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Casing Deflection and Bow-Spring Centralizer Spacing Calculations

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Abstract

In the present work, the experimental determinations for a bow-spring centralizer of $5^1/_2$ in and the obtained results regarding the API 10 D assessed conditions are presented. The obtained results were used for a calculus algorithm with the aim of establishing the optimal distance between the centralizers, in order to accomplish the API 10 D conditions.

Key words: *Bow-spring Centralizer, Casing Deflection*

The centralizers, which are important parts of the casing string, are subjected to many mechanical loads and, in the same time, they must provide a minimum clearance between the wall of the hole and the casing column. Generally, two types of centralizers are used: the elastic ones (“bow-spring design”, having welded or detachable springs) and the rigid ones (“rigid blade design”, having welded or body-milled blades) [4].

The bow-spring casing centralizers are placed along the whole cemented area, carefully paying attention to oil bearing beds, dangerous sticking zones and deflections. The purpose of their seating on the casing columns is to achieve a standoff with a value of less than 67% of the space between the casing and the borehole.

The centralizers’ utilization efficiency depends on the characteristics of the well, on the exact calculus of the seating distance and also on their mechanical characteristics, which are experimentally evaluated.

Because of their constructive shape and their arrangement mode along the casing column, it must be experimentally evaluated the needed force to introduce the centralizers in the borehole and, also, the elastic characteristics of the centralizers and their springs. The calculus of the centralizers` number and of the seating distance depends on those forces` values. In addition to this, these values depend on the physical and mechanical characteristics of the centralizers’ springs` materials and on the applied heat treatments.

Hence the need of the testing before the centralizers` delivery, on test stands, according to API 10 D [1], with the aim of verifying the correspondence with the assessed prescriptions and, also, with the purpose of giving the necessary data to realize all the needed calculus in order to establish, in a correct manner, the centralizers` number and the distance between them.

In the present work, the experimental determinations for a bow-spring centralizer of $5^1/_2$ *in* and the obtained results regarding the API 10 D assessed conditions are presented. The obtained results were used for a calculus algorithm with the aim of establishing the optimal distance between the centralizers, in order to accomplish the API 10 D conditions.

Casing Deflection and Centralizers` Spacing

In the case of inclined or curved boreholes, the casing columns having centralizers cannot maintain the axial placement because:

- the casing column strains because of its weight and the tangent tensile force/effective tension *T* (see fig.1);
- the bow-spring casing centralizers strain because of the normal force *N*/lateral load (compression) to which they are submitted (see fig. 1).

The distance (spacing) between two centralizers must be established so that, in every point from that area, the clearance between the wall of the hole and the casing column should not drop below the value given by (see also fig. 2):

$$0,67(D_s - D_e)/2 \tag{1}$$

The number of centralizers, which are installed along an area of the casing column, depends on: the diameter of the borehole D_s, the outside diameter of the casing D_b, the effective buoyed casing weight W_e, the effective tension *T*, the inclination angle θ, the density of fluid ρ_{fluid} and the mechanical characteristics of the centralizer.

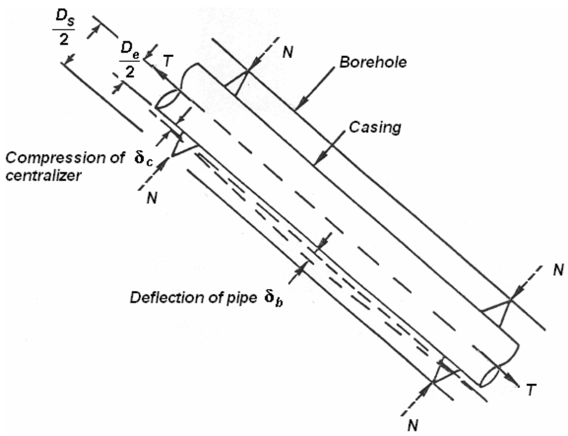

Fig. 1. The minimum distance between the casing and the borehole, assessed by API 10 D

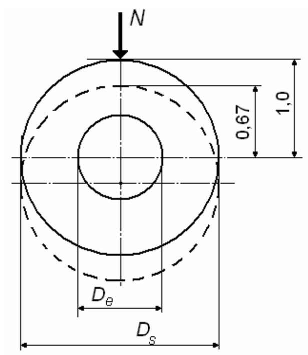

Fig.2. The strain of casing column and centralizers

Taking into account that the casing column can be modelled as a continuous beam lying through centralizers against the borehole's walls, we can calculate the static deflection δ_b of the casing with respect to the well's axis. The general case of a deviated well will be taken into account. At the middle of the spacing between centralizers, the static deflection of the casing is given by [1, 3] (see also fig. 1, 2 and 3):

$$\delta_b = \frac{NL^3}{384EI} \cdot \frac{24}{u^4}\left(\frac{u}{2} - \frac{u\,\mathrm{ch}u - u}{u}\right), \tag{2}$$

where:

$$u = \sqrt{\frac{TL^2}{4EI}}. \tag{3}$$

In (1), (2), (3), one notes: *N* – the lateral load, in *N; L* – the centralizers` spacing, in *m*; *E* – the modulus of elasticity, in N/m^2; *I* – the moment of inertia of the casing, in m^4; *T* – the effective tension below the centralizer, in *N*.

The lateral load *N* is given by the casing weight between two centralizers, W_eL, and in the curved zones also by the effective tension *T*. ($W_e = W\left(1 - \frac{\rho_{\text{fluid}}}{\rho_{\text{steel}}}\right)$ – *W* casing weight in air N/m).

In the general case, the lateral load N has two components: with a choice of a coordinate system, a component along the normal axis of the curve described by the well's axis on the given area, N_n, and a component along the binormal axis, N_b (see fig. 3).

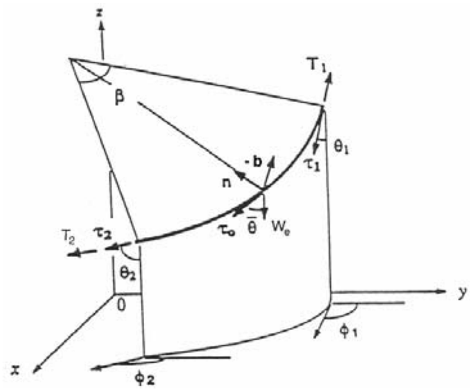

Fig. 3. Element of the casing column in the general case of a deviated well [1].

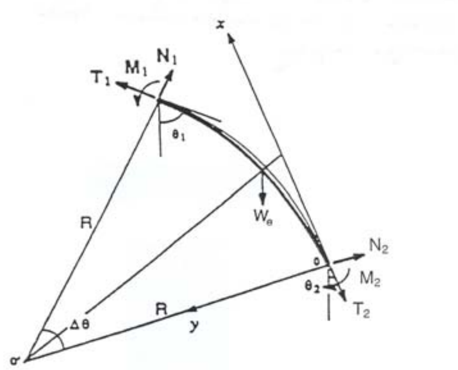

Fig. 4. Element of a casing column in the case of a vertical well[1].

They are given by [1, 3]:

$$N_n = W_e L \cos\gamma_n + 2T_2 \sin\frac{\beta}{2} \tag{4}$$

$$N_b = W_e L \cos\gamma_b \tag{5}$$

where:

$$\cos\gamma_n = \frac{\sin\bar{\theta}}{\sin\beta}\cos\left(\frac{\phi_1 - \phi_2}{2}\right)\sin(\theta_1 - \theta_2); \tag{6}$$

$$\cos\gamma_b = \frac{\sin\theta_1 \sin\theta_2 \sin(\phi_1 - \phi_2)}{\sin\beta}; \tag{7}$$

and

$$\bar{\theta} = \frac{\theta_1 + \theta_2}{2}.$$

Also: θ is the inclination angle, in degrees; ϕ – azimuth angle, in degrees; β – total angle change between centralizers, in degrees:

$$\cos\beta = \cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2 \cos(\phi_2 - \phi_1). \tag{8}$$

The total lateral load is:

$$N = \sqrt{N_n^2 + N_b^2}. \tag{9}$$

For the vertical well ($\phi_1 = \phi_2$), $N_b = 0$, and N_n is bigger when the well's inclination decreases (fig. 4).

The second component of the casing deflection, which occurs because of the centralizers` compression, can be determined if their strain-stress characteristic curve is known:

$$\delta_c = f(N). \tag{10}$$

The total displacement of the casing column with respect to the well's axis, at the half distance between two centralizers, is:

$$\Delta = \delta_b + \delta_c. \tag{11}$$

This displacement is considered to be acceptable if lower than the admitted value Δ_{max} [1]:

$$\Delta \le \Delta_{max} = \frac{1}{3}\frac{D_s - D_e}{2}. \tag{12}$$

For a casing column with a given outside diameter and unit mass, cemented into a well with a known diameter and characterized, from a spatial point of view, by deviation measurements, in order to establish the number of centralizers and the distance between them (spacing), an iterative calculus based on the previous formula is necessary.

We started by dividing the casing column in elements with a length l_b = 9 m and the calculus began with the inferior end of the column. Under the first centralizer we considered $T_2 = 0$. We adopted a distance L to the second centralizer and we calculated N_n, N_b, N and the deflection δ_b.

The compression δ_c of the centralizer as a function of N is determined and finally the deflection Δ of the considered segment is obtained. If the condition (13) is not accomplished, the length L is decreased and the calculus is repeated.

We calculated the tensile force T_1 which occurs at the first centralizer:

$$T_1 = T_2 + W_e L \cos\theta_1 , \qquad (13)$$

and then the calculus for the second transom could be made.

Usually, the length L is a multiple of l_b, a centralizer often being installed along each casing.

The Force-Deflection Curve of the Bow-Spring Centralizer

In order to determine the correct distance between two successive centralizers, in the case of casing column cementing the correlation between loads and spring's strain it is necessary to be known (11).

So, in order to be able to control the way that the centralizers correspond to the assessed requests, three types of forces must be defined [1, 3, 5]:

- F_p- the starting force, which represents the minimum tensile force, necessary to introduce the centralizer along the casing column;
- F_m- the running force, which represents the minimum force necessary to place the centralizer into the borehole;
- F_r- the restoring force, which represents the maximum force that occurs when the centralizer weighs on the borehole's walls, with the aim of maintaining the minimum accepted clearance.

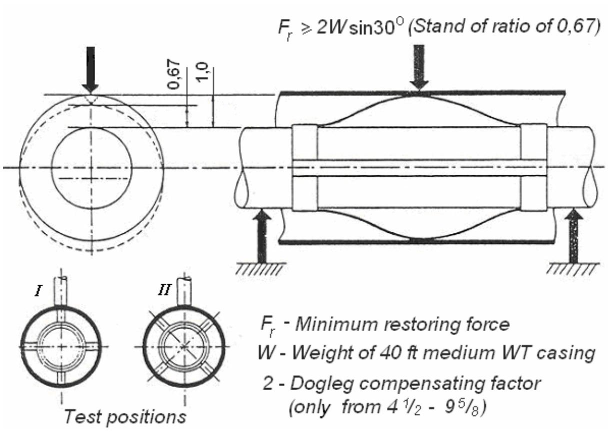

Fig. 5. The test stand's block for determining the restoring force

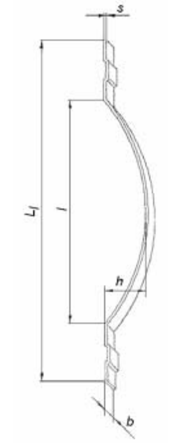

Fig. 6. Spring C38

The restoring force represents the force that the centralizer's springs need to realize in order to maintain the minimum clearance between the casing and the borehole's walls.

API established the minimum value for the restoring force that value which corresponds to a 67% misalignment of the casing column, in the following conditions:

- the mean weight of the casing column corresponding to 40 *ft* (12.2 *m*);
- a 30° inclination of the well;
- a dogleg compensating factor having the value equal to 2, in order to take into account the dogleg severity effects.

Before starting the test for determining the restoring force, each spring is pressed against a plan 12 times, in order to stabilize its shape, namely to keep constant the curvature radius.

In figure 5, the test stand's block for determining the restoring force of the centralizer is presented. At every increase of 1.6 *mm* of the deflection, the values of the force-deflection pairs are recorded and, also, the values of the F_r for which an eccentricity of 67% is obtained.

Generally, the centralizers' performances depend on their geometrical characteristics and on the mechanical characteristics of the steel from which they are made.

In order to determine the mechanical characteristics, we used, for the experimental study, 10 centralizers C142-139,7 ($5^1/_2$"), STAS 125424/1-87. The centralizers were equipped with C38 springs (see fig. 6).

For the C38 spring, according to [3], we have: $s = 5mm$; $l = 330\ mm$; $L_l = 530\ mm$; $b = 40\ mm$; $h = 38\ mm$.

One of the centralizers was disassembled and the four springs were used for experimental tests. The tests were made on the universal testing machine Z30. The springs were placed on a plane surface and the force was applied at the half distance of the dimension L_l (see fig. 6). The spring's deflection was measured with the help of a dial gauge having a 0,01 *mm* precision.

For all the four springs, the recordings are presented in table 1. For these values, the variation of δ_l as a function of N was determined, using interpolation:

$$\delta_l = 0.013943923N. \tag{14}$$

The manufacturer Weatherford proposed the following formula to calculate the spring's deflection:

$$N = \frac{2Ebs^3\delta'_l}{l^3} \tag{15}$$

from which, for the C38 spring, we obtained:

$$\delta'_l = 0.017112857N. \tag{16}$$

The two laws of variation are shown in figure 7.

Table 1. The spring's deflection

N, in [N]	Deflection δ_l, in [mm]			
	Spring 1	Spring 2	Spring 3	Spring 4
15.20031	0.31	0.23	0.26	0.27
196.133	2.9	3.3	3	2.9
392.266	7.8	5.8	5.4	6.2
588.399	10.5	8.62	8	8.85
784.532	13.7	11.8	10.4	10.95
980.665	16.1	14.3	12.8	12.85
1176.798	19.7	17.2	15	15.7
1372.931	22.3	20.5	17.45	18.2
1569.064	25.4	23.08	20.2	21.3
1765.197	28	26.1	22.8	24
1961.33	30.5	29.3	25.1	27

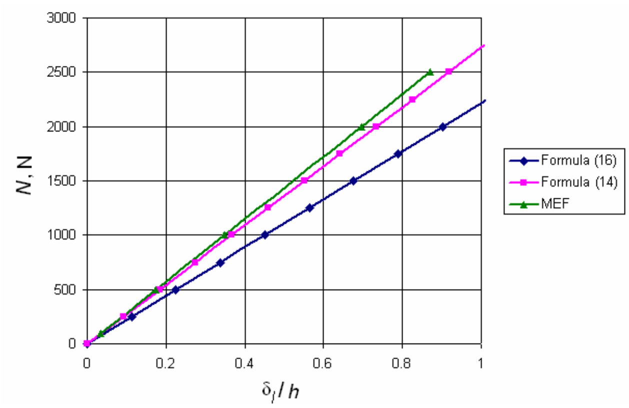

Fig. 7. Variation of ratio δ_l / h versus normal force N for the spring C38.

Because the centralizers manufacturer does not offer the variation $\delta_l /h = f(N)$, which is not assessed by [3], and because the springs are made of calibrated strip steel having no variation of the modulus of elasticity E, we used the FEM with the aim of drawing this variation.

Hence, the spring was modelled as a SHELL63 element type. To simulate the contact between spring and casing and between spring and the surface applying the load N, we used the "surface on surface" contact elements, the adopted value of the friction coefficient being 0,2 (see fig. 8). The meshed model was loaded with different values of the force N and the maximum deflection was recorded (fig. 9). Based on these values, the deflection's variation versus normal force graph was drawn, as it is shown in figure 7.

The Deflection Characteristics of the Bow-Spring Centralizer

The standards [1, 3] assess that the restoring force must be determined using special test stands whose blocks were presented in figure 5. In [3] it is specified that, for the bow-spring centralizers C and S, the restoring force's verification must be made for five centralizers from a lot of 50 having the same dimension. If, after verifications, one traces an inadequate centralizer, the entire lot's pieces are verified.

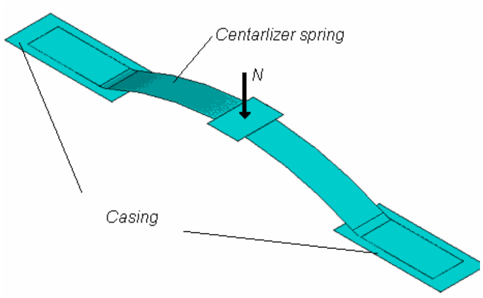

Fig. 8. The spring C38 model.

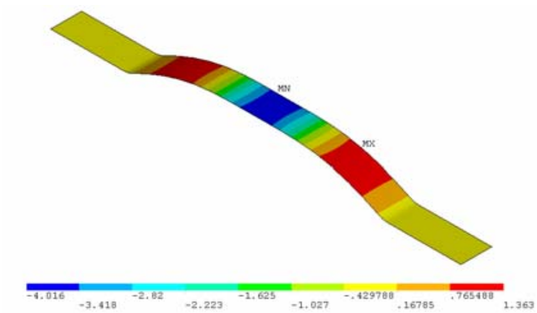

Fig. 9. Spring's deflection under the normal force $N = 250$ N.

In order to determine the restoring force, eight centralizers C142-139.7 ($5^1/_2$"), STAS 125424/1-87, were tested on the universal testing machine Z 100, as it is shown in figure 10. The spring's deflection was measured using a dial gauge (having a 0.01 *mm* precision).

The centralizers were placed on a casing with outside diameter D_e = 139.7 mm ($5^1/_2$") and were introduced in a casing with inner diameter D_s = 190.5 mm ($7^1/_2$"). After placing the centralizer on the casing of $5^1/_2$", we measured for each spring the initial deflection h. The obtained values are presented in table 2.

Every centralizer was tested both in positions I and II (fig. 4), for each spring and for each pair of springs, respectively. The mean values of the obtained deflections are presented in table 3.

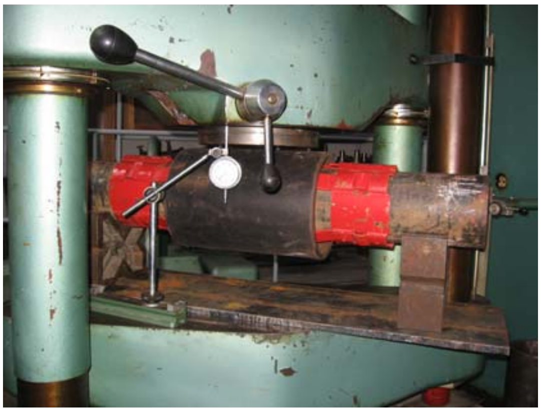

Fig. 10. Test stand for experimental determination of the variation $\delta_c = f(N)$

Table 2. The initial deflection of spring.

Centr.	*h*, in [mm]			
	Spring 1	Spring 2	Spring 3	Spring 4
1	34.8	36.8	35.8	33.3
2	35.9	34.1	36.3	34.9
3	37.3	34.3	33.3	34.8
4	35.8	37.8	33.8	35.3
5	34.3	35.3	34.9	36.1
6	35.3	33.8	31.3	30.8
7	29.3	39.3	37.3	29.3
8	34.3	36.3	33.3	34.3

Using these values, with the help of TableCurve program we determined the laws of variation of the deflection, as a function of force N:

- for case I:

$$\delta_{c1} = 0.05593122 + 0.00035275923 N^{1.1597185}, \quad (17)$$

- for case II:

$$\delta_{c2} = 0.0016444123 + 0.0019870864 N^{0.99076721}. \quad (18)$$

Using these laws of variation, we determined the restoring force for the analyzed centralizers ($5^1/_2$").

Table 3. The deflection of centralizer.

Force ***N***		Case I: δ_{c1}, in [mm]							
[kgf]	[N]	Centr.1	Centr. 2	Centr. 3	Centr. 4	Centr.5	Centr. 6	Centr. 7	Centr. 8
200	1961.33	0.45	1.3	1.1	0.5	1.65	0.85	3.2	2
400	3922.66	0.9	6.2	3.75	2.65	4.1	3.5	6.5	3.8
600	5883.99	4.4	12	6.6	7.4	8.5	8	10.4	6.6
800	7845.32	7.8	18.3	10.9	13	14	13.2	13	9.3
1000	9806.65	12.75	20.4	14.6	18	17	16.4	15.1	13.6
1200	11767.98	17.6	23.8	17	20.7	20.4	21.2	17	15.55
1400	13729.31	20.95	24.55	18.9	23.35	22.5	23.4	18.2	17.8
Force ***N***		Case II: δ_{c2}, in [mm]							
200	1961.33	2.7	3.4	2.6	3.2	2.5	1.2	4	4.4
400	3922.66	5.7	6.8	6	6.35	6.5	4.9	7	9
600	5883.99	10.5	12.3	9.7	10.5	10.3	8.3	11.2	12.2
800	7845.32	14.3	17.2	14.9	15	15.35	13	15.2	16.6
1000	9806.65	18.8	20.7	19	19.3	18.2	15.8	18.25	19.8
1200	11767.98	21.9	23.3	22.4	23.25	21.3	17.3	21	22.1
1400	13729.31	24	25.4	25.6	25.55	24.6	19.6	23.4	25

So, for the case I, we obtained F_{r1} = 5900 *N* and for the case II, F_{r2} = 4560 *N*, for a deflection calculated using (12), $\Delta_{\max}$ = 8.38 *mm*, whom the standoff is 17.02 *mm*. These values are bigger than the assessed value as it specified both in the Romanian standard and in the American one, where F_r = 2755 N.

A Case Study

To exemplify the calculus of the number of centralizers and of the distance between them, we used the experimental data from the 715 Cilioaia well. The last recorded data from this well are shown in table 4.

Table 4. The recorded data from 715 Cilioaia well.

Station no.	Depth, in [m]	Inclin. in [deg]	Azimuth, in [deg]	Station no.	Depth, in [m]	Inclin., in [deg]	Azimuth, in [deg]	Station no.	Depth, in [m]	Inclin., in [deg]	Azimuth, in [deg]
1	20	0.5	10	30	395	16.5	38	59	645	18	43
2	40	0.5	230	31	404	17.5	38	60	652	17.75	42
3	60	0.25	30	32	414	18.5	38	61	662	17.5	40
4	80	0.5	355	33	423	19	38	62	671	17.75	38
5	100	0.5	350	34	432	19.5	38	63	679	17.75	38
6	120	0.75	310	35	441	20.25	38	64	686	17.75	36
7	140	1	300	36	450	21	38	65	698	18	36
8	160	1.75	290	37	459	21.75	39	66	707	18.25	36
9	180	1	115	38	467	22.5	38	67	716	18.25	37
10	200	1	100	39	476	23.25	39	68	726	18.25	37
11	216	1.5	330	40	485	23.5	39	69	735	18.25	37
12	224	1.75	310	41	494	23.5	40	70	744	18.5	38
13	234	1.5	300	42	503	23.5	40	71	753	18.5	38
14	244	2	0	43	512	23.5	40	72	763	18.75	37
15	252	1.75	5	44	521	23.75	41	73	772	18.75	40
16	268	2.25	10	45	530	23.75	41	74	781	19	40
17	277	3.25	15	46	539	23.75	42	75	790	19	40
18	286	3.75	25	47	548	23.75	42	76	800	19	41
19	295	4.75	30	48	555	23.75	43	77	809	19	42
20	304	5.5	35	49	567	24	43	78	818	19	42
21	313	6.75	38	50	576	24.25	44	79	827	19.25	43
22	322	7.75	38	51	584	24.25	44	80	836	19	42
23	331	8.75	38	52	593	24.5	45	81	845	19.25	43
24	340	10	38	53	598	24	46	82	854	19.25	43
25	350	11	38	54	607	23	46	83	863	19.25	42
26	359	12	39	55	616	21	45	84	875	19.25	43
27	368	13	39	56	625	19	45	85	883	19.25	43
28	378	14.5	38	57	634	18.5	45	86	891	19.25	44
29	386	15.5	38	58	637	18.5	45	87	900	19.25	44

We considered that this well has the diameter D_s = 190.5 *mm* along all its depth and it is cased with casings having the outside diameter D_e = 139.7 *mm*, the unit weight W = 23.1 *kg/m* and the wall thickness s = 6.98 *mm*. The drilling fluid's density was considered to be ρ_f = 1250 kg/m^3. The characteristics of elasticity for the centralizers C142-139.7 ($5^1/_2$"), STAS 125424/1-87, are defined by (17) and (18). For the considered case, the maximum admitted deflection calculated with (12) is Δ_{max} = 8.38 *mm*. The results of calculations are shown in table 5.

Because only two intervals of 18 *m* length were showed up, the considered well will be cased using a centralizer for each casing, excepting the casing from the 612 depth, which will be cased using two centralizers.

As it can be seen, the maximum normal force N_{max} = 2226 *N* does not exceed the minimum value of the restoring force experimentally determined for this centralizer, F_{r2} = 4560 *N*.

The total value of the normal force is N_{tot} = 62602 *N*, so a total friction force, for a friction coefficient μ = 0.2, is: F_f = 0,2·62602 = 12520.4 N.

Table 5. The centralizer and casing deflections and centralizer spacing for 715 Cilioaia well.

Depth, in [m]	θ, in [deg]	ϕ, in [deg]	T_2, in [N]	T_1, in [N]	N, in [N]	δ_b, in [mm]	δ_{c1}, (17) in [mm]	δ_{c2}, (18) in [mm]	Δ_1, (17) in [mm]	Δ_2, (18) in [mm]	L, in [mm]
900	19,25	44									
891	19,25	44	0	1619	565	0,87	0,6	1,06	1,48	1,93	9
882	19,25	43	1619	3238	565	0,87	0,6	1,06	1,48	1,93	9
873	19,25	43	3238	4857	565	0,87	0,6	1,6	1,48	1,93	9
864	19,25	42	4857	6467	566	0,87	0,61	1,06	1,48	1,93	9
855	19,25	43	6467	8095	567	0,87	0,61	1,06	1,48	1,93	9
846	19,25	43	8095	9714	565	0,86	0,6	1,06	1,47	1,93	9
837	99	42	9714	11340	516	0,8	0,55	0,97	1,34	1,75	9
828	19,25	43	11340	12960	623	0,95	0,67	1,16	1,62	2,11	9
819	19	42	12960	14580	505	0,77	0,54	0,95	1,31	1,71	9
810	19	42	14580	16200	558	0,85	0,6	1,05	1,44	1,89	9
801	19	41	16200	17820	567	0,86	0,61	1,06	1,46	1,92	9
792	19	40	17820	19440	569	0,86	0,61	1,06	1,47	1,92	9
783	19	40	19440	20106	558	0,84	0,6	1,05	1,44	1,88	9
774	18,75	40	20106	21730	460	0,69	0,5	0,7	1,18	1,55	9
765	18,75	37	21730	23350	677	1,01	0,73	1,26	1,75	2,28	9
756	18,5	38	23350	24980	460	0,7	0,5	0,9	1,2	1,6	9
747	18,65	38	24980	26600	616	0,92	0,66	1,15	1,58	2,07	9
738	18,25	37	26600	28230	379	0,56	0,4	0,71	0,97	1,28	9
729	18,25	37	28230	29860	537	0,8	0,6	1	1,4	1,8	9
720	18,25	37	29860	31490	537	0,8	0,6	1	1,4	1,8	9
711	18,2	36,5	31490	33120	515	0,76	0,55	0,96	1,31	1,73	9
702	18,17	36	33120	34750	525	0,77	0,56	0,98	1,34	1,76	9
693	17,82	36	34750	36380	307	0,45	0,33	0,56	0,8	1,03	9
684	17,75	36	36380	38010	477	0,7	0,51	0,89	1,21	1,6	9
675	17,75	38	38010	39640	672	0,98	0,73	1,25	1,71	2,24	9
666	17,65	39	39640	41270	500	0,73	0,53	0,94	1,26	1,67	9
657	17,6	41	41270	42900	661	0,96	0,71	1,24	1,68	2,2	9
648	17,85	42,5	42900	45510	800	1,16	0,88	1,49	2,04	2,65	9
639	18,4	45	45510	47140	1175	1,7	1,34	2,19	3,04	3,9	9
630	18,75	45	47140	48760	844	1,22	0,93	1,57	2,15	2,8	9
621	**19,5**	**45**	**48760**	**50380**	**1221**	**1,76**	**1,4**	**2,27**	**3,16**	**4,03**	**4,5**
616,5	**20,75**	**45,25**	**50380**	**51180**	**1414**	**0,27**	**1,64**	**2,62**	**1,91**	**2,89**	**4,5**
612	22	45,5	51180	51970	1449	0,28	1,69	2,69	1,97	2,97	9
603	23,5	46	51970	53540	2073	2,98	2,53	3,84	5,51	6,81	9
594	24,5	45	53540	55100	1111	2,45	2,03	3,16	4,47	5,6	9
585	24,25	44	55100	56660	615	0,88	0,66	1,15	1,54	2,03	9
576	24,25	44	56660	58220	704	1	0,76	1,31	1,76	2,31	9
567	24	43	58220	59790	613	0,87	0,66	1,15	1,53	2,02	9
558	23,87	43	59790	61360	556	0,79	0,6	1,04	1,39	1,83	9
549	23,75	42	61360	62930	715	1,01	0,78	1,33	1,79	3,35	9
540	23,75	42	62930	64500	690	0,98	0,75	1,29	1,73	2,27	9
531	23,75	41	64500	66070	832	1,18	0,92	1,55	2,09	2,73	9
522	23,75	41	66070	67650	691	0,97	0,75	1,29	1,72	2,26	9

Table 5. The centralizer and casing deflections and centralizer spacing for 715 Cilioaia well.(cont.)

Depth, in [m]	θ, in [deg]	ϕ, in [deg]	T_2, in [N]	T_1, in [N]	N, in [N]	δ_b, in [mm]	δ_{c1}, (17) in [mm]	δ_{c2},(18) in [mm]	Δ_1, (17) in [mm]	Δ_2,(18) in [mm]	L, in [mm]
513	23,5	40	67650	69220	619	0,87	0,66	1,16	1,53	2,03	9
504	23,5	40	69220	70790	684	0,96	0,74	1,23	1,7	2,24	9
495	23,5	40	70790	72360	684	0,96	0,74	1,23	1,7	2,24	9
486	23,5	39	72360	73950	856	1,2	0,94	1,6	1,14	2,8	9
468	**22,5**	**38**	**73950**	**77120**	**526**	**4,47**	**0,56**	**0,98**	**5,03**	**5,45**	**18**
459	21,75	39	77120	78710	645	0,9	0,7	1,2	1,6	2,1	9
450	21	38	78710	80310	665	0,92	0,72	1,24	1,64	2,16	9
441	20,25	38	80310	81920	468	0,65	0,5	0,88	1,14	1,52	9
432	19,5	38	81920	85130	510	0,7	0,54	0,96	1,25	1,66	9
414	**18,5**	**38**	**85130**	**88380**	**426**	**3,46**	**0,45**	**0,8**	**3,92**	**4,26**	**18**
405	17,5	38	88380	90020	1041	1,42	1,17	1,94	2,59	3,36	9
396	16,5	38	90020	91660	1098	1,5	1,24	2,04	2,74	3,54	9
387	15,5	38	91660	93310	1156	1,57	1,31	2,15	2,89	3,72	9
378	14,5	38	93310	94970	1214	1,65	1,39	2,26	3,04	3,91	9
369	13	39	94970	96640	2160	2,93	2,65	4	5,58	6,93	9
360	12	39	96640	98320	1345	1,82	1,56	2,5	3,37	4,32	9
351	11	38	98320	100000	1446	1,95	1,69	2,68	3,64	6,64	9
342	10	38	100000	101700	1462	1,97	1,71	2,71	3,68	6,68	9
333	8,75	38	101700	103400	1976	2,66	2,4	3,66	5,06	6,32	9
324	7,75	38	103400	105100	1588	2,13	1,87	2,95	4	5,08	9
315	6,75	38	105100	106800	1648	2,2	1,95	3,06	4,16	5,26	9
306	5,5	35	106800	108500	2266	3,03	2,8	4,19	5,83	7,22	9
297	4,75	30	108500	110200	1548	2,06	1,82	2,87	3,88	4,94	9
288	3,75	25	110200	111900	1962	2,61	2,38	3,63	4,99	6,24	9
279	3,25	15	111900	113600	1497	1,97	1,75	2,78	3,74	4,76	9
270	2,25	10	113600	115300	1988	2,63	2,41	368	5,05	6,31	9
261	2,12	7,5	115300	117000	279	0,37	0,3	0,52	0,67	0,89	9
252	1,75	5	117000	118700	730	0,96	0,79	1,36	1,76	2,32	9

The value of the friction force is smaller than the casing column's buoyed weight (in drilling fluid), G = 171500 N, meaning that, for the considered well, the casings move down under their weight force's influence.

Conclusions

The bow-spring casing centralizers` efficiency depend: on the well's characteristics, on the precision of the calculus for the distance between them and, also, on their mechanical characteristics which can be experimentally evaluated.

The experimental tests, realized on the $5^1/_2$" Romanian centralizers, pointed out the following aspects:

- the centralizers` springs had not the geometrical characteristics assessed by [3];
- for the same load, the spring's deflection calculated with FEM and the experimentally determined one are smaller than the deflection calculated with the formula proposed by Weatherford International Ltd.;
- the values of the spring's deflection calculated with FEM and those experimentally determined are comparable, so the using of FEM is adequate, in order to determine this mechanical characteristic;
- the Romanian centralizers` springs are more rigid than the Weatherford centralizers` ones;
- the centralizers have a different response under the action of the normal force N, having a bigger stiffness when the force is applied to one spring;
- the studied centralizers accomplish the [1] and [3] assessments, because the restoring force is bigger than the specified one in both testing cases.

The obtained results permitted the definition of the function $\delta_c = f(N)$, used for a calculus algorithm with the aim of establishing the optimal distance between the centralizers, in order to accomplish the requirements imposed by [1], meaning a minimum clearance between the casing column and the walls of the borehole.

The methodology and the calculus program were used for many well profiles and many casing programs, in the present work a single example being presented.

After the analysis, the following conclusions can be presented:

- for the same length of the casing's segment we conclude that, together with the well's inclination increasing, the casing's deflection increase, and also the normal force applied to the centralizer. The same result is obtained in the case of the azimuth's increasing.
- one observe that the inclination's decreasing together with the azimuth's increasing, for the same length of the casing's segment, have the same effect as in the case of inclination's increasing. It means that, when the difference $\theta_2 - \theta_1$ increases, the casing's deflection δ_b and the force N_b increase. In the same time, these values increase together with the increasing of the difference $\phi_1 - \phi_2$.
- the azimuth's increasing or decreasing does not modify the values of δ_b and N_b.
- the influence of the drilling fluid's density on the casing's deflection and on the normal force is not significant for the same well and for the same casing program.
- the total normal force N_{tot}, and accordingly the total friction force F_f, does not depend on the number of centralizers.
- the number of centralizers and the distance between them depend, in the main, on the well's profile and, to a small extent, on the geometrical characteristics of the well, casing and centralizers.

Finally, it results the necessity of the tests made by manufacturers and the placing of the mechanical characteristics at the users` disposal, especially the force-deflection curve, so that the calculus of the number of centralizers and the distance between them can be correctly made.

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Calculul deformării burlanelor de cimentare şi a distanţei dintre centrori

Rezumat

În lucrare sunt prezentate determinările experimentale efectuate şi rezultatele obţinute privind condiţiile impuse de API 10 D pentru un centror de $5^1/_2$ inprodus de UZTEL Ploieşti. Rezultatele obţinute au fost folosite în cadrul unui algoritm de calcul pentru stabilirea distanţei dintre centrori astfel încât să se respecte condiţiile impuse de API 10 D.