International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Influence of Anchor Connector Stiffness on Displacement-Internal Force of Steel-Concrete Frame

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***Abstract*: In the article, the author introduces how to determine the equivalent hardness of steel-concrete composite beam element, stiffness matrix and nodal load vector of steel-concrete beam element. Thereby, to build and solve the problem of analyzing the structural steel frame of concrete considering the anchor stiffness, programming and clarifying the impact of anchor stiffness associated with displacement - internal force of the frame.**

***Keywords*: Shear connectors, steel - concrete frame; cutting anchors, conjugated beams, incomplete interaction**

I. INTRODUCTION

In the construction structure, the structure of steel - concrete composite frame is quite popular. Steel - concrete composite frame structure is made up of structural steel - concrete beams with steel columns or steel - concrete composite columns. In particular, steel composite beams - concrete is formed by structural steel beams and concrete floor structures, linking them through anchors. Anchor bonding is effective against sliding at the contact surface between steel structure and concrete structure, the most common form is the cap welding cap [2]. The fact shows that the anchors have finite stiffness, they are deformed when force is created by relative slippage at the contact surface, and affect the working of the conjugated structure should be needed. must consider in calculation [1, 9]. In addition, commercial software SAP 2000 or ETABS does not have a sample element, steel-concrete composite beam elements [3, 6], making it difficult to analyze structural problems and survey the effect of degree hard anchor linking to displacement - internal force in the steel - concrete composite frame structure. Therefore, clarifying the impact of anchor stiffness linked to displacement, internal forces in the steel-concrete composite frame structure is necessary and practical

Revised Manuscript Received on 30 July 2019.
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II. THEORY

A. Limited research

Study on flat frame with steel-concrete composite beam components, subject to static load;

Constructed of solid reinforced concrete floor slabs working in conjunction with steel beams.

B. Some common assumptions and symbols

a) Some assumptions

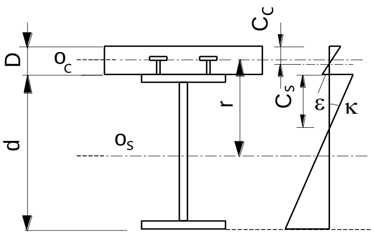
Steel, concrete and anchor materials work in the elastic phase;

The conjugated effect occurs on the contact surface between steel and concrete;

Cross section of cross section remains flat after deformation;

There is no detachment of anchor links from steel and concrete cross-section surfaces.

b) General symbols



A_c, A_s, A_{st} - the cross-sectional area of concrete slab, steel beam, vertical steel in the floor (mm2);

I_c, I_s, I_{st} - the inertial moment of components of concrete slab, steel beam, vertical steel in the floor for their axis (mm4);

E_c, E_s, E_{st} - elastic modulus of concrete slab, steel beam, vertical steel in floor (N / mm2);

D, d - thickness of concrete slab and height of steel beam cross section (mm);

r - g eometric axis distance of concrete plate and steel beam (mm);

$(EI)^{\infty}_{comp}, (EI)_{comp}, (EI)^{0}_{comp}$ - anti-bending stiffness of the conjugate beam corresponds to the anchor with absolute hardness, partial hardness and no link anchor (kN.mm2);

κ - curvature of steel beams and concrete slabs after deformation;

ε_{slip} - relative sliding on concrete surfaces and steel beams;

K_s - link anchor hardness (N / mm); a - link anchor distance (mm)

Retrieval Number: B3353078219/19©BEIESP
DOI: 10.35940/ijrte.B3353.078219
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
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C. Basic equation of a flat bar structure analysis problem.

The basic equation of finite element method in the problem of structural analysis subject to static load is [3]:

$$[K]\{U\} = \{R\} \tag{1}$$

Inside: [K], {R} - stiffness matrix and nodal load vector of the structure in the general coordinate system;

{U} - button displacement vector.

Accordingly, the stiffness matrix [K] and the payload vector {R} are determined from the stiffness matrices [Ke] and the nodal load vector {Re} of the element in the local coordinate system thanks to coordinates conversion matrix [Te] and positioning matrix [Le]. The matrices [Te] and [Le] are mentioned in the literature on finite element methods, and the matrix [Ke] and vector {Re} will be mentioned later.

D. Equivalent stiffness of conjugated beams.

The construction of equivalent hardness of steel - concrete composite beams has been presented in the literature [3, 4, 7]. Here the author only gives the calculation results:

-When interacting between steel beams and zero concrete slab, equivalent stiffness of beams:

$$(EI)^0_{comp} = \sum EI = E_c.I_c + E_s.I_s \tag{2}$$

- When the interaction between steel beams and concrete slabs is complete, the equivalent stiffness of the beam:

$$(EI)^{\infty}_{comp} = E_c I_c + E_s I_s + \overline{EA}r^2 = \sum EI + \overline{EA}r^2 = (EI)^0_{comp} + \overline{EA}r^2 \tag{3}$$

- When interaction between steel beams and concrete slabs is incomplete, equivalent stiffness of beams:

$$EI_{comp} = EI^{\infty}_{comp} - \overline{EA}.r.\varepsilon_{slip} / \kappa \tag{4}$$

From formula (4), the relationship between the bending moment and the deflection of the conjugated beam element is no longer linear, the equivalent stiffness of the conjugated beam when the interaction is not entirely dependent on the shear strain at the next surface. contact.

The formulas (2), (3) and (4) to determine the equivalent stiffness corresponding to the combined beam with the compression zone are on the side of the slab. In the case, the combined beam has a drag zone on the side of the concrete slab, which is common in cross section positions in the support of the continuous beam, then the tensile resistance of the concrete is ignored, and instead is vertical steel in slab:

$$EI_{un.comp} = E_s(I_s + A_s z_w^2) + E_{st}(I_{st} + A_{st}C_{st}^2) \tag{5}$$

Inside: z_W - distance from the center of the equivalent section to the central axis of steel beam (mm);

I_{st} , A_{st} - inertial moment (mm4) and floor reinforcement area (mm2);

C_{st} - distance from the center of the tensile floor reinforcement to the central axis of the steel beam (mm).

E. Equilibrium differential equations of conjugated beams with incomplete interaction anchors.

According to [3, 4, 7], the equilibrium equation of the conjugate beam element with the interconnected anchor is incomplete:

$$\frac{d^4y}{dx^4} - \frac{k}{\overline{EA}}\frac{(EI)^{\infty}_{comp}}{(EI)^0_{comp}}\frac{d^2y}{dx^2} + \frac{1}{(EI)^0_{comp}}\frac{d^2M}{dx^2} - \frac{k}{\overline{EA}.(EI)^0_{comp}}M = 0 \tag{6}$$

Special case:

- When the link anchor has a very large sliding module, it means that there is no sliding on the contact surface, k = ∞, equation (6) returns to the case of a fully integrated beam:

$$EI^{\infty}_{comp}(d^2y / d^2x) + M = 0 \tag{7}$$

- When the link anchor has zero stiffness, free sliding on the surface of concrete - steel, k = 0, equation (6) returns to the case of interactive beams with zero:

$$EI^0_{comp}(d^2y / d^2x) + M = 0 \tag{8}$$

F. Hardness matrix of conjugated beam elements

The construction of the stiffness matrix of conjugated beams has been presented in documents [3, 4, 7]. Then the associated beam element stiffness matrix is written as follows:

$$[K_e] = \frac{(EI)^{\infty}{}_{comp}}{L}\begin{bmatrix} 12\varphi_1/L^2 & (4\varphi_2+2\varphi_3)/L & -12\varphi_1/L^2 & (4\varphi_2+2\varphi_3)/L \\ 6\varphi_1/L & 4\varphi_2 & -6\varphi_1/L & 2\varphi_3 \\ -12\varphi_1/L^2 & -(4\varphi_2+2\varphi_3)/L & 12\varphi_1/L^2 & -(4\varphi_2+2\varphi_3)/L \\ 6\varphi_1/L & 4\varphi_3 & -6\varphi_1/L & 4\varphi_2 \end{bmatrix} \tag{9}$$

with :

$$\varphi_1 = \frac{(EI)^0{}_{comp}(\alpha L)^3.\sinh\alpha L}{(EI)^0{}_{comp}.(\alpha L)^3.\sinh\alpha L + 2\left((EI)^{\infty}{}_{comp} - (EI)^0{}_{comp}\right)(12 + 6\alpha L\sinh\alpha L - 12\cosh\alpha L)}$$

$$\varphi_2 = \frac{3}{4}\frac{(EI)^0{}_{comp}(\alpha L)^3.\sinh\alpha L}{\left[(EI)^0{}_{comp}(\alpha L)^3\sinh\alpha L + 2((EI)^{\infty}{}_{comp} - (EI)^0{}_{comp})(12 + 6\alpha L\sinh\alpha L - 12\cosh\alpha L)\right]} + \frac{1}{4}$$

$$\varphi_3 = \frac{3}{2}\frac{(EI)^0{}_{comp}(\alpha L)^3\sinh\alpha L}{\left[(EI)^0{}_{comp}(\alpha L)^3\sinh\alpha L + 2((EI)^{\infty}{}_{comp} - (EI)^0{}_{comp})(12 + 6\alpha L\sinh\alpha L - 12\cosh\alpha L)\right]} - \frac{1}{2}$$

The terms in the stiffness matrix $[K_e]$ satisfy the condition:

$$6\varphi_1 = 4\varphi_2 + 2\varphi_3 \tag{10}$$

In special cases, beams have constant cross section and made of a material (such as steel beams), stiffness matrix has the form:

$$[K_e] = \frac{(EI)_{un.comp}}{L}\begin{bmatrix} 12/L^2 & 6/L & -12/L^2 & 6/L \\ 6/L & 4L & -6/L & 4L \\ -12/L^2 & -6/L & 12/L^2 & -6/L \\ 6/L & 4L & -6/L & 4L \end{bmatrix} \quad (11)$$

G. The equivalent button load vector of the composite beam element.

According to documents [3, 4, 7], with steel-concrete composite beams subjected to evenly distributed load and subjected to concentrated load, the equivalent nodal load vector of the beam element does not depend on hardness. anchors on contact surfaces between beams combined with concrete slab, values taken as regular beam elements.

III. RESULTS AND DISCUSION

A. Develop a calculation program.

Based on the $[K_e]$ and $\{R_e\}$ matrices of the newly formed beam elements, the author built the software in Mathlab language to analyze the structure of steel-concrete composite frame with interconnected anchor. not working perfectly. The software is called APCB-03.

B. Calculation example

1) Calculated data

Considering the 2-tier 2-span conjugate frame, the size of the combined beam section, as shown in Fig. 1. The frame is subjected to the distribution load q = 100kN / m, and the concentrated load P = 50kN, shown in Fig. 2. Beams steel using CCT38 steel material has a calculated intensity f = 230N / mm2, Es = 2.1.105N / mm2; Concrete floor using B25 material has Rb = 14.5N / mm2, Ec = 2.65.104 N / mm2.

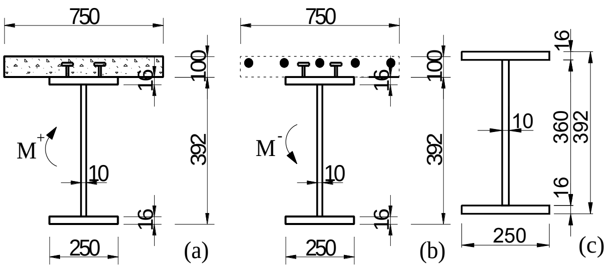

Fig. 1. Cross section of combined beams and steel columns (a - cross section at the span; b - cross section at the pillow; c - cross section)

2) Requirements for calculation

- Verify the reliability of APCB-03, corresponding to special cases compared to the results of analysis, the case of complete anchor, $k = \infty$, and the case of zero anchor, k = 0 .

- Investigate the internal displacement of the frame, with the stiffness of the anchor connected in turn to receive the values through the sliding module, k = 0,01%E_s; 0,5%E_s; 5%E_s; 50%E_s and very large is 4000%E_s.

3) Calculation results

Steel floor use according to EN 10080 3 standard, S500 type has elastic limit when pulling $f_{sk} = 5.10^5$kN/m^2, elastic module $E_s = 2{,}1.10^8$kN/m^2. Thickness of steel protective concrete layer is 1.5cm. Plastic strength of reinforced concrete floor F_s with reliability coefficient γ_s = 1,15 and Ast steel floor area subjected to A_{st} = 5.78,54.10^{-6}m^2 is: $F_s = A_{st}.f_{sk} / \gamma_s = 5.78{,}54.10^{-6}.5.10^5 / 1{,}15 = 170{,}73$kN

Plastic strength of section steel when subjected to pulling, with $f_y = 220.10^3$kN/m^2:

$F_a = A_s.f_y / \gamma_a = 116.10^{-4}.220.10^3 / 1 = 2552$kN (with $\gamma_a = 1$ a safety factor for shaped steel materials).

Because $F_a > F_s$ and $F_a - F_s$ = 2381kN > 1760kN, with the value of $2b_f t_f f_y/\gamma_a$ = 2.0,25.0,016.220.10^3/1 = 1760kN, the neutral axis goes through the steel girder plate.

$z_w = F_s/(2t_w f_y/\gamma_a)$=170,73/(2.0,01.220.103)= 0,039m = 39mm; r = (0,392/2 - z_w) + 0,085= 0,242m

I_s = 0,25.0,3923/12 – 2.0,12.0,363/12 = 3,218.10^{-4}m^4; I_{st} = π.0,0124/64 = 1,017.10^{-9}m^4

With the assumption that the bearing capacity of the tensile concrete part is ignored, the flexural stiffness is equivalent to that of the combined beam section, $EI_o = E_s.I_s + E_s.I_{st}$ = 2,1.108.3,21.10^{-4} + 2,1.108.1,017.10^{-9} = 6,75.10^{4}kNm^2; equivalent tensile strength of the combined beam section:

$\overline{EA} = E_s.A_{st}.E_s.A_s/(E_s.A_s + E_s.A_{st})$

= (2,1.10^8.5.78,54.10^{-6}).(116.10^{-4})/(5.78,54.10^{-6} + 116.10^{-4}) = 7,976.10^4 kN

So, the equivalent stiffness of the conjugated beam: $EI_\infty = E_s I_s + E_s I_{st} + \overline{EA} r^2 = 7{,}283.10^4$kNm^2

Using APCB-03 calculator, perform calculations:

First calculation: assuming the conjugate beam has constant hardness over the entire length is (EI_∞), we find the position with the bending moment value, M = 0, corresponding to the position of moment diagram, that point is 2m from the frame node.

The second calculation: updating element stiffness matrices, corresponding to positive moments and negative moments (i.e. the area under compression or tensile zone at the side of the slab). For the compressive zone on the side of the slab (positive torque) corresponds to elements 3, 4, 8, 9, 14, 15, 19 and 20 (conjugated beam elements); with drag zone with slab (negative torque) with elements 2,5,7,10,13,16,18 and 21 (steel beam and floor steel elements).

Verify the reliability of the APCB-03 calculation program, by comparing the calculation results of the internal force (M, V, N) of the program with SAP 2000 software, without considering the conjugate work of the version floor, calculated with ordinary steel beams, the results are shown in Tab. 1.

Tab. 1. Internal results of some elements according to APCB - 03 and SAP 2000

Element	Knot	Internal results follow ACPB – 03			Internal results follow SAP2000			Difference		
		N(kN)	V(kN)	M(kN.m)	N(kN)	V(kN)	M(kN.m)	N(%)	V(%)	M(%)
(2)	2	76,59	373,91	-406,71	77,86	372,41	-397,47	1,67	0,40	2,27
	3	76,59	173,91	141,12	77,86	172,41	147,35	1,67	0,87	4,41
(3)	3	76,59	173,91	141,12	77,86	172,41	147,35	1,67	0,87	4,41
	4	76,59	-26,09	288,94	77,86	-27,09	292,16	1,67	3,86	1,11
(6)	7	-1679,08	38,20	-92,16	-1685,59	37,94	-91,95	0,39	0,67	0,23
	6	-1679,08	38,20	60,63	-1685,59	37,94	59,82	0,39	0,67	1,34
(7)	6	89,35	398,77	-511,18	84,66	400,55	-515,55	5,24	0,45	0,85
	8	89,35	198,77	86,36	84,66	200,55	85,54	5,24	0,89	0,95
(8)	8	89,35	198,77	86,36	84,66	200,55	85,54	5,24	0,89	0,95
	9	89,35	-1,23	283,90	84,66	-1,25	286,64	5,24	1,40	0,96
(12)	2	-365,13	-158,41	282,74	-363,50	-152,42	269,30	0,45	3,78	4,75
	13	-365,13	-158,41	-350,90	-363,50	-152,42	-340,38	0,45	3,78	3,00
(14)	14	-208,41	165,13	179,36	-202,42	163,50	186,63	2,87	0,99	4,05
	15	-208,41	-34,87	309,62	-202,42	-36,50	313,64	2,87	4,67	1,30
(20)	19	-182,97	19,36	305,72	-177,28	20,05	309,16	3,11	3,58	1,13
	20	-182,97	-180,64	144,43	-177,28	-179,05	151,06	3,11	0,88	4,59

a) Result of bending moment in frame

The results of bending moment in the frame corresponds to the normal steel frame and the survey results affect the anchor stiffness associated with the internal force frame by the program of calculating APCB-03, recorded in Tab.s 2 and 3.

Tab. 2. Torque bending results at the beginning of the column element (kN.m)

Element	PT1	Difference (%)	PT6	Difference (%)	PT12	Difference (%)	PT17	Difference (%)
Steel frame	-123,97	//	-92,16	//	282,74	//	58,14	//
k=0	-110,18	11,13	-91,21	1,03	256,34	10,30	57,29	1,49
$k=0,01\%E_s$	-90,04	18,27	-89,34	2,05	218,57	14,73	55,80	2,61
$k=0,5\%E_s$	-89,93	0,13	-89,28	0,07	218,37	0,09	55,78	0,04
$k=5\%E_s$	-85,85	4,54	-88,16	1,26	210,83	3,58	55,40	0,69
$k=50\%E_s$	-85,83	0,02	-88,15	0,01	210,79	0,02	55,39	0,01
$k=4000*E_s$	-85,83	0,00	-88,15	0,00	210,79	0,00	55,39	0,00

(123,97-110,18)/123,97*100=11,13%; (110,18-90,04)/110,18*100=18,27%;....

Tab. 3. Torque bending results at the beginning of the beam element (kN.m)

Element	PT2	Difference (%)	PT7	Difference (%)	PT13	Difference (%)	PT18	Difference (%)
Steel frame	-406,71	//	-511,18	//	-350,90	//	-571,71	//
k=0	-366,51	9,88	-469,11	8,23	-314,46	11,59	-524,26	9,05
$k=0,01\%E_s$	-308,62	15,80	-411,69	12,24	-262,65	16,47	-460,96	12,07
$k=0,5\%E_s$	-308,30	0,10	-411,19	0,12	-262,34	0,12	-460,44	0,11
$k=5\%E_s$	-296,68	3,77	-401,63	2,33	-251,99	4,11	-450,51	2,20
$k=50\%E_s$	-296,62	0,02	-401,60	0,01	-251,93	0,02	-450,50	0,00
$k=4000*E_s$	-296,62	0,00	-401,61	0,00	-251,93	0,00	-450,50	0,00

(406,71-366,51)/406,71*100=9,88%; (366,51-308,62)/366,51*100=15,8%;...

b) Results of vertical displacement and horizontal displacement of the frame

- Results of vertical displacement of the frame, corresponding to the normal steel frame and survey results of anchor stiffness associated with frame displacement by APCB-03, shown in Tab. 4 and Fig. 4

Tab. 4. Results of vertical displacement of frame node (mm)

Knot PT	Knot 2	Knot 3	Knot 4	Difference Knot 4(%)
Steel frame	-1,22	-14,00	-20,41	//
k=0	-1,22	-12,28	-17,41	14,69
$k=0,01\%E_s$	-1,22	-11,23	-15,57	10,56
$k=0,5\%E_s$	-1,22	-9,63	-12,57	19,26
$k=5\%E_s$	-1,22	-9,07	-11,54	8,19

Knot PT	Knot 13	Knot 14	Knot 15	Difference Knot 15(%)
Steel frame	-1,81	-17,16	-23,86	//
k=0	-1,82	-14,98	-20,34	14,75
k=0.01%Es	-1,82	-13,67	-18,21	10,47
k=0.5%Es	-1,82	-11,74	-14,87	18,34
k=5%Es	-1,82	-11,07	-13,73	7,67

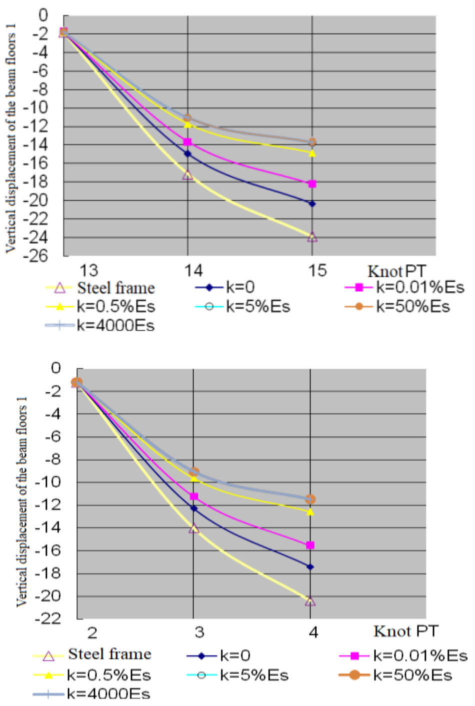

Fig. 4. Shows the vertical displacement of the frame button

- Results of horizontal displacement of the frame node, with the steel frame and the results of surveying the influence of anchor stiffness to horizontal displacement of the frame by the program of calculating APCB-03, shown in Fig. 5.

Tab. 5. Results of horizontal displacement of frame node (mm)

Knot element	Knot 2	Difference (%)	Knot 13	Difference (%)
SAP2000	4,63	//	10,44	//
k=0	4,56	1,53	10,10	3,37
$k=0,01\%E_s$	4,51	1,11	9,87	2,30
$k=0,5\%E_s$	4,39	2,73	9,43	4,67
$k=5\%E_s$	4,34	1,15	9,25	1,94
$k=50\%E_s$	4,34	0,00	9,24	0,10
$k=4000E_s$	4,34	0,00	9,24	0,00

1,53%=(4,63-4,56)/ 4,56*100;
1,11=(4,56-4,51)/ 4,51*100;...
3,37%=(10,44-10,1)/10,1*100;
2,3%=(10,1-9,87)/9,87*100;..

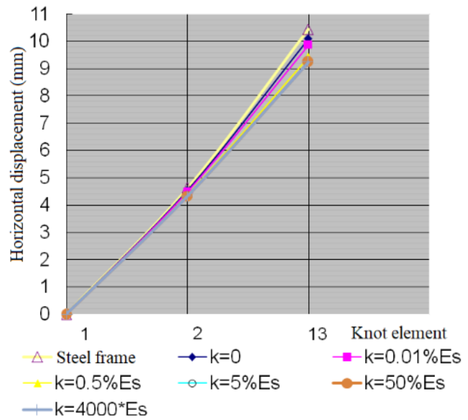

Fig. 5. Demonstration of horizontal displacement at the elevation elevation (mm)

(3.3) Comment on calculation results

According to **Tab. 1**, the results of integrated frame calculation according to SAP2000 software and APCB software are not significantly different. APCB-03 software is reliable enough in conjugate frame analysis.

According to **Tab. 2**, the maximum bending moment of the column elements is for the case of steel beams, the smallest bending moment corresponds to the case of conjugated beams with finite anchor stiffness (temporarily taken as k = 4000Es). The largest bending torque difference in the case of the first column column (element 1) is 34%. Seeing that, the anchor stiffness affects quite a bit on the internal force of the frame column, in the case of link anchor with zero stiffness (k = 0) and finite hardness (temporarily, k = 4000Es), the difference internal results are quite large: with element 1 being (-110.18 + 85.83) / - 110.18 = 22.08%, with element 12: (256.34-210.79) / 256 , 34 = 17.77%.

According to Tab. 3, the bending moment of beam elements is greatest with the case of steel beams, the smallest bending moment corresponds to the case of conjugated beams with finite anchor stiffness. The largest bending torque difference with case of beam 2 (element 13) is 32.3%. The anchor stiffness affects quite a lot to the internal force of the frame beam, in case the anchor has zero stiffness (k = 0) and has finite hardness, the difference in internal force is: with element 2 (- 366.51 + 296.62) / - 366.51 = 19.06%, with element 13: (-314, .46-251,93) / - 314.46 = 19.88%

According to Tab. 4, the graph in Fig. 4, the vertical displacement of the girder is the largest corresponding to the case of steel beams, and the smallest displacement corresponds to the case of conjugated beams with finite anchor stiffness.

The vertical displacement difference of beams is 52.96% for beams of first and 51.52% for beams of the second floor. Where anchors have zero stiffness (k = 0) and have finite hardness, difference The displacement results are quite large: with node 4 being (-17.41 + 11.5) / - 17.41 = 33.94%, with node15: (-20,34-13,69) / - 20, 34 = 32.69%. The vertical displacement difference of the frame girder has the most significant change in the case of link anchor having the hardness k = 0% Es to k = 5% Es. In addition to this range, the displacement difference is negligible. From these results, we find that the anchor stiffness greatly affects the vertical displacement of the frame girder.

According to the graph in Fig. 5, horizontal displacement at the elevation of the floors is largest with the case of steel beams, the smallest horizontal displacement corresponding to the case of conjugated beams with finite hardness. The difference in horizontal displacement of the frame at elevations 1 and 2 is 7% and 12.36% respectively, from which we see that the anchor anchor stiffness greatly affects the horizontal displacement of the frame.

IV. CONCLUSION

- Built APCB-03 software and reliable APCB-03 software. The influence of the anchor stiffness parameter was clarified, through the sliding module at the steel surface - concrete, to the displacement - internal force in the frame. The results of numerical research show that, and also show that the anchor stiffness affects quite a lot of displacement - internal forces in the conjugate frame.
- Need to study the effect of anchor stiffness linked to internal force - displacement in the flat frame structure, when subjected to dynamic load.

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