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EFFECT OF TRIPPING VELOCITY PROFILES ON WELLBORE PRESSURES AND DYNAMIC LOADING OF DRILLSTRING

1. INTRODUCTION

Tripping is one of the main parts of a drilling process. The optimization and automation of tripping velocity is one of the major issues in the developments of drilling automation systems. To achieve the optimization and automation of tripping, we need to fully study the phenomena generated during tripping. Surge or swab pressures in the wellbore and dynamic loading of drillstringwill be generated during tripping. Surge pressure will be generated when we run the drillstring into the wellbore and swab pressure will occur when we pull the drillstring out of the wellbore. Surge and swab pressures have been known to cause formation fracture, lost circulation and well control problems. Accurate prediction of these pressures is of crucial importance to keep the wellbore pressure within specified limits between the pore and fracture pressures. At the same time, dynamic loading of drillstring and dynamic drillstring velocity will be generated during tripping. Due to the compressibility of drillstrings, the loading is different at different positions of the drillstring. The velocity we input for the drillstring at the surface is not the same as the velocity of the drillstring at the bottom of the wellbore.

Tripping velocity profiles will influence the dynamic behavior of drillstring and wellbore pressure. To achieve the optimized tripping velocity profiles, dynamic loading of the drillstring, dynamic drillstring velocity and transient downhole pressure changes should be accurately calculated.Dynamic loading of the drillstringand transient downhole pressure changes can be considered as restrictions of the optimization procedure. It is not easy to estimate accurately the real limits of tripping velocity profiles with long drillstrings, complex wellbore geometries and narrow geo-pressure windows.

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Besides tripping velocity profile, there are other factors that influence dynamic loading of drillpipe, downhole pressure changes and dynamic drillstring velocity.These factors include drillstring components, position of drillstringin the wellbore, wellbore geometry and drilling fluid properties.

Also, since dynamic loading of drillstring, dynamic drillstring velocity and dynamic wellbore pressure will behave differently when the drillstring is at different positions of the wellbore, we select different tripping velocity profiles correspondingly. Optimization of tripping velocity profile for drillstring at both deep position and shallow positionsin the wellbore has not been fully studied.

The influences of tripping velocity profiles, components of drillstringand drillstring positions on dynamic behavior of drillstring and wellbore pressureare investigated in this paper. We utilize Bergeron's graphical method and Lubinski's approach to perform the simulations of dynamic phenomena. The problem of how to minimize tripping time with the restraints including strength of drillstring and downhole pressure changes is addressed in this work.In the end, the selection of drillstring velocity profilesas a function of depthis presented.

2. SIMULATION

We need to know the influence of tripping velocity profile on dynamic downhole pressure, loading of drillstring and dynamic drillstring velocity to optimize tripping velocity profile and to obtain the minimum tripping time.Thus, the simulations include three parts, which are dynamic loading of drillstring, dynamic drillstring velocity and dynamic downhole pressure surge. The dynamic behavior of drillstring and downhole pressure is simulated using Bergeron's graphical method and Lubinski's approach.After finishing these simulations, we can provide a strategy for tripping velocity profile selection when the drillstring is at different positions in the wellbore. At the same time, the influence of tripping velocity profiles on dynamic phenomena can be easily observed. Since we want to observe the influence of tripping velocity profile on dynamic behavior of the drillstring and the wellbore pressure surge for different lengths of drillstring, we make the assumption that the drillstring consists only of drillpipe. Thus, no tool joints or drill collars are taken into consideration. With this assumption it is possible to observe the effect of drillstring length on dynamic behavior of the drillstring and wellbore pressure surge since the drillstring length is the only variable.

3. DRILLSTRING DYNAMICS

Since the drillstring is compressible, a dynamic force is generated when the drillstring is run into or pulled out of the wellbore. Also, dynamic velocity, which is the velocity at the bottom of drillstring, is different from the velocity we input at surface. One usually uses partial differential equations to solve drillstringdynamics. In this work, Bergeron's graphical method is used for this purpose.

In wave propagation problems, one generally considers force and particle velocity at one point of the system vs. time, or at one time vs. the location of the point. Thus partial differential equations are derived. On the other hand, Bergeron considers force and particle velocity as seen by an observer moving with the velocity of propagation, which is the velocity of sound. Bergeron proved that for such an observer, the graph of force vs. particle velocity is a straight line. Thus, instead of partial differential equations, one obtains first-degree linear algebraic equations. The slope, S, of the straight line is the characteristic impedance:

$$S = \frac{c\rho A}{g}$$

where:

ρ/g – mass density,
c – celerity, for steel, c = 16893 ft/sec [5149 m/s],
A – cross-sectional area.

Consider the simplified system in Figure 1b, consisting of drillpipe and wireline, with no drill collarandno tool joint. The unit of time, the Bergeron unit (BU), is the time of propagation from S (surface) to B (bottom). The weight of the drillpipe is W, as shown in Figure 1b, and direction of weight is indicated by the downward arrow. At time 0, a upward (positive) velocity, $\mathbf{V_s}$, is suddenly applied at S through the wireline. The input velocity vs. time is shown in Figure 1a.

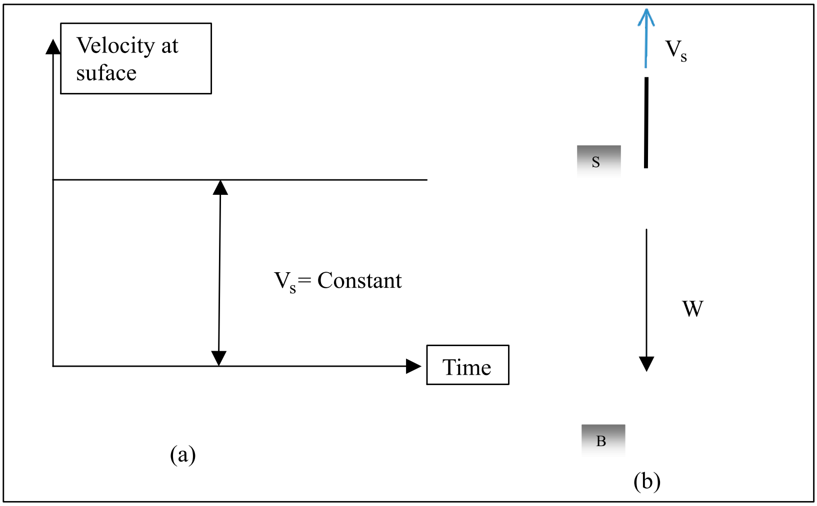

Fig. 1. Simple drillpipe and wireline system

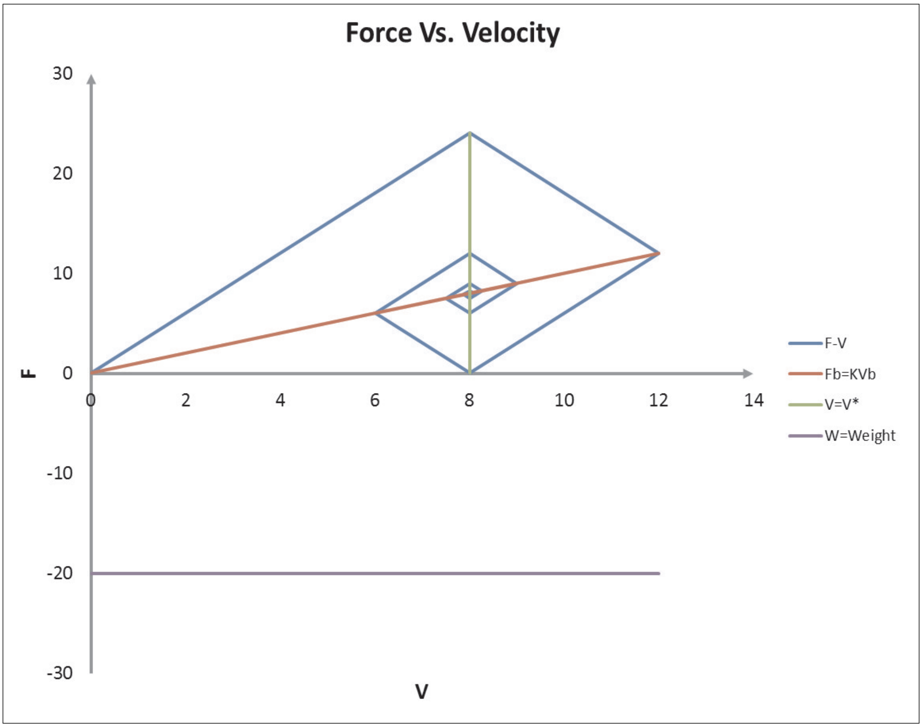

Fig. 2. Solution procedure for K < S

The solutions of this simple system depend on damping of the system. If the damping value, K, is greater than S, the whole system acts as a large resistance. If K is less than the characteristic impedance, S, the whole system acts as a small resistance. Figure 2 is the graphical solution procedure in Bergeron's notation. The system is a small-resistance system and the line V = **Kv** = V is characteristic of resistance at B. The constant velocity imposed by wireline is 8 and the weight of drillpipe is 20. The characteristic impedance 3 and the damping factor is 1 for this scenario. For this small resistance system, both dynamic loading and dynamic velocity will oscillate back and forth between values greater than and values less than the steady flow pressure until reaching steady-state value. Figure 3 is the graphical solution procedure in Bergeron's notation for large resistance. The line V = KV = 5 V is the characteristic of resistance at B. The constant velocity imposed by wireline is 8 and the weight of drillpipe is 20. The characteristic impedance is3 and the damping factor is 5 for this scenario.In a large resistance system, both dynamic loading and dynamic velocity will build up in steps to steady-state values.

We can apply this solution method to a real drillstring system and several linear equations can be easily solved to obtain the dynamic loading of drillstring and dynamic drillstring velocity.

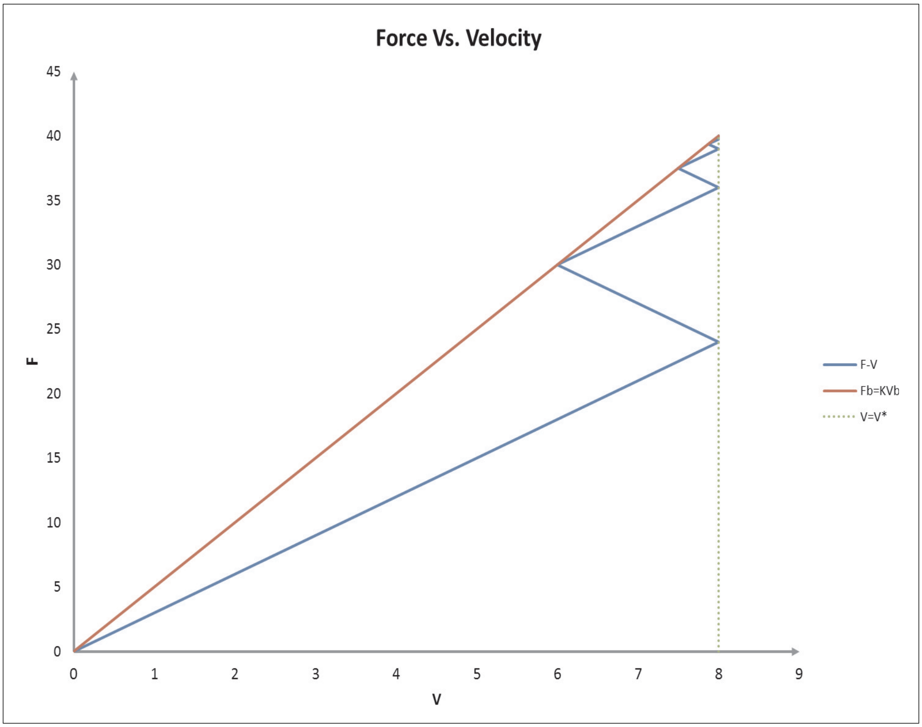

Fig. 3. Solution procedure for K > S

4. DYNAMIC DOWNHOLE PRESSURE

Pressure surges and swabs are transient variations (fluctuations) in fluid pressure produced by movement of pipe in mud-filled boreholes. Dynamic pressure changes are induced by the compressibility of drilling fluid, drillstring and wellbore.

In Bergeron’sgraphical method, pressure and flow rateare measured by imaginary observers moving upstream and downstream with the velocity of propagation. In this way, partial differential equations are replaced by easy to solve algebraic linear equations. This is similar to the solution procedure for dynamic loading of drillstring.

When we apply Bergeron’s technique to a real tripping problem, we divided the flow system into several sections connected by junctions. Also, we use artificial orifices, placed at some of the junctions along the flow, to represent frictional pressure losses. At junctions without artificial orifices, we obtain two equations of propagation. On the other hand, we add the equation of continuity and equation of pressure drop at junctions with artificial orifices. The pressure drop is calculated after determining whether the flow is laminar or turbulent. The fluid is assumed to be a Bingham Plastic fluid.

In this simulation, we use the same wellbore data and fluid properties. We calculate the dynamic loading of drillstring, drillstring dynamic velocity and dynamic downhole pressure when the drillstring is short and long, respectively. The wellbore data and fluid properties are shown in Table 1.We use the same kind of drillstring, but in different lengths. The short drillstring, which is the drillstring in a shallow position of the wellbore, is 2500-ft long. The long drillstring, which is the drillstringin a deep position inthe wellbore, is 10,000-ft long. Detailed data concerning these two drillstrings are shown in Table2. The viscous damping in this simulation is 3.2 pounds per 90-ft stand of drillpipe. This damping value is far less than the characteristic impedance.

Table 1

Wellbore data and fluid data

Factors	**Input Data**	**Value**
Wellbore	Length	18000-ft
	Diameter	6-1/2 inch
Fluid	Density	14.0 lb/gal
	Yield Value	30 lbf/100 ft^2 (14.4 Pa)
	Plastic Viscosity	45 cp

Table 2

Drillstring data

Drillstring	Length	OD/ID
Drillstring 1	2,500-ft	4-1/2 inch/3.826 inch
Drillstring 2	10,000-ft	4-1/2 inch/3.826 inch

Firstly, we need to see how the dynamic loading of drillstring and dynamic drillstring velocity change corresponding to the different lengths of drillstring. There are five tripping velocity profiles to be tested in this procedure, which are shown in Figure 4 and Figure 5. For velocity profiles 1, 2 and 3, the shapes are trapezoid. In velocity profile 1, the acceleration value and deceleration values are both 9 ft/. The maximum velocity for both velocity profile 1 and velocity profile 2 is 9 ft/sec; however, the acceleration and deceleration values in velocity profile 2 are 3 ft/. Velocity profile 3 has the same acceleration and deceleration values as velocity profile 2. But the maximum velocity in velocity profile 3 is 12 ft/sec.Velocity profile 4 has a triangular shape and velocity profile 5 has a parabolic shape. The areas covered by the velocity profiles and x-axis are both 90-ft. It takes 10 seconds to trip one stand of drillstring in both velocity profiles 4 and 5. In velocity profile 4, it takes 5 seconds to accelerate the drillstring and 5 seconds to decelerate the drillstring. The maximum velocity in velocity profile 4 is 18 ft/sec. The controlling equation of velocity profile 5 is:

$$V = -0.54t^2 + 5.4t \ (0 \le t \le 10)$$

where:

V – velocity, ft/sec,
t – time, sec.

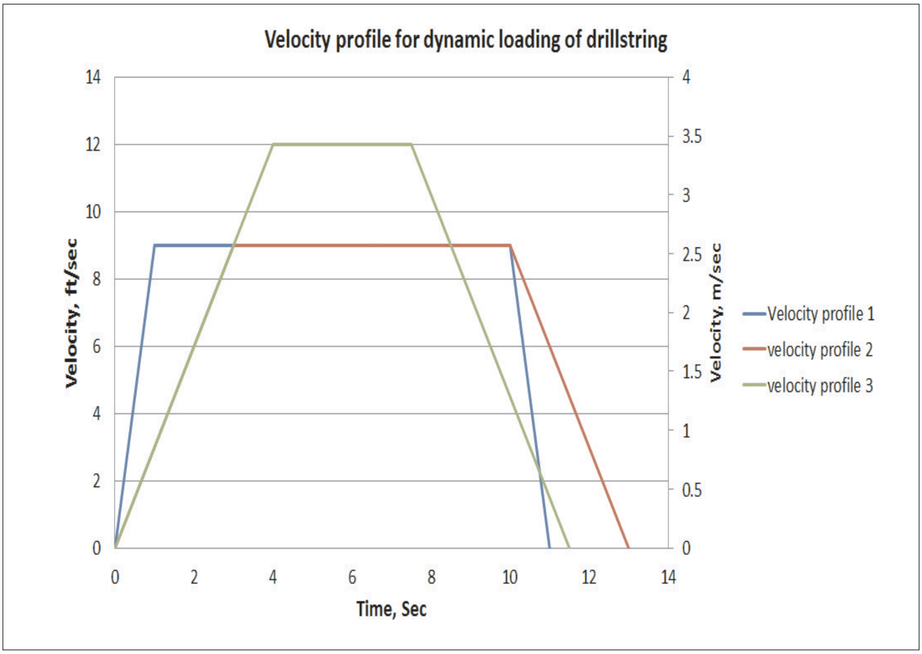

Fig. 4. Velocity profile for dynamic loading of drillstring

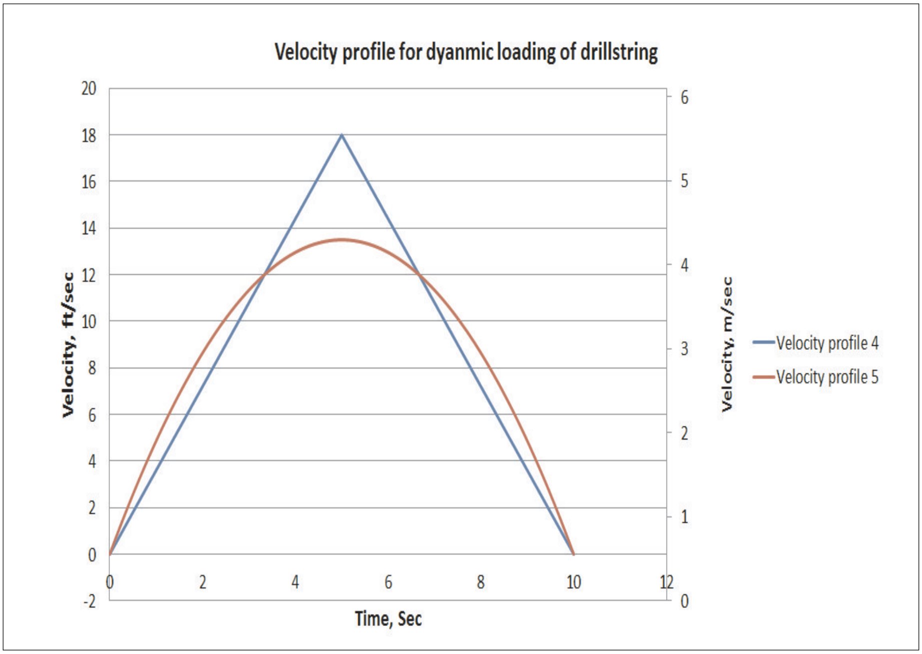

Fig. 5. Velocity profile for dynamic loading of drillstring

In the next step, we need to see how the dynamic downhole pressure changes with different lengths of drillstring. There are six tripping velocity profiles to be tested in this procedure, which are shown in Figure 12 and Figure 13.For velocity profiles 1, 2 and 3, the shapes are trapezoidal. In velocity profile 1, the acceleration value and deceleration values are both 3 ft/. The maximum velocity for both velocity profile 1 and velocity profile 2 is 3 ft/sec; however, the acceleration and deceleration values in velocity profile 2 is 1 ft/. Velocity profile 3 has the same acceleration and deceleration values as velocity profile 2. But the maximum velocity in velocity profile 3 is 4 ft/sec.Velocity profile 4 and 5 are triangularshape with maximum velocity of 6 ft/sec and 9 ft/sec respectively. Velocity profile 6 is a parabolic shape profile with the following control equation:

$$V= -0.02t^2 + 0.6t \ (0 \le t \le 13.5)$$

5. DISCUSSION AND RESULTS

The first part of the results is the dynamic loading of drillstring and dynamic drillstring velocity correspondingto different lengths of drillstrings. Figures 6 and 7 are the dynamic loading of short drillstring corresponding to the five input velocity profiles. We can see that both tripping velocity and tripping acceleration influence the dynamic loading of short drillstring. Since the acceleration and deceleration value in tripping velocity profile 1 is three times as great as those in profile 2 and 3, the amplitude of dynamic loading corresponding to velocity profile 1 is much higher than the other two. Since the difference betweenmaximum velocity in velocity profile 2 and 3 is not high, the amplitude of dynamic loading between velocity 2 and 3 is similar. However, we can still observe the change of oscillation shape of dynamic loading between these two. The oscillation amplitude of dynamic loading for velocity 4 and velocity 5 are similar. This is because they both change their velocity slowly. Because the maximum velocity in velocity profile 4 is slightly higher than that in velocity profile 5, the amplitude of loading for profile 4 is slightly higher than in profile 5. Figures 8 and 9 show dynamic loading of long drillstring correspond to the five input velocity profiles. We find that tripping velocity profiles have almost the same effect on dynamic loading of long drillstring as that of short drillstring.

Figures 10 and 11 show the dynamic velocity for long drillstring corresponding to the input five velocity profiles. The tripping velocity profiles havealmost the same effect on dynamic loading of long drillstring and dynamic velocity of long drillstring. When the drillstring is short, the dynamic effect on velocity at the bottom of the drillstring is very low. Therefore, the dynamic drillstring velocity, which is the velocity at the bottom of drillstring, is similar to the input velocity at the surface. This is the reason that the results of dynamic velocity for short drillstring are not shown here.

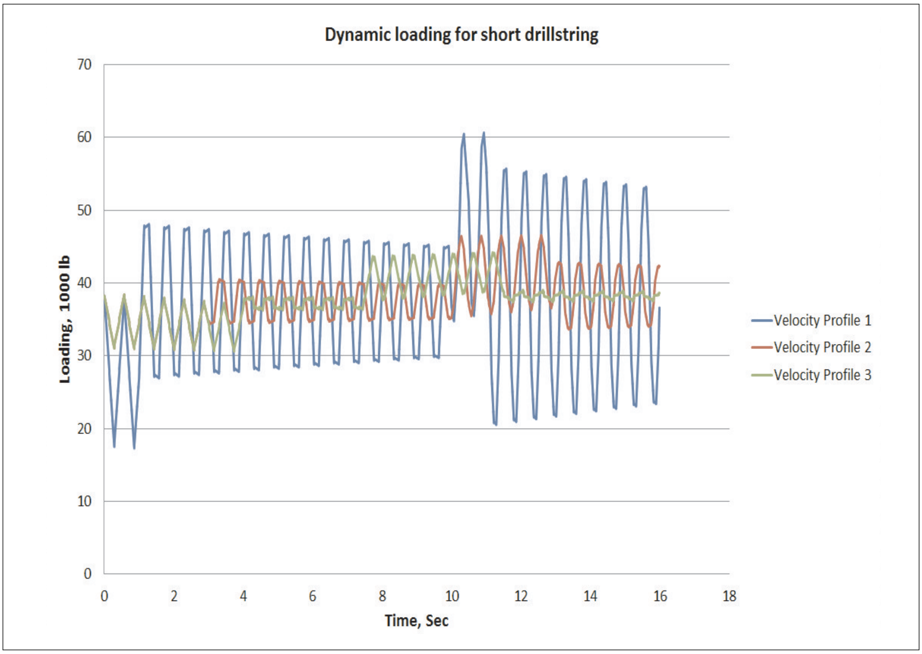

Fig. 6. Dynamic loading for short drillstring

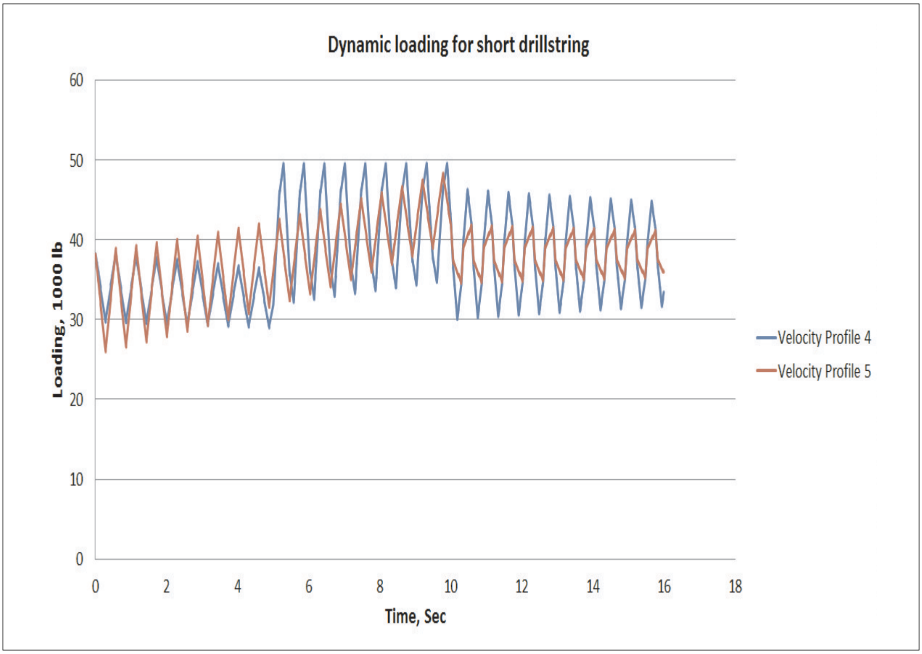

Fig. 7. Dynamic loading for short drillstring

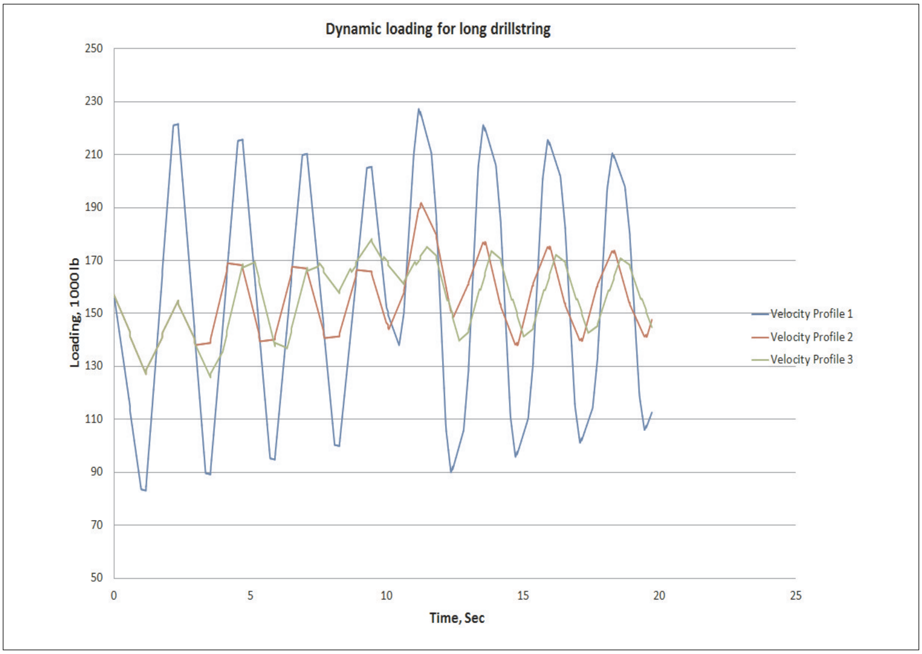

Fig. 8. Dynamic loading for long drillstring

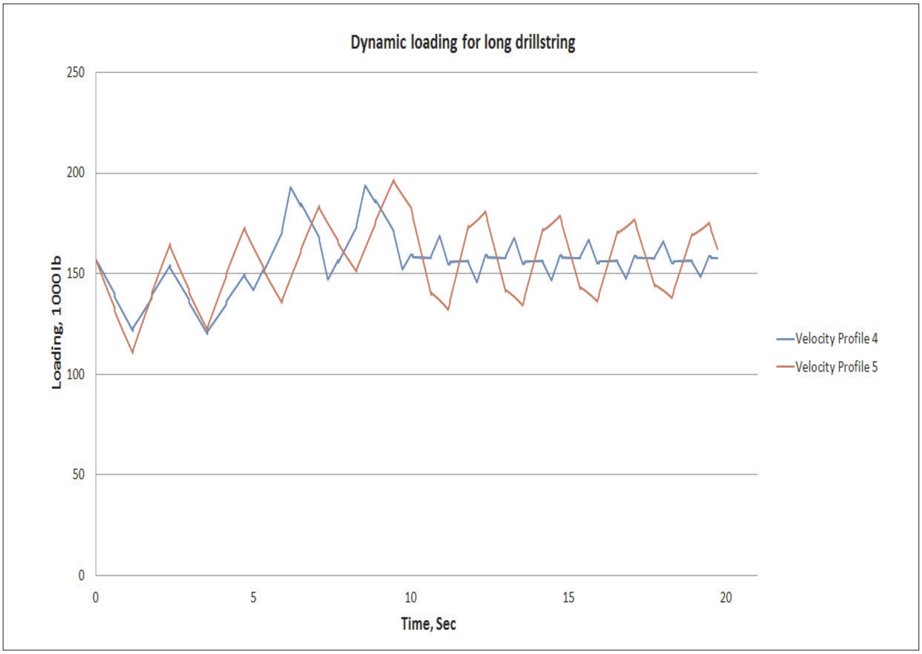

Fig. 9. Dynamic loading for long drillstring

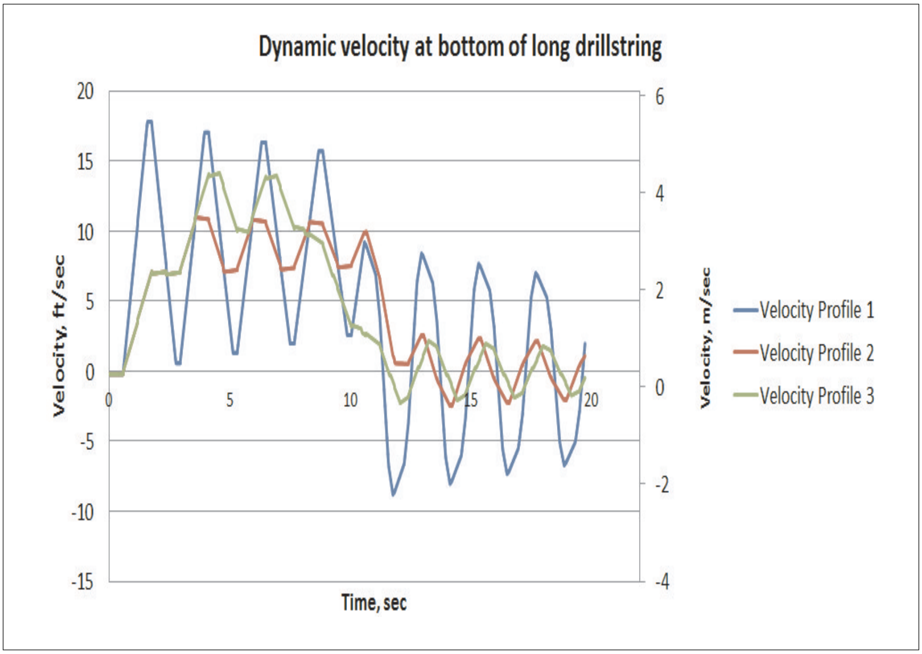

Fig. 10. Dynamic velocity at bottom of long drillstring

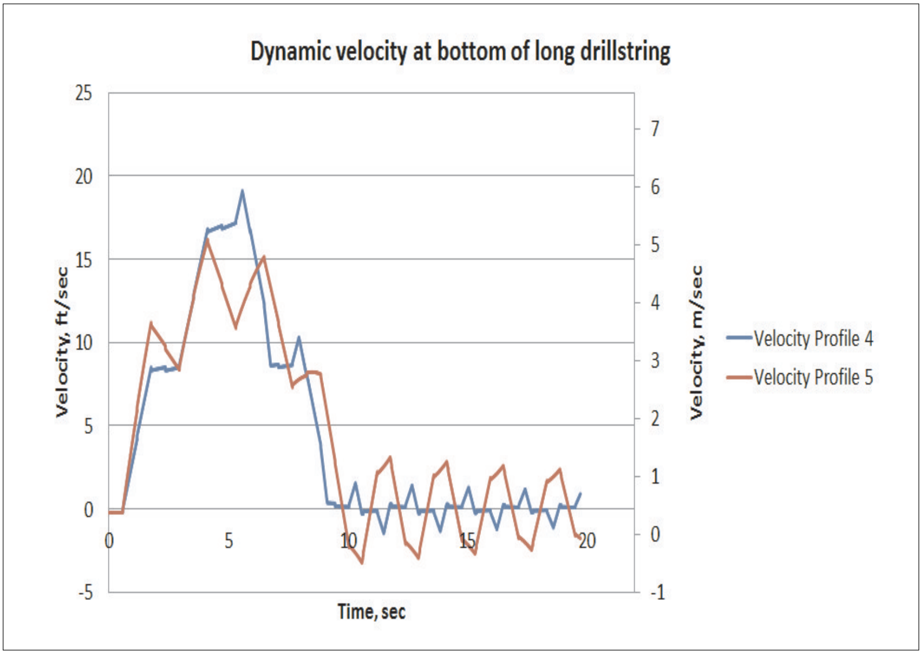

Fig. 11. Dynamic velocity at bottom of long drillstring

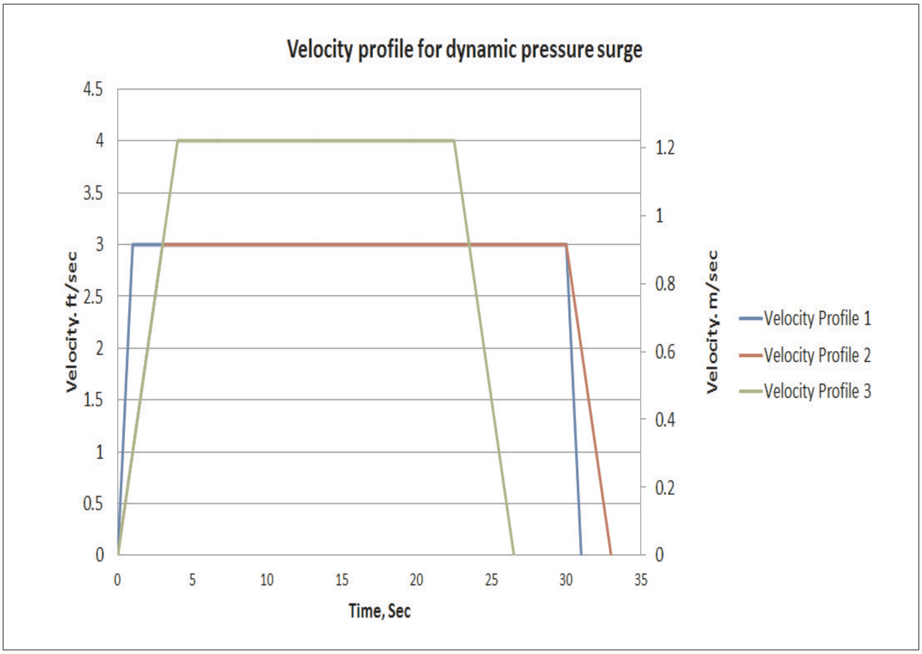

Fig. 12. Velocity profile for dynamic pressure surge

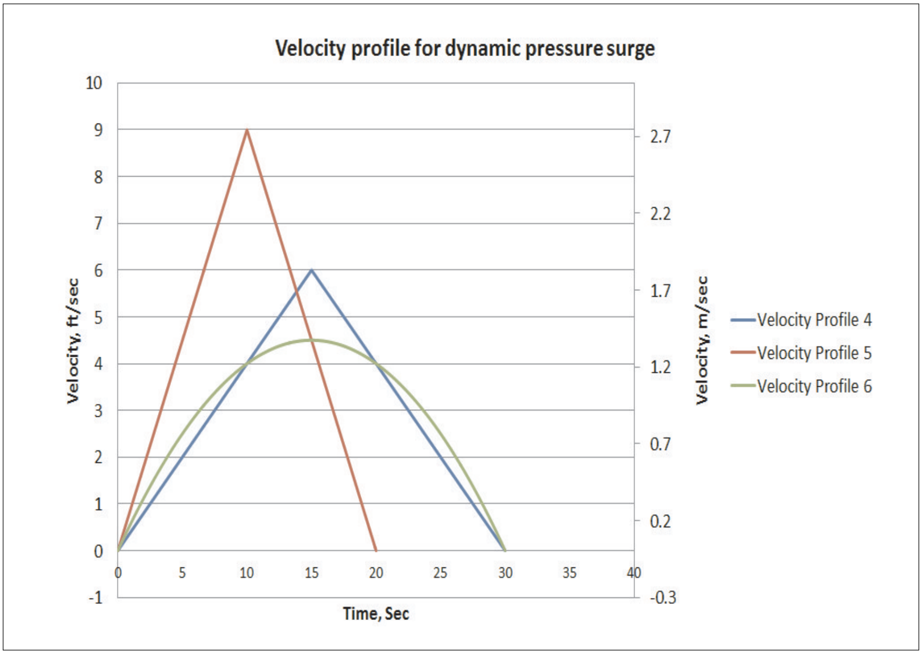

Fig. 13. Velocity profile for dynamic pressure surge

The second part of the results involvesthe dynamic downhole pressure surge corresponding to different lengths of drillstrings. Figures 14, 15, 16 and 17 are the dynamic downhole pressure surges corresponding to the six input velocity profiles when the drillstring is short and in a shallow position of the wellbore. Through observing and analyzing the results, we can make the following statements: the oscillation amplitude of downhole pressure for profile 1 is higher than that for profile 2 for the reason that the acceleration and deceleration value in velocity profile 1 is higher than those in profile 2;since tripping velocity in profile 3 is higher than that in profile 2, the amplitude of dynamic downhole pressure surge corresponding to velocity profile 3 is higher than the amplitude of dynamic downhole pressure surge corresponding to velocity profile 2; because the maximum velocity, acceleration and deceleration values in velocity profile 5 are all higher than those in profile 4, the dynamic downhole pressure surge value corresponding to profile 5 is higher than that corresponding to profile 4; the oscillation amplitude of dynamic loading for velocity 4 and velocity 6 are similar because they both change velocity slowly.

Figures 18 and 19 show the dynamic downhole pressure surges correspond to the input six velocity profiles when the drillstring is long and in a deep position of the wellbore.

Tripping velocity, acceleration and deceleration have different effects on dynamic downhole pressure changes when the drillstring is short and long. Even though the acceleration and deceleration values in velocity profile1 and 2 are not the same, the dynamic downhole pressure changes corresponding to these two velocity profiles are similar.

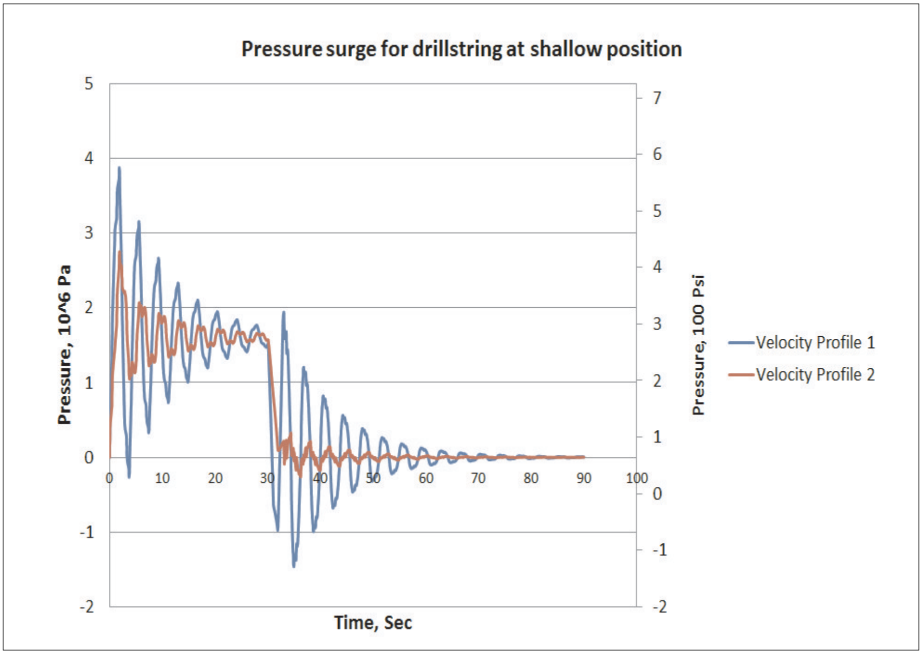

Fig. 14. Pressure surge for drillstring at shallow position

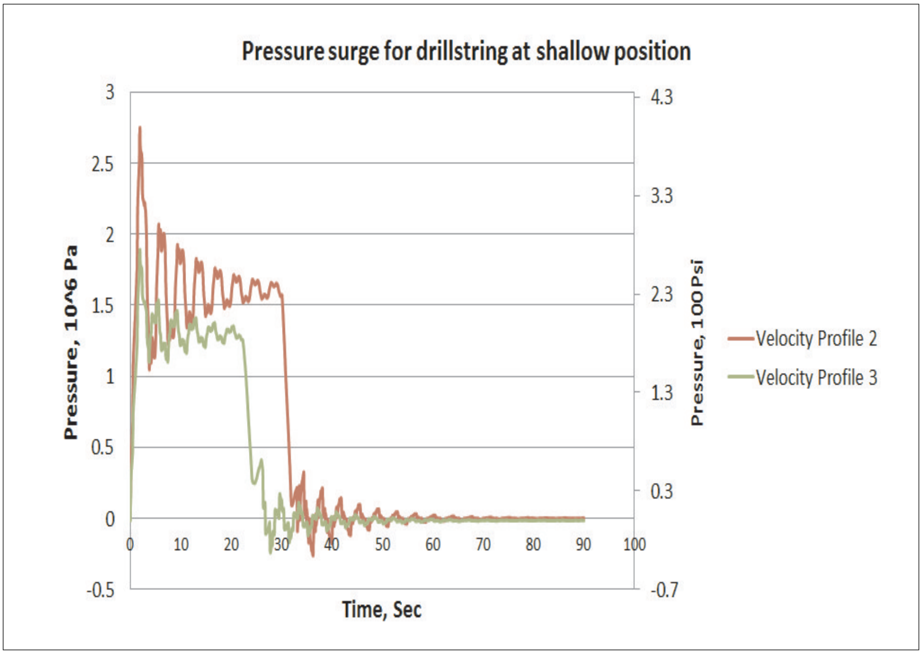

Fig. 15. Pressure surge for drillstring at shallow position

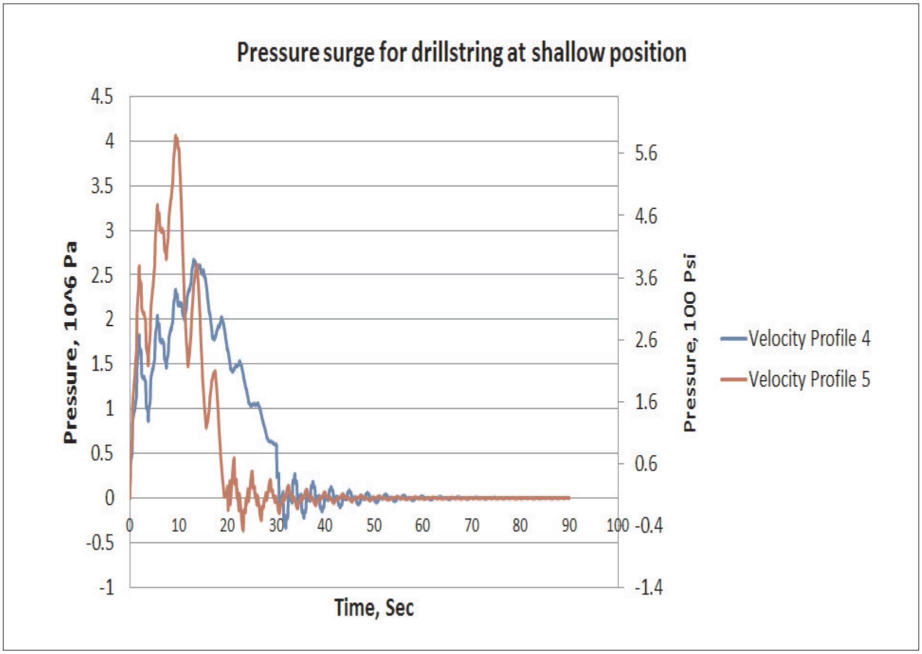

Fig. 16. Pressure surge for drillstring at shallow position

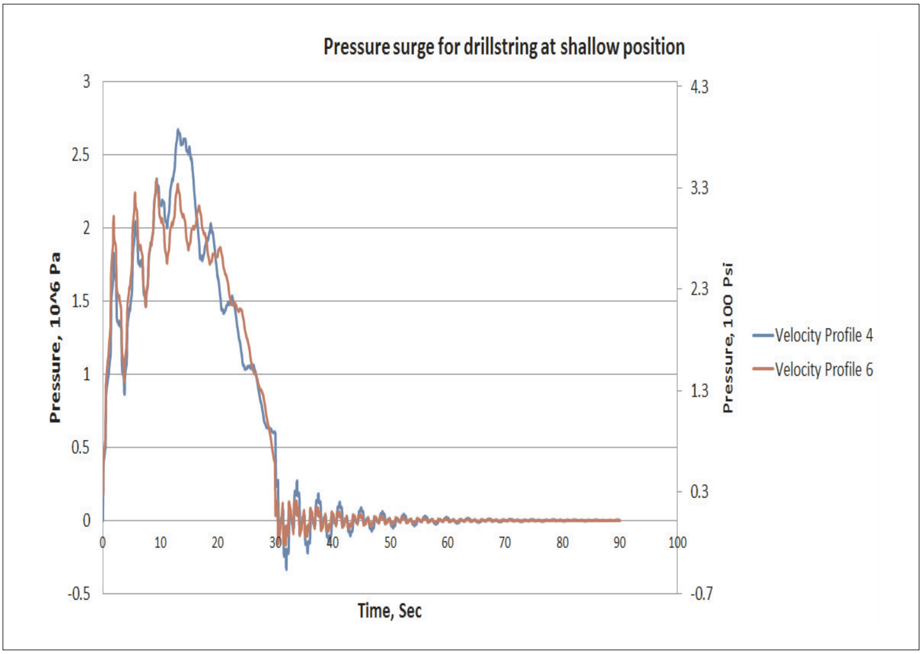

Fig. 17. Pressure surge for drillstring at shallow position

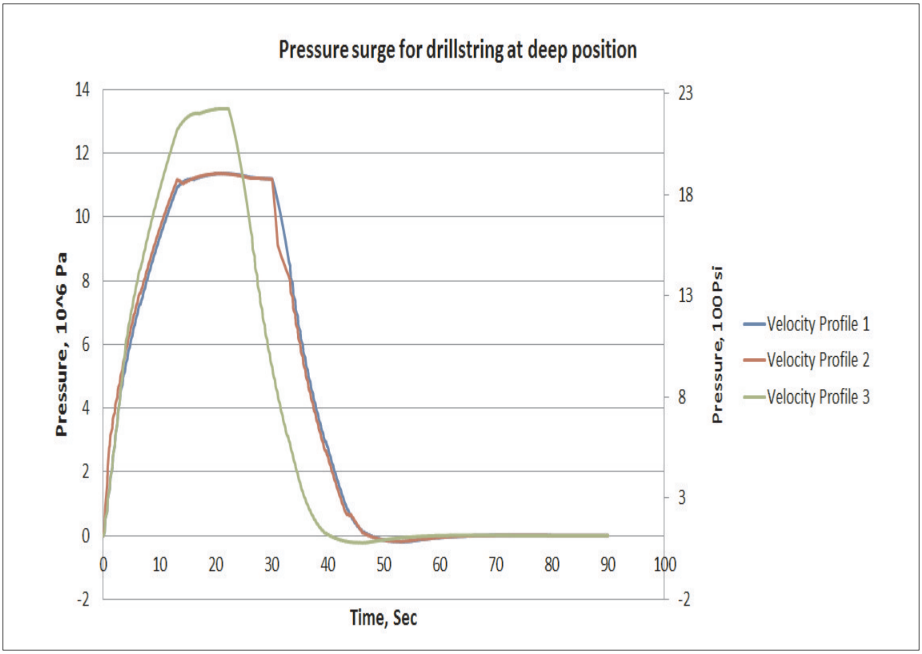

Fig. 18. Pressure surge for drillstring at deep position

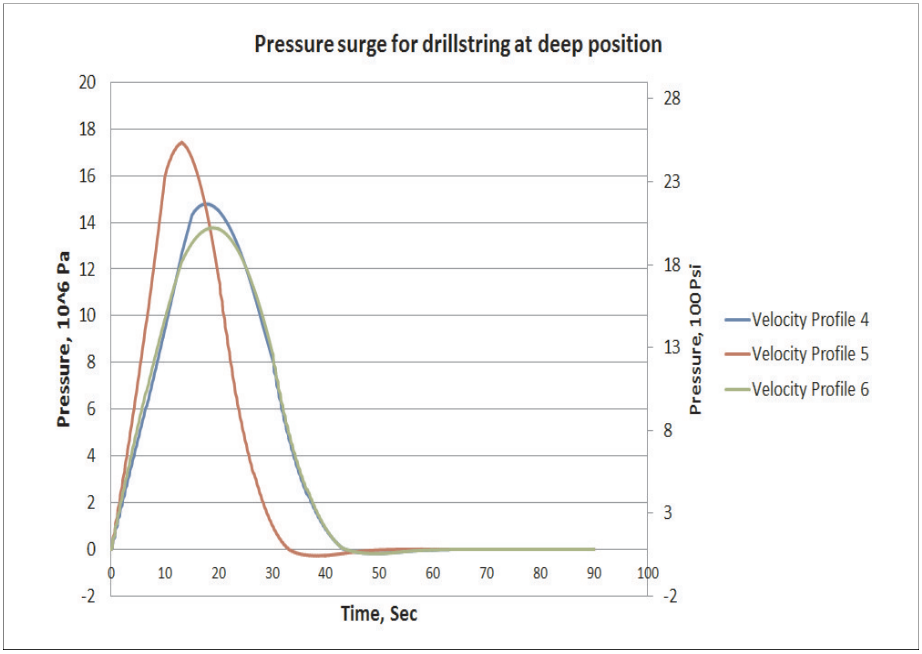

Fig. 19. Pressure surge for drillstring at deep position

On the other hand, the dynamic downhole pressure surge for velocity profile 3 is higher than those for velocity profile 1 and 2 because the maximum velocity in profile 3 is higher than that in profiles 1 and 2. From Figure 19, we can see that maximum tripping velocity is the only factor that influences dynamic downhole pressure surge regardless of the shape of the tripping velocity profile.

6. CONCLUSIONS

1. Tripping velocity profiles have a great influence on dynamic loading ofdrillstring, dynamic drillstring velocity and wellbore pressure changes. The dynamic loading of drillstring is influenced by both tripping velocity and acceleration when the drillstring is in shallow or deep position in the wellbore. On the other hand, tripping velocity is the major factor that influences dynamic wellbore pressure changes when the drillstring is in a deep position in the wellbore. Dynamic wellbore pressure changes are influenced by both tripping velocity and accelerationwhen the drillstring is in a shallow position in the wellbore.
2. The current optimization and automation of tripping programs should consider drillstring velocity profiles. Selection of a tripping velocity profile should be adapted to

depth. It is better to choose a lower maximum tripping velocity and trapezoid profile when the drillstringis in a deep position in the wellbore. When the drillstring is in a shallow position in the wellbore, we can choose a larger maximum tripping velocity and either a triangular or a parabolic velocity profile.

Acknowledgements

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