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Chapter 33 Investigations for Ground Water Resources Development

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Acknowledgments

Chapter 33 was prepared under the guidance of **John S. Moore,** national hydrogeologist, Natural Resources Conservation Service, Washington, DC.

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Contents:

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631.3300 Introduction

The purpose of this chapter is to provide guidance in the determination of critical collapse pressure in the design of water well casing. Considered are some of the most commonly used materials for water well casing that meet criteria in Conservation Practice Standard 642, Water Well (No.).

Maximum allowable collapse pressure of water well casing is based on collapse resistance (hydraulic pressure) associated with the maximum anticipated differential head. The term *differential head* applies to the difference in water levels between the inside and outside of the casing. For unconfined aquifers, maximum anticipated differential head is determined by subtracting the depth of maximum anticipated drawdown from the highest anticipated elevation of the water table. For confined aquifers, use the highest potentiometric surface.

631.33.01 Determining critical collapse pressure in design of water well casing

(a) Steel well casing

The main factors affecting collapse resistance of steel casing are the diameter, wall thickness, and eccentricity (out-of-roundness). Eccentricity can originate from rough handling in transport or on the job site. Small eccentricity can result in significant loss of collapse resistance. Consider for example, 6.625-inch (outside diameter) steel casing with a wall thickness of 0.25 inch. The design collapse pressure for a perfect cylinder (no eccentricity) is 3,826 pounds per square inch (8,838 feet). However, by factoring in values for eccentricities of 0.5, 1.0, and 1.5 percent, the design collapse pressures are accordingly reduced to 1,576 pounds per square inch (3,639 feet), 1,231 pounds per square inch (2,844 feet), and 1,024 pounds per square inch (2,365 feet), respectively. For this reason, collapse resistance for steel casing is calculated by the Timoshenko Elastic Formula, which has an adjustment for eccentricity.

Table 33–1 gives differential head limitations calculated by the Timoshenko Elastic Formula using Young's Modulus of Elasticity (E) = 3 x 10^7 pounds per square inch; Poisson's ratio (μ) = 0.30; casing eccentricity (e) = 0.01 (1%); yield strength (Y_p) = 35,000 pounds per square inch, and ultimate tensile strength = 60,000 minimum pounds per square inch, for selected sizes of ASTM A-139 Grade B carbon steel casing. Values for head in table 33–1 are rounded down to the nearest 5 feet.

Table 33–1 Differential head limitations for steel casings

	Nominal casing size (inches) 4	5	6	8	10	12	14	16	18	24
Wall thickness	Outside diameter (inches)									
(uncoated)	4.50	5.563	6.625	8.625	10.75	12.75	14.00	16.00	18.00	24.00
Gage (*inches*)	Maximum differential head limitations (feet)									
20 Ga (0.036)	60	35	20	0	0	0	0	0	0	0
18 Ga (0.048)	140	75	45	20	0	0	0	0	0	0
16 Ga (0.060)	250	145	90	40	20	0	0	0	0	0
14 Ga (0.075)	460	260	160	80	40	25	20	0	0	0
12 Ga (0.105)	1,040	630	400	200	110	70	50	35	0	0
10 Ga (0.135)	1,810	1,140	750	390	220	135	105	70	50	0
8 Ga (0.164)	2,660	1,740	1,190	640	360	230	180	125	90	0
7 Ga (0.179)	3,130	2,090	1,450	790	460	290	230	160	110	0
3/16 (0.188)	3,415	2,300	1,610	890	520	330	260	180	130	60
7/32 (0.219)	4,430	3,070	2,200	1,260	750	500	390	270	200	90
Sch. 40 (0.237)	5,035	---	---	---	---	---	---	---	---	---
1/4 (0.250)		3,880	2,840	1,680	1,030	690	550	390	290	130
Sch. 40 (0.258)		4,090	---	---	---	---	---	---	---	---
Sch. 40 (0.280)			3,490	---	---	---	---	---	---	---
9/32 (0.280)				2,140	1,350	910	730	520	390	180
5/16 (0.312)				2,625	1,690	1,160	930	680	510	240
Sch. 40 (0.322)				2,785	---	---	---	---	---	---
11/32 (0.344)					2,065	1,445	1,175	860	650	310
Sch. 40 (0.365)					2,325	---	---	---	---	---
3/8 (0.375)						1,970	1,420	1,055	800	390
Sch. 40 (0.406)						2,045	---	---	---	---
Sch. 40 (0.438)							1,975	---	---	---
7/16 (0.438)								1,490	1,145	580
Sch. 40 (0.500)								1970	---	---
Sch. 40 (0.562)									1,965	---
Sch. 40 (0.688)										1,645

Design collapse pressure (P_d) is the solution of the Timoshenko Elastic Formula

$$P_d^2 - P_d\left\{\frac{2Y_p}{(SDR-1)} + P_{cr}\left[1+3e(SDR-1)\right]\right\} + \frac{2Y_pP_{cr}}{SDR-1} = 0 \quad [33\text{–}1]$$

where:

- P_d = design collapse pressure, lb/in^2 [alternatively, 2.31(P_d) = head, in ft]
- Y_p = yield strength, lb/in^2
- e = casing eccentricity
- P_{cr} = critical collapse pressure of a perfect cylinder, lb/in^2, given by

$$P_{cr} = \frac{2E}{(1-\mu^2)\left[SDR(SDR-1)^2\right]}$$

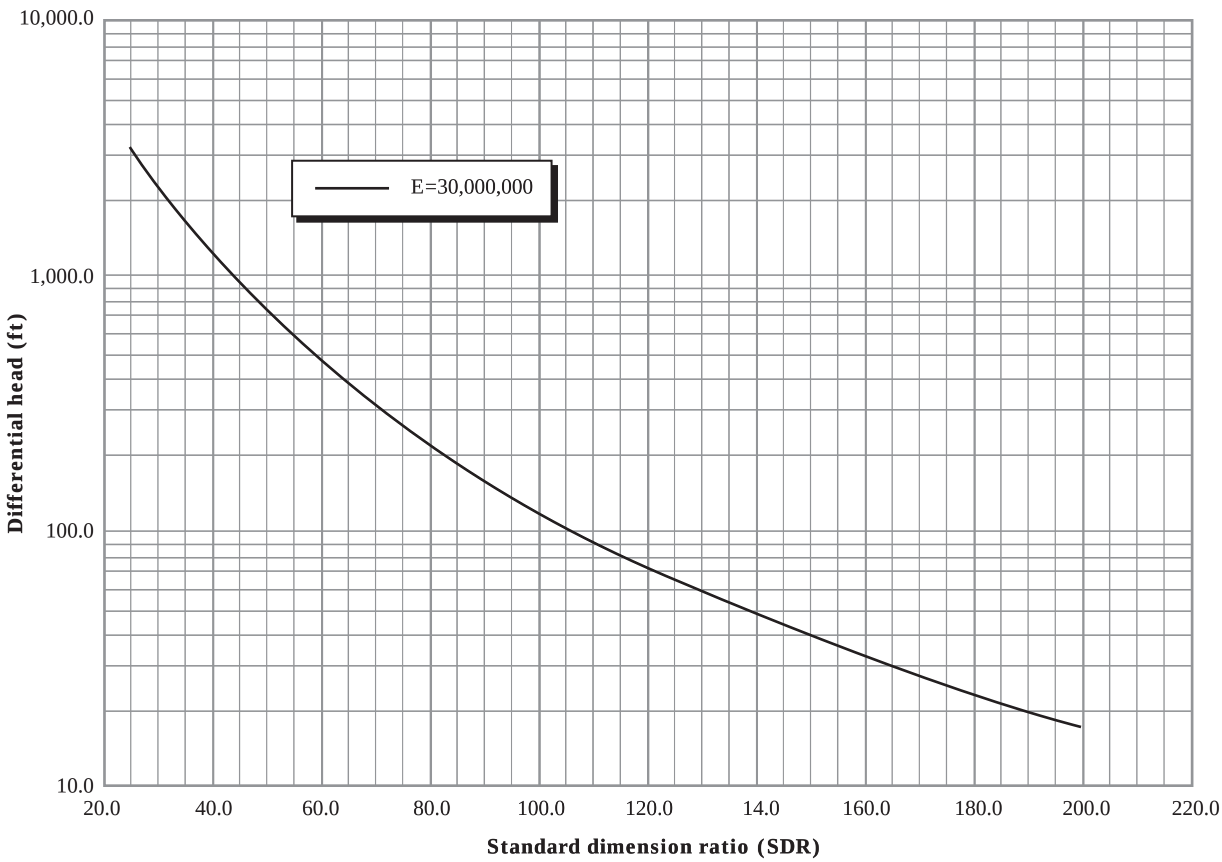
where:

- E = Young's modulus of elasticity, lb/in^2
- μ = Poisson's ratio
- SDR = standard dimension ratio, d/t
  where:
  - d = outside diameter of casing, in
  - t = wall thickness of casing, in

Figure 33–1 may be used to determine maximum allowable differential head for ASTM A-139 Grade B carbon steel casing. The curve in figure 33–1 is a smooth plot of SDR's for steel casing in table 33–1 versus calculated critical collapse pressures (expressed as head, in feet) using equation 1. The curve simplifies the determination without having to run the Timoshenko calculation. The curve (P_{cr} is in feet of head) may be expressed as:

$$P_{cr} = 1.4897 \times 10^7 (SDR)^{-2.5526} \quad [33\text{–}2]$$

Figure 33–1 Maximum allowable differential head for steel pipe



Example 33–1 Collapse resistance for steel casing

Problem: A rancher is drilling a stock water supply well and would like to use some new 6-inch (nominal) Grade B Carbon steel casing on hand. Determine whether it meets criteria for maximum allowable head.

Given: The aquifer is unconfined, and the greatest anticipated differential head in the well is determined to be 925 feet. The steel casing has the following characteristics:

outside diameter = 6.625 in
8 gage steel = 0.164 in

Solution: Step 1—Calculate the Standard Dimension Ratio:

$$\text{SDR} = \frac{6.625}{0.164} = 40.4$$

Step 2—Determine maximum differential head limitation for 8 gage, 6.625 (outside diameter) steel casing, from table 33–1:

Answer = 1.190 ft

Step 3—Alternative. Use equation for curve in figure 33–1 to calculate maximum allowable differential head (result should be close to answer from Step 2):

$$P_{cr} = 1.4897 \times 10^{7} (40.4)^{-2.5526} = 1{,}182 \text{ ft}$$

Step 4—Decision. Because the greatest anticipated differential head, 925 feet, is less than the maximum allowable 1,190 feet, the rancher's casing can be used in this well.

(b) Plastic casing

Critical collapse resistance for standard dimension ratio pressure-rated plastic pipe, denoted either SDR-PR or SR-PR, including ABS, PVC, and SR, is determined by the Clinedinst Equation (ASTM F-480). The Clinedinst Equation is:

$$P_{cr} = \frac{2E}{\left(1-\mu^2\right)\left[SDR\left(SDR-1\right)^2\right]} \qquad [33\text{–}3]$$

where:

- P_{cr} = critical collapse pressure, lb/in² [alternatively, $2.31(P_{cr})$ = head in ft]
- E = Young's modulus of elasticity, lb/in² = Poisson's ratio
- SDR = standard dimension ratio, d/t,
  where:
  - d = outside diameter of casing, in
  - t = wall thickness of casing, in

Table 33–2 gives the maximum allowable differential head limitations for selected PVC, ABS, and SR plastic pipe (SDR-PR) based on equation 33–3 using $\mu = 0.38$.

Table 33–3 gives dimension and differential head limitations for PVC-12454 plastic pipe, schedules 40 and 80, constructed of material with E = 400,000 pounds per square inch and $\mu = 0.38$, based on the Clinedinst equation. Factors given at the bottom of table 33–3 may be used in determining limitations for ABS schedules 40 and 80 plastic pipe.

Table 33–4 provides dimension and differential head limitations for representative sizes of reinforced plastic (RPMP) well casings.

Figure 33–2 may be used to determine maximum allowable differential head for SDR-PR plastic pipe, including PVC (12454 and 14333), SR, and ABS (434 and 533). Four curves are plotted for representative values of E = 500,000, 400,000, 300,000, and 200,000 pounds per square inch and $\mu = 0.38$, according to the Clinedinst equation. The maximum allowable differential head for different values of E may be determined either by interpolation from the curves in figure 33–2 or by direct calculation from equation 33–3.

Table 33–2 Maximum allowable differential head for selected plastic pipe (SDR-PR)

SDR	- - Material (modulus of elasticity, E, lb/in²) - - -			
	PVC-12454	ABS-434	SR and PVC-14333	ABS-533
	(400,000)	(360,000)	(320,000)	(260,000)
	- - - Maximum allowable differential head - - -			
	(ft)	(ft)	(ft)	(ft)
13.5	1,020	920	815	665
17.0	495	445	395	320
21.0	255	230	205	165
26.0	130	120	105	85
32.5	65	60	50	40

Table 33–3 Dimension and differential head limitations for selected PVC-12454 plastic pipe, schedules 40 and 80

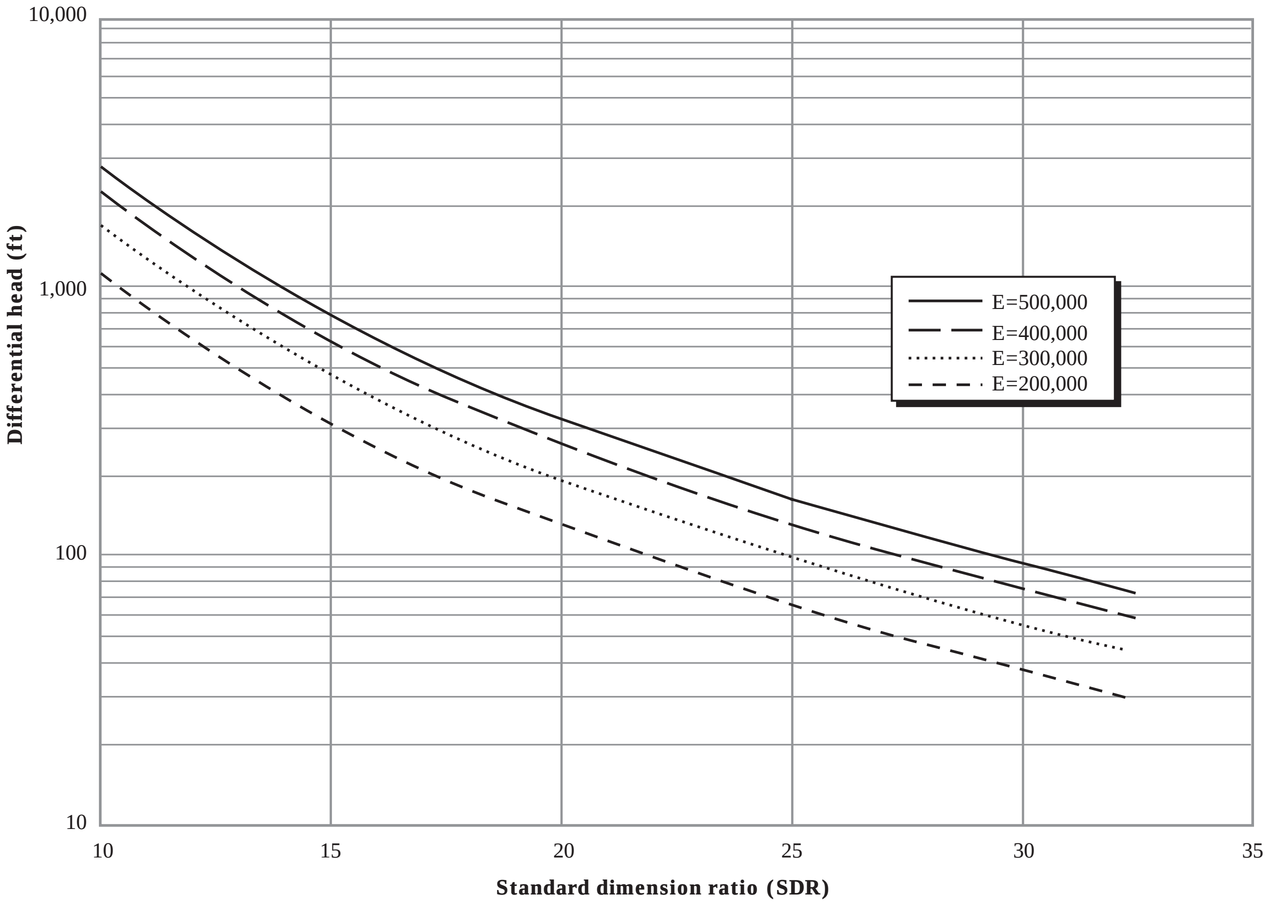
		Schedule 40			Schedule 80		
Nominal diameter (inches)	Outside diameter (inches)	Minimum wall thickness (inches)	SDR	Maximum head (feet)	Minimum wall thickness (inches)	SDR	Maximum head (feet)
2	2.375	0.154	15.4	675	0.218	10.9	2,020
2.5	2.875	0.203	14.2	870	0.276	10.4	2,350
3	3.500	0.216	16.2	575	0.300	11.7	1,610
3.5	4.000	0.226	17.7	435	0.318	12.6	1,270
4	4.500	0.237	19.0	350	0.337	13.4	1,045
5	5.563	0.258	21.6	235	0.375	14.8	765
6	6.625	0.280	23.7	175	0.432	15.3	690
8	8.625	0.322	26.8	120	0.500	17.3	470
10	10.750	0.365	29.5	90	0.593	18.1	405
12	12.750	0.406	31.4	70	0.687	18.6	375

Note: Table 33–3 is for PVC schedule pipe having a modulus of elasticity of 400,000 pounds per square inch. For PVC schedule pipe having a modulus of elasticity of 360,000 pounds per square inch, multiply the maximum head by a factor of 0.9. For PVC schedule pipe having a modulus of elasticity of 320,000 pounds per square inch, use a factor of 0.8. For ABS schedules 40 and 80 pipe having a modulus of elasticity of 250,000 pounds per square inch, use a factor of 0.625. In all cases, μ = 0.38.

Table 33–4 Dimension and differential head limitations for reinforced plastic (RPMP) well casings

Casing diameter	Maximum differential head (feet)								
	20	60	100	200	300	400	500	750	1,000
(inches)	Minimum wall thickness (inches)								
8	0.17	0.17	0.23	0.23	0.23	0.29	0.29	0.33	0.33
10	0.17	0.17	0.28	0.28	0.28	0.36	0.36	0.41	0.41
12	0.18	0.19	0.34	0.34	0.34	0.43	0.43	0.46	0.46
14	0.19	0.22	0.34	0.34	0.40	0.43	0.46	0.46	0.46
15	0.19	0.24	0.34	0.34	0.46	0.46	0.46	0.46	0.46
16	0.20	0.25	0.36	0.36	0.46	0.46	0.46	0.46	0.46
18	0.21	0.28	0.40	0.40	0.46	0.46	0.46	0.52	0.52
20	0.21	0.31	0.42	0.42	0.46	0.46	0.46	0.54	0.54
21	0.21	0.33	0.48	0.48	0.48	0.48	0.48	0.57	0.57
24	0.24	0.38	0.48	0.48	0.48	0.57	0.57	0.57	0.57
27	0.26	0.40	0.49	0.49	0.49	0.62	0.62	0.62	0.62
30	0.29	0.44	0.49	0.49	0.49	0.68	0.68	0.68	0.68
33	0.32	0.44	0.60	0.60	0.60	0.75	0.75	0.75	0.75
36	0.35	0.48	0.65	0.65	0.65	0.82	0.82	0.82	0.82

Figure 33–2 Maximum allowable differential head for SDR-PR plastic pipe



(c) Safety factors

The data in table 33–1 are plotted in figure 33–1 and are calculated with an assumed eccentricity value of 1.0 percent (0.01) for steel casing. This adjustment is provided to account for out-of-roundness (deviation from rigorous production standards) that may arise in normal shipping and handling. Eccentricity up to 1.5 percent (0.015) can most likely be tolerated. However, collapse pressure needs to be recalculated using equation 33–1, the Timoshenko Elastic Formula with eccentricity adjustment. Used casing and casing with obvious eccentricity or other defects should be rejected.

Data for allowable differential head (collapse resistance) in tables 33–1 to 33–4 take into account only unbalanced hydrostatic pressure. Overburden pressure at depth in a vertical well is the sum of the weight of the overburden material and the contained ground water. Ordinarily, the weight of the formation is borne by the formation itself. Under some circumstances, part or all of the overburden pressure can be transmitted to the interstitial ground water and may result in casing collapse. Design must also take into consideration conditions that can result in collapse forces (static or dynamic) that exceed hydrostatic pressure.

Example of static conditions:

- Deep confined aquifers can generate significant artesian head on the outside of the casing.

Examples of dynamic conditions:

- Heavily pumped, deep, unconsolidated aquifers are subject to compaction and consolidation processes that can result in formation settlement, movement, and subsidence.
- An improperly installed filter pack (with bridged particles or pockets) can suddenly collapse, resulting in rupture of the casing or screen.
- In a fine sand aquifer, quick conditions can arise from an upward movement of ground water. The sand goes into suspension and is then unable to support the weight of the formation. Effective pressure is reduced to zero, and under-designed casing and screen could collapse.
- Earthquakes and blasting can generate temporary forces that result in rearrangement, consolidation, and settlement of aquifer materials that could cause otherwise satisfactory casing and screen to collapse. Sudden ground motions also can induce liquefaction of saturated fine sands and silts with similar deleterious effects on casing or screens.

(d) Design guidance

If the well may be bailed or pumped dry, such as during development or when pumping a low yield well, the elevation of the bottom of the well should be substituted for the maximum drawdown elevation. Also, if maximum drawdown cannot be determined with confidence, it is a prudent practice to use the elevation of the bottom of the well.

If, in addition to unbalanced hydrostatic pressure, conditions at the well site are anticipated to result only in static pressure increases on the casing and screen, use 40 percent of the maximum allowable differential head values provided in the tables and figures. If dynamic increases in pressure are anticipated, the values should be even less. See example conditions in (c) Safety factors.

631.3302 References

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