Analysis of the effects of column-to-ground semi-rigid connection on the mechanical properties of assembled rack

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Abstract. For the different column-to-ground semi-rigid connection coefficients of assembled rack, with common beam pallet rack as research object, the orthogonal experiment was designed, which is composed of 11 groups of connection schemes and 4 kinds of load conditions. In this work, finite element analysis software, based on SAP84, is used to calculate the maximum stress and displacement. The results are compared, and get some useful conclusions.

Introduction

With the development of modern industry, the demand for storage systems is increasing, there are more and more kinds of racks. Assembled rack has the advantages of simple installation and flexible forms, gradually become the mainstream of the market. Column is the main bearing component of assembled rack, the security of column-to-ground connection will be directly affect the overall properties of the rack. The column base connection can be roughly divided into welded connection and assembled connection [1]. When designing the rack, usually assume that the column-to-ground connection is rigid, but in fact the welded connection and the assemble connection are both semi-rigid connection.

The semi-rigid connection [2] is between rigid and articulated on the mechanics characteristic, the connection can not only withstand some bending moment, but also have a certain rotation. Scholars at home and abroad have done a lot of research on the mechanics properties of steel frame with semi-rigid connection, Cabrero J M and Bayo E [3] put forward a practical method for the design of steel frame with semi-rigid connection, Kestutis Urbonas et al. [4] considering the effect on the beam-to-column semi-rigid connection under the combination of axial force and bending moment, Wang Qiong [5] found the relationship between the coefficients of beam-to-column semi-rigid connection and the bearing capacity of the rack. At present, most studies are focused on the effects of beam-to-column semi-rigid connection on the properties of the rack, the analysis of the effects of column-to-ground semi-rigid connection on the properties of the rack is rarely.

In order to know the effect of different coefficients of column-to-ground semi-rigid connection on the stiffness and strength of the rack, this paper analyzed and calculated the common beam pallet rack in different coefficients of beam-to-column semi-rigid connection by using the Rack Computer-Aided FEA System which is based on SAP84 and developed by Logistics Institute of USTB. By making a comparative analysis of maximum stress and displacement, draw some useful conclusios, provide a theoretical basis for the analysis and design of assembled rack.

Calculation Model

Structural Model. In this paper, take common beam pallet rack as the research object, the rack is mainly composed of column, beam, diagonal bracing and row spacer. The population parameter of the rack is shown in table 1, the overall grid structure is shown in figure 1.

Table 1 Population parameter of the rack

Number of columns	Number of rows	Number of layers	Length of goods case(mm)	Width of goods case(mm)	Height of goods case(mm)		
					Bottom layer	Top layer	others
10	4	7	2400	1000	2050	205	1650

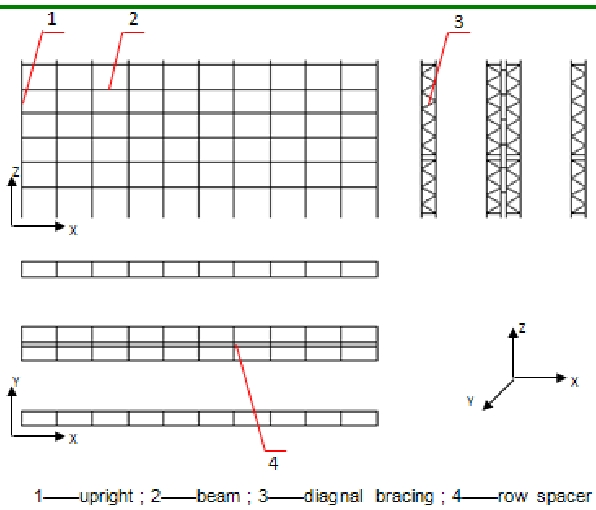

Fig. 1 Overall grid structural model

Finite Element Model. SAP84 is the kernel software of the Rack Computer-Aided FEA System, therefore, modeling in accordance with the relevant provisions of SAP84, simplify the main components of rack to frame element, constraint the nodes and elements of each component.

1. Connection mode: The column-to-ground connection is not completely rigid, the connection can have a certain rotation, release a certain bending moment. The ratio of the bending moment to the one of ideal rigid connection is the coefficient of semi-rigid connections. This paper set up the beam-to-column and the column-to-ground connection in the XOZ plane as semi-rigid connection, other connection is rigid. The coefficient of beam-to-column connection is 0.5, the coefficient of column-to-ground connection is range from 0 to 1.

2. Node constraint: Meshing the structure on the basis of its natural grid, that is set up a node at each intersection point. All nodes of frame element have six degrees of freedom in SAP84, three translational degrees of freedom and three rotational degrees of freedom, which can be expressed as R=0, 0, 0, 0, 0, 0. When the column-to-ground connection is rigid, the degrees of freedom of the connected nodes is all constrained, that means there is no degrees of freedom, which can be expressed as R=1, 1, 1, 1, 1, 1. When the column-to-ground connection is articulated around the Y axis in the XOZ plane, the connected nodes of column-to-ground connection release the rotational degree of freedom along the Y axis, which can be expressed as R=1, 1, 1, 1, 0, 1.

3. Element constraint: SAP84 release the force and bending moment of both ends of the three-dimensional frame elements by setting the coefficients of semi-rigid connection. When the coefficient of semi-rigid connection is 1 indicate that the force and bending moment at both ends of the elements is not released, which is rigid connection; When the coefficient of semi-rigid connection is 0 indicate that the force and bending moment at both ends of the elements is full released, which is ideal articulated connection; When the coefficient of semi-rigid connection is between 0~1 indicate that part of the force and bending moment at both ends of the elements is released, which is semi-rigid connection.

Calculation conditions and loading. In order to analyze the effect of different load combinations on the mechanical properties of rack, select the following four calculation conditions to be studied.

Normal condition one: constant load + live load

Normal condition two: constant load + live load + impact load

Normal condition three: constant load + live load + horizontal load in X direction

Normal condition four: constant load + live load + horizontal load in Y direction

Two pallets are placed in each good cases, the load of each pallet is 1000kg, calculation coefficient of impact load is 50%, calculation coefficient of horizontal load is 1% [6]. Choose the calculation method of ultimate limit state, the loads and partial coefficient are shown in table 2.

Table 2 Loads and partial coefficient

Load type	Explanation	Partial coefficient
Constant load	Weight of the rack	1.2
Live load of goods	Weight of goods unit	1.4
Vertical impact load	50% of the maximum static load of goods unit	1.4
Horizontal load	Divide into horizontal load in X direction and Y direction，1% of the sum of total Constant load and Live load	1.4

Simulation Experiment Scheme. According to the calculation model above, analyze the effect of column-to-ground semi-rigid connection on the strength and stiffness of assemble rack in different calculation conditions by changing the coefficients of column-to-ground semi-rigid connection. The orthogonal experiment was designed, which is composed of 11 groups of connection schemes and 4 kinds of load conditions, set analysis indicators for different calculation conditions, the simulation experiment schemes are shown in table 3.

Table 3 Simulation experiment scheme

Calculation conditions / Semi-rigid coefficients	Condition 1	Condition 2	Condition 3	Condition 4
0，0.01，0.05，0.1，0.15，0.2，0.3，0.5，0.7，0.9，1	①The maximum stress of column elements ②The maximum displacement of nodes (including X, Y and Z directions)	①The maximum stress of column elements ②The maximum displacement of nodes (including X, Y and Z directions)	①The maximum stress of column elements ②The maximum displacement of nodes (including X, Y and Z directions) ③The bending moment and axial force of the maximum stress element	①The maximum stress of column elements ②The maximum displacement of nodes (including X, Y and Z directions)

Result Analysis

The 11 experiment schemes are analyzed and calculated respectively. As the column-to-ground connection is semi-rigid in the XOZ plane, and the normal condition three considering the lateral force along the X axis, therefore, analyze it alone. The results are summarized as follow.

Result analysis of condition three. Select the maximum stress of column elements and the maximum displacement of column nodes as the research object, the displacement and stress results under different semi-rigid coefficients of condition three are shown in Table 4, figure 2 and figure 3.

As can be seen from the experimental data：

1. The coefficients of column-to-ground connection have a great effect on the X-displacement of nodes, but nearly no effect on Y-displacement and Z-displacement of nodes. The maximum X-displacement of nodes decreases with the increase of the coefficients of semi-rigid connection, it decreases greatly when the coefficient is in the range of 0~0.2, and then leveled off; the maximum Y-displacement and Z-displacement of nodes nearly unchanged with the increase of the coefficients of semi-rigid connection.

2. When the semi-rigid connection coefficient is in the range of 0~0.05, the maximum stress of elements decreases with the increase of the coefficient of semi-rigid connection, because the bending moment of elements decreases greatly with the increase of the coefficient of semi-rigid connection,

meanwhile the axial force increases slightly; when the semi-rigid connection coefficient is in the range of 0.05~1, the maximum stress of elements increases with the increase of the coefficient of semi-rigid connection, because the bending moment of elements increases with the increase of the coefficient of semi-rigid connection, and the axial force remains unchanged.

Table 4 Displacement and stress under different semi-rigid coefficients of condition three

Semi-rigid coefficient	X-displacement (mm)	Y-displacement (mm)	Z-displacement (mm)	Stress (MPa)	Axial force(N)	Bending moment(N.M)
0	30.996	0.210	3.513	149.941	82358.872	650379.159
0.01	28.704	0.210	3.513	143.478	82361.083	513424.410
0.05	23.644	0.210	3.513	137.387	83642.130	371190.571
0.1	21.469	0.210	3.513	142.236	83643.065	473846.154
0.15	20.456	0.210	3.513	144.529	83643.256	522406.737
0.2	19.870	0.210	3.513	145.870	83643.244	550820.501
0.3	19.219	0.210	3.513	147.377	83643.076	582733.387
0.5	18.645	0.210	3.513	148.725	83642.730	611307.172
0.7	18.382	0.210	3.513	149.349	83642.486	624517.850
0.9	18.232	0.210	3.513	149.708	83642.314	632132.466
1	18.178	0.210	3.513	149.836	83642.247	634846.030
Fluctuation	70.514%	0%	0%	9.138%	1.559%	75.214%

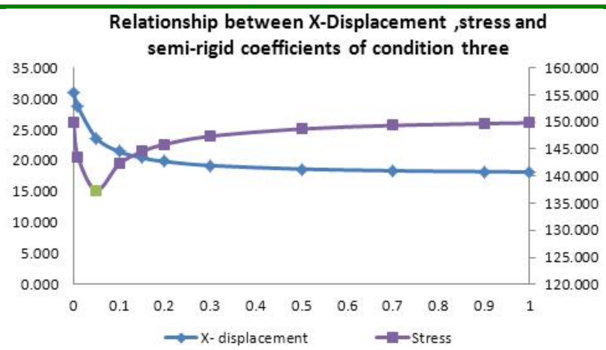

Fig. 2 Relationship between X-Displacement ,stress and semi-rigid coefficients of condition three

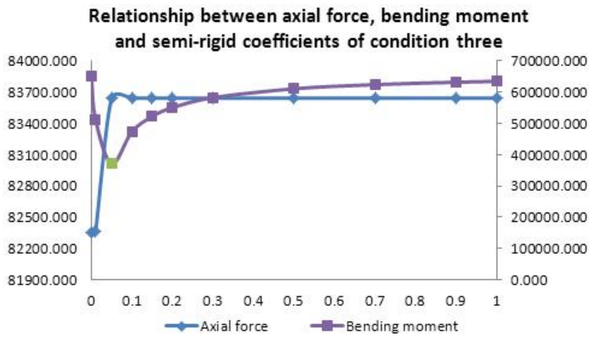

Fig. 3 Relationship between axial force, bending moment and semi-rigid coefficients of condition three

Result analysis of condition one, two, four. The displacement and stress results under different semi-rigid coefficients of condition one, two, four are shown in table 5, figure 4 and table 6.

As can be seen from the experimental data：

1. The coefficient of column-to-ground connection have little effect on the stress of elements, the maximum stress of elements increases slightly with the increase of the coefficient of semi-rigid connection, the fluctuations is less than 1%.

2. When the coefficient of column-to-ground connection is in the range of 0.01~1, the maximum X-displacement, Y-displacement and Z-displacement of nodes nearly unchanged with the increase of the coefficient of semi-rigid connection; When the coefficient of column-to-ground connection is 0

which means the column-to-ground connection is fully articulated, the maximum X-displacement of condition 1, the maximum Y-displacement , Z-displacement of condition 2 and 4 is smaller compared with the case of semi-rigid connection.

Table 5 Stress under different semi-rigid coefficients of condition one, two, four

Semi-rigid coefficient	Condition 1-Stress(MPa)	Condition 2-Stress(MPa)	Condition 4-Stress(MPa)
0	119.911	119.911	137.206
0.01	119.972	119.972	137.256
0.05	120.154	120.154	137.406
0.1	120.297	120.297	137.523
0.15	120.390	120.390	137.600
0.2	120.454	120.454	137.652
0.3	120.537	120.537	137.720
0.5	120.621	120.621	137.789
0.7	120.663	120.663	137.823
0.9	120.687	120.687	137.843
1	120.696	120.696	137.850
Fluctuation	0.655%	0.655%	0.469%

Table 6 Stress under different semi-rigid coefficients of condition one, two, four

Semi-rigid coefficient	Condition 1			Condition 2			Condition 4		
	X	Y	Z	X	Y	Z	X	Y	Z
0	0.651	0.210	3.512	0.738	2.307	3.544	0.652	2.505	3.631
0.01	0.828	0.210	3.512	1.125	2.399	3.544	0.829	2.562	3.631
0.05	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.1	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.15	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.2	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.3	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.5	0.828	0.210	3.512	1.126	2.399	3.543	0.829	2.562	3.631
0.7	0.828	0.210	3.512	1.127	2.399	3.543	0.829	2.562	3.631
0.9	0.828	0.210	3.512	1.127	2.399	3.543	0.829	2.562	3.631
1	0.828	0.210	3.512	1.127	2.399	3.543	0.829	2.562	3.631
Fluctuation	27.189%	0%	0%	52.710%	3.988%	0.028%	27.147%	2.275%	0%

Summary

This paper designed and analyzed the common beam pallet rack in different coefficients of column-to-ground semi-rigid connection by using the FEA software, and gets the results of displacement and stress under different semi-rigid coefficients.

The research shows that, in the ideal state without considering the lateral force, when the column-to-ground connection is semi-rigid, the coefficient of semi-rigid connection has little effect on the displacement and stress; when the column-to-ground connection is fully articulated, the maximum displacement and stress is smaller compared with the case of semi-rigid connection, i.e. the articulated connection is beneficial to the rack structure.

In the condition which considering the lateral force, the maximum X-displacement of nodes decreases with the increase of the coefficient of semi-rigid connection. The maximum stress of elements decreases first and then increases with the increase of the coefficient of semi-rigid connection, the stress decreases when the coefficient between 0~0.05 , increases when the coefficient between 0.05~1, which shows that moderate coefficient of column-to-ground connection is beneficial to the rack, but the displacement and stress will become large when the coefficient is too small and the connection is nearly articulated, which is not conducive to the safety of the rack structure.

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