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An Experimental Study on the Stability Bearing Capacity of a New Type of Steel Formwork

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Abstract

With high-speed development of the construction industry in China, higher stability and bearing capacity of the formwork are required in the process of construction. In this paper, a new type of steel formwork is introduced and relevant experiments are carried out. According to the experiments, when the single formwork and the composition formwork respectively are loaded to the allowable deformation value of the formwork their bearing capacities are above the related indicators of Technical Code for Safety of Forms in Construction (JGJ162-2008). And then the load continues and does not fail. When the load is removed, the formwork is able to achieve elastic recovery. The experiments indicate that this type of steel formwork is featured with favorable bearing capacity and economic practicality, and it solves the existing problems of bamboo formwork and wood formwork.

Key words

A new type of steel formwork, stability bearing capacity, deflection, experimental study

1. Introduction

In recent years, the general situation of construction safety across the country has been relatively stable, and the occurrence of safety accidents and quality accidents has decreased [1]. However, the quality incidents triggered by formwork projects still account for a large proportion, and formwork deformation is the main cause of concrete structure quality accidents. Therefore, further research concerning the deformation mechanism of construction formwork still needs to be conducted. Most of the accidents associated with the template are caused by improper construction and load [2]. In engineering, it will cause a lot of accidents [3] if the formwork support system is collapsed. In addition, template engineering is very critical, it will lead to poor construction quality or safety accidents by the improper handling. Taking into account the economic and security, the design of the new template has received more and more attention from researchers [2]. Currently, due to the economic, more project are still in the use of bamboo and wood template, but there is a problem that strength of bamboo and wood are much lower than the steel [4]. And their surfaces are easy to burr, easy deformation, and easy to mildew, resulting in rough surface after repeated usages, not easy to demould. Also, after the subsequent concreting, these formworks are liable to bond with the concrete, absorb moisture, bulk and mildew, and the forms are hard to remove. Because the main parameter of the template is the roughness [5], it is clear that the bamboo and wood template is difficult to meet the requirements. As a result, bamboo formwork and wood formwork could not be applied more than once and could not achieve consistent results. The usage of the composition steel formwork is able to effectively eliminate these drawbacks. Since its introduction from Japan in 1979, the composition steel formwork has been under large-scale research and promotion with the guidance of national economic policy of "replace wood with steel" and government advocacy at that time [6-7]. As indicated by the experiments and related specifications [8-9] and literature review [10-11], the new type of steel formwork has advantages like high capacities, reusability and easy of application, which solves the existing problems of bamboo formwork and wood formwork. Also, this steel formwork is able to restore elasticity after complete removal.

2. Experimental Design

2.1 Experimental Materials

The test product is provided by Shuntian Hardware Products Ltd. in Leling City, Shandong Province. The formwork and back beams adopt hot dip galvanizing process and laser cutting and welding, with a stencil thickness of 0.8mm, thereby ensuring welding quality and cutting accuracy. And weld joint surface is uniformly continuous, almost no spatter, and no meat shortage phenomenon. Related weld joint technical indicators of *Technical Code for Safety of Forms in Construction* (JGJ162-2008) are referred, and test procedure and test data are detected in accord with the requirements about defects, damage and deformation of *Technical standard for Inspection of Building Structures* (GB / T50344-2004).

2.2 Test Procedure

(1)To level the land and prepare the materials, single formworks with a plane size of 0.2m×1m (the frame steel beam is 20mm×20mm square steel tube; the surface slab is 1.2mm-thick galvanized steel), single formworks with a plane size of 0.3m×1.0m (the frame steel beam is 20mm×20mm square steel tube; the space of the one-way steel beam is 140mm; the surface slab is 1.2mm-thick galvanized steel), single formworks with a plane size of 1.0m×1.0m (both the frame steel beam and the intermediate steel beam is 20mm×20mm square steel tube; the space of the one-way steel beam is 160mm; the surface slab is 1.2mm-thick galvanized steel), and composition formworks consisting 2-cross(0.3m+0.2m+0.2m)×1.0m and 2-cross 1.0m×1.0m.

(2)To prepare, mount, and assemble test pieces.

(3)To adjust the test piece platform, the first step is the general use of a 2m ruler to measure the ground level. At the same position, in the cross direction of the measurement, if the lower part of ruler is more than 3 mm or even 5 mm gap from the ground. This shows that the ground is uneven. And then the test piece is putted to the test piece platform. Last step is to measure the level of the platform. Until the platform leveling, using tape measures the span of L.

(4) To install the dial indicator, it is determined by the size of the formwork. The experiments are divided into the following situations:

①When single formworks with a plane size of 0.2m×1m and 0.3m×1m are tested, dial indicators are installed on the two steel beams middle position of the test pieces that needs to be measured;

②When single formworks with a plane size of 1m×1m are tested, dial indicators are respectively installed on the two minor beams, the intermediate steel beam and the middle parts of the test pieces.

③In the experiments of composition formwork, dial indicators are installed on the three minor beams and two intermediate steel beams.

(5) After dial indicators are installed, the test platform should be checked again to see if it is leveled. If leveled, the dial indicator should be reset; otherwise the platform should be re-leveled.

(6)Apply loads by class and read the dial indicator: due to the limitations of the test conditions, the load is made up with small steel ingots and sandbags that each one of them is 60 kg and that are individually weighed. The weight of people joining in experiment (65kg) may be added if necessary. An external load is gradually applied on the test platform every 2 min until any one the measured indicator reading on a certain position reaches the allowable value of deformation. The value of the load is written down, which is the critical load. Then the load continues to be added until the test piece fails. In terms of examples, 0.2m×1m is taken as the single formwork, and 2-across (0.3m+0.2m+0.2m) ×1.0m is taken as the composition formwork. The experimental process is shown in Figure 1 to Figure 5.

Figure 1: 0.2m × 1m formwork diagram
(after the dial indicator is adjusted to zero)

Figure 2: Elastic load stage diagram of the 0.2m × 1m formwork

Figure 3: The process diagram of 0.2 m×1.0m×1.0m formwork bending failure

Figure4:2-Cross(0.3m+0.2m+0.2m)× formwork leveling

Figure 5: 2-Cross (0.3m + 0.2m + 0.2m) × 1.0m formwork load diagram

3. Results and Analysis

3.1 Test Results and Analysis of Single Formwork

(1) The plane size of single formwork is 0.2m×1m. The allowable deformation value is 800/500=1.6mm. The results are shown in Table 1:

Table 1 Load-deflection Table of 0.2m×1.0m Single Formwork

Number of load	Amount of load (pieces or bags)	Accumulative load (KN)	The deflection of frame steel beam 1 (mm)	The deflection of frame steel beam 2 (mm)
1	5	1.17	0.76	0.59
2	2	1.72	1.16	0.96
3	2	2.32	1.51	1.30
4	1	2.65	1.72	1.57

As illustrated in Table 1, the first three loading processes fail to meet the allowable deformation value of the formwork (steel beam), so this process is in the stage of elastic deformation. At the fourth load, it reaches and exceeds the allowable deformation value of the formwork (steel beam). According to the interpolation method, when it is loaded to the allowable deformation value of the formwork (steel beam)—L/500(1.6mm), its carrying capacity is 13.25KN/m^2. When the cumulative load is increased to 5.54KN (27.70 KN/m^2), the formwork has not yet failed. Under the limited experimental conditions, no failure occurs after the deformation of the formwork (steel beam) exceeds the limit. After removal, the formwork is able to restore elasticity.

(2) The plane size of single formwork is 0.3m×1.0m. The allowable deformation value is 800/500=1.6mm. The results are shown in Table 2:

Table 2 Load-deflection Table of 0.3m×1.0m Single Formwork

The class of load	Amount of load (pieces or bags)	Accumulative load (KN)	The deflection of frame steel beam 1 (mm)	The deflection of frame steel beam 2 (mm)
1	9	2.83	1.14	1.10
2	6	4.33	1.53	1.43
3	2	4.78	1.65	1.56
4	5	5.77	1.91	1.77
5	1	6.17	2.00	1.86
6	After removal	0.00	0.00	0.14

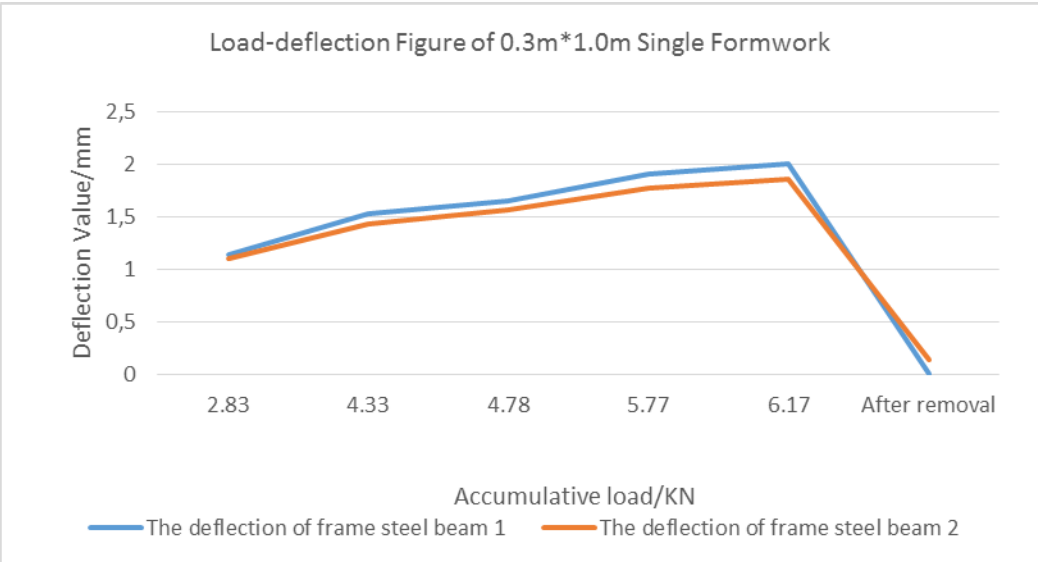

Figure 6: Load and Unload Diagram of 0.3m×1.0m Single Formwork

As illustrated in Table 1and Figure 6, deformation values are taken by the class of load, with the interpolation method. When it is loaded to the allowable deformation value of the formwork (steel beam)—L/500(1.6mm), its carrying capacity is 15.93KN/m^2. When the cumulative load is increased to 6.17KN (20.57 KN/m^2), the formwork still remains stable and does not fail. After removal, the formwork is able to restore elasticity.

The plane size of single formwork is 1.0m×1.0m. The allowable deformation value of steel beam is 800/500=1.6mm. The allowable deformation value of minor beam is 1000/500=2.0mm. The results are shown in Table 3:

Table 3 Load-deflection Table of 1.0m×1.0m Single Formwork

The class of load	Amount of load (pieces or bags)	Accumulative load (KN)	The deflection of minor beam 1 (mm)	The deflection of minor beam 2 (mm)	The deflection of intermediate beam 1 (mm)	The deflection of the center of formwork (mm)
1	17	4.81	1.34	1.12	2.17	2.42
2	2	5.81	1.61	1.49	2.37	2.65
3	2	6.81	1.84	1.67	2.78	3.05
4	2	7.81	2.21	1.87	3.13	3.35
5	2	8.81	2.33	2.08	3.47	3.68
6	2	9.81	2.69	2.31	3.81	4.11
7	2	10.81	2.96	2.50	4.17	4.47
8	After removal	0.00	0.07	0.22	0.90	0.15

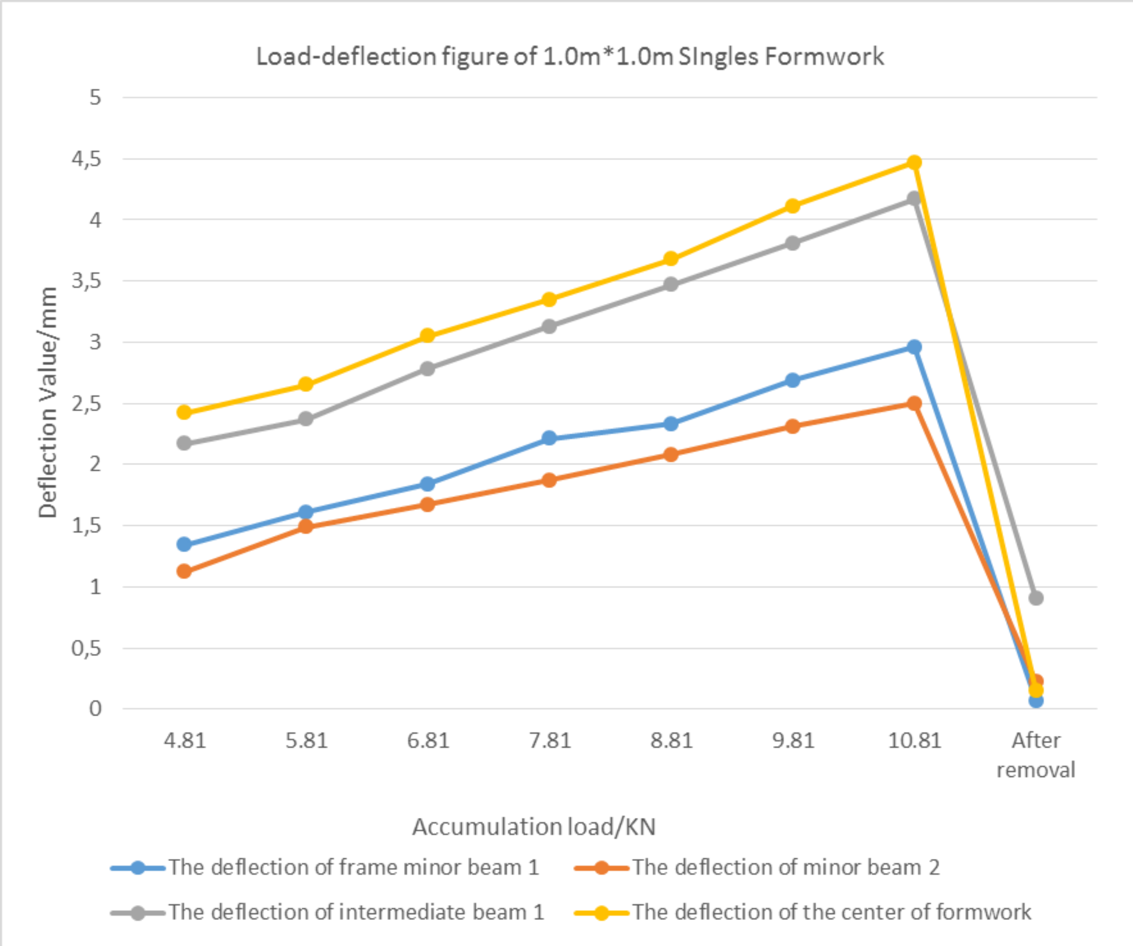

Figure 7: Load and Unload Diagram of 0.1m×1.0m Single Formwork

As seen from the Table 3 and Figure 7 and using the interpolation method, when the load reaches the allowable deformation value of minor beam—L/500(2.0mm), its carrying capacity is 7.81KN/m^2. When the load reaches to the allowable deformation value of the formwork (steel beam)—L/500(1.6mm), its carrying capacity is 10.81KN/m^2. After removal, the formwork is able to restore elasticity.

3.2 Test Results and Analysis of Composition Formwork

Flat composition: 2-Cross (0.3m+0.2m+0.2m)×1.0m: the allowable deformation value of steel beam is 800/500= 1.6mm, and the allowable deformation value of minor beam is 1100/500 = 2.2mm;The results are shown in Table 4:

Table 4 Load-deflection Table of 2-Cross (0.3m+0.2m+0.2m)×1.0m

The class of load	Amount of load (pieces or bags)	Accumulat-ive load (KN)	The deflection of minor beam 1 (mm)	The deflection of intermedia-te steel beam 1 (mm)	The deflection of minor beam 2 (mm)	The deflection of intermedia-te steel beam 2 (mm)	The deflection of minor beam 3 (mm)
1	9	4.50	0.87	1.18	0.83	1.07	0.73
2	9	9.00	1.77	2.46	1.69	2.31	1.54
3	6	13.45	2.65	3.49	2.49	3.41	2.38

According to the experimental data, when the load reaches the allowable deformation value of the minor beam—L/500 (2.2mm), its carrying capacity is 8.44KN/m^2 (calculated by the interpolation method). When it is loaded to the deformation value of minor beam—L/438(2.51mm), the deformation value of the formwork (steel beam) is L/1170 (0.68mm), which does not reach the allowable deformation value. But in fact, the carrying capacity of the formwork has reached 9.64KN/m^2. After removal, the formwork is able to restore elasticity.

(2) Flat composition: 2-Cross 1.0m×1.0m: the allowable deformation value of steel beam is 800/500 =1.6mm, and the allowable deformation value of minor beam is 1100/500 = 2.2mm: The results are shown in Table 5:

Table 5 Load-deflection Table of 2-Cross 1.0m×1.0m

The class of load	Amount of load (pieces or bags)	Accumula-tive load (KN)	The deflection of minor beam 1 (mm)	The deflection of intermedi-ate steel beam 1 (mm)	The deflection of minor beam 2 (mm)	The deflection of intermedi-ate steel beam 2 (mm)	The deflection of minor beam 3 (mm)
1	12	6.00	1.14	1.06	1.09	1.32	0.76
2	12	12	3.71	3.29	2.35	2.78	2.06
3	8	18.36	4.63	4.75	3.96	4.27	2.94

As shown by the experimental data, when the load reaches the allowable deformation value of the minor beam—L/500(2.51mm), its carrying capacity is 5.11KN/m^2 (calculated by the interpolation method). When it is loaded to the deformation values of minor beam—L/438 (2.51mm), the deformation value of the formwork (steel beam) is L/1642 (0.48mm), which does not reach the allowable deformation value. But in fact, the carrying capacity of the formwork has reached 9.18KN/m^2. After removal, the formwork is able to restore elasticity.

Conclusion

Based on above the test data, figures and the result analysis, the deformation characteristic of steel formwork is first linear elastic, and after continuous load, it enters the non-linear phase. According to the experimental data, when the load imposed by single formwork and composition formwork reaches the allowable deformation value of the formwork, the carrying capacities are above the related indicators of *Technical Code for Safety of Forms in Construction* (JGJ162-2008). And they continue to load until the allowable deformation value, and the formwork does not fail. When the load is removed, the formwork is able to restore elasticity. This experiment indicates that steel formwork has relatively large carrying capacity. Also, because galvanized steel is thin, laser welding is applied to achieve the surface smoothness of the formwork less than 2 mm required in the construction, which facilitates the removal of forms, and solves the existing shortage of bamboo formwork and wood formwork. Thus, as a recycling and reusable and environmentally friendly product, steel formwork enjoys better economic practicality.

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