Effectiveness of ChromX Steel in Congested Concrete Columns

By

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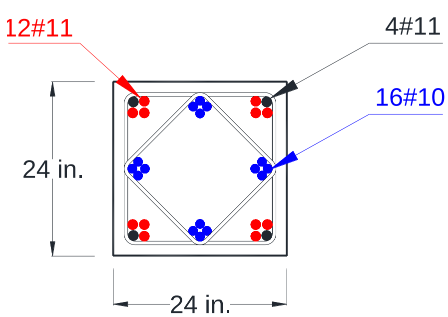
Introduction

Recent advances in reinforcing steel chemistry have allowed the introduction of the corrosion resistant, high strength reinforcing bar to the construction industry. The bars are marketed under the trade name of ChromX Steel. The bars have a yield strength of 100 ksi (700 MPa), ultimate strength of 150 ksi (1050 MPa), and excellent mechanical properties, as per ASTM A1035 standards. This reinforcement allows for reduction of up to 40 percent of the weight of the Grade 60 "black bars". It thus allows for significant reduction of the congestion in the concrete member. In addition, when used in structures subject to corrosive conditions, the ability of the bars to resist corrosion greatly enhances life expectancy and virtually eliminates expensive maintenance. ChromX 9100 bars with 9 percent chromium content have been shown to be five times more corrosion-resistant than conventional steel rebar. ChromX 4100 has been shown to be better performing than epoxy coated steel. ChromX 2100 with 2 percent chromium is still more corrosion resistant than black steel and 67 percent stronger, while its cost premium is minimal.

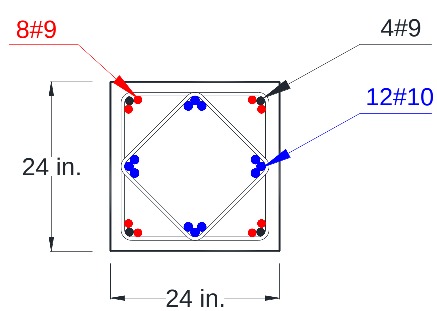
The objective of this report is to determine the best value arrangements for axially loaded columns with various steel and concrete grades. First, we will consider straight conversion of Grade 60 to Grade 100 steel, while keeping the column size and number of bars unchanged.

Simplified Conversion to ChromX Steel

Figures 1 and 2 show the cross section and elevation of an interior column in a six-story parking structure. The column is 24 in. by 24 in. in cross section and 60 ft tall. Concrete strength is 5,000 psi.



(a)



(b)

Figure 1- Cross section of a column at the lowest story of a six-story parking structure. Figure (a) shows Grade 60 reinforcement. Fig. 1(b) shows Grade 100 ChromX reinforcement

The Fig. 1 (a) shows the reinforcement with ASTM A615 Grade 60 steel. It is 16#11 plus 16#10 in the first two stories of the building. It has a total area of 45.28 in^2 and weight of 154 pounds per foot. If it is desired to convert the reinforcement to ASTM A1035 Grade 100 ChromX steel while minimizing changing in bar layout or arrangement, the conversion results in 12#9 plus 12#10. The total area of steel = 27.24 in^2. The weight of the bars is 93 pounds per foot.

This type of conversion is the simplest conversion from Grade 60 to Grade 100 ksi steel. When the steel is fully utilized as in mostly axially compressed members, the conversion factor is simply the ratio of yield strengths of the respective steel grades.

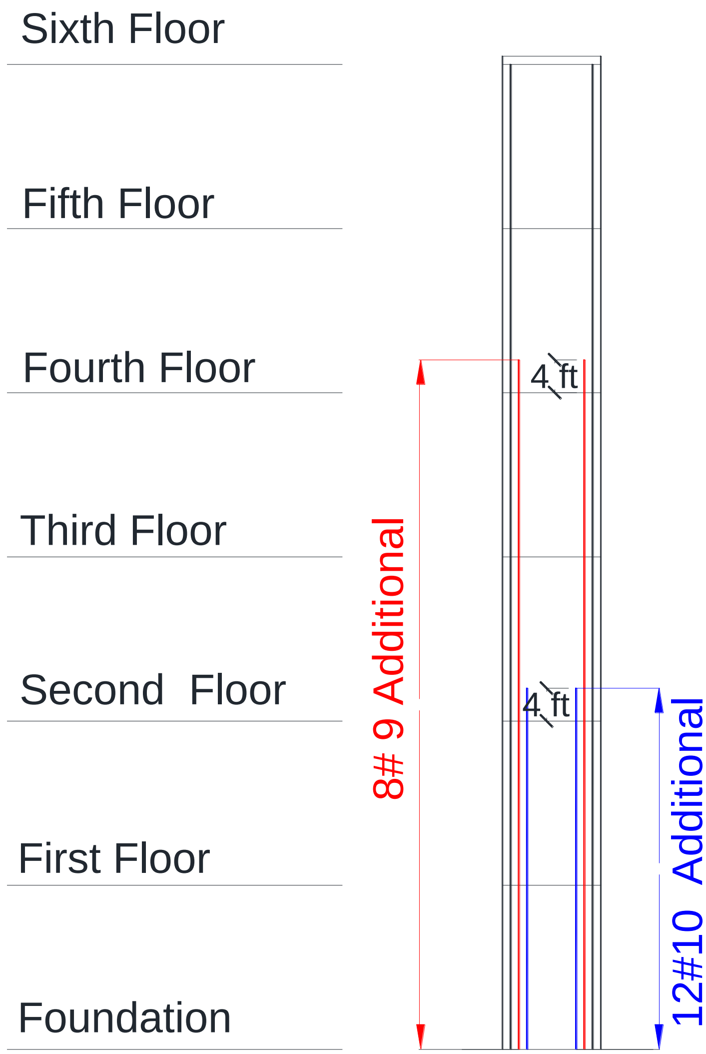


Figure 2- Elevation of column showing bar terminations at various elevations

Comprehensive Analysis

In most cases, full efficiency is realized when the total structural system is fully analyzed for combined effects of flexure, axial load, shear and torsion, and optimized with the purpose of attempting to achieve the lowest total costs.

As a simplified illustration, we will perform a parametric study of the column just described, taking into account column size, concrete strength and steel strength. Specifically, the following parameters are examined:

- Three levels of reinforcement , 1%, 4% and 8% of the concrete area
- Two grades of reinforcement, ASTM A615 Grade 60 steel and ASTM A1035 Grade 100 ChromX steel
- Three grades of concrete compressive strength, 5, 9 and 16 ksi

Table 1 shows four main cases being considered: Case 1 involves the basic commonly used assumptions of 5 ksi concrete and 60 ksi steel with three levels of reinforcement. The remaining three cases change the concrete strength to 9 or 16 ksi and the steel strength to 100 ksi. The axial compression design strength is maintained about the same for each level of reinforcement. Thus, for 1 percent reinforcement, one can use 14 x 14 in. column as it is allowed to use 16 ksi concrete and 100 ksi steel. This illustrates the significant benefit in column size reduction and the associated benefit in leasable space increase. This comparison appears to be incomplete as higher strength materials require higher strength unit costs.

Table 1 Effect of variation of concrete and steel strengths on column size and reinforcement per given axial capacity

Case #	Sub Case #	f'_c (ksi)	f_y (ksi)	Cross Section	A_g (in^2)	Reinforcement	A_{st} (in^2)	*0.85* $f'_c*(A_g-A_{st})$	$f_y.A_{st}$	ϕ P_n (ksi)
Case 1 Baseline	A light steel	5	60	24 by 24"	576	4#11	6.2	2421.5	374	1454
	B moderate steel	5	60	24 by 24"	576	16#11	25.0	2341.9	1497.6	1997
	C heavy steel	5	60	24 by 24"	576	16#11 plus 16#10	45.3	2255.6	2716.8	2586
Case 2	A light steel	5	100	23" by 23"	529	4#11	6.2	2221.7	624	1480
	B moderate steel	5	100	22" by 22"	484	12#11	18.7	1977.4	1872	2002
	C heavy steel	5	100	21" by 21"	441	20#11	31.2	1741.7	3120	2528
Case 3	A light steel	9	100	18" by 18"	324	4#9	4.0	2448.0	400	1481
	B moderate steel	9	100	18" by 18"	324	8#11	12.5	2383.1	1248	1888
	C heavy steel	9	100	18" by 18"	324	16#11	25.0	2287.7	2496	2488
Case 4	A light steel	16	100	14" by 14"	196	4#7	2.4	2633.0	240	1494
	B moderate steel	16	100	15" by 15"	225	6#11	9.4	2932.7	936	2012
	C heavy steel	16	100	15" by 15"	225	8#11 plus 8#10	22.6	2752.1	2264	2608

Thus, a cost comparison is conducted as illustrated in Table 2. For the cost comparison it is assumed that the unit cost of the concrete is $400 per cubic yard (including forming and labor) for 5 ksi concrete, $450 for 9 ksi concrete and $500 for 16 ksi concrete. The unit cost of the steel is assumed to be $1.00 per pound fabricated for Gr. 60 steel and $1.25 per pound for Gr. 100 ChromX steel. The table shows the total cost for a 12 ft tall column in one story. It can be seen that the most percent savings is realized when the highest concrete strength and ChromX steel are used. The same information is presented in Figure 3 for moderately reinforced columns (with 4 percent steel).

Table 2 Percent change in cost due to use of a combination of high strength steel and high strength concrete for the same column capacity

Case #	f'_c (ksi)	f_y (ksi)	Cross Section	Reinforcement	Total column cost	Relative Cost
Case 1 Baseline	5	60	24 by 24"	4#11	$965.70	100
	5	60	24 by 24"	16#11	$1,729.48	100
	5	60	24 by 24"	16#11 plus 16#10	$2,558.54	100
Case 2	5	100	23" by 23"	4#11	$971.33	100.6
	5	100	22" by 22"	12#11	$1,552.25	89.8
	5	100	21" by 21"	20#11	$2,135.64	83.5
Case 3	9	100	18" by 18"	4#9	$654.00	67.7
	9	100	18" by 18"	8#11	$1,086.48	62.8
	9	100	18" by 18"	16#11	$1,722.96	67.3
Case 4	16	100	14" by 14"	4#7	$424.87	44
	16	100	15" by 15"	6#11	$824.58	47.7
	16	100	15" by 15"	8#11 plus 8#10	$1,501.86	58.7

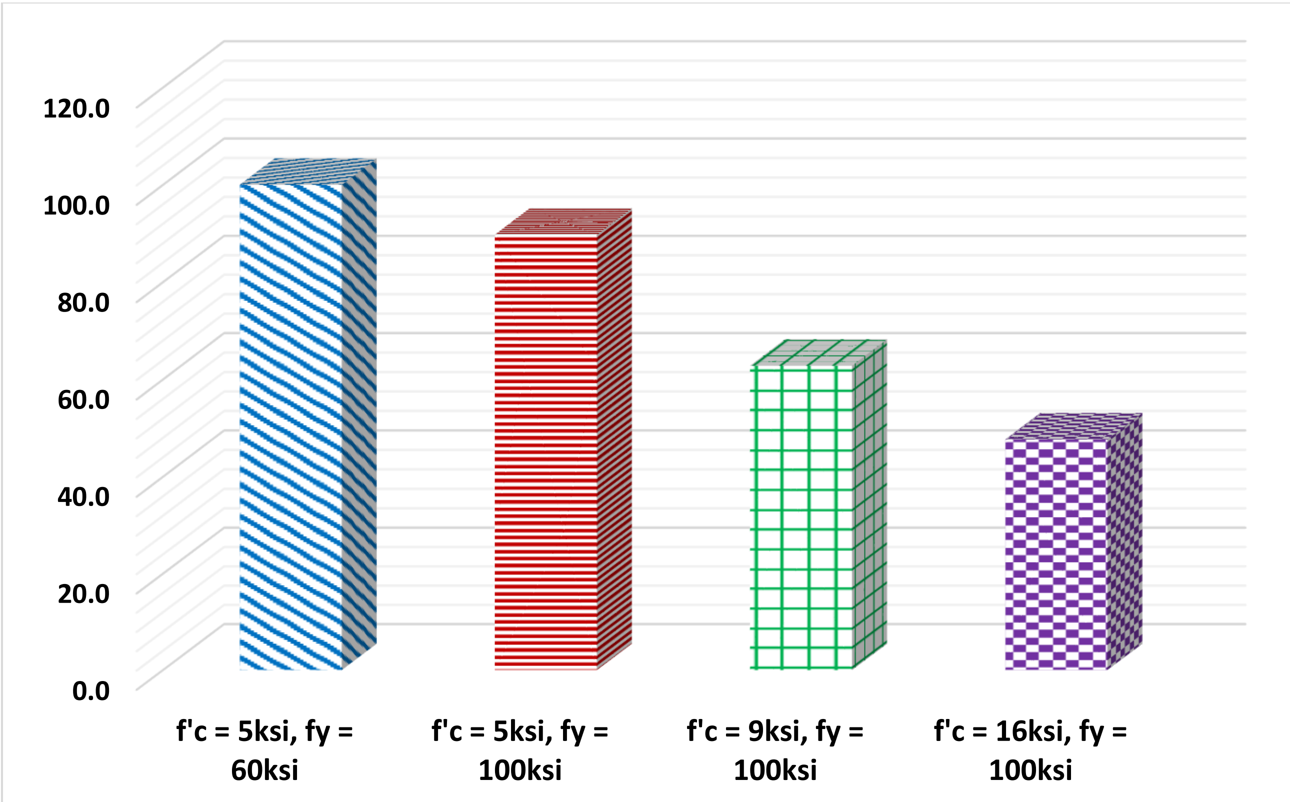


Figure 3 Relative cost of a column reinforced with 4 percent steel and subject to the same axial load

Conclusions

(1) A quick conversion for preliminary evaluation of the feasibility of conversion from ASTM A615 Grade 60 steel to ASTM A1035 Grade 100 ChromX steel is to use the yield strength ratio (60/100) as a conversion factor. It should be cautioned that this ratio may not be fully realized except for special cases when the steel in both cases is fully utilized. For example, it is not accurate in compression-controlled flexural members or when minimum reinforcement controls design.

(2) Owners and contractors are encouraged to explore the benefits of using ChromX steel beyond a simple conversion factor. A much higher value is achieved when a total system analysis is performed. Such analysis could result in reduction of floor thickness, concrete quantities, formwork, and steel fabrication and placement. Secondary, but significant, improvements in architectural, mechanical, and electrical systems may be realized.

(3) As a way of illustrating the benefits of an integrated structural design approach of a compression member, a 24 by 24 in. column in a six-story parking structure was analyzed. Analysis showed that:

> (A) Column cost can decrease by as much as 56 percent with the increase in concrete and steel strengths for the same axial capacity.
> (B) Increasing materials strengths also results in reduced column size which increases the value of the leasable space.