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Co-Patch

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Author/s: Y. Zhang and M. K. Chryssanthopoulos

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1 INTRODUCTION

The present work is part of the framework of Task 3.1 “Materials selection and characterization for laboratory tests”. The laboratory experiments were performed at UniS in February and March 2011 to characterize the yield and tensile strength and to verify the modulus of elasticity of steel. The tested specimens were manufactured by CARDAMA and sent to UniS. On the basis of ASTM standard E8/E8M-09 and ISO standard 6892-1:2009, the geometric configurations of specimens, test procedure and experimental instrumentations were planed with adaptation.

This report includes the description of the steel specimens, the experimental instrumentation and test procedure, and the experimental results including the strength and modulus of elasticity.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Specimen configurations

Provided by CARDAMA, sixteen steel coupons were cut from a 12 m $\times$ 2 m steel plate (Naval Steel A class) and their positions are shown in Fig.1. Concerning the distribution of material properties within the steel plate, the specimens were not cut from a single location but taken from different locations around the plate. Among the sixteen specimens, eight specimens were located in the longitudinal direction while the other eight in the transverse direction. Half of the specimens (eight) were cut from the centre of the steel plate whereas the other half from the side of the plate. The specimen matrix is summarized in Table 1.

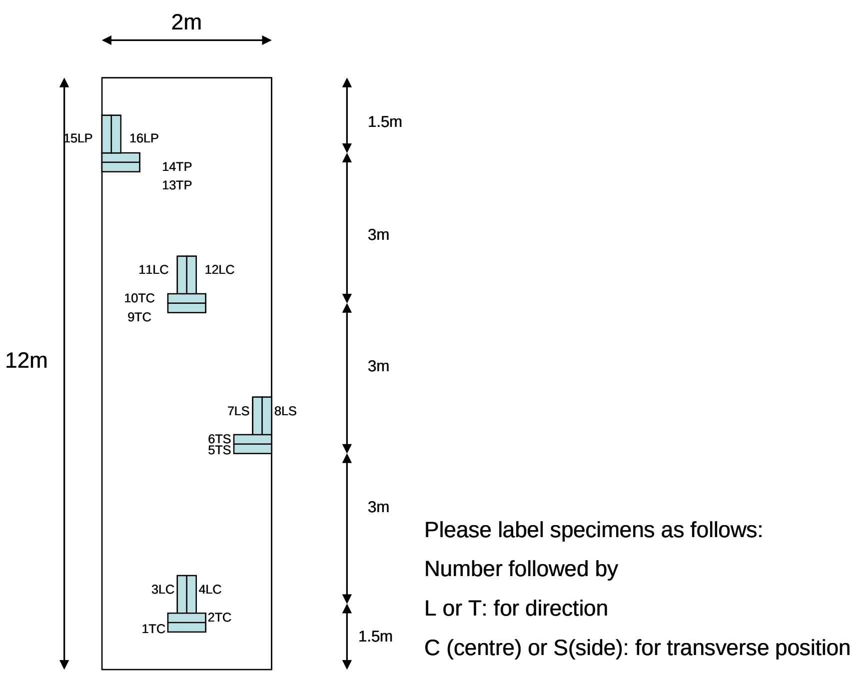


Fig.1: Indication of coupon positions.

Table 1: Position and instrumentations of specimens.

Direction	**Position**	**Specimens**	
		1st series of tests for strength	**2nd series of tests for elastic modulus**
Transverse	Centre (Group 1)	1TC*, 2TC+, 10TC+	9TC×
	Side (Group 2)	5TS*, 6TS+, 13TP+	14TP× (not tested)
Longitudinal	Centre (Group 4)	3LC*, 4LC+, 11LC+	12LC×
	Side (Group 4)	7LS*, 8LS+, 15LP+	16LP×

*: with two strain gauges

+: with one strain gauge

×: with one strain gauge and one extensometer

The specimen dimensions are shown in Fig. 2. The standard rectangular specimens (25 mm × 250 mm) were employed with a thickness of 5 mm. The length between the wedge grips was 40 mm on each side. For every specimen, its relevant dimensions were measured at three cross-sections in the central region of the specimen, following the instruction in [2]. All measurements are presented in Appendix A. According to these measurements, the average width, thickness and cross-sectional area are calculated.

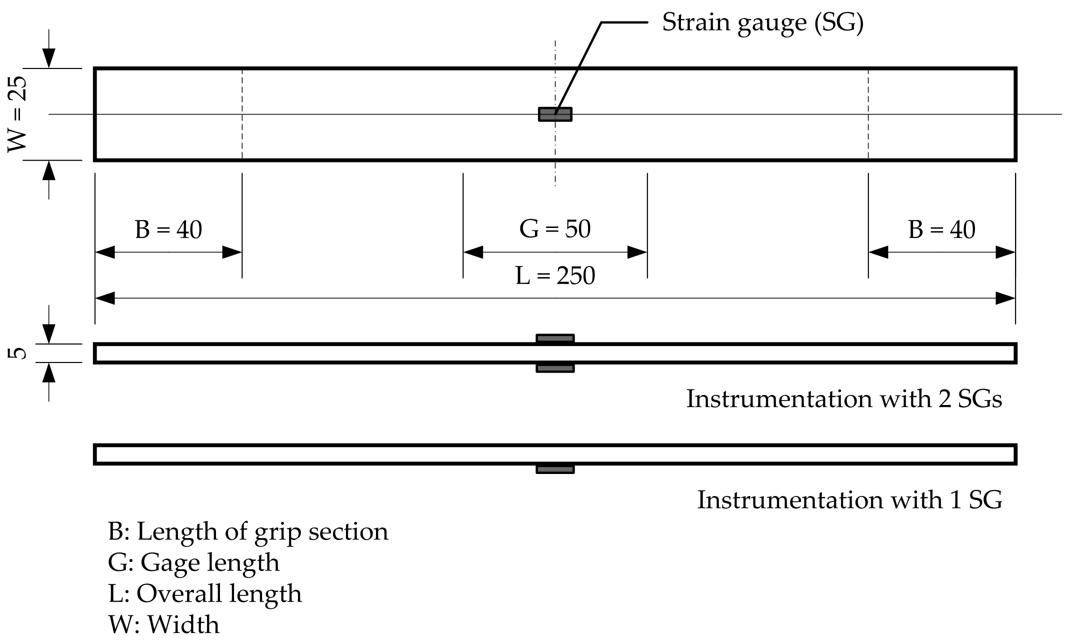


Fig.2: Dimensions and instrumentations of steel coupons for tensile testing.

2.2 Experimental set-up and instrumentations

The displacement controlled tensile tests were performed using an INSTRON 1185 machine with a capacity of 100 kN. Two series of experiments were undertaken: the first series is to measure the yield and tensile strength and the second one is to verify the modulus of elasticity.

In the first series of experiments, twelve specimens, shown in Table 1, were loaded in tension until necking occurred. As prescribed in [2], very slow strain rate must be used for measuring the yield strength (f_y) while after yielding higher strain rate may be used to obtain the tensile strength (f_u). Thus in the first series of tests, the displacement rate was 0.3 mm/min when the displacement was less than 5 mm, which ensured the occurrence of yielding. Once 5 mm displacement was reached, the displacement rate was increased to 5 mm/min until tensile failure occurred. The instrumentations for the first series of experiments are noted in Table 1 and shown in Fig. 2. For four specimens (1TC, 3LC, 5TS and 7LS), two strain gauges (VISHAY CEA-06 6 mm gauges, 120 Ohm) were used to measure the strain and to verify specimen alignment within the test grips. They were placed in the central region of the specimens (see Fig. 2), one gauge for each side. For the other eight specimens, the strain gauge (SHOWA N11-FA 5 mm gauge, 120 Ohm) was only placed on one side (see Figs. 2 and 3(a)). During the test, the electrical signals of the load, displacement from the machine and the strain from the strain gauges were gathered by a VISHAY P-3500 strain indicator and recorded at a frequency of 10 Hz.

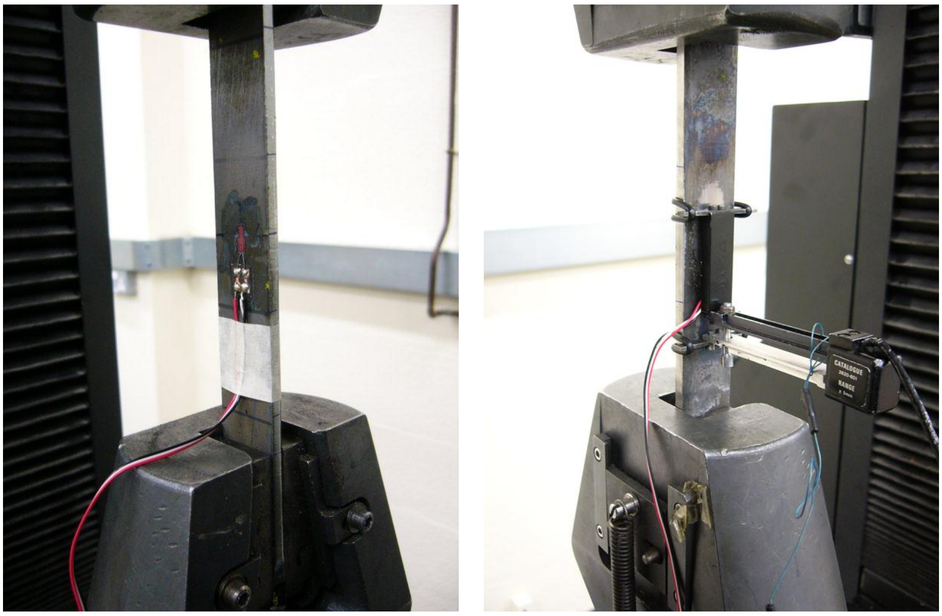


Fig.3: Instrumentations: (a) the strain gauge and (b) extensometer respectively in the first and second series of tensile experiments.

In the second series of tests, three specimens were employed to obtain the modulus of elasticity of steel (E), as presented in Table 1. Each specimen experienced three cycles of the loading-unloading process to obtain three measurements of E. Thus the maximum applied load was not allowed to exceed 25 kN to ensure strains remained in the elastic range and no irreversible deformation occurred. The displacement rate remained as 0.3 mm/min throughout testing. An INSTRON extensometer (mode 2620-601, full-scale range $\pm$5 mm) with a gauge length of 50 mm and a strain gauge were employed and placed on the same side of the specimen, see Fig.3(b). The comparison of E values calculated based on the strain gauge and extensometer were presented in section 3.4. The same data gathering device and recording frequency were used as in the first series.

3 EXPERIMENTAL RESULTS

3.1 Verification of system alignment

Four specimens were equipped with two strain gauges to check the system alignment (see Table 1). The stress-strain response of a selected specimen (3LC) is presented in Fig. 4. Almost the same results were obtained from two strain gauges. It indicates that the present tensile system was well aligned so that the bending effects can be ignored.

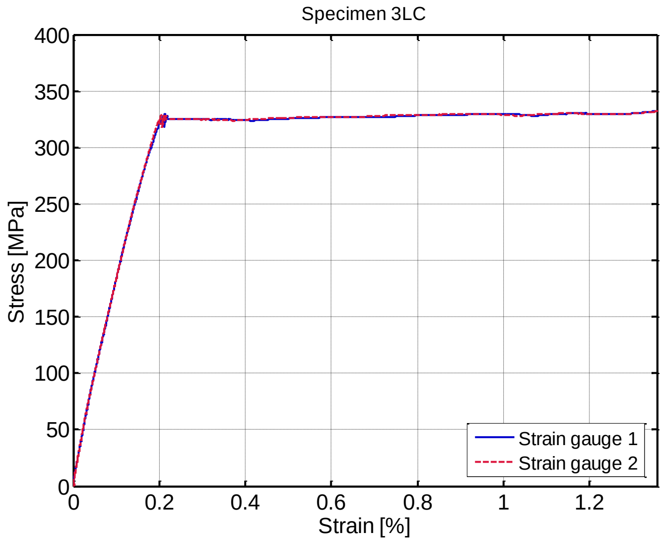


Fig.4: Stress-strain response of specimen 3LC equipped with two strain gauges.

3.2 Failure modes

The typical failure modes of selected specimens are shown in Figs. 5 and 6. For most of specimens, the necking region was located in the center or very close to the center of the specimen. There was only one exception, specimen 5TS (see Fig. 5), whose necking region was observed towards the edge, close to the grips.

One interesting observation has to be mentioned: a metallic flake (see Figs. 7) was found on the surface of the wedge grip after the failed specimen (6TS) was removed from the machine. This product was separated from the base material as a result of the friction between grips and the specimen. As defined in ASTM G15 [3], exfoliation can be a form of corrosion that “proceeds laterally from the sites of initiation along planes parallel to the surface, generally at grain boundaries, forming corrosion products that force metal away from the body of the material, giving rise to a layered appearance”. However, exfoliation corrosion primarily affects aluminium alloys, rather than steel. In this case, the exfoliated product probably relates to a type of coating used in marine steels to prevent corrosion from occurring when plates are left in outdoor environments for a prolonged period of time.

Fig.5: Typical failure modes of selected specimens (1TC, 3LC, 5TS and 7LS).

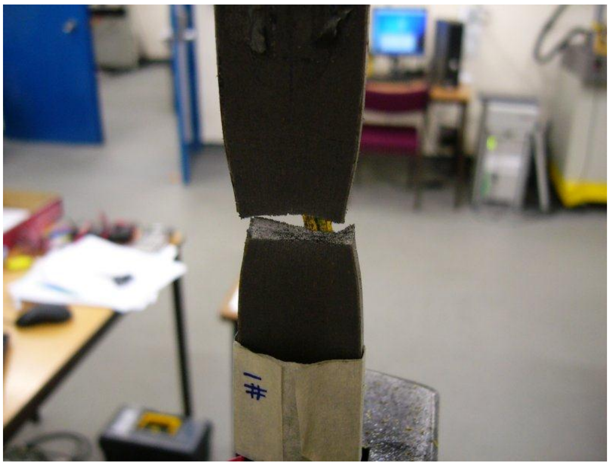
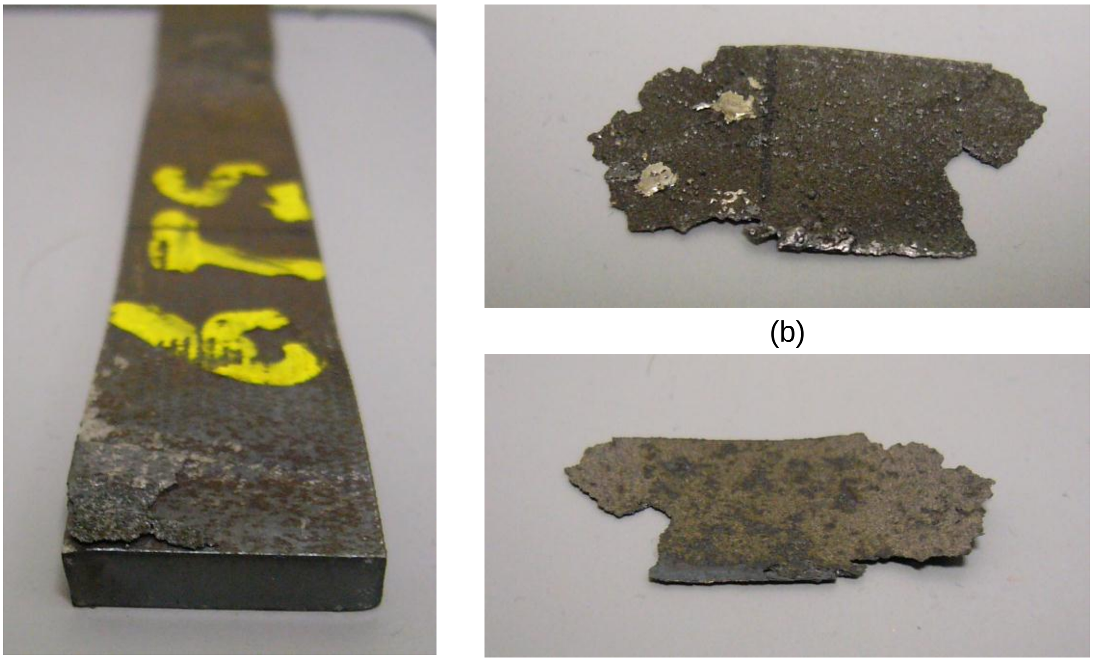


Fig.6: Rupture of specimen 7LS.



(b)

(a)

(c)

Fig.7: Exfoliation of specimen 6TS: (a) the product remaining on the specimen surface; (b) the outer and (c) inner surfaces of the exfoliated product.

3.3 Yield and tensile strength

The load-displacement and stress-strain responses of the selected specimens (7LS and 4LC) are shown in Figs. 7 and 8. Following the instruction in [1] and [2], the yield and tensile strength were determined for twelve specimens (three specimens from each position group, see Table 1) and are presented in Table 2. The average yield and tensile strength were 314.57 MPa and 454.83 MPa respectively with 3.1% and 2.1% standard deviation. The yield strength is around 35% higher than the nominal yield strength of Naval Steel A Class (235 MPa provided by CARDAMA). Almost the same results were obtained from specimens in different position groups and no dependency of the strength on the specimen position was noticed.

An estimation of the ultimate strain has also been made, as shown in Table 2. The mean ultimate tensile strain is 19.7%. The post-yield behaviour of a typical specimen (4LC) is shown in Fig. 9, which shows a plateau followed by non-linear strain hardening region.

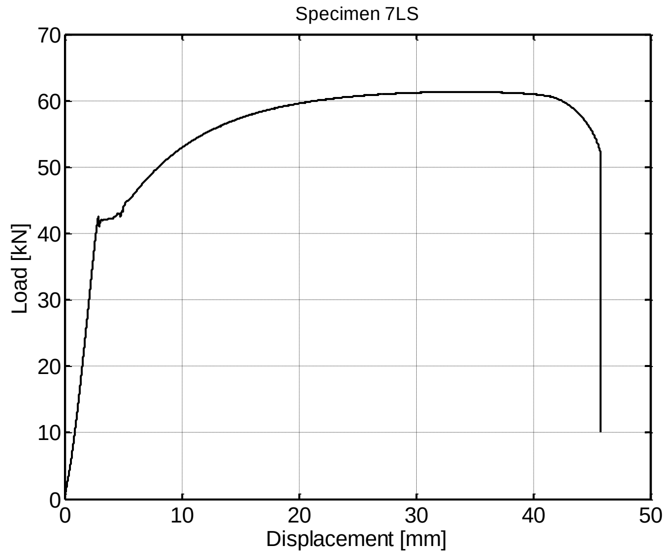


Fig.8: Load-displacement response of specimen 7LS.

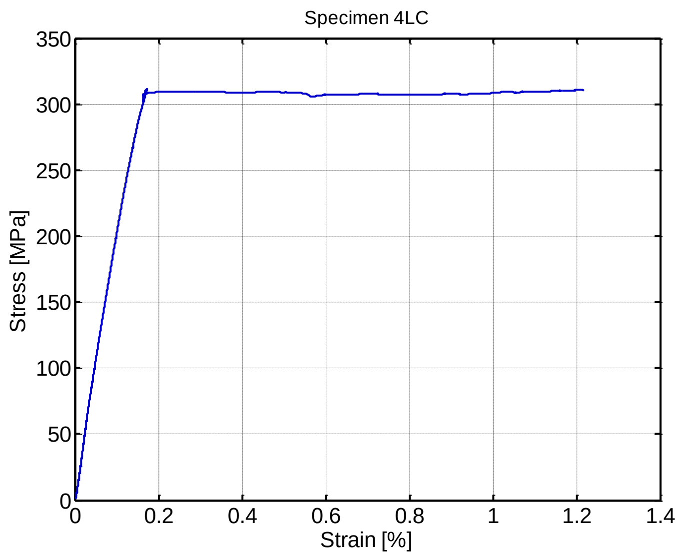


Fig.9: Stress-strain response of specimen 4LC.

Table 2: Specimen dimensions, yield and tensile strength, and ultimate strain.

Position		Specimen	Width [mm]	Thick -ness [mm]	Cross-sectional area [mm^2]	Yield strength [MPa]	Tensile strength [MPa]	Ultimate strain [%]
Transverse	Centre	1TC	25.57	5.28	135.01	333.69	452.00	20.77
		2TC	25.60	5.40	138.24	314.43	442.45	19.32
		10TC	25.55	5.23	133.63	302.32	456.31	20.74
		Sub-mean	-	-	-	316.81±15.82	450.26±7.09	20.28±0.83
	Side	5TS	25.37	5.12	129.89	314.47	466.25	20.22
		6TS	25.47	5.30	134.99	318.70	454.76	20.01
		13TP	25.85	5.32	137.52	305.12	443.02	21.12
		Sub-mean	-	-	-	312.77±6.95	454.68±11.61	20.45±0.59
Longitudinal	Centre	3LC	25.35	5.07	128.52	326.02	469.19	18.41
		4LC	25.50	5.33	135.92	309.02	442.54	18.97
		11LC	25.67	5.15	132.20	302.11	450.22	18.44
		Sub-mean	-	-	-	312.39±12.30	453.98±13.72	18.61±0.32
	Side	7LS	25.78	5.10	131.48	319.63	466.29	19.49
		8LS	25.85	5.13	132.61	320.25	459.60	18.47
		15LP	25.47	5.20	132.44	309.09	455.28	20.11
		Sub-mean	-	-	-	316.32±6.27	460.39±5.55	19.36±0.83
12 spec.		Mean	-	-	-	314.57±9.66	454.83±9.37	19.67±0.97

3.4 Modulus of elasticity

The elastic modulus was calculated as the slope of the linear part of stress-strain curve between 100 MPa and 200 MPa stresses, and presented in Table 3. Considering nine measurements from three specimens, the average elastic modulus depending on the strain measured by the extensometer and strain gauge was 201.89 GPa and 203.40 GPa respectively with the standard deviation less than 5%. The difference between the two strain measuring approaches was less than 1%. The value of elastic modulus was as expected (≈200 GPa) and the two strain measuring approaches were both proved to be successful.

4 CONCLUSIONS

As part of the framework of Task 3.1, the material properties of the steel were obtained through the tensile experiments. The mean yield and tensile strength values were found equal to 314 MPa and 455 MPa respectively and the mean modulus of elasticity was found equal to 203 GPa. The measured yield strength was higher than the nominal yield strength given by the material supplier whereas the elastic modulus was as expected. The exfoliation observed during testing suggests that the specimens may have experienced long-term outdoor environments before being shipped for testing.

Table 3: Specimen dimensions and modulus of elasticity in the second series of experiments.

Specimen	Width [mm]	Thickness [mm]	Cross-sectional area [mm^2]	Cycle	Modulus of elasticity [GPa]	
					Measured by extensometer	Measured by strain gauge
9TC	25.60	5.47	140.03	1	207.58	236.16
				2	207.28	206.88
				3	207.30	206.98
12LC	25.40	5.15	130.81	1	194.44	196.16
				2	199.51	197.86
				3	200.56	198.68
16LP	25.60	5.13	131.33	1	195.33	192.85
				2	202.65	197.34
				3	202.38	197.73
Mean	-	-	-	-	201.89±4.97	203.40±13.15
Mean regardless of measuring methods					202.69±8.51	

References

[1] ASTM E8 / E8M - 09 Standard Test Methods for Tension Testing of Metallic Materials
[2] ISO 6892-1:2009 Metallic materials - Tensile testing - Part 1: Method of test at room temperature.
[3] ASTM G15-08 Standard Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010).

APPENDIX A

Table 1: Measured width and thickness of specimens (through three cross-sections).

Position		Specimen	Thickness [mm]				Width [mm]			
			t_1	t_2	t_3	t	W_1	W_2	W_3	W
Transverse	Centre	1TC	5.25	5.30	5.30	5.28	25.60	25.60	25.50	25.57
		2TC	5.40	5.40	5.40	5.40	25.60	25.60	25.60	25.60
		9TC	5.50	5.50	5.40	5.47	25.65	25.60	25.55	25.60
		10T	5.30	5.20	5.20	5.23	25.50	25.55	25.60	25.55
	Side	5TS	5.10	5.10	5.15	5.12	25.30	25.40	25.40	25.37
		6TS	5.50	5.10	5.30	5.30	25.40	25.50	25.50	25.47
		13TP	5.40	5.30	5.25	5.32	25.90	25.85	25.80	25.85
		14TP	5.10	5.15	5.20	5.15	25.80	25.85	25.90	25.85
Longitudinal	Centre	3LC	5.10	5.05	5.05	5.07	25.30	25.35	25.40	25.35
		4LC	5.40	5.40	5.20	5.33	25.40	25.50	25.60	25.50
		11LC	5.15	5.15	5.15	5.15	25.65	25.70	25.65	25.67
		12LC	5.25	5.10	5.10	5.15	25.35	25.35	25.50	25.40
	Side	7LS	5.10	5.10	5.10	5.10	25.75	25.80	25.80	25.78
		8LS	5.20	5.10	5.10	5.13	25.90	25.85	25.80	25.85
		15LP	5.35	5.15	5.10	5.20	25.45	25.50	25.45	25.47
		16LP	5.10	5.10	5.20	5.13	25.60	25.60	25.60	25.60