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AN EXPERIMENTAL STUDY ON THE LOAD CAPACITY OF STEEL SCAFFOLDS WITH LINED SETUPS

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Due to high clearances and large spans, some areas of reinforced concrete buildings, such as the entrance lobby of a hospital or the stage area of an auditorium, often need to design large-scale isolated reinforced concrete beams to support the weights from slabs and beams. On construction sites, the falsework of single-line steel scaffolds is often set up underneath these isolated beams based on the lined setup. Since the setup of these steel scaffolds is unique and data available for designing are lacking, single-line steel scaffolds are often installed on construction sites based on workers' experience. Study results show that the load capacities of one-bay, two-story door-type steel scaffolds (2D) are similar to those of one-bay, three-story door-type steel scaffolds (3D). When adopting multi-bay setups, the load capacities of two-story door-type steel scaffolds (2D) and of one-door, one-square, two-rectangle steel scaffolds (DS2R) increase with the number of bays. Although the height of the DS2R setup is higher than that of the 2D setup, the load capacity of the DS2R setup is still higher than that of the 2D setup, indicating that the strength of the combined setup of steel scaffolds is higher than that of pure door-type steel scaffolds. By applying the second loading using reusable materials, to simulate the load capacity of the steel scaffolds under the worst conditions, this study obtained the strength reduction factors of the steel scaffolds using reusable materials.

Keywords: Critical load, Nonlinear analysis, Reusable materials, Load capacity.

1 INTRODUCTION

Due to the internal layout of a building structure, large-scale reinforced concrete beams are often designed to bear the load from the top of the structure. Underneath these beams and in a longitudinal direction, the contractor often sets up single-line steel scaffolds with different setups to support the weight of the fresh concrete in the beams. If the designer fails to get hold of the variations in strength of single-line steel scaffolds, the collapse risk could be very high.

To this day, there have been many studies on the structural behaviors of falsework. Weesner & Jones (2001) carried out load capacity tests on four kinds of modular frame-type scaffolds. Zhang and Rasmussen *et al*. (2012) also investigated the failure modes of steel scaffolds, the effects of different random variables on structural strength, and the reliability analysis of the scaffolding structures. Yu *et al*. (2004) explored the load capacities of multi-story modular door-type steel scaffolds by nonlinear analyses and loading tests. Peng *et al*. (2010) conducted loading tests of two-story systems with wooden shores, or adjustable steel shores based on construction site setups, in order to identify the causes of collapse and suggest improvements. Peng *et al*. (2007) explored the load capacities of different setups of steel scaffold structural systems under different loads.

The above-mentioned studies on falsework mainly focus on various scaffolding structures with unit or multi-line setups. Studies on single-line steel scaffolds with different setups are lacking, and can only serve as a reference. It is necessary to study the load capacities and failure modes of single-line steel scaffolds with different setups.

2 TEST PLANNING

To cope with the conditions of the construction site, this study uses two types of single-line steel scaffolds: one-bay steel scaffolds and multi-bay steel scaffolds. Two loadings are applied to each setup. The first loading is applied to obtain the load capacity of each setup. After unloading, each setup of steel scaffolds is reset, and then the second loading is applied to determine the load capacity of the steel scaffolds under the worst conditions on the construction site.

In this study, tests were conducted on one-bay steel scaffolds to provide reference for tests on single-line steel scaffolds. The steel scaffolds consisted of a 170-cm high door scaffold (D), a 91.3-cm high square scaffold (S), and a 49-cm high rectangle scaffold (R) (see Figure 1).

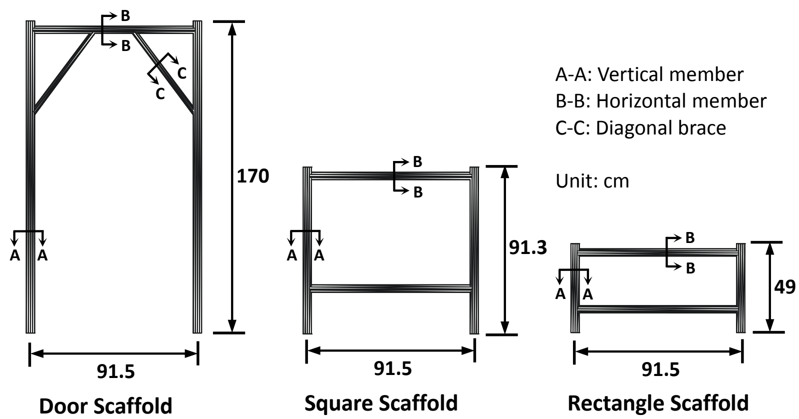

Figure 1. Dimensions of members of steel scaffolds.

2.1 One-Bay Steel Scaffolds

The tests of one-bay, two-story door-type steel scaffolds (2D) and one-bay, three-story door-type steel scaffolds (3D) are shown in Figure 2. A combined setup of one door, one square and one rectangle steel scaffolds (DSR), a combined setup of one door, one square and two rectangle steel scaffolds (DS2R), and a combined setup of two door, one square and one rectangle steel scaffolds (2DSR) are shown in Figure 3.

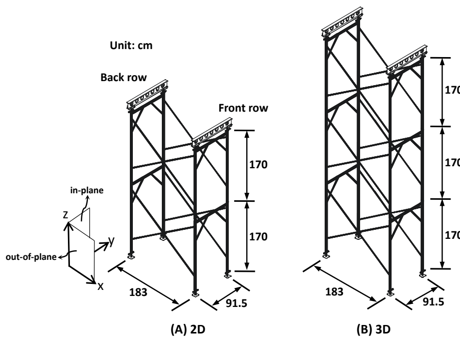

Figure 2. Setup of (2D) and (3D).

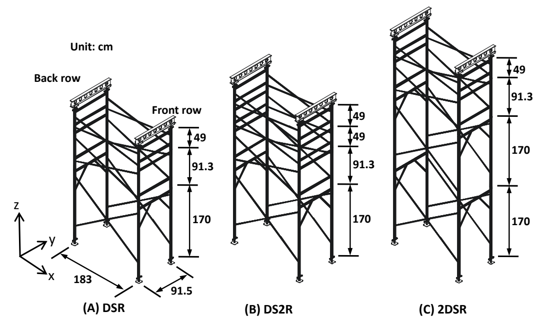

Figure 3. Setup of (DSR), (DS2R) and (2DSR).

2.2 Multi-Bay Steel Scaffolds

The setup of single-line, multi-bay steel scaffolds is different depending on the cross-section dimensions and the length of the beam. For a beam with smaller cross-sections and lengths (since the weight of the beam is lighter), the multi-bay steel scaffolds can be set up with larger spans. Figure 4 shows the setups of two-story, multi-bay steel scaffold systems (2D-2B), (2D-3B) and (2D-4B). Figure 5 shows the setups of one-door, one-square, two-rectangle, multi-bay steel scaffold systems (DS2R-2B), (DS2R-3B) and (DS2R-4B).

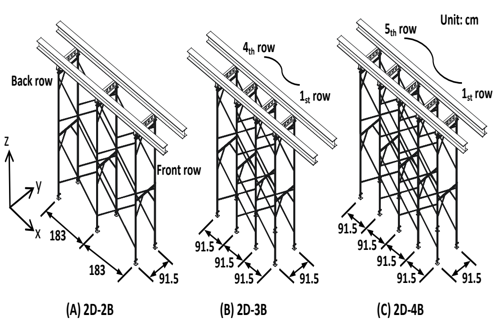

Figure 4. Setup of (2D-2B)~(2D-4B).

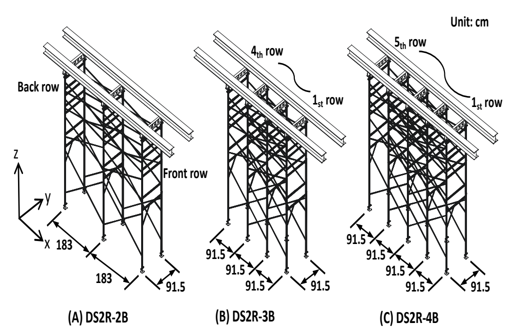

Figure 5. Setup of (DS2R-2B)~(DS2R-4B).

3 DIMENSIONS AND MATERIAL PROPERTIES

In Figure 1, section A-A shows the vertical main tube of the steel scaffolds with D (external diameter) = 48.26 mm and t (thickness) = 2.39 mm. Section B-B shows the horizontal bar of the steel scaffolds with D = 42.06 mm and t = 2.1 mm. Section C-C shows the diagonal bar of the steel scaffolds with D = 26.89 mm and t = 1.65 mm. In addition, the cross-bracing used in the combined setup has D = 21.27 mm and t = 1.59 mm. The elastic moduli of the material are obtained from tests on three randomly-selected steel scaffolds. The mean value of the three elastic moduli is 186.872 kN/mm^2, which is close to the nominal value 200.124 kN/mm^2.

4 RESULTS AND DISCUSSIONS

4.1 One-Bay Steel Scaffolds

Tests were conducted on five setups of one-bay steel scaffolds (2D), (3D), (DSR), (DS2R) and (2DSR). Results show that the failure modes of the five setups in both loadings are similar. The average maximum load of (2D) of the first loadings is 200.350 kN and that of the second loadings is 150.738 kN, which is 75% that of the first loadings. The average maximum load of (3D) of the first loadings is 199.585 kN and that of the second loadings is 128.291 kN, which is 64% that of the first loadings.

The average maximum load of (DSR) of the first loadings is 284.373 kN and of the second loadings is 150.052 kN, which is 53% that of the first loadings. The average maximum load of (DS2R) of the first loadings is 285.079 kN and of the second loadings is 134.675 kN, which is 47% that of the first loadings. The results show that the load capacity of (DS2R) is close to (DSR), indicating that the effect of adding one more rectangle steel scaffold on top of the structure on the load capacity is not apparent. The average maximum load of (2DSR) of the first loadings is 239.420 kN and of the second loadings is 102.970 kN, which is 43% that of the first loadings. This result indicates that the structural stiffness of the door-type steel scaffold is comparatively smaller than that of the square-type and rectangle-type steel scaffolds.

4.2 Multi-Bay Steel Scaffolds

Based on the lowest and the highest load capacities and similar heights of the above-mentioned tests, two types of steel scaffolding structures (2D) and (DS2R) were conducted. Each type of steel scaffolding structure was tested on three multi-bay setups: the two-bay setup, the interlaced three-bay setup, and the interlaced four-bay setup. The two-bay setup is suitable for smaller and lighter isolated beams, and the interlaced setups are suitable for larger and heavier isolated beams. All tests were conducted on six setups of multi-bay steel scaffolds: (2D-2B)~(2D-4B) and (DS2R-2B)~(DS2R-4B).

The average maximum load of (2D-2B) of the first loadings is 284.285 kN and of the second loadings is 151.768 kN, which is 53% that of the first loadings. The load capacity of (2D-2B) is 1.4 times that that of (2D). The average maximum load of (2D-3B) of the first loadings is 418.143 kN and of the second loadings is 280.694 kN, which is 67% that of the first loadings. The load capacity of (2D-3B) is 2.1 times that of (2D). The average maximum load of (2D-4B) of the first loadings is 460.373 kN and of the second loadings is 264.731 kN, which is 58% that of the first loadings. The load capacity of (2D-4B) is 2.3 times that of (2D).

The average maximum load of (DS2R-2B) of the first loadings is 383.009 kN and of the second loadings is 228.132 kN, which is 60% that of the first loadings. The load capacity of (DS2R-2B) is 1.3 times that of (DS2R). The average maximum load of (DS2R-3B) of the first loadings is 529.602 kN and of the second loadings is 298.475 kN, which is 56% that of the first loadings. The load capacity of (DS2R-3B) is 1.9 times that of (DS2R). The average maximum load of (DS2R-4B) of the first loadings is 649.465 kN and of the second loadings is 285.484 kN, which is 44% that of the first loadings. The load capacity of (DS2R-4B) is 2.3 times that of (DS2R). These results indicate that the interlaced multi-bay setup is conducive to enhance the load capacity, and the more number of bays, the higher the load capacity.

5 COMPARISON OF LOAD CAPACITIES OF STEEL SCAFFOLDS

Figure 6 shows the comparison of test results of (2D) ~ (2D-4B). The load capacity of (2D-2B) is 1.4 times, (2D-3B) is 2.1 times, and (2D-4B) is 2.3 times (2D). When dividing the test results by the number of rows in (2D), (2D-2B), (2D-3B), and (2D-4B) respectively, the average load capacities of a row is 97.9 kN.

Figure 7 shows the comparison of test results of (DS2R) ~ (DS2R-4B). The load capacity of (DS2R-2B) is 1.3 times, (DS2R-3B) is 1.9 times, and (DS2R-4B) is 2.3 times that of (DS2R). When dividing the test results by the number of rows in (DS2R), (DS2R-2B), (DS2R-3B), and (DS2R-4B) respectively, the average load capacities of a row is 133.1 kN. The data can serve as a reference for quickly estimating the load capacity of single-line, multi-bay, one-door, one-square, two-rectangle steel scaffolds.

Although the height of (DS2R) is higher than (2D), the average load capacity of a row of (DS2R) is higher than (2D). This result indicates that the structural stiffness of (DS2R) is higher than (2D). The rectangle and the square steel scaffolds are conducive to enhance the load capacity of the steel scaffolds.

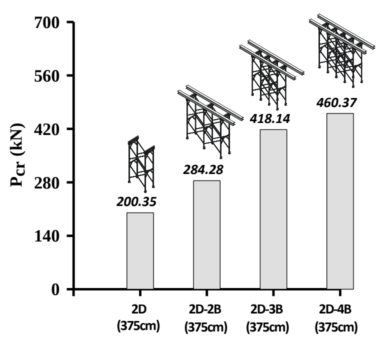

Figure 6. Comparison of (2D)~(2D-4B).

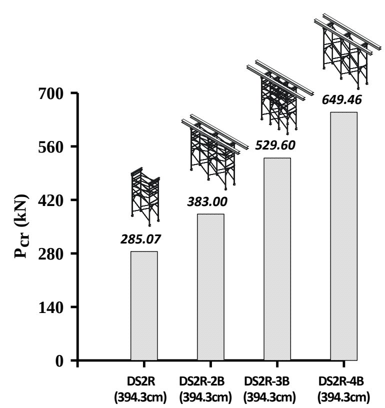

Figure 7. Comparison of (DS2R)~(DS2R-4B).

6 LOAD CAPACITY OF REUSABLE MATERIAL

The test results of the second loading can be regarded as the worst condition of the steel scaffolds using reusable material, which can be compared with those of the first loading. The average ratio of dividing the load capacities of the second loading by those of the first loading is μ = 0.625, with a standard deviation of σ = 0.133. Subtracting one-fold, two-fold and three-fold standard deviation from the average ratio of the steel scaffolds using reusable material (μ-σ, μ-2σ and μ-3σ), we obtain 0.492, 0.359 and 0.226 respectively. Figure 8 shows the comparison of the load capacities of the steel scaffolds using reusable material subtracting one to three-fold standard deviations. The designer can choose proper strength reduction factors (ϕ) of reusable material based on project fund and safety requirements to serve as a reference for determining the strength reduction of the steel scaffolds using reusable material.

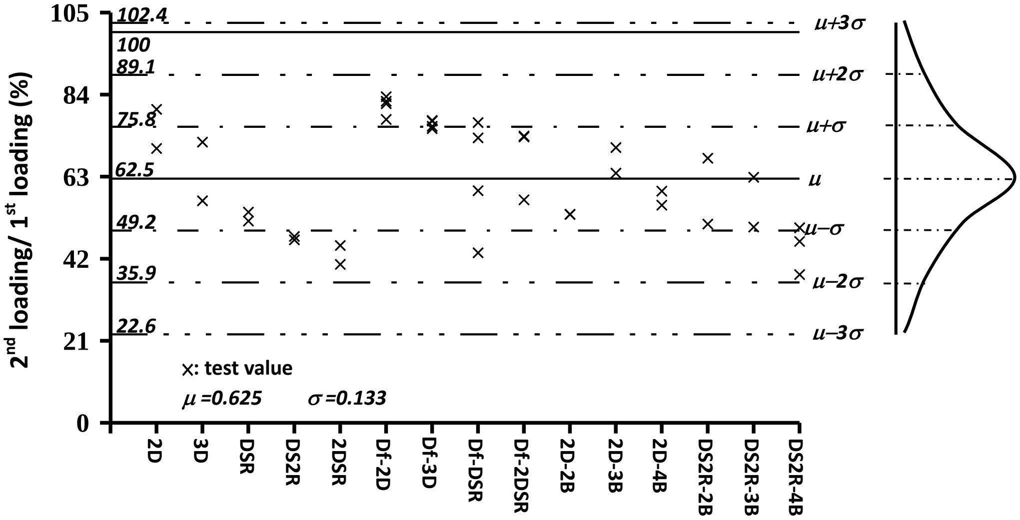

Figure 8. Comparison of load-carrying capacities of steel scaffolds using reusable material.

7 CONCLUSIONS

This study explored the structural behaviors of single-line steel scaffolds with different setups to determine the load capacities and failure modes of these scaffolding structures. Tests results show that the load capacities of (3D) are close to those of (2D). The load capacity of (2D-2B), (2D-3B) and (2D-4B) are 1.4, 2.1 and 2.3 times that of (2D) respectively. In addition, although with the same overall length, the load capacity of (2D-4B) is 1.6 times that that of (2D-2B). This result indicates that increasing the number of bays is conducive to enhance the load capacity of door-type steel scaffolds. The average ratio of dividing the load capacities of the second loading by those of the first loading is μ = 0.625, with a standard deviation of σ = 0.133. The designer can choose proper strength reduction factors (ϕ) of reusable material based on design requirements.

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