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Impact Effects on Scaffold from Safety Harness Attachments

HSL/2007/46

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Science Group: **Hazard Reduction**

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EXECUTIVE SUMMARY

Objectives

To determine what the consequences would be to the scaffold structure, when a scaffolder falls off during construction. To investigate forces on a lanyard during a simulated fall, and the effects this would have on the scaffold structure itself.
To make measurements of resultant forces in ties and at the base of the structure, compared to the applied force in the lanyard would give an indication of the consequences if such an event happened.

Main Findings

At low lift count the energy of a fall is more likely to produce damage to the structure rather than pull out ties.

Unified tie pull out forces are generally higher for upper ledger attachments than lower ledger attachments.

For a given location on any lift, the unified tie pull out force is generally independent of the lift.

1 INTRODUCTION

1.1 BACKGROUND

During the construction of scaffold structures, scaffolders are protected from the consequences of a fall by wearing safety harnesses secured at suitable attachment points. There may be times when the required number of ties required to the parent structure will not be correct, i.e. just before installation of the ties, it is at this point when a fall may cause most force in the existing ties.

Mr. Martin Holden of the Construction Division Technology Unit, HSE asked the Health and Safety Laboratory, Field Engineering Section, to determine what the consequences to a scaffold structure, would be of a scaffolder falling off. HSL were asked to investigate forces on the lanyard during a simulated fall, and the effect the fall would have on the scaffold structure itself. Measurements of resultant forces in ties and at the base of the structure, compared to the applied force in the lanyard would give an indication of the consequences if such an event happened.

1.2 PROJECT OBJECTIVES

The main objectives of the project were as follows:

- To determine the loading effect on a partially built scaffold structure by a mass of 100kg to simulate a 95th percentile adult male falling from the scaffold,
- To measure the dynamic force in the attachment lanyard during the fall,
- To achieve 6kN[1] and 10kN[2] dynamic force in the lanyard.
- To measure the resultant dynamic forces at the base of the structure and the tie back to the support structure,
- Drop tests to be conducted at a number of locations,
- To assess visible effects on the scaffold.

[1] 6kN is the maximum permitted load allowed in a lanyard, defined in section 4.4 of BS EN 355

[2] Generating a load of 10kN in the lanyard meant that the ledgers and standards were subjected to excessive and damaging loads. This objective was eventually omitted.

2 DESIGN OF SCAFFOLD

2.1 SUPPORT STRUCTURE

The structure to which the experimental scaffold was tied back, consisted of two RMD towers bolted onto a large concrete test pad. The towers were 12m high and spaced 4m apart as shown in Figure 4. The right hand tower had an internal scaffold structure constructed to facilitate access to the experimental scaffold and lifting mechanism.

2.2 LIFTING MECHANISM

Two RMD 'super slim' beams were attached to the top of the right hand RMD tower, cantilevered out by 2m to provide two anchor points (see Figure 5). To these anchor points a system of Maillon Rapides, Petzl pulleys and lengths of static rope provided a horizontally variable positioning pulley point, as shown in figure 1.

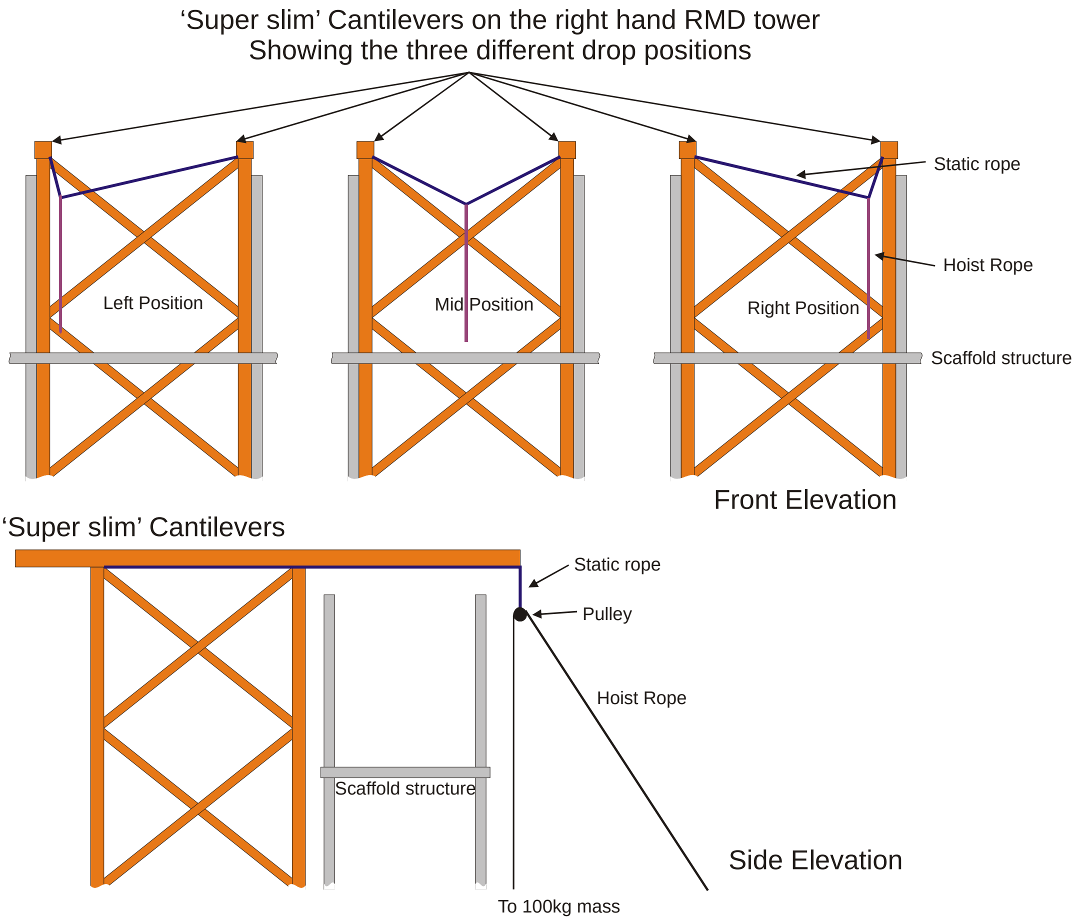


Figure 1 - Schematic of positioning system

A hoisting cable was lowered and raised over the pulley point using a ground anchored 12V automotive winch. Attached to the free end of the hoisting cable was a electrically operated bomb release, SWL 2 tonnes. This lifting arrangement allowed any drop height up to 13m to be achieved at any point between the two cantilevered 'super slims'.

2.3 EXPERIMENTAL STRUCTURE

The experimental structure initially consisted of a single lift of scaffold, four bays wide. The right hand RMD tower facilitated access to the 2nd bay from the right. Each lift was built to a partial finish, front and rear upper ledgers were installed, however, toe boards, handrails and intermediate handrails were not fitted.
A scaffold contract company was recruited to install each lift using their usual method of construction.
The preceding lift was finished with toe boards, handrails and intermediate handrails.
Each upright had a 2 tonne shear beam loadcell located at the base to record the vertical reactive force upon the concrete test pad as shown in Figures 2 and 3.

Figure 2 - Showing Base Loadcells

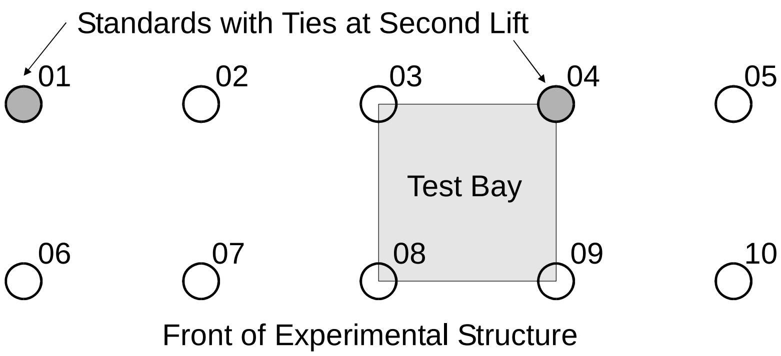


Figure 3 - Location of Base Loadcells

As each stage progressed a further lift was added to simulate a structure being constructed. At the second lift, two box ties were installed back to the supporting RMD towers. One of the box ties was replaced by an instrumented loadcell system to record the horizontal force experienced by the tie. All tests were conducted in the bays (increasing lifts) immediately to the left of the instrumented tie, see Figure 4 (note Figure 4 is a schematic and to avoid complexity, bracing handrails and hoisting mechanism are not shown). Figure 5 shows the test facility in its final stage. Figure 6 shows the original rear box tie between the scaffold and the right hand RMD tower. Figure 7 shows how this was modified to provide an instrumented tie.

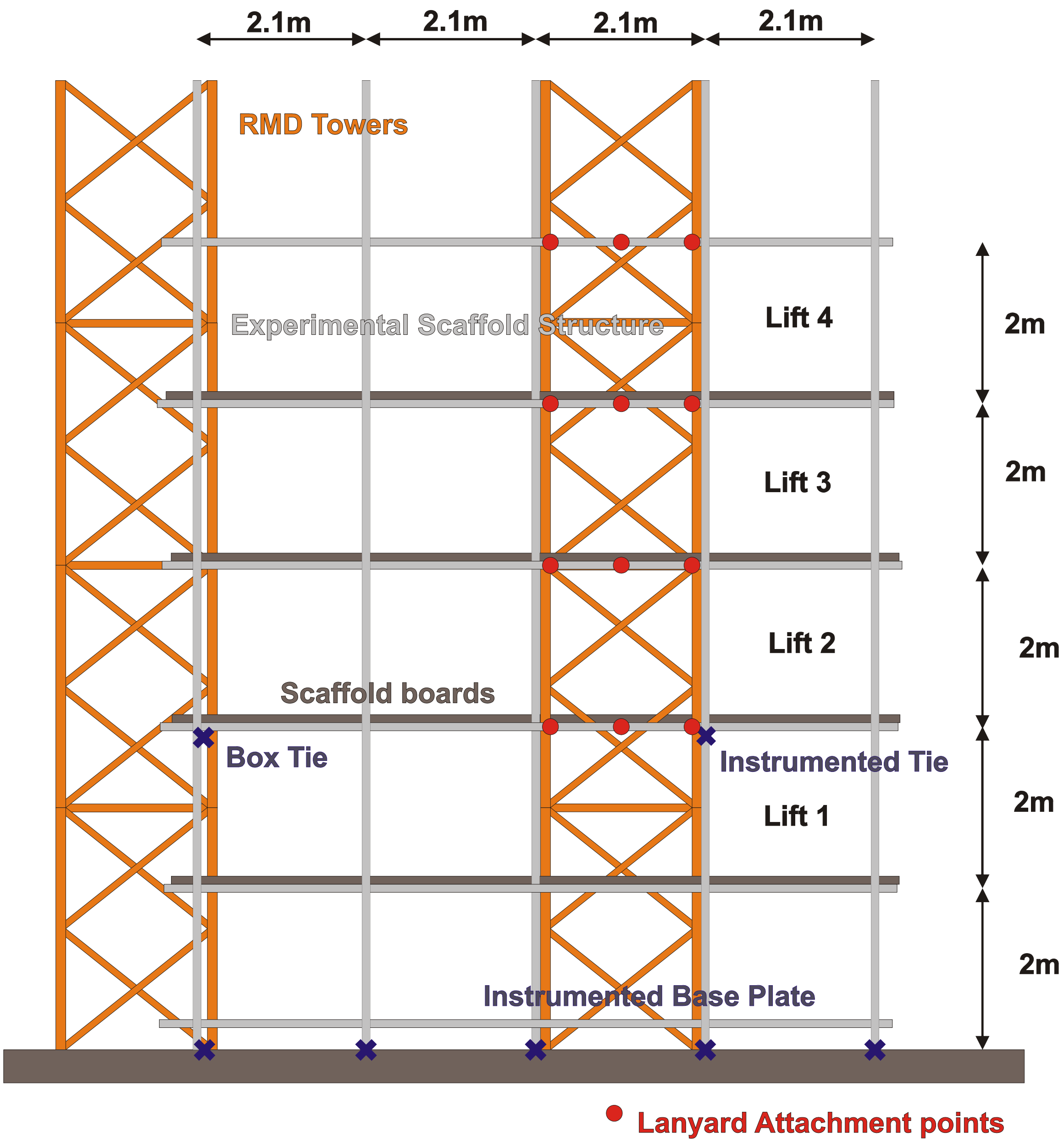


Figure 4 - Schematic of Experimental Rig and Support Structure (Front Elevation)

Figure 5 - Completed Experimental scaffold

Figure 6 - As installed Box Tie

Figure 7 - Modified Instrumented Tie

2.4 LOADING MECHANISM

To achieve the dynamic force of a 95th percentile adult male falling, a canvas bag was filled with dry builders sand to a mass of 100 kg. The bag was not to a specific standard as its requirement was to achieve the desired impact forces. A sand bag was chosen so that if the mass was to swing into the scaffold structure after the drop, the shock would not be as severe as say a steel mass. To produce as consistent a dynamic force as possible, and to remove as many variables as possible to the loading mechanism, it was decided to use a webbing lanyard with the shock absorber removed. Each end of the lanyard had sewn loop terminations, which held karabiners. One end of the lanyard was attached to the scaffold at predetermined attachment points by a scaffold karabiner. To the other end of the lanyard, a screw gate karabiner was connected to a loadcell via an eyebolt. This loadcell was connected, in series, to the canvas bag using an eyebolt and a Maillon Rapide. The arrangement is shown as a schematic in Figure 8.

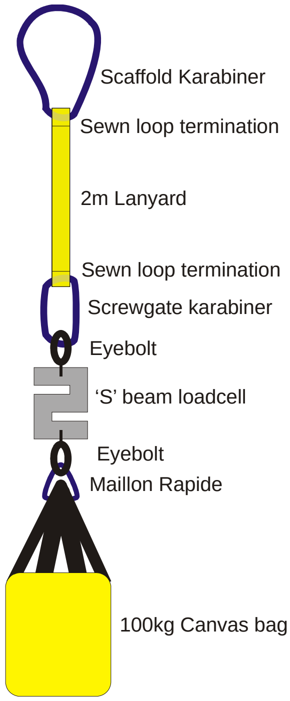
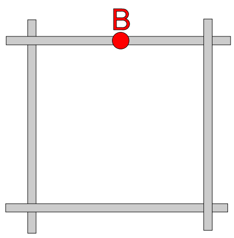


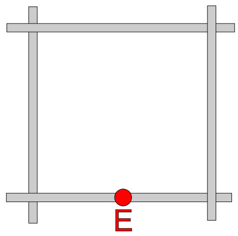
Figure 8 - Schematic of loading system

The six predetermined attachment points on the experimental scaffold were: (all attachment points at rear ledgers)
Elevation Rear Face
Mid Bay

Upper Ledger

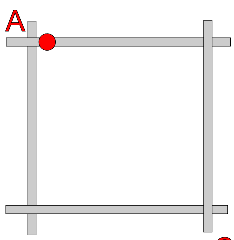


Lower Ledger

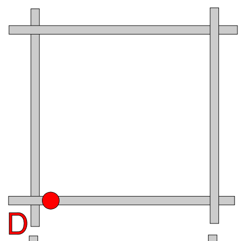


Left of Bay (furthest from instrumented tie)

Upper Ledger

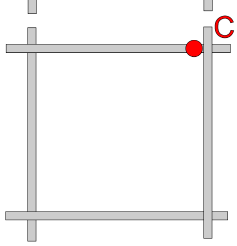


Lower Ledger



Right of Bay (closest to instrumented tie)

Upper Ledger



Lower Ledger

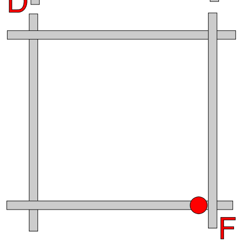


Figure 9 shows a schematic side elevation of the experimental rig, detailing the path the lanyard follows during loading.

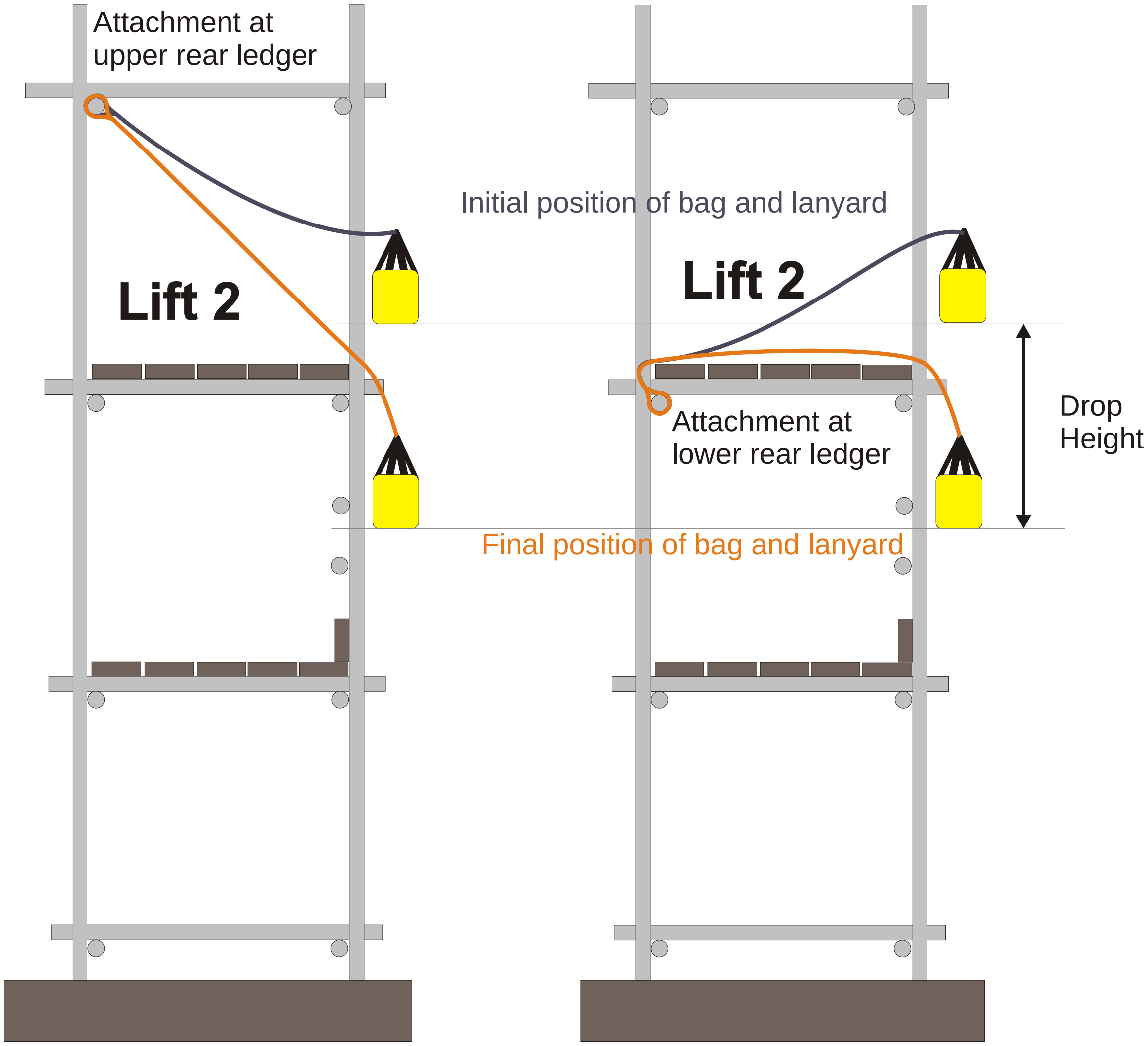


Figure 9 - Loading mechanism (Side Elevation)

3 INSTRUMENTATION

3.1 BASE AND TIEBACK LOADCELLS

The ten base loadcells and the tieback loadcell were 20kN EMS type 5300 shear beam. During the course of the project it was found that two of the base loadcells (Foot05 and Foot06) had failed and a number of others started to show levels of noise (Foot01 and Foot 04). Due to the construction of the rig, it was too complex a procedure to replace these loadcells. These loadcells were calibrated in a Denison Mayes test machine.

3.2 LANYARD LOADCELL

The lanyard loadcell was a 20kN Tedea-Huntleigh ‘S’ Beam loadcell, with eyebolt fittings at each end. This loadcella was calibrated in a Denison Mayes test machine.

3.3 DATA LOGGER

Flying leads from all 12 loadcells were laid into an instrumentation hut adjacent to the experimental scaffold on the test pad. The data logger was an Intercole VHS Spectra configured for transducer input. The acquisition rate was 2000 samples per second. Logging was started and ceased manually. Files were recorded to a PC for subsequent data analysis. The data logger was calibrated with a Time Voltage calibrator.

4 TEST RESULTS

4.1 FIRST LIFT

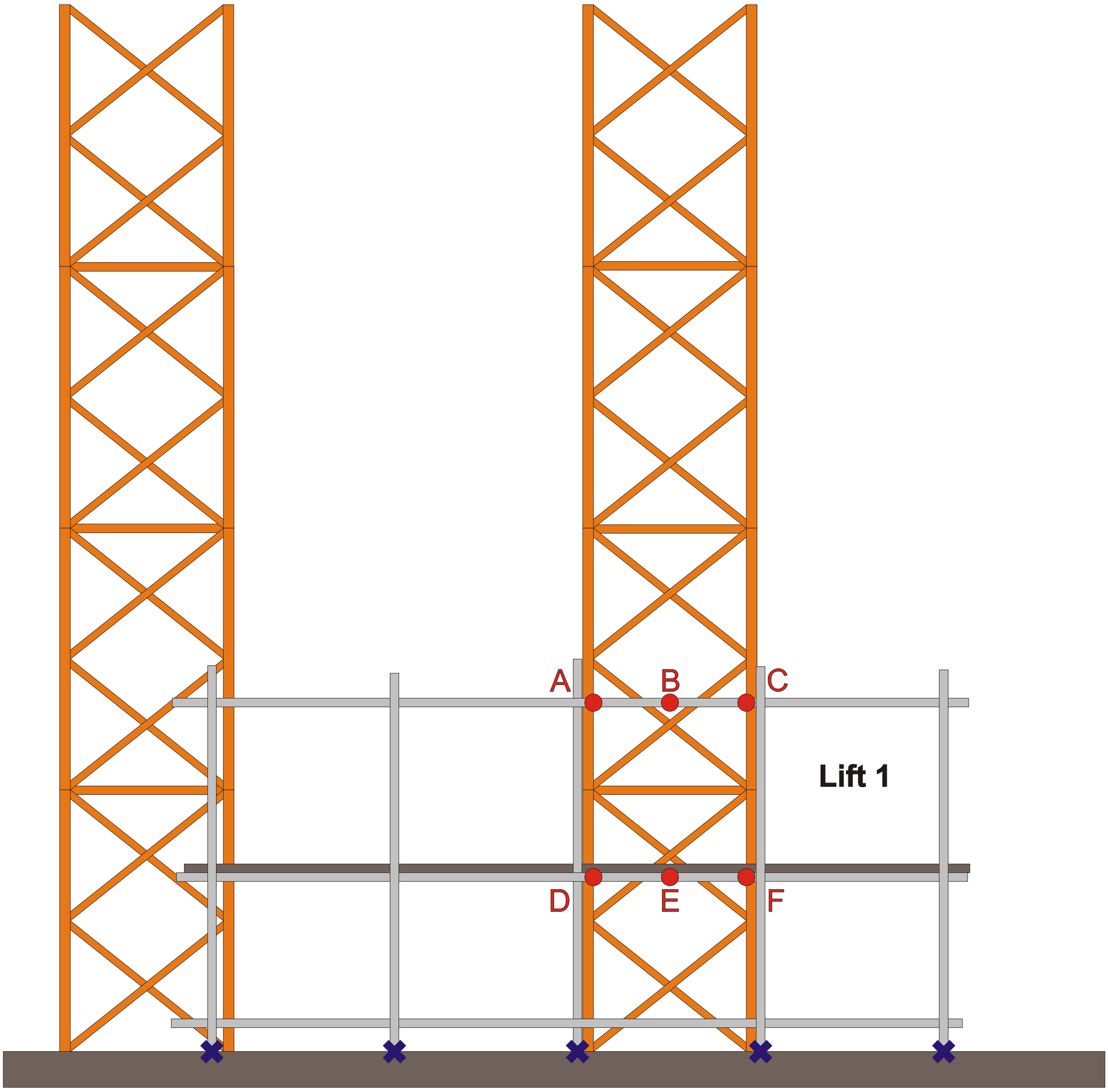


Figure 10 - Attachment points for Lift 1

Commissioning tests on the first lift showed that the scaffold structure was unstable at low force levels (base loadcells indicated that the two standards had lifted from the ground) and had a tendency to bend the ledger at the attachment point. It was decided to progress to the second lift and fit ties back to the supporting structure, as shown in Figures 6 & 7.

4.2 SECOND LIFT

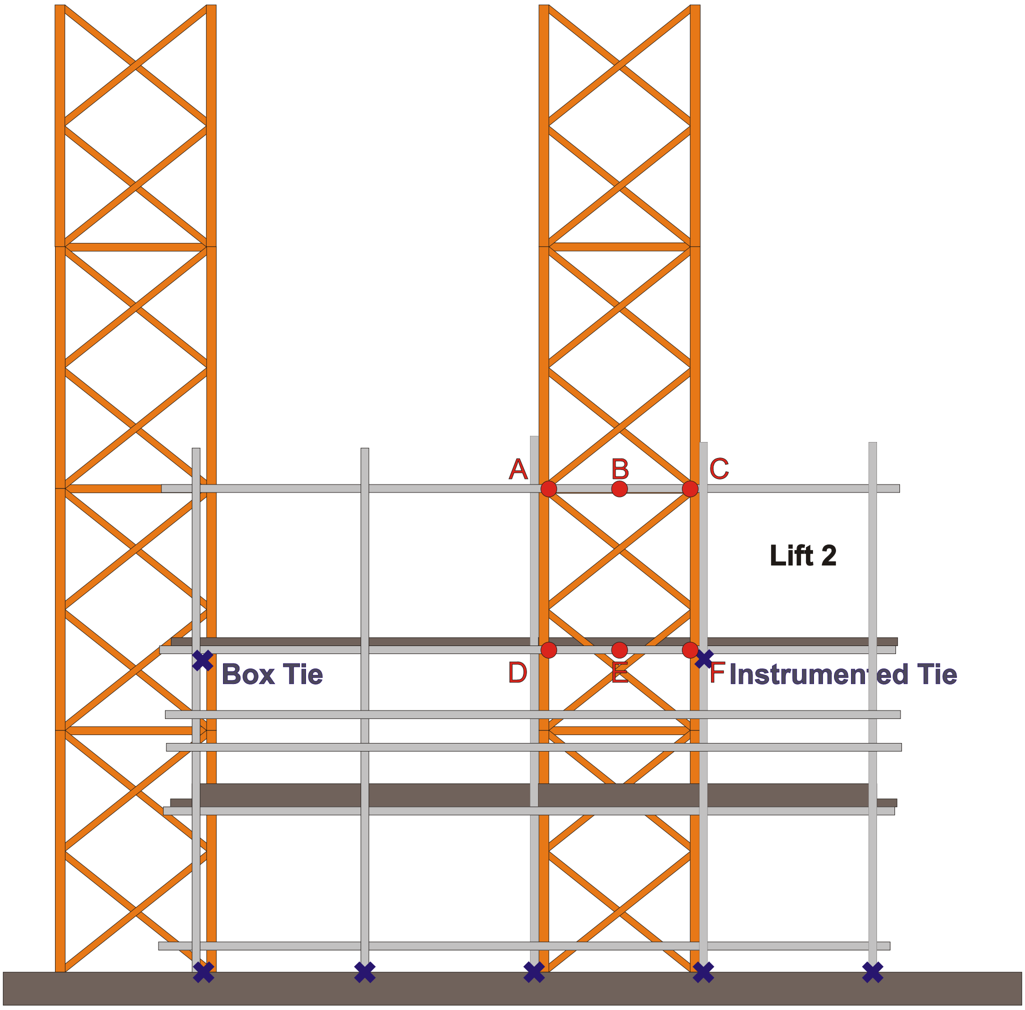


Figure 11 - Attachment points for Lift 2

The second lift was installed and the test programme resumed.

Commissioning tests at various drop heights were used to determine the dynamic force in the lanyard, shown in Table 1

Table 1 – Height to Force Correlation	
Drop Height (mm)	Peak Dynamic Lanyard Force (kN)
700	4.2
1000	5.6
1100	5.7
1700	6.9
1700	6.6
2100	7.4
2600	9.2

It was noticed that attempting to achieve the higher force levels of 10kN in the lanyard was producing detrimental effects to the scaffold. These included bent ledgers and standards. It was agreed with the customer to limit the test programme to a dynamic force in the lanyard of approximately 6kN.

Table 2 shows the results for the drop tests on the second lift. The data includes test number, drop height, forces in the tie and lanyard, ratios of tie force to lanyard force and position of attachment. 'Relative' indicates dynamic forces not including any static offset. 'Absolute' indicates the total force including any static offset. Components of the static offset include the horizontal force caused by the mass of the experimental scaffold and force caused by the slight deflection in the supporting structure when the drop mass is hoisted.

The ratio value shows the relationship of tie force to lanyard force e.g. a ratio of 0.25 with a lanyard force of 6kN would indicate a tie force of 1.5kN

The minimum values in the tie reflect the compressive force seen by the tie, i.e. into the supporting structure, when the drop mass swings into the structure after being arrested by the lanyard.

Table 2. Second Lift Forces (kN)

Test	Drop Height (m)	Tieback				Lanyard		Ratio: Tieback:Lanyard		Position
		Relative		Absolute						
		Min	Max	Min	Max	Min	Max	Relative	Absolute	
T01	1.5	-1.76	**1.78**	-1.47	2.07	-0.03	**6.38**	0.28	0.32	E
T02	1.5	-1.37	**1.44**	-1.14	1.66	-0.02	**6.73**	0.21	0.25	E
T03	1.4	-1.28	**1.33**	-1.03	1.58	-0.02	**6.92**	0.19	0.23	E
T04	1.1	-1.14	**1.34**	-0.89	1.59	-0.02	**5.85**	0.23	0.27	E
T05	1.1	-0.97	**1.38**	-0.72	1.62	-0.01	**5.73**	0.24	0.28	E
T06	2.3	-1.99	**2.01**	-1.72	2.28	-0.03	**9.24**	0.22	0.25	E
T07	2.4	-2.42	**2.45**	-2.24	2.63	-0.02	**9.25**	0.27	0.28	E
T08	2.4	-1.23	**1.48**	-1.14	1.57	-0.01	**10.41**	0.14	0.15	E
T09	1.4	-1.89	**2.71**	-1.73	2.87	-0.03	**6.56**	0.41	0.44	B
T10	1.3	-2.27	**2.83**	-2.04	3.06	-0.03	**7.00**	0.40	0.44	B
T11	1.1	-2.21	**2.91**	-1.96	3.16	-0.01	**7.04**	0.41	0.45	B
T12	1.0	-2.11	**2.11**	-1.85	2.36	-0.02	**6.17**	0.34	0.38	B
T13	2.0	-2.43	**3.74**	-2.21	3.96	-0.04	**8.20**	0.46	0.48	B
T14	1.4	-1.85	**1.76**	-1.62	1.99	-0.01	**7.78**	0.23	0.26	F
T15	1.5	-1.85	**1.76**	-1.47	2.14	-0.01	**7.78**	0.23	0.27	F
T16	1.5	-1.88	**1.80**	-1.45	2.23	-0.01	**8.08**	0.22	0.28	F
T17	1.5	-2.95	**3.22**	-2.51	3.66	-0.01	**6.71**	0.48	0.55	C
T18	1.4	-3.07	**4.17**	-2.96	4.28	-0.02	**7.34**	0.57	0.58	C
T19	1.4	-3.28	**3.81**	-3.09	4.00	-0.05	**6.52**	0.58	0.61	C
T20	1.4	Void Test								D
T21	1.3	-2.81	**2.28**	-2.60	2.49	-0.03	**8.01**	0.28	0.31	D
T22	1.3	Void Test								D
T23	1.3	-2.17	**1.79**	-1.99	1.97	-0.02	**7.47**	0.24	0.26	D
T24	1.2	-1.76	**1.52**	-1.60	1.68	-0.02	**6.97**	0.22	0.24	D
T25	1.0	-2.56	**1.95**	-2.39	2.13	-0.02	**6.25**	0.31	0.34	A
T26	1.0	-2.94	**1.85**	-2.69	2.11	-0.02	**6.37**	0.29	0.33	A
T27	1.0	-3.05	**2.14**	-2.85	2.33	-0.02	**6.42**	0.33	0.36	A

Base forces and sample graph T16 are shown in Appendix C

4.3 THIRD LIFT

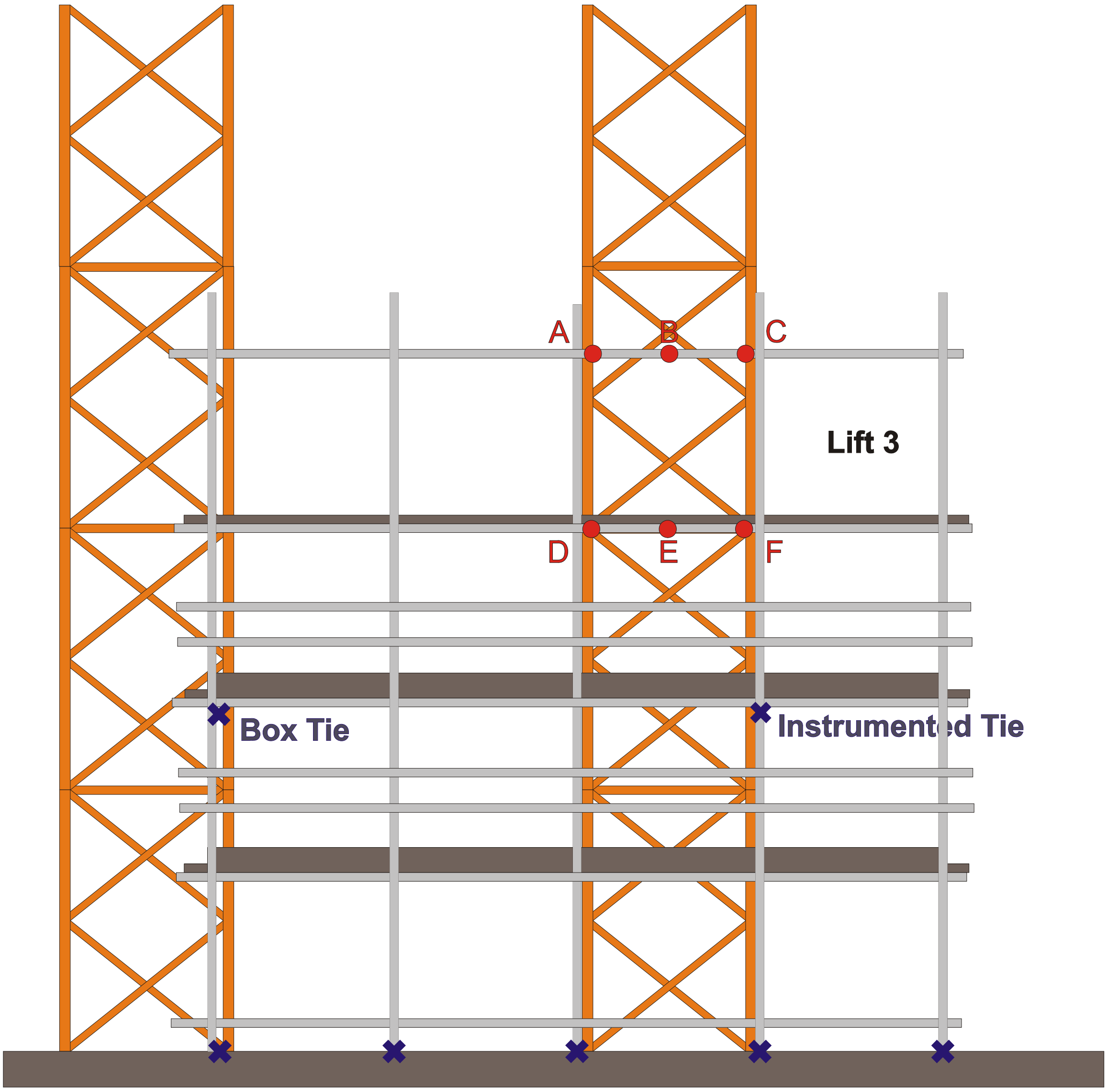


Figure 12 - Attachment points for Lift 3

During construction of the third lift, it was reported back by the scaffold contractors that the rig had suffered cumulative damage by the previous testing and required a substantial rebuild. Ledgers and standards had been bent and needed to be replaced. Transoms had slipped through couplers and were reset and the couplers re-tightened.

Table 3. Third Lift Forces (kN)

Test	Drop Height (mm)	Tieback				Lanyard		Ratio Tieback:Lanyard		Position
		Relative		Absolute						
		Min	Max	Min	Max	Min	Max	Relative	Absolute	
T28	1.1	-2.20	**1.47**	-1.99	1.68	-0.02	**7.15**	0.21	0.24	E
T29	1.1	-2.42	**1.56**	-2.14	1.85	-0.03	**7.34**	0.21	0.25	E
T30	1.0	-2.52	**1.41**	-2.15	1.78	-0.02	**7.34**	0.19	0.24	E
T31	1.0	-2.33	**2.33**	-1.99	2.68	-0.02	**6.02**	0.39	0.44	B

T32	1.0	-2.39	**2.37**	-2.22	2.54	-0.01	**6.72**	0.35	0.38	B
T33	1.0	-2.47	**2.46**	-2.41	2.52	-0.01	**5.86**	0.42	0.43	B
T34	1.0	-2.60	**1.92**	-2.47	2.05	-0.01	**5.16**	0.37	0.40	A
T35	1.1	-2.52	**1.74**	-2.33	1.94	-0.02	**5.39**	0.32	0.36	A
T36	1.1	-2.48	**2.00**	-2.31	2.17	-0.01	**6.07**	0.33	0.36	A
T37	1.1	-2.24	**1.54**	-2.16	1.62	-0.02	**5.82**	0.27	0.28	D
T38	1.1	-2.05	**1.33**	-1.83	1.55	-0.03	**6.51**	0.20	0.24	D
T39	1.1	-2.36	**1.50**	-2.20	1.66	-0.01	**6.36**	0.24	0.26	D
T40	1.1	-2.65	**1.47**	-2.49	1.63	-0.02	**5.61**	0.26	0.29	F
T41	1.1	-2.87	**1.57**	-2.64	1.80	-0.03	**6.32**	0.25	0.28	F
T42	1.1	-3.04	**1.48**	-2.67	1.85	-0.02	**6.35**	0.23	0.29	F
T43	1.1	-2.56	**2.39**	-2.04	2.91	-0.01	**4.93**	0.49	0.59	C
T44	1.1	-2.15	**2.91**	-2.00	3.06	-0.01	**5.75**	0.51	0.53	C
T45	1.1	-2.15	**2.78**	-2.13	2.80	-0.02	**5.49**	0.51	0.51	C

Base forces and sample graph T39 are shown in Appendix C

4.4 FOURTH LIFT

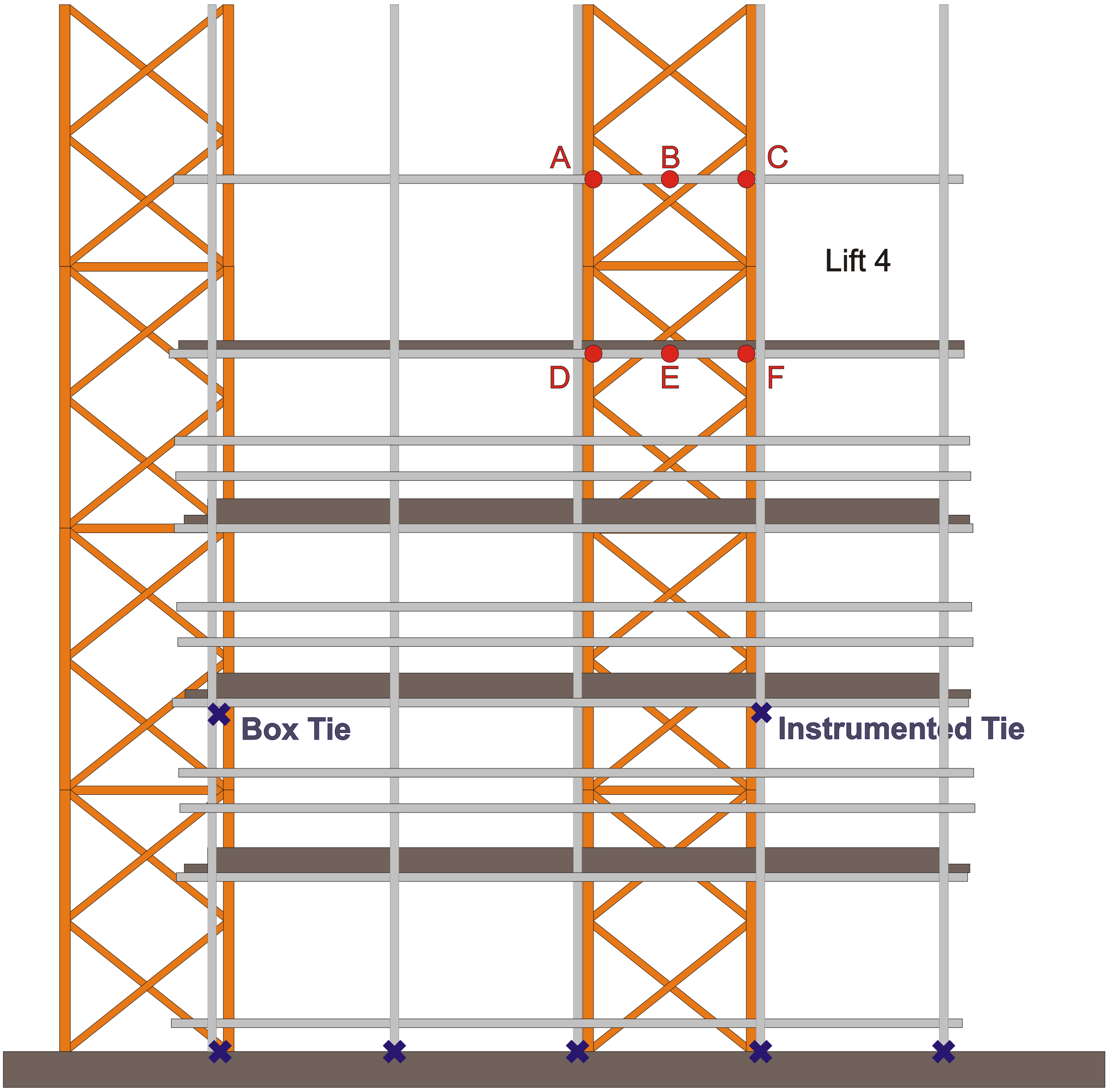


Figure 13 - Attachment points for Lift 4

No remedial work was required during the fourth lift construction. Little cumulative damage was noted.

Table 4. Fourth Lift Forces (kN)

Test	Drop Height (mm)	Tieback				Lanyard		Ratio Tieback:Lanyard		Postion
		Relative		Absolute						
		Min	Max	Min	Max	Min	Max	Relative	Absolute	
T46	1.1	-1.09	**2.03**	-1.11	2.01	-0.01	**4.53**	0.45	0.44	E
T47	1.1	-1.65	**1.46**	-1.67	1.44	-0.01	**6.01**	0.24	0.24	E
T48	1.1	-1.58	**1.44**	-1.55	1.47	-0.01	**5.66**	0.25	0.26	E
T49	1.1	Test Void								E
T50	1.1	-1.50	**1.36**	-1.54	1.32	-0.06	**0.06**	0.31	0.30	E
T51	1.2	-1.43	**1.49**	-1.43	1.49	0.00	**6.68**	0.22	0.22	E

T52	1.2	-1.85	**1.90**	-1.82	1.94	-0.01	**5.50**	0.35	0.35	B
T53	1.2	-2.07	**2.68**	-2.23	2.52	-0.01	**6.58**	0.41	0.38	B
T54	1.2	-2.04	**2.76**	-2.23	2.57	-0.02	**6.42**	0.43	0.40	B
T55	1.2	Test Void								C
T56	1.2	-2.11	**2.53**	-2.31	2.33	-0.02	**5.23**	0.48	0.45	C
T57	1.2	-2.15	**2.70**	-2.33	2.52	-0.02	**5.35**	0.50	0.47	C
T58	1.3	-2.10	**2.77**	-2.33	2.53	-0.02	**5.43**	0.51	0.47	C
T59	1.3	-1.69	**2.31**	-1.95	2.04	-0.02	**6.20**	0.37	0.33	F
T60	1.3	-1.61	**2.27**	-1.86	2.02	-0.02	**7.27**	0.31	0.28	F
T61	1.3	-1.63	**2.19**	-1.86	1.95	-0.02	**7.12**	0.31	0.27	F
T62	1.3	-1.69	**1.58**	-1.97	1.30	-0.01	**4.92**	0.32	0.26	D
T63	1.4	-1.71	**1.65**	-1.95	1.42	-0.01	**5.73**	0.29	0.25	D
T64	1.4	-1.61	**1.74**	-1.87	1.47	-0.01	**5.88**	0.30	0.25	D
T65	1.5	-1.78	**1.80**	-2.05	1.53	-0.02	**5.66**	0.32	0.27	D
T66	1.3	-1.78	**1.61**	-1.95	1.44	-0.01	**4.99**	0.32	0.29	A
T67	1.4	-2.03	**2.04**	-2.29	1.77	-0.01	**5.68**	0.36	0.31	A
T68	1.5	-2.09	**1.90**	-2.28	1.71	0.00	**6.04**	0.31	0.28	A

Minor damage was noted at the end of the fourth lift testing. There was a slight bend in the top ledger.

Base forces and sample graph T68 are shown in Appendix C

5 DISCUSSION AND CONCLUSION

From Table 1 it is shown that the relationship between drop height and resultant lanyard force is not accurately reproducible. Many variables contribute to this effect including friction between the lanyard and scaffold boards, atmospheric conditions (humidity and temperature effects on the lanyard), and the cumulative effects of loading the scaffold structure. Because of this it proved difficult to produce a uniform dynamic force for each test.

However, to simplify results and remove the variance of the simulated load, the ratio of tieback load to lanyard force was used to provide a dimensionless figure.

It can be seen from Tables 2, 3 and 4 that for each lift, tie force to lanyard force ratios are greater for upper ledger than lower ledger attachment.

Table 5 in Appendix A shows average values of the tie force to lanyard force ratios for each of the eighteen test locations.

Appendix B shows a comparison of the force recorded in the base loadcells to the lanyard force.

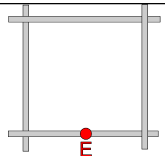
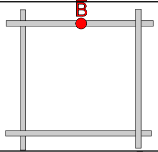
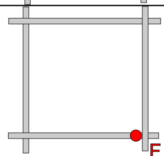
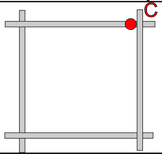
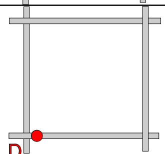
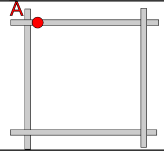
Appendix C shows three sample graphs, one for each lift, out of the 68 in total.

The tie force to lanyard force ratios for a given location remain similar independent of the lift tested, this could be explained by the force being spread out over the structure as it gets larger.

At low lift count the energy of a fall is more likely to produce damage to the structure rather than pull out ties.
Severe damage to the scaffold structure was evident during the early stages of the programme, whereas in the later stages, very little damaged was noted. It is likely that stiffer structures, such as a single, or double lift are more prone to experience plastic deformation. Larger structures have more capacity to absorb the energy as elastic deformation, and show less gross damage.

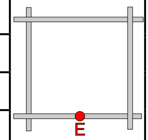
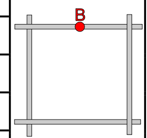
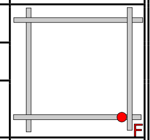
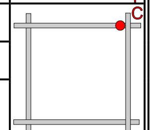
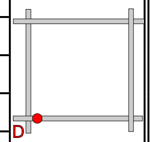
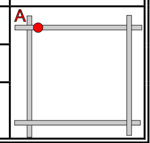
6 APPENDIX A – AVERAGE RATIO VALUES

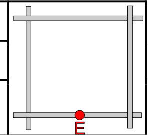
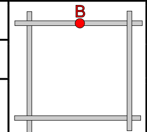
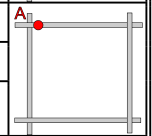
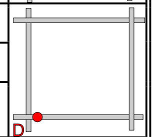
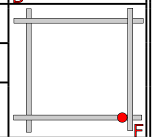
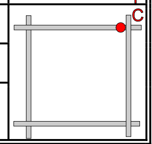
Table 5 – Average Ratio Values

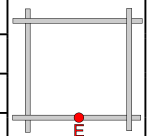
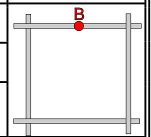
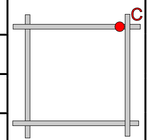
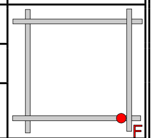
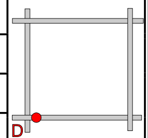
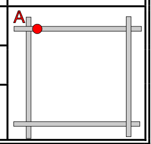
Position	2nd Lift		3rd Lift		4th Lift	
	Relative	Absolute	Relative	Absolute	Relative	Absolute
	0.23[1]	0.27[1]	0.20	0.24	0.30	0.29
	0.41	0.44	0.39	0.42	0.39	0.38
	0.23	0.27	0.25	0.29	0.33	0.29
	0.54	0.58	0.50	0.54	0.50	0.46
	0.25	0.27	0.23	0.26	0.31	0.26
	0.31	0.34	0.34	0.37	0.33	0.29

Note 1: The tie force from test number T08 has been excluded from the averaging, as the value recorded was substantially lower from the other values. As this test was the most severe it is possible that forces from the impact were translated into plastic deformation and the tie did not experience the full force.

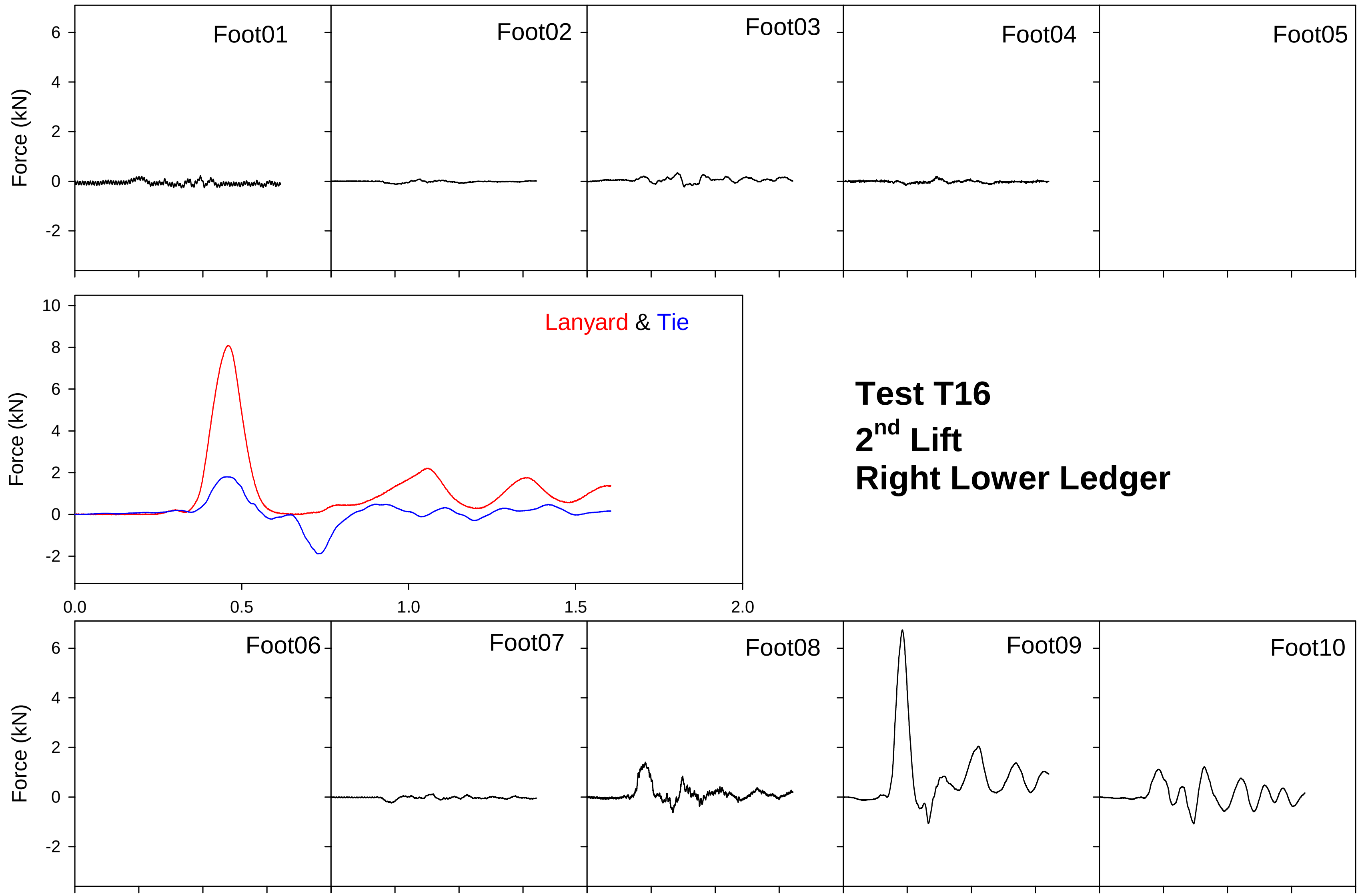
7 APPENDIX B – BASE FORCES (KN)

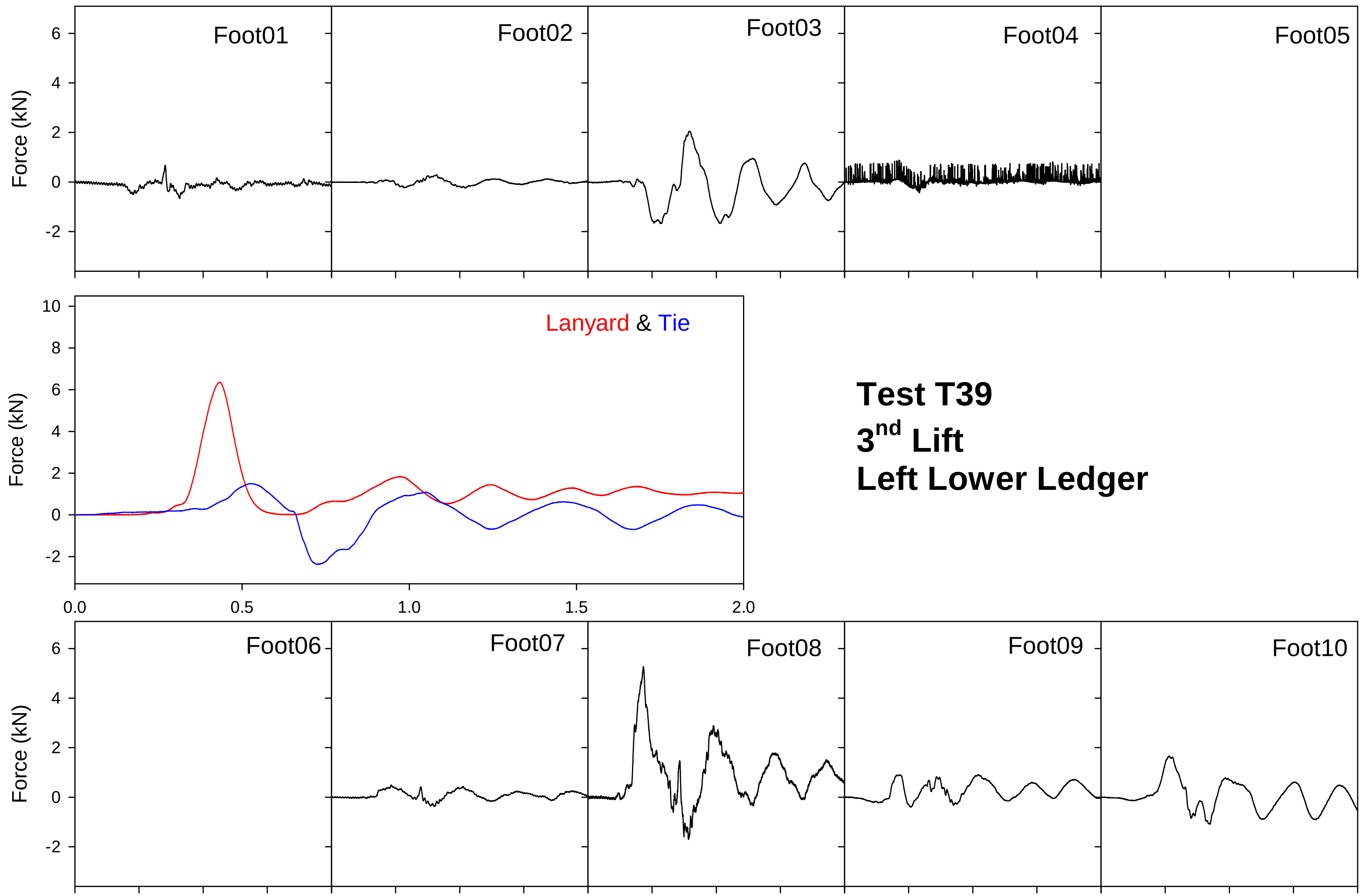
Test	Lanyard		Foot01		Foot02		Foot04		Foot03		Foot07		Foot08		Foot09		Foot10		Position
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
T01	-0.03	6.38	-0.08	0.31	-0.29	0.21	-0.54	1.29	-0.78	3.35	-0.42	0.13	-3.23	4.68	-0.36	2.30	-0.98	1.04	
T02	-0.02	6.73	-0.25	0.21	-0.20	0.18	-0.29	1.39	-0.68	3.00	-0.42	0.10	-3.37	4.79	-0.60	2.57	-0.76	0.65	
T03	-0.02	6.92	-0.17	0.20	-0.17	0.18	-0.22	1.47	-0.63	2.72	-0.39	0.06	-3.37	4.71	-0.69	2.63	-0.60	0.74	
T04	-0.02	5.85	-0.16	0.18	-0.17	0.16	-0.28	1.42	-0.55	2.98	-0.30	0.12	-3.03	3.99	-0.24	2.22	-0.60	0.70	
T05	-0.01	5.73	-0.16	0.21	-0.17	0.15	-0.25	1.52	-0.53	2.99	-0.31	0.08	-2.88	3.91	-0.24	2.42	-0.75	0.97	
T06	-0.03	9.24	-0.27	0.33	-0.33	0.26	-0.43	1.37	-0.82	3.20	-0.68	0.16	-3.35	6.20	-0.62	3.96	-0.75	0.97	
T07	-0.02	9.25	-0.20	0.33	-0.47	0.23	-0.41	1.45	-0.62	3.61	-0.67	0.19	-3.51	6.11	-0.61	3.82	-0.81	1.32	
T08	-0.01	10.41	-0.16	0.37	-0.20	0.21	-0.35	1.32	-0.47	2.37	-0.72	0.15	-3.49	7.08	-1.68	4.94	-0.39	0.59	
T09	-0.03	6.56	-0.45	0.57	-0.74	0.32	-0.52	2.89	-0.67	4.24	-0.42	0.47	-3.49	2.24	-0.80	1.19	-1.73	1.30	
T10	-0.03	7.00	-0.57	0.39	-0.65	0.28	-0.66	2.35	-1.43	3.18	-0.83	0.39	-2.14	2.47	-1.09	1.26	-2.25	0.47	
T11	-0.01	7.04	-0.66	0.32	-0.67	0.26	-0.61	2.98	-1.45	3.02	-0.61	0.41	-2.11	2.49	-1.41	1.00	-2.31	0.41	
T12	-0.02	6.17	-0.52	0.31	-0.63	0.25	-0.51	2.79	-1.42	2.73	-0.62	0.35	-1.79	2.84	-1.12	1.21	-2.18	0.81	
T13	-0.04	8.20	-0.73	0.73	-0.80	0.17	-0.69	2.56	-1.48	3.24	-1.10	0.47	-1.63	2.67	-1.58	0.97	-2.36	0.80	
T14	-0.01	7.78	-0.32	0.22	-0.12	0.08	-0.18	0.19	-0.16	0.43	-0.21	0.14	-0.91	1.35	-0.89	6.48	-1.24	1.40	
T15	-0.01	7.78	-0.32	0.22	-0.12	0.08	-0.18	0.19	-0.16	0.43	-0.21	0.14	-0.91	1.35	-0.89	6.48	-1.24	1.40	
T16	-0.01	8.08	-0.27	0.22	-0.13	0.09	-0.17	0.19	-0.23	0.34	-0.24	0.12	-0.63	1.40	-1.06	6.74	-1.08	1.23	
T17	-0.01	6.71	-0.64	0.70	-0.48	0.44	-0.76	3.09	-0.93	1.87	-0.41	0.53	-2.21	1.80	-1.47	1.78	-1.74	2.14	
T18	-0.02	7.34	-0.47	0.94	-0.67	0.46	-0.89	3.34	-1.28	1.97	-0.32	0.51	-2.29	2.59	-1.49	1.46	-2.74	0.90	
T19	-0.05	6.52	-0.40	0.74	-0.72	0.35	-1.04	2.89	-1.51	1.65	-0.28	0.41	-1.99	2.77	-1.45	1.66	-2.65	0.57	
T20	Test Void																		
T21	-0.03	8.01	-0.44	0.35	-0.31	0.26	-0.19	0.17	-1.31	1.13	-0.34	0.35	-1.85	6.91	-0.32	1.04	-1.67	1.15	
T22	Test Void																		
T23	-0.02	7.47	-0.43	0.24	-0.26	0.29	-0.15	0.18	-1.10	0.82	-0.30	0.29	-1.98	6.42	-0.36	0.57	-1.30	0.95	
T24	-0.02	6.97	-0.50	0.13	-0.23	0.23	-0.11	0.18	-0.95	0.73	-0.24	0.26	-1.79	6.21	-0.41	0.59	-1.17	1.00	
T25	-0.02	6.25	-0.79	0.30	-0.44	0.41	-0.47	0.65	-1.32	3.30	-0.41	0.61	-1.48	3.28	-0.85	1.10	-1.71	0.73	
T26	-0.02	6.37	-0.93	0.31	-0.45	0.38	-0.31	0.69	-1.38	2.91	-0.38	0.55	-1.69	3.88	-0.74	0.76	-1.48	1.34	
T27	-0.02	6.42	-0.75	0.55	-0.56	0.28	-0.50	0.74	-1.52	3.17	-0.33	0.66	-1.67	3.81	-0.69	1.07	-1.62	0.77	

Test	Lanyard		Foot01		Foot02		Foot04		Foot03		Foot07		Foot08		Foot09		Foot10		Position
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
T28	-0.02	7.15	-0.44	0.26	-0.26	0.32	-0.64	0.49	-1.37	2.58	-0.74	0.40	-2.54	4.77	-1.12	3.46	-1.73	1.41	
T29	-0.03	7.34	-0.40	0.27	-0.33	0.30	-0.49	0.67	-1.35	2.85	-0.71	0.46	-2.94	4.73	-0.96	3.57	-1.48	1.71	
T30	-0.02	7.34	-0.49	0.18	-0.29	0.28	-0.32	0.67	-1.41	2.67	-0.65	0.40	-2.79	4.50	-1.00	4.21	-1.56	1.73	
T31	-0.02	6.02	-0.52	0.30	-0.81	0.24	-0.66	3.00	-1.83	3.23	-0.63	0.53	-3.03	5.42	-0.90	1.08	-2.21	1.77	
T32	-0.01	6.72	-0.92	0.21	-0.88	0.28	-0.89	3.19	-1.94	2.97	-0.67	0.50	-3.07	6.09	-1.27	1.29	-2.66	1.54	
T33	-0.01	5.86	-0.78	0.21	-0.78	0.29	-1.18	2.89	-1.95	3.20	-0.69	0.41	-3.13	5.29	-1.53	1.68	-3.02	1.20	
T34	-0.01	5.16	-0.72	0.22	-0.53	0.36	-0.75	1.81	-2.01	3.11	-0.67	0.36	-2.76	5.56	-0.52	1.77	-2.33	1.13	
T35	-0.02	5.39	-0.67	0.18	-0.58	0.23	-0.90	1.35	-2.14	2.71	-0.72	0.37	-2.67	5.62	-0.55	1.39	-2.49	1.47	
T36	-0.01	6.07	-0.74	0.35	-0.76	0.27	-0.86	1.62	-2.13	2.56	-0.66	0.33	-2.14	6.32	-0.84	1.14	-2.60	1.46	
T37	-0.02	5.82	-0.67	0.14	-0.21	0.39	-0.48	1.02	-1.72	2.28	-0.60	0.33	-2.20	4.61	-0.64	1.37	-1.78	1.06	
T38	-0.03	6.51	-0.81	0.35	-0.25	0.25	-0.36	1.04	-1.57	2.27	-0.52	0.48	-2.50	5.14	-0.41	1.21	-1.74	1.28	
T39	-0.01	6.36	-0.66	0.68	-0.23	0.29	-0.44	0.89	-1.67	2.06	-0.37	0.49	-1.71	5.27	-0.40	0.90	-1.09	1.65	
T40	-0.02	5.61	-0.43	0.28	-0.22	0.23	-0.51	0.79	-1.46	2.10	-0.42	0.33	-2.03	1.91	-0.33	5.18	-1.44	1.30	
T41	-0.03	6.32	-0.40	0.36	-0.22	0.24	-0.42	0.95	-1.38	2.19	-0.42	0.37	-2.17	1.72	-0.49	5.61	-1.65	1.32	
T42	-0.02	6.35	-0.45	0.27	-0.19	0.20	-0.46	0.78	-1.21	2.12	-0.52	0.25	-2.21	1.71	-0.55	5.69	-1.00	1.40	
T43	-0.01	4.93	-0.81	0.15	-0.80	0.23	-0.91	3.83	-2.01	1.99	-0.54	0.35	-2.41	3.68	-1.69	2.06	-2.43	2.04	
T44	-0.01	5.75	-0.80	0.27	-0.80	0.32	-1.26	4.19	-1.80	2.38	-0.51	0.40	-2.70	3.66	-1.85	2.29	-3.19	1.44	
T45	-0.02	5.49	-0.71	0.26	-0.72	0.28	-1.30	3.25	-1.83	2.62	-0.54	0.46	-2.82	4.47	-1.81	1.82	-3.35	1.07	

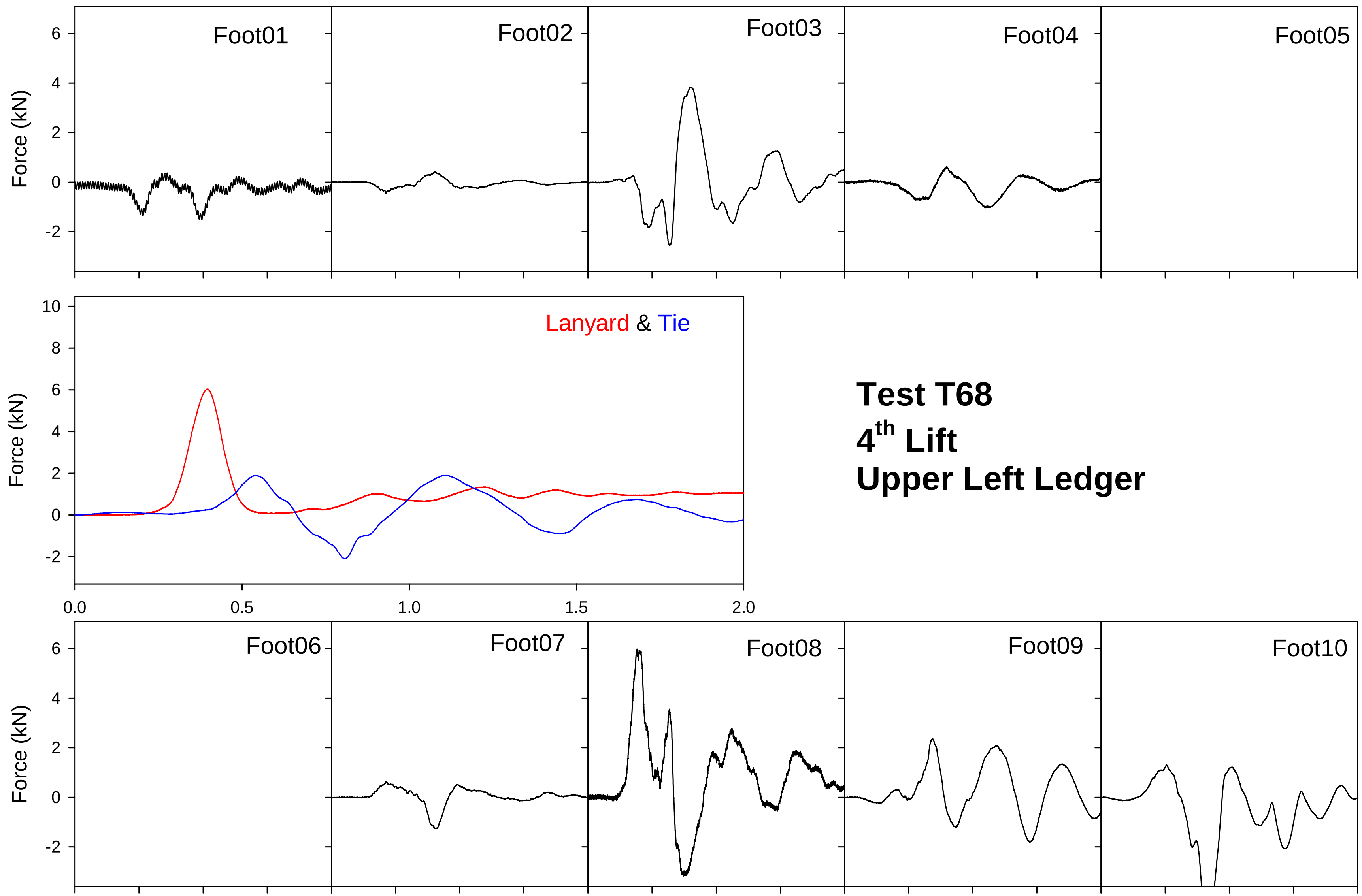
Test	Lanyard		Foot01		Foot02		Foot04		Foot03		Foot07		Foot08		Foot09		Foot10		Position
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
T46	-0.01	4.53	-1.48	0.44	-0.52	0.24	-0.91	1.13	-2.84	0.79	-1.14	0.63	-0.86	4.71	-0.91	2.62	-3.34	2.18	
T47	-0.01	6.01	-0.81	0.79	-0.27	0.18	-0.80	1.35	-1.34	1.31	-0.60	0.43	-0.90	4.27	-0.94	2.45	-3.03	2.63	
T48	-0.01	5.66	-0.92	1.03	-0.18	0.29	-0.95	1.19	-1.19	1.21	-0.71	0.41	-0.91	4.30	-1.12	2.44	-3.22	2.29	
T49	Test Void																		
T50	-0.06	0.06	-0.52	0.10	-0.18	0.25	-0.74	0.17	-1.55	1.42	-0.74	0.33	-1.80	3.40	-0.84	2.44	-2.93	1.36	
T51	0.00	6.68	-0.58	0.23	-0.21	0.25	-0.84	0.18	-1.70	1.68	-0.83	0.48	-2.46	4.55	-1.49	3.74	-3.15	1.59	
T52	-0.01	5.50	-1.08	0.30	-0.62	0.33	-0.65	1.26	-2.09	4.40	-0.96	0.48	-3.91	3.70	-1.67	2.13	-4.25	1.38	
T53	-0.01	6.58	-1.17	0.34	-0.79	0.35	-1.03	1.69	-3.20	3.93	-1.07	0.73	-3.42	5.97	-2.66	2.40	-5.21	0.89	
T54	-0.02	6.42	-0.91	0.57	-0.75	0.38	-1.11	1.53	-3.16	3.76	-1.20	0.63	-3.37	5.95	-2.79	2.59	-5.63	0.62	
T55	Test Void																		
T56	-0.02	5.23	-0.75	0.44	-0.42	0.37	-1.16	1.63	-3.29	3.36	-0.95	0.49	-3.32	4.44	-2.68	2.40	-5.60	0.42	
T57	-0.02	5.35	-0.89	0.31	-0.46	0.34	-1.29	1.62	-3.39	3.34	-0.92	0.51	-3.42	4.57	-2.72	2.40	-5.58	0.58	
T58	-0.02	5.43	-1.10	0.36	-0.46	0.32	-1.27	1.66	-3.35	3.32	-0.88	0.54	-3.38	4.51	-2.93	2.46	-5.50	0.61	
T59	-0.02	6.20	-0.77	0.23	-0.27	0.34	-1.16	0.60	-2.67	3.61	-1.04	0.44	-3.29	3.27	-2.29	5.16	-5.48	0.40	
T60	-0.02	7.27	-0.64	0.31	-0.24	0.37	-1.01	0.54	-2.59	3.51	-0.98	0.47	-3.29	3.25	-2.56	5.90	-5.30	0.74	
T61	-0.02	7.12	-0.68	0.35	-0.26	0.35	-0.98	0.43	-2.55	3.53	-0.95	0.42	-3.29	3.23	-2.73	6.03	-5.18	0.70	
T62	-0.01	4.92	-0.82	0.25	-0.25	0.31	-0.80	0.33	-1.49	3.33	-0.92	0.44	-2.54	5.07	-1.39	2.10	-4.66	1.11	
T63	-0.01	5.73	-0.83	0.30	-0.25	0.36	-0.90	0.41	-1.52	3.39	-1.04	0.44	-2.72	5.57	-1.46	1.72	-4.66	0.66	
T64	-0.01	5.88	-0.86	0.30	-0.28	0.35	-0.91	0.43	-1.74	3.15	-1.03	0.44	-2.78	5.74	-1.29	1.90	-4.74	0.95	
T65	-0.02	5.66	-1.11	0.34	-0.29	0.40	-1.01	0.48	-1.65	3.85	-1.14	0.47	-2.99	5.44	-1.67	2.06	-4.78	1.73	
T66	-0.01	4.99	-0.85	0.57	-0.41	0.31	-0.83	0.48	-1.62	3.54	-0.84	0.62	-3.03	4.60	-1.41	1.97	-4.48	1.49	
T67	-0.01	5.68	-1.32	0.63	-0.38	0.42	-1.00	0.65	-2.43	3.77	-1.19	0.57	-3.26	5.74	-1.79	2.60	-5.22	0.96	
T68	0.00	6.04	-1.52	0.37	-0.43	0.42	-1.03	0.62	-2.54	3.84	-1.27	0.62	-3.18	5.99	-1.81	2.36	-5.17	1.30	

8 APPENDIX C – SAMPLE GRAPHS





Foot01
Foot02
Foot03
Foot04
Foot05
Force (kN)
6
4
2
0
-2
Lanyard & Tie
10
8
0.0
0.5
1.0
1.5
2.0
Foot06
Foot07
Foot08
Foot09
Foot10
Test T39
3rd Lift
Left Lower Ledger



Test T68
4^{th} Lift
Upper Left Ledger