AN EMPIRICAL CORRELATION TO ESTIMATE SOLID STRESSES FOR DIFFERENTIALLY STUCK PIPES

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ABSTRACT

A new correlation to calculate the solid stresses at the contact face between the pipe and the mud cake, for the case of differential pipe sticking (DPS), is developed.

The proposed correlation takes into consideration the effect of setting (contact) time, thickness of mud cake, and viscosity of mud filtrate on the behavior of the solid stresses.

A good match is obtained between the present correlation,the measured values, and terzaghi trend for calculating the resulted solid stresses. This in turn leads to estimate the minimum force required to free the stuck pipe.

الخلاصة

تم تطوير علاقة تجريبية جديدة لحساب الاجهادات الصلبة عند منطقة التماس بين كيك الطين وأنبوب الحفر لحالة الأنابيب المستعصية تفاضلياً. هذه العلاقة المقترحة تأخذ بنظر الاعتبار تأثير زمن التماس (الاستقرار)، سمك كيك الطين، ولزوجة راشح الطين على سلوك الاجهادات الصلبة. كما تم الحصول على تطابق جيد بين العلاقة الحالية وقيم الإجهاد المقاس وقيم طريقة Terzaghi لحساب الاجهادات الصلبة الناتجة. إن هذا بدوره يقود إلى تقدير القوة اللازمة لتحرير أنبوب الحفر الذي تعرض للاستعصاء.

KEY WORDS:
Differential pipe sticking, wall stacking, solid stresses, sticking force,pulling force.

INTRODUCTION

Pipe sticking is one of the most common and serious problems in drilling different wellbores.

Differential pipe sticking (DPS) or wall sticking is defined as: stuck pipe caused by differential pressure force from an overbalanced mud column acting on the drill string against a filter cake deposited on a permeable formation (Adams 1977) (Rabia 1985). Excessive differential pressures across lower-pressure permeable zones can cause the drill string to be pushed into the wellbore wall where it becomes stuck. It usualy occurs while the pipe is stationary and is indicated by full circulation and no up/down rotary freedom (Haden and welch 1961) (Hempkins 1987).

BASIC EQUATIONS

The sticking force

One of the basic relations for calculating the sticking force can be expressed by the following equation (chilingarian and Vorabuter 1981) (Hadduch et al. 1994):

$$F_S = \Delta p \times A_C \times S_C \qquad (1)$$

Where:

F_s = sticking force or the minimum pulling force required to free the pipe, lb

Δp= differential pressure, psi

A_c= area of contact between the pipe and the filter cake,in^2

S_c= sticking (friction) coefficient between the pipe and the filter cake, dimensionless.

The differntial pressure (Δp) is expressed by :

$$\Delta p = P_h - P_f \qquad (2)$$

Where:

P_h = hydrostatic pressure of mud column, psi

P_f = formation pressure, psi.

The differential pressure is imposed by the magnitude of the hydrostatic pressure because formation pore pressure is at fixed levels. Thus one method to minimize this effect is to drill with minimum mud weights (Moore 1974). The potential effect of the filter cake on the contact area is shown in **Fig. (1).**

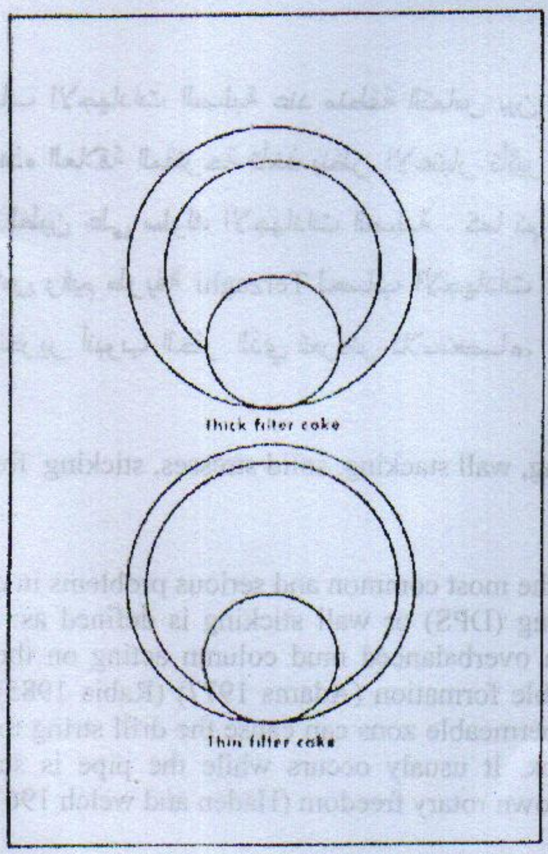

Fig.1 Effect of filter cake thickness on contact area .

It is noted that the area of contact may be more than doubled by a thickening of the filter cake. Thus one of the primary concern to the operator is the filter-cake thickness (Hanna 1998).

The sticking coefficient is a measure of how strongly the pipe becomes stuck in the presence of given mud system. Sticking coefficient is not constant but it is time dependent and also dependent on the thickness and composition of the filter cake (Courtlier and Zurdo 1985).

Terzaghi Trend

Another trend for calculating the sticking force is through the calculation of the solid stresses at the face of the mud cake. The solid stress calculation may be treated as one-dimensional problem in view of the relative thinness of mud cake and relatively high permeability of the formation (Terzaghi 1957).

It was concluded that :

While:

For the second period, the solid stress may be approximated by:

$$s(h,T)/\Delta P=\left\{1-\frac{1}{2}\exp-\left[\left(\left(\frac{12T}{\sqrt{\pi}}-\frac{1}{2}\right)\right)\right]\right\} \qquad \textbf{(4)}$$

$$\text{For } \frac{\pi^2}{24}\le T\le\infty\text{...........}(2nd.period)$$

$$\text{In which } T=\frac{\pi^2 kt}{4\mu\beta h^2} \qquad \textbf{(5)}$$

Where: S (h,T) /Δ p = dimensionless solid stress, dimensionless

k = permeability of mud cake, (cm^4/gm – sec) cp.

t = set time , sec

μ = viscosity of filtrate, cp

β = coefficient of consolidation, cm^2/gm

h = filter cake thickness, cm

The ratio k/β in eq. 5 is considered to be fairly constant and equals to 10^{-5} (cm^2 .cp/sec).

THE PROPOSED CORRELATION

As seen in eq.1, it is necessary to measure the value of sticking coefficient (Sc). Sticking coefficient is time dependent and it is difficult, most of the times, to measure the value of Sc.

Terzaghi equations require the delineation of the sticking period, whether it is first or second period. It also requires the determination of the parameter T, for which, the value of k/β is considered to be constant.

The proposed correlation presents a direct relation between the solid stress and the set time, mud cake thickness, and the viscosity of the mud filtrate (which reflects the type of the mud).

Based on 387 data points representing measured values of (S/Δ p) (table1), a multivariable regression technique is used to develop the following correlation:

$$(S/\Delta P)=A\times Set^{B}\times\mu^{A1}/(h+C)^{D} \qquad \textbf{(6)}$$

Where :

(s/Δ p) = dimensionless solid stress, dimensionless

Set = contact (setting) time, sec

μ = viscosity of mud filtrate, cp

h = mud cake thickness, cm

The regression coefficients are:-

A= 0.161906686 A1= -0.40228998 B=0.400184

C= 0.950534 D=1.7467058

Table (1) The measured solid stress values

	SET	μ	h	s/Δ p		SET	μ	h	s/Δ p
1	5.000	0.500	1.00	0.095	41	90.000	0.500	0.100	1.000
2	10.000	0.500	1.00	0.134	42	100.050	0.500	0.100	1.000
3	15.000	0.500	1.00	0.164	43	120.005	0.500	0.100	1.000
4	20.000	0.500	1.00	0.190	44	150.000	0.500	0.100	1.000
5	30.000	0.500	1.00	0.232	45	180.000	0.500	0.100	1.000
6	45.000	0.500	1.00	0.285	46	210.000	0.500	0.100	1.000
7	60.000	0.500	1.00	0.329	47	240.000	0.500	0.100	1.000
8	75.000	0.500	1.00	0.367	48	300.000	0.500	0.100	1.000
9	90.000	0.500	1.00	0.402	49	5.000	0.500	0.300	0.316
10	100.050	0.500	1.00	0.424	50	10.000	0.500	0.300	0.447
11	120.005	0.500	1.00	0.465	51	15.000	0.500	0.300	0.547
12	150.000	0.500	1.00	0.520	52	20.000	0.500	0.300	0.629
13	180.000	0.500	1.00	0.569	53	30.000	0.500	0.300	0.752
14	210.000	0.500	1.00	0.613	54	45.000	0.500	0.300	0.864
15	240.000	0.500	1.00	0.652	55	60.000	0.500	0.300	0.925
16	300.000	0.500	1.00	0.720	56	75.000	0.500	0.300	0.959
17	5.000	0.500	1.00	0.063	57	90.000	0.500	0.300	0.977
18	10.000	0.500	1.00	0.089	58	100.050	0.500	0.300	0.985
19	15.000	0.500	1.00	0.110	59	120.006	0.500	0.300	0.993
20	20.000	0.500	1.00	0.126	60	150.000	0.500	0.300	0.998
21	30.000	0.500	1.00	0.155	61	180.000	0.500	0.300	0.999
22	45.000	0.500	1.00	0.190	62	210.000	0.500	0.300	1.000
23	60.000	0.500	1.00	0.219	63	240.000	0.500	0.300	1.000
24	75.000	0.500	1.00	0.245	64	300.000	0.500	0.300	1.000
25	90.000	0.500	1.00	0.268	65	5.000	0.400	2.000	0.053
26	100.050	0.500	1.00	0.283	66	10.000	0.400	2.000	0.075
27	120.005	0.500	1.00	0.310	67	15.000	0.400	2.000	0.092
28	150.000	0.500	1.00	0.346	68	20.000	0.400	2.000	0.106
29	180.000	0.500	1.00	0.379	69	30.000	0.400	2.000	0.130
30	210.000	0.500	1.00	0.410	70	45.000	0.400	2.000	0.159
31	240.000	0.500	1.00	0.438	71	60.000	0.400	2.000	0.184
32	300.000	0.500	1.00	0.490	72	75.000	0.400	2.000	0.205
33	5.000	0.500	1.00	0.864	73	90.000	0.400	2.000	0.225
34	10.000	0.500	1.00	0.977	74	100.050	0.400	2.000	0.237
35	15.000	0.500	1.00	0.996	75	120.005	0.400	2.000	0.260
36	20.000	0.500	1.00	0.999	76	150.000	0.400	2.000	0.290
37	30.000	0.500	1.00	1.000	77	180.000	0.400	2.000	0.318
38	45.000	0.500	1.00	1.000	78	210.000	0.400	2.000	0.344
39	60.000	0.500	1.00	1.000	79	240.000	0.400	2.000	0.367
40	75.000	0.500	1.00	1.000	80	300.000	0.400	2.000	0.411

	SET	μ	h	s/Δ p		SET	μ	h	s/Δ p
81	5.000	0.400	2.500	0.042	121	120.004	0.400	1.500	0.346
82	10.000	0.400	2.500	0.060	122	150.000	0.400	1.500	0.387
83	15.000	0.400	2.500	0.073	123	180.000	0.400	1.500	0.424
84	20.000	0.400	2.500	0.085	124	210.000	0.400	1.500	0.458
85	30.000	0.400	2.500	0.104	125	240.000	0.400	1.500	0.490
86	45.000	0.400	2.500	0.127	126	300.000	0.400	1.500	0.547
87	60.000	0.400	2.500	0.147	127	5.000	0.400	0.500	0.212
88	75.000	0.400	2.500	0.164	128	10.000	0.400	0.500	0.300
89	90.000	0.400	2.500	0.180	129	20.000	0.400	0.500	0.424
90	100.050	0.400	2.500	0.190	130	30.000	0.400	0.500	0.520
91	120.001	0.400	2.500	0.208	131	45.000	0.400	0.500	0.633
92	150.000	0.400	2.500	0.232	132	60.000	0.400	0.500	0.720
93	180.000	0.400	2.500	0.255	133	75.000	0.400	0.500	0.786
94	210.000	0.400	2.500	0.275	134	90.000	0.400	0.500	0.837
95	240.000	0.400	2.500	0.294	135	100.050	0.400	0.500	0.864
96	300.000	0.400	2.500	0.329	136	120.002	0.400	0.500	0.905
97	5.000	0.400	1.000	0.106	137	150.000	0.400	0.500	0.945
98	10.000	0.400	1.000	0.150	138	180.000	0.400	0.500	0.968
99	20.000	0.400	1.000	0.212	139	210.000	0.400	0.500	0.981
100	30.000	0.400	1.000	0.260	140	240.000	0.400	0.500	0.989
101	45.000	0.400	1.000	0.318	141	300.000	0.400	0.500	0.996
102	60.000	0.400	1.000	0.367	142	5.000	0.400	0.750	0.141
103	75.000	0.400	1.000	0.411	143	10.000	0.400	0.750	0.200
104	90.000	0.400	1.000	0.450	144	20.000	0.400	0.750	0.283
105	100.050	0.400	1.000	0.474	145	30.000	0.400	0.750	0.346
106	120.003	0.400	1.000	0.520	146	45.000	0.400	0.750	0.424
107	150.000	0.400	1.000	0.580	147	60.000	0.400	0.750	0.490
108	180.000	0.400	1.000	0.633	148	75.000	0.400	0.750	0.547
109	210.000	0.400	1.000	0.679	149	90.000	0.400	0.750	0.599
110	240.000	0.400	1.000	0.720	150	100.050	0.400	0.750	0.629
111	300.000	0.400	1.000	0.870	151	120.007	0.400	0.750	0.684
112	5.000	0.400	1.500	0.071	152	150.000	0.400	0.750	0.752
113	10.000	0.400	1.500	0.100	153	180.000	0.400	0.750	0.805
114	20.000	0.400	1.500	0.141	154	210.000	0.400	0.750	0.846
115	30.000	0.400	1.500	0.173	155	240.000	0.400	0.750	0.879
116	45.000	0.400	1.500	0.212	156	300.000	0.400	0.750	0.925
117	60.000	0.400	1.500	0.245	157	5.000	0.400	0.100	0.913
118	75.000	0.400	1.500	0.274	158	10.000	0.400	0.100	0.991
119	90.000	0.400	1.500	0.300	159	20.000	0.400	0.100	1.000
120	100.050	0.400	1.500	0.316	160	30.000	0.400	0.100	1.000

	SET	μ	h	s/Δ p		SET	μ	h	s/Δ p
161	45.000	0.400	0.100	1.000	201	300.000	0.500	0.500	0.989
162	60.000	0.400	0.100	1.000	202	5.000	0.500	0.500	0.190
163	75.000	0.400	0.100	1.000	203	10.000	0.500	0.500	0.268
164	90.000	0.400	0.100	1.000	204	20.000	0.500	0.500	0.379
165	100.050	0.400	0.100	1.000	205	30.000	0.500	0.500	0.465
166	120.006	0.400	0.100	1.000	206	45.000	0.500	0.500	0.569
167	150.000	0.400	0.100	1.000	207	60.000	0.500	0.500	0.652
168	180.000	0.400	0.100	1.000	208	75.000	0.500	0.500	0.720
169	210.000	0.400	0.100	1.000	209	90.000	0.500	0.500	0.774
170	240.000	0.400	0.100	1.000	210	100.050	0.500	0.500	0.805
171	300.000	0.400	0.100	1.000	211	120.020	0.500	0.500	0.853
172	5.000	0.400	0.300	0.353	212	150.000	0.500	0.500	0.905
173	10.000	0.400	0.300	0.500	213	180.000	0.500	0.500	0.938
174	20.000	0.400	0.300	0.697	214	210.000	0.500	0.500	0.960
175	30.000	0.400	0.300	0.816	215	240.000	0.500	0.500	0.974
176	45.000	0.400	0.300	0.913	216	300.000	0.500	0.500	0.989
177	60.000	0.400	0.300	0.959	217	5.000	0.500	0.750	0.126
178	75.000	0.400	0.300	0.981	218	10.000	0.500	0.750	0.179
179	90.000	0.400	0.300	0.991	219	20.000	0.500	0.750	0.253
180	100.050	0.400	0.300	0.994	220	30.000	0.500	0.750	0.310
181	120.020	0.400	0.300	0.998	221	45.000	0.500	0.750	0.379
182	150.000	0.400	0.300	1.000	222	60.000	0.500	0.750	0.438
183	180.000	0.400	0.300	1.000	223	75.000	0.500	0.750	0.490
184	210.000	0.400	0.300	1.000	224	90.000	0.500	0.750	0.537
185	240.000	0.400	0.300	1.000	225	100.050	0.500	0.750	0.565
186	300.000	0.400	0.300	1.000	226	120.000	0.500	0.750	0.617
187	5.000	0.500	0.500	0.190	227	150.000	0.500	0.750	0.684
188	10.000	0.500	0.500	0.268	228	180.000	0.500	0.750	0.739
189	20.000	0.500	0.500	0.379	229	210.000	0.500	0.750	0.785
190	30.000	0.500	0.500	0.465	230	240.000	0.500	0.750	0.822
191	45.000	0.500	0.500	0.569	231	300.000	0.500	0.750	0.879
192	60.000	0.500	0.500	0.652	232	5.000	0.600	2.000	0.043
193	75.000	0.500	0.500	0.720	233	10.000	0.600	2.000	0.061
194	90.000	0.500	0.500	0.774	234	20.000	0.600	2.000	0.087
195	100.050	0.500	0.500	0.805	235	30.000	0.600	2.000	0.106
196	120.200	0.500	0.500	0.853	236	45.000	0.600	2.000	0.130
197	150.000	0.500	0.500	0.905	237	60.000	0.600	2.000	0.150
198	180.000	0.500	0.500	0.938	238	75.000	0.600	2.000	0.168
199	210.000	0.500	0.500	0.960	239	90.000	0.600	2.000	0.184
200	240.000	0.500	0.500	0.974	240	100.030	0.600	2.000	0.194

	SET	μ	h	s/Δ p		SET	μ	h	s/Δ p
241	120.003	0.600	2.000	0.212	280	30.000	0.600	0.300	0.697
242	150.000	0.600	2.000	0.237	281	45.000	0.600	0.300	0.816
243	180.000	0.600	2.000	0.260	282	60.000	0.600	0.300	0.881
244	210.000	0.600	2.000	0.281	283	75.000	0.600	0.300	0.932
245	240.000	0.600	2.000	0.300	284	90.000	0.600	0.300	0.959
246	300.000	0.600	2.000	0.335	285	100.003	0.600	0.300	0.971
247	5.000	0.600	2.500	0.035	286	120.006	0.600	0.300	0.985
248	10.000	0.600	2.500	0.049	287	150.000	0.600	0.300	0.994
249	20.000	0.600	2.500	0.069	288	180.000	0.600	0.300	0.998
250	30.000	0.600	2.500	0.085	289	210.000	0.600	0.300	0.999
251	45.000	0.600	2.500	0.104	290	240.000	0.600	0.300	1.000
252	60.000	0.600	2.500	0.120	291	300.000	0.600	0.300	1.000
253	75.000	0.600	2.500	0.134	292	5.000	0.600	0.500	0.173
254	90.000	0.600	2.500	0.147	293	10.000	0.600	0.500	0.245
255	100.050	0.600	2.500	0.155	294	15.000	0.600	0.500	0.300
256	120.020	0.600	2.500	0.170	295	20.000	0.600	0.500	0.346
257	150.000	0.600	2.500	0.190	296	30.000	0.600	0.500	0.424
258	180.000	0.600	2.500	0.208	297	45.000	0.600	0.500	0.520
259	210.000	0.600	2.500	0.224	298	60.000	0.600	0.500	0.599
260	240.000	0.600	2.500	0.240	299	75.000	0.600	0.500	0.665
261	300.000	0.600	2.500	0.268	300	90.000	0.600	0.500	0.720
262	5.000	0.600	0.100	0.816	301	100.002	0.600	0.500	0.752
263	10.000	0.600	0.100	0.959	302	120.003	0.600	0.500	0.805
264	20.000	0.600	0.100	0.998	303	150.000	0.600	0.500	0.864
265	30.000	0.600	0.100	1.000	304	180.000	0.600	0.500	0.905
266	45.000	0.600	0.100	1.000	305	210.000	0.600	0.500	0.934
267	60.000	0.600	0.100	1.100	306	240.000	0.600	0.500	0.954
268	75.000	0.600	0.100	1.000	307	300.000	0.600	0.500	0.977
269	90.000	0.600	0.100	1.000	308	5.000	0.600	0.750	0.115
270	100.050	0.600	0.100	1.100	309	10.000	0.600	0.750	0.163
271	120.005	0.600	0.100	1.000	310	15.000	0.600	0.750	0.200
272	150.000	0.600	0.100	1.000	311	20.000	0.600	0.750	0.231
273	180.000	0.600	0.100	1.100	312	30.000	0.600	0.750	0.283
274	210.000	0.600	0.100	1.000	313	45.000	0.600	0.750	0.346
275	240.000	0.600	0.100	1.000	314	60.000	0.600	0.750	0.400
276	300.000	0.600	0.100	1.100	315	75.000	0.600	0.750	0.447
277	5.000	0.600	0.300	0.289	316	90.000	0.600	0.750	0.490
278	10.000	0.600	0.300	0.408	317	100.003	0.600	0.750	0.515
279	20.000	0.600	0.300	0.577	318	120.050	0.600	0.750	0.565

	SET	μ	h	s/Δ p		SET	μ	h	s/Δ p
319	150.000	0.600	0.750	0.629	354	240.000	0.600	1.500	0.400
320	180.000	0.600	0.750	0.684	355	300.000	0.600	1.500	0.447
321	210.000	0.600	0.750	0.731	356	5.000	0.500	2.000	0.047
322	240.000	0.600	0.750	0.771	357	10.000	0.500	2.000	0.067
323	300.000	0.600	1.000	0.833	358	15.000	0.500	2.000	0.082
324	5.000	0.600	1.000	0.087	359	20.000	0.500	2.000	0.095
325	10.000	0.600	1.000	0.122	360	30.000	0.500	2.000	0.116
326	15.000	0.600	1.000	0.150	361	45.000	0.500	2.000	0.142
327	20.000	0.600	1.000	0.173	362	60.000	0.500	2.000	0.164
328	30.000	0.600	1.000	0.212	363	75.000	0.500	2.000	0.184
329	45.000	0.600	1.000	0.260	364	90.000	0.500	2.000	0.201
330	60.000	0.600	1.000	0.300	365	100.005	0.500	2.000	0.212
331	75.000	0.600	1.000	0.335	366	120.003	0.500	2.000	0.232
332	90.000	0.600	1.000	0.367	367	150.000	0.500	2.000	0.260
333	100.003	0.600	1.000	0.387	367	180.000	0.500	2.000	0.285
334	120.005	0.600	1.000	0.424	369	210.000	0.500	2.000	0.307
335	150.000	0.600	1.000	0.474	370	240.000	0.500	2.000	0.329
336	180.000	0.600	1.000	0.519	371	300.000	0.500	2.500	0.367
337	210.000	0.600	1.000	0.561	372	5.000	0.500	2.500	0.038
338	240.000	0.600	1.000	0.599	373	10.000	0.500	2.500	0.053
339	300.000	0.600	1.000	0.665	374	15.000	0.500	2.500	0.065
340	5.000	0.600	1.500	0.058	375	20.000	0.500	2.500	0.076
341	10.000	0.600	1.500	0.082	376	30.000	0.500	2.500	0.093
342	15.000	0.600	1.500	0.100	377	45.000	0.500	2.500	0.113
343	20.000	0.600	1.500	0.115	378	60.000	0.500	2.500	0.131
344	30.000	0.600	1.500	0.141	379	75.000	0.500	2.500	0.146
345	45.000	0.600	1.500	0.173	380	90.000	0.500	2.500	0.160
346	60.000	0.600	1.500	0.200	381	100.001	0.500	2.500	0.169
347	75.000	0.600	1.500	0.224	382	120.005	0.500	2.500	0.185
348	90.000	0.600	1.500	0.245	383	150.000	0.500	2.500	0.207
349	100.002	0.600	1.500	0.258	384	180.000	0.500	2.500	0.227
350	120.030	0.600	1.500	1.283	385	210.000	0.500	2.500	0.245
351	150.000	0.600	1.500	0.316	386	240.000	0.500	2.500	0.262
352	180.000	0.600	1.500	0.346	387	300.000	0.500	2.500	0.293
353	210.000	0.600	1.500	0.374					

RESULTS AND DISCUSSION

The present correlation obviously does not need to identify the sticking period (whether it is first or second) as in Terzaghi trend. It also does not require the measurement of the sticking coefficient, at different time periods, as in eq. (1)

The solid stress values calculated by the proposed equation are tested and compared with the measured and these obtained from Terzaghi trend , as shown in **Table (2).** The data shown in **Table (2)** have not been included in the main analysis; thus they represent a verification of the proposed correlation. Column (7) represents stress values calculated by Terzaghi trend whereas columns 3&6 show the proposed and measured values . A good match of the results was obtained a long with a high value correlation coefficient (R=0.972).

Fig. (2) presents a comparative interpretation of the measured solid stress values and those calculated by the proposed correlation.

Table (2) comparison of Proposed , measured, and solid stress Terzaghi values

No.	SET	Proposed solid stress	μ	h	Measured solid stress	Terzaghi solid stress
1	60.000	0.343	0.500	1.000	0.329	0.342
2	75.000	1.000	0.500	0.100	1.000	1.000
3	90.000	0.214	0.400	2.000	0.225	0.213
4	100.050	0.460	0.400	1.000	0.474	0.462
5	120.004	0.332	0.400	1.500	0.346	0.329
6	150.000	0.908	0.400	0.500	0.945	0.908
7	180.000	0.739	0.400	0.750	0.805	0.738
8	210.000	1.000	0.400	0.100	1.000	1.000
9	240.000	1.000	0.400	0.300	1.000	1.000
10	300.000	1.000	0.500	0.500	0.989	0.988
11	5.000	0.213	0.500	0.500	0.190	0.212
12	10.000	0.213	0.500	0.750	0.179	0.213
13	20.000	0.100	0.600	2.000	0.087	0.101
14	30.000	0.089	0.600	2.500	0.085	0.088
15	45.000	0.837	0.600	0.100	1.000	0.836
16	60.000	0.693	0.600	0.300	0.888	0.692
17	75.000	0.584	0.600	0.500	0.665	0.583
18	90.000	0.476	0.600	0.750	0.490	0.476
19	100.003	0.391	0.600	1.000	0.387	0.390
20	120.030	0.282	0.600	1.500	0.283	0.281
21	150.000	0.240	0.500	2.000	0.260	0.241
22	180.000	0.196	0.500	2.500	0.227	0.195
23	240.000	0.220	0.500	2.500	0.262	0.221
24	300.000	0.317	0.500	2.000	0.367	0.316

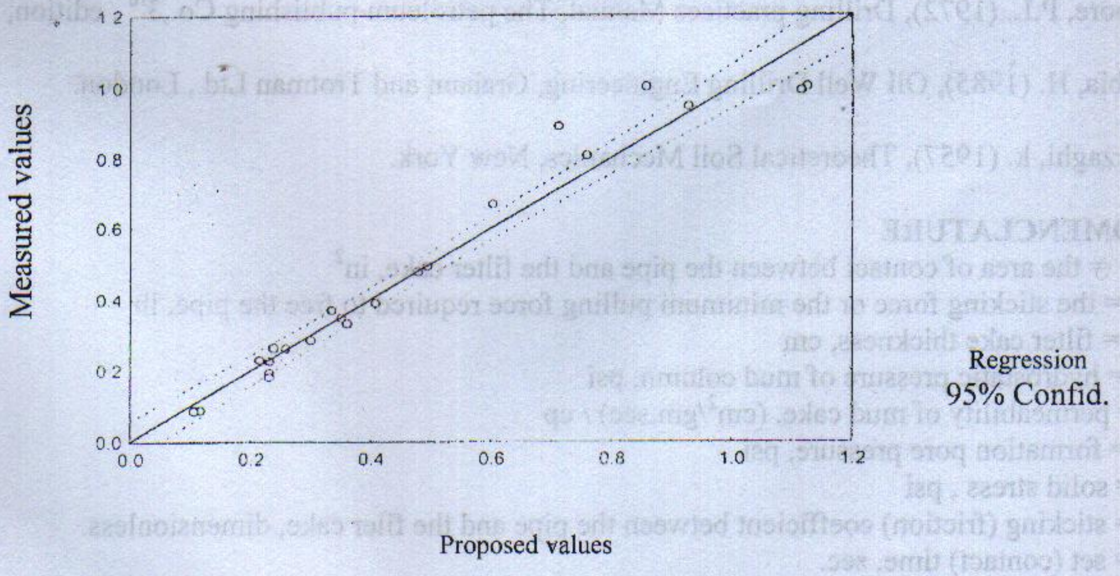

Fig. (2) comparison between proposed and measured solid stress values.

CONCLUSIONS

An improved empirical correlation for estimating solid stresses is developed. The proposed correlation calculates the solid stress for differentially stucked pipes as a function of setting (contact time), thickness of mud cake, and viscosity of mud filtrate. The developed correlation revealed a good match with the measured & Terzaghi equation for the case of differentially stuck pipes.

On the other hand, the present equation does not need the delineation of the sticking period (whether it is first or second) as in Terzaghi equation. It, therefore, represents an easier and a practical solution for the DPS problems.

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NOMENCLATURE

Ac = the area of contact between the pipe and the filter cake, in^2
Fs = the sticking force or the minimum pulling force required to free the pipe, lb
h = filter cake thickness, cm
p_h = hydrostatic pressure of mud column, psi
k = permeability of mud cake. (cm^2/gm.sec) / cp
P_f = formation pore pressure, psi
S = solid stress , psi
S_c= sticking (friction) coefficient between the pipe and the filer cake, dimensionless.
T = set (contact) time, sec.
β = coefficient of consolidation, cm^2/gm
Δ p =the differential pressure, psi
μ = viscosity of mud filtrate, cp

SI Metric Conversion Factors

in. × 2.54*=cm
lb. × 0.454 = kg
lb./in^2. × 7.030695 10^{-3} = kg/cm^2
* Conversion factor is exact.