ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007

THE FEM ANALYZE OVER THE ANGULAR CHARACTERISTICS OF THE THREAD SHOULDERED CONNECTIONS, USED FOR THE LARGE DIAMETRER DRILL STEM

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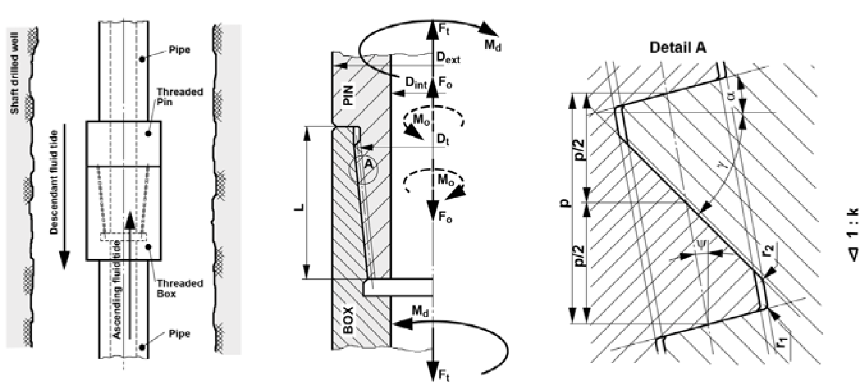
Key words: large diameter drilling, special asymmetric thread, stress distribution

Abstract
In large diameter drilling, the drill stem and its joints are under special load condition: the axial load (preload and resultant weight forces) and torque moments are always in higher levels than in usual drilling case. By consequence, these large diametric joints need special shouldered threads; the conical thread has an asymmetric profile. This paper proposes a FEM stresses analyze of the shouldered connection, meaning the optimization of the taper and, also, for better thread angular profile choice.

1. General overview

1. 1. Specific features in the large diameter drilling domain

The large diameter drilling can be made by two distinctive methods: in descending or ascending system. Both use large diametric drill stems, much larger than those for conventional drilling domain. Among the three connecting solutions – thread shouldered, flanged or bayonet – the main in mention is similar to the oil and gas drill stem joints; some constructive and dimensional characteristics are, this case, certain different [3], [5].
This case, the underlined drill stem weight will determine a high level loading and huge axial forces. Same time, on drill stem and its connections are high (or very high) pre-load torques in work [4]. It determines, as necessary, special conical threaded joints; these are always diametric bigger and using a special asymmetric thread profile.



a. The Large Diameter Stem Connection in Work
b. The Coplex Pin-Box Joint, on Axial and Torsional Load
c. Main Geometric Elements of Conical Thread for the Shouldered Connection

Fig. 1. The special conical thread shouldered connection used for the large diameter drilling stem joints

1. 2. Specific thread features for large diameter drill domain

For large diameter drill stem connections, the thread shouldered joints are conformed to dimensional and load characteristics. The immediate pipe junctions – or special PIN-BOX tool joints – always have a conic shouldered thread.

According to API standards [10] – as Romanian standards too – the (1 : *k*) tapering in use, for conventional drill joints, are higher: 1 : 4 or 1 : 6. Same time, the thread is all cases symmetric in radial sense, with a 60^{o} apical thread profile angle.

In large diameter drilling domain, we can use for stem connections the same kind of the shouldered threads. Having a reasonable tubular thickness, the usual tapering must be at lower level values: 1 : 6 or 1 : 8. Regarding thread profile in use, most of manufacturing companies chose asymmetric profile, by according to condition [2], [3], [5], [6], [9]:

$$\alpha + \gamma = 60^{o} \quad (1)$$

It must be mentioned that thread asymmetry refers to different angular values for these profiles: reduced values for the active flank angle ($\alpha = 15^{o}$, or close) and higher for the passive flank angle ($\gamma = 45^{o}$, or close). This special option (fig. 1., *b*) was imposed by the very high axial load level in the torsion pre-load situation – F_o force, induced by the M_o torque – and, same hand, by the high axial cumulative weight force (F_e) or by the drill torque (M_d), in work situation [3], [5], [6].

2. Main objectives and research development

2.1. Objectives

The research development by FEM tackles a multiple analyze over the stress and deformation state, for special thread shouldered connections used in large diameter drilling [3]. It meant a critical examination over both load and geometrical parameter influences. This paper concentrates only to the influences of angular parameters over the stress distribution:

- The (common) tapering for both components, PIN-BOX, (1 : *k*);
- The angular parameters of the thread profile, α and γ.

The reference parameters aim at three threaded joints of FM 200M thread, a Romanian special type designed for PIN-BOX pairs of size of 10, $14^{3}/_{8}$ and 20 inch.

2.2. Chosen Program and PIN-BOX modeling

The FEM analyze used ANSYS 5.6 software for Structural Static Analysis. By running this soft, we could get the stress and displacement distribution, for both joint components, in all nodes involved to this structure:

- the held element, as a conical threaded PIN;
- the holding element, as a conical threaded BOX.

This way, it was possible to determine the tri-directional stress values (σ_y, σ_x, şi σ_z) and also the equivalent (σ_{ech}) one, von Mises stress:

$$\sigma_{ech} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - (\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)} \quad (2)$$

The assembly model structuring (PIN-BOX, shown in fig. 2., *a*) is detailed in the work [3]. Thus, strategic reasons of research determine the option for the parametric initialization of the thread; it gives the possibility of varying the geometrical elements (in successive runs): tapering, active and passive flank angles or others.

Considering the structure complexity, the thread modeling difficulties and, also, the software run possibilities, it was chosen a 2D model, axis-symmetric, by using contact pair elements. Using some preliminary running, there was possible to establish the main interest zones of the model (for both components); these were the specific stress concentrating zones for PIN and Box elements.

For these specific areas, the final analyze model differentiates the whole structure by the incremental choice, by the specific role in stress distribution. The particular high stress (σ_y, σ_x, σ_z or σ_{ech}) areas become denser in node prescribing: the joint shoulder, active flank or thread root (fig. 2., *b*).

The model design followed the PIN-BOX dimensions of the14 $^3/_8$ inch drill stem connection (average diametric value, in measurement plane is $d_{2,m}$ = 372.334 mm) [6], [9].

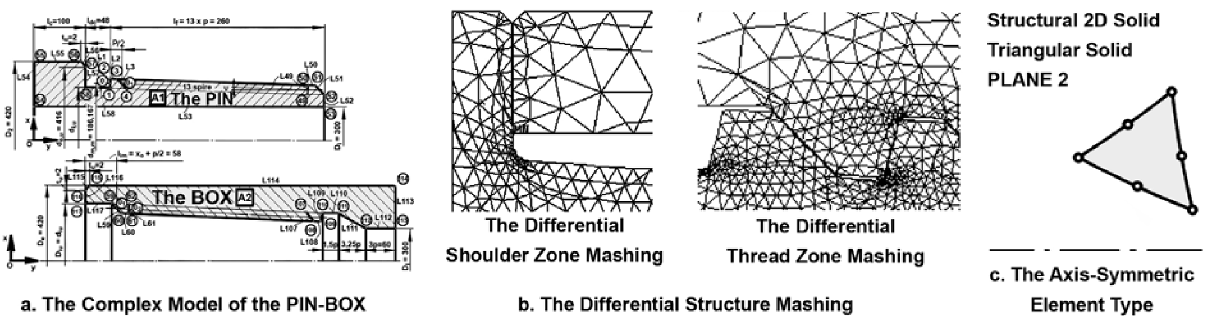


Fig. 2. The PIN-BOX model for FEM analyze, differential structure meshing and element type in use

The final model characteristics are following:

- *Element Type*: PLANE 2 (fig. 2., *c*), elements with 6 nodes, 2D type;
- *The Final Element Number*, for all the structure: 8 696;
- *The Final Node Number*: 17 722;
- *The Number and Contact Element Type*: TARGE – 169 and CONTA – 172, considering the friction factor of μ = 0.08.

2.3. The model load system

The model load system considers one of the most critical drilling stages: running or extracting the bit (tools) into the well – *withdrawing of the drill stem*. This critical case, each connection (*k* rank) of the stem is under a cumulated load:

- Axial load of traction-compression, by the F_o force (traction for PIN, compression for BOX), generated by the make up joint torque, M_o;
- Axial load of traction, by the F_t axial force (for PIN); this is a resultant axial force including the total weight force, F_e; the cumulative F_t force is different from the down hole level (1 rank connection) to the higher (ground) level (*n* rank connection).

By consequence, the higher loaded connection is situated up the well (*n* rank joint). This load case is correspondent by the maximum well depth (H_{max}).

In load simulation of the model, there were necessary most determinations for the resultant weight of stem assembly, made for each well depth. Than, for each weight resultant force (F_e), it was necessary the pre-load force determination, (F_o), using the well known *Force-Deformation Diagram Theory*. For the make up joint torque determination, for each *k* rank connection, can use the equation:

$$M_o^{(k)} = M_{th} + M_{sh} \tag{3}$$

where M_{th} is the resultant friction torque moment over the thread and M_{sh} is the resultant friction torque over the assembly shoulder. Extending the (3) equation, we get the formula:

$$M_o^{(k)} = F_o^{(k)} \cdot \left[\frac{d_{2,m}}{2} \cdot \mathrm{tg}\left(\beta_m + \varphi'\right) + \frac{\mu_{sh}}{3} \cdot \frac{d_{e,sh}^3 - d_{i,sh}^3}{d_{e,sh}^2 - d_{i,sh}^2} \right] \tag{4}$$

The operands in equation (4) are the acknowledged ones: $d_{2,m}$ is the thread diameter for the measurement plane; $d_{e,sh}$ and $d_{i,sh}$ are the external and internal limits of the shoulder; β_m is the incline angle of the thread spire; φ' is the friction ratio ($\varphi' = \text{arctg}\left(\mu_{th} / \cos\delta\right)$) and μ_{sh} is the friction factor for the shoulder area.

When simulates a type of combined load (***p/f***), the model is – as a matter of fact – under two specific and distinctive loads:

- The axial pre-load (***p***), meaning a pressure over the ring-shaped area of model shoulder; this simulates the F_o load effect;
- The axial weight resultant load (***f***), meaning a pressure on extremities of PIN and BOX; this simulates the F_e equivalent force.

The described load combinations are shown in the table 1.

Table 1. Combined loads considered in the FEM applications

Real load components	$M_o^{(k)}$ equivalent [kN·m]	$F_o^{(k)}$ equivalent [kN]	$F_e^{(k)}$ equivalent [kN]		Strain type model	Symbol
$M_o^{(k)}$ and $F_e^{(k)}$	39	1125	normal value	1360	pressure	***p*50 / *f*20**
			maximal value	3400	pressure	***p*50 / *f*50**
	78	2251	normal value	1360	pressure	***p*100/ *f*20***
			maximal value	3400	pressure	***p*100 / *f*50**
	117	3376	normal value	1360	pressure	***p*150 / *f*20**
			maximal value	3400	pressure	***p*150 / *f*50**

*** *p*100 / *f* 20** is the normal combined load for angular variant cases

3. The MEF analyze main results

3.1. The tapering influence, 1 : *k*

This first analyze tackle brings the joint tapering influence over the stresses and displacements, for both PIN-BOX components. For this, it was necessary the model combined loading, by axial pre-load, F_o and weight resultant load, F_e; it was selected the medium charging level of ***p*100 / *f*20**. All the geometric characteristics were this case invariable, except the tapering. Two cases had to be fixed:

- The tapering 1 : 6 – corresponding to practical drill pipe size of 10 in;
- The tapering 1 : 8 – corresponding to practical drill pipe sizes of 10, 10 $^3/_8$, 10 $^7/_8$, **14 $^3/_8$** and 20 in.

The solving problem by ANSYS conducted to the output data, meaning stress list for all model nodes and, also, maps of σ_y, σ_x, σ_z and σ_{ech}, all over the structure and detailed selected parts (fig. 3). A higher relevance we got by selecting the very first spires of the thread and the shoulder specific area. Same time, it was possible to get the node displacement lists (*dy* and *dx*), for nodes all over the contour.

The overall FEM analyze made [3] created a special preview over the max-stress zones; it was a good opportunity and guide for special node selections for this stress evolutional comparison. Therefore, the specified selected nodes in table 2 are those belonging of the thread spire roots of the PIN.

Otherwise, each (1 to 13) spire root, by the active flank side, is a stress concentrator. This observation is available to both PIN and BOX thread spires; a higher comparative stress levels are, anyway, on the PIN thread. That's why the only selected nodes shown in table 2 belong to the threaded PIN.

Table 2. Stress comparative values, for the PIN selected nodes

Spire no.	Node no.	σ_y [N/mm^2]		increase, decrease [%]	σ_x [N/mm^2]		increase, decrease [%]	σ_z [N/mm^2]		increase, decrease [%]	σ_{ech} [N/mm^2]		increase, decrease [%]
		1 : 6	1 : 8		1 : 6	1 : 8		1 : 6	1 : 8		1 : 6	1 : 8	
1	226	339.8	336.1	↓1.0	36.8	39.3	↑6.8	128.4	128.5	↑0.1	327.6	324.3	↓1.0
2	278	675.7	638.9	↓2.8	220.6	224.2	↑1.6	284.3	274.0	↓3.6	773.3	745.3	↓3.6
3	328	361.4	339.0	↓6.2	119.9	119.5	↓0.3	146.8	139.7	↓4.8	414.2	396.1	↓4.4
4	378	255.9	239.7	↓6.3	83.4	81.4	↓2.4	93.8	88.4	↓5.8	292.7	274.1	↓6.4
5	428	215.5	200.1	↓7.1	70.4	69.0	↓2.0	70.8	66.2	↓6.5	245.6	231.0	↓5.9
6	480	146.9	139.4	↓5.1	111.0	104.7	↓5.7	58.8	55.5	↓5.6	229.2	213.4	↓6.9
7	528	176.8	163.9	↓7.3	56.8	56.2	↓1.0	50.4	47.5	↓5.8	211.7	192.9	↓8.9
8	578	155.2	146.0	↓5.9	49.9	49.3	↓1.2	42.6	40.8	↓4.2	186.5	172.4	↓7.6
9	628	135.3	125.5	↓7.2	42.4	42.6	↑0.5	35.7	33.9	↓5.0	160.2	153.1	↓4.4
10	678	112.0	106.6	↓4.8	34.9	36.1	↑3.4	28.0	27.6	↓1.4	135.2	130.4	↓3.5
11	728	94.6	94.0	↓0.6	29.5	30.8	↑4.4	22.2	22.8	↑2.7	114.7	113.5	↓1.0
12	778	88.1	86.5	↓1.8	27.8	29.1	↑4.7	20.0	19.4	↓3.0	106.8	106.8	0
13	830	91.3	73.7	↓19	33.8	52.9	↑56	20.8	19.9	↓4.3	115.5	117.3	↑1.6

This numeric data list is enclosed to the comparative stress maps. As more relevant, here are selected some of the pair maps – only for detailed areas - concerning σ_y, σ_x, and σ_{ech} stresses, for both tapering (fig. 3).

These selected areas mean the first three thread spires, containing also the max-stress of the structure (MX), in all load cases.

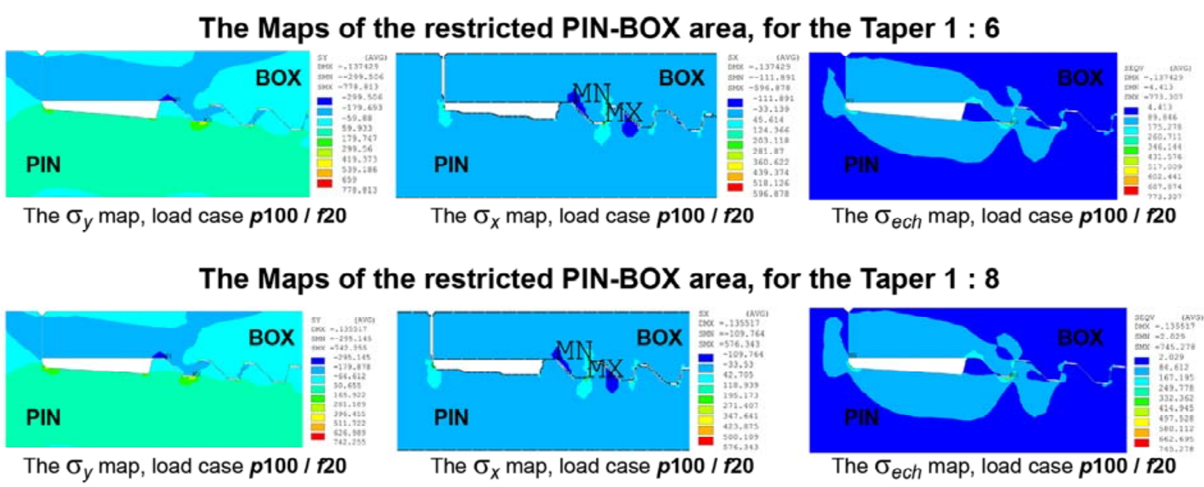


Fig. 3. Selected stress maps over the most hard loaded PIN-BOX area, for these two different tapering values: 1 : 6 and 1 : 8

Same relevance comes from other pair maps, got as detail from the most stress affected areas: the *first engaged spire of the pin* (spire no.2) and the contact shoulder plane. These maps are pairs extracted for each considered taper: 1 : 6 and 1 : 8 (fig. 4).

The stresses analyze – data list and maps – can show some relevant aspects:

- The general aspect of stress maps indicates the same position of the maximal values of σ_y and σ_{ech}, for each 1 : 6 and 1 : 8 tapering: at the node no. 278, first load engaged thread spire;

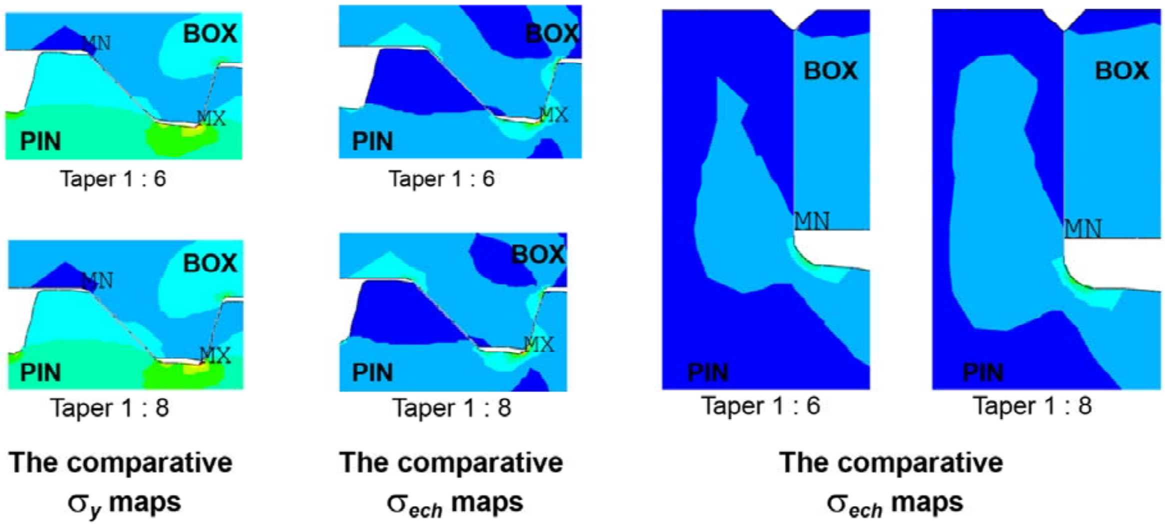


Fig. 4. Comparative stress maps for the most loaded thread spire and for the PIN-BOX shoulder area, determined for both cases of 1 : 6 and 1 : 8 tapering

- The 1 : 8 tapering, comparative to the 1 : 6 tapering, shows an obvious stress reduction, over all three axes (and von Mises stress too);
- The σ_x stress has an unspecific variation; a sensitive decrease on the 3rd to 8th spire, for the 1 : 8 tapering, is quite visible;
- The circumferential (σ_z) stress level is low, it's decrease is more evident on the 4th to the 7th spire;
- Von Mises stresses at the BOX thread spire basis has a favorable decrease, for the zone of 1st to 9th thread spires: it's reduction is about 0.8…11.8 %;
- In the pin shoulder root area, the equivalent stresses are favored by the higher tapering 1 : 6; chousing the 1 : 8 tapering, von Mises stresses are increasing by 4.7% and axial ones by 6.6%;
- For the node no. 278 (the MX all over the structure) the equivalent stress level decrease by 3.6%, for the 1 : 8 tapering case.

3.2. The angular *α* and *γ* influence

The α and γ angular values (keeping condition $\alpha + \gamma = 60^o$) determines a special thread asymmetric geometry. Its variability entails some following effects:

- Keeping the thread pitch invariable, the (α) increase determines the spire basement reducing; as a result is the thread bending strength reduction;
- Same preliminary geometric conditions, when (α) increase determines a similar friction component increase and, same way, a make up and screw off torque growing;
- Same preliminary geometric conditions, when (α) increase determines a relative thread contact unload, as a length active flank growing effect;
- Same preliminary geometric conditions, when (α) decrease determines a substantial top spire thickness reduction; it determines a bending strength capacity reduction;

With the view of stress and displacement analyze, there were designed three assembly variant, by the active flank angle: $\alpha = 5^o$, $\boldsymbol{\alpha = 15^o}$ (usual type) and $\alpha = 25^o$. For these three models, all the other geometric parameters were invariant: thread pitch, characteristic diameters, tapering, thread heights and profile angle ($\alpha + \gamma = 60^o$).

The model load simulation kept same level as the preceding analyzed case: ***p*100 / *f* 20**. After program running, same kind of results – data lists and maps (σ_y, $\sigma_{x,}$ σ_z and σ_{ech}) – were already got, for each meaning case.

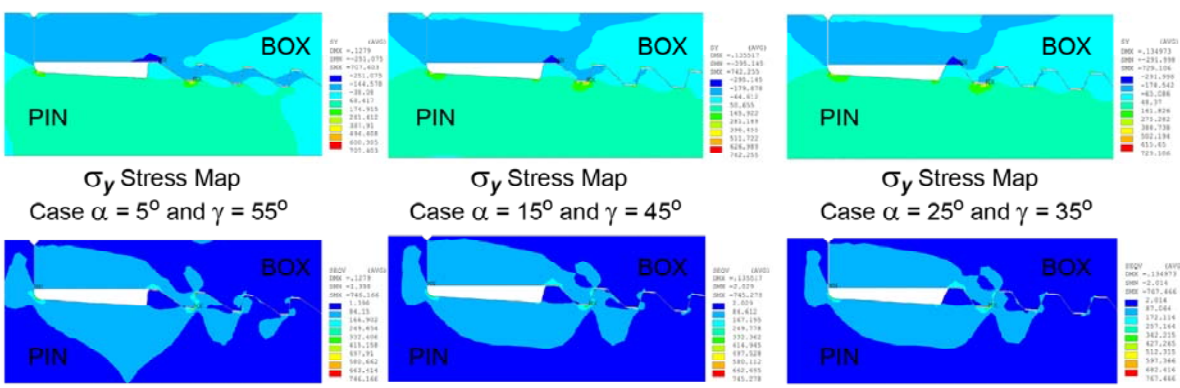
Data results for representative *von Mises* stress values – only for selective (contour) PIN nodes – are selected in table 3; its position correspond from the 1st to the 13th spire rank. The stress maps selected here refers also to a restricted area: first three contact thread pairs, for all distinctive angular cases.

Table 3. Von Mises stress comparative values, for PIN selected nodes in three (α and γ) angular cases

Spire no.	Case of angular values $\alpha = 5^o$ and $\gamma = 55^o$		Case of angular values $\alpha = 15^o$ and $\gamma = 45^o$		Case of angular values $\alpha = 25^o$ and $\gamma = 35^o$	
	Node no.	Von Mises stress, σ_{ech} [N/mm^2]	Node no.	Von Mises stress, σ_{ech} [N/mm^2]	Node no.	Von Mises stress, σ_{ech} [N/mm^2]
1	n 226	241.5	n 226	324.3	n 224	314.7
2	**n 282**	**746.2**	**n 278**	**745.3**	**n 276**	**767.5**
3	n 330	451.5	n 328	396.1	n 326	393.2
4	n 376	332.0	n 376	274.9	n 372	291.3
5	n 426	260.4	n 428	231.0	n 420	246.1
6	n 478	202.7	n 478	213.4	n 468	223.2
7	n 528	158.0	n 528	192.9	n 516	203.2
8	n 578	127.2	n 578	172.4	n 564	179.5
9	n 628	106.3	n 628	153.1	n 612	153.6
10	n 678	92.3	n 678	130.4	n 660	131.2
11	n 728	81.4	n 728	113.5	n 708	112.6
12	n 778	73.6	n 778	106.8	n 756	106.7
13	n 828	81.5	n 828	117.3	n 804	118.0

Regarding the data and graphic results (fig. 5), there are some remarks to be done:

- The general stress statement in both elements shows a relative uniform distribution (on 90% of entire section), for all the distinctive angular cases;
- In all cases, the concentrating areas keep the same location;



σ_y Stress Map Case $\alpha = 5^o$ and $\gamma = 55^o$ | σ_y Stress Map Case $\alpha = 15^o$ and $\gamma = 45^o$ | σ_y Stress Map Case $\alpha = 25^o$ and $\gamma = 35^o$

σ_{ech} Stress Map Case $\alpha = 5^o$ and $\gamma = 55^o$ | σ_{ech} Stress Map Case $\alpha = 15^o$ and $\gamma = 45^o$ | σ_{ech} Stress Map Case $\alpha = 25^o$ and $\gamma = 35^o$

Fig. 5. The comparative σ_y and σ_{ech} stress maps for three thread profile angular cases

- Decreasing the active flank angle ($\alpha = 5^o$), entails some results:
  - at the PIN spire roots the concentrating effect increase, from the 2nd to 5th spire, by 2 to 21% (von Mises stress);
  - at the BOX spire roots the stress level modification is similar;
  - at the PIN shoulder root, the radius concentrator effect rises: von Mises stress level increase from 3.1 to 18.4%;

- at the shoulder root zone, the circumferential stress level is higher; that means the PIN tendentiously swell out;

- Increasing the active flank angle ($\alpha = 25^o$), entails some results:
  - the threaded PIN roots increase von Mises stress levels;
  - the maximum von Mises stress (in 276 and 278 nodes) grows about 3%;
  - at the threaded BOX roots, von Mises stress levels are quite similar, in all three cases.

4. Conclusions

The FEM analyze of the threaded PIN-BOX connection directs to some conclusions, useful for geometric and dimensional design optimization:

- For large diameter thread shouldered connections there is recommended a gentle tapering choice, comparing by usual (oil and gas) drill stem joints; this special drilling case, the 1 : 8 tapering value brings a general stress decreasing, even for the stress concentrator areas;
- For large diameter thread shouldered connections – meaning over 10 inch diametric nominal size – the best load distributing results come when asymmetric thread is involved;
- Always, by technological and strength capacity reasons, the summative angular condition $\alpha + \gamma = 60^o$ have to be set;
- By simultaneous PIN-BOX perspective, the angular choice of $\alpha = 15^o$ and $\gamma = 45^o$ brings pretty much the optimal solution;
- Some special cases – when drill process involves ultra-high axial load – the special asymmetric thread can be designed towards active flank angle at lower values ($\alpha \rightarrow 10^o$ even $\alpha \rightarrow 5^o$).

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