Casing Design

- What casing size?
  - Set by Pump, Packer, Tubing Requirements and Limited by meeting pressure and economic objectives.
    - Where is the largest tubing? The casing has to accommodate the tubing.
    - Are kickoffs planned? – what size tubular is in the kickoff?
    - What about pump and other equipment needs – and sizes….
    - How many casing strings are needed to make depth?
- A casing string is designed from the bottom to the top and from the inside to the outside.

Slim Hole Wells

- Slim hole wells are often drilled and completed to try to meet economic goals.
- From completion, stimulation, reliability, lift and workover considerations, a slim hole well is often the very worst choice.
- Choose wisely!

Casing Design Example

- Simple hand-worked design using collapse, burst and tensile in the design.
- First example – a multiple weight/grade pick to show where strength is required – avoid this design in the real world if possible.
- Second – calculation of a single pipe weight and grade that can be used.

NOTE - This example problem is not intended to teach casing design, nor is it a replacement for modern casing design methods. More modern equations (e.g., API equations) are available as are a variety of computer simulations that are much more accurate that this approximation.

Buoyancy – brine offsets part of all of the pipe weight

$$W_b = W_a\,(1 - \rho_f / \rho_s)$$

W_b = buoyed weight of casing in a fluid

W_a = air weight of casing

ρ_f = density of fluid, lb/gal

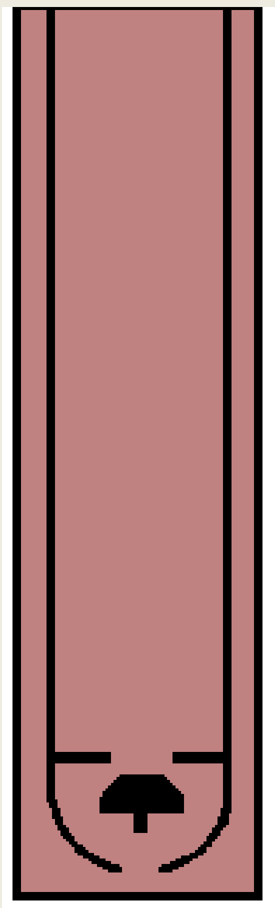
ρ_s = density of steel = 65 lb/gal

Simple Buoyancy Example

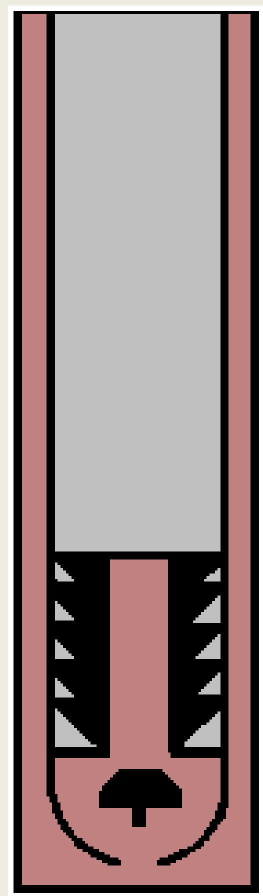
- 10,000 ft string, 7”, 26 lb/ft, 12 lb/gal mud
- W_{air} = (10,000 ft) (26 lb/ft) = 260,000 lb
- W_{buoyed} = (260,000 lb) (1- (12/65.4)) =
  = 212,294 lb
- For larger pipe strings and heavier brine, the effect of buoyancy is increased. Very large pipe in heavy brine can actually float.

Calculated Hook Load Changes

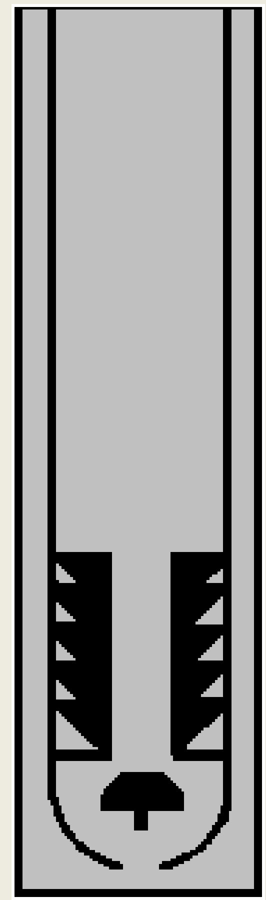
Mud in Hole
Mud in Csg
212,300 lb



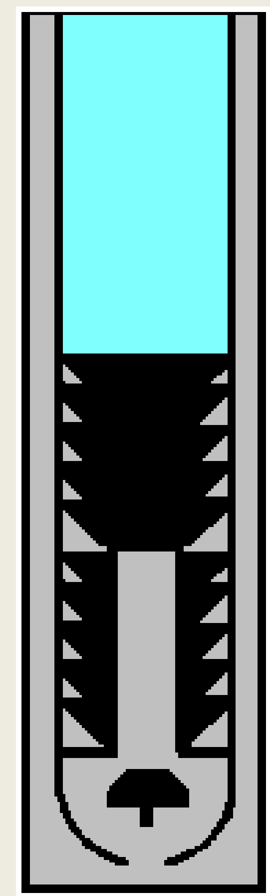
Mud in Hole
Cmt in Csg
283,600 lb



Cmt in Hole
Cmt in Csg
195,600 lb



Cmt in Hole
Water in Csg
65,936 lb



Downhole Causes of Axial Compression

- Sources of Axial Compression:
  - Buoyancy – before cement sets
  - Poisson's effect – if casing is landed or sticks
  - Reverse ballooning – too much outside pressure
  - Thermal expansion – only if both ends fixed
  - Borehole friction – deviated holes and doglegs
  - Drag – same as friction in most cases
  - Slack-off – same as landing

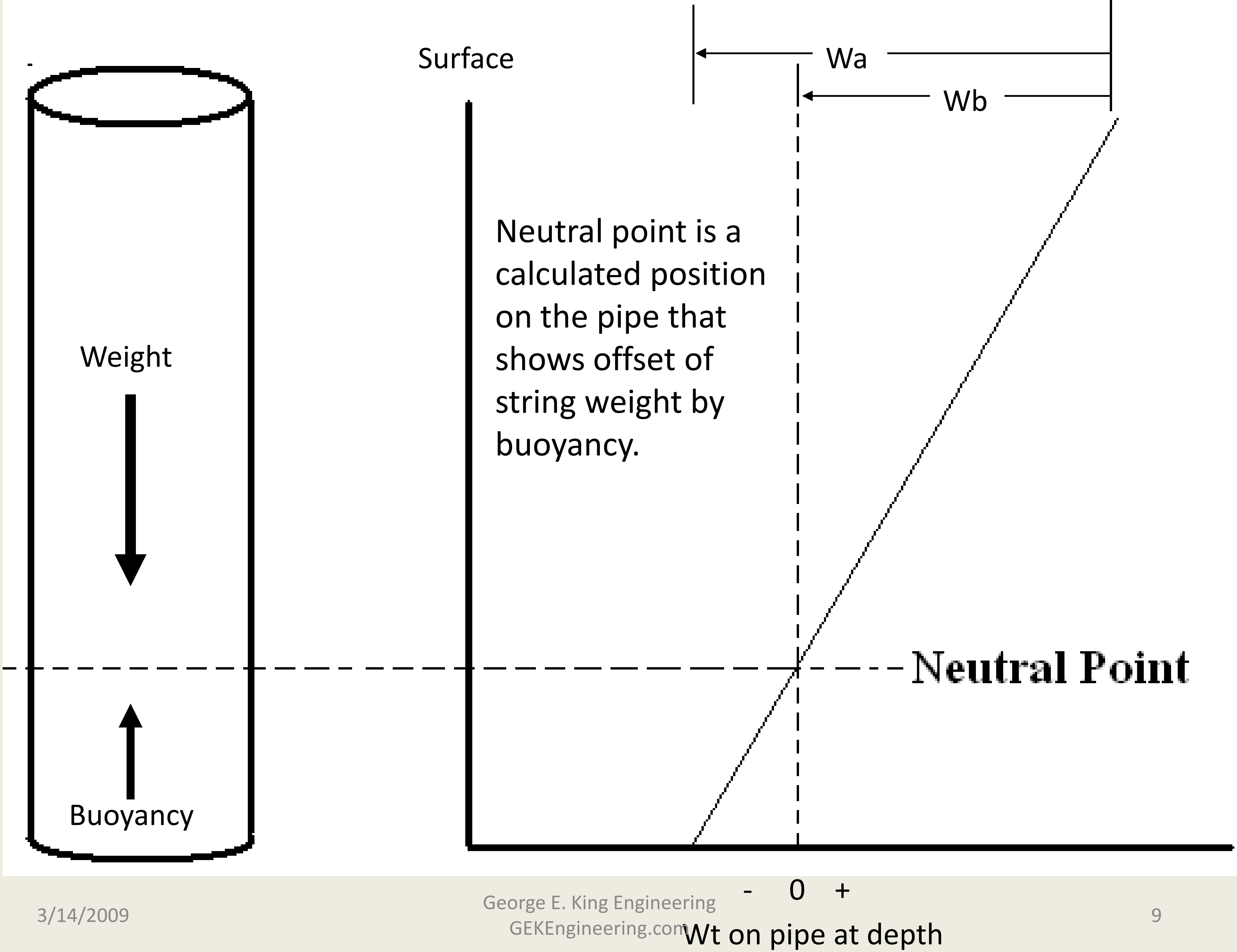
Axial (Tensile) Force versus Depth in a Casing String

- 12,000 ft, 9-5/8”, 53.5 lb/ft casing (0.545 wall), suspended in 16 lb/gal mud.

- W_a = (12,000 ft) (53.5 lb/ft) = 642,000 lb

- W_{buoyed} = (642,000 lb) (1- (16/65.4)) =484,935 lb

- Buoyancy force = 642,000 – 484,935 = 157.065 lb


Surface
Wa
Wb
Neutral point is a calculated position on the pipe that shows offset of string weight by buoyancy.
Weight
Buoyancy
Neutral Point
- 0 +
Wt on pipe at depth

Buoyancy Neutral Point – remember – this is a calculation aid, not a real point in the well.

1. Casing below the neutral point is considered to be in "compression" for the purposes of the calculations and collapse forces dominate the casing strength design.
2. Casing above the neutral point is in tension and burst strength dominates the design. However, casing in tension must be derated for the effect of tension on collapse rating.

Collapse Design – Be careful, this type of design considers only initial, static froces and does not consider dynamic, production and thermal forces

$Pcx = 0.052\ \rho_f\ Dx$

Pcx = collapse pressure exerted by the mud at a depth Dx

ρ_f = density of mud, lb/gal

Dx = depth

With this formula a collapse pressure at an estimated depth is calculated (safety factor has not been applied yet).

Casing Design Example – Note – this is the old method that uses multiple picks of string weight and grade – it is useful for showing how a simple design works, but many pipe grades and weights would create confusion at the well during casing running.

Design a 10,000 ft string of 7” casing.

Pore pressure = 8000 psi at 10,000 ft.

Mud weight = 16.3 lb/gal.

Frac gradient = 0.9 psi/ft.

Convert to gradients:

Pore pressure = 8000/10,000 = 0.8 psi/ft

Mud weight = 16.3 lb/gal * (0.052) = 0.85 psi/ft

Frac gradient = 0.9 psi/ft

Calculate the “Theoretical” Buoyancy Neutral Point.

N.P. = Dx (1- (fluid density/steel density)

= 10,000 ft (1 – (16.3/65.4)

= 7500 ft

This is the equivalent amount of the string weight at the surface. If a heavier fluid was used, the N.P. would be shallower in the well (more of the pipe weight would be offset by the buoyancy).

Maximum Collapse Force

Pcx = (10000 ft) * (0.85 psi/ft) = 8500 psi

Since it is a force and not a rating, the safety factor is multiplied:

Pcx = (8500) * (1.1) = 9350 psi

Now, select a pipe with a collapse pressure minimum that will handle the load…. No need to derate the pipe number, the safety factor has already been applied on the force (or load).

First pick… 7”, 32 lb/ft, C-95, Pc = 9730 psi.

This is the bottom joint – there is less strength required as the strength analysis comes up the well – until it nears the top. The strength required is maximum at the bottom (collapse is maximum) and at the top (burst is maximum).

Although this method would lead to many different weights and grades, the best approach is a single selection of strong casing.

Casing Strength Pick

- Start with a casing of the right alloy, and select the first pick in the middle of the range.

Weight, lb/ft	Collapse, psi	Grade
23	4150	C-95
26	5870	C-95
29	7820	C-95
32	9730	C-95
35	11,640	C-95
28	13,420	C-95

Next, select a lower strength string…

Pick 7”, 29 lb/ft, C-95, Pc = 7820 psi

Pcx = 7820/1.1 = 7109 psi collapse strength

How deep can it be set?

Depth = 7109 psi/0.85 psi/ft = 8360 ft

Set Point – for the 32 lb/ft top

- The bottom of the 29 lb/ft sets the top of the 32 lb/ft. Note – the 32 lb/ft string can be run higher but the 29lb/ft is theoretically cheaper and lighter.
- The 32 lb/ft runs from 8360 to 10,000 ft.

Select a third string.....

7”, 26 lb/ft,   C-95,   Pc = 5870 psi

Safety factor = 1.1, Pcx = 5870/1.1 = 5330 psi

Set depth = 5330/0.85 = 6270 ft

Neutral Point = 7500 ft – since this depth is above the N.P., the calculations switch to burst design rather than collapse design.

Deration of the collapse for tension effects is common – use 4% deration as a starting point, but the final effect is usually between 1% and 2% except in extreme cases.

Effect of axial loads on collapse and burst

Casing in tension is weaker in collapse and stronger in burst – consider it for collapse calculations.

Casing in compression is weaker in burst and stronger in collapse – ignore it for collapse calculations.

Derate for collapse:

1. Derate maximum depth by 4% (this is an experience estimate, the correct value is usually between 2% and 4%).

2. Calculate unit tensile stress:
   St = (7500 ft – 6020 ft) * 26 lb/ft = 38480 lb

3. Axial load factor = (unit tensile stress/tensile body strength)
   = (38480 / 717,000) = 0.054

4. Derating factor (from deration tables for casing) = 0.985

5. Pc = (5330 psi)(0.985) = 5280 psi

6. Collapse check = (5250 / 0.85) = 6176 ft,
   first guess of 6020 ft is OK.

Design to this point:

Interval	Weight	Grade
10,000’ to 8360’	32 lb/ft	C-95
8360’ to 6020’	29 lb/ft	C-95
6020’ to ?	26 lb/ft	C-95

Since the depth is now above the buoyancy neutral point, burst becomes the basis for design.

Safety Factors

Safety factors used in the calculations vary with the application. The following as general estimates for this example. Safety factors must be set by engineering experts well versed in your application.

- For this problem:
  - Collapse – risk: lose a section of the well, safety factor of 1.1 is typical.
  - Burst – risk: life endangered justifies a must higher safety factor, 1.2 to 1.4 is typical.
  - Tension – risk: dropping the string. Because of variances in coupling make-up strength, a safety factor is 1.5 to 1.7.

Burst Design

Worst case– blow out with gas bubble in the hole.

At Surface:

$$Ps = (0.052\ \rho_p\ Dx) - (Gg\ Dx)$$

ρ_p = pore pressure equivalent wt., lb/gal

Dx = depth to pay

Gg = Gas gradient, 0.1 psi/ft for this problem

Calculate a Surface Pressure Estimate.

Lesser of:

Fracture gradient less a gas gradient

$$Ps = (0.9 - 0.1)\text{psi/ft} * 10{,}000 \text{ ft} = 8{,}000 \text{ psi}$$

Formation pressure less a gas gradient (0.1 psi/ft)

$$Ps = (0.8 - 0.1) * 10{,}000 \text{ ft} = 7{,}000 \text{ psi}$$

Use 7,000 psi as maximum surface pressure

Now, how shallow can the 26 lb/ft C-95 be set?

Pb = 8600 psi, with safety factor of 1.4

Pb = 8600/1.4 = 6140 psi

Shallowest set depth:

$$Dx = [(7000 \text{ psi} - 6140 \text{ psi}) / (0.8 - 0.1)]$$

$$Dx = 1230 \text{ ft}$$

26 lb/ft runs from 6020 ft to 1230 ft.

Need a stronger pipe to run to surface.....

A stronger pipe must be set to surface....

Select 26 lb/ft, P-110

Pb = 9960 psi, safety factor of 1.4

Pb = 9960/1.4 = 7110 psi

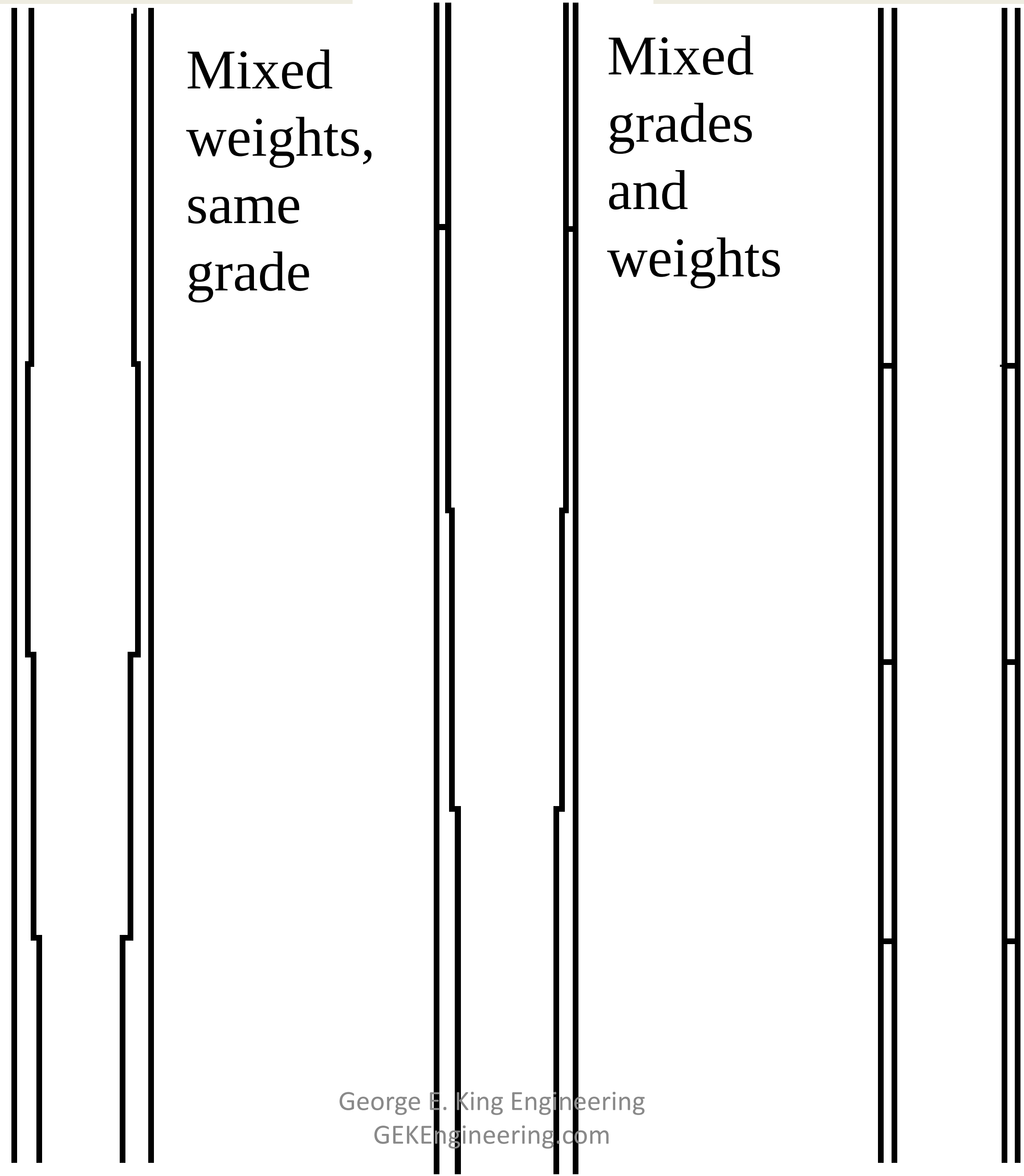
Dx = [(7000 – 7110) / (0.8 – 0.1)] < 0

The P-110 can be run to surface.

Why would a multiple weight or multiple grade casing string be a problem?

- Hard to keep the weight and grades in correct order – would take much longer to run the string.
- A multiple inside diameter string would also create setting problems for packers.

Casing Design Options – think about running and setting packers.



What happens if a joint of the heaviest weight casing (smallest ID) is accidently set at the surface?

Tensile Ratings

- Two ratings for tensile rating:
  - Body Yield = used in collapse rating calculations
  - Joint Yield = used in tensile design
- Connection Strength
  - API connection, body stronger than threads
  - Premium connections, joint often stronger than body

Tension Design (just pipe above the "neutral point shown"), s.f. = 1.7 for the example.

Pipe Length	Wt/ft	Grade	Load lb	Cummul ative lb	Joint Rating lb
7500 – 6020 ft	29	C-95	42,920	42,920	683,000/1.7 = 487,850
6020 – 1230 ft	26	C-95	124,540	167,460	593,000/1.7 = 348,820
1230 – 0 ft	26	P-110	31,980	199,440	693,000/1.7 = 495,000

Final Design – multiple casing

Interval, ft	Wt/ft	Grade	Connection
0 – 1230	26	P-110	LT&C
1230 – 6020	26	C-95	LT&C
6020 – 8360	29	C-95	LT&C
8360 – 10,000	32	C-95	LT&C

A Better Design?

- A simpler approach that yields a reliable design may be to use one weight and grade of casing that can handle the forces anywhere in the well.
- Exceptions:
  - Very long strings.
  - Corrosion control changes along the well.
  - Limitations of rig lifting power,
  - Etc.

Single String – Quick Look

- Take the 32 lb/ft, 7”, C-95 that was suitable for the bottom section (collapse resistance).
- Check it against the burst requirement at surface: Pb = 11760 psi / 1.4 = 7685 psi, which is more than the 7,000 psi max Ps – OK
- Check the tensile rating: 768,000 / 1.7 = 451,764 lb capacity (max string weight was 199, 440.
- The 32 lb/ft., C-95, 7” can be run from bottom to top, satisfying simple loads of collapse, burst and tensile.

Quiz – Casing Problem

1. For a 10000 ft deep well, with 9.0 lb/gal mud. Select a single casing size (minimum 6.1” ID), grade and weight that can be run to bottom in a 9-1/4” hole and will withstand the collapse pressure of the mud to a 1.1 safety factor and the burst pressure (3600 psi is maximum surface pressure from the zone, 4600 psi is BHP) to a 1.4 safety factor. Make assumptions as needed, but record the assumptions with the solution.