CHALLENGE JOURNAL OF STRUCTURAL MECHANICS 1 (2) (2015) 90–95

Challenge Journal of Structural Mechanics

The research of the behavior of the rigidity connections between columns in industrial buildings under the influence of temperature variation, earthquake and wind

Cemal Eyyubov *, Şükran Genç, Canan Yılmaz

Department of Civil Engineering, Erciyes University, 38039 Kayseri, Turkey

ABSTRACT

In this study, there are the research results of the stress conditions under the influence of temperature variations in rigidity shear members between columns having different constructive formations. Here, the connections are conveyed that characterize the variation of internal forces resulting from temperature variations in rigidity shear members related to the length and height of the structural system. Principles are investigated in order to be able to calculate the earthquake and wind loads of rigidity shear by taking the combinations with the loads resulting from the temperature variation into consideration.

ARTICLE INFO

Article history:
Received 15 May 2015
Accepted 13 June 2015

Keywords:
Rigidity connections
Rigidity shear
Temperature variation
Temperature deformations
Internal forces

1. Introduction

Engineering investigations of Buhara (1976), Erzincan (1992), Adana (1998), Marmara (1999), Düzce (1999) and other destructive earthquakes have suggested that great deformations and ruptures are observed during the earthquake in the rigidity connection members between columns. Engineering investigations into the effect of destructive earthquakes on buildings and engineering structures also point out that buildings which are designed and constructed without considering the rigidity connections between columns widely collapse during the earthquake. In these buildings, because of excessive horizontal and vertical deformations, it is often observed that damages, which may cause the stoppage of using the buildings such as leaving of filling walls, bending of ray beams under crane, breaking and spoiling on rays-joist joints, blister and big detachments on the roof coating (Eyyubov, 1978; Eyyubov, 1988; Eyyubov, 2004).

Rigidity connections between beams must be able to provide the necessary rigidity towards the longitudinally use conditions of buildings. Rigidity connections must receive the force forming from the working of bridged cranes in industrial buildings, from the effect of wind, earthquake, from the failure of basic grounds which is not uniform, from the climate changes and from the temperature variations due to hot technical applications and must have the capacity for transferring them to the base of the building.

Exhausting of rigidity connections between columns because of the long lasting temperature variations, investigation of the endurance from the dynamic effect of the loads forming from the working of cranes and wind and preparation of calculation methods which can be applied in the building planning practice related to its conclusions are the current problems. Furthermore, the behavior of the carrying system of the building depends on the characteristic of the settlement of rigidity connections on its length.

Formation of rigidity struts between columns, constructive formation of columns, their joints and sections determine to a great deal the behaviour of rigidity shear walls as a whole. It is enough to design for tension of the sections of both two diagonal struts in the model which provides the other diagonal cover with elastic buckling, a diagonal towing of rigidity shear bars (Belenya, 1985; Melnikov, 1980). There are rigidity shear wall construction practices that use bars, which are described as

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* *Corresponding author.* Tel.: +90-352-2076666 ; Fax: +90-352-4375784 ; E-mail address: ceyyubov@erciyes.edu.tr (C. Eyyubov)

"buckling prevented" (Karataş and Çelik, 2009; Melnikov, 1980; Wakabayashi et al., 1973; Xie, 2005). In this paper, characteristics of inner force determination, which is formed by the effects of seasonal heat changes in these bars will be given regardless of the formational characteristics of the joint and sections.

Research results on the calculation of the internal forces occurring in the rigidity shear members depending on the length and the height of the building, and also optimal formations' arrangement of the settlement of the rigidity shears between columns in industrial structural system have been stated here.

2. Selection of the Research Method

Researches have been carried out suitably to two-type formations of the rigidity shears in structural system. In the first type formation, rigidity shear was placed in the middle of the building in structural system (Figs. 1, 3, 5), as for second type formation, it was placed at two sides of it (Figs. 2, 4 and 6) (Arda and Uzgider, 1978; Belenya, 1985). Stress condition of the building rigidity shear was also analyzed independently of the structural system. On each type of arrangement, structural system which was 66 m, 78 m, 90 m, 102 m, 114 m, and 126 m in length was analyzed. On these lengths, conditions in which the structural system was 6 m, 12 m and 18 m in height were taken as an analysis object. In cases where these structural system models (t_2-t_1) taken into consideration for analysis were 30°C, 40°C, 50°C and 60°C, rates of internal forces were calculated in rigidity shear members and columns placed in edge-side sections related to the length of the building.

Here, t_1 is the average seasonal temperature when the building was constructed; t_2 is maximum temperature affecting the structural system during the usage of it. Calculations were made by using the SAP2000 program. By this way, variation character of internal forces depending on the length, height and t_2-t_1 rates of the building in its side columns and rigidity shear members was investigated.

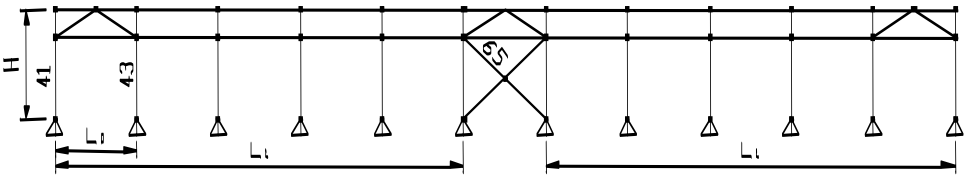

Fig. 1. Type-1 (H = 6 m).

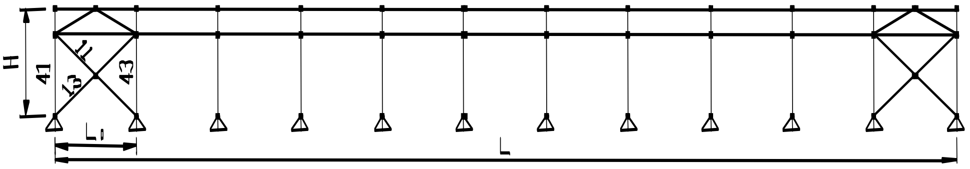

Fig. 2. Type-2 (H = 6 m).

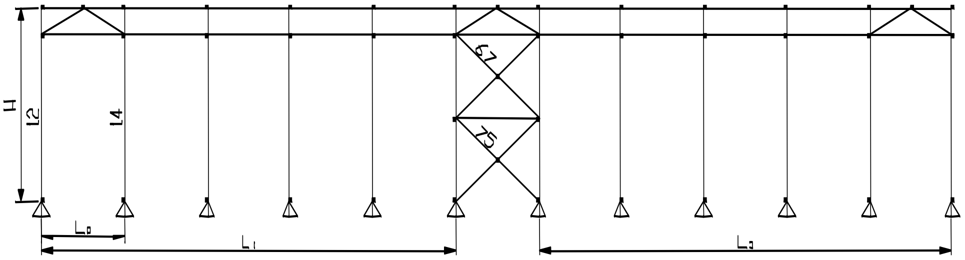

Fig. 3. Type-1 (H = 12 m).

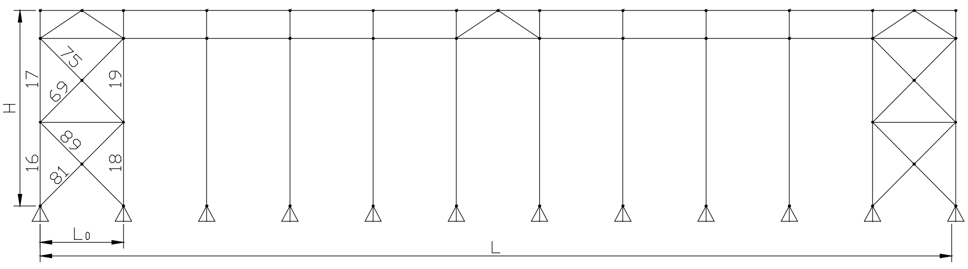

Fig. 4. Type-2 (H = 12 m).

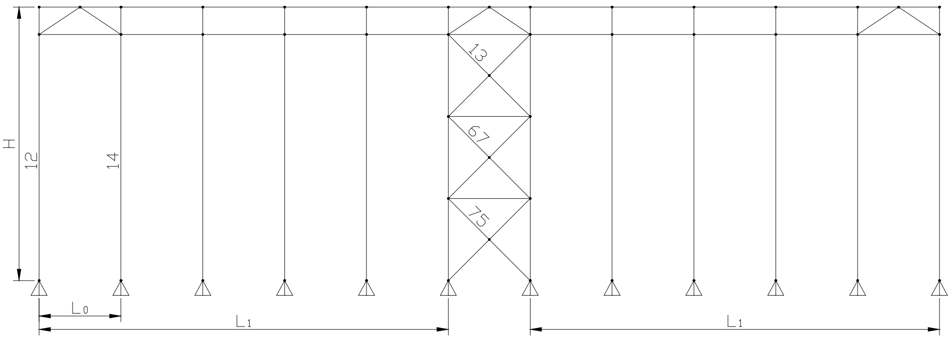

Fig. 5. Type-1 (H = 18 m).

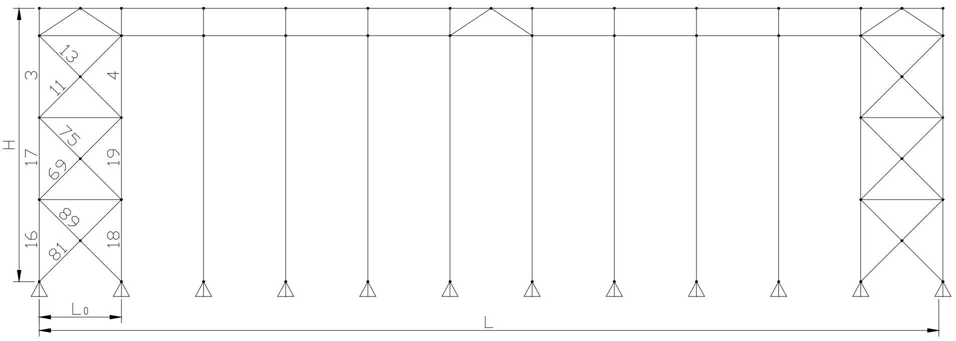

Fig. 6. Type-2 (H = 18 m).

3. Determination of Displacement and Forces Resulting from the Effect of the Temperature Variation in Rigidity Shear between Columns

Strain of the structural system due to the effect of temperature variation and the rate of the effective loads depend on the arrangement of the structural system. In the first type arrangement of structural system, horizontal strain rate suitable to high level of the structural system's side columns can be calculated with

$$\Delta_t = \alpha L_1 (t_2 - t_1)\,. \tag{1}$$

Here, α is the linear expansion modulus of structural system material. It can be taken as $12\text{x}10^{-6}$ for steel. L_1 is the width from rigidity shear side column in structural system to building side column.

As for the second type arrangement of structural system, due to the length of structural system, when rigidity shear of both sides is taken into consideration as it is shown in Fig. 2, a strain limitation close to $\Delta_t \to 0$ is at issue. In this case, effective load rate in the high level of the column to the each of the side shears can be calculated with the

$$F_{tkp} = \frac{3EJ\alpha L_0}{H^3 c}(t_2 - t_1)\,. \tag{2}$$

Here, E column material elasticity modulus- can be taken as $E = 2{,}06 \cdot 10^4$ kN/cm^2 for steel. H is the height of column and L_0 is the distance between the internal columns of shear in Fig. 2 in the length of structural system. c will be calculated with

$$c = 1 + (\alpha_1)^3 \mu\,, \tag{3}$$

in variable sectional columns in terms of height. $\alpha_1 = H_y/H$ and $\mu = J//J_y$ can be calculated with equations. H_y is the height of higher part of J_y column cross-section from the changed point and the inertia moment of sections appropriate to the same height. J is the column cross-sectional inertia moment in stable cross-sectional columns. As for variable sectional columns, the lower part of the column is cross-sectional inertia moment. When structural systems arranged with stable cross-sectional columns due to its height are applied, it will be taken as $c = 1$ in Eq. (2) (Belenya, 1985). Moreover, from the effect of the temperature variation of vertical rigidity shear itself, the load occurring towards the horizontal bar in the top part of its columns can be calculated with

$$F_{tp} = \frac{0.5AA_1E\alpha(t_2 - t_1)b}{H[A_1 + A(K_1 + 2.83)]}\,. \tag{4}$$

Here, it can be found with $K_1 = b/H$ equation. b is the distance between columns in rigidity shear. A is the column cross-sectional area, A_1 is the rigidity shear cross-sectional area of other columns.

In accordance with this research, in the first type structural system arrangement, effective load rate from the general temperature variation occurring in the height of the building to rigidity shear can be as $F_t \to 0$. But, in this case, load rate resulting from the effect of temperature in rigidity shear itself will be calculated with Eq. (4). As for the second type structural system arrangement, formation of rigidity shear to the two edge side of the building widely limits the horizontal strain under the influence of temperature. In other words, $\Delta_t \rightarrow 0$ and horizontal load rate effective in rigidity shear can come closer to F_t maximum in this case (Timoshenko, 1955; Belenya, 1985). Also in this case; the total effect of power occurring due to the temperature variation in whole of the building height in rigidity shear and the power occurring due to the temperature variation in rigidity itself will take place. In this case again, effective load to building shear will be calculated with

$$F_t = F_{tkp} + F_{tp}\,. \tag{5}$$

When Eqs. (2) and (4) are taken into consideration in Eq. (5), it will be as

$$F_t = \frac{0.5E\alpha(t_2-t_1)}{H}\left[\frac{6Jl_0}{H^2c} + \frac{AA_1b}{A_1+A(K_1+2.83)}\right]. \tag{6}$$

4. The Calculation of Internal Forces under the Influence of Temperature Variation in Rigidity Shear Members between Columns

In structural system, rigidity shear members between columns having different geometrical characteristics, SAP2000 program was used during the determination of internal forces suitable to different temperature variations. According to this, when rigidity shear in a structural system which is at a height of 6 m and 66 m in length is arranged as type 1 and temperature variation is 30°C, normal force in side column (member no 41) is 0.055 kN; normal force in rigidity shear diagonals (member no 65) is -51.719; 0.184kN and 0 when shearing force is suitable; 1.102 kNm and 0 when bending moment is suitable. When the effect of temperature is 60°C in the same structural system, internal forces double. When the length of the structural system is taken as 78 m and 30°C temperature variation takes place in member no 41, normal force is 0.209 kN and it is -51.744 kN in member no 65. It is also taken as 0.216 kN and 0 when shearing force is suitable and bending moment as -1.297kN and 0. When the same building length is 90 m and temperature variation is 40°C, normal force is -0.629 kN in member no 41, 69.080 kN in member no 65; shearing force is taken as 0,332 kN ; 0, and bending moment as -1.989 kNm. When the building is at the height of 6 m, 12 m, 18 m and 66 m, 90 m and 126 m in length, calculation results of internal forces suitable to 40°C temperature variation are given in Table 1.

According to the rates given in this table, when the length of the building steps up to 126 m from 66 m, normal force rate suitable to 40°C temperature variation is 24 in member no 41, bending moment is 1.88, shearing force is 1.88. Normal force has increased 1.009 times in member no 65.

When the building is at a height of 6 m and 66 m in length (Fig. 2) and the rigidity shear is placed in two sides of the building (Type-2), internal force in 30°C temperature variation is -91.715 kN, +193.627 kN in internal column, 85.010 kN in tensile diagonal (member no 11) and -229.112 kN in stress diagonal. As for shearing force and bending moment rate, it is taken as little as to be disregarded. Under the influence of 60°C temperature variation in the same structural system , normal force is -183.429 kN in the side column of rigidity shear, 387.253 kN in internal column, 170.021 kN in tensile diagonal (member no 11), -458.225 kN in stress diagonal (member no 13). In this case also, shearing force and bending moment can be ignored. As for the temperature variation marked negatively, rates of internal forces in side and internal columns of rigidity shears are stable, but their markers will be reverse. According to the rates given in Table 1, when the length of the building increases from 66 m to 126 m, normal force rate suitable to 40°C temperature variation increases to 12.52 kN in side column, 11.32 kN in internal side column, 12.6 kN in tensile diagonal, 11.1 kN in stress diagonal.

When the length of the building is 126 m and temperature variation is 40°C, proportion of the normal forces of the members in a structural system formed according to Type-2 to normal forces of system members formed according to Type-1 is 87 in external side column and 4.88 in stress diagonal (member no 13).

Depending on the rates given in Table 1, when the length of the building is 66m and internal forces of rigidity shear members of the Type-1 and Type-2 formations are compared in 40°C temperature variation; rates of the formations according to Type-1 in proportion to the formations according to Type-2, normal force was seen to decrease 1675 times in left side column, 3536 times in internal side column and 4.43 times in stress diagonal.

Furthermore, when the length of the building was 66 m and temperature variation was 40°C, in Type-1 structural system model, normal force decreased 3.38 times in external side columns. This happened when the height was increased from 12 m to 18 m. As for Type-2, normal force increased 1.06 times in external side columns with the increase of height. A simplified method to determination of the inner force of stiffness brace in industrial buildings due to variation of temperature is proposed (Eyyubov, 2011).

Rates given in Table 1 of internal forces resulting from the temperature variation in the columns of building and rigidity shear members $\Delta_t = t_2\text{-}t_1 = 40°\text{C}$ were calculated considering the seasonal temperature variation. This is because seasonal temperature variation widely seen in Turkey is close to 40°C. For the determination of internal forces forming in the building rigidity shear and columns due to desired temperature variation, that is enough to multiply the rates given in Table 1 with the K_t modulus (Eyyubov, 2010).

$$K_t = \Delta t_i / \Delta t_0\,. \tag{7}$$

Here, Δt_i rate is the seasonal temperature variation rate in the region where the desired building is settled. It is determined with the statistical methods by depending on the meteorology service data and it is stated in the agreements prepared by Turkish Standards Institute (TSE). Δt_0 is the temperature variation reference value by which appropriate construction member is calculated. Here, Δt_0 will be taken as 40°C.

Variation diagram of internal force rate in building side columns depending on the length of the building and the height of Type-1 shear structural system is given in

Fig. 7. According to this, internal force rate forming in the members and columns of shear structural system changes linearly in accordance with the length of the building. Suitable rate of the internal force to the desired length of the building in the members and the columns of the shear can be found by multiplication of the rates given in Table 1 with the K_l modulus (Eyyubov, 2010).

$$K_l = l_i/l_0 \,. \tag{8}$$

Here, l_0 was calculated beforehand or is the distance from the shear side column of the building whose reference value have been given in Table 1 to the side column of the building, l_i is the same distance in the building whose design we have undertaken.

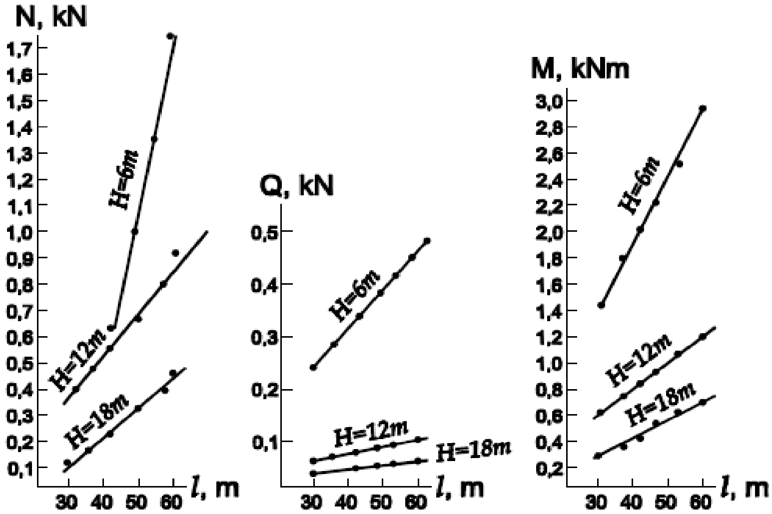

Fig. 7. Type-1: Variation diagram of internal force rates depending on building length and height in rigidity shear members.

Table 1. Internal forces in columns and rigidity shear members in the arrangement of structural system related to Type-1 and Type-2.

L (m)	INTERNAL FORCES	H	6 m				12 m							
		Element	41		65		12		14		67		75	
		Number	41	43	11	13	16	17	18	19	75	69	89	81
126	Axial Force (t)	Type 1	-0.1752		-6.9557		-0.0920		0.0920		1.3850		-7.0140	
		Type 2	-15.3066	29.2320	14,2587	-33.9493	-40.3658	-17.3049	45.5826	18.2136	18.5917	-19.8806	12.7286	-25.7599
	Shear Force (t)	Type 1	0.0461				0.0099		0.0089					
		Type 2	-0.0034	-0.0110			0.0096	-0.0176	-0.0183	0.0155				
	Bending Moment (tm)	Type 1	-0.2764				-0.1193		-0.1073					
		Type 2	0.0203	0.0660			-0.0576	0.0479	0.1095	0.0166				

L (m)	INTERNAL FORCES	H	18 m											
		Element	12			14			13		67		75	
		Number	16	17	3	18	19	4	13	11	75	69	89	81
126	Axial Force (t)	Type 1	-0.0473			0.0473			-0.2985.		1.4738		-7.0377	
		Type 2	-4S.6916	-34.6986	-11.8546	58,7577	32.1771	14.4663	12.4965.	-16.1918	16.1127	-12.5497	7.2365	-21.4698
	Shear Force (t)	Type 1	0.0039			0.0035								
		Type 2	0.0030	-0.0068	-0.0004	-0.0180	0.0191	-0.0048						
	Bending Moment (tm)	Type 1	-0.0704			-0.0634								
		Type 2	-0.0178	0.0227	0.0250	0.1081	-0.0064	0.0225						

The stiffness members which located between columns inner force values due to variation of temperature and building length are written as (Eyyubov, 2011);

$$N_{lt} = K_1 K_t l N_a \ , \ Q_{lt} = K_1 K_t Q_a \ , \ M_{lt} = K_1 K_t M_a \,. \tag{9}$$

K_l, K_t the coefficients can be calculated by (7) and (8). N_a, Q_a, M_a are reference values of axial force, shear force and bending moment respectively. They can be chosen according to reference building length (126 m) and reference temperature variation (Δt_a = 40°C) from Table 1 or the diagram giving in the Fig. 7.

The inner force values of the longitudinal exterior stiffness braces due to wind and earthquake effects can be calculated by relevant regulations.

Normal force rates forming in the crosswise of the rigidity shear can be applied in design depending on the length of the building, and it can be accepted as constant.

5. The Design of the Industrial Building Structural System Depending on the Temperature Variation

When rigidity connection system arranged longitudinally between columns in industrial buildings is formed in accordance with Type-2, wind affects the rigidity shears in two sides of the building. Moreover, internal forces forming from the effect of the wind then can be added.

The analysis of the rates given in Table 1 and diagram shows that temperature strains in all of the members of the rigidity shear are subject to the accumulation of it with the strains resulting from the effect of the wind and earthquake. Here, internal forces forming from the temperature variation always can be taken into consideration in the same combination with the one, two or three of the internal forces resulting from the effect of the wind, earthquake, machines or mechanisms when they are activated and stopped.

When the rigidity shear is placed in the middle of the building (Type-1), the rate of the internal forces resulting from the temperature variation in rigidity shear members can be ignored as it is low. Calculation will be made considering that in this case, the absorption effect and active stress of the wind will be countered by the single rigidity shear placed in the middle of the building length. The same approach will be adopted when the effect of earthquake is taken into consideration in the design of the building.

Thus, the placement of rigidity shear between columns into the middle of the building length may cause a decrease in the internal forces forming in the structural system members and simplification of the construction and the design of the building. For example, a rigidity shear instead of two rigidity shears can be placed into the building whose length reaches to 120 m. This provides a great economical benefit for industrial building construction.

6. Conclusions

The research results of the behaviors of the rigidity connections between columns in industrial buildings can be summarized as follows:

- The engineering research of the destructive earthquakes has showed that the behavior of the industrial buildings during an earthquake is based on the formation of the rigidity connections between columns. With twisting, breakage and deformations in joints in rigidity connection members can be encountered during an earthquake. These deformations forming in the rigidity shears affect the usage conditions of the buildings.
- The placement of the rigidity shear in the structural system into the middle of the building causes a decrease in the forces depending on temperature variation affecting the connection member and it also causes to the simplification in the formation of the structural system. The length of the industrial building depending on the temperature variation can be accepted as 100 m. In this case, it is offered that rigidity shear between columns should be placed in the middle of the building. Optimal rate of the distance of rigidity shear to the building sides can be 40 m~60 m.
- When the members of the industrial building structural system are dimensioned, it is required that the loads resulting from the temperature variation should be considered. The loads resulting from the temperature variation can be included in the load combinations as static loads.

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