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Finite Element Analysis of Cable-Stayed Cantilever Material Transfer Platform Under Varying Loading Conditions

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Abstract: During the construction of building structures, the transfer platform is the main passage of materials entering or departing the floor, and it is an important facility for site operation. In recent years, a large number of construction accidents have occurred due to unsafe design and unreasonable site practices of the transfer platform, and serious accidents may result in injury or death. Aiming at the decrease of construction accidents of the transfer platform, this paper studied the force characteristics of the cable-stayed cantilever material transfer platform under varying loading conditions using the finite element method. The maximum load-carrying capacity of the transfer platform was obtained, and the most unfavorable position of the material load was analyzed. The performance in service of the transfer platform under various adverse conditions such as partial load and anchorage failure was studied. The results show that when the load area is less than or equal to 0.5m×0.5m, the maximum load-carrying capacity of the transfer platform is 8kN after considering the dynamic coefficient. When the material load is located in the middle of the transfer platform, the transfer platform has a good safety margin. And when the main girder anchor bodies or wire rope anchorages are not anchored, the transfer platform cannot be used.

Keywords: Transfer Platform, Adverse Conditions, Finite Element Method, Load-Carrying Capacity

1. Introduction

Accidents are likely to occur during building constructions, and serious accidents may affect people's lives and property, as well as social stability and industry development. Cable-stayed cantilever material transfer platform is used to transport materials and small equipment between floors and floors, and it is a common temporary facility in construction projects [1]. However, due to violation operation or unreasonable use of the transfer platform, there are potential safety hazards in construction production, that may cause serious construction accidents [2-16]. For example, on November 28, 2020, a transfer platform capsized during the construction of the third phase project of Yuan Banqiao in Beijing, China, resulting in 3 deaths [17]. A series of studies have been carried out on the construction safety and the load state of the transfer platform. Mohamed investigated the relationship between construction site safety and worker behavior by employing questionnaires, and the safety awareness of the workers should be strengthened to improve construction site safety [18]. Rafindadi found that workers' unsafe actions may result in fall-related accidents [19]. Yang designed an identification system for accidents [20]. Bryan recommended that workers were tied off with the lanyard to remain stable when working on the mast climbing work platforms [21]. Bošnjak analyzed the stress state in the critical zone of a mobile elevating work platform [22]. Erinç compared the stress distribution of three hydraulic truck unloading platforms in different operating positions [23]. Wang studied the working mechanism and characteristics of the separated unloading sheet pile wharf with the finite element method [24].

Now, the force states of the transfer platform under varying loading conditions are unclear. In order to solve the problem, a series of parametric analysis was conducted in this paper.

2. Basic Configuration of Transfer Platform

The basic configuration of the common cable-stayed cantilever material transfer platform is shown in Figure 1. The transfer platform was composed of main girders, secondary girders, platform panel, and wire ropes. The two groups of wire ropes were set on each side of the transfer platform, with the inner wire ropes as the safety ropes and the outer wire ropes as the pulling ropes, respectively. One end of the main girder was held by the floor connection with anchor bolts, and the other end was connected with the pulling and safety ropes. The secondary girders were set on the two main girders, and the platform panel was welded above the secondary girders. The material load was transmitted to the main girders through the secondary girders, and then to the floor through the main girders and the wire ropes. In order to simplify the analysis, in this paper the transfer platform size was 2.5m×4.5m, the height of guardrails was 1.5m, the spacing of secondary girders was 0.85m, the length of main girders was 6m, and the platform panel thickness was 4mm. The design parameters of the transfer platform are shown in Table 1.

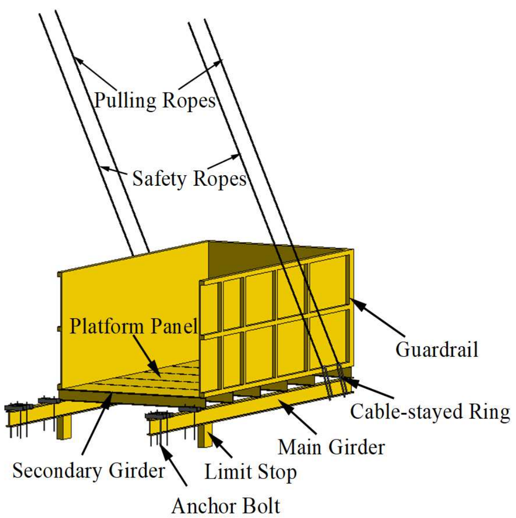


Figure 1. *Cable-stayed cantilever material transfer platform.*

Table 1. *Design parameters of the transfer platform.*

Number	Member	Material	Type
1	Main girder	Q235	I 20a
2	Secondary girder	Q235	I 14a
3	Wire rope	/	φ21.5mm
4	Platform panel	Q235	4mm figured steel panel
5	Guardrail	Q235	square steel tube with 50mmx3mm
6	Cable-stayed ring	/	φ20mm steel bar
7	Limit stop	Q235	I 14a
8	Anchor bolt	/	φ20mm steel bar

Note: The strength of the wire rope is 1850MPa.

3. Loading Condition Analysis

3.1. Numerical Model

The transfer platform was modeled and analyzed using ABAQUS software, as shown in Figure 2. The main girders and secondary girders were modeled using beam element B32, the platform panel was modeled using shell element S4R, and the wire ropes were modeled using truss element T3D2 which can sustain only tensile axial deformation. The connections between platform panel and main girders, platform panel and secondary girders were assumed rigid, and the connections between main girders and floor, main girders and wire ropes, floor and wire ropes, and limit stop and floor were assumed hinge. The dead weight of platform guardrails was considered as a uniform load arranged around the transfer platform [25-31].

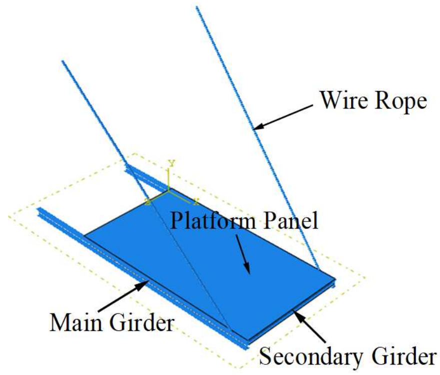


Figure 2. *Cantilevered transfer platform finite element model.*

3.2. Normal Conditions

3.2.1. Normal Working

The normal working condition was used to model that the material load was applied as a distributed load in the area 0.5m×0.5m at the outer end of the transfer platform [32], as shown in Figure 3. The material load was applied to 20kN with six levels (see Table 2) to analyze the effect of varying material loads on the transfer platform.

Table 2. *Material load classification.*

Classification	1	2	3	4	5	6
Material load(kN)	2.5	5	10	12.5	15	20

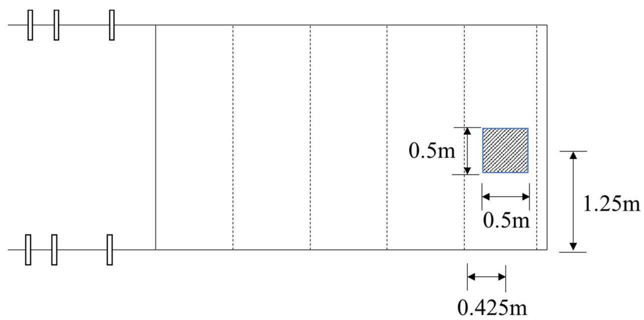
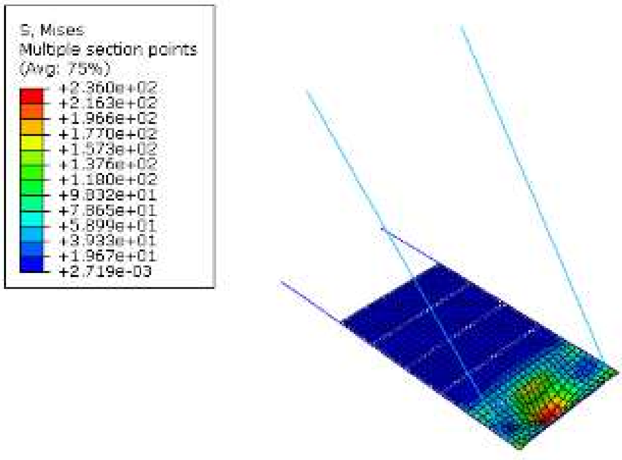


Figure 3. *Layout of the material load.*

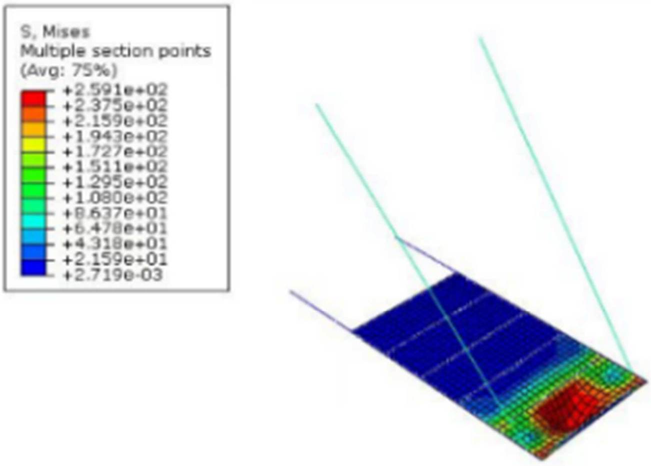
As shown in Figure 4, the maximum platform panel stress appears in the middle of the load area, the platform panel is in the elastic stage when the material load is less than 10kN, when the material load is 10kN or larger, the platform panel yields, however, other members are still in the elastic stage.

Figure 5 shows the wire rope stress and the main girder deflection under varying material loads. In general, the main girder deflection and the wire rope stress increase linearly with the material load increases. When the material load reaches to 10kN, the main girder deflection is 2.35mm, which is less than the limit value of 18mm (4500/250=18mm) provided by the GB50017-2017 code [33], and the wire rope stress is 58MPa, far less than the tensile strength of 1850MPa. However, due to the yield of the platform panel, the transfer platform is deemed as reaching the ultimate bearing capacity.

Considering the dynamic coefficient of 1.25 [34], the maximum material load of the transfer platform is 8kN when the load area is 0.5m×0.5m.

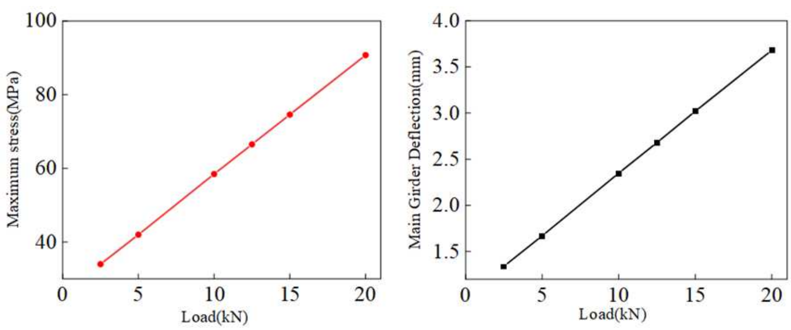


(a) 10kN of material load



(b) 20kN of material load

Figure 4. *Stress state of the transfer platform.*



(a) Wire rope stress (b) Main girder deflection

Figure 5. *Response of the transfer platform.*

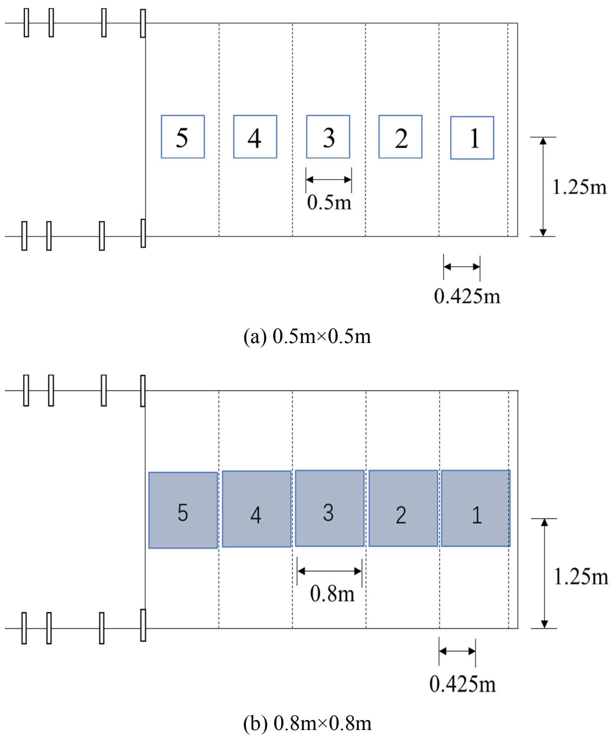


Figure 6. *Material load positions.*

3.2.2. Normal Operation

The normal operation condition was used to model that the material load with 10kN was located at varying positions on the transfer platform, and the load area was assumed to be 0.5m×0.5m and 0.8m×0.8m, respectively, as shown in Figure 6.

Similar to Figure 4, the maximum stress location is in the middle of the load area. As shown in Figure 7, when the load area is 0.5m×0.5m, the platform panel yields at all positions. When the load area is 0.8m×0.8m, the platform panel stress at 1 and 5 positions are greater than that at 2, 3, and 4 positions, and the stress is 175MPa at 1 and 5 positions and 159MPa at 2, 3, and 4 positions. This indicates that the variation of the platform panel stress is very small during the normal operation condition, and none of them reaches to the yield stress. The reason is that the 0.8m is close to the secondary girder spacing of 0.85m. For the main girder deflection and the wire rope stress, there are negligible changes between the load area 0.5m×0.5m and 0.8m×0.8m. And the main girder deflection and wire rope stress are reduced as the material load closes to the floor. According to the results of normal operation, when the material load is located at 1 position, the transfer platform has the maximum response, indicating that the 1 position is the most unfavorable position.

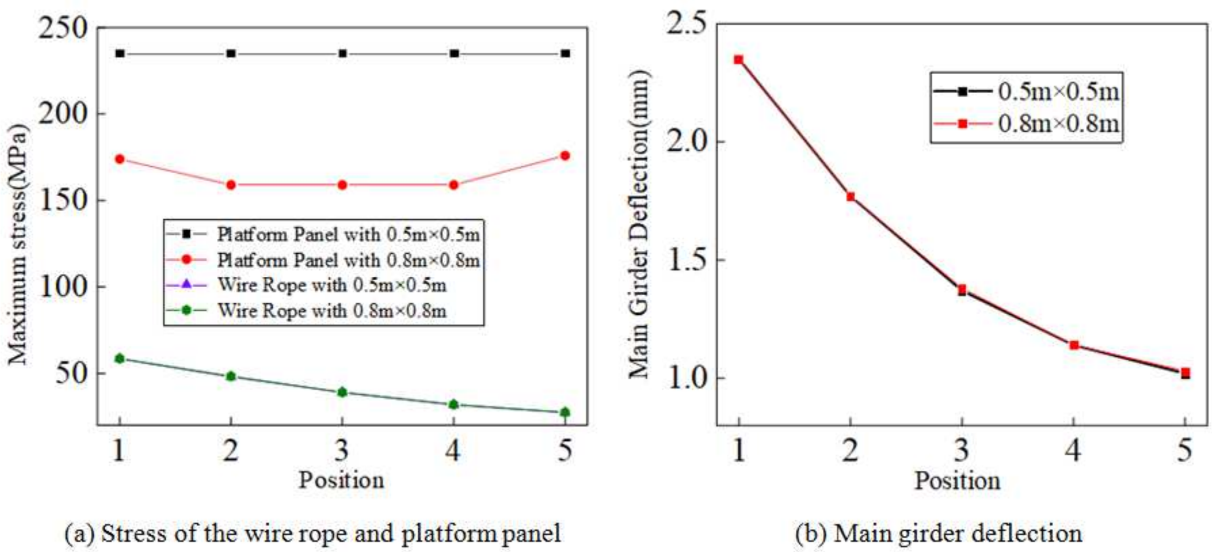


Figure 7. *Response of the transfer platform.*

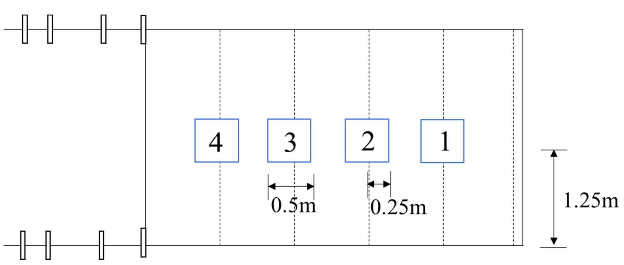
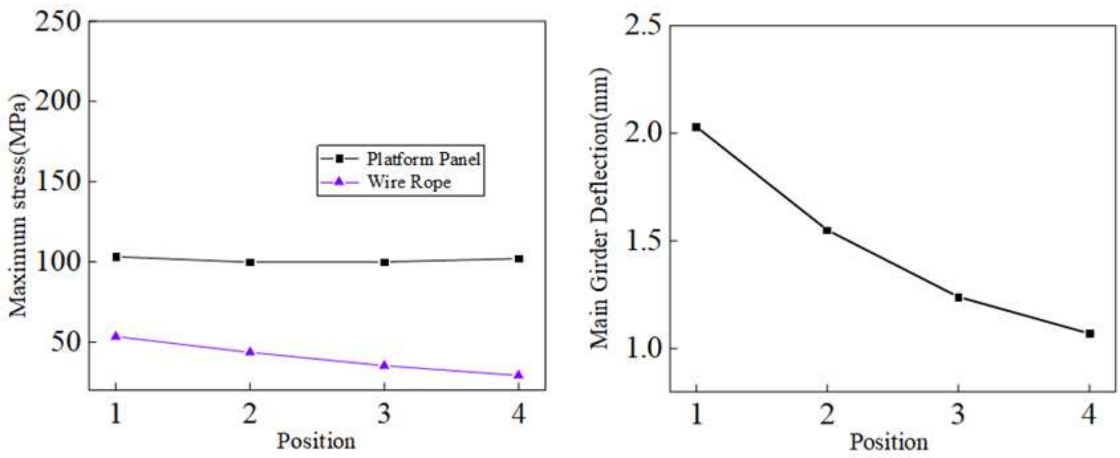


Figure 8. *Material load positions.*

3.2.3. Optimization Scheme

From the above results, it was found that when the material load was located on the platform panel with area 0.5m×0.5m, as shown in Figure 6a, the transfer platform was in an unfavorable situation. Now it is envisaged that the material load with 10kN is located on the secondary girder, the load positions are shown in Figure 8.

As shown in Figure 7 and Figure 9, compared with the material load positions on the platform panel, the wire rope stress, the platform panel stress, and the main girder deflection are all properly decreased. The reason is that the material load is immediately transmitted to the main girders through the secondary girders.



a) Stress of the wire rope and platform panel

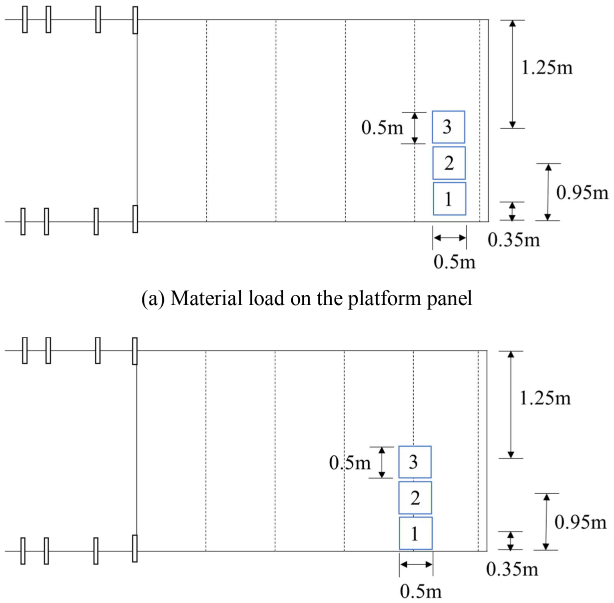
(b) Main girder deflection

Figure 9. *Response of the transfer platform.*

3.3. Unfavorable Conditions

3.3.1. Eccentric Load Condition

When the material load is located at the one side of the transfer platform, the transfer platform may be inclined due to the eccentric load, even overturning. In order to study the unfavorable effect, the load positions of 1, 2, and 3 with area 0.5m×0.5m were considered, as shown in Figure 10. The material load with 10kN was located on the platform panel and the secondary girder, respectively.

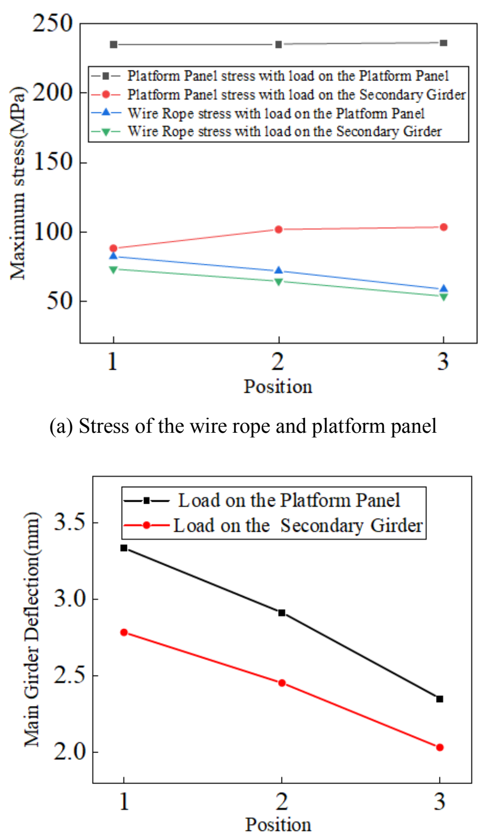


(a) Material load on the platform panel

(b) Material load on the secondary girder

Figure 10. *Material load positions.*

As shown in Figure 11, when the material load is located on the platform panel, the platform panel stress shows no significant change as the eccentric load positions gradually reach to the middle of the platform panel due to the yield of the platform panel, and the main girder deflection and the wire rope stress gradually decrease. Taking 1 and 3 positions as an example for comparison, the main girder deflection is 3.33mm and 2.35mm, and the wire ropes stress is 82MPa and 58MPa, respectively. When the material load is located on the secondary girder, the stress and deflection response of the transfer platform show greatly reduced compared with that on the platform panel, especially for the platform panel stress.



(a) Stress of the wire rope and platform panel

(b) Main girder deflection

Figure 11. *Response of the transfer platform.*

3.3.2. Anchorage Failure Condition

The main connecting elements of the transfer platform are the anchor bodies (connecting the main girders and the floor), the limit stops, and the anchorages (connecting the wire ropes and the floor). If the main girder anchor bodies or the wire rope anchorages are not anchored, may result in accidents. This paper analyzed the effect of the number of the main girder anchor bodies, the limit stops, and the wire rope anchorages.

In order to simulate the limit stops, the limit stops and the floor were modeled using solid element, and since the floor limited the horizontal and vertical displacements of the limit stops, the nonlinear spring element was used to connect the limit stop and the floor [35-37]. The analysis was carried out by releasing the freedom of the main girder anchor bodies, the limit stops, and the wire rope anchorages. Four working conditions were considered: (1) the main girder anchor bodies, the limit stops and the wire rope anchorages were anchored, the material load was located at the area shown in Figure 3; (2) all the main girder anchor bodies were not set, the vertical and horizontal displacements of the transfer platform were limited by the limit stops, and the wire rope anchorages were anchored; (3) the main girder anchor bodies and the limit stops were anchored, the wire rope anchorages were not anchored; (4) the main girder anchor bodies and the limit stops were anchored, only one side of the wire rope anchorages was anchored. For cases 2, 3, and 4, the material load was the same as the case 1.

As shown in Table 3, the platform panel stress reaches to the yield stress in case 1. The calculation of the case 2 does not converge, indicating that when the main girder anchor bodies are not anchored and the transfer platform is only constrained by the limit stops and the wire ropes, the transfer platform cannot bear the material load. In the case 3, the platform panel stress and the main girder deflection exceed the limit value. The transfer platform without wire ropes support is simplified as a cantilever beam, which cannot meet the use requirement. In the case 4, the main girder deflection on the unanchored side is 63.3mm, exceeding the limit value. These results show that when the main girder anchor bodies or the wire rope anchorages are not anchored, the transfer platform is in an unusable state. The builder must check that the transfer platform has sufficient anchorages before use.

Table 3. *Response of the transfer platform.*

Case	Platform panel stress (MPa)	Wire rope stress (MPa)	Main girder deflection (mm)
1	235	58	2.35
2	---	---	---
3	264	---	48.3
4	264	---	63.3

4. Conclusion

The finite element analysis of varying factors affecting the response of the transfer platform was carried out. The following conclusions are obtained:

(1) When the load area is less than or equal to 0.5m×0.5m, the transfer platform material load should not exceed 10kN. Considering the dynamic coefficient of 1.25, the maximum material load of the transfer platform is 8kN.

(2) With the eccentric load close to the middle of the transfer platform, the main girder deflection and the wire rope stress are decreased, then the eccentric load condition should be avoided. Compared with the material load located on the platform panel, the transfer platform has small stress and deflection response when the material load is located on the secondary girder.

(3) When the main girder anchor bodies or the wire rope anchorages are not anchored, the transfer platform is unsafe.

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