INVESTIGATION OF PRE-ENGINEERED STEEL BUILDINGS ACCORDING TO DEFORMATION SYSTEMS CONSIDERING SEMI-RIGID CONNECTION

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Abstract: This research is for investigating the pre-engineered steel buildings according to deformation systems considering semi-rigid connection, which is considered as a correct model. Semi-rigid connection was proposed by Aleksander. K, in which the value of semi-rigid joint is dependent on connection types, material and section details. In this research, the deformation systems were analyzed using second order effects (P-Δ effects) by Sap2000. P-Δ effects and semi-rigid connection were simultaneously combined in evaluating the internal forces and displacement of the structure. In order to evaluate the accuracy of the current research method, the results were then compared with those designed by the current Vietnamese standard. The results show that the combination of P-Δ effect and semi rigid connection have great effect in calculate the pre-engineered steel structures compared with other models.

1. Introduction

In present, the Vietnamese standard of Steel structures are used in designing the pre-engineered steel buildings, in which the joints between beam and column is considered rigid. However, these connections are not totally rigid. Therefore, the design structures of pre-engineered steel buildings using the current Vietnamese standard is approximate and there are potential risks.

The considering of semi-rigid connections of steel structures has been researched by various researchers in the world. In 1934, Batho and Rowan proposed the straight-line common beam method to classify semi-rigid connection [2]. In 1936, Rathburn considered the stiffness of the connection in the moment distribution method [8]. Baker, William and Sourochnikoff had investigated the influence of semi-rigid connections on the steel frame structures [9]. Monforton and Wu [6, 7] were among of the first researchers applied the stiffness matrix method to analyze the plane frame structures with semi-rigid connection. In which, the stiffness matrix and nodal force vector of each element depend on the linear stiffness of the connection. Kim, S.E. and Choi, S.H proposed a novel method to analyse the spatial frame considering the material nonlinearity and large deflection effect [4]. The linear and nonlinear semi-rigid connection models were also interested by Hadianfard and Razani in 2003 [3].

In present research, the initial stiffness and moment resistance of joints were two main design parameters. These values were determined by the model proposed by Aleksander K. [1]. The internal forces and the displacement of the pre-engineered steel frame structures has been investigated. The results were then compared with the allowable results of the current Vietnamese standard.

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2. Initial stiffness and moment resistance of steel

Initial stiffness and moment resistance are two parameters that formed the hardness of the connection between columns and beams. These two values were calculated using the proposed model of Aleksander K. *et al* [1]. The reliability of this model has been verified by comparing the experimental results according to Euro code 3 standard (EC. 3) (Fig. **1**).

The moment resistance of steel M_{Rd} and the initial stiffness of steel $S_{j,ini}$ are determined as the following:

$$M_{Rd} = 7.4 \times 10^{-5} \times h_c^{0.62} \times h_b^{1.2} \times t_p^{0.4} \times d^{0.85} \tag{1}$$

$$S_{j,ini} = K_1 \times h_c^{0.44} \times h_b^{1.2} \times t_p^{0.35} \times d^{0.005} - K_2 \tag{2}$$

where $S_{j,ini}$ is initial stiffness (kNm/rad); S_j is the elastic stiffness of the connection (kNm/rad) which is determined as:

$$S_j = {S_{j,ini}}/{\eta} \tag{3}$$

h_c (mm) is the height of the column section (HEB); h_b (mm) is the height of the beam section (IPE); t_p (mm) is the thickness of the end plate and d (mm) is the bolt diameter; $K_1 = 1.5$ and $K_2 = 19211$ are identified from experimental results [1].

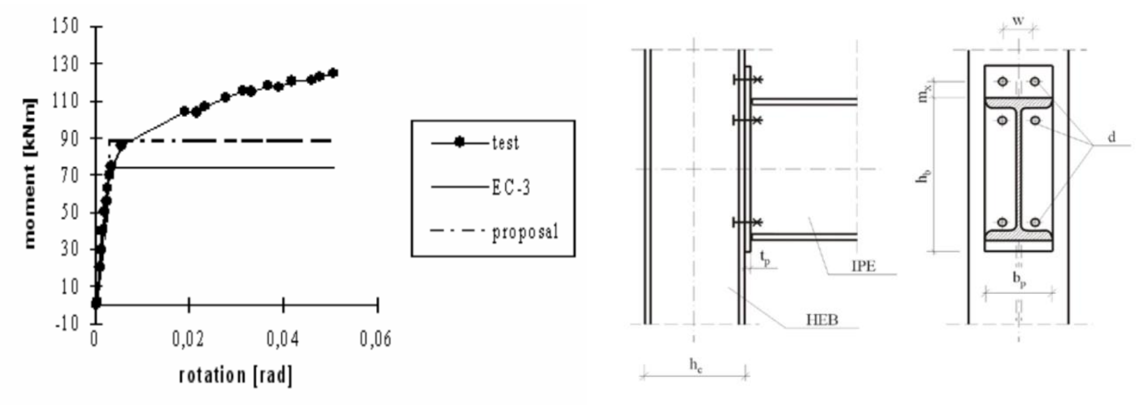


Fig. 1: *Validation of the Aleksander's model by comparison with EC-3 and experimental results [1]*

3. Numerical calculation of the initial forces and the displacement of the structures

For evaluating the accuracy of the calculation using deformation systems considering semi-rigid connection, four models has been suggested as following:

Model 1: Non-deformed frame, rigid connections;

Model 2: Deformed frame, rigid connections;

Model 3: Non-deformed frame, semi-rigid connections;

Model 4: Deformed frame, semi-rigid connections.

3.1. Input parameters

Consider a pre-engineered steel frame which is described in Fig. **2** and Table 1. The initial stiffness $S_{j,ini}$ and the moment resistance M_{Rd} were defined from input parameters and the expressions (1) $\div$ (3) and presented in Table 2.

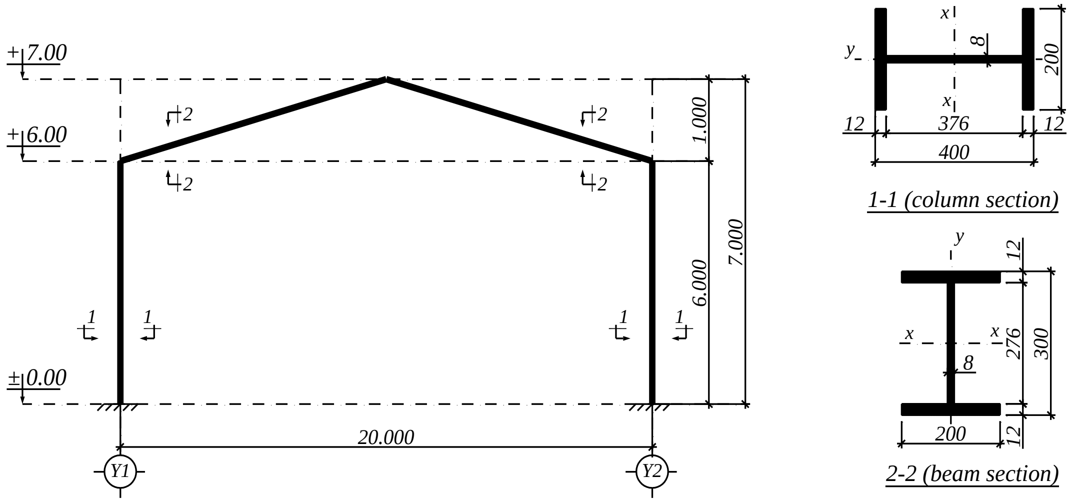


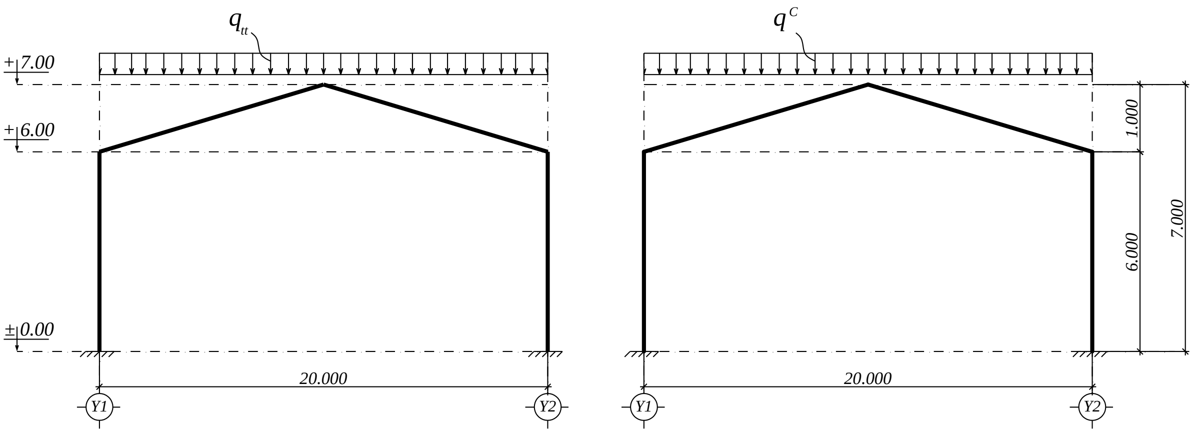
Fig. 2: *Structural diagram and section details*

Table 1: *Geometry parameters of the frame structure*

Input parameters	Test data	Units
Building width (L)	20.0	m
Eave height (H)	6.0	m
Roof pith (α)	5.71	Degree
Modulus (E)	2.1×10^{8}	kN/m^{2}
Dead loads (q_{tt})	1.64	kN/m
Live loads (q^{C})	0.235	kN/m

Table 2: *The initial Stiffness* $S_{j,ini}$ *and the moment resistance* M_{Rd}

h_c	h_b	t_p	d	M_{Rd}	$S_{j,ini}$	η	S_j
mm	mm	mm	mm	$kN.m$	$kN.m/rad$		$kN.m/rad$
400.0	300.0	20.0	20.0	160.66	37727.86	2.000	18863.93



(a) *(b)*

Fig. 3: *Load diagrams of the structure: Dead load (a) and Live load (b)*

3.2. Evaluation of the calculation results

The calculation of the internal force and the displacement of the pre-engineered steel frame has been conducted using four above models. The results are compared between various models which is summarized in Table 3.

Table 3: *Numerical results using various models*

Output parameters	Mode 1	Mode 2	Mode 3	Mode 4	Units
Moment at the bottom of the column	90.60	94.33	93.73	97.09	*kN.m*
Moment at the top of the column	12.77	117.61	57.50	52.05	*kN.m*
Moment at the bottom of the beam	12.77	117.61	57.50	52.05	*kN.m*
Moment at the top of the beam	63.49	74.73	21.49	25.36	*kN.m*
Axial force of the column	55.82	55.82	27.97	27.97	*kN.m*
Axial force of the beam	40.74	39.68	16.23	16.23	*kN.m*
Displacements at the ridge line	0.09252	0.11889	0.0309	0.0399	*m*

For evaluating the accuracy of the proposed models (Model 2,3 and 4), the calculation results of these models are considered with those obtained by using Model 1. The comparison is represented in Table 4.

In the Model 4, the P-Δ effect and semi-rigid connection were simultaneously combined in evaluating the internal forces and displacement of the structure. The calculation results using Model 4 shows that the moment at top of the column decreases

7.94%, while the moment at the top of the beam increases 17.69%. It represents the redistribution of the internal forces of the structure in case of considering the P-Δ effect and semi-rigid connection. That also can be seen in the variance of the moment at the bottom of the column (+4.12%) and of the displacement at the ridge line (+28.5%).

Table 4: *The variance of the calculation results of Model 2,3,4 in comparison with the results obtained by using the Model 1 (%)*

Output parameters	**Mode 2**	**Mode 3**	**Mode 4**
Moment at the bottom of the column	3.46%	7.17%	4.12 %
Moment at the top of the column	-54.99%	-59.25%	-7.94%
Moment at the bottom of the beam	-54.99%	-59.25%	-7.94%
Moment at the top of the beam	-66.14%	-60.06%	17.69%
Axial force of the column	-49.90%	-49.90%	0.00%
Axial force of the beam	-60.17%	-60.17%	-2.62%
Displacements at the ridge line	-66.60%	-56.87%	28.50%

In order to investigate the influence of P-Δ effect, the calculations results were compared between Model 1 and Model 2. As it can be seen in Table 4, the results are significantly difference. A huge reduction of various internal forces and displacements of the structure can be clearly obtained, which are almost above 50%. The markedly decreasing the internal force and displacement of the structures proves that the considering of P-Δ effect in the structure calculation has great effect.

Figure 4 shows the convergence of the internal force results between the models, while the convergence of the displacement at the ridge line is represented in Figure 5.

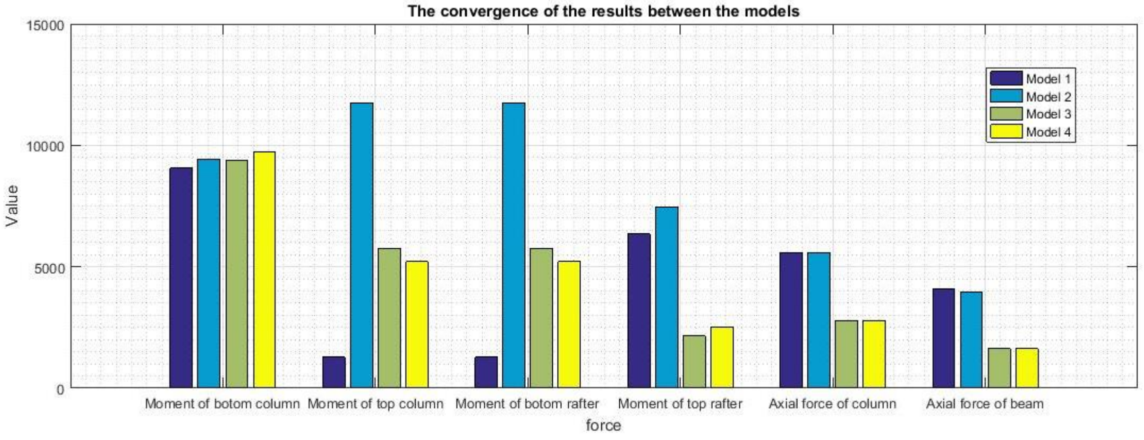


Fig. 4: *The diagrams of the results between the models (force)*

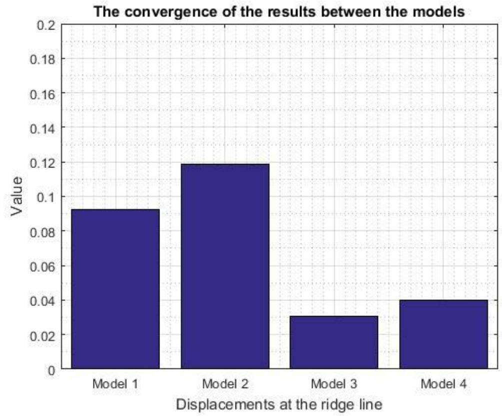


Fig. 5: *The diagrams of the results between the models (Displacements at the ridge line)*

As it can be seen from Figure 4 and Figure 5, the internal forces and the displacement of the structure which is calculated using Model 4 have significantly difference from those using Model 1. The smallest values of internal forces and displacements represent the more accurate of the structure calculation although the safety factor is higher when applying the model 1. It proves that the consideration of P-Δ effect in combination with semi rigid connections has great effect in calculate the pre-engineered steel structures compared with other models.

Comparing the results obtained between the model 3 and model 4 shows that the internal forces and displacement of the structures are almost similar. It means that the stiffness of the connection has important role in the redistribution of the internal force and displacement of the structures.

4. Conclusions

In this research, the calculation of pre-engineered steel structures has been performed considering P-Δ effect in combination with semi rigid connections. Four different models have been used in evaluating the accuracy of the calculation. The redistribution of the internal force and displacement have been fully investigated. The results show that the combination of P-Δ effect and semi rigid connection have great effect in calculate the pre-engineered steel structures compared with other models. However, in order to evaluate the accuracy of the calculation using Model 4, other researches must be performed. The research will be expanded with random parameters that influences internal forces and displacement using Model 4.

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TÓM TẮT

KHẢO SÁT SỰ LÀM VIỆC CỦA KHUNG NHÀ CÔNG NGHIỆP BẰNG THÉP TIỀN CHẾ THEO SƠ ĐỒ BIẾN DẠNG CÓ KỂ ĐẾN ĐỘ CỨNG CỦA CÁC NÚT LIÊN KẾT

Nghiên cứu này nhằm mục đích khảo sát sự làm việc của khung ngang nhà công nghiệp bằng thép tiền chế theo sơ đồ biến dạng có kể đến độ cứng của các nút liên kết. Phương pháp xác định độ cứng nút khung đã được Aleksander. K đề xuất và hiệu ứng P-Δ được kết hợp đồng thời khi nghiên cứu nội lực và chuyển vị của kết cấu. Để đánh giá tính chính xác của kết quả nghiên cứu dựa trên mô hình kết hợp hiệu ứng P-Δ với liên kết nửa cứng, kết quả thu được đã được so sánh với kết quả thiết kế theo tiêu chuẩn Việt Nam hiện hành về thiết kế kết cấu khung nhà thép tiền chế.