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FALSEWORK WITH IMPROVED RIGIDITY OF THE STRUCTURE

Keywords: falsework, nuremberg scissors, rigidity.
Тірек сөздер: төсеніштер, нюрнберг қайшылары, қатаңдық.
Ключевые слова: подмости, нюрнбергские ножницы, жесткость.

1. Introduction. We have developed a scheme of falsework, practically coinciding with the scheme based on the falsework «Nuremberg scissors». The designs on the this scheme superior to constructions based on the «Nuremberg scissors» by Parameters rigidity. We designed and created experimental construction of falsework (PMD-2.2) with the rise of the working area up to 4 meters. Here we give a comparative analysis of rigidity – designs «ПМД-2.2» and its analogue on the basis of «Nuremberg scissors.» Calculations showed that the rigidity of the «ПМД-2.2» on average twice as much rigidity «NN», and lateral rigidity even more.

Abroad are widely used falsework based on «Nuremberg scissors» («NN»). Analysis of the scheme «NN» showed that it still has potential to increase rigidity. The authors devised a scheme which by its characteristics better scheme «NN» in rigidity. This scheme has all the qualities of «NN», and also has a greater «longitudinal» and «lateral» rigidity. This is due to the introduction of an additional slider, located on the rack. This engineering solution for falsework has received several patents of the Republic of Kazakhstan for utility model and industrial sample [1-4]. Adding slider poses yet another the reference point in the design of in space of motion. As you know, foreign designs based falsework «HH» have only support points in the plane lying horizontal frame. To demonstrate the advantages of the proposed scheme, falsework will do a comparison of two models of rigidity. To analyze the structural rigidity falsework built finite element model (FEM). They consist of 40 nodes (Figure 1).

We consider two finite-element models (Fig. 1), all nodes are the same. For the construction of the «ПМД-2.2» additional sliders move by rigid vertical guide, and for construction of the «NN» – they are free from them (Table 1).

2. Structure and cross-sectional geometry, material properties. Of the finite element models are the same for both FEM. The cross sectional area of the rod finite element (RFE) is A=12000E-02. The moments of inertia, the elastic modulus and Poisson's ratio is: $I_V = 198e\text{-}05$, $I_W = .1790e\text{-}06$, $E = 2*10^{11}$, $\nu = 0.3$. Consistency between RFE and FEM nodes are in Table 2.

To account – fastenings and geometry FEM: in the corresponding nodes implemented restrictions, in the corresponding joints of between RFE introduced rotational and translational pairs (Table 3, 4).

Weight of the structure is ignored, and the external forces for both models are given the same (Table 5).

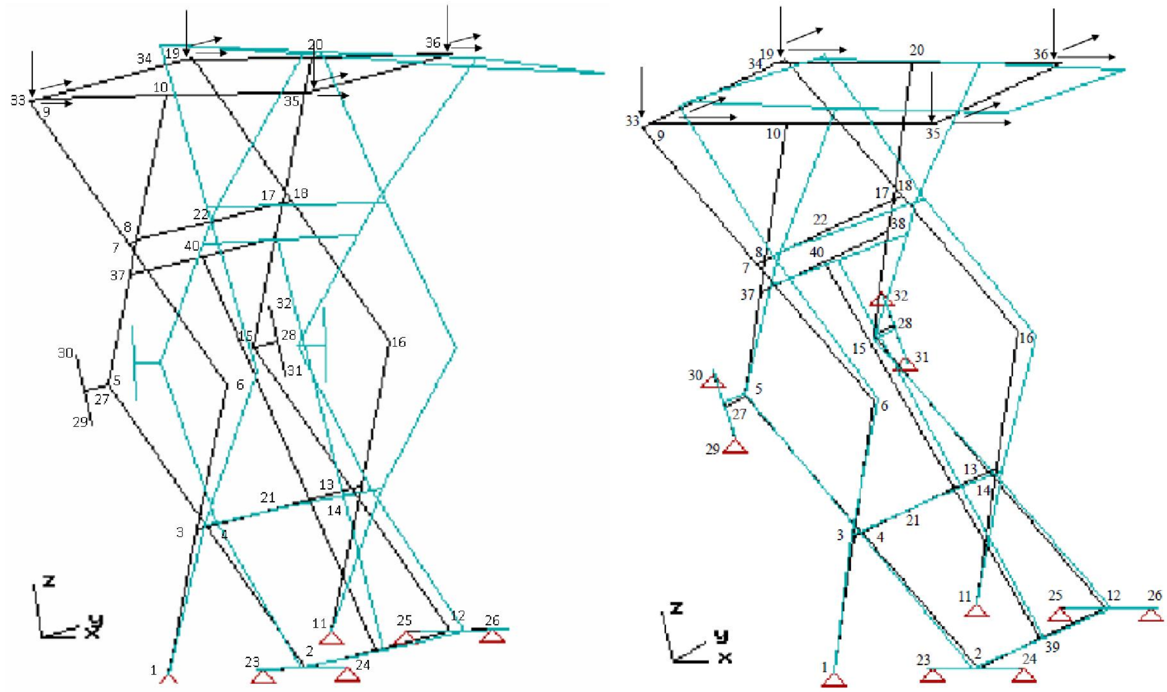

Figure 1 – The finite-element model of «Nuremberg scissors» and «ПМД-2.2». Green lines show the deformed state

Table 1 – Coordinates of the models

N – node number; (X, Y, Z) – coordinates of the node							
N	X	Y	Z	N	X	Y	Z
1	.00000e+00	-.40000e-01	.00000e+00	21	.29686e+00	.30000e+00	.55000e+00
2	.59372e+00	.00000e+00	.00000e+00	22	.29686e+00	.30000e+00	.16500e+01
3	.29686e+00	-.40000e-01	.55000e+00	23	.39372e+00	.00000e+00	.00000e+00
4	.29686e+00	.00000e+00	.55000e+00	24	.79372e+00	.00000e+00	.00000e+00
5	.00000e+00	.00000e+00	.11000e+01	25	.39372e+00	.60000e+00	.00000e+00
6	.59372e+00	-.40000e-01	.11000e+01	26	.79372e+00	.60000e+00	.00000e+00
7	.29686e+00	-.40000e-01	.16500e+01	27	.00000e+00	-.10000e+00	.11000e+01
8	.29686e+00	.00000e+00	.16500e+01	28	.00000e+00	.70000e+00	.11000e+01
9	.00000e+00	-.40000e-01	.22000e+01	29	.00000e+00	-.10000e+00	.96667e+00
10	.59372e+00	.00000e+00	.22000e+01	30	.00000e+00	-.10000e+00	.12333e+01
11	.00000e+00	.64000e+00	.00000e+00	31	.00000e+00	.70000e+00	.96667e+00
12	.59372e+00	.60000e+00	.00000e+00	32	.00000e+00	.70000e+00	.12333e+01
13	.29686e+00	.60000e+00	.55000e+00	33	.00000e+00	.00000e+00	.22000e+01
14	.29686e+00	.64000e+00	.55000e+00	34	.00000e+00	.60000e+00	.22000e+01
15	.00000e+00	.60000e+00	.11000e+01	35	.12500e+01	.00000e+00	.22000e+01
16	.59372e+00	.64000e+00	.11000e+01	36	.12500e+01	.60000e+00	.22000e+01
17	.29686e+00	.60000e+00	.16500e+01	37	.22561e+00	.00000e+00	.15180e+01
18	.29686e+00	.64000e+00	.16500e+01	38	.22561e+00	.60000e+00	.15180e+01
19	.00000e+00	.64000e+00	.22000e+01	39	.59372e+00	.30000e+00	.00000e+00
20	.59372e+00	.60000e+00	.22000e+01	40	.22561e+00	.30000e+00	.15180e+01

Table 2 – Consistency between RFE and FEM nodes

ENR - number of RFE; KNR1, KNR2 - starting and ending nodes RFE											
ENR	KNR1	KNR2	ENR	KNR1	KNR2	ENR	KNR1	KNR2	ENR	KNR1	KNR2
1	1	3	14	13	15	26	2	24	38	10	35
2	2	4	15	14	16	27	12	25	39	20	34
3	3	4	16	15	38	28	12	26	40	20	36
4	4	5	17	16	18	29	5	27	41	33	34
5	3	6	18	17	18	30	15	28	42	35	36
6	5	37	19	18	19	31	27	29	43	8	37
7	6	7	20	17	20	32	27	30	44	17	38
8	7	8	21	4	21	33	28	31	45	37	40
9	7	9	22	13	21	34	28	32	46	38	40
10	8	10	23	8	22	35	9	33	47	39	40
11	11	14	24	17	22	36	19	34	48	2	39
12	12	13	25	2	23	37	10	33	49	12	39
13	13	14									

Table 3 – Fastening border nodes in the directions of the axes
(different for of both FEM)

KNR - number fastened node, (VX, VY, VZ) and (DX, DY, DZ) - directions of linear and angular fastening													
KNR	VX	VY	VZ	DX	DY	DZ	KNR	VX	VY	VZ	DX	DY	DZ
1	1	2	3	4	5	6	Distinctive additions to the construction «ПМД-2.2»:						
11	1	2	3	4	5	6	29	1	2	--	4	5	6
23	--	2	3	4	5	6	30	1	2	--	4	5	6
24	--	2	3	4	5	6	31	1	2	--	4	5	6
25	--	2	3	4	5	6	32	1	2	--	4	5	6
26	--	2	3	4	5	6							

Table 4 – Accounting joints (same for both FEM)

ENR - RFE with a hinge; KNL - local node (1-initial,2-final) RFE; KZ - local degree of freedom																	
ENR	KNL	KZ	ENR	KNL	KZ	ENR	KNL	KZ	ENR	KNL	KZ	ENR	KNL	KZ	ENR	KNL	KZ
1	1	5	2	1	5	6	1	5	7	1	5	35	1	4	20	2	5
11	1	5	12	1	5	16	1	5	17	1	5	9	2	5	37	1	1
3	1	4	4	2	5	5	2	5	8	1	4	36	1	4	38	1	1
13	2	4	14	2	5	15	2	5	18	2	4	19	2	5	39	1	1
												10	2	5	40	1	1

Table 5 – Nodal loading (the same for both FEM)

NUMM - node number of loading; (X, Y, Z) - coordinates of the node							
NUMM	X	Y	Z	NUMM	X	Y	Z
33	.25e+03	.25e+03	-0.375e+03	35	.25e+03	.25e+03	-0.375e+03
34	.25e+03	.25e+03	-0.375e+03	36	.25e+03	.25e+03	-0.375e+03

3. Elastic displacement FEM nodes. So one finite element model corresponds falsework «ПМД-2.2», and the other – on the basis of scaffolding «NN», the widely used abroad. Rigidity was calculated using computer complexes «Лира» and «Inventor» [5,6]. We find the elastic displacement FEM nodes (Table 6, 7).

Table 6 – The elastic displacement nodes FEM «NN» (Fig. 1)

N - node number; (X, Y, Z) - directions of linear displacements							
N	X	Y	Z	N	X	Y	Z
1	0.0000E+00	0.0000E+00	0.0000E+00	21	6.4600E-05	2.3840E-04	-2.8052E-05
2	-1.0234E-04	1.7849E-06	-2.3637E-07	22	3.2241E-04	1.4912E-03	-5.2760E-05
3	-5.9553E-05	2.3843E-04	4.0525E-05	23	-1.0234E-04	0.0000E+00	0.0000E+00
4	-5.2743E-05	2.3845E-04	2.9854E-05	24	-1.0234E-04	0.0000E+00	0.0000E+00
5	3.1050E-04	8.5604E-04	2.3132E-04	25	3.4307E-04	0.0000E+00	0.0000E+00
6	-1.3055E-04	7.8744E-04	7.8712E-05	26	3.4307E-04	0.0000E+00	0.0000E+00
7	2.8027E-04	1.4911E-03	3.0043E-04	27	2.9320E-04	8.5604E-04	3.4050E-04
8	2.7255E-04	1.4911E-03	2.5638E-04	28	7.0005E-05	8.5560E-04	- 2.8329E-04
9	7.0906E-04	2.2394E-03	5.3205E-04	29	2.9320E-04	7.1048E-04	3.4050E-04
10	4.1190E-04	2.5215E-03	1.7988E-04	30	2.9320E-04	1.0016E-03	3.4050E-04
11	0.0000E+00	0.0000E+00	0.0000E+00	31	7.0005E-05	7.0547E-04	-2.8329E-04
12	3.4307E-04	1.8228E-06	- 2.6585E-06	32	7.0005E-05	1.0057E-03	-2.8329E-04
13	1.8459E-04	2.3834E-04	-9.3418E-05	33	6.9687E-04	2.2394E-03	4.7592E-04
			Table 5 continued				
14	1.9189E-04	2.3832E-04	-1.0620E-04	34	3.8460E-04	2.2395E-03	-3.6043E-04
15	4.2043E-05	8.5560E-04	-1.7069E-04	35	0.0000E+00	3.1708E-03	-2.7794E-04
16	5.6570E-04	7.7321E-04	-3.1045E-04	36	-3.6411E-04	3.1707E-03	-1.1211E-03
17	3.9519E-04	1.4913E-03	-3.6217E-04	37	2.5712E-04	1.3462E-03	2.6429E-04
18	3.9312E-04	1.4913E-03	-4.0622E-04	38	3.0751E-04	1.3460E-03	-3.1429E-04
19	3.7438E-04	2.2395E-03	-4.1700E-04	39	1.3962E-04	1.8322E-06	-1.6348E-05
20	8.7195E-04	2.5041E-03	-6.2232E-04	40	2.5703E-04	1.3461E-03	-4.5339E-06

Table 7 – The elastic displacement nodes KEM « ПМД-2.2» (Fig. 1)

N - node number; (X, Y, Z) - directions of linear displacements							
N	X	Y	Z	N	X	Y	Z
1	0.0000E+00	0.0000E+00	0.0000E+00	21	1.1540E-05	1.9593E-06	-6.1919E-06
2	-9.6255E-05	-8.9390E-07	1.1116E-07	22	1.0626E-04	3.0529E-04	-7.2099E-05
3	-5.6460E-05	2.0043E-06	3.0490E-05	23	-9.6255E-05	0.0000E+00	0.0000E+00
4	-5.4738E-05	1.9998E-06	2.7127E-05	24	-9.6255E-05	0.0000E+00	0.0000E+00
5	6.5962E-06	2.0944E-06	6.7645E-05	25	1.5765E-04	0.0000E+00	0.0000E+00
6	-3.2745E-05	1.3027E-04	1.6295E-05	26	1.5765E-04	0.0000E+00	0.0000E+00
7	6.0637E-05	3.0516E-04	6.5380E-05	27	4.1895E-07	1.8194E-06	7.3721E-05
8	5.4355E-05	3.0512E-04	4.7616E-05	28	-1.6055E-07	1.6200E-06	-9.7723E-05
9	2.5147E-04	6.9941E-04	1.6871E-04	29	0.0000E+00	0.0000E+00	7.3721E-05
10	2.3535E-04	9.0925E-04	-5.1497E-05	30	0.0000E+00	0.0000E+00	7.3721E-05
11	0.0000E+00	0.0000E+00	0.0000E+00	31	0.0000E+00	0.0000E+00	-9.7723E-05
12	1.5765E-04	-8.5157E-07	- 1.4423E-06	32	0.0000E+00	0.0000E+00	-9.7723E-05
13	8.3699E-05	1.9188E-06	-4.3201E-05	33	2.4721E-04	6.9941E-04	1.4495E-04
14	8.7135E-05	1.9234E-06	-4.7589E-05	34	1.5032E-04	6.9949E-04	-2.0004E-04
15	-3.6498E-06	1.8649E-06	-9.1293E-05	35	0.0000E+00	1.5132E-03	-4.0588E-04
16	2.7793E-04	1.1183E-04	-1.5186E-04	36	-3.2172E-04	1.5131E-03	-7.8247E-04
17	1.7726E-04	3.0546E-04	-1.9097E-04	37	2.7848E-05	2.3852E-04	6.1272E-05
18	1.7573E-04	3.0549E-04	-2.0844E-04	38	1.2199E-04	2.3826E-04	-1.6035E-04
19	1.4788E-04	6.9949E-04	-2.2430E-04	39	4.8067E-05	-8.8614E-07	-1.5366E-05
20	5.2330E-04	8.9390E-04	-3.8043E-04	40	5.3820E-05	2.3840E-04	-3.0277E-05

The most dangerous position when the operator's work at height - is its highest position of the working area. We find the linear the elastic displacements to the uppermost position of both structures. Consider the ratios of the corresponding elastic displacements nodes FEM «NN» and FEM nodes «ПМД-2.2» (Table 7).

As seen from Table 8, the rigidity of the construction "ПМД-2.2" as compared with the rigidity construction based on the «NN» increased on average by at least twice, and lateral rigidity (OY – axis displacement), and the addition of more. Thus, the introduction of an additional slider has markedly upgraded rigidity of the structure as a whole. Based on these studies the authors have designed and built an experimental model of construction falsework «ПМД-2.2» with a lifting height of the working area up to 4 meters (Figure 2).

Table 8 – Ratios of the corresponding elastic displacements nodes FEM «NN» and FEM nodes « ПМД-2.2»

N - node number; (X, Y, Z) - the ratio of linear displacements on directions							
N	X	Y	Z	N	X	Y	Z
1	.000	.000	.000 - stationary rack	21	5.598	121.676	4.530
2	1.063	-1.997	-2.126 - a minus sign indicates the reverse displacement on Y and Z	22	3.034	4.885	.732
				23	1.063	.000	.000 - displacement only by X
3	1.055	118.959	1.329	24	1.063	.000	.000 - displacement only by X
4	.964	119.237	1.101	25	2.176	.000	.000 - displacement only by X
5	47.073	408.728	3.420	26	2.176	.000	.000 - displacement only by X
6	3.987	6.045	4.830	27	699.845	470.507	4.619
7	4.622	4.886	4.595	28	-436.032	528.148	2.899
8	5.014	4.887	5.384	29	.000	.000	.000 - displacement only by Z
9	2.820	3.202	3.154	30	.000	.000	.000 - displacement only by Z
10	1.750	2.773	-3.493	31	.000	.000	.000 - displacement only by Z
11	.000	.000	.000 - stationary rack	32	.000	.000	.000.- displacement only by Z
12	2.176	-2.141	1.843	33	2.819	3.202	3.283
13	2.205	124.213	2.162	34	2.559	3.202	1.802
14	2.202	123.906	2.232	35	.000	.000	.000
15	-11.519	458.791	1.870	36	1.132	2.095	1.433
16	2.035	6.914	2.044	37	9.233	5.644	4.313
17	2.229	4.882	1.896	38	2.521	5.649	1.960
18	2.237	4.882	1.949	39	2.905	-2.068	1.064 - a minus sign indicates the reverse displacement on Y
19	2.532	3.202	1.859				
20	1.666	2.801	1.636	40	4.776	5.646	.150

Figure 2 – Experimental sample «ПМД-2.2». In the upper and transport positions

Conclusion. Calculations showed that the rigidity of the «ПМД-2.2» on average twice as much rigidity «NN», and lateral rigidity even more. Thus, the introduction of an additional slider has markedly upgraded rigidity of the structure as a whole.

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Резюме

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ҚҰРЫЛЫМДАРЫНЫҢ ҚАТАҢДЫҒЫ ЖАҚСАРТЫЛҒАН ТӨСЕНІШТЕР

Нюрнберг қайшылары негізіндегі сүлбелердің кинематикалық параметрлеріне сәйкестенген төсеніштер сүлбесі жасалған. Осы сүлбе базасында жасалған құрылма өзінің қатаңдық қасиеттері жөнінен нюрнберг қайшылары негізіндегі төсеніштерден асып түседі. Жұмысшы алаңшасы 4 метрге дейін көтерілетін ПМД-2,2 төсенішінің эксперименттік құрылымы жасалды. Нюрнберг қайшылары негізіндегі төсеніштер баламасы ПМД-2,2 төсенішінің құрылмасының салыстырмалы түрде қатаңдық талдауы және беріктік жағдайы берілген.

Автор ұсынылып отырған төсеніш құрылмасының артықшылығын көрсету үшін оның баламасы Нюрнберг қайшылары негізінде жасалған ПМД-2,2 төсеніш құрылмасының салыстырмалы түрде соңғы элементтер үлгісінің қатаңдық талдауын жасаған.

Тірек сөздер: төсеніштер, нюрнберг қайшылары, қатаңдық.

Резюме

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ПОДМОСТИ С УЛУЧШЕННОЙ ЖЕСТКОСТЬЮ КОНСТРУКЦИИ

Разработана схема подмостей, практически совпадающая по своим кинематическим параметрам со схемой подмостей на основе «нюрнбергских ножниц». Конструкции на базе этой схемы превосходят по своим жесткостным характеристикам аналогичные конструкции на базе «нюрнбергских ножниц». Создана экспериментальная конструкция таких подмостей – ПМД-2.2, с подъемом рабочей площадки до 4 метров. Дается сравнительный анализ жесткости и условий на устойчивость конструкций – ПМД-2.2 и аналога на базе «нюрнбергских ножниц».

За рубежом широко применяются шарнирно-рычажные подмости, имеющие в своей кинематической основе «нюрнбергские ножницы». Автором разработана кинематическая схема, которая по своим жесткостным характеристикам лучше кинематической схемы «нюрнбергские ножницы». Обладая всеми достоинствами «нюрнбергские ножницы», эта схема имеет повышенную «продольную» и «боковую» жесткость за счет введения дополнительной ползунной пары, расположенной на дополнительно введенной вертикальной направляющей стойке. На это инженерное решение подмостей автором получены несколько патентов Республики Казахстан на полезную модель и промышленный образец. Для показа преимущества разработанной автором схемы подмостей дается сравнительный жесткостной анализ конечно-элементных моделей конструкций подмостей ПМД-2.2 и их аналога на базе «НН».

Ключевые слова: подмости, нюрнбергские ножницы, жесткость.

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