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# The Security Analysis of Movable Self-enlargement Workshop Based on Finite Element Method under Severe Environment

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**Abstract** As the basic assistive device of substation equipment maintenance, the movable workshop in substation plays an important role to ensure the security of power system construction and the reliable operation of the substation equipment. In order to meet the actual needs of on-site maintenance of substation equipment, this paper designs a kind of movable and self-enlargement workshop, which has the characteristics of low cost, one-touch control, excellent insulation, easy operation as well as high security. The finite element model of the workshop is elaborated under the circumstance of wind, snow and other extreme condition; then the maximum displacement and ultimate stress of the workshop are calculated considering the extreme condition. The results indicate that the designed workshop greatly meets the security and reliability in substation under severe environment.

## 1. Introduction

With the increasing scale and voltage level of power grid, it is increasingly more frequent for power system to construct the large-scale power supply engineering, expand substations or carry out other infrastructure construction. Especially high permeability intermittent energy and user access to the two-way interactive demand [1] put forward higher request for the construction project of smart grid. So it has important practical significance to design and develop the basic auxiliary equipment for construction on-site, which can improve the work efficiency and ensure the safety of personnel and equipment in the process of engineering construction.

In china, substation construction and power equipment maintenance usually are carried out in remote areas. The large-scale wind farm, PV power station and other new energy power generation project, generally locate in the desert or mountains. So there are several problems in the process of engineering construction [2]-[3], such as working tools damaged severe due to layout in the open-pit, the poor construction environment, high cost and electric leakage risk of filed-lease, personnel or equipment accidents, and so on. These problems are main difficulties that deeply influence the practical work of infrastructure engineering in smart grid.

In order to solve these problems, domestic and foreign scholars put forward the idea of using container [4]-[5], which can solve the goods carriage of construction site, ports, mining and other region by taking advantages of multilayer modular and being easy to site assembly, but that is not suitable for people to live or to use. Then someone propose to enlarge the application range of the container, they covert the container into the model of the building, and develop the mechanical performance analysis of the modular container in impact [6]-[7] and common load conditions [8], but no further research about the security and reliability of the device under severe environment. The

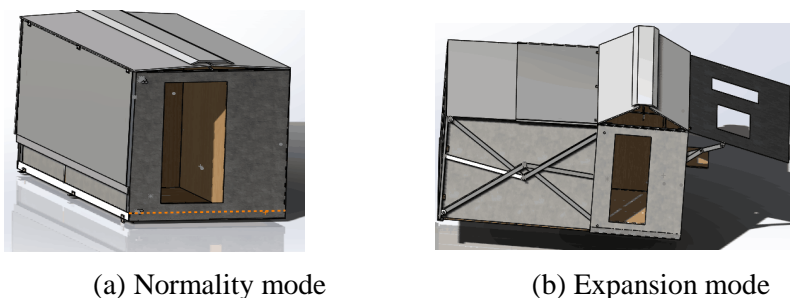


stiffness, vertical yield capacity [9] and ultimate bearing capacity of container house are involved in [10]-[11], which adopt the finite element method to build the model, and determine the corresponding bearing capacity design value.

In this paper, combining with the advantages of container building [12] and tracked vehicle [13], we design and develop a multi-function and self-enlargement workshop based on the vehicle transportation and automatic loading, which has characteristics of low cost, high security, excellent insulation and convenient movement. In the first stage, the overall structure framework and function of the workshop are designed and developed. In the second stage, considering snowstorm and strong wind, such as this extreme weather conditions, the finite element model of workshop is built, and the maximum displacement and ultimate stress under the severe environment are calculated. The research provides basic technical support for the safety and reliability of workshop in substation.

## 2. Overall framework of workshop

The proposed movable self-enlargement workshop framework in the normality and expansion mode is depicted in figure 1. The workshop has 5m long, 2m wide and 2.5m high. Joist steel and square steel are welded to form framework, stainless steel plate is used as the outer skin, polyurethane foam board is filled between the cover for thermal insulation, and the boards are connected with each other by riveting, welding or hinging. To realize overall lifting, diaphragm turnover, folding, straight drive or rotational combination, DG-JB80E hydraulic cylinder and DG-JB50E are used to drive workshop by the driving mode combined of servo control and electric cylinder. When the workshop is extended, it can form an open workspace and a close rest area. In the workspace, the equipment needed for substation construction are fixed, and commonly used spare part materials as well as security tools are placed; The rest area is fixed with 3 air-conditioners and folding desks.



**Figure 1.** Three - dimensional modelling of workshop steel structure

## 3. Finite element calculation model

When a multifunctional movable self-expanding workshop is used in a substation, it is necessary to consider the rainstorm, snowstorm, strong wind, or a comprehensive situation. Due to rainwater's liquidity, its transient load is less than the load of snow and wind imposed by the finite element analysis. Therefore, we mainly consider snowstorm, strong wind, and the combination of these two severe weather conditions. By using ANSYS, a finite element calculation model is established to analyse the maximum displacement and ultimate stress of the workshop considering the ultimate load tests [14]-[15].

### 3.1. The Snowstorm Condition

According to the code for load of building structure GB5009-2001, the standard value of snow load on the roof horizontal projection plane is calculated in (1):

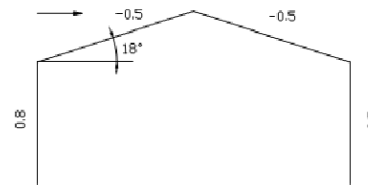
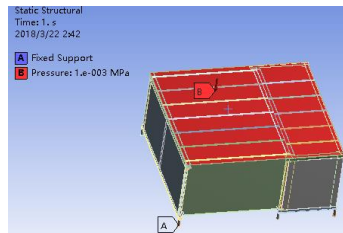
$$S_k = \mu_r S_0 \quad (1)$$

where,  $S_k$  is the standard value of snow loads ( $\text{kN/m}^2$ );  $\mu_r$  is the snow distribution coefficient of roof, in here the roof slope is less than  $25^\circ$ ,  $\mu_r$  runs 2;  $S_0$  is the basic snow pressure ( $\text{kN/m}^2$ ).

When the average density of snow cover is  $150\text{kg/m}^3$  and the thickness of snow cover is  $20\text{cm}$ , the result of calculation is:

$$S_k = 2 \times 150 \times 0.2 \times 10^{-3} = 0.06 \text{ kN/m}^2. \quad (2)$$

Figure 2 shows the loading cases. When the roof is assumed to be a flat plane, in where  $S_k$  is  $0.06\text{kN/m}^2$  and the safety factor is greater than 1.5 (The material object is showed in figure 1. The inclination of the left side is about  $18^\circ$ , and the shape of the right side is like the Chinese character of eight. In the paper, the flatness of loading model in the various conditions is same.)



**Figure 2.** The loading simulation model of snow load      **Figure 3.** The shape coefficient of wind load

### 3.2. The Strong Wind Condition

Consulting the code for load of building structure GB5009-2001, the standard value of wind load which is perpendicular to the surface of the building plane is calculated in (3):

$$W_k = \beta_z \mu_s \mu_z W_0 \quad (3)$$

Where,  $W_k$  is the standard value of wind loads ( $\text{kN/m}^2$ );  $\beta_z$  is the wind vibration coefficient at height  $Z$ . As the height of the workshop is only  $2.5\text{m}$ , the  $\beta_z$  value is  $1.0$ .  $\mu_s$  is the shape coefficient of wind load (as shown in figure 3). When the angle of roof is less than  $15^\circ$ ,  $\mu_s$  values  $-0.6$ ; when the angle of roof is equal to  $30^\circ$ ,  $\mu_s$  values  $0$ . As the angle of this structure is designed to be  $18^\circ$ ,  $\mu_s$  values  $-0.5$  based on the linear interpolation.  $\mu_z$  is the wind pressure height coefficient. In this paper, the roughness of the bottom surface is in class B, and the roof height is less than  $5\text{m}$ , so the value of  $\mu_z$  is  $1.0$ .  $W_0$  is the basic wind pressure ( $\text{kN/m}^2$ ).

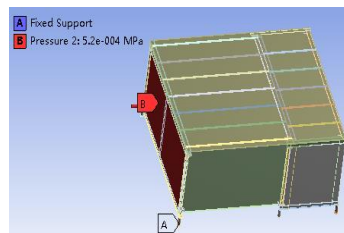
The conversion relation between wind speed and wind pressure is shown in (4). When the wind speed is 9, 10 or 11, the wind pressure at different parts of the workshop is shown in table 1.

$$W_0 = \frac{\gamma}{2g} v^2 \approx \frac{v^2}{1600} \quad (4)$$

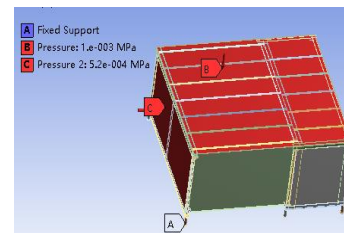
According to the calculated results from table 1, the loading simulation model of strong wind loads is as shown in figure 4, where, the finite element model from two directions is established according to the wind speed of level 11.

**Table 1.** The loading simulation model of snow load

Wind speed level	Wind speed (m/s)	Basic wind pressure ( $\text{kN/m}^2$ )	roof of wind pressure ( $\text{kN/m}^2$ )	Leeward wind pressure ( $\text{kN/m}^2$ )	Wind pressure against windward ( $\text{kN/m}^2$ )
9	23.5	0.35	-0.175	-0.175	0.28
10	28.4	0.5	-0.25	-0.25	0.4
11	32.3	0.65	-0.325	-0.325	0.52



**Figure 4.** The simulation model of strong wind load



**Figure 5.** The simulation model of the comprehensive condition

### 3.3. The Integrated Blizzard Condition

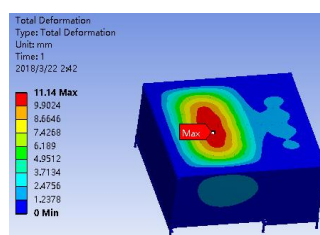
The integrated blizzard condition combines the snowstorm condition with the strong wind condition. Under this severe circumstance, the loading simulation model is built in figure 5, where, the corresponding load is the superposition of wind load and snow load.

## 4. Security analysis

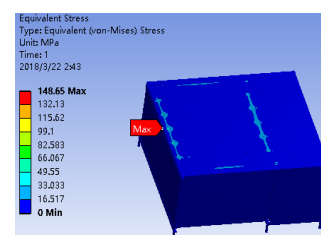
### 4.1. The Snowstorm Condition

Under the snowstorm condition, we adopt the gravity stack way to simulate the snow load. In particular, the counterweight is directly loaded in workshop panel, then the snow load is allotted equivalent to each load point according to the equivalence principle of mechanics. By means of multi-point loading, the workshop panel will not be damaged and the simulation results are more accurate.

The calculation results of workshop under equivalent snow load of 20cm snow cover are given in figure 6. It can be seen from figure 6 (a) that the maximum squat of the roof at the left expansion position is 11.14mm, but the ultimate stress is distributed at the position where the beams on both sides meet the ceiling, which is basically consistent with the actual profit situation. The simulation results show that the workshop is more suitable to the condition of 20cm snowfall by the optimization design of the skeleton.



(a) The deformation nephogram



(b) The stress nephogram

**Figure 6.** Calculation results under the snowstorm condition

### 4.2. The Strong Wind Condition

Under the strong wind condition, we adopt the hole-punching way to simulate the wind load. In particular, the distributive girder of jack is directly loaded in windward side and roof of workshop, and the stress distribution of each panel is determined according to the wind grade. By means of the punching and lifting way, the gravity load is loaded in each point of the workshop panel, and the gravity stack way is adopted on the workshop roof to ensure the effectiveness of simulation.

According to the simulation model of the workshop under strong winds, we get the calculation results, which are shown in figure 7. From it, we can see the maximum displacement of workshop is 10.97mm, and the ultimate stress of workshop is 105.9Mpa, which all meet the load carrying requirement of the wind speed of level 11. In order to ensure the security of the workshop, reinforcing

bars are added on the inside of the surrounding panel walls to enhance the stability and reliability of the workshop operation.



(a) The deformation nephogram

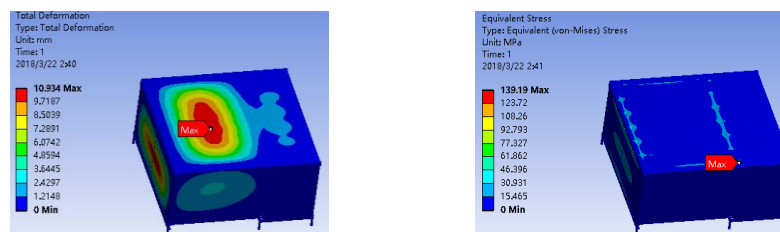
(b) The stress nephogram

**Figure 7.** Calculation results under strong wind condition

#### 4.3. The Integrated Blizzard Condition

Under the comprehensive condition of wind and snow, the load is loaded by gravity stack and hole-punching way. Specifically speaking, the gravity stack is adopted to simulate the snow load by directly loading the weight on the workshop panel without drilling holes at the loading point. The main advantage of this method is no damage to the workshop panel, and the simulation results are more accurate due to large loading area. The wind load is simulated by the hole-punching way in workshop panel, which is drilling holes in the position of loading points on the workshop panel, hanging rope at the hole, and applying load of suspended weight on the panel. The advantages of this method are less work, convenient operation and easy to control the load level.

According to the above simulated calculation values, the simulation results are shown in in figure 8. From it, we can see the maximum displacement of workshop is 10.934mm, and the ultimate stress of workshop is 140Mpa. As the yield stress of Q235 material is 235Mpa, the designed workshop meets the operation demand under the corresponding working conditions. According to the corresponding calculation and simulation, the overall structure of the workshop is stable and reliable, which meets the requirements of physical production.



(a) The deformation nephogram

(b) The stress nephogram

**Figure 8.** Calculation results under integrated blizzard condition

## 5. Conclusion

This paper has developed a kind of movable multi-function and self-enlargement workshop. Under the circumstance of snowstorm, strong wind and other integrated blizzard condition, the finite element model is elaborated to calculate the maximum displacement and ultimate stress of the workshop. The results indicate that the designed workshop greatly meets the security and reliability in substation under severe environment, which can effectively improve the work efficiency, to ensure the safety of personnel and equipment in the process of substation construction. Also, it has a great application value in the field of engineering, field working, risk and disaster.

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