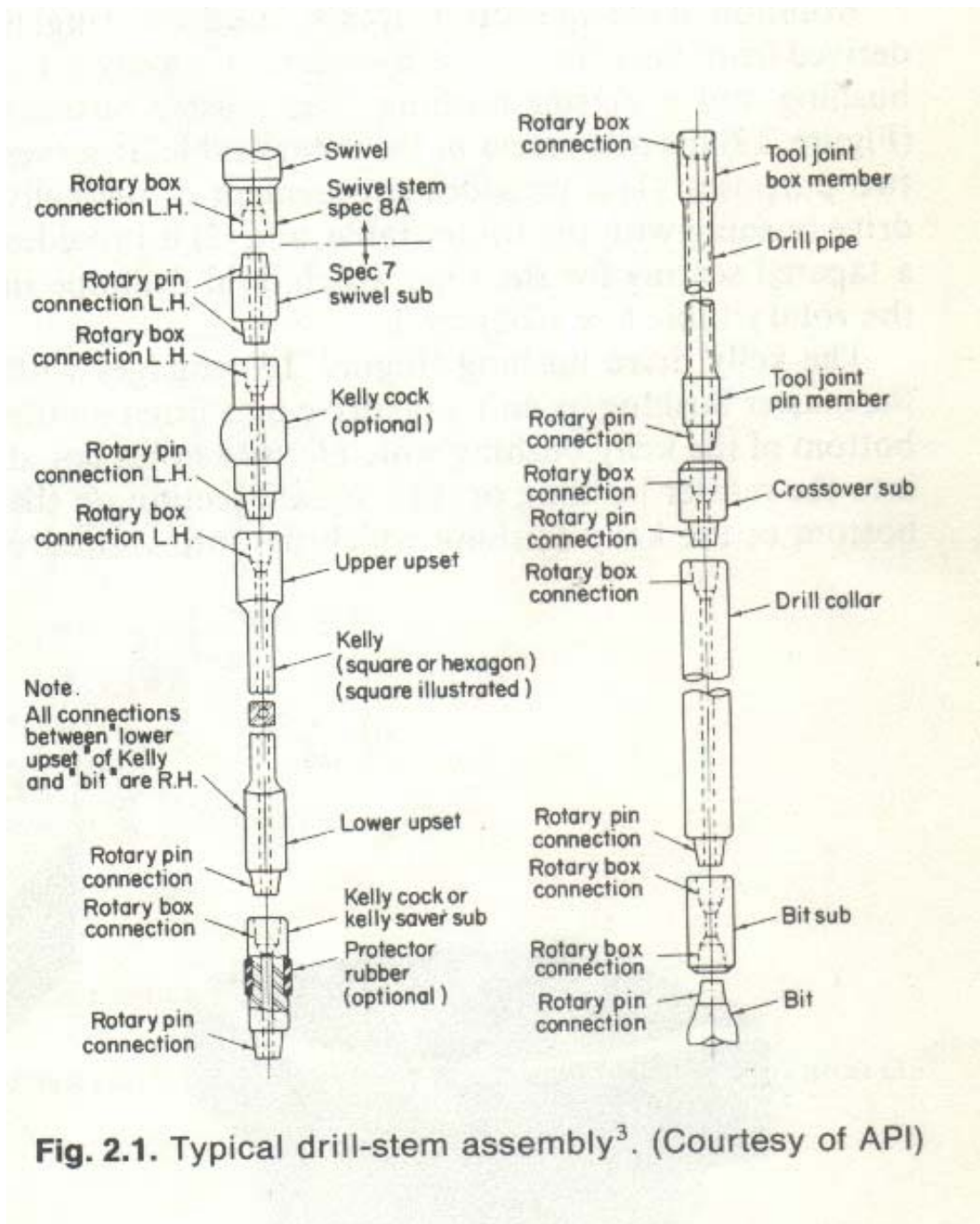


# Drill String Design

The following topics will be discussed

- Kelly
- Drill pipe
- Drill collars
- Accessories; heavy wall drill pipe, jars, stabilizers, reamers, shock sub and bit sub
- Drill bits



**Fig. 2.1.** Typical drill-stem assembly<sup>3</sup>. (Courtesy of API)

## Kelly

- Used to transmit rotation and weight to bit via drill pipe and drill collars
- Rotation and weight on bit are essential for breaking rock and making hole
- Manufactured from high grades of chrome molybdenum steel and heat treated
- Has either square or hexagonal shape
- Hexagonal is stronger than square
- Lengths are 40 ft (12.2 m) or 54 ft (16.5m)
- Manufactured in various sizes

Square	Hexagonal
2 1/2	3
3	3 1/2
3 1/2	4 1/4
4 1/4	5 1/4
5 1/4	6
6	

- Kelly is connected to Kelly drive bushing
- Kelly drive bushing engages in master bushing
- Rotation of rotary table transmits to master bushing to the Kelly bushing to the Kelly
- Kelly accessories
  - Kelly saver sub; small sub connected to the Kelly at the bottom to protect its threads from excessive wear
  - Kelly cock; a small sub installed on the top of the Kelly, or below the saver sub protect equipment above Kelly from high pressure, can be used to shut in drill pipe in case of kick

## Drill pipe

- Function to transmit rotation and drill mud under pressure to bit
- Subjected to different types of loading:

- Axial due to weight carried and its own
- Radial due to well bore pressure
- Cyclic stress reversals, due to bend in dog legs
- Must withstand all these loads
- Manufactured as seamless pipe with external (EU), internal (IU) or internal external upset (EIU)
- Upset means increasing metal size
- Manufactured in three ranges
  - Range 1: 18-22 ft
  - Range 2: 27-30 ft
  - Range 3 38-45 ft
- Five grades are available, D, E, X95, G105, S135
- The grades are manufactured in different sizes; 2 3/8, 2 7/8, 3 1/2, 4, 4 1/2, 5, 5 1/2, 6 5/8 in
- Each grade specified by nominal weight, internal diameter, collapse resistance, internal yield pressure and pipe body yield strength
- These specifications changes with time because of wear
- According to degree of wear pipe are
  - Class one: new pipe
  - Premium: uniform wear and min. wall thickness 80%
  - Class 2: min. wall thickness 65%
  - Class 3: min. wall thickness 55%
  - Tables show these specifications for each grade

### Tool joints

- Short cylindrical piece attached to each end of drill pipe via a flash weld or inertia weld process
- Threaded either internally or externally
- Externally called pin while internally called box
- Joined by stabbing the pin to the box
- Thread should have min yield strength of 120,000 psi and min tensile of 140,000 psi
- Dimensions are required for calculating the approximate weight of the drill pipe and tool joint assembly

## **Thread forms**

- **Distinguished by width of thread crest, radius of thread root, angle between flanks of adjacent threads and number of threads per inch**
- **Adapted format V-numerical number**
- **Number refers to either the width of the crest flat or the radius of the root**

## **Rotary shoulder connections**

- **Refers to the threads of the pin and box**
- **The pin of one joint engages the box of the other during make-up torque**
- **The actual seal is metal-to-metal contact**
- **API suggests the use of the term number connection (NC) to refer to pitch diameter**
- **For pitch diameter 1.063 in, the first two figures are used and NC10 will describe the rotary connection**

## **Drill collars**

- **Thick walled pipe used to provide weight on bit (WOB) to keep drill pipe in tension**
- **Drill pipe has relatively low stiffness, make it susceptible to buckling when under compression**
- **Buckling may lead to failure**
- **Failure eliminated by keeping neutral point (point of zero tension and zero compression) below drill pipe**
- **80 to 85% of buoyant weight of drill collar put under compression for safety factor of 1.15**
- **Manufactured in an average length of 31 ft**
- **Pin and box are cut from the body of the pipe**
- **Connection has tapered threads jack screw**
- **Threads are normally strengthened by cold-working the thread roots**

## **Drill collar features**

- **Fishing necks; allow DC to be fitted with small connections and fishing jobs**
- **Stepped-bore drill collars; to increase pipe strength to internal pressure**
- **Slip and elevator recess; allows DC to be handled as DP with slips and elevators**
- **Spiral grooving; to reduce possibility of sticking due to differential pressure**
- **Square drill collars; special drilling purpose such as reducing deviation in crooked hole formation**
- **K-monel drill collars; non-magnetic steel for survey instrument**

## **Drill String Accessories**

### **Heavy-wall drill pipe**

- **Has the same OD of drill pipe and reduced ID**
- **Used between DP and DCs**
- **Manufactured in four sizes: 3 1/2, 4, 4 1/2, 5 in. and in length 0f 30.5 ft**
- **Can be safely run in compression**
- **Used to provide WOB in directional and horizontal wells**
- **Number of joints used varies from 30 to 70 joints**

### **Drilling jar**

- **Defined as a mandrel slides within a sleeve**
- **The free end of the mandrel is shaped in the form of a hammer to provide a sticking action against the force of an anvil**
- **Jarring is used to free stuck pipe**
- **Can provide up word or down word forces**
- **Recommended to be run in tension**
- **Placed above the neutral point**
- **Three types: mechanical, hydraulic and mixed or hydromechanical**

## **Stabilizers**

- **Placed above the bit to control hole deviation, minimize dog-leg and prevent differential sticking**
- **Allow the bit to rotate perpendicular to the hole**
- **Two types: rotating or non-rotating**
- **Rotating includes: integral blades, sleeve, and welded blades**
- **Non-rotating comprises a rubber sleeve and mandrel**

## **Reamers**

- **Rotary reamers are provided with tungsten carbide rollers set vertically in the body of the reamer**
- **Can be three or six reaming cutters**
- **Run behind the bit to provide gauge hole**

## **Shock subs**

- **Also named a vibrating dampener**
- **Placed between the bit and drill collars**
- **Absorb vibrations and impact loads caused by drill string movement**
- **Steel rubber spring design to absorb torsional and vertical vibration**
- **Placed normally above the bit**
- **Stabilization requirement dictate placement 30 to 50 above the bit**

## **Drill string design**

- **Design means determination of length, weight, grades of drill pipe to be used during drilling, coring or any other operation**
- **Depends on: hole depth, hole size, mud weight, safety factor and/or margin of pull, length and weight of DCs, drill pipe size and inspection calls**
- **Criteria used are: tension, collapse, shock loading and torsion**

## **Tension**

- **Submerged weight should be considered**
- **Magnitude depends on mud density and steel density**

- Steel density = 489.5 lb/cu ft or 7850 kg/cu m
- Tabulated API properties should be considered for design

$$\text{➤ } P = (L_{dp} \times W_{dp} = L_{dc} \times W_{dc}) \times BF \dots\dots\dots(1)$$

$$\text{➤ } BF = \left(1 - \frac{\rho_m}{\rho_s}\right) = \left(1 - \frac{\gamma_m}{\gamma_s}\right) \dots\dots\dots(2)$$

$$\text{➤ } P_a = P_t \times 0.9 \dots\dots\dots(3)$$

$$\text{➤ } MOP = P_a - P \dots\dots\dots(4)$$

$$\text{➤ } SF = \frac{P_a}{P} = \frac{P_t \times 0.9}{(L_{dp} \times W_{dp} = L_{dc} \times W_{dc}) \times BF} \dots\dots\dots(5)$$

$$\text{➤ } L_{dp} = \frac{P_t \times 0.9}{SF \times W_{dp} \times BF} - \frac{W_{dc}}{W_{dp}} L_{dc} \dots\dots\dots(6)$$

$$\text{➤ } L_{dp} = \frac{P_t \times 0.9 - MOP}{W_{dp} \times BF} - \frac{W_{dc}}{W_{dp}} L_{dc} \dots\dots\dots(7)$$

**Collapse**

- Defined as external pressure required to cause yielding of drill pipe or casing
- In normal operation the mud column inside and outside drill pipe are both equal in height and in density
- Therefore zero differential pressure across pipe body and in turn zero collapse

- In some cases (DST) pipe is run partially full to encourage fluid flow for test
- The maximum differential pressure across drill pipe for DST calculated as follows
- $\Delta P = 0.052 \times \rho_1 \times L - 0.052 \times \rho_2 \times (L - Y) \dots \dots \dots (8)$
- For completely empty drill pipe  $Y = 0$
- Collapse safety factor determined as follows
- $SF = \frac{\text{Collapse Resistance}}{\text{Collapse Pressure } (\Delta P)} \dots \dots \dots (9)$
- Safety factor of 1.125 is normally used
- Collapse resistance is reported in API tables
- Collapse pressure is calculated from Eq. 8
- Normally, pipe is subjected to collapse and tension together
- Corrected collapse resistance has to be done as follows:
- Determine tensile stress at joint under consideration by dividing the tensile load by the pipe cross section
- Determine the ration between the tensile stress and the average yield strength
- Use biaxial yield stress curve, determine the % reduction in collapse resistance corresponding to the ratio calculated
- Use this value for collapse safety factor calculation

**Shock loading**

- Arises between slips area set and moving drillpipe
- Can contribute to parting of pipe in marginal design
- Add additional tensile force,  $F_s$  to the pipe
- $F_s = 3200 \times W_{dp} \dots \dots \dots (10)$



**Torsion**

- **Drill pipe torsional yield strength subjected to pure torsion is given by:**

- $Q = \frac{0.096167 x J x Y_m}{D} \dots\dots\dots(11)$

- **When pipe subjected to torsion and tension**

- $Q = \frac{0.096167 x J}{D} \sqrt{Y_m^2 - \frac{P^2}{A^2}} \dots\dots\dots(12)$

- $J = \frac{\pi}{32} (OD^4 - ID^4) = 0.098175 (OD^4 - ID^4) \dots\dots(13)$

**Stretch of drill pipe**

- **Drill pipe stretches under the action of DCs and its own weight**

**Stretch due to weight carried**

**Due to weight of DC's**

- **In ft.lb system**

- $\Delta L_1 = \frac{W_{dc} x L_{dc} x L_{dp}}{735444 W_{dp}} \dots\dots\dots(14)$

- **In metric system**

- $\Delta L_1 = 373.8 x 10^{-10} \left( \frac{W_{dc} x L_{dc} x L_{dp}}{W_{dp}} \right) \dots\dots\dots(15)$

**Due to own weight**

➤ **In ft.lb system**

$$\Delta L_2 = \frac{L_{dp}}{9.625 \times 10^7} (65.44 - 1.44) \rho_m \dots \dots \dots (16)$$

➤ **Mud density in ppg and length and stretch in ft**

➤ **In metric system**

$$\Delta L_2 = 2.346 \times 10^{-8} L_{dp} (65.44 - 1.44 \rho_m) \dots \dots \dots (17)$$

➤ **Mud density in kg/l, length and stretch in meter**

### Critical rotary speed

- **Components of drill string can vibrate in three modes**
- **Axial or longitudinal; can be recognized at surface**
- **Torsional; cannot be seen due to rotary table control of angular motion**
- **Transverse or lateral; possible only with drill pipe**
- **Vibration cause resonance and hence wear and fatigue**
- **Pipe vibration should coincide with bit rotation**
- **Calculated based on drill string length and drill pipe dimensions or drill collar length**

### Calculation based on total length and drillpipe dimesions

$$\text{rpm} = \frac{258\,000}{L} \text{ (longitudinal vibration)} \dots \dots \dots (19)$$

$$\text{rpm} = \frac{4760000}{L(\text{inch})} \left( OD^2 - ID^2 \right)^{1/2} \quad (\text{transversel vibration}).(19)$$

- **Example: Determine the critical rotary speed for a 10,000 ft drill string consisting of 5 in OD/4.276 in ID drill pipe and 800 ft drill collars**
- **Solution:**
- **Longitudinal rpm (Eq. 18) = 25.8 rpm**
- **Transversal rpm (Eq. 19) = 242 rpm**

### Drill collar length

- **Drill collars assumed to be fixed at the drill bit and free at the drill collar/drill pipe interface**
- **Drill bit displacement frequencies are consistently three cycles for every bit revolution for three-cone bits**
- **Frequency of vibration at the bit is given by:**

$$f = 3N \times \left( \frac{1}{60} \right) \quad \text{cycles/sec} \dots \dots \dots (20)$$

➤ **N rotary speed of bit**

➤ **Critical rotary speed can be calculated as:**

$$N = 20xf \quad \text{rpm} \dots \dots \dots (21)$$

➤ **The natural frequency of longitudinal vibration  $f_1$**

$$f_1 = \frac{4212}{L_{dc}} \quad \text{cycles/sec} \dots \dots \dots (22)$$

➤ **The natural torsional frequency of drill collar**

$$f_2 = \frac{2662}{L_{dc}} \quad \text{cycles/sec} \dots \dots \dots (23)$$

- **Bit rotation must be tolerated at a speed less than or greater than the natural frequencies  $f_1$  and  $f_2$**
- **Example: Determine the critical rotary speed of 10,000 ft drill string with 800 t drill collars**
- **Solution**
- **$f_1 = 4212/800 = 5.265$  c/s**
- **$f_2 = 2662/800 = 2.3275$  c/s**
- **$N_1 = 20 \times 5.265 = 105$  rpm**
- **$N_2 = 20 \times 2.3275 = 67$  rpm**
- **Then drill pipe must be rotated below 67 rpm or greater than 105 rpm**
- **The two method shows great variation**
- **String vibration can be reduced by changing the natural frequencies: using shock absorber or increasing the drill collar length or using HWDP**
- **Increasing or applying mechanical damping**