Master of
Well Engineering

Directional Drilling

Directional Drilling

- When is it used?
- Type I Wells (build and hold)
- Type II Wells (build, hold and drop)
- Type III Wells (build)
- Directional Well Planning & Design
- Survey Calculation Methods

What is Directional Drilling?

Directional Drilling is the process of directing a wellbore along some trajectory to a predetermined target.

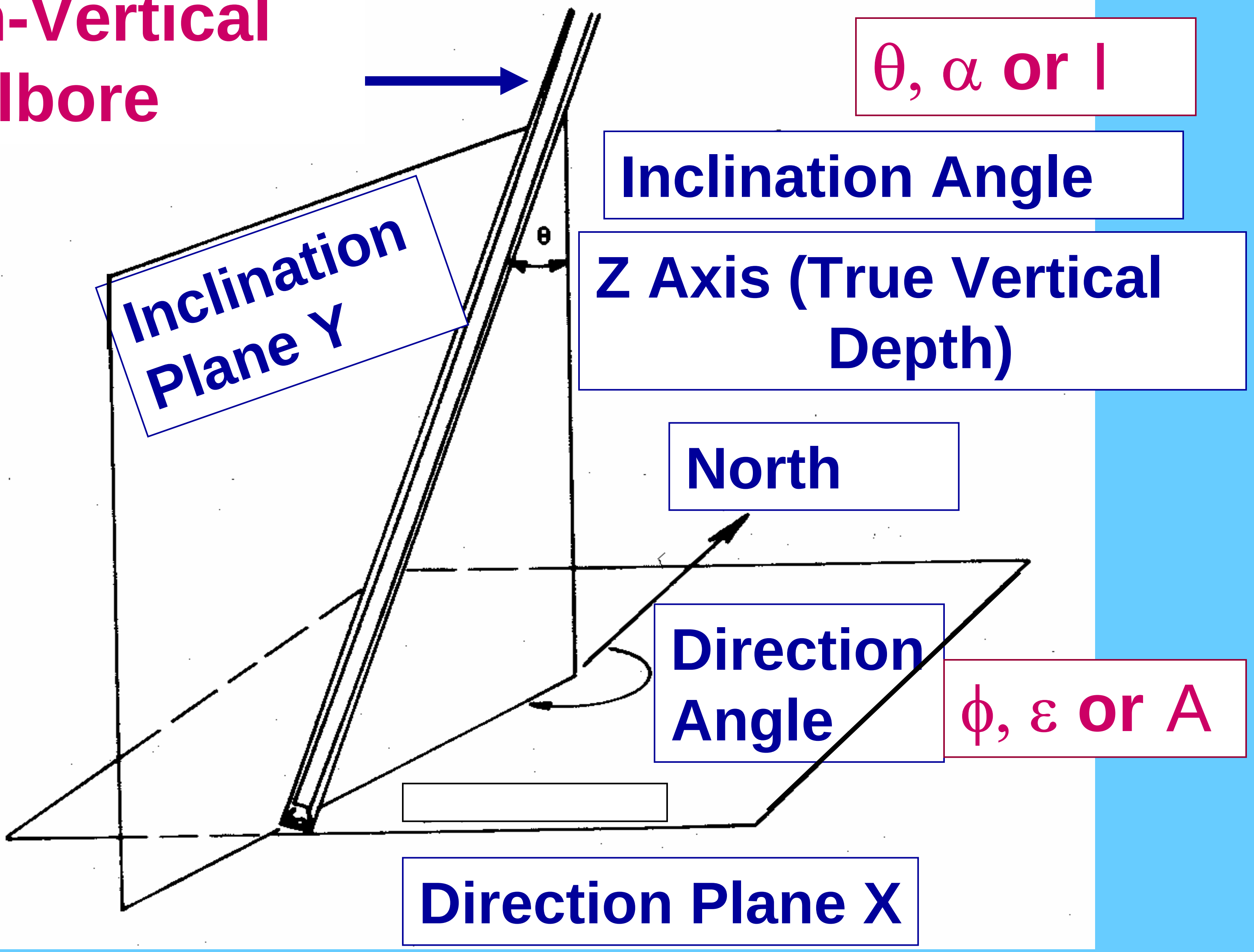
Basically it refers to drilling in a non-vertical direction. Even “vertical” hole sometimes require directional drilling techniques.

Examples: Slanted holes, high angle holes (far from vertical),
Extended Reach Holes, and Horizontal holes.

Reasons for directional wells

- **Cannot drill to target from with a vertical wellbore (more economic)**

Non-Vertical Wellbore



θ, α or I

Inclination Angle

Z Axis (True Vertical Depth)

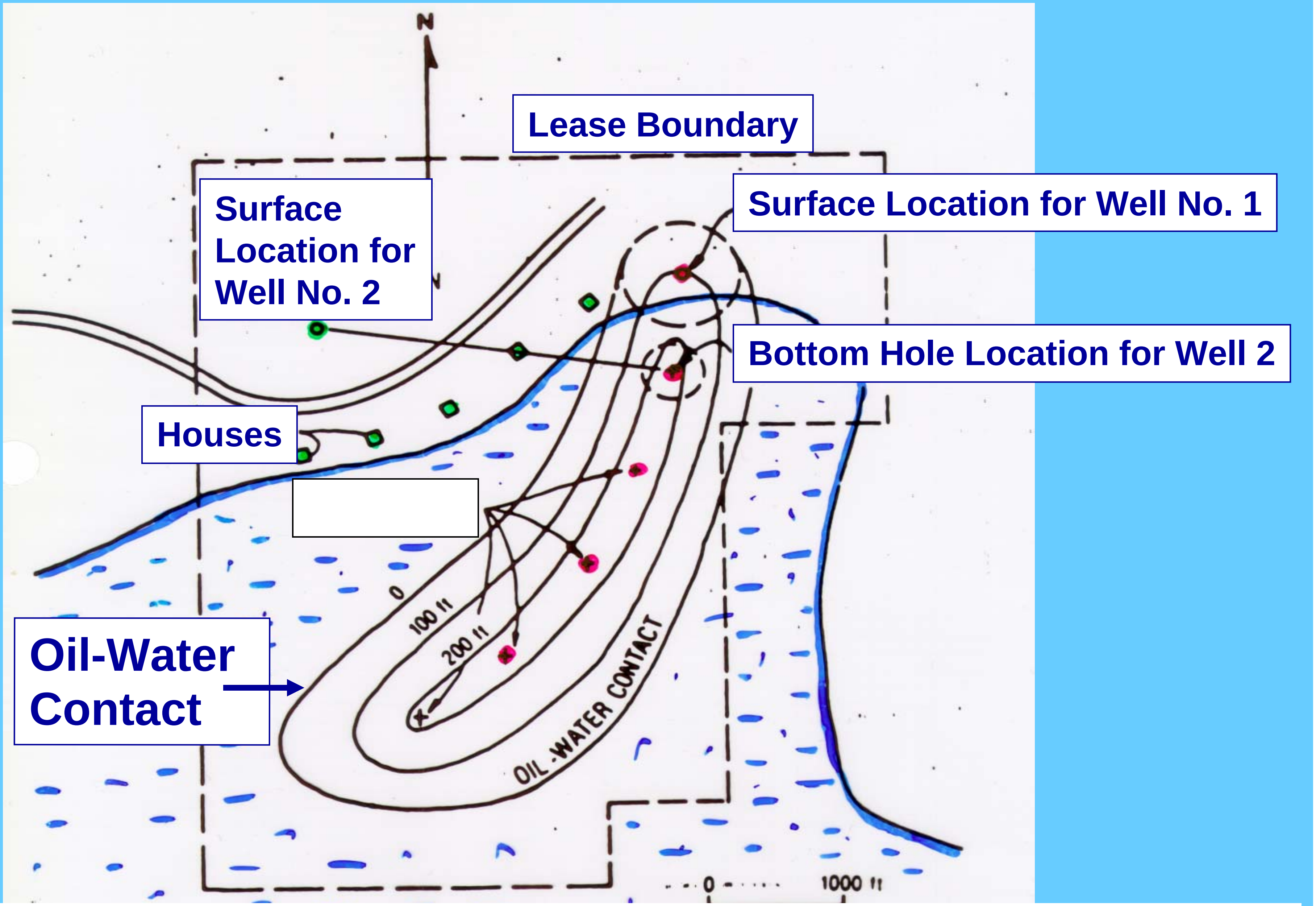
Inclination Plane Y

North

Direction Angle

ϕ, ε or A

Direction Plane X



Lease Boundary

Surface Location for Well No. 1

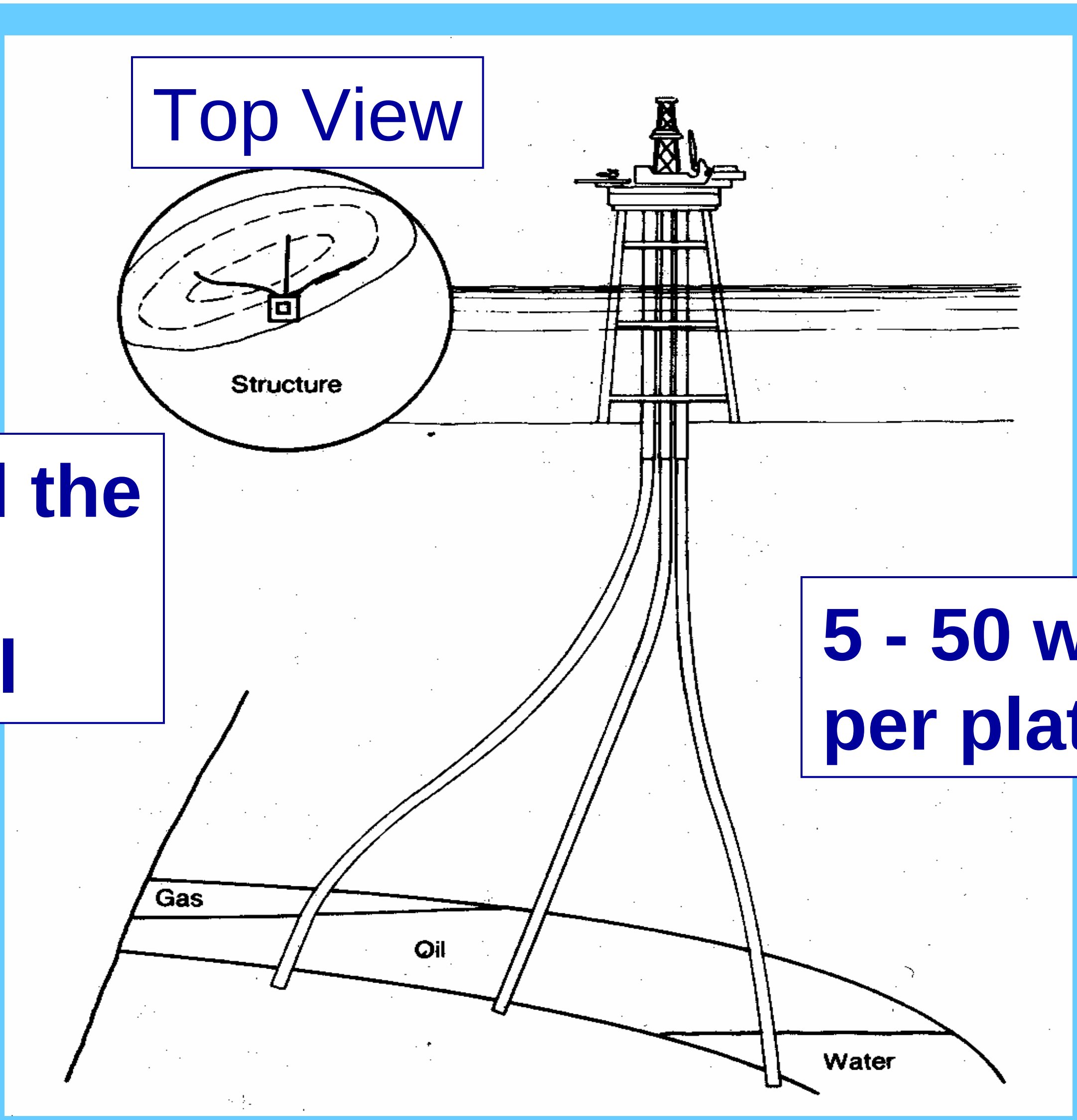
Surface Location for Well No. 2

Bottom Hole Location for Well 2

Houses

Oil-Water Contact

Figure 8.2 - Plan view of a typical oil and gas structure under a lake showing how directional wells could be used to develop it. Best locations? Drill from lake?



NOTE: All the wells are directional

5 - 50 wells per platform

Figure 8.3 - Typical offshore development platform with directional wells.

Drilling Rig Inside Building

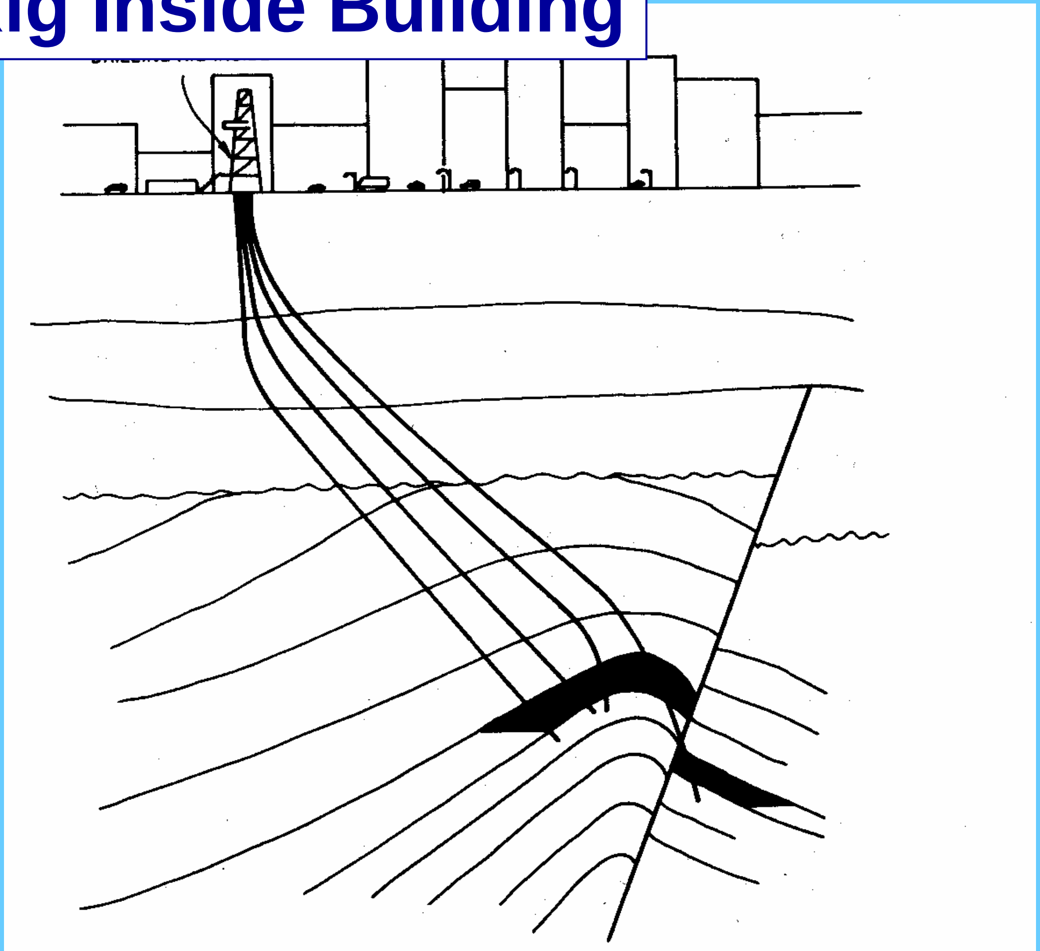
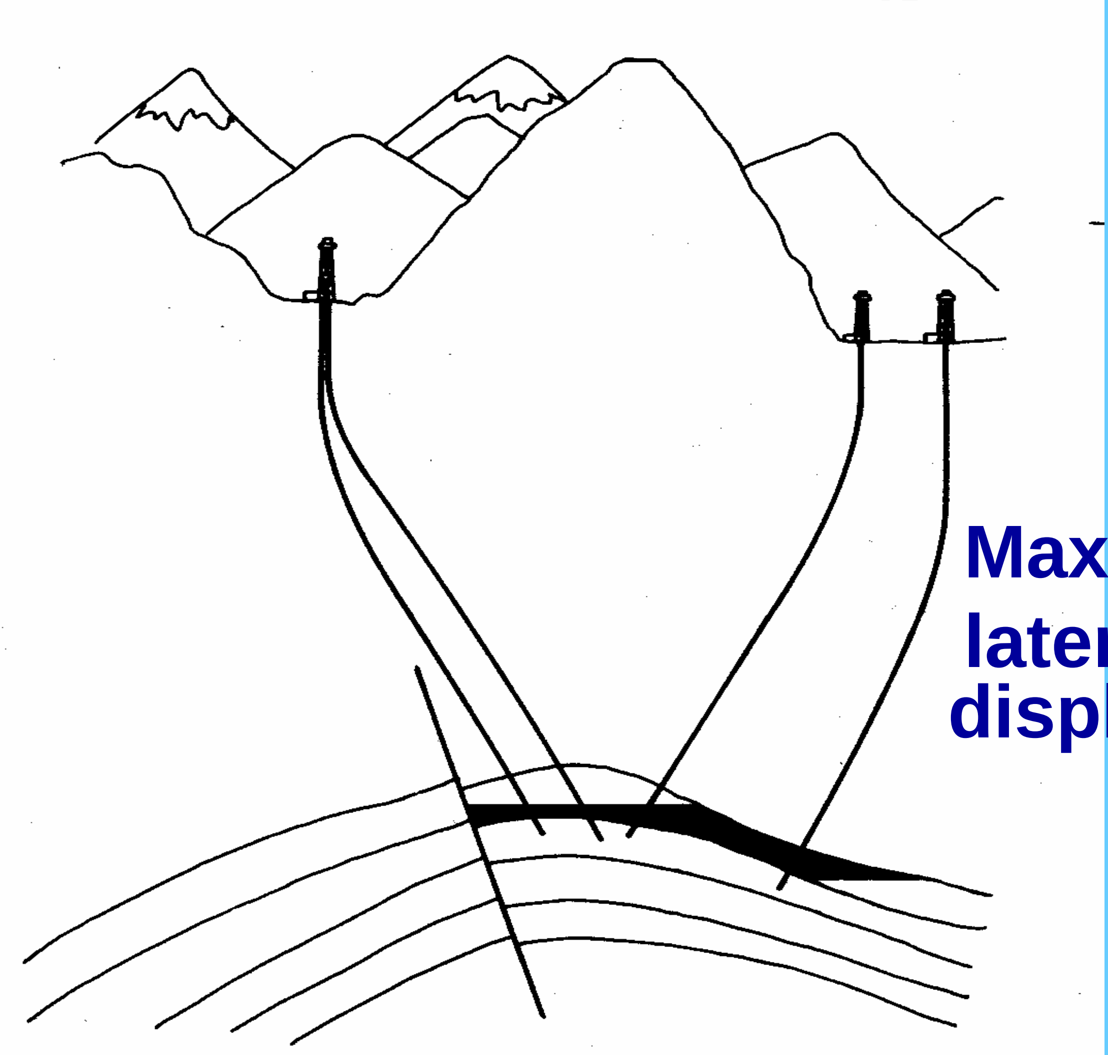


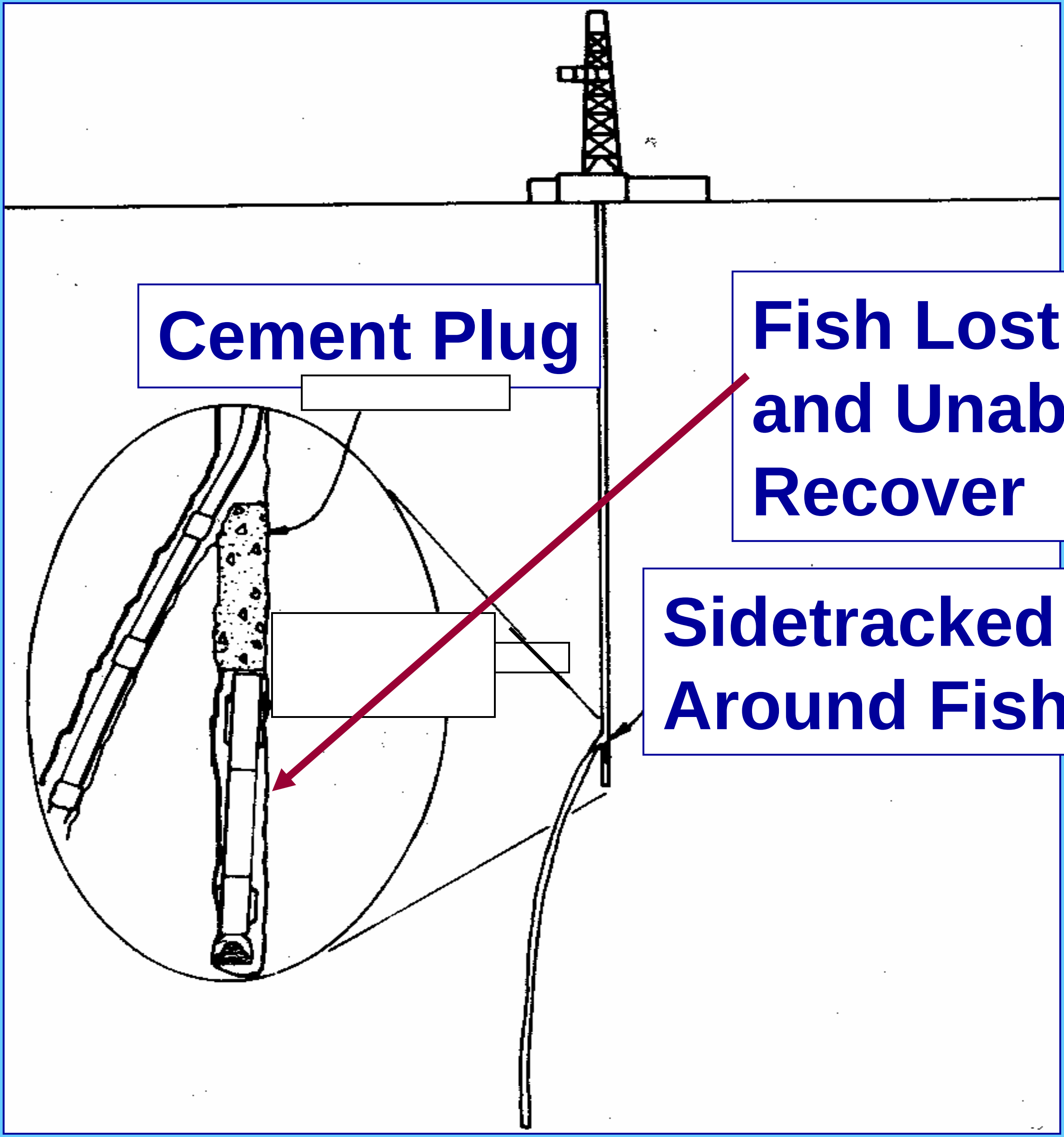
Figure 8.4 - Developing a field under a city
using directionally drilled wells.

Why not drill from top of mountain ?



Maximum lateral displacement

Fig. 8.5 - Drilling of directional wells where the reservoir is beneath a major surface obstruction.



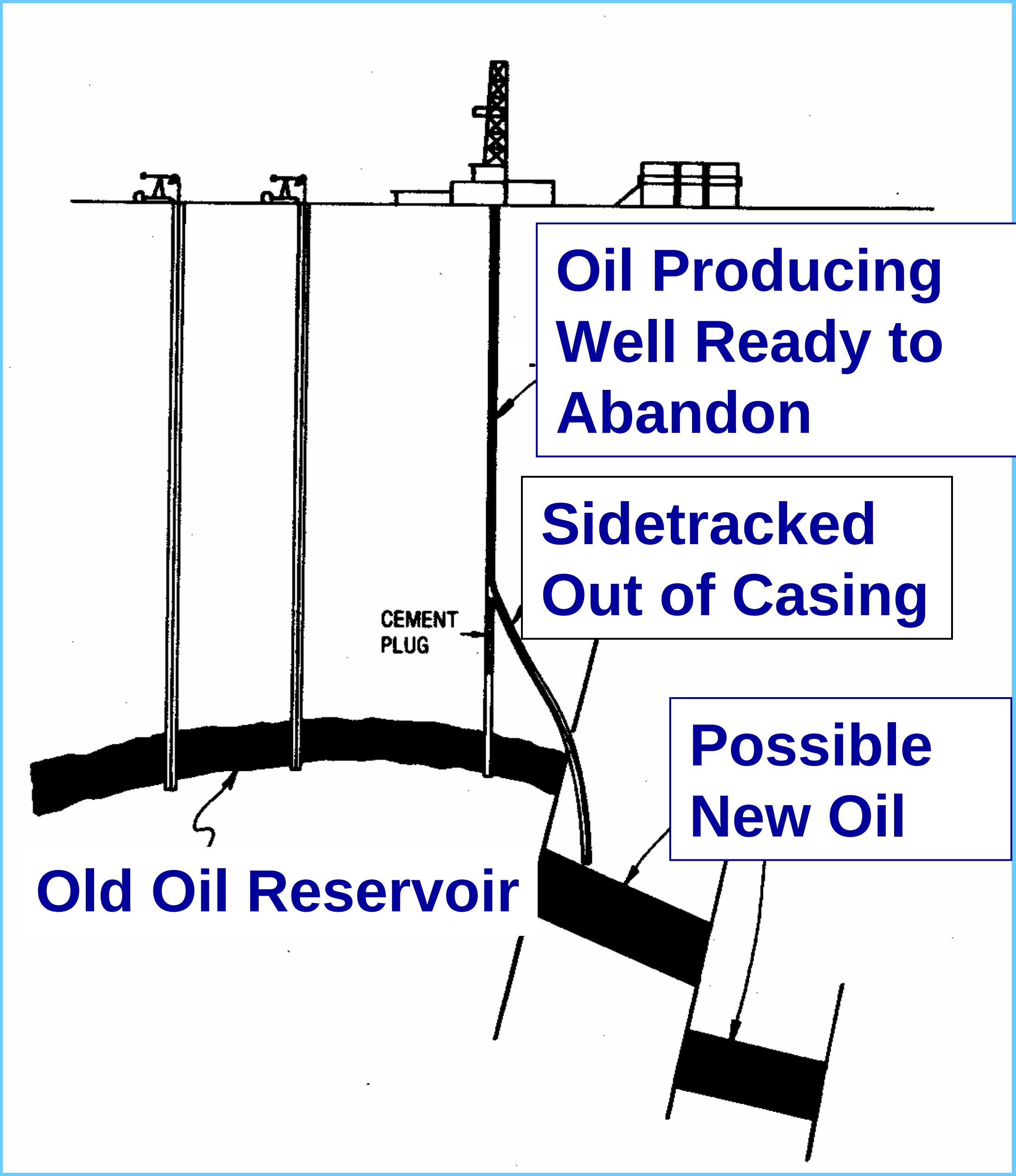
Cement Plug

Fish Lost in Hole and Unable to Recover

Sidetracked Hole Around Fish

Figure 8.6 - Sidetracking around a fish.

Figure 8.7 - Using an old well to explore for new oil by sidetracking out of the casing and drilling directionally.

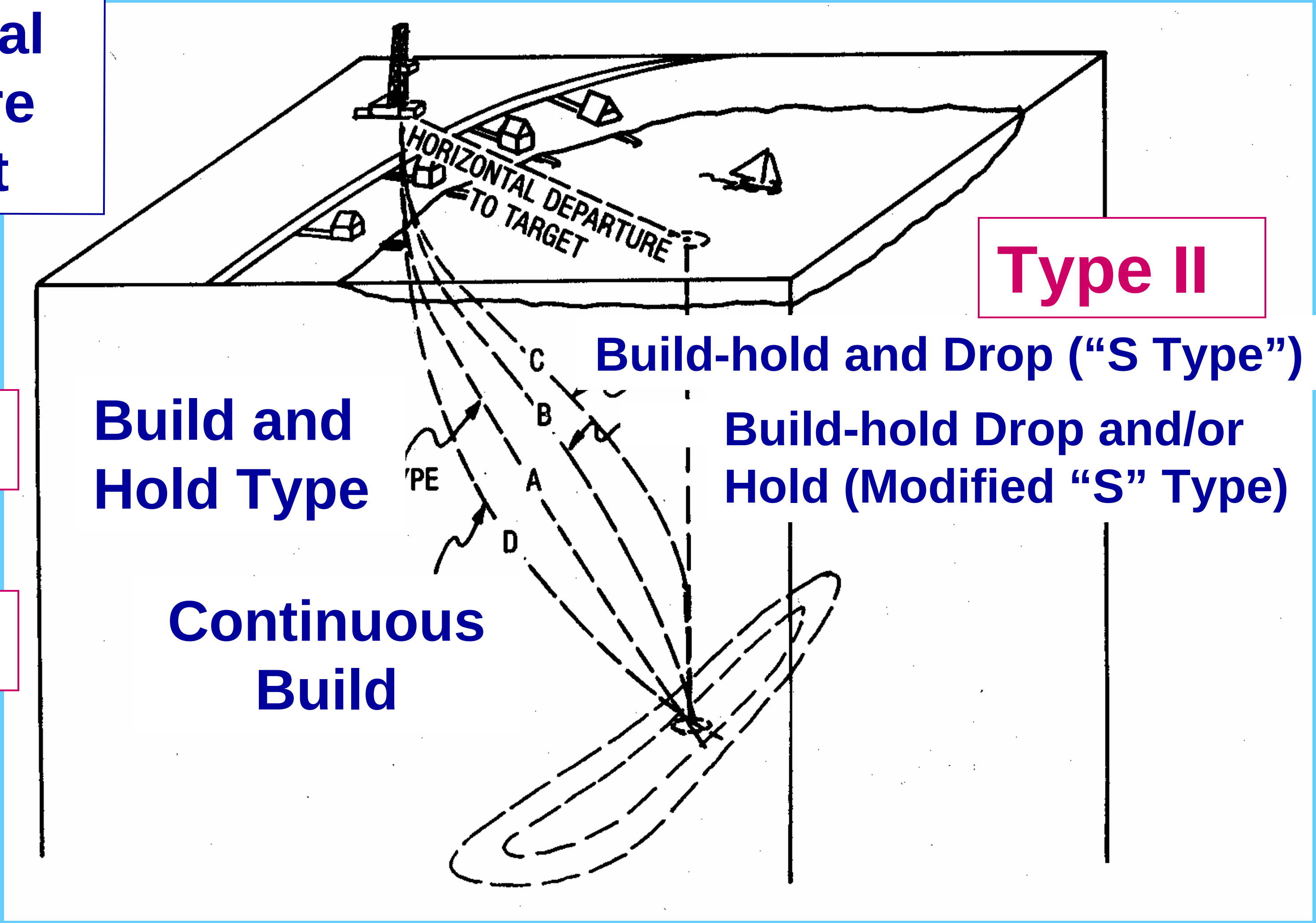


Oil Producing Well Ready to Abandon

Sidetracked Out of Casing

Possible New Oil

Old Oil Reservoir



Horizontal Departure to Target

Type I

Build and Hold Type

Type II

Build-hold and Drop (“S Type”)

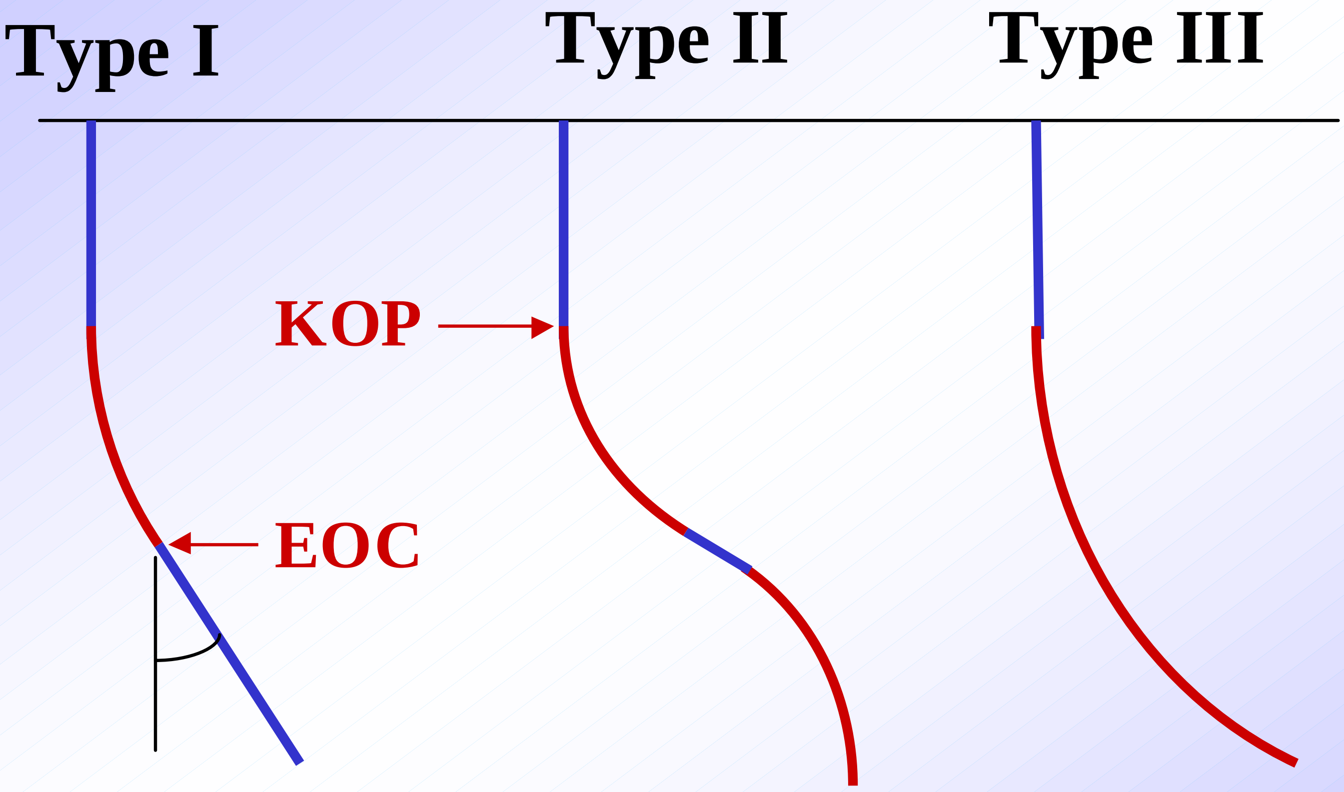
Build-hold Drop and/or Hold (Modified “S” Type)

Type III

Continuous Build

Figure 8.8 - Major types of wellbore trajectories.

Types of directional wells



Type I

Type II

Type III

KOP

EOC

Build and Hold

Build-Hold and Drop

Continuous Build

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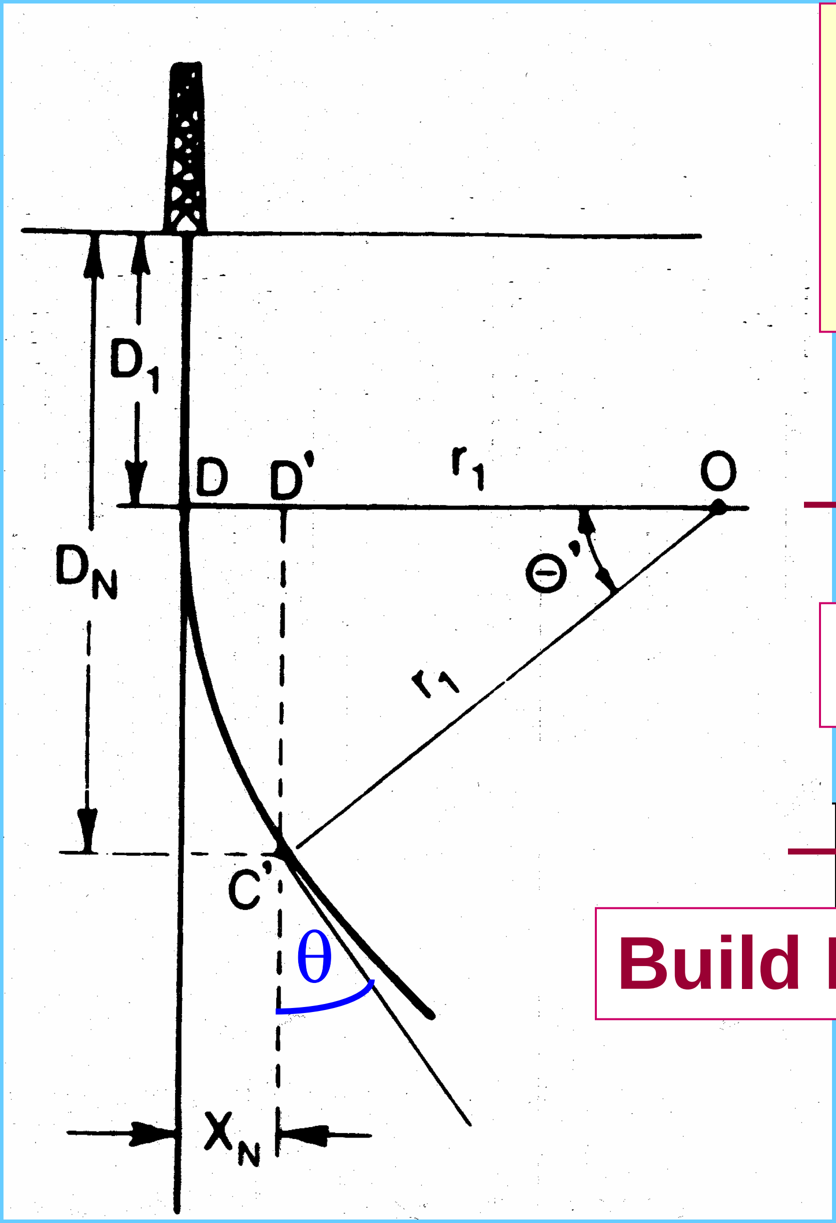
Figure 8.10 - Geometry of the build section.



Build Section

Build Radius:

$$r_1 = \frac{18,000}{\pi * \mathbf{BUR}}$$

Build Section:

Length of arc, $L = r_1\theta_1$

Vertical depth = C'D' = $r_1 \sin \theta_1$

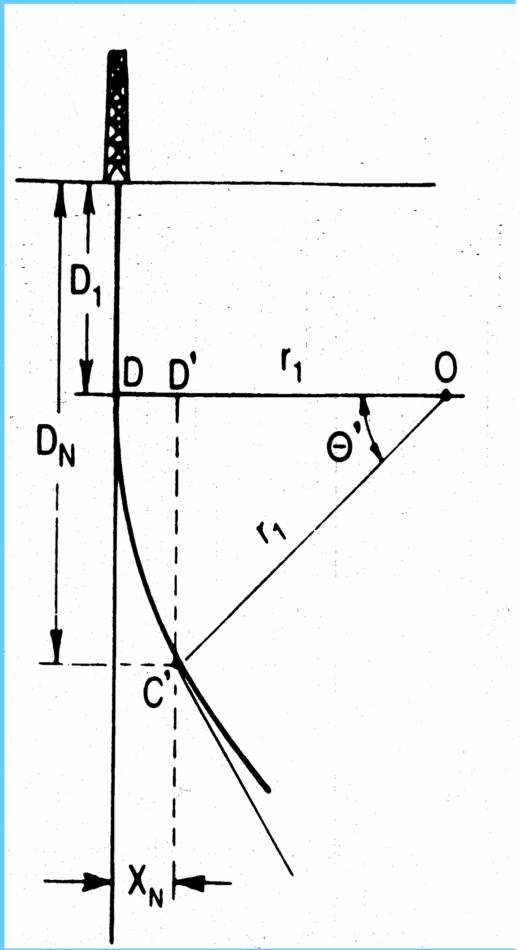
Horiz. Depart. = DD' = $r_1 (1-\cos \theta_1)$

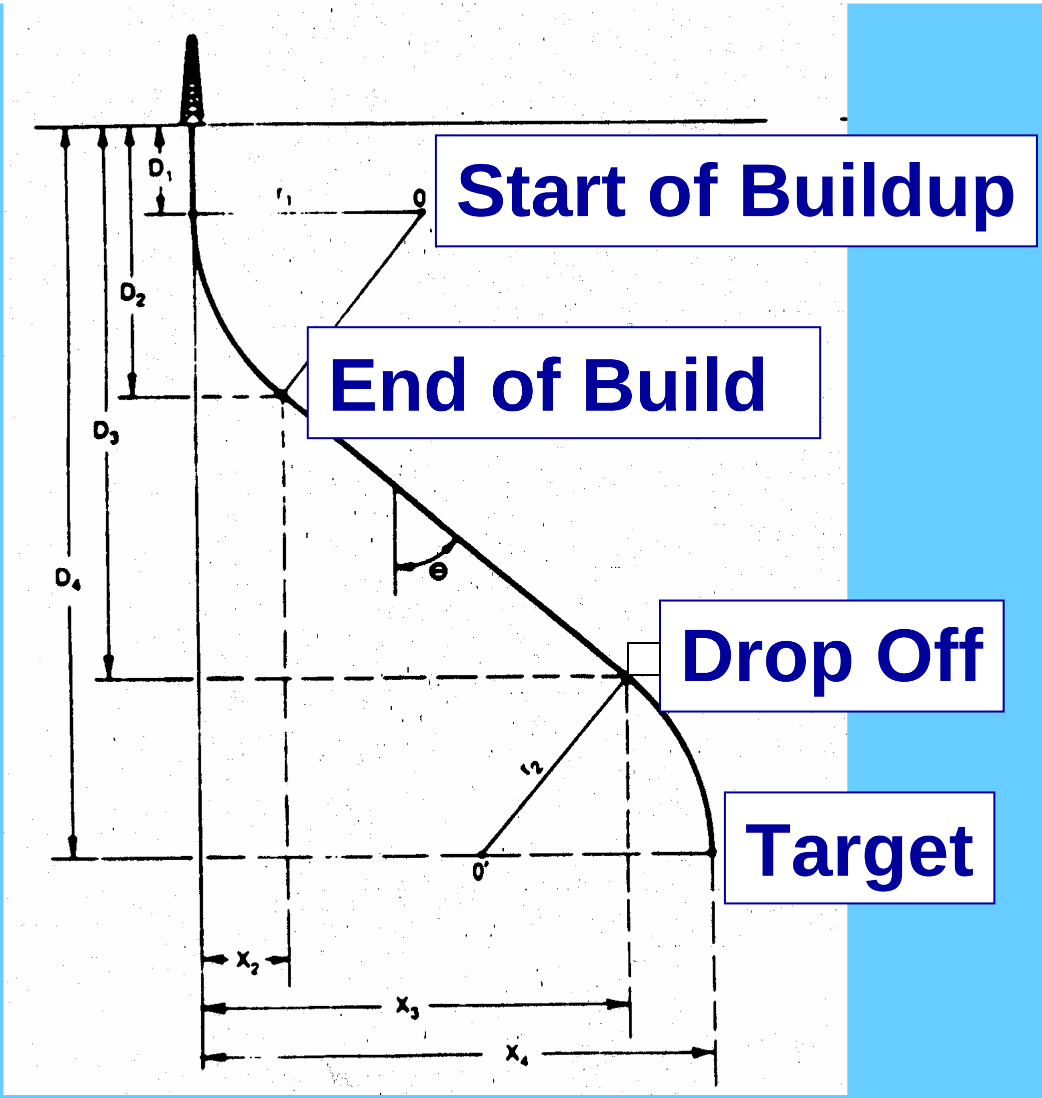
$$r_1 = \frac{L_1}{\theta_1} = \frac{100}{\theta_1 * \frac{\pi}{180}}$$

↑ rad ↑ deg

$$\boxed{r_1 = \frac{18{,}000}{\pi * \mathbf{BUR}}}$$

BUR = build rate in deg/100 ft





Start of Buildup

End of Build

Drop Off

Target

Type II

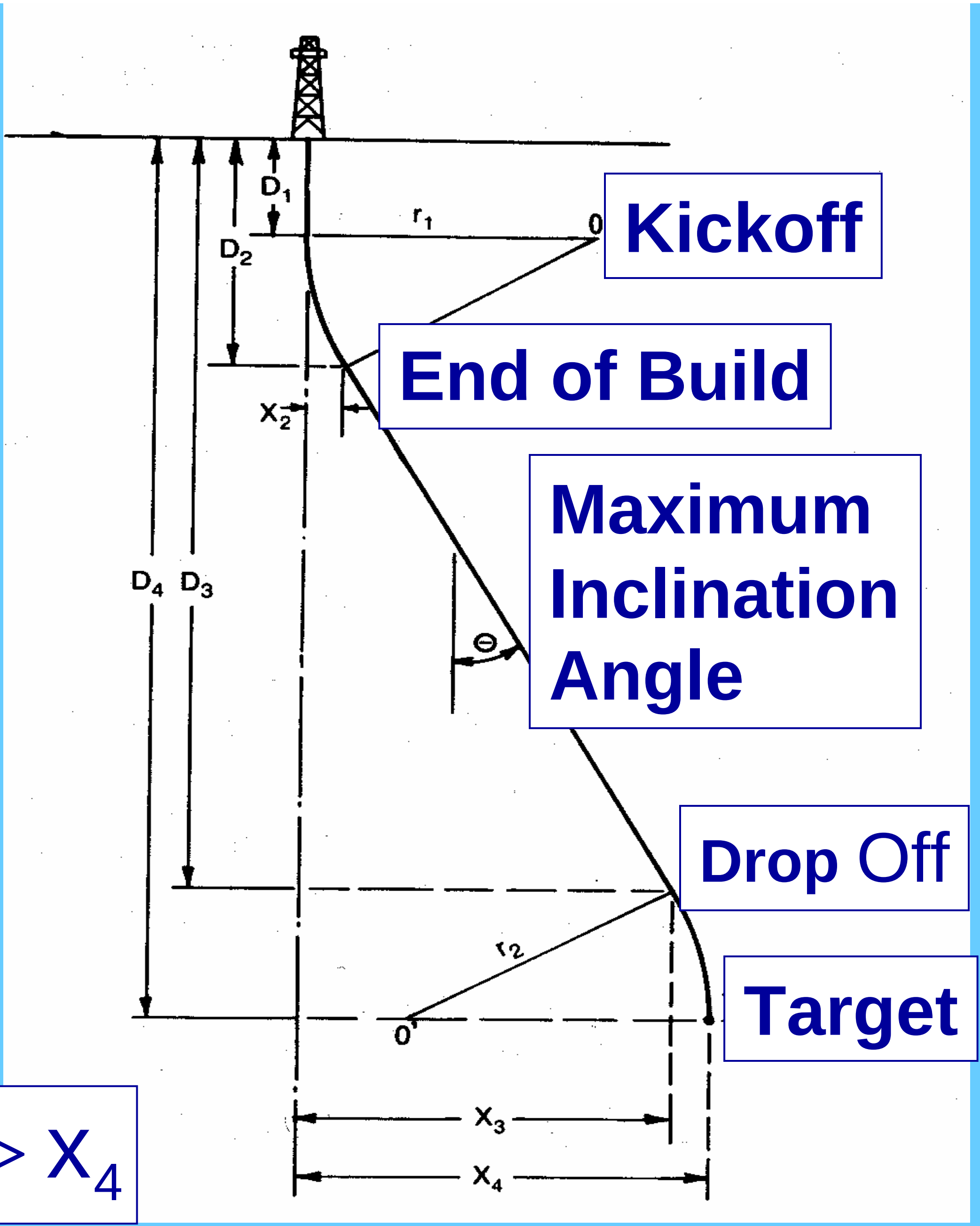
Build-hold-and drop for the case where:

$$r_1 < x_3 \text{ and } r_1 + r_2 < x_4$$

Type II

Build-hold-and drop for the case where:

$$r_1 < x_3 \text{ and } r_1 + r_2 > x_4$$



Kickoff

End of Build

Maximum Inclination Angle

Drop Off

Target

Maximum Inclination Angle

$$\theta_{\max} = 2\tan^{-1}\left[\frac{D_4 - D_1 - \sqrt{x_4^2 + (D_4 - D_1)^2 - 2(r_1 + r_2)x_4}}{2(r_1 + r_2) - x_4}\right]$$

Planning Trajectory

Design a directional well with the following restrictions:

- **Total horizontal departure = 4,500 ft**
- **True vertical depth (TVD) = 12,500 ft**
- **Depth to kickoff point (KOP) = 2,500 ft**
- **Rate of build of hole angle = 1.5 deg/100 ft**
- **Type I well (build and hold)**

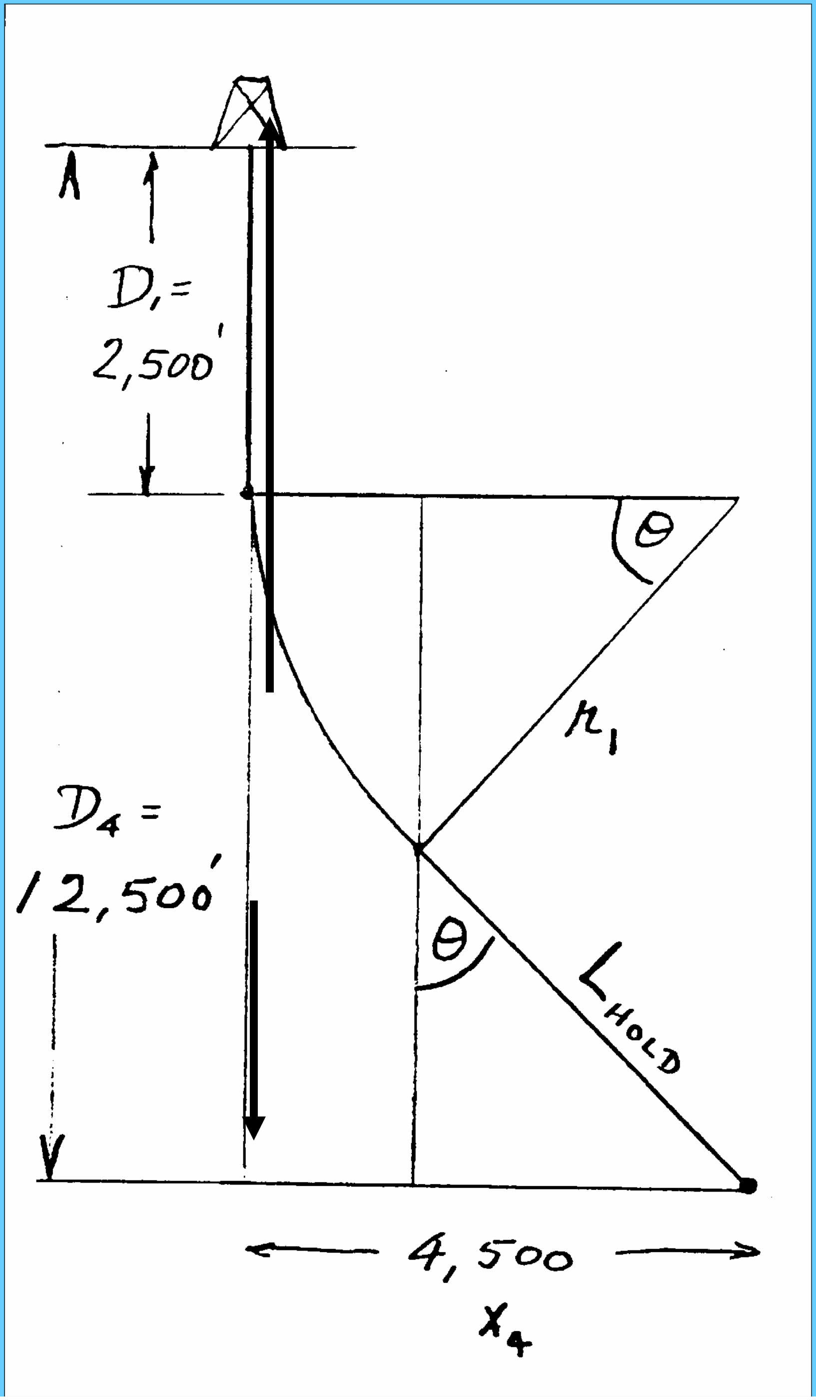
Example 1: Design of Directional Well

(i) Determine the maximum *hole angle* ***required.***

(ii) What is the total *measured depth* ***(MD)?***

(MD = well depth measured along the wellbore,

not the vertical depth)



(i) Maximum Inclination Angle

$$r_1 = \frac{18{,}000}{1.5\ \pi}$$

$$r_2 = 0$$

$$\left(D_4 - D_1\right)$$

$$= 12{,}500 - 2{,}500$$

$$= 10{,}000\ \ ft$$

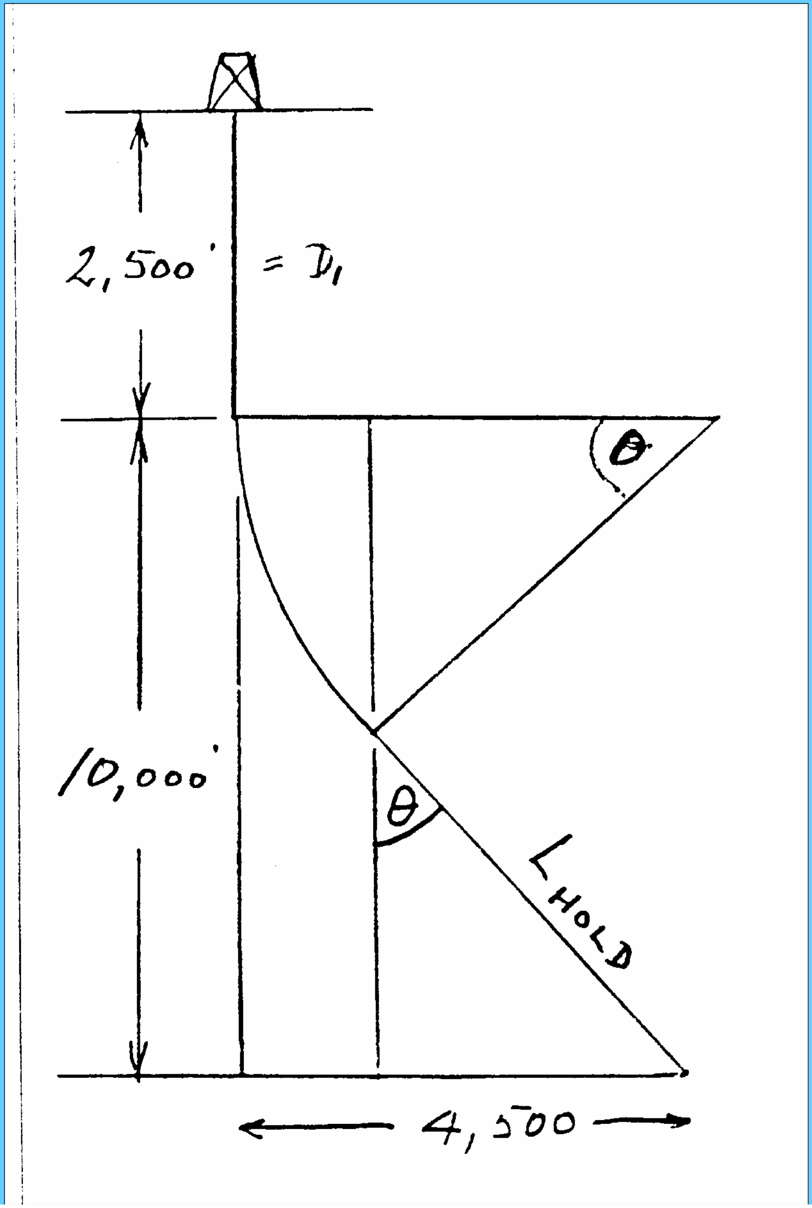
(i) Maximum Inclination Angle

$$\theta_{\max} = 2\tan^{-1}\left[\frac{D_4 - D_1 - \sqrt{x_4^2 + (D_4 - D_1)^2 - 2(r_1 + r_2)x_4}}{2(r_1 + r_2) - x_4}\right]$$

$$= 2\tan^{-1}\left[\frac{10{,}000 - \sqrt{4{,}500^2 + 10{,}000^2 - 2(3{,}820)4{,}500}}{2(3{,}820) - 4{,}500}\right]$$

$$\boxed{\theta_{\max} = 26.3^\circ}$$

(ii) Measured Depth of Well



$$x_{Build} = r_1(1 - \cos\theta)$$

$$= 3{,}820(1 - \cos 26.3^\circ)$$

$$= 395 \text{ ft}$$

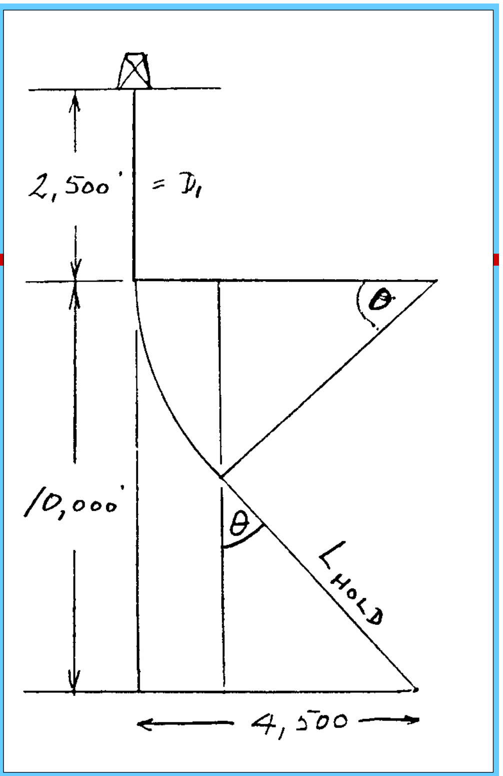
$$\therefore x_{Hold} = 4{,}500 - 395$$

$$= 4{,}105 \text{ ft}$$

$$\therefore L_{Hold} \sin\theta = 4{,}105$$

$$\therefore L_{Hold} = 9{,}265 \text{ ft}$$

(ii) Measured Depth of Well



$$MD = D_1 + r_1\theta_{rad} + L_{Hold}$$

$$= 2{,}500 + 3{,}820\left(\frac{26.3\pi}{180}\right) + 9{,}265$$

$$\boxed{MD = 13{,}518 \text{ ft}}$$

Example 1: Design of Directional Well

Design a directional well with the following restrictions:

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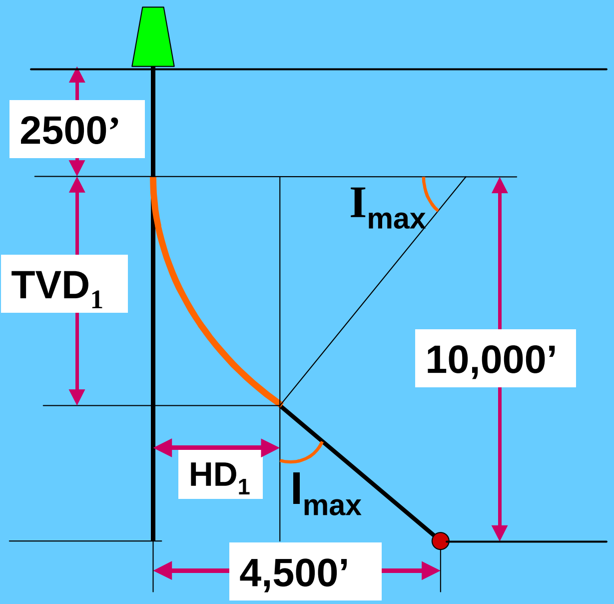
- **Depth to kickoff point (KOP) = 2,500 ft**
- **Rate of build of hole angle = 1.5 deg/100 ft**

Example 1: Design of Directional Well

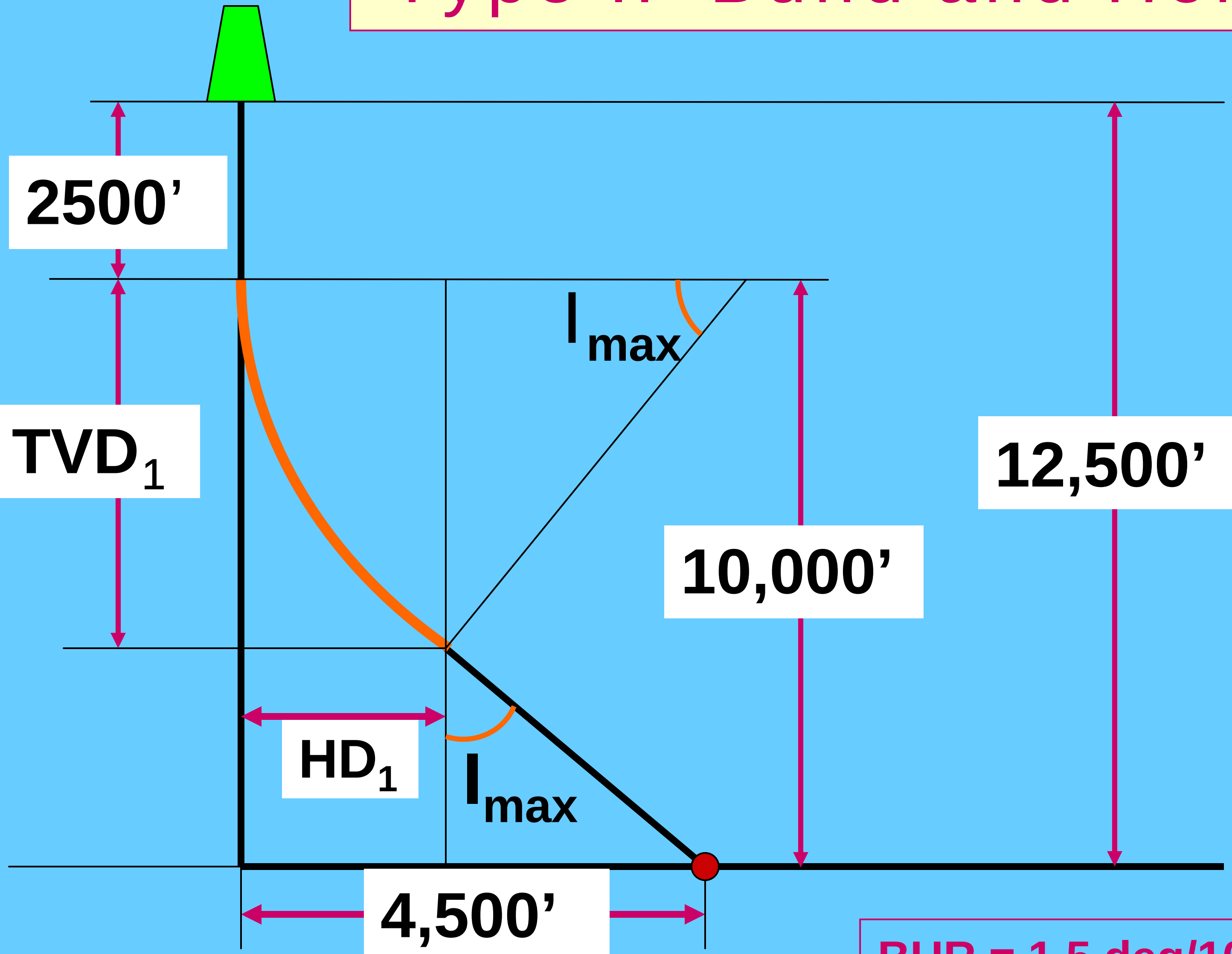


- **This is a Type I well (build and hold)**

  (i) Determine the maximum hole angle (inclination) required.

  (ii) What is the total measured depth of the hole (MD)?

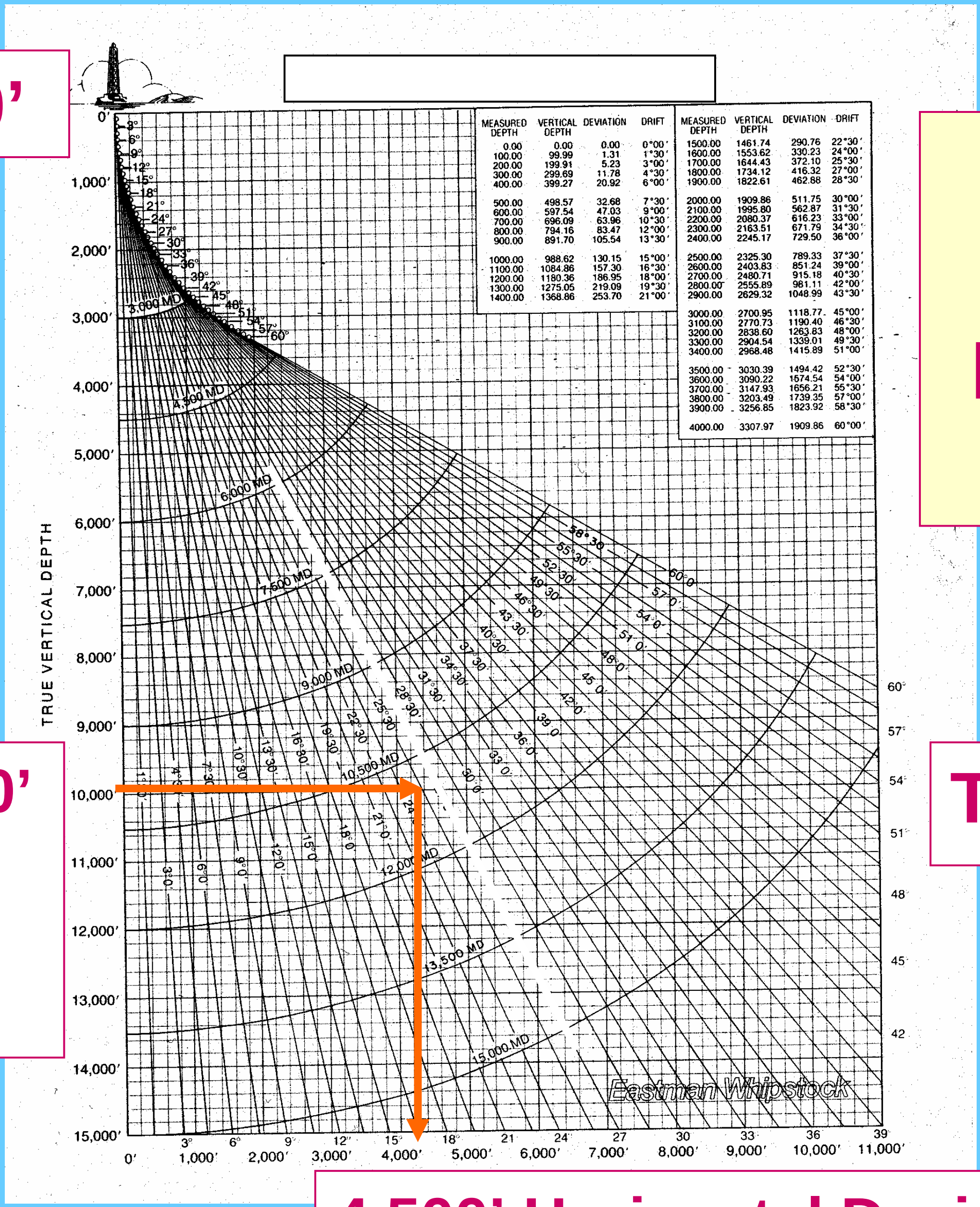
Type I: Build-and-Hold



BUR = 1.5 deg/100 ft

Uniform 1'30" Increase in Drift per 100 ft of hole drilled

0'



MEASURED DEPTH	VERTICAL DEPTH	DEVIATION	DRIFT
0.00	0.00	0.00	0°00'
100.00	99.99	1.31	1°30'
200.00	199.91	5.23	3°00'
300.00	299.69	11.78	4°30'
400.00	399.27	20.92	6°00'
500.00	498.57	32.68	7°30'
600.00	597.54	47.03	9°00'
700.00	696.09	63.96	10°30'
800.00	794.16	83.47	12°00'
900.00	891.70	105.54	13°30'
1000.00	988.62	130.15	15°00'
1100.00	1084.86	157.30	16°30'
1200.00	1180.36	186.95	18°00'
1300.00	1275.05	219.09	19°30'
1400.00	1368.86	253.70	21°00'
1500.00	1461.74	290.76	22°30'
1600.00	1553.62	330.23	24°00'
1700.00	1644.43	372.10	25°30'
1800.00	1734.12	416.32	27°00'
1900.00	1822.61	462.88	28°30'
2000.00	1909.86	511.75	30°00'
2100.00	1995.80	562.87	31°30'
2200.00	2080.37	616.23	33°00'
2300.00	2163.51	671.79	34°30'
2400.00	2245.17	729.50	36°00'
2500.00	2325.30	789.33	37°30'
2600.00	2403.83	851.24	39°00'
2700.00	2480.71	915.18	40°30'
2800.00	2555.89	981.11	42°00'
2900.00	2629.32	1048.99	43°30'
3000.00	2700.95	1118.77	45°00'
3100.00	2770.73	1190.40	46°30'
3200.00	2838.60	1263.83	48°00'
3300.00	2904.54	1339.01	49°30'
3400.00	2968.48	1415.89	51°00'
3500.00	3030.39	1494.42	52°30'
3600.00	3090.22	1574.54	54°00'
3700.00	3147.93	1656.21	55°30'
3800.00	3203.49	1739.35	57°00'
3900.00	3256.85	1823.92	58°30'
4000.00	3307.97	1909.86	60°00'

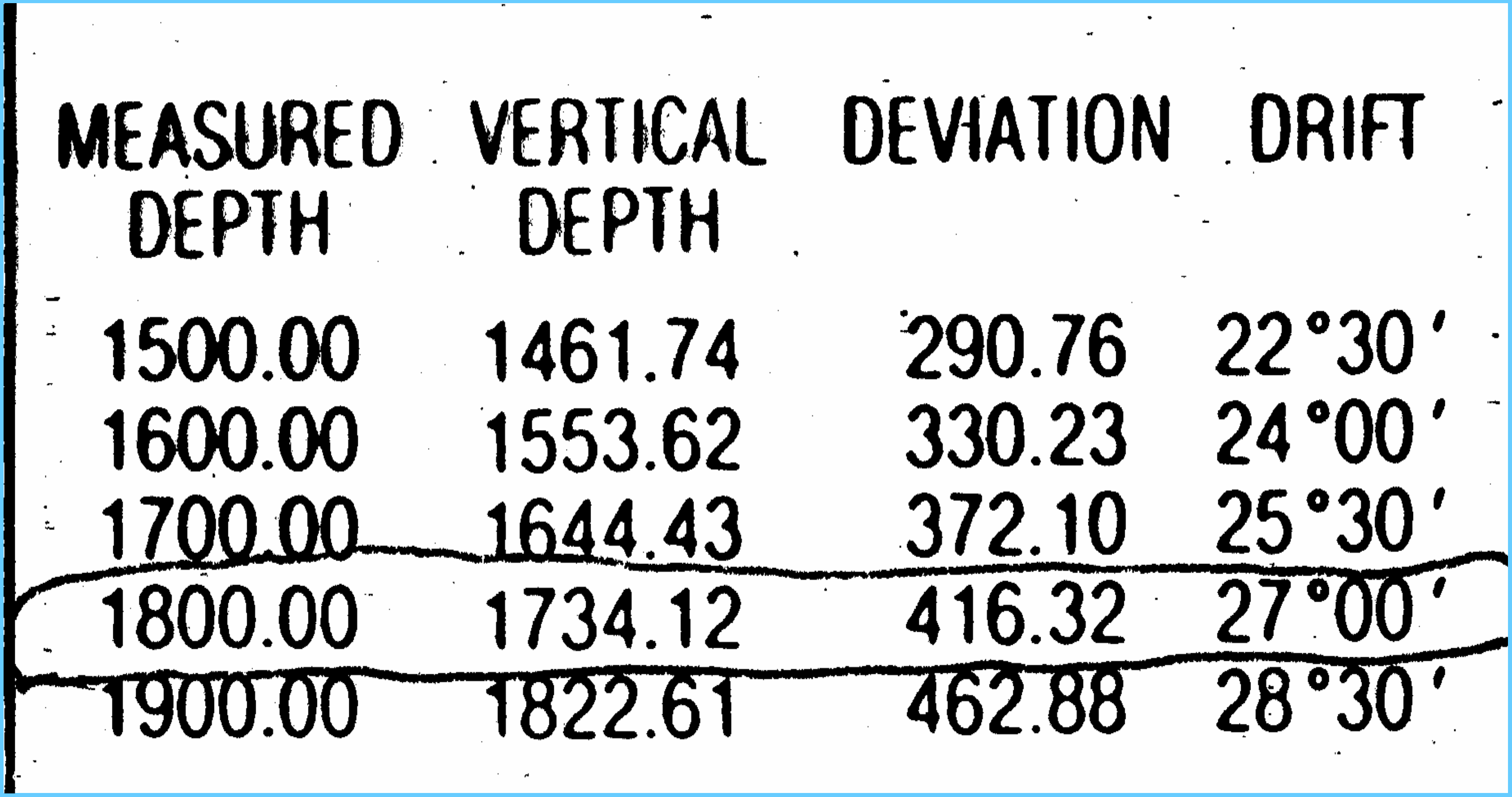
Try $I_{max} = 27^o$??

10,000'

Vert.

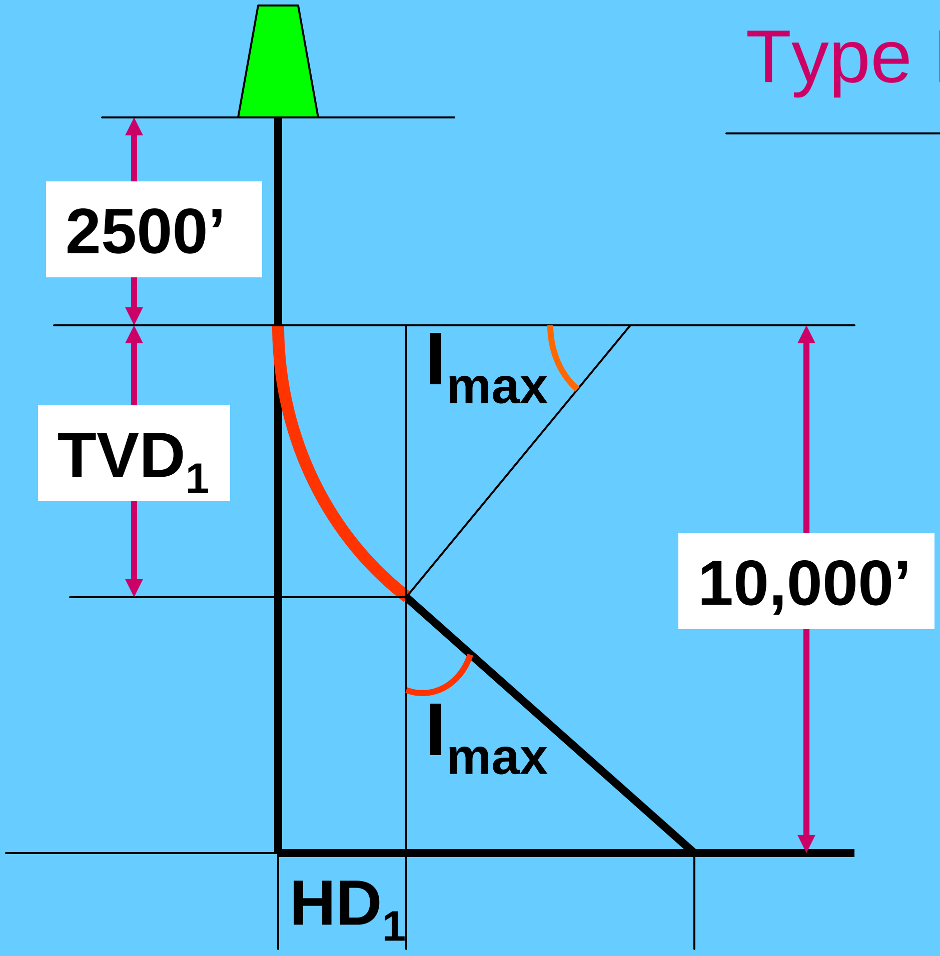
Depth

4,500' Horizontal Deviation



MEASURED DEPTH	VERTICAL DEPTH	DEVIATION	DRIFT
1500.00	1461.74	290.76	22°30′
1600.00	1553.62	330.23	24°00′
1700.00	1644.43	372.10	25°30′
1800.00	1734.12	416.32	27°00′
1900.00	1822.61	462.88	28°30′

Solution



Type I Well 1.5 deg/100’

Available depth

= 12,500-2,500

= 10,000’

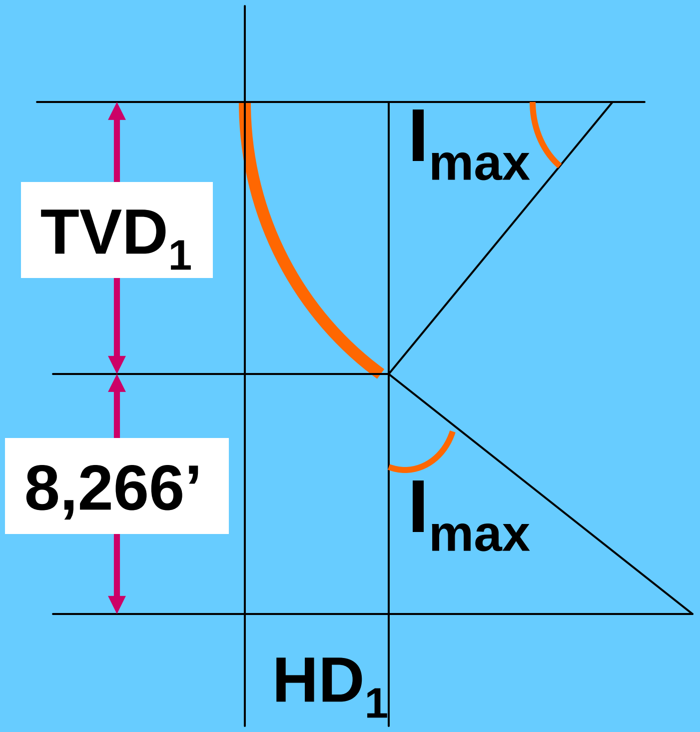
From Chart,

Try I_{max} = 27^o

Build Section

From chart of 1.5 deg/100', with I_{max} = 27^o

In the BUILD Section:



MD_1 = 1,800'   (27/1.5)

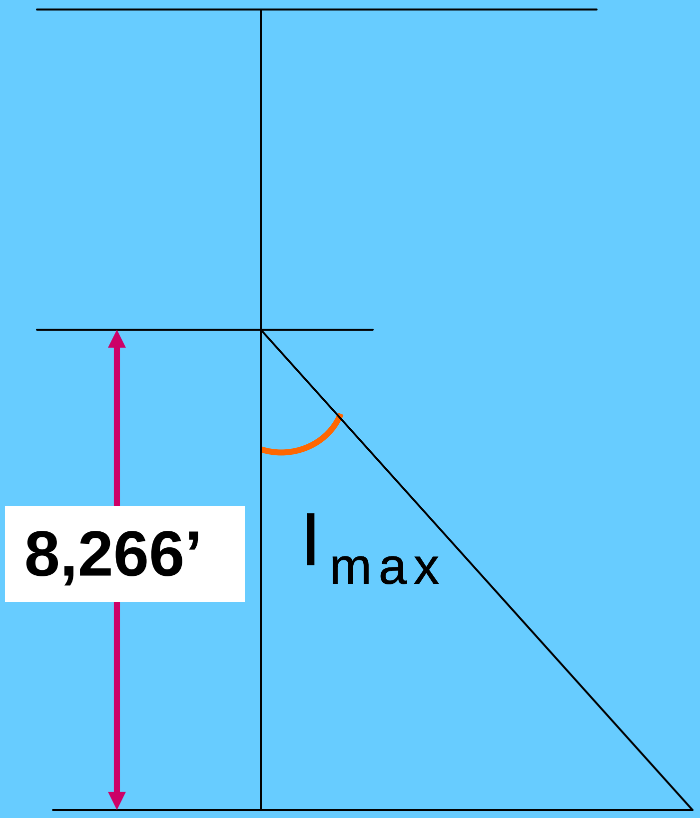
TVD_1 = 1,734'

HD_1 = 416'

Remaining vertical height

= 10,000 - 1,734 = 8,266'

Solution



Horizontally:

416 + 8,266 tan 27^o = 4,628

We need 4,500’ only:

Next try I_{max} = 25’ 30 min

MD_2 = 1,700’ (25.5/1.5)

TVD_2 = 1,644’

HD_2 = 372’

Solution:

Remaining vertical depth
= 10,000-1,644

= 8,356 ft.

∴ Horizontal departure
= 372+8,356 tan 25.5

= 4,358 ft. { <4,500 }

$$\boxed{\frac{4{,}628+4258}{2}=4{,}443}$$

Approx. maximum angle = 26 1/4°

What is the size of target?

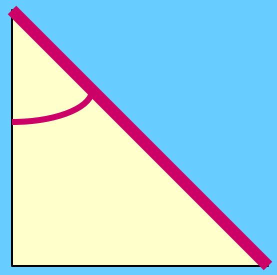
$MD = MD_{vert} + MD_{build} + MD_{hold}$

$$MD \text{ at } 27^\circ = 2{,}500' + 1{,}800' + \frac{8{,}266}{\cos 27^\circ}$$

$$= 13{,}577'$$

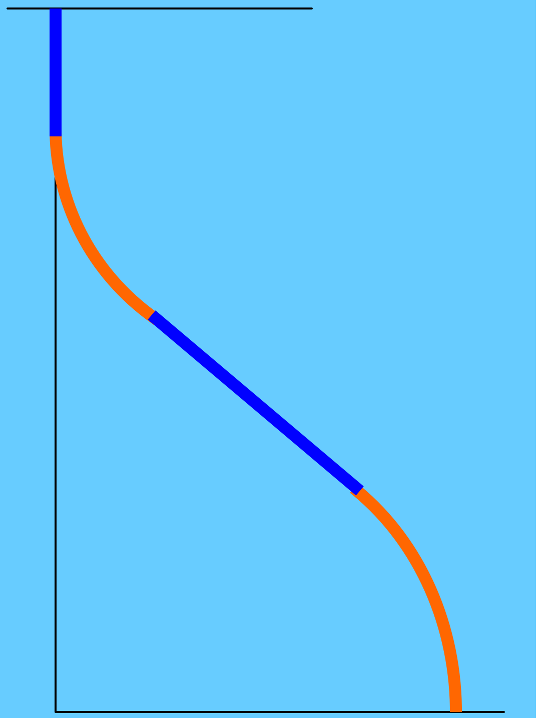
$$MD \text{ at } 25.5^\circ = 2{,}500 + 1{,}700 + \frac{8{,}356}{\cos 25.5}$$

$$= 13{,}458'$$



$$\boxed{\therefore\ MD \cong 13{,}500'}$$

Type II Pattern



Given: **KOP = 2,000 feet**

TVD = 10,000 feet

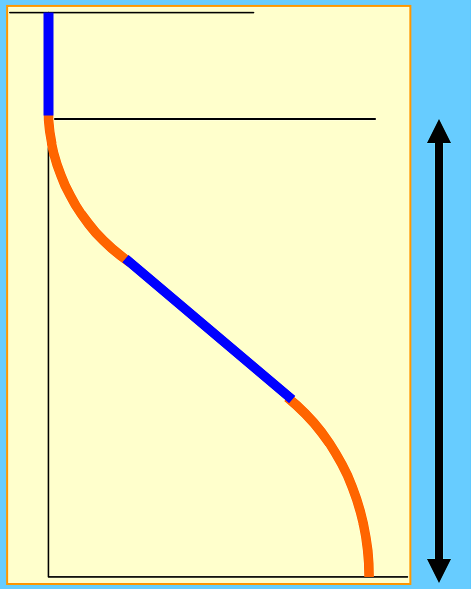
Horiz. Depart. = 2,258 feet

Build Rate = 2^o per 100 feet

Drop Rate = 1^o 30’ per 100 feet

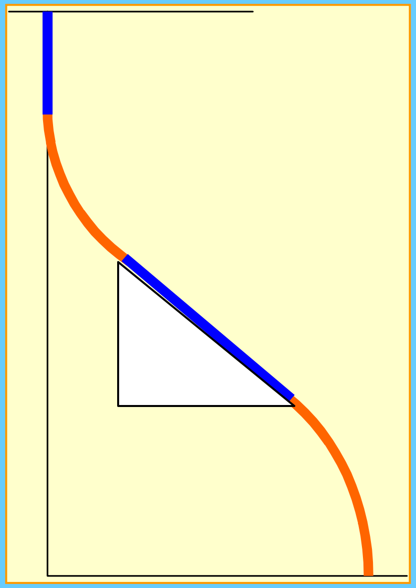
The first part of the calculation is the same as previously described.

Procedure - Find:



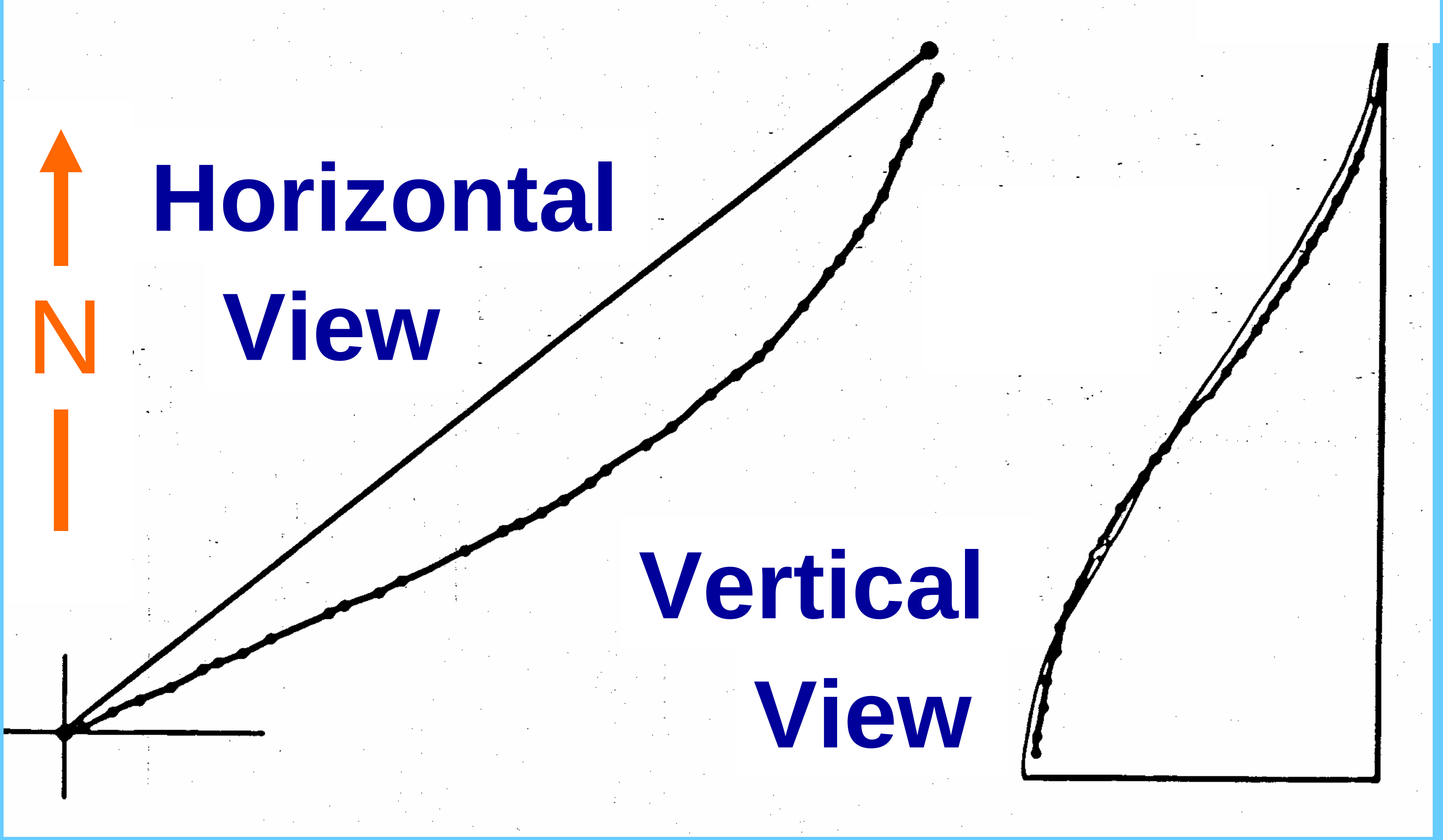
- a) The usable depth (8,000 feet)
- b) Maximum angle at completion of buildup (e.g., try 18^{o}) using 2^{o}/100 ft chart
- c) Measured depth and vertical depth at completion of buildup (M.D.=900 ft. and TVD = 886)
- d) Measured depth, horizontal departure and TVD for 1.5^{o}/100 ft from chart.

Solve:

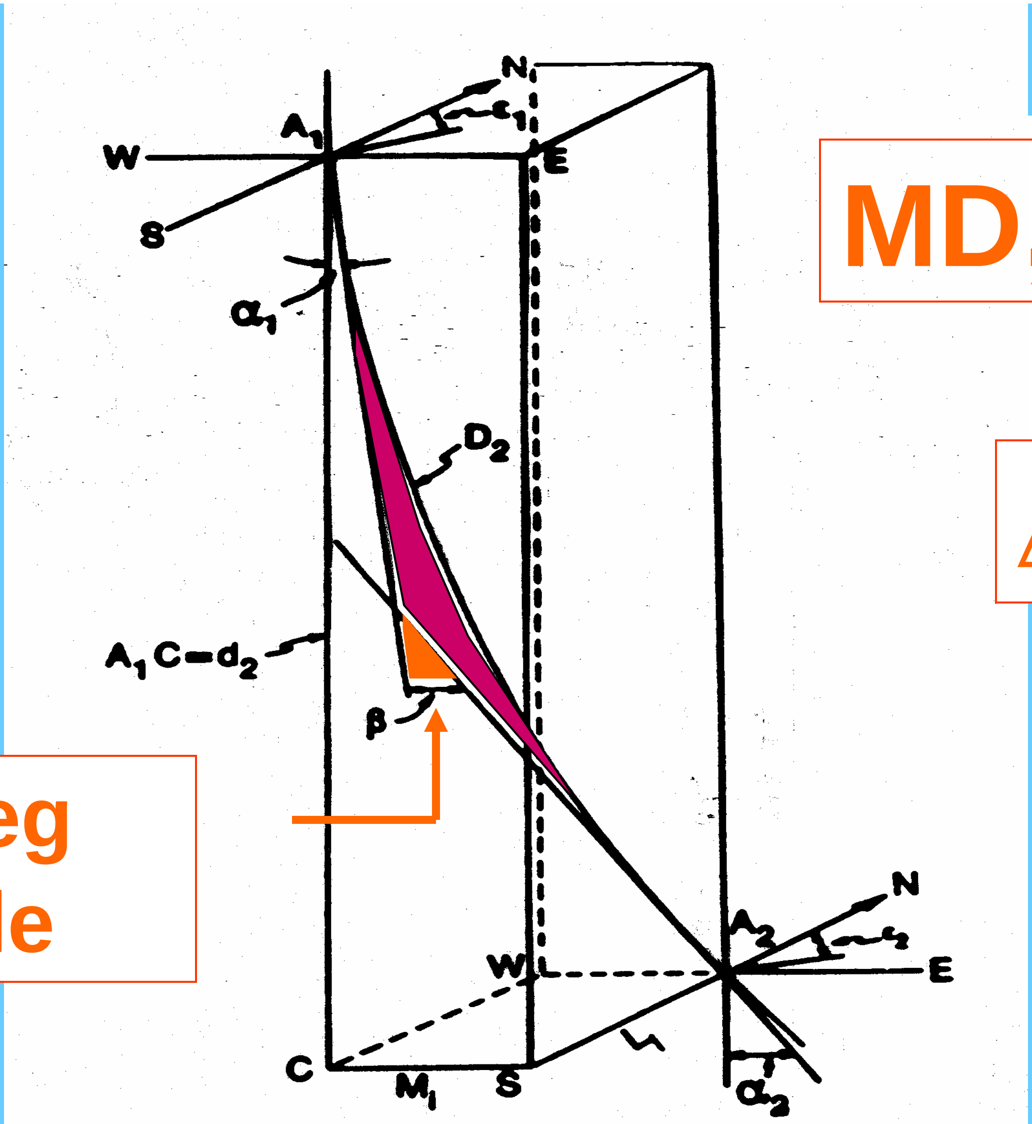


- For the distances corresponding to the sides of the triangle in the middle:

- Add up the results.
- If not close enough, try a different value for the maximum inclination angle, I_{max}



We may plan a 2-D well, but we always get a 3D well (not all in one plane)



MD, α_1, ε_1

ΔMD

α_2, ε_2

β = dogleg angle

Fig. 8-22. A curve representing a wellbore between survey stations A_1 & A_2

Bottom Hole Location

Direction : N 53 ° E

Distance : 2,550 ft

TVD : 10,000

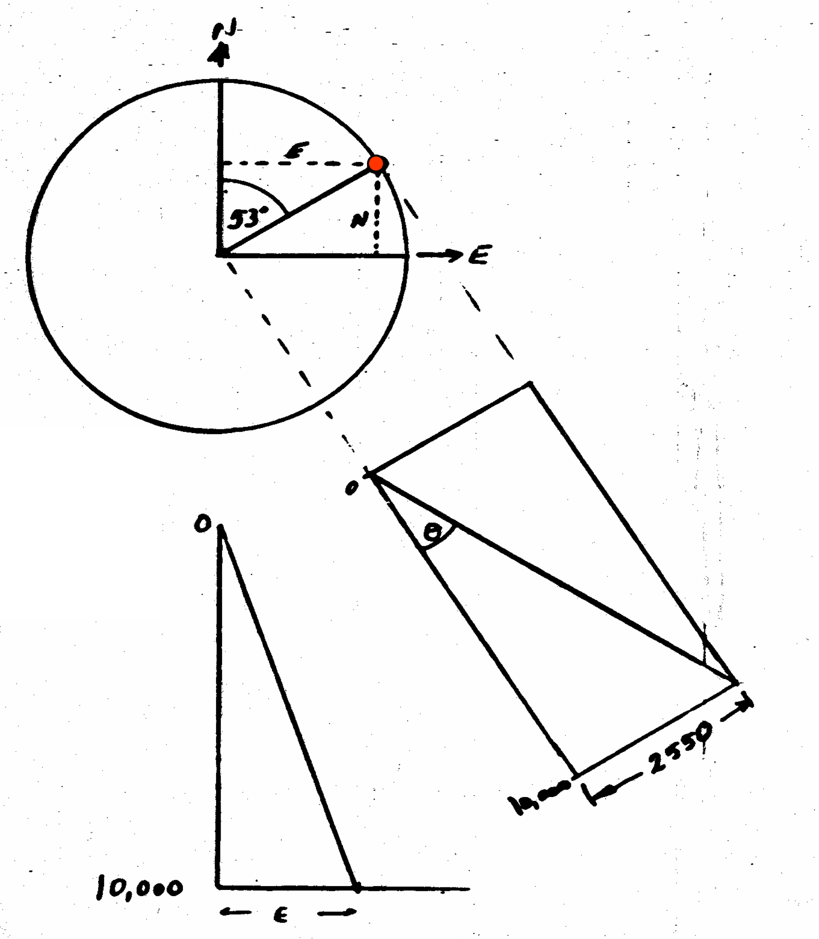
$$E = 2{,}550 \ \sin\ 53^\circ$$

$$= 2{,}037 \ \text{ft}$$

$$N = 2{,}550 \ \cos\ 53^\circ$$

$$= 1{,}535 \ \text{ft}$$

$$\text{Closure} = 2{,}550 = \sqrt{E^2 + N^2}$$



$$\text{Closure Direction} = \tan^{-1}\left(\frac{E}{N}\right) = 53^o$$