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Shore Load Monitoring During Concrete Placement

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Abstract: The purpose of this work is to determine and compare the actual and theoretical shore loads in steel scaffold-type formwork supporting systems. A detailed on-site survey was conducted in four pour areas of a multi-storey shopping centre project in Sydney, Australia.

Keywords: Experimental; Theoretical; Construction Load; Structure; Scaffolds; Concrete.

1. Introduction

Steel support scaffolds are commonly used in construction as shoring systems while building the formwork to support reinforced concrete structures. A steel support scaffold frame normally consists of standards (column members), ledgers (beam members), braces and jacks (Figure 1 – 3). The standards are connected to ledgers via various types of connections, such as wedge-type joints and cuplok joints. The base of scaffold frames consist of jack bases whose length can be adjusted to accommodate irregularity of the ground.

Although steel scaffolds are temporary structures, their failure often has fatal consequence. The main causes of scaffold collapses are overloading (Hadipriono & Wang, 1987). Current practice in the design of steel scaffold systems is to use the load capacity recommended by the manufacturers based on load tests, and then apply a judgmental safety factor. By investigating the dead and live loads that occur during multiple on-site investigations, and comparing these with theoretical shore loads, it will be possible to understand and make judgement on the variability of shore loads.

This paper details the equipment and experimental procedure used to acquire shore load data on a multi-storey concrete construction site. In four separate pour areas, uprights of the scaffold system were instrumented with load cells during both

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the concrete casting and curing phases to obtain the actual loads transmitted to the supporting scaffolds. The load survey data are then presented and compared with theoretical shore loads calculated using tributary areas. The two components of the shoring load, i.e., the dead load and the live load, are investigated. Statistical analysis of shore loads is performed. Factors that may cause variability and non-uniform load distributions in shores are identified. The shore load information will be used to investigate the adequacy of the current shore load calculation and provide design guidelines for safer and more reliable formwork supporting systems. The work presented in this paper is part of an ongoing project which aims to develop a probabilistic-based design methodology for scaffold-type formwork supporting systems.

2. Site Investigation Details

The building under investigation was a 4 storey shopping complex in Merrylands, Sydney. The general construction was a post-tensioned, one-way slab spanning 8.7m between beams and columns, as seen in Figure 1a. Floor to Floor heights ranged from 3.8m to 7.7m, slab thicknesses ranged from 170mm to 320mm, grid spacing was 8.2m in north-south direction and 8.7m in east-west direction. Experiments were conducted on three levels of the building. However no experiments were conducted where the base plates of the standards bore on ground, in turn eliminating any differential settlement occurring in base plates. Investigation into differential settlement effects are expected to begin in the near future. The client and owner of the site was Stocklands™, the project manager and contractor was Brookfield Multiplex Pty Ltd, whilst the formwork subcontractor was Rediform Pty. Ltd.

The general arrangement of formwork was 17mm soffit plywood, Truform 95 x 65 LVL Joists and Truform 150 x 77 LVL Bearers which spanned between U-heads and the consequential scaffolding bays which ranged in size from 1.0 to 1.83m in perpendicular directions. Furthermore, there was typically three 1.5m lifts of scaffolding with an average top jack extension of 300mm.

Four separate pour areas were investigated on level one and level two of the site. Level one being future retail space and level two being a rooftop car park slab. In each investigation, data was collected for at least 24 hours at each location from twenty shores which each had a 100 kN load cell installed (Figure 4). Concrete was pumped through a 100mm diameter hose by a gang of 6-10 concreters. The pump rate was typically 60 m^3/hr and the average hose suspension height above slab soffit was approximately 350mm. The concrete placement pattern was in a typical “s-shape” across the pour area (Figure 6). The concrete type and grade was a Boral

Post-Tensioned 40 MPa mix. The concrete density was determined on an average of each truck load by the supplier. The concrete density for pour areas 1 – 4 was determined to be 22.531, 22.114, 22.899, 23.144 kN/m^3, respectively.

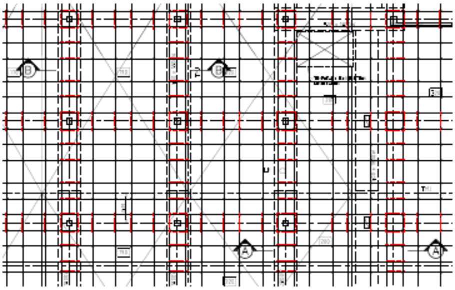

Fig. 1. Snapshot of the General Arrangement of Level 2 beams, slabs and scaffolding layout.

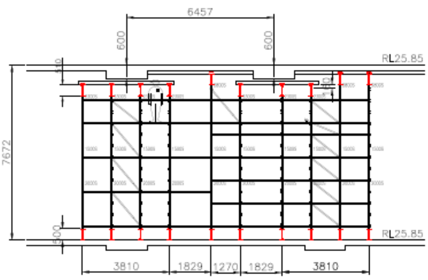

Fig. 2. Elevation A-A from fig 1.

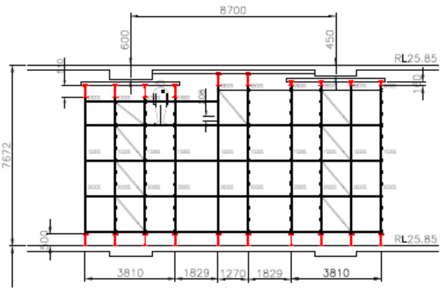

Fig. 3. Elevation B-B from fig 1.

2.1. Instrumentation Used

20 modified U-heads were utilised for the site investigation in all four tests. The modified U-heads contained a strain gauge based stainless steel load cell with 100kN capacity (Figure 4).

Fig. 4. Load cell contained in U-head support.

A site box was used to store the testing equipment including the data acquisition system and cabling, a single computer, a cooling fan and camera equipment; whilst the test was being conducted. The site box was completely waterproofed, earthed, locked and chained at all times. A single 20 channel Vishay V5000 data acquisition module was used to collect data at a sample rate of 0.5 seconds for each of the 20 channels. A single computer was used to store the data automatically as it was recorded by the Vishay system. The data was then exported from Strain Smart V4.01 software and interrogated using Matlab.

2.2. Experimental Study

Each on-site experimental study included the following procedure:

1. Determine the locations for each of the 20 load cells.
2. Unscrew old and install the instrumented U-heads in these locations ensuring that the top plate of the old and the top plate of the new U-heads are in the exact same position in the vertical plane.
3. Connect all 20 load cells back to the data acquisition system using each load cells associated and calibrated cable.
4. Initiate data recording prior to concrete placement to measure dead and live loads during concrete placement and curing.

Fig. 5. Typical experimental set up with U-heads in place and cables attached.

As one could anticipate, experimental site investigations occurring on a commercial site are quite complex to undertake due to time pressures, co-ordination of activities with other subcontractors, health and safety issues, accreditation etc. In this respect the site experimentation did not have the same freedom and precision as a controlled laboratory environment.

3. Site Investigation Results

Instrumentation and data acquisition was undertaken in four separate pour areas on four separate days between 21st June and the 1st of August 2011. A summary of the four site investigations is highlighted in Table 1.

Table 1. Initial Summary of Statistics for Results

RATIO OF AVG VALUES	Test 1		Test 2		Test 3		Test 4	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Relative Dead Load (Actual /Theoretical)	0.720	0.149	1.038	0.341	1.181	0.237	0.986	0.231
Initial Shore Pre-load (Actual / Theoretical)	-	-	0.790	0.771	0.293	0.241	0.638	0.622
Relative Live Load (Actual /Theoretical)	0.964	0.25	0.753	0.201	0.645	0.219	0.596	0.291
Actual Live Load (kPa)	0.964		0.75		0.65		0.6	

The Relative Dead Load is the ratio of actual to theoretical dead load and includes the weight of wet concrete, steel reinforcement and timber formwork. Dead load was measured after concrete had been poured and all workers and equipment were off the slab.The Relative Live Load is the ratio of actual to theoretical live load and during pouring includes the weight of workmen and equipment as well as the temporary mounding of concrete. The Initial Shore Pre-load is the ratio of actual to theoretical load in shores prior to concreting and as such includes the weight of formwork and steel reinforcement.

3.1. Site Investigation One

The on-site process of installing load cell devices in site investigation one, were performed in a different manner to site investigations two-four. The methodology was consistent with how the formwork subcontractors typically adjust the U-head supports and as such no initial shore pre-load could be recorded.

3.2. Site Investigation Two

The results of site two are quite reliable. A good mean result is indicative of a fairly accurate test, since on average over the entirety of the pour, the theoretical and average dead load was quite close with a mean relative value of 1.04. However again there is considerable variance between the actual (measured) and theoretical (predicted) dead loads. Although this initial investigation has only utilised the tributary area method to calculate theoretical load, it is apparent that the large standard deviation of the results comes as a result of the large variance in shore load across all four site investigations. In fact for tests two to four the smallest value of standard deviation was in test four, s.d.= 0.23. As an example, for site investigation two, table 2 paints a picture of the considerable variances between actual and theoretical dead loads. There are two outlier load cells yet on average the results are accurate. This suggests that the data collection and actual loads recorded are accurate to the theoretical loads on an overall scale, but points the finger at the high variability between individual shores.

Table 2. Variability of 3 test Results from Test # 2

	Cell # 1 (Outlier)	Cell # 3 (Typical)	Cell #8 (Outlier)	**AVERAGE** (all 20 cells)
Actual/Recorded Load (kN)	19.829	24.409	8.189	**19.762**
Theoretical/Calculated Load (kN)	10.384	23.276	12.673	**20.402**
Ratio (Actual/Theoretical)	1.910	1.049	0.646	**1.034**

3.3. Live Load

The Live Load results were determined as the difference between the Dead Load and the peak maximum load observed after concrete pouring had occurred. Peak live loads were observed either during the pour process; when the gang of concrete workers were pouring the area, or during the process of “power trowelling”, when one or two workers were working the surface of the wet concrete with a power trowel machine. These peaks were observed either during the pour process or 4-6hrs after the pour had occurred.

Interestingly in tests 2 – 4, the theoretical live loads were greater than the actual or measured live loads in all cases. Even though no factor of safety was used in either actual or theoretical calculations, it is clear that the actual live load results are quite conservative compared to the 1kPa theoretical live load required in AS3610-1995.

4. Site Investigation Results

On the basis of the survey results, it appears that the actual shore loads, on average, give good agreement with the predicted values using the tributary area method. The results of the investigation have been analysed by engineers at Acrow Formwork and Scaffolding who have over 25years in the industry. Their analysis notes the similarity between actual and theoretical values is “within expected limits”. The following Figure 6 shows the measured load data for all 20 load cells for one of the areas investigated.

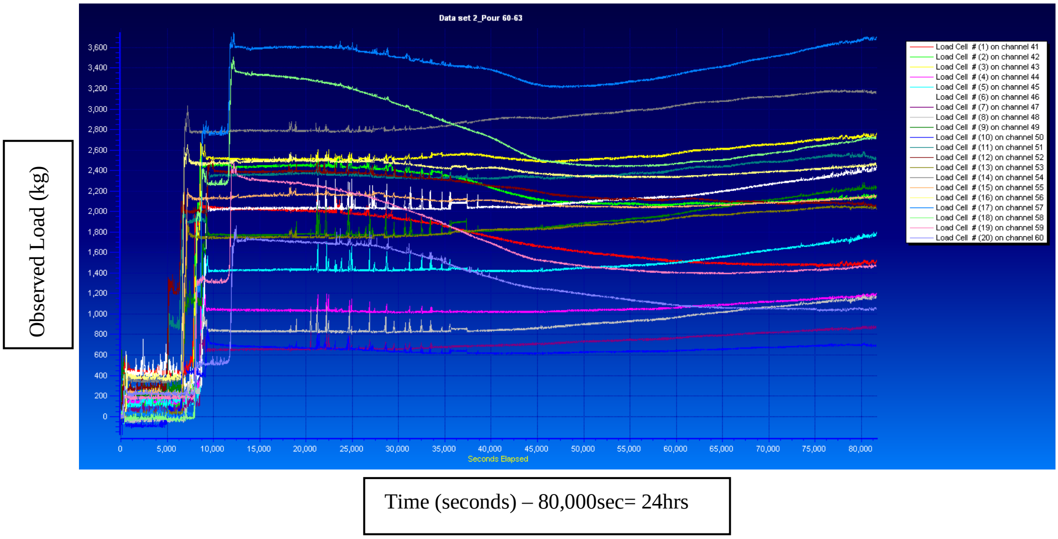

Figure 6: Site Investigation Number Two Loads

4.1. Variability in Shore loads

There were some key factors identified on-site that caused cases of distinct variability and non-uniform load distributions in shores. These were identified during the testing and account for the variability between actual and theoretical dead loads. They included:

- Distinct looseness at the interface of the top jack and the timber bearers, even with an apparent laser levelling of the formwork system. The effect of which would contribute to the apparent overloading and under loading occurring in some of the jacks or U-head connections. It is postulated that this is as a result of the sensitivity of the screw to small rotations and/or caused by bearers bridging over a central jack; evidently this initial looseness in the U-heads might have contributed to overloading of particular shores in some cases by 50-100% (as seen in Table 1).
- The tributary area concept might also be a source of the discrepancy between the actual and calculated shore loads, since the continuity of the bearers were not considered in our calculations.

Variations in shore pre-load may have occurred due to:

- Small loads: the highest initial shore pre load was only 4% of load cell capacity (larger variations in accuracy at these low loads) hence the effects of temperature differentials and variation in jack height, play a more dominant role.

- Initial shore pre-load values on some load cells may include a portion of live load due to a small number of men still working on the deck at the time that the values were recorded.

The shore load information is also used to investigate the adequacy of the current shore load calculation and provide design guidelines for safer and more reliable formwork supporting systems. The work presented in this paper is part of an ongoing project which aims to develop a probabilistic-based design methodology for scaffold-type formwork supporting systems.

5. Conclusion

This full scale survey of construction live and dead loads occurring on an actual construction site in Sydney, gives an adequate baseline for comparison to theoretical loads. This paper explicitly details the equipment and experimental procedure used to acquire load data on construction sites. In total four pour areas were surveyed during both the concrete casting and curing phases to obtain the actual loads transmitted to the supporting scaffolds. The validity of the research is quite significant due to the complexity, cost and time required to measure and gather such load data. The results of the investigation have been conclusive and show good correlation between actual and theoretical dead and live load statistics. Furthermore, a newfound understanding into the causes of variability in shore loads has already initiated safer and more reliable construction techniques in the erection of scaffolding. Critically this investigation contributes to the distinct lack of data available with respect to evolution and magnitude of construction loads, particularly construction live loads.

6. References

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