Analysis and optimization of hemispherical gable reconstruction scheme for old coal shed

Chenguang Yang*
School of Civil engineering, Zhengzhou University, Zhengzhou, China

*Corresponding author e-mail: superyang1994@163.com

Abstract. Nowadays, many old dry coal sheds are able to meet the structural safety requirements. However, due to the high requirements of environmental indicators in recent years, the open coal shed on both sides is unable to meet the environmental protection specifications. Aiming at the further closed design of the old dry coal shed, the design scheme is adopted, and the transformation scheme of the hemispherical gable wall is adopted, and the parameter optimization is carried out, which can be used for reference in the future design. And a wide range of promotion and implementation.

1. Introduction
In the early twenty-first Century, there was a boom in the construction of dry coal shed at home and abroad. As the sealing effect of dry coal shed was better than that of the windbreak and dust suppression network, it was widely applied. Now the relevant government documents and the state’s laws and regulations on energy conservation and environmental protection are becoming more and more stringent. It is divided into two cases. For demolition of structures that do not meet the requirements of the new code, of course, demolition plans should be taken. For the structural safety that can meet the new specifications, the scheme of totally enclosed transformation on the basis of the previous building structures should be adopted, and the scheme transformation lacks the corresponding technical solutions. Therefore, based on the actual project, a new hemispherical gable technology scheme is adopted.

2. Structural modelling and analysing
2.1. Project overview
A dry coal shed was originally a strip dry coal shed, surrounded by wind and dust suppression nets, height of about 16m, coal shed length 150m, effective 60 thousand tons of coal storage, the original dry coal shed length, width 108m, dry coal shed north side about 40m reserved space, the main design parameters and internal structure are set as follows.
2.2. **Software introduction**

3D3S can complete the design of light portal steel frame, grid and reticulated shell structure. In view of the advantages of 3D3S for space truss design, the grid structure in this project chooses 3D3S as the design analysis software and carries out structural system modeling, and MIDAS acts as the task of computational analysis: 1. after completing the modeling of 3D3S, the numerical input of constant load, live load, wind load and snow load and the selection of the loading surface were completed. 2. the 3D3S model was packaged into MIDAS/GEN, and the eigenvalue analysis was carried out. 3. Lanczos method in MIDAS was used to get the model state and analyze the feasibility of the structure.

2.3. **Calculation assumption**

The calculation and analysis show that for the space grid structure, no matter what form the node takes, the load often acts on the node. The internal force of the member is mainly axial force, and the bending moment caused by the stiffness of the node is usually very small. Therefore, when the grid structure is calculated, the influence of the internal force of the member caused by secondary stress and the stiffness of the node can be neglected. It can be assumed that the connection between the members is the transfer. The influence of the grid structure displacement and the stiffness of the nodes after loading can be assumed that the connection between the members is hinged. The mesh structure displacement after loading is a small deflection category without considering the geometric nonlinearity caused by large deflection and large displacement [1].

1. Assuming that the joint is a spatial hinge joint, the rod only bears axial force and ignores the influence of node stiffness.
2. It is assumed that the deformation of the structure is very small under load and is calculated according to the theory of small deflection.
3. The material is assumed to work in the elastic stage, and the material obeys Hooke's law.

2.4. **Load calculation**

2.4.1. **Load value.** Referring to the unified standard for reliability design of buildings (GB50068-2018) [5] and the code for loading of building structures (GB50009-2012) [3], the following loads are obtained:

1. constant load: 0.3kN/m² (roof panel + purlin weight)
2. live load: 0.5kN/m² (for main load-bearing structure design)
3. wind load: ground roughness B, basic wind pressure 0.35kN/m².
4. temperature effect: inquire about the local temperature change. According to the standard, the temperature will be increased at 25 degrees centigrade, and the temperature will be reduced by -25 C.
5. earthquake action: according to the seismic intensity 7 degree design acceleration, the peak ground acceleration of the 0.1g ground motion should be 0.0727g and the response spectrum characteristic period 0.25s. According to the technical specification for space grid, the first 30 vibration modes of the structure should be analyzed.
2.4.2. **Load combination.** 1. load combinations under constant load and live load:

   (1) 1.3 dead load + 1.5 live + 1.5 wind load
   (2) 1.3 dead load + 1.5 live + 1.5 temperature
   (3) 1.3 dead load + 1.5 live load + 1.5*0.6 wind load + 1.5 temperature
   (4) 1.3 dead load + 1.5 live load + 1.5 wind load + 1.5*0.6 temperature
   (5) 1.3 dead load + 1.5 live load + 1.5 earthquake load

2. load combinations under constant load and live load:

   (6) 0.95 dead load + 1.5*0.7 live + 1.5 wind load
   (7) 0.95 dead load + 1.5*0.7 live + 1.5 temperature
   (8) 0.95 dead load + 1.5*0.7 live load + 1.5*0.6 wind load + 1.5 temperature
   (9) 0.95 dead load + 1.5*0.7 live load + 1.5 wind load + 1.5*0.6 temperature
   (10) 0.95 dead load + 1.5*0.7 live load + 1.5 earthquake load

2.5. **Review of original structure**

   Analysis of calculation results:

   Through Midas finite element analysis, the maximum stress load combination and other stress conditions are listed.

   **Table 1. Maximum stress of working condition combination**

   | Working condition combination | Maximum pulling force (kN) | Maximum pressure (kN) |
   |-------------------------------|---------------------------|-----------------------|
   | 4 | 265.85 | -849.82 |
   | dead load | 49.28 | -168.89 |
   | Live load | 90.61 | -149.29 |
   | Wind load | 226.21 | -272.84 |
   | temperature load | 132.13 | -132.13 |

   The maximum tensile force of the structure is 265.85kN, the maximum pressure is 849.82kN, the maximum stress ratio of the bar is 0.83, which is less than 0.85 of the specification. The maximum displacement of the structural node XYZ three is Z, the displacement is 132.838mm, less than the 1/250 span (432mm) specified in the specification[4].

   **Table 2. Node maximum displacement table**

   | Working condition | Maximum pulling force (kN) | Maximum pressure (kN) | X maximum displacement (mm) | Y maximum displacement (mm) | Z maximum displacement (mm) |
   |-------------------|-----------------------------|-----------------------|-----------------------------|-----------------------------|-----------------------------|
   | Horizontal earthquake | 12.031 | -12.031 | 8.628 | 1.189 | 0.39 |
   | Vertical earthquake | 1.982 | -1.982 | 0.271 | 1.815 | 7.016 |

   As shown in the table, the structure is triggered by the local earthquake load corresponding to the constant load of 10% magnitude, so the structure can meet the local seismic demand.

2.6. **Hemispherical gable reconstruction**

   (1) if the remaining 40m in front of the structure is known, after the 10m is subtracted from the traffic demand, the gable length should be controlled at 30m. The design parameters of the gables can be obtained through consulting the relevant design data[5], and the 3D3S can be modeled.
(2) through Midas finite element analysis, the maximum stress load combination and other stress conditions are listed.

| Working condition combination | Maximum pulling force (kN) | Maximum pressure (kN) |
|-------------------------------|---------------------------|-----------------------|
| 4                             | 333.69                    | -559.48               |
| dead load                     | 44.89                     | -178.17               |
| Live load                     | 83.45                     | -147.48               |
| Wind load                     | 218.99                    | -106.13               |
| temperature load              | 170.64                    | -170.64               |

The maximum stress of the structure is decreased from the table to the original structure. The maximum tensile force of the bar is 333.69kN, the maximum pressure is 559.48kN, the maximum stress ratio is 0.78, the maximum displacement of the structure XYZ is Z, the maximum displacement is -70.424mm., and the maximum spatial displacement is 77.179mm, which appears in the middle of the back wind. When the structure is subjected to transverse (0 degree) and longitudinal (90 degree) wind loads, the pressure bearing structural plane is the upwind side of the structure, and the bearing structural plane is the leeward side of the structure. When the structure is subjected to transverse wind loads, the maximum displacement of the upper part of the back face of the cylindrical surface of the structure appears, and the maximum displacement of the top of the circular gable wall on the leeward side appears when the structure is subjected to longitudinal wind load.
Table 4. Stress and displacement results of structures under earthquake conditions

| Working condition       | Maximum internal force (kN) | Maximum pressure (kN) | Xmax (m) | Ymax (m) | Zmax (m) |
|-------------------------|-----------------------------|-----------------------|----------|----------|----------|
| Horizontal earthquake   | 7.768                       | -7.768                | 4.326    | 0.054    | 0.782    |
| Vertical earthquake     | 2.55                        | -2.55                 | 0.098    | 1.826    | 5.136    |

From the table 4, we can see that the structure is triggered by the local earthquake load corresponding to the constant load of 10% magnitude, so the structure can meet the local seismic demand.

3. Parameter optimization

In the actual operation of the space grid structure, the performance of the structure itself will be affected by the parameters of the structure itself. No matter the shape of the structure, the selection of the gable section, or the material used by the structure, it will affect the tensile and compressive load performance of the structure. The influence of various factors on the structural law is discussed, and the parameters of the final optimization of the structure are given.

3.1. Grid size

Table 5. Comparison of mechanical properties of structures with different mesh sizes

| Size scheme (mm) | Maximum bar tension (kN) | Maximum pressure bar (kN) | Maximum stress ratio of bars | Maximum displacement of space (mm) | Steel consumption (kg) |
|------------------|--------------------------|---------------------------|------------------------------|-----------------------------------|------------------------|
| 3750*2200        | 270.4                    | -460.8                    | 0.76                         | 98.83                             | 1027727                |
| 1875*4400        | 197.4                    | -460.11                   | 0.74                         | 99.06                             | 1061807                |
| 3750*4400        | 333.6                    | -559.5                    | 0.78                         | 77.18                             | 961942                 |

Through the data observed in the table, when selecting the 3750*2200mm size program, the maximum rod tension is reduced by 63.2kN compared with the 3750*4400mm scheme, the maximum pressure is reduced by 98.7kN, and the consumption of steel is increased. When 6.8% chooses the 1875*4400mm size scheme, the maximum rod tension is reduced 136.2kN compared with the 3750*4400 scheme, and the pressure reduction effect is the same as that of the 3750*2200 size scheme. The consumption of steel is increased relatively 10.4%. The maximum stress ratio of the first two schemes is not much different from that of the 3750*4400mm scheme.

Although the 3750*2200mm and 1875*4400mm schemes can reduce the stress of structural members, displacement control is particularly important in the design of space structures. The first two designs increase by nearly 40% compared with the original design (3750*4400mm), and the third schemes are more economical in terms of steel consumption, and the stress has met the requirements of relevant codes.
3.2. Shell thickness

Table 6. Stress comparison of different reticulated shell thickness

| Grid thickness (mm) | Maximum bar tension (kN) | Maximum pressure bar (kN) | Maximum stress ratio of bars | Maximum displacement in space (mm) | Steel consumption (kg) |
|---------------------|--------------------------|---------------------------|-----------------------------|----------------------------------|------------------------|
| 2000                | 266.01                   | -460.5                    | 0.88                        | 99.64                            | 860376                 |
| 4000                | 333.6                    | -559.5                    | 0.78                        | 77.18                            | 961942                 |
| 6000                | 372.89                   | -560.67                   | 0.83                        | 98.91                            | 1058741                |

The observation table shows that when the thickness of the gable net shell is 2.0m, the maximum tensile force of the structure is reduced by 67.6kN compared with the thickness of the reticulated shell 4.0m, the maximum pressure decreases by 99kN, and the steel consumption decreases by 10.6%. However, the maximum stress ratio of the bar does not meet the control requirement of not more than 0.85 in the specification. When the thickness of the reticulated shell is 6.0m, the structure increases 39.3kN compared with the thickness of 4.0m, the pressure shadow play is smaller, and the consumption of steel increases 10.06%.

It is concluded from the above conclusion that the magnitude of the structural stress increases with the increase of the thickness of the reticulated shell. Although when the thickness of the structure is selected by 2.0m, the amount of steel consumed is reduced, and the structural stress is reduced, but the structure can not meet the maximum stress ratio requirement. Therefore, it can not be selected. When the thickness is chosen 6.0m, the value of the structure is higher than the thickness of 4.0m when it is subjected to force and displacement.

3.3. Bearing position

Table 7. Stress comparison of different support position

| Bearing position | Maximum bar tension (kN) | Maximum pressure bar (kN) | Maximum stress ratio of bars | Maximum displacement of space (mm) | Steel consumption (kg) |
|------------------|--------------------------|---------------------------|-----------------------------|----------------------------------|------------------------|
| Upper chord brace| 333.6                    | -559.5                    | 0.78                        | 77.18                            | 961942                 |
| Bottom chord brace| 332.63                  | 560.09                    | 0.80                        | 77.05                            | 938903                 |

According to the table, the bottom chord brace and the upper chord support have little effect on the force and displacement of the structure, but because of the original structure design for the upper chord brace, it is considered in the integrity and aesthetics, and the structure chooses the upper chord brace.

4. Conclusion

In this paper, the field data are recorded on the basis of the engineering data of the dry coal shed in a certain arch net truss, and the dry coal shed is modeled by the original engineering data. The current standard load is checked for the structure. After the completion of the review, the whole closed optimization design of the hemispherical gable is carried out on the basis of the original dry coal shed, and in the parameter optimization. In the premise of structural safety, we should pursue the economic efficiency of the project and reduce the consumption of steel as much as possible.

1. first of all, the initial unclosed arch dry coal shed is modeled according to the engineering data. After importing the design necessary load in 3D3S, the MIDAS is transferred to the original structure for static analysis and eigenvalue analysis. Results can be obtained from statistics. The maximum
The stress of the four cone conical shell dry coal shed is -849.82kN, the maximum deflection of the structure is 135.131mm, and the stress ratio meets the requirements. In line with the latest regulations, no replacement and reinforcement measures are needed.

2. In this paper, a hemispherical gable closure scheme is designed and checked. It is found that the wind load mainly accounts for the control role of load in the checking calculation. The maximum stress is -559.48kN, and the displacement is decreased relative to the original structure displacement, which is 77.179mm, which meets the specification requirements and meets the local seismic requirements.

3. In the process of parameter optimization, the maximum stress of the structure will be reduced, but the displacement will increase as well as the consumption of steel. The maximum stress of the structure will increase as the thickness of the reticulated shell increases. When the grid size is 3750*4400, the shell thickness is 4.0m, and the support form chooses the upper chord brace, it not only meets the specification requirements, but also reduces the load and displacement value as far as possible, thus achieving further structural safety and economy.

References
[1] Yaozhi Luo. Large span coal storage structure: Design and construction. M. China electric power press: Beijing, 2017: 113-114.
[2] Dexun Han. Calculation Method of Arbitrary Three-center Arch. J. Coal Engineering, 1986, 10: 8-9.
[3] GB 50009-2012. Load code for the design of building structures. S. Beijing: China Building Industry Press, 2012.
[4] JGJ7-2010. Technical specification for space frame structures. S. Beijing: China building industry press, 2010.
[5] GB 50068-2018. Unified standard for reliability design of building structures. S. Beijing: China building industry press, 2018.