

Detection and Cause Analysis of the Deformation of the Purlin in a Certain Portal Frame Structure Factory Building

Mingnan Ji

Inspection and Certification Co., Ltd. MCC, Beijing, China
Email: 785694396@qq.com

How to cite this paper: Ji, M.N. (2024) Detection and Cause Analysis of the Deformation of the Purlin in a Certain Portal Frame Structure Factory Building. *Open Journal of Applied Sciences*, 14, 3366-3378.
<https://doi.org/10.4236/ojapps.2024.1411221>

Received: November 1, 2024

Accepted: November 26, 2024

Published: November 29, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

During the renovation process of a certain factory building, significant deflection deformation occurred in the purlins. To identify the reasons for the deformation of the purlins and eliminate potential safety hazards, a comprehensive structural inspection was carried out on this factory building, the inspection results indicate that the sectional dimension deviations of the measured steel components and the strength of the steel are in line with the design and code requirements. However, the mid-span deflections of some purlin components fail to meet the code requirements. The bearing capacity of the suspended loads under different working conditions was analyzed: Among the 9 hanging load working conditions of the purlins, the bearing capacity of the purlins in 4 working conditions did not meet the code requirements; among the 2 hanging load working conditions of the main frame, the bearing capacity of the frame beam components in 1 working condition did not meet the code requirements, and the deflections of the frame beams in both 2 working conditions did not meet the code requirements. In response to the above results, practical and feasible treatment suggestions were put forward.

Keywords

Purlin, Deflection Deformation, Inspection and Appraisal, Treatment Measures

1. Project Overview and Research Purposes

1.1. Project Overview

The structural form of a certain factory building adopts the portal frame structure, with a length of 112.0 meters from east to west and 48.0 meters from north to south.

building was carried out. The inspection results indicate:

1) In the area of axes 13 to 16, the lower flange of the purlin at the hanging point of the suspended pipe load has undergone considerable deformation, as shown in **Figure 2**.

2) In the area of axes 13 to 15, the purlin has presented significant deflection, as shown in **Figure 3**.

3) The welding quality of the suspended hanging pieces and the main frame is poor, as shown in **Figure 4**.

4) Corrosion exists on the bolt nodes of the main frame components, the nodes of the purlins and the tension rods, as shown in **Figure 5**.



Figure 2. Local considerable deformation of the lower flange of the purlin.



Figure 3. Significant deflection of the purlin.



Figure 4. Poor welding quality between the suspended load fixture and the rigid frame.



Figure 5. Corrosion of the node bolts of the rigid frame components.

2.2. Inspection of the Structural System

The factory building is a one-story portal frame structure, where the foundation form adopts independent foundations under columns. It measures 112.0 meters from east to west, 48.0 meters from north to south, has a building height of 6.3 meters, and has a floor area of 5497.5 square meters. The current status of the roof and wall envelope systems is basically intact.

The on-site inspection of the structural plane layout and structural system reveals that the structural form, component selection, structural construction, connection, and support systems all comply with the design and code requirements.

However, the arrangement of the hanging points after the renovation does not conform to the drawings. It is necessary to further select the portal frames and purlins in the areas with dense hanging loads and significant forces for testing and bearing capacity analysis.

3. Field Detection Outcomes

3.1. Recheck of Component Layout

On-site laser rangefinders and tape measures were employed to recheck the layout of the structural plane. The outcome indicated that the layout of the structural plane conformed to the original design drawings.

3.2. Inspection of the Cross-Sectional Dimensions of Steel Structural Members

Steel tape measures, ultrasonic thickness gauges, and other tools were employed to conduct sampling inspections of the cross-sectional dimensions of the steel components in this project. The inspection results indicated that the deviations in the cross-sectional dimensions of the measured steel components in this project conformed to the design and specification requirements [6].

3.3. Testing of the Strength of Steel Structural Members

The Leeb hardness tester was adopted to conduct sampling tests on the material strength of steel structural members, such as the rigid frame columns and rigid frame beams in this project. The test data indicate that the strength of the steel materials of the steel structural members in this project satisfies the design requirements [7].

3.4. Testing of the Deflection of Steel Structural Members

Total station and plumb bob were employed to conduct deflection tests on purlins and rigid frame beam components in areas with dense hoisting loads and significant forces. The test results indicate that the mid-span deflection deformations of the four inclined beams of the rigid frames at 11/A-C, 11/C-E, 16/E-G, and 16/G-J all satisfy the requirements of the specifications. Among the 10 purlins inspected, 7 purlins, namely 7-8/(2/D), 9-10/(2/D), 10-11/(3/A), 15-16/(1/H), 15-16/(2/B), 14-15/(1/C), and 14-15/(2/B), do not meet the limit requirement of $L/240$ stipulated [8]. The remaining 3 purlins, 11-12/(2/B), 14-15/(2/G), and 13-14/(1/C), although meeting the limit requirement, are close to the critical value, with a relatively small margin.

4. Checking Calculation of Bearing Capacity

4.1. Checking Calculation of the Bearing Capacity of Purlins

An on-site investigation was carried out regarding the hanging status of the purlins in this project. Nine loading conditions with denser hanging loads and larger forces in the loading area were selected for the checking calculation of bearing

capacity. The layout plans of these nine conditions are presented in **Figure 6**. According to the load of the air ducts and pipes' specifications and the on-site hanging arrangement, the calculation diagrams of the nine conditions were derived, and the bearing capacity of the purlins under the corresponding conditions was calculated [9]. The calculation results are shown in **Table 1**.

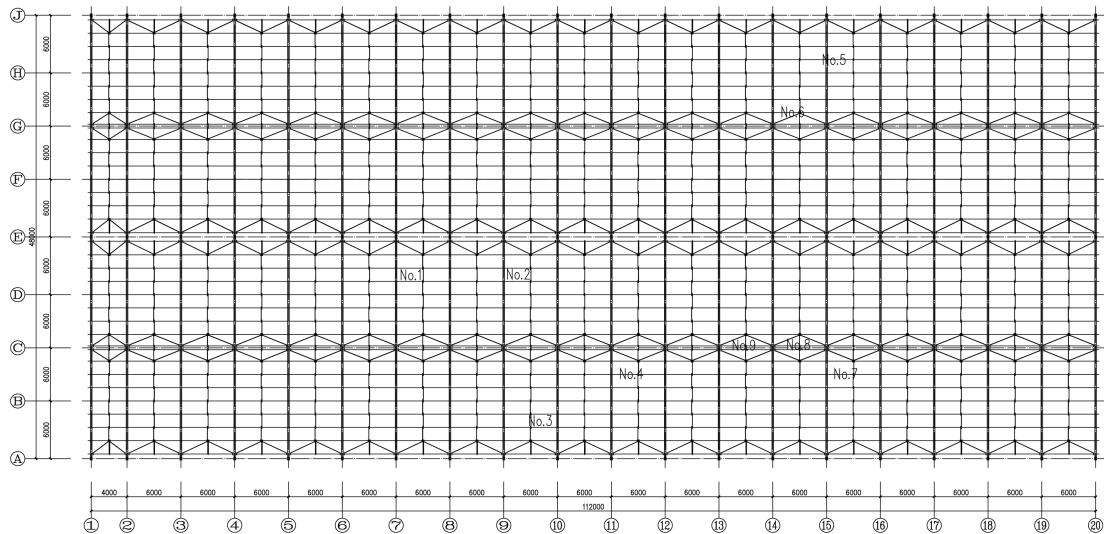


Figure 6. Plane layout of rafters under various working conditions.

Table 1. Calculation results of the bearing capacity of rafters under various working conditions.

Serial number of working conditions	Purlin position	Equivalent calculation sketch (kN)	The result of bearing capacity calculation
Working condition one	7-8/(2/D)		Fail to satisfy the requirements of the specification
Working condition two	9-10/(2/D)		Fail to satisfy the requirements of the specification
Working condition three	10-11/(3/A)		Fail to satisfy the requirements of the specification
Working condition four	11-12/(2/B)		Satisfy the requirements of the specification

Continued

Working condition five	15-16/(1/H)		Satisfy the requirements of the specification
Working condition six	14-15/(2/G)		Satisfy the requirements of the specification
Working condition seven	15-16/(2/B)		Satisfy the requirements of the specification
Working condition eight	14-15/(1/C)		Fail to satisfy the requirements of the specification
Working condition nine	13-14/(1/C)		Satisfy the requirements of the specification

4.2. Verification of Bearing Capacity of the Main Steel Frame, Beam Deflection and Lateral Displacement

An on-site investigation was carried out regarding the hanging condition of the main frame structure of this project. Two loading conditions with denser hanging loads and greater forces, namely the 16th and 11th frames, were selected for verification of bearing capacity, beam deflection, and lateral displacement [10].

I) Verification of the bearing capacity of the 16th frame

On one side of this frame, two DN150 and three DN65 pipes were hung, and on the other side, two DN150 and one DN65 pipe were hung. Considering other linear loads, a hanging load of 1.1 kN/m was taken on one side and 0.9 kN/m on the other side for this bearing capacity calculation. The verification results of the stress ratio are shown in **Figure 7**.

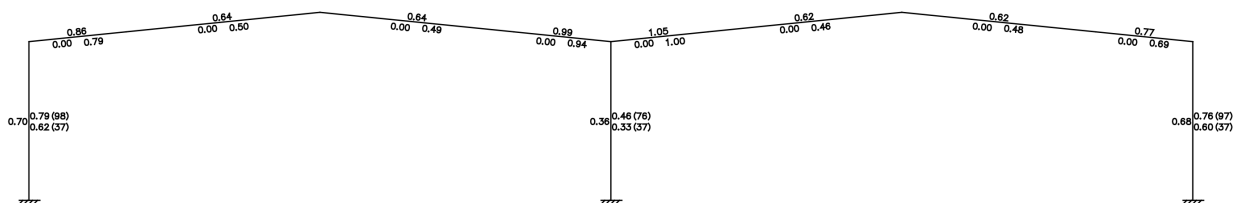


Figure 7. The stress ratio verification results of the 16th bay portal frame steel structural members.

The calculation outcomes indicate that the bearing capacity safety margin of the gable truss beam 16/E-F is 0.95, failing to fulfill the requirements of the specification.

II) Computation of deflection deformation and lateral displacement of the 16th bay truss girder

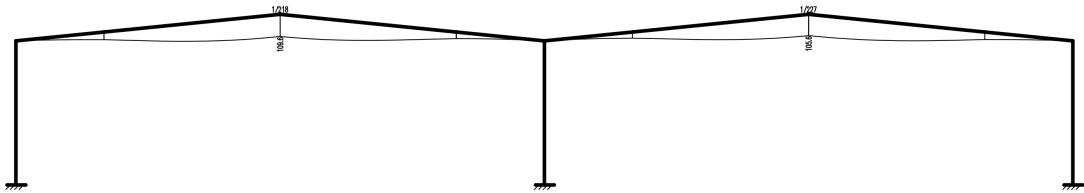


Figure 8. The calculation results of deflection of the 16th bay portal frame beams.

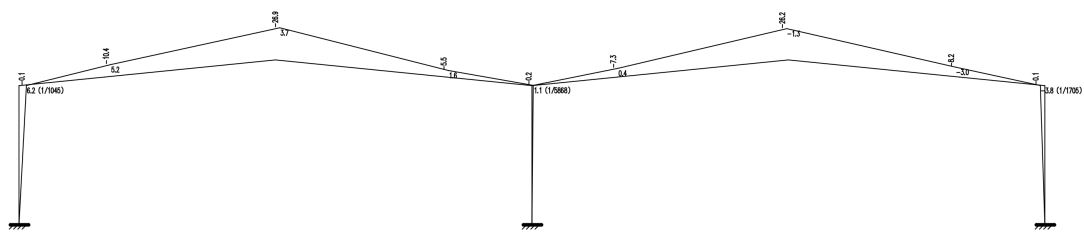


Figure 9. The calculation results of lateral displacement of the 16th bay portal frame (left wind 1).

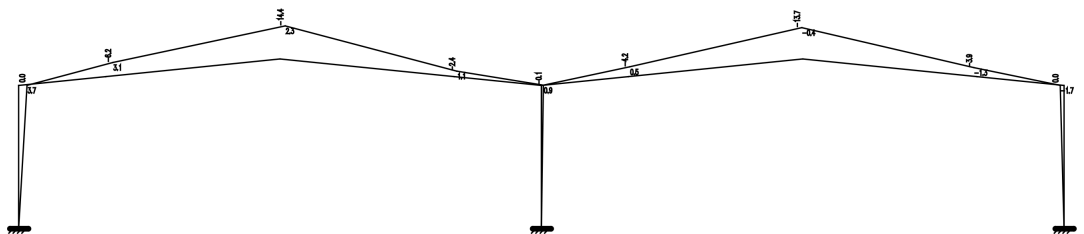


Figure 10. The calculation results of the lateral displacement of the 16th bay portal frame (left wind 2).

The calculation outcomes indicate that the deflection of the portal frame beams fails to comply with the requirements of the code, as shown in Figure 8, but the calculation results of the lateral displacement satisfy the code requirements, as shown in Figure 9 and Figure 10.

III) Verification of the bearing capacity of the 11th frame

This truss bay has four DN100 and one DN150 suspended on one side. Considering other line loads, the hanging load on this side is assumed to be 1.0 kN/m for the current bearing capacity calculation. The stress ratio verification results are presented in Figure 11.

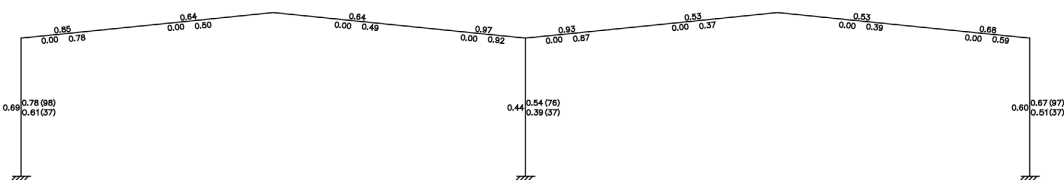


Figure 11. The stress ratio verification results of the 11th bay portal frame steel structural members.

The calculation outcomes demonstrate that the safety margins of the bearing capacity of the portal frame components are all greater than 1, fulfilling the requirements of the code.

IV) Computation of deflection deformation and lateral displacement of the 16th bay truss girder

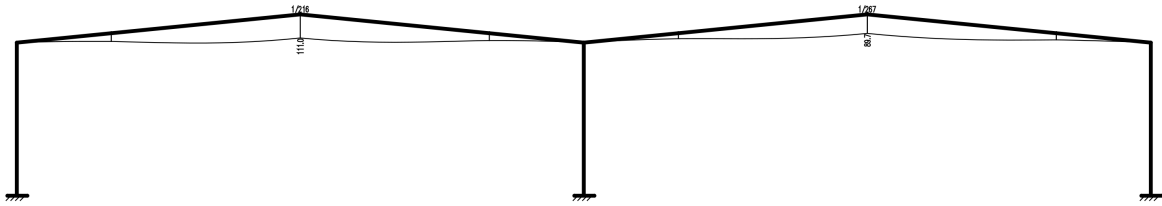


Figure 12. The calculation results of deflection of the 11th bay portal frame beams.

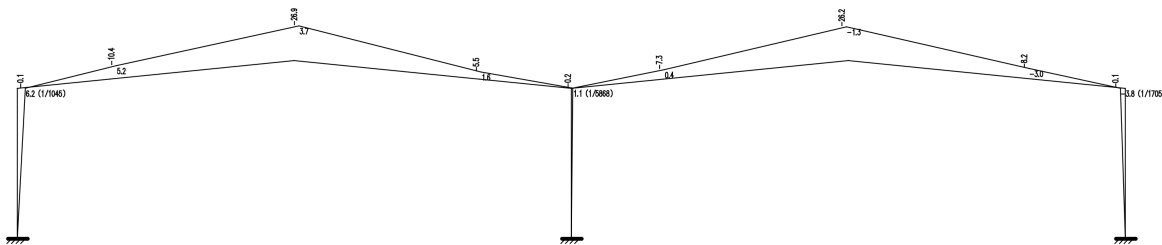


Figure 13. The calculation results of lateral displacement of the 11th bay portal frame (left wind 1).

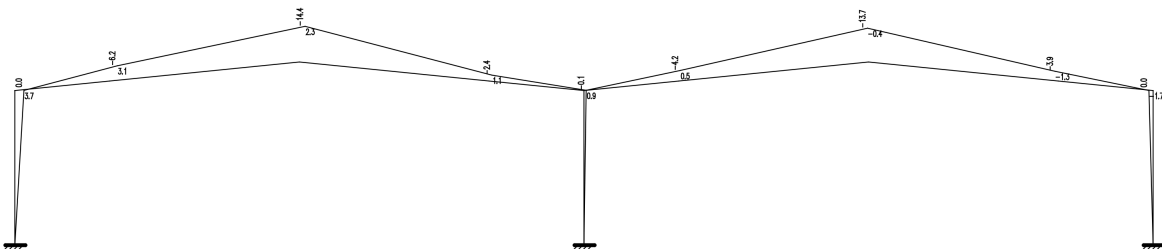


Figure 14. The calculation results of the lateral displacement of the 11th bay portal frame (left wind 2).

The computational results indicate that the deflection of the portal frame beams fails to comply with the requirements of the code, as shown in **Figure 12**, whereas the calculation results of the lateral displacement conform to the code requirements, as shown in **Figure 13** and **Figure 14**.

V) Summary of the check results for the bearing capacity of the main frame

The bearing capacity of the main frame under two hoisting load conditions was verified, and the conclusions are as follows:

1) In the bearing capacity verification results of the 16th truss frame, the safety margin of the bearing capacity of the 16/E-F frame beam is 0.95, which fails to meet the requirements of the code. The calculation result of the deflection of the portal frame beam does not meet the requirements of the code, while the calculation result of the lateral displacement meets the requirements of the code.

2) In the bearing capacity verification results of the 11th truss frame, the safety

margins of the bearing capacity of the portal frame components are all greater than 1, which can meet the requirements of the code. The calculation result of the deflection of the portal frame beam does not meet the requirements of the code, while the calculation result of the lateral displacement meets the requirements of the code.

5. Analysis of Causes

5.1. Analysis of Insufficient Deflection and Bearing Capacity of Purlin Components

Deflection tests and bearing capacity verifications were conducted for nine hoisting load cases of purlins. The results indicate that the bearing capacity of purlins meets the requirements under the fourth, fifth, sixth, seventh, and ninth load cases. However, it fails to meet the requirements under the first, second, third, and eighth load cases. Moreover, the deflection of purlins fails to meet the requirements under the first, second, third, fifth, and eighth load cases. The reasons for this are as follows:

1) In the first load case, as two relatively large air ducts are fully spanned and arranged along the direction of the purlin, the purlin is subjected to a significant load, resulting in the inability of the bearing capacity to meet the code requirements and the failure of the deflection to meet the requirements.

2) In the second load case, due to the considerable weight of the 2500 mm × 500 mm air duct, even though it is single-layer and full-span arranged, the purlin still undergoes a large load, leading to the inability of the bearing capacity to meet the code requirements and the failure of the deflection to meet the requirements.

3) In the third load case, because of the large number of air ducts hung on the purlin and the multi-layer arrangement of the ducts, the purlin is subjected to a significant load, causing the bearing capacity to fail to meet the code requirements and the deflection to fail to meet the requirements.

4) In the eighth load case, as the suspended load is arranged unevenly across spans, with a large span and a three-layer arrangement of air ducts, the purlin is subjected to a significant load, resulting in the inability of the bearing capacity to meet the code requirements and the failure of the deflection to meet the requirements.

5) In the fifth load case, the bearing capacity of the purlin meets the code requirements, but the load arrangement is overly concentrated, causing excessive local deformation and the failure of the deflection to meet the requirements.

6) In the fourth, sixth, seventh, and ninth load cases, the bearing capacity of the purlin meets the code requirements, but the deflection is at the critical value of the allowable deflection. It is recommended to carry out reinforcement treatment.

5.2. Analysis of Insufficient Deflection and Bearing Capacity of Frame Beam Components

By calculating the bearing capacity of two frames, it can be obtained that the safety

margin of the bearing capacity of the frame beam on one side of the E-axis of the 16th frame is 0.95, which fails to meet the requirements of the code. The safety margin of the bearing capacity of the frame beam on the other side of the E-axis of the 16th frame is 1.01. Although it meets the requirements of the code, the safety margin is relatively small. Similarly, the safety margins of the frame beams on both sides of the E-axis of the 11th frame are relatively small. The calculated deflection of the frame beams does not meet the requirements of the code, and the measured deflection on site is also at the critical value of the allowable deflection. Considering adverse factors such as snow load, it is recommended that reinforcement measures be taken for the frame beams of the main frames in the hoisting load area [11].

6. Appraisal Conclusions and Treatment Suggestions

6.1. Appraisal Conclusions

After conducting on-site inspection, testing, calculation, and analysis of the buildings in this project, the following appraisal conclusions are reached:

- 1) Through on-site inspection, it was discovered that the purlin exhibited significant deformation of the lower flange at the hanging point, large mid-span deflection, poor welding quality of the hanging fittings to the steel frame, and corrosion of bolts at the node of the steel frame members, purlin nodes, and tension rods. The planar layout of the structural components of this project, as well as the support and construction, are in accordance with the original design drawings.
- 2) The measured cross-sectional dimensions of the steel components and the strength of the steel in this project comply with the design and code requirements.
- 3) The measured mid-span deflection of some purlin components in this project fails to meet the code requirements.
- 4) On-site investigations were carried out on the densely loaded areas with significant loads. Nine load cases were selected for the verification of the bearing capacity of the purlin. Among them, the bearing capacity of the purlin in four load cases fails to meet the code requirements. Two load cases were selected for the verification of the bearing capacity, beam deflection, and lateral displacement of the main steel frame. Among them, in one load case, the bearing capacity of one beam component of the steel frame fails to meet the code requirements. The beam deflections do not meet the code requirements, while the lateral displacements of the steel frame meet the code requirements.

6.2. Treatment Recommendations

- I) Hanging purlin
 - 1) It is proposed that the purlin under the measured hanging load conditions in this project, the purlin for hanging the 2500 mm × 500 mm air duct, and the purlin for hanging two or three layers of air ducts at axes 13 - 15 be strengthened.
 - 2) It is suggested that the purlin with a relatively large deformation on the lower flange, the purlin with overly dense hanging, and the purlin with hanging loads

arranged across spans in this project be optimized for the hanging arrangement.

3) It is recommended that the rusted components of the roof purlin system be derusted.

II) Hanging main steel frame

1) It is recommended that reinforcement measures be taken for the main steel frame in the hanging load area.

2) It is recommended that the rusted node bolts of the main steel frame in the hanging load area be derusted.

3) It is recommended that the poorly welded hanging fittings of the steel frame be re-welded.

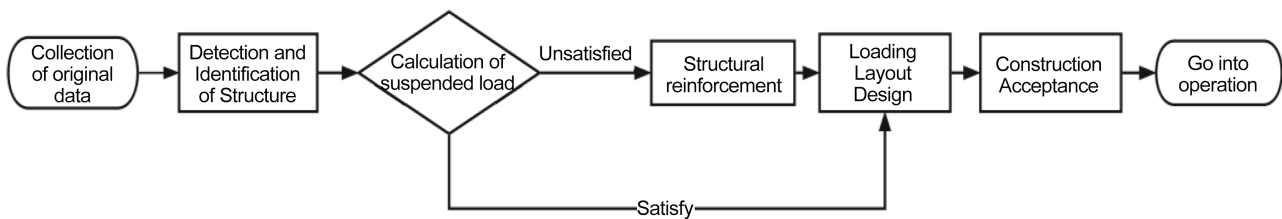


Figure 15. Flowchart of the renovation of suspended loads.

7. Conclusion

During the process of factory building renovation, sufficient attention must be given to the transformation of suspended equipment. It is necessary to recheck and calculate the bearing components. For equipment with large loads, the suspension points must be set reasonably to ensure uniform load distribution, and the entire procedure is depicted in **Figure 15**. This can prevent safety accidents and avoid huge losses [12] [13].

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] Zhou, J.H. (2024) Discussion on the Safety Inspection and Reinforcement Technology of Building Structures. *China Housing Facilities*, **9**, 67-69.
- [2] Bi, Y.C. (2019) The Impact of Hanging Loads in Textile Factory Buildings on Light-Duty Portal Frame Structures. *Engineering Construction and Design*, **13**, 48-50. <https://doi.org/10.136/16/j.cnki.gcjsysj.2019.07.015>
- [3] Yi, Y.P. (2024) Research on Structural Safety Assessment and Identification of Industrial Buildings. *New Urban Construction Science and Technology*, **33**, 124-126.
- [4] Jiang, Y.F. (2015) Structural Identification and Reinforcement Analysis of Pure Naphthalene Frame Structure in a Chemical Factory. Master's Thesis, University of Science and Technology of Liaoning.
- [5] Jin, L.J., Zhang, X.P. and Xing, L.N. (2011) Structural Reliability Identification and Calculation Analysis of a Heavy Industrial Factory Building. *Building Structure*, **41**, 320-323. <https://doi.org/10.19701/j.jzjg.2011.s2.083>
- [6] Chinese Standard (2019) GB/T 50344, Technical Standard for Inspection of Building

Structure.

- [7] Chinese Standard (2010) GB/T 50621, Technical Standard for In-Situ Inspection of Steel Structures.
- [8] Chinese Standard (2015) GB/51022, Technical Code for Steel Structures of Portal Frame Lightweight Buildings.
- [9] Chinese Standard (2012) GB/50009, Load Code for the Design of Building Structures.
- [10] Chinese Standard (2019) GB/50144, Standard for Appraisal of Reliability of Industrial Buildings and Structures.
- [11] Zhang, Z.Y. and Yu, M.M. (2024) Analysis of Key Points in Structural Design of Portal Frame Industrial Workshop Buildings. *Sichuan Cement*, **10**, 109-110+113. (In Chinese) <https://doi.org/10.20198/j.cnki.scsn.2024.10.083>
- [12] Liu, W.T. (2020) Analysis of Some Issues in the Design of Portal Frame Light Steel Structure. *Smart City*, **6**, 139-140. (In Chinese) <https://doi.org/10.19301/j.cnki.znzs.2020.15.066>
- [13] Chen, Y.H. (2024) Research on Structural Design in the Functional Transformation of Factory Buildings. *Building Construction*, **46**, 1503-1507. (In Chinese) <https://doi.org/10.14144/j.cnki.jzsg.2024.09.031>