

The research about parameters influence on the mechanical performance of haunch connection

YongJuan Liu^{1,2} Yan Wang³

(1. Institute of civil engineering ,XI'AN University of Architecture And Technology, XI'AN 710055, China; 2. Department of Architecture engineering ,WeiHai Vocational College,WeiHai 264200,China; youke37@126.com;3. Institute of civil engineering, Qingdao Technological University, Qingdao 266033,China, yanwang123@qtech.edu.cn)

Keywords:haunch connection ; parameters influence;theoretical calculation ; ansys simulation

Abstract:To research about parameters influence on the mechanical performance of haunch connection with haunch only on bottom beam flange, On the based of the analysis about haunch connection design step, theoretical calculation and ansys simulation were used to study the effect of haunch length, height ,beam span.The researches show:With the increase of haunch length,the top and bottom beam flange groove weld stress gradually decrease, the haunch flange axial stress and the shear stress of haunch web become bigger.The energy dissipation and the ultimate bearing capacity of specimens increase gradually;With the increase of haunch height, the bottom beam flange groove weld stress and the shear stress of haunch web gradually bigger, the top beam flange groove weld stress and haunch flange axial stress decrease.The energy dissipation and ultimate bearing capacity slightly decrease;With increase of beam span, the top and bottom beam flange groove weld stress,the haunch flange axial stress and the shear stress of haunch web gradually decrease.The energy dissipation and ultimate bearing capacity decreased significantly,the stiffness degradation is significantly.

Introduction

The haunch connection is a type of the improved node,which can effectively realize plastic hinge offshoring, has good seismic performance, has better ductility compared with RBS nodes^[1],and which is very effective and economic by applied in the large span steel structure^[2,3]. The haunch connection has always been the concern of the researchers over the years.But the researches about parameters influence on the mechanical performance of haunch connection also have not been very system. On the based of the analysis of haunch connection design, theoretical calculation and ansys simulation were used to study the effect of haunch length, height ,beam span on mechanical performance of improved haunch connection.

The analysis of impact parameter

The contribution of haunch web to axial stiffness of the haunch flange is minor and can be ignored. The haunch is idealized as a spring in AISC steel design guide series12^[4].

According to the America design specification^[4], the plastic bending moment M_{pb} only is associated with the geometrical characteristic value of beam section, and shear force V_{pd} relates to the bending moment M_{pb} ,the beam span and haunch length without regard to the weight of floor slab and beam.

The Important effect factor on mechanical performance of the haunch connection is β_{min} which

has relation to plastic bending moment M_{pb} , shear force V_{pd} , haunch length, the haunch angle and the geometrical characteristics of the cross section. When the beam section is the same, β_{min} is only in relation to shear force V_{pd} , haunch length, the haunch angle. The actual value β is related to haunch length and haunch width, haunch angle, haunch flange area; The top and bottom beam flange groove weld stress and haunch flange axial stress are related to actual value β , shear force V_{pd} , haunch length, haunch angle, haunch plate flange area and so on.

Above all, the main effect factors on mechanical performance of the haunch connection can be summarized as the geometrical characteristic value of beam section, haunch length, height, beam span. While the haunch length and width determine the haunch angle.

The theoretical calculation

The beam-column intermediate nodes are selected, beam :HN250x125x6x8 (cross section area $A_b=34.04 \text{ cm}^2$, section elastic modulus $W_b = 285.59 \text{ cm}^3$, section plastic modulus $W_{pb}=324.134 \text{ cm}^3$; steel column :HW250x 250x14x14 (the section area $A_c = 101.08 \text{ cm}^2$, section elastic modulus $W_c = 882.775 \text{ cm}^3$, plastic modulus $W_{pc} = 998.484 \text{ cm}^3$). The steel material uses Q345B steel. The node were designed according to AISC steel design guide series12^[4]. The calculation results are shown in table 1, 2 and 3.

The influence of haunch length

The haunch height takes 1/3 times of beam height (namely $b=84\text{mm}$) and both sides of the beam span takes 3 meters in Table1. To research haunch length affect on the node performance systematically, the haunch length take the value from 0.5 to 0.6 times of beam height. Haunch web thickness is for 6mm which meets the design requirements.

Table 1 the connection mechanical calculation results with different haunch length

number	Haunch size (mm)	β_{min}	$A_{lf_{mi}}$	A_{lf}	β	f_{wt}	f_{wb}	$\frac{\beta V_{pd}}{A_{lf} \sin \theta}$	τ_{hw}
	a: haunch length		mm^2	mm^2		$10^3 \text{ kN} \cdot \text{m}^2$	$10^3 \text{ kN} \cdot \text{m}^2$	$10^3 \text{ kN} \cdot \text{m}^2$	$10^3 \text{ kN} \cdot \text{m}^2$
	b: haunch height								
1	a = 0.5h _b = 125mm <i>b = atgθ = 84mm</i> (θ = 34°)	1.716	1070	125*10	1.879	388.53	211.61	290.94	117.58
2	a = 0.52h _b = 130mm <i>b = atgθ = 84mm</i> (θ = 33°)	1.673	1078	125*10	1.847	387.17	204	295.65	129.81
3	a = 0.54h _b = 135mm <i>b = atgθ = 84mm</i> (θ = 32°)	1.634	1084	1250	1.809	386.59	200.98	298.01	133.59
4	a = 0.58h _b = 145mm <i>b = atgθ = 84mm</i> (θ = 30°)	1.557	1103	125*10	1.745	384.33	188.99	307.13	140.26
5	a = 0.6h _b = 150mm <i>b = atgθ = 84mm</i> (θ = 29.5°)	1.531	1106	125*10	1.699	384.114	181.6	308.49	145.41

The table 1 shows that the plastic bending moment in the beam plastic hinge of all specimens is the same in the same beam-column joints when regardless of the weight of the floor slab and beam. When haunch height is constant, with the increase of haunch length, the beam span L'

between haunch reduce, the plastic shear V_{pd} increase;The value of β_{min} reduce gradually. The haunch flange required minimum sectional area A_{hfmin} increase gradually.To eliminate the influence of the haunch flange cross sectional area , haunch flange plate section area take the same value which meet the design requirements.With the increase of haunch length, the value of β is smaller, the top beam flange groove weld stress f_{wt} and the beam bottom flange groove weld stress gradually decrease, but the top beam flange the groove weld stress are close to limit stress state,which play a decisive role.The axial stress of haunch flange $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ increase gradually,the shear stress of haunch web τ_{hw} become bigger.

By the observation,we can be found when haunch length take 0.5 times of beam height,the value of β_{min} , β , f_{wt} , f_{wb} are the largest among all components.When haunch length take 0.6 times of beam height, the value of $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ are the biggest among all components and is close to the limit state.

Total,the reasonable values of haunch length should be close to in the middle of the position of between the 0.5- 0.6 times of beam height.

The influence of haunch height

Table 2 show the mechanical performance changes of haunch connection with the change of the haunch height when the haunch length is constant.The haunch length take $0.54h_b$,namely 135mm.The both sides of the beam span takes 3 meters.The haunch angle is from 25^0 to 30^0 .To eliminate the influence of haunch web,the thickness of haunch web take 6mm uniformly and the actual haunch flange plate area of all specimen take 1250mm^2 which meet the design requirements.

Table2 the connection mechanical calculation results with different haunch height

number	Haunch size (mm)	β_{min}	$A_{hf\ mi}$	A_{hf}	β	f_{wt}	f_{wb}	$\frac{\beta V_{pd}}{A_{hf} \sin \theta}$	τ_{hw}
	a: haunch length								
	b: haunch height		mm^2	mm^2		10^3kN. m^2	10^3kN. m^2	10^3kN. m^2	10^3kN. m^2
1	a=0.54hb=135mm b=69 ($\theta = 27^0$)	1.522	1178	125*10	1.594	394.003	193.407	306.594	130.49
2	a=0.54hb=135mm b = atg $\theta = 78\text{mm}$ ($\theta = 30^0$)	1.59	1117	125*10	1.733	388.84	196.396	302.568	132.05
3	a=0.54hb=135mm b = atg $\theta = 84\text{mm}$ ($\theta = 32^0$)	1.634	1084	125*10	1.809	386.593	200.985	298.007	133.59
4	a=0.54hb=135mm b=94 $\theta = 35^0$	1.694	1038	125*10	1.91	384.01	210.264	289.175	136.54

The table 2 shows that the beam plastic bending moment M_{pd} beam plastic shear V_{pd} of all specimens is the same for the same beam-column joints when the haunch length is constant.With the increase of haunch height(namely haunch angle), β_{min} became larger, while haunch flange required minimum sectional area A_{hfmin} are smaller.When haunch flange plate section area take the same values, with increase of haunch height, β is larger;the beam top flange groove weld stress f_{wt} and haunch flange axial stress $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ gradually decrease; the beam bottom flange groove weld stress

f_{wb} increase. but the beam flange groove weld stress is bigger a lot than beam bottom flange groove weld stress, which is closer to the limit state and play a decisive role; the shear stress of haunch web became large with the increase of haunch height.

When the haunch height is 69 mm, namely haunch angle is 27° , the value of f_{wt} , $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ are the largest among four components and are close to the limit state. So haunch height get bigger appropriately, the haunch connection mechanical performance is more reasonable. But haunch height is too large, the value β is too large, the shear of beam is less transferred to haunch flange plate. When the value of β is larger than 1 and is close to 2, the beam web shear in haunch region became larger, which bring burden to the beam web clipboard. When the value of β is equal to 2, the beam web shear in haunch region and that of specimen without haunch connection is equal.

The influence of the beam span

Table 3 shows the mechanical performance changes of haunch connection with the change of the beam span when the parameters of the haunch length, haunch height, haunch angle are the same. The haunch length take $0.54h_b$, namely 145 mm. The haunch height is 84 mm, namely taking the $1/3$ times of beam section height, and haunch angle is 30° used commonly. To eliminate the influence of haunch web, The thickness of haunch web take 6 mm uniformly and the actual haunch flange plate area of all specimen take 1250 mm^2 which meet the design requirements.

Table 3 the connection mechanical calculation results with different the beam span

nuber	beam span	V_{pd} kN	β_{min}	$A_{hf min}$ mm^2	β	f_{wt} $10^3 \text{ kN} \cdot \text{m}^2$	f_{wb} $10^3 \text{ kN} \cdot \text{m}^2$	$\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ $10^3 \text{ kN} \cdot \text{m}^2$	τ_{hw} $10^3 \text{ kN} \cdot \text{m}^2$
1	L=2700	125.29	1.449	1169	1.545	390.88	193.91	309.69	140.76
2	L=3000	110.01	1.557	1103	1.745	384.33	188.98	307.14	140.26
3	L=3300	98.05	1.665	1051	1.945	379.21	185.15	305.76	139.89

The table 3 shows that when the node parameters are unchanged, the beam plastic bending moment M_{pd} is the same. With the increase of the beam span, beam plastic shear V_{pd} gradually increase, β_{min} became larger, while haunch flange required minimum sectional area $A_{hf min}$ are smaller. When haunch flange plate section area take the same values, accompanying with increase of beam span, β is larger; the beam top flange groove weld stress f_{wt} , beam bottom flange groove weld stress f_{wb} and haunch flange axial stress gradually decrease; but the beam flange groove weld stress is bigger a lot than beam bottom flange groove weld stress, which is closer to the limit state and play a decisive role; the shear stress of haunch web highly reduce with the increase of beam span.

When the beam span is 2700 mm, the value of f_{wt} , f_{wb} , $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$, τ_{hw} are the biggest among the three components, and the value of f_{wt} , $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ are close to the limit state. So with the increase of beam span, the haunch connection mechanical performance is more reasonable. But span is too large, the value β is too large, the beam web shear in haunch region became larger to trend that of specimen without haunch connection.

The numerical analysis

Numerical analysis of the specimen had been conducted by ansys12.1. The SOLID92 3D entity unit was selected. The unit defined by ten points and each node has three degrees of freedom: the

node displacement of x, y, and z direction. And the unit has the capacity of plasticity, creep, expansion, stress stiffening, large deformation and large strain. The multiple linear servo reinforcement material model was used^[5] and the elastic-plastic nonlinear constitutive relation was established. The top and bottom end of column was hinged. The low cyclic reverse displacement load was applied on the two beam end.

The influence of haunch length

The hysteresis curve

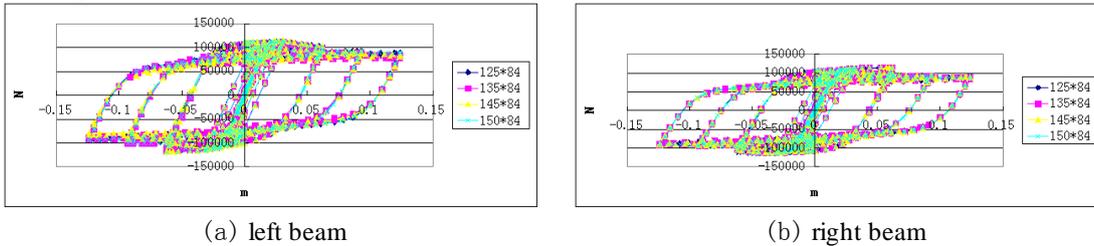


Fig.1 the hysteresis curves with different haunch length

that The left and right beam hysteresis curves are shown as fig.1. The hysteresis curves of all components with different haunch length are relatively full and are close. When the haunch height are unchanged, with the increase of haunch length, the area contained by the hysteresis curve trend to become large, which suggest that the energy dissipation of specimens become better gradually.

The skeleton curve

The skeleton curve reflects the specimens' carrying capacity. The skeleton curves of haunch connection with different haunch length are shown as fig.2. It can be seen that with the increase of haunch length, the specimens' ultimate bearing capacity whose haunch length are within the range of (0.5 -0.6) times of beam height are close and become large. When haunch length range is in (0.54-0.58) times of beam height, the ultimate bearing capacity of specimens increase is larger shown as fig.3(a).

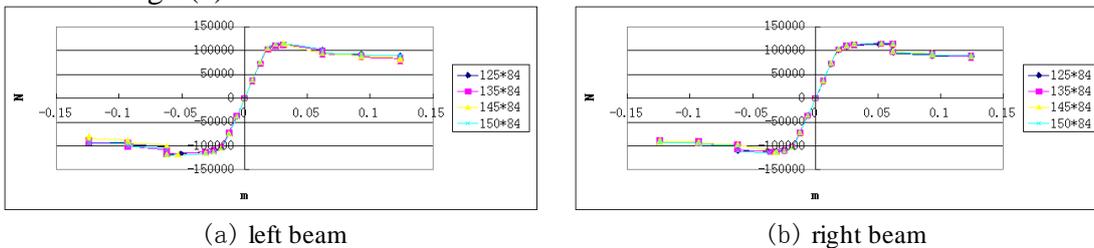


Fig.2 the skeleton hysteresis curves with different haunch length

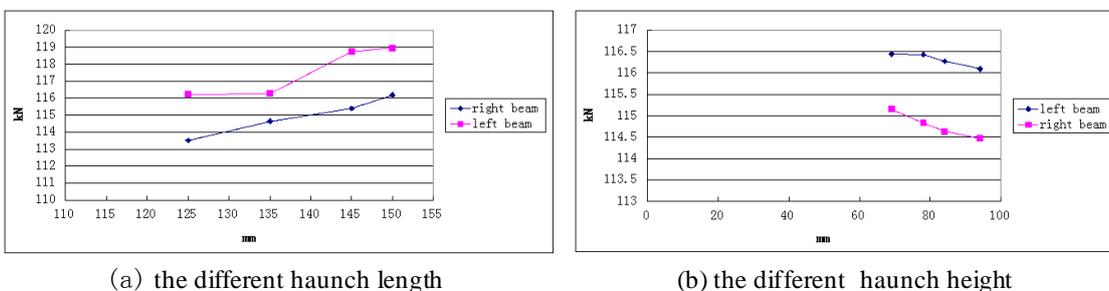
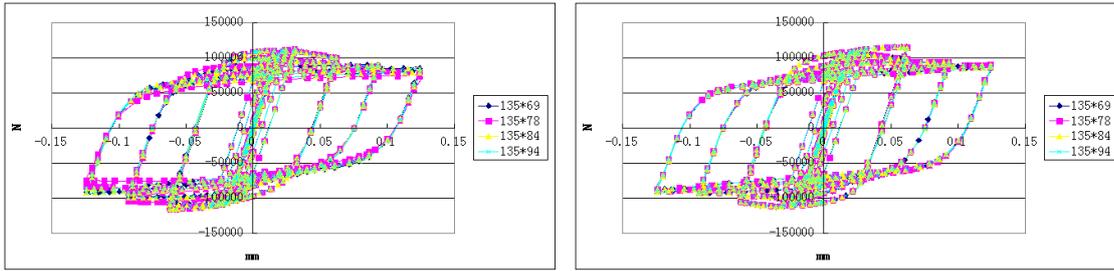


Fig.3 the ultimate bearing capacity change

The influence of haunch height

The hysteresis curve



(a) left beam

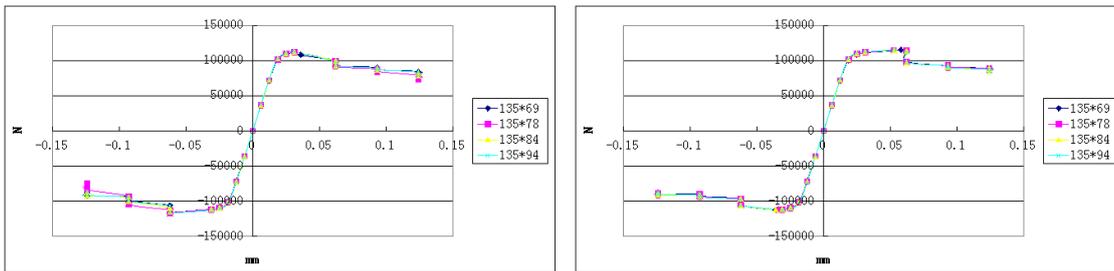
(b) right beam

Fig.4 the hysteresis curves with different haunch height

The hysteresis curves of all components with different haunch height shown as fig.4 are relatively full and are very close. The impact of haunch height on the energy dissipation ability of component is not very obvious. When the haunch height are unchanged, the area contained by the hysteresis curve became slightly smaller, which suggest that the energy dissipation of specimens slightly decrease .

The skeleton curves

The skeleton curves of haunch connection with different haunch height shown as fig.5, are very close. With the increase of haunch height, the specimens' ultimate bearing capacity slightly decrease. The impact of haunch height on ultimate bearing capacity of component is not very obvious shown as fig.3(b).



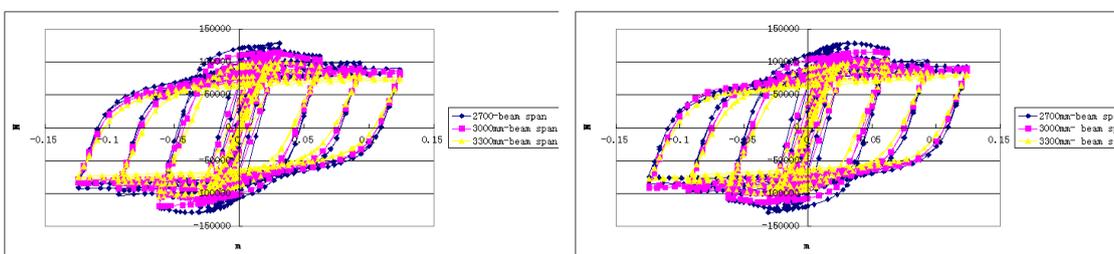
(a) left beam

(b) right beam

Fig.5 the skelon cuetrves with different haunch height

The influence of the beam span

The hysteresis curve



(a) left beam

(b) right beam

Fig.6 hysteresis curves with different beam span

By the left and right beam hysteresis curve shown as Fig.6, we can see : the hysteresis curve of all components with different beam span are relatively full. And with the increase of the beam span, the area contained by the hysteresis curve gradually less, which suggest that the energy dissipation of specimens weaken gradually.

The skeleton curves

The skeleton curves of haunch connection with different beam span are shown in fig.7. It can be seen that with the increase of beam span, the ultimate bearing capacity of the beam is decreased significantly, the stiffness decreases and stiffness degradation is obvious.

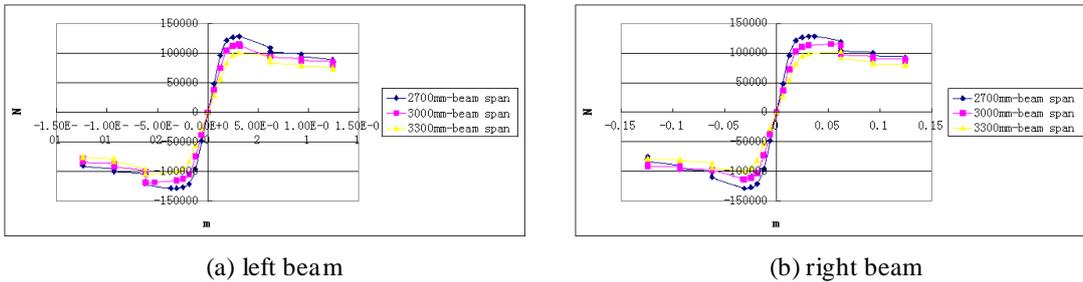


Fig.7 the skeleton curves with different beam span

Conclusion

1. With the increase of haunch length, the value of β , the top and bottom beam flange groove weld stress f_{wt} , f_{wb} gradually decrease, but the haunch axial stress $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$, the shear stress of haunch web τ_{hw} become bigger. The energy dissipation and the ultimate bearing capacity of specimens increase gradually.

2. With the increase of haunch length, the value of β , the bottom beam flange groove weld stress f_{wb} , the shear stress of haunch web τ_{hw} gradually bigger, but the top beam flange the groove weld stress f_{wt} , the haunch axial stress $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$ become decrease. The impact of haunch height on the energy dissipation and ultimate bearing capacity of component are not very obvious. The energy dissipation and ultimate bearing capacity slightly decrease.

3. With increase of beam span, β is larger; the top and bottom beam flange groove weld stress f_{wt} , f_{wb} , the haunch axial stress $\frac{\beta V_{pd}}{A_{hf} \sin \theta}$, the shear stress of haunch web τ_{hw} gradually decrease. But the energy dissipation and ultimate bearing capacity decreased significantly, the stiffness degradation is significantly.

4. When haunch height length is constant, the reasonable values of haunch length should take the range from 0.54 to 0.58 times of beam height. When haunch length is invariant, the height length should take the smaller one, the seismic performance will be more excellent. For the same haunch connection, the beam span should not be too long, otherwise it is disadvantage for the seismic performance.

Acknowledgments

This work was financially supported by the China national natural science fund project (No.51278259) and the ministry of education special fund for the doctoral program of higher education (No.20103721110003).

Reference

- [1] DiYun Huang, Li JunWang,JunBao Zhang,The seismic performance study of beam-column welded haunch connection of steel structure [J]. Journal of building structures,2004,34 (6):49-50(in Chinese)
- [2] Narayanan R. Design development in long span flooring system in the U K. In :Proceedings , International Conference on Steel and Aluminium Structures,ICSAS91 ,Singapore ,Lon2don : Elsevier ;1991.121 Liew J Y R. A resource book for structural steel design and construction. Singapore.SSSS/BCA Joint Publication ,2001
- [3] Liew J Y R. A resource book for structural steel design and construction. Singapore :SSSS/BCA Joint Publication ,2001.
- [4]AISC steel design guide series12[S].2003
- [5]Xin-min Wang, 《ANSYS numerical analysis of engineering structure》 [M], people's traffic publishing house, 2010(in Chinese)