06	
7		9.6	9.6	9.6	9.6	9.66	9.64	9.70	9.67	+0.07	
8		9.5	9.6	9.5	9.5	9.60	9.58	9.62	9.60	+0.10	
D 1	9.66	9.3	9.4	9.4	9.4	9.38	9.38	9.43	9.40	0.00	0.26
2	9.70	9.3	9.3	9.3	9.3	9.39	9.40	9.43	9.41	+0.11	0.29
3	9.69	9.3	9.3	9.4	9.3	9.35	9.42	9.42	9.40	+0.10	0.29
4	9.68	9.3	9.3	9.3	9.3	9.36	9.37	9.39	9.37	+0.07	0.31
5	9.68	9.3	9.3	9.3	9.3	9.42	9.36	9.43	9.40	+0.10	0.28
6	9.69	9.3	9.3	9.3	9.3	9.39	9.41	9.44	9.41	+0.11	0.28
7	9.72	9.3	9.3	9.4	9.3	9.35	9.37	9.40	9.37	+0.07	0.35
8	9.75	9.3	9.3	9.4	9.3	9.39	9.42	9.44	9.42	+0.12	0.33
								MEAN		0.10	0.32

TABLE 5

Thickness measurements: Thorney Island fascia

Position	Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
		(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A 1	9.59	9.3	9.3	9.3	9.3	9.30	9.31	9.30	9.30	0.00	0.29
2	9.63	9.3	9.4	9.3	9.3	9.34	9.33	9.33	9.33	+0.03	0.30
3	9.59	9.3	9.3	9.3	9.3	9.31	9.32	9.32	9.32	+0.02	0.27
4	9.66	9.3	9.3	9.3	9.3	9.35	9.34	9.33	9.34	+0.04	0.32
5	9.70	9.3	9.3	9.3	9.3	9.33	9.33	9.33	9.33	+0.03	0.37
6	9.64	9.3	9.3	9.3	9.3	9.33	9.31	9.32	9.32	+0.02	0.32
7	9.68	9.3	9.4	9.3	9.3	9.34	9.33	9.35	9.34	+0.04	0.34
B 1		9.6	9.6	9.6	9.6	9.62	9.63	9.63	9.63	+0.03	
2		9.6	9.6	9.6	9.6	9.57	9.58	9.58	9.58	–0.02	
3		9.5	9.5	9.5	9.5	9.53	9.55	9.56	9.56	+0.06	
4		9.5	9.5	9.5	9.5	9.57	9.55	9.56	9.56	+0.06	
5		9.5	9.5	9.5	9.5	9.54	9.53	9.54	9.54	+0.04	
6		9.5	9.5	9.6	9.5	9.58	9.59	9.59	9.59	+0.09	
7		9.6	9.6	9.6	9.6	9.64	9.63	9.63	9.63	+0.03	
C 1		9.3	9.3	9.3	9.3	9.41	9.41	9.41	9.41	+0.11	
2		9.2	9.3	9.3	9.3	9.34	9.32	9.35	9.34	+0.04	
3		9.0	9.0	9.0	9.0	9.03	9.08	9.04	9.05	+0.05	
4		9.0	9.0	9.0	9.0	9.12	9.06	9.08	9.09	+0.09	
5		9.0	9.0	9.0	9.0	9.11	9.08	9.08	9.09	+0.09	
6		–	9.2	9.0	9.1	8.62	8.62	8.65	8.63	–0.47*	
D 1	9.65	9.2	9.3	9.2	9.2	9.28	9.26	9.28	9.27	+0.07	0.38
2	9.59	9.2	9.2	9.2	9.2	9.30	9.28	9.27	9.28	+0.08	0.31
3	9.45	9.1	9.1	9.1	9.1	9.21	9.15	9.13	9.16	+0.06	0.29
4	9.56	9.0	9.0	9.0	9.0	9.16	9.16	9.15	9.16	+0.16	0.40
5	9.70	9.0	9.0	9.0	9.0	9.16	9.18	9.16	9.17	+0.17	0.53
6	9.54	9.1	9.1	9.1	9.1	9.17	9.19	9.17	9.18	+0.08	0.36
									MEAN	0.04	0.34

* Area of localised corrosion around support.

TABLE 6

Thickness measurements: Thorney Island sheltered

Position		Total thickness including rust (mm) (micrometer)	Steel thickness measured by EMA Probe (mm)				Steel thickness measured by micrometer after derusting (mm)				Difference micrometer – EMA Probe	Total rust thickness (from micrometer readings)
			(1)	(2)	(3)	Average	(1)	(2)	(3)	Average		
A	1	10.51	8.8	8.7	8.7	8.7	9.03	8.95	9.03	9.00	+0.30	1.51
	2	10.34	8.8	8.7	8.8	8.8	8.94	8.93	8.94	8.94	+0.14	1.40
	3	10.60	8.7	8.7	8.7	8.7	8.94	9.05	9.02	9.00	+0.30	1.60
	4	11.64	9.0	9.0	9.0	9.0	8.73	8.75	8.99	8.82	–0.18	2.82
	5	11.17	8.8	8.8	8.8	8.8	9.10	9.05	9.02	9.06	+0.26	2.11
	6	11.14	8.8	8.8	8.8	8.8	8.90	8.89	8.89	8.89	+0.09	2.25
	7	11.05	8.8	8.8	8.8	8.8	8.92	8.91	8.90	8.91	+0.11	2.14
	8	11.00	8.8	8.7	8.7	8.7	8.97	8.92	8.97	8.95	+0.25	2.05
B	1		9.0	9.0	9.0	9.0	9.27	9.26	9.28	9.27	+0.27	
	2		9.0	9.0	9.0	9.0	9.37	9.38	9.36	9.37	+0.37	
	3		9.1	9.1	9.1	9.1	9.36	9.36	9.38	9.37	+0.27	
	4		9.1	9.1	9.1	9.1	9.29	9.31	9.28	9.29	+0.19	
	5		9.1	9.0	9.0	9.0	9.40	9.37	9.40	9.39	+0.39	
	6		9.1	9.1	9.1	9.1	9.30	9.29	9.29	9.29	+0.19	
	7		8.9	8.8	8.8	8.8	9.08	9.05	9.13	9.09	+0.29	
	8		9.0	9.0	9.0	9.0	9.11	9.05	9.14	9.10	+0.10	
C	1		8.7	8.7	8.8	8.7	9.03	9.00	9.01	9.02	+0.32	
	2		8.7	8.7	8.7	8.7	9.09	9.09	9.11	9.10	+0.40	
	3		8.7	8.7	8.7	8.7	8.99	9.10	9.02	9.04	+0.34	
	4		–	–	–	–	9.08	9.16	9.07	9.10	–	
	5		8.4	8.4	8.4	8.4	8.70	8.70	8.74	8.72	+0.32	
	6		8.2	8.2	8.2	8.2	8.80	8.65	8.68	8.71	+0.51	
	7		–	–	–	–	8.63	8.81	8.82	8.75	–	
	8		–	8.9	8.9	8.9	9.21	9.20	9.22	9.21	+0.31	
D	1	9.61	8.9	8.8	8.9	8.9	9.08	9.03	9.05	9.05	+0.15	0.56
	2	10.58	8.9	9.0	9.0	9.0	9.20	9.19	9.21	9.20	+0.20	1.38
	3	10.60	9.0	9.0	9.0	9.0	9.21	9.17	9.20	9.19	+0.19	1.41
	4	10.45	9.0	9.0	9.0	9.0	9.21	9.19	9.22	9.21	+0.21	1.24
	5	11.00	8.8	8.8	8.9	8.8	9.04	9.03	9.03	9.03	+0.23	1.97
	6	10.81	8.4	–	8.5	8.5	8.77	8.77	8.74	8.76	+0.26	2.05
	7	10.88	8.7	8.7	8.7	8.7	8.92	8.89	8.92	8.91	+0.21	1.97
	8	10.69	9.0	8.9	9.0	9.0	9.16	9.11	9.15	9.14	+0.14	1.55
									MEAN		0.24	1.75

TABLE 7

Difference in steel thickness as measured by micrometer and ultrasonic probe

Specimen	Average rust thickness per surface* mm	Difference in steel thickness measurements (micrometer-probe) mm	
		Mean	Range
Tinsley fascia	0.18	0.06	–0.09 to 0.14
Tinsley sheltered	0.10	0.05	0.01 to 0.14
Crowthorne fascia	0.21	0.10	0.01 to 0.21
Crowthorne sheltered	0.16	0.10	0.00 to 0.17
Thorney Island fascia	0.17	0.04	–0.47 to 0.17
Thorney Island sheltered	0.88	0.24	–0.18 to 0.51

* Estimated from $\left(\frac{\text{Total thickness including rust} - \text{Thickness after derusting}}{2}\right)$

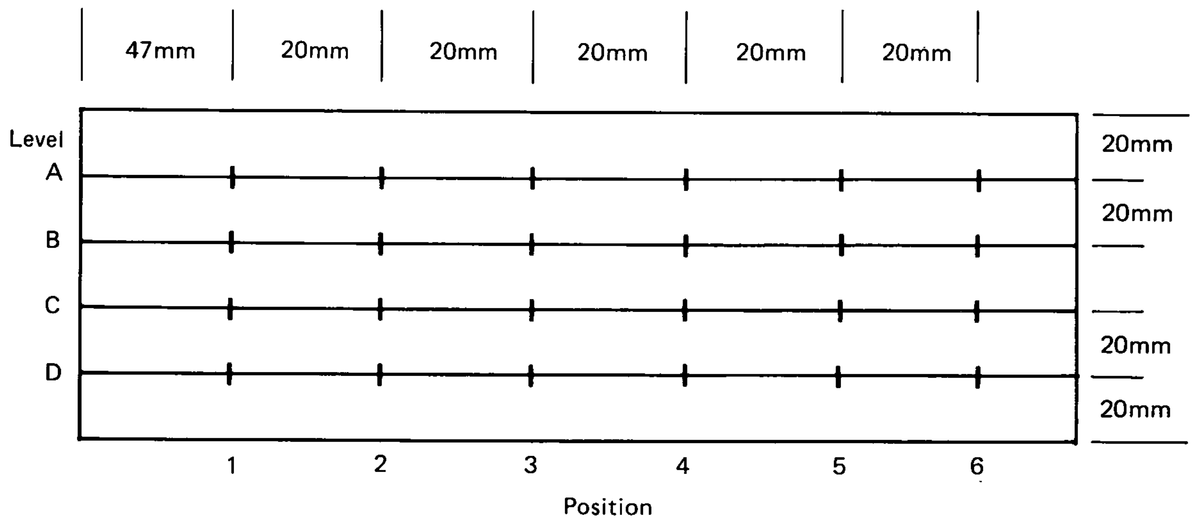

Fig. 1 Bottom flange of test specimen: measurement positions

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