Column Design Capacity Comparison with High Strength Reinforcing Bars per ACI 318-14 and ACI 318-19

ACI 318-19 introduced new provisions for high-strength reinforcing bars (HSRB) with 80 ksi and 100 ksi strengths. Table 21.2.2 in ACI 318-19 defines the strength reduction factor ϕ, for tension-controlled sections as an expression of f_y, for all reinforcement grades. Previously in ACI 318-14 Fig. R21.2.2b, the tension-controlled strain limit was set to 0.005. Therefore, beginning with the 2019 Code, the expression ($\varepsilon_{ty} + 0.003$) defines the lower limit on ε_t for tension-controlled behavior. The new limit leads to a constant transition zone range from ε_{ty} to $\varepsilon_{ty} + 0.003$. Previously in ACI 318-14, the constant value of the tension-controlled limit produced narrower transition-zone ranges as the reinforcement grade increased. The compression-controlled limit remains the same in ACI 318-19. A detailed study of HSRB strength is given in Column Design with High-Strength Reinforcing Bars per ACI 318-19.

This article compares column design strength with Grade 60 and Grade 80 reinforcement while taking into account the changes in the provisions between ACI 318-14 and ACI 318-19. The column section and material properties for this example are as follows:
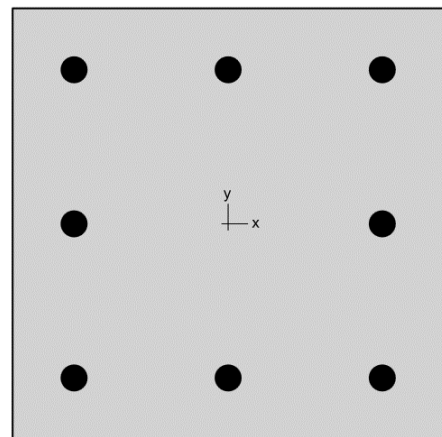
$f_c' = 10{,}000$ psi

$f_y = 60{,}000$ psi and $f_y = 80{,}000$ psi

Cover to longitudinal reinforcement = 2.0 in.

Column dimension = 18 in. x 18 in.

Reinforcement = 8 - #9

$A_s = 8$ in^2 (reinforcement ratio, $\rho = 2.47\%$)


Rectangular 18 x 18 in   2.47% reinf.

Using the spColumn engineering software program, the Table below summarizes the key control points for the factored P-M interaction diagram when using 60 ksi and 80 ksi steel bar strengths per ACI 318-14 and ACI 318-19.

Table 1 - Factored P-M Interaction Diagram Control Points Summary						
Key Control Points	**ϕP_n, kips**			**ϕM_n, kip-ft**		
Reinforcing bar strength	60 ksi	80 ksi	80 ksi	60 ksi	80 ksi	80 ksi
ACI 318 Standard	318-14/19	318-14	318-19	318-14/19	318-14	318-19
Max compression, ϕP_0	2058	2162	2162	0	0	0
Allowable compression, $\phi P_{n,max}$	1646	1729	1729	238	233	233
$\varepsilon_s = \varepsilon_{ty}$ [Compression-controlled limit]	576	449	449	413	413	413
$\varepsilon_s = \varepsilon_{ty} + 0.003$ [Tension-controlled limit]	377	323	244*	452	481	456*
Pure bending	0	0	0	266	346	346
Max tension	-432	-576	-576	0	0	0
* Modified manually to reflect new tension-controlled limit in ACI 318-19						
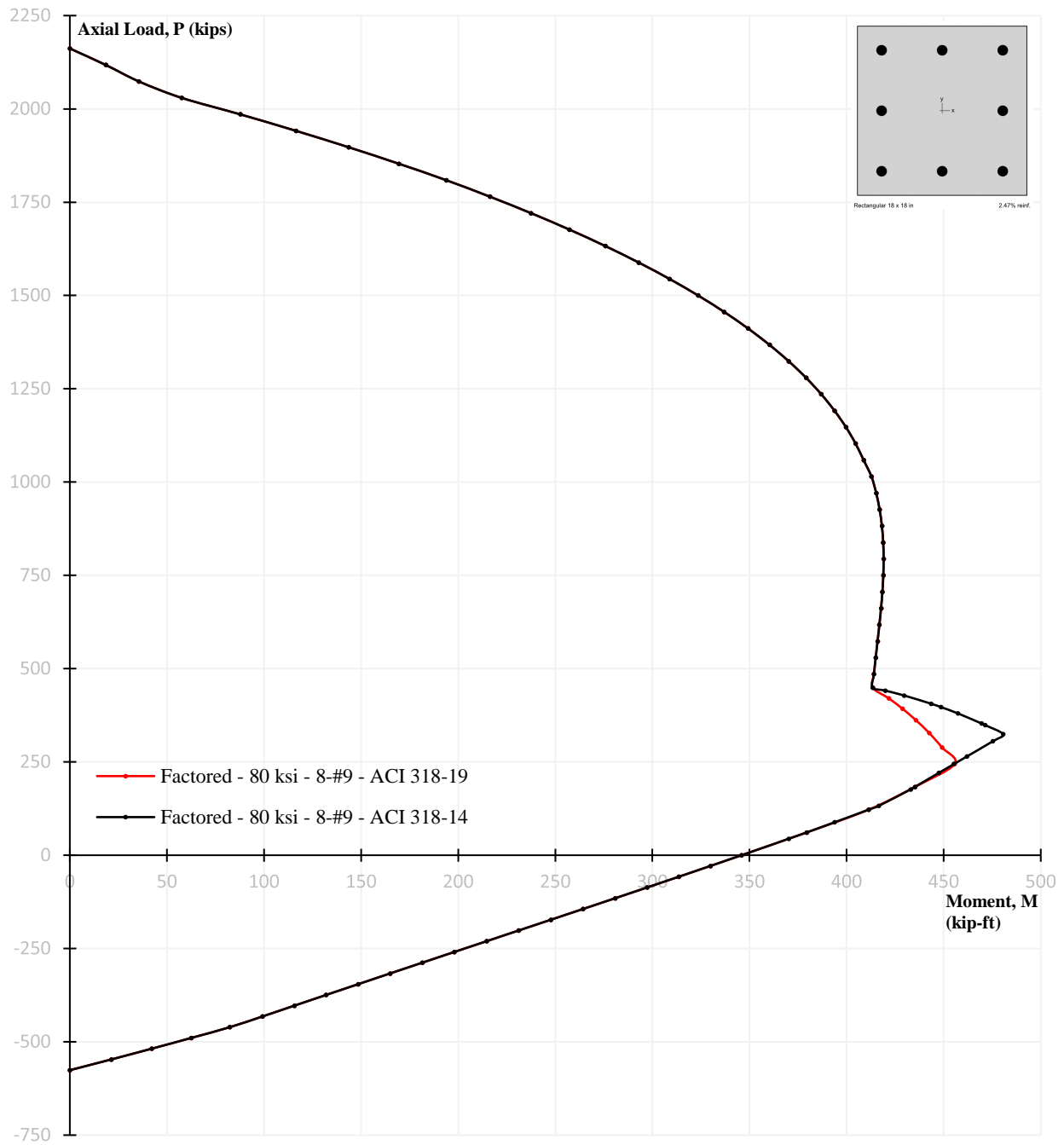
The Figure above shows factored P-M interaction diagrams for a column section with Gr 80 reinforcement per ACI 318-14 where the tension-controlled limit was 0.005 and per ACI 318-19 where the tension-controlled limit for Gr 80 is 0.00576 (e_{ty} + 0.003). The change in the tension-controlled limit leads to the reduction of axial load and moment capacities in the transition zone for this column section designed in accordance with ACI 318-19.
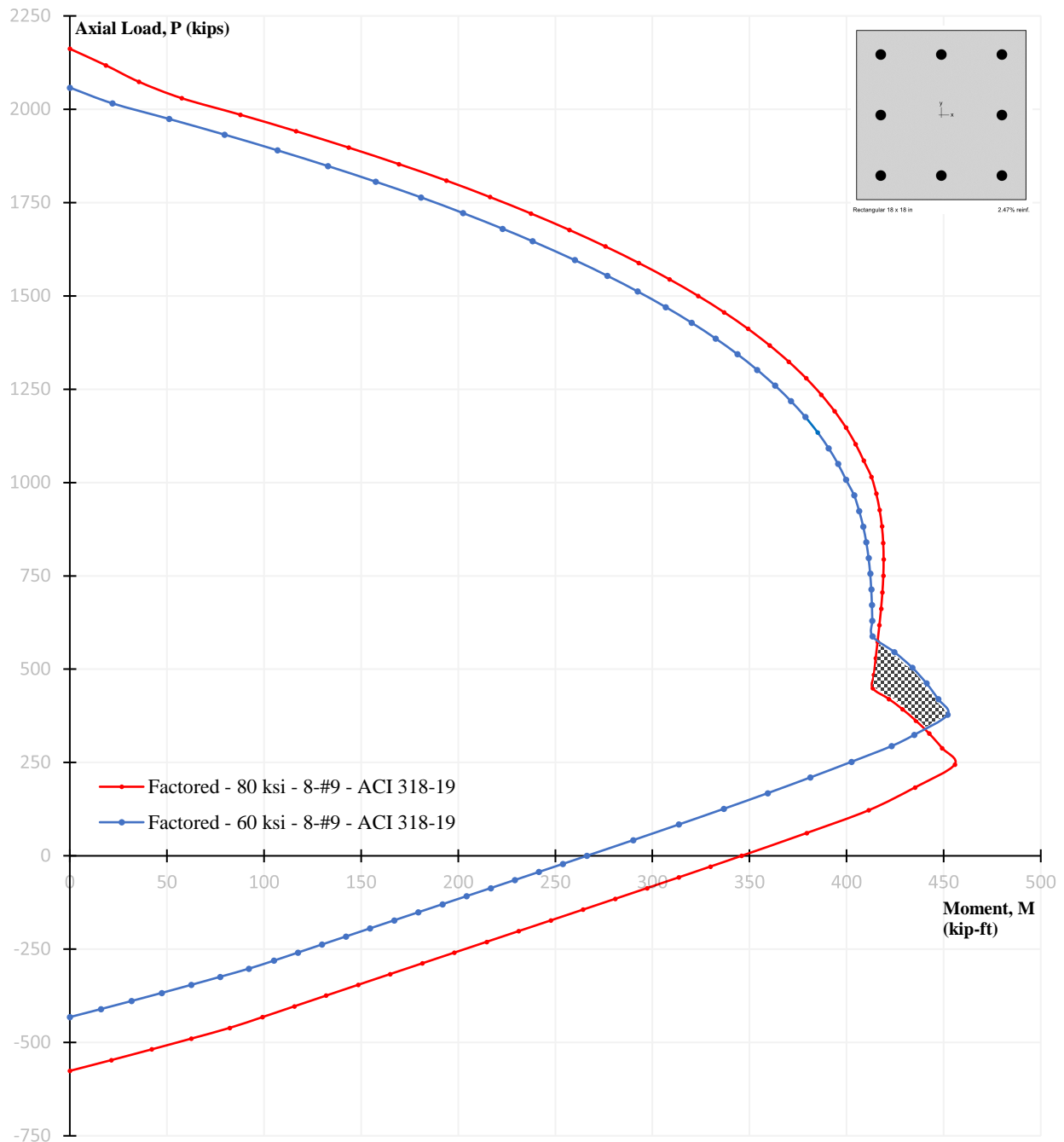
The Figure above shows factored interaction diagrams for a column section with Gr 60 and Gr 80 reinforcement per ACI 318-19.

Notes

1. Per ACI 318-19, the maximum factored axial compressive strength, $\phi P_{n,max}$ of a column with Gr 80 reinforcement is only slightly (5%) greater than that of a column with Gr 60 reinforcement.

2. Per ACI 318-19, the factored moment capacity of a column with Gr 80 reinforcement is greater than that of a column with Gr 60 reinforcement with the exception of the transition zone region of a column with Gr 60 reinforcement. (See shaded area in the figure above).
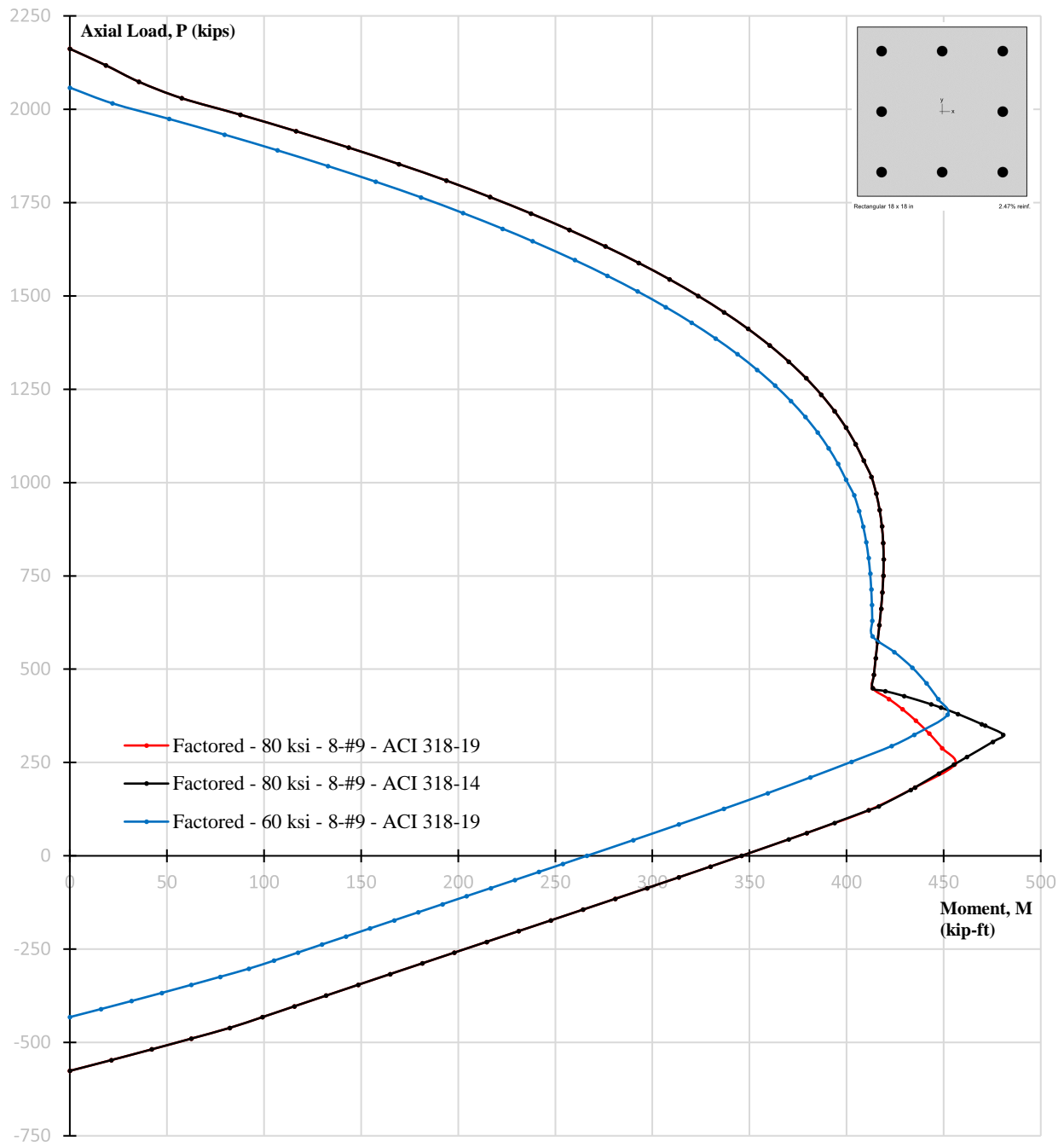
Axial Load, P (kips)

Legend:
- Factored - 80 ksi - 8-#9 - ACI 318-19
- Factored - 80 ksi - 8-#9 - ACI 318-14
- Factored - 60 ksi - 8-#9 - ACI 318-19

Moment, M (kip-ft)

Rectangular 18 x 18 in   2.47% reinf.

The Figure above shows factored interaction diagrams for a column section with Gr 60 and Gr 80 reinforcement per ACI 318-19 as well as Gr 80 reinforcement per ACI 318-14.

In summary it can be seen in the figure above that ACI 318-19 revised the tension-controlled strain limit in Table 21.2.2 as an expression of f_y, to explicitly cover all nonprestressed reinforcement grades. This revision provides a uniform and consistent treatment of the strength reduction factor, ϕ, throughout the transition zone up until the tension-controlled strain limit for all reinforcement grades and, therefore, eliminates the pointed zone that may be created at the transition zone in ACI 318-14.

Structure Point
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Appendix: Tabulated Factored Interaction (P-M) Diagram Numerical Values.

φ Pₙ, kip			φ Mₙ, kip-ft		
60 ksi	80 ksi	80 ksi	60 ksi	80 ksi	80 ksi
318-19	318-14	318-19	318-19	318-14	318-19
2057.9	2161.9	2161.9	0.0	0.0	0.0
2015.9	2117.8	2117.8	21.9	18.5	18.5
1973.9	2073.7	2073.7	51.2	35.5	35.5
1931.9	2029.5	2029.5	79.7	57.6	57.6
1889.9	1985.4	1985.4	106.9	87.8	87.8
1847.9	1941.3	1941.3	132.8	116.4	116.4
1805.9	1897.2	1897.2	157.5	143.6	143.6
1763.9	1853.1	1853.1	180.9	169.4	169.4
1721.9	1808.9	1808.9	202.5	193.9	193.9
1679.9	1764.8	1764.8	222.8	216.3	216.3
1646.3	1720.7	1720.7	238.3	237.5	237.5
1595.9	1676.6	1676.6	260.0	257.3	257.3
1553.9	1632.5	1632.5	276.8	275.8	275.8
1511.9	1588.3	1588.3	292.4	292.9	292.9
1469.9	1544.2	1544.2	306.9	308.9	308.9
1427.9	1500.1	1500.1	320.2	323.5	323.5
1385.9	1456.0	1456.0	332.5	337.0	337.0
1343.9	1411.9	1411.9	343.7	349.2	349.2
1301.9	1367.7	1367.7	353.9	360.3	360.3
1259.9	1323.6	1323.6	363.1	370.3	370.3
1217.9	1279.5	1279.5	371.4	379.1	379.1
1175.9	1235.4	1235.4	378.7	387.0	387.0
1133.9	1191.3	1191.3	385.1	393.8	393.8
1091.9	1147.1	1147.1	390.7	399.7	399.7
1049.9	1103.0	1103.0	395.6	404.6	404.6
1008.0	1058.9	1058.9	399.7	408.8	408.8
966.0	1014.8	1014.8	403.8	412.8	412.8
924.0	970.6	970.6	406.5	415.2	415.2
882.0	926.5	926.5	408.5	417.0	417.0
840.0	882.4	882.4	410.1	418.2	418.2
798.0	838.3	838.3	411.3	418.9	418.9
756.0	794.2	794.2	412.1	419.1	419.1
714.0	750.0	750.0	412.7	418.9	418.9
672.0	705.9	705.9	413.0	418.4	418.4
630.0	661.8	661.8	413.2	417.7	417.7
588.0	617.7	617.7	413.4	416.9	416.9
546.0	573.6	573.6	424.6	416.0	416.0
504.0	529.4	529.4	433.9	415.0	415.0
462.0	485.3	485.3	441.2	414.1	414.1
420.0	449.3	449.3	447.1	413.4	413.4
378.0	428.0	420.2	452.0	429.7	421.8
324.0	406.2	392.7	434.7	443.5	428.8
294.0	380.0	362.0	423.1	457.4	435.7
252.0	348.9	327.6	402.6	471.3	442.5
210.0	305.4	288.7	381.3	475.3	449.2
168.0	244.4	244.6	359.4	455.3	455.7
126.0	183.3	183.3	336.8	435.2	435.2
84.0	122.2	122.2	313.6	411.4	411.4
42.0	61.1	61.1	290.1	379.4	379.4
0.0	0.0	0.0	266.2	345.9	345.9
-21.6	-28.8	-28.8	253.9	329.8	329.8
-43.2	-57.6	-57.6	241.5	313.6	313.6
-64.8	-86.4	-86.4	229.1	297.3	297.3
-86.4	-115.2	-115.2	216.7	280.8	280.8
-108.0	-144.0	-144.0	204.3	264.3	264.3
-129.6	-172.8	-172.8	191.8	247.7	247.7
-151.2	-201.6	-201.6	179.4	231.2	231.2
-172.8	-230.4	-230.4	167.0	214.6	214.6
-194.4	-259.2	-259.2	154.6	198.0	198.0
-216.0	-288.0	-288.0	142.2	181.4	181.4
-237.6	-316.8	-316.8	129.8	164.9	164.9
-259.2	-345.6	-345.6	117.4	148.4	148.4
-280.8	-374.4	-374.4	105.1	132.0	132.0
-302.4	-403.2	-403.2	92.1	115.6	115.6
-324.0	-432.0	-432.0	77.4	99.2	99.2
-345.6	-460.8	-460.8	62.5	82.4	82.4
-367.2	-489.6	-489.6	47.3	62.5	62.5
-388.8	-518.4	-518.4	31.8	42.2	42.2
-410.4	-547.2	-547.2	16.0	21.3	21.3
-432.0	-576.0	-576.0	0.0	0.0	0.0