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A COMMENT ON THE USE OF POLYMER-IMPREGNATED CONCRETE IN BRIDGE DECKS TO ACHIEVE A REDUCTION IN MATERIAL VOLUME AND FIRST COST

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

June 1975
VHTRC 75-R68

SUMMARY

Three 130', simple span, composite plate girder structures were designed to approximate the material requirements and first cost associated with a polymer-impregnated concrete as compared to those for a conventional concrete bridge deck. The structures were designed by the working stress method, and although the AASHTO code was applied where applicable, some assumptions were made in the design of the polymer-impregnated deck.

The results indicate that by using polymer-impregnated concrete rather than conventional concrete in a bridge deck, material requirements may be altered as follows, depending upon the assumptions and specifications applied in the design.

1. Deck concrete — 0 to 41% less
2. Deck reinforcing steel — 0 to 115% more
3. Structural steel — 0 to 16% less
4. Substructure — 0 to 17% less

Assuming that polymer-impregnated concrete costs about twice as much as conventional concrete, the structures with a polymer deck cost from 0.5% less to 10.5% more than the structure with a conventional deck. Based on these findings it appears that the material savings that can be achieved by using polymer-impregnated concrete in a bridge deck may tend to offset the high unit cost of the concrete, but not enough to justify its use on a first cost basis. However, performance specifications for concrete polymer materials must be developed before an accurate determination of material savings can be made.

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INTRODUCTION

Concrete may be impregnated or loaded with a monomer to form a composite material that exhibits a much greater compressive strength, modulus of elasticity, modulus of rupture, freeze/thaw resistance, hardness, impermeability, and resistance to many corrosive materials and conditions than does ordinary concrete.[1,2,3] The extent of the improvement depends upon the monomer material and technique used to form the concrete polymer.[1,3]

The improvements in characteristics cited suggest that concrete polymer materials could provide an improvement over conventional concrete for bridge deck construction. However, the former costs more than the latter (polymer-impregnated concrete costs about twice as much as conventional concrete)[1] and, therefore, to be an economical alternative material, it must provide a reduction in material requirements and/or a reduction in maintenance costs to offset the higher unit cost. Relative maintenance costs can best be determined by a long-term comparative field study. On the other hand, the material savings that can be achieved through a reduction in sectional areas can be estimated with a comparative design calculation. However, the validity of the design comparison will depend on how well the assumptions used in the design satisfy performance specifications for concrete polymer materials, which have yet to be established.[4,5]

OBJECTIVE

The objective of this report is to present an estimate of the material requirements and first cost associated with the use of polymer-impregnated concrete as compared to those for conventional concrete in the deck of a composite plate girder bridge structure.

COMPARATIVE DESIGNS

The three 130'-0", simple span, plate girder structures discussed in this report are shown in Figure 1, and the basic design information is presented in Appendix A. The structures were designed by the working stress method, and, although the AASHTO code[6] was applied where applicable, many assumptions were made in the design of the polymer decks shown in plans B and C. For example, the polymer-impregnated concrete specified for plans B and C has a compressive strength four times greater and a modulus of elasticity two times greater than those for the A4 concrete specified for plan A. Because concrete polymer materials of this quality have been obtained only with impregnated and polymerized precast members,[1,7] full-width transverse precast deck sections are specified for plans B and C, and it is assumed that composite action is achieved with the deck-to-girder connections. The following general notes apply to each of the three designs.

1. Main reinforcement conforms to ASTM A615-60 grade steel.

2. The deck slabs are designed to take fatigue into account by limiting the specified stress to 3/4 of the allowable.

3. The deck thickness, t, includes a ½" monolithic wearing surface.

4. The cover over the reinforcing steel in the deck is 2" on the top and 1¼" on the bottom.

5. $A'_s = \frac{1}{2} \times A_s$.

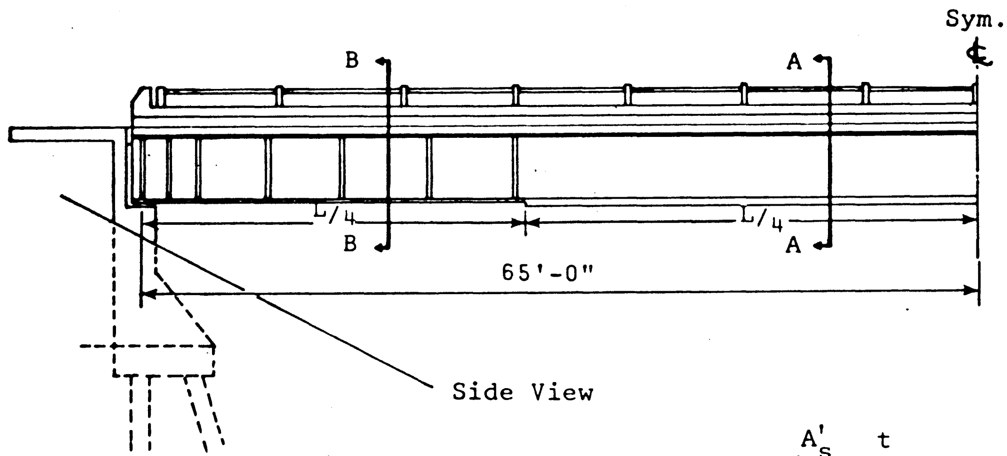
6. The design section for the deck is located at the centerline of the span.

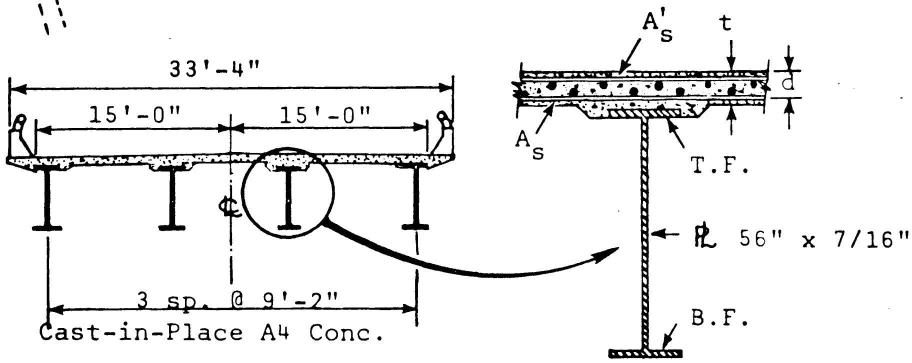
7. The live load design moment for the slab is equal to

   $$\frac{S + 2}{32} \times 16{,}000 \times .8.$$

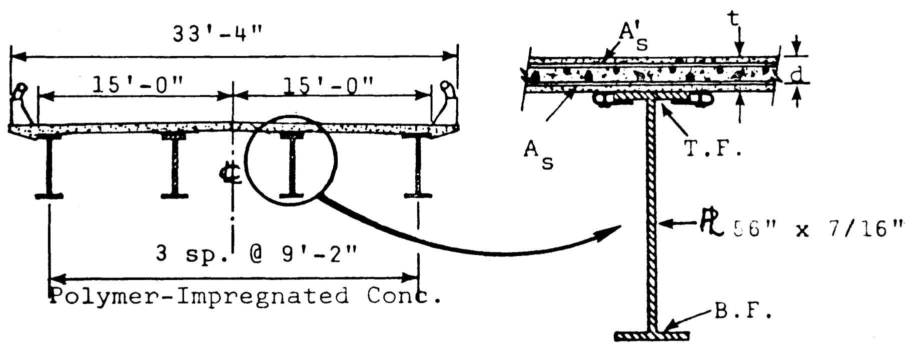
8. The dead load design moment for the slab is equal to $\frac{1}{10} wS^2$.

9. Parapets consist of A4 concrete.





Section A-A or B-B (Plan A)



Section A-A or B-B (Plan B & C)

Comparative Member Sizes (inch)

Plan	Section A-A			Section B-B		
	t	T.F.	B.F.	t	T.F.	B.F.
A	8½	2 x 18	3 x 18	8½	1½ x 18	2¼ x 18
B	5	1½ x 18	2½ x 18	5	1 x 18	1-3/4 x 18
C	6½	1-3/4 x 18	2-3/4 x 18	6½	1¼ x 18	2 x 18

Figure 1. Final design for the three plate girder structures.

10. Parapets and rails provide 512 lbs/ft dead load per lane.

11. Structural steel conforms to ASTM A36.

12. Substructure consists of A3 concrete.

13. Piles conform to ASTM A36 grade steel.

14. Capacity is based on HS 20-44 loading.

15. Span length = 130' - 0".

16. Bridge width = 33' - 4".

17. Roadway width = 30' - 0".

18. Girder spacing = 9' - 2".

19. Girder web dimensions are 56" x 7/16".

Plan A — Conventional A4 Concrete Deck

Class A4 concrete with a minimum laboratory compressive strength at 28 days of 4,000 psi is specified for the conventional deck. The design calculations for this deck indicate that an 8½" deck thickness is required to support the midspan moments. This thickness is equal to the minimum allowed by the Concrete Deck Slab Design Specifications used by the Virginia Department of Highways & Transportation.[8]

Plan B — 5" Polymer-Impregnated Concrete Deck

Polymer-impregnated concrete with a minimum laboratory compressive strength at 28 days of 16,000 psi is specified for plan B. The design calculations for the deck indicate that a 5" deck thickness is required to support the midspan moments. This thickness is much less than the 8½" required by the Concrete Deck Slab Design Specifications used by the Virginia Department of Highways and Transportation and the 7-3/8" thickness specified by Table 1.5.27 of the AASHTO code. Also the calculation is based on a value of n ($n = E_s/E_c$) equal to 4.6, which is less than the minimum allowed by Section 1.5.2 of the AASHTO code.

The purpose of specifying the 5" deck thickness for plan B, which does not comply with the AASHTO code or the specifications used by the Virginia Department of Highways & Transportation, is to point out the relative difference in material requirements that could be achieved if performance specifications for polymer-impregnated concrete indicate that deck slab design can be based on a midspan moment up to a minimum thickness much less than the minimum currently required for conventional concrete. In addition the 5" deck thickness provides for a structure representative of the material savings necessary to offset the higher unit cost of polymer-impregnated concrete. It is quite likely that a slab geometry (i.e., a voided prestressed slab) other than the one shown in plan B would provide for a greater deck thickness and a reduction in deck reinforcing steel requirements while maintaining the other material volumes represented by plan B.

Plan C — 6½" Polymer-Impregnated Concrete Deck

Strains, cracking, and deflection rather than moment often control the design of structures consisting of high strength materials.[9] The 6½" deck thickness specified for plan C was determined by modifying the minimum thickness value given in Table 1.5.27 of the AASHTO code on the basis that deflection is proportional to 1/EI, where E equals the modulus of elasticity of the 16,000 psi (28-day strength) polymer-impregnated concrete, which was assumed to be twice that of conventional concrete. As in plan B the deck thickness in plan C is less than the minimum required for conventional concrete by the AASHTO code (7-3/8") and the specifications used by the Virginia Department of Highways and Transportation (8½").

The purpose of specifying the 6½" deck thickness for plan C is to point out the relative difference in material requirements that could be achieved if performance specifications for polymer concrete indicate that deck slab design can be based on live load deflection up to a minimum thickness much less than the minimum currently required for conventional concrete. In addition the 6½" deck thickness is equal to the minimum allowed by the AASHTO code, regardless of girder spacing.

MATERIAL QUANTITY COMPARISONS

An indication of the relative material requirements for plans A, B, and C is shown in Tables 1 and 2.

Table 1

Concrete and Structural Steel Requirements
for Superstructure of Plans A, B, and C

Plan	Deck Concrete	Deck Thickness	Concrete C.Y.*	Structural Steel (lbs x 10-3)**
A	A4	8½"	113.6	192.5
B	Polymer	5"	66.8	160.7
C	Polymer	6½"	86.8	176.7

* Deck concrete only

** Excluding reinforcing steel

Table 2

Percentages of Material Requirements
for Plans B and C with respect to Plan A

Plan	Deck Materials		Structural Steel	Substructure Materials
	Concrete	Reinforcing Steel		
A (8½" deck)	100.0	100	100.0	100.0
B (5" deck)	58.8	215	83.5	82.7
C (6½" deck)	76.4	143	91.7	92.0

FIRST COST COMPARISONS

According to information included in another project conducted by the author,(10) it can be assumed that the relative costs of the various materials and labor that go into the construction of a 30', simple span, plate girder structure are as follows:

Deck concrete	10.6%
Deck reinforcing steel	6.4%
Structural steel	35.8%
Substructure materials	22.9%

Based on these percentages and the assumption that polymer-impregnated concrete costs twice as much as conventional concrete, the percentage difference in the first cost of plans B and C with respect to the first cost of plan A is shown in Table 3.

Table 3

Percentage Difference in the First Cost of Plans B and C with respect to Plan A

Plan	Deck Materials		Structural Steel	Substructure Materials	TOTAL
	Concrete	Reinforcing Steel			
B (5" deck)	+1.87	+7.36	-5.91	-3.96	-0.64
C (6½" deck)	+5.61	+2.75	-2.97	-1.83	+3.56

The reduction in the material requirements is adequate to offset the higher unit cost of the polymer-impregnated concrete in plan B but not adequate in plan C.

CONCLUSIONS

The relative change in material volume and first cost associated with the use of polymer-impregnated concrete as compared to A4 concrete in a composite concrete slab bridge deck depends on the following factors.

1. The relationship between the structural properties of the polymer-impregnated concrete and the A4 concrete.

2. The specifications, constraints, and assumptions applied in the design of the decks.

In this report polymer-impregnated concrete is assumed to have four times the compressive strength, two times the modulus of elasticity, and twice the cost of conventional A4 concrete. Based on these relationships, the percentage differences in the first cost associated with the use of the polymer-impregnated concrete, with respect to A4 concrete, in accordance with various design specifications, are shown in Table 4.

Table 4

Percentage Differences in First Cost Associated with the Use of Polymer-Impregnated Concrete Rather than Conventional A4 Concrete in Accordance with the Indicated Specifications

Design Specifications and/or Condition	Minimum Deck Thickness	Percentage Change in First Cost				
		Deck Materials		Structural Steel	Substructure Materials	TOTAL
		Concrete	Reinforcing Steel			
Va. Dept. of Highways and Transportation	8½"	+10.6	0	0	0	+10.6
AASHTO	7½"	+ 8.10	+1.2	-1.4	-0.8	+ 7.1
AASHTO* with design based on deflection	6½"	+ 5.61	+2.75	-2.97	-1.83	+ 3.56
AASHTO** with design based on midspan moment	5"	+ 1.87	+7.36	-5.91	-3.96	- 0.64

* Without regard to Section 1.5.1 (B) and 1.5.2 (4) and with adjustment to Table 1.5.27.

** Without regard to Section 1.5.1 (B) and 1.5.2 (4) and Table 1.5.27.

Based on the analysis presented in this report an 8½" thick conventional deck can be replaced by a 5¼" precast polymer-impregnated concrete deck for the same first cost. However, a 5¼" deck may not be serviceable because of deflection, cracking or brittle fracture. Furthermore, if composite action between the precast slab and steel stringers cannot be achieved, the structural steel requirements for plans B and C would have to be increased. If it is necessary to use cast-in-place polymer-cement concrete (maximum compressive strength is much less than 16,000 psi) to obtain composite action, the deck thicknesses specified for plans B and C would have to be increased, which would also result in a decrease in material savings. Performance specifications for concrete polymers must be developed if its high strength characteristics are to be used to the fullest advantage in concrete slab deck construction. The use of more sophisticated superstructure geometries with concrete polymers should provide additional savings. Conventional slab deck geometries consisting of polymer-impregnated concrete and designed by Virginia Department of Highways & Transportation specifications will not provide for material savings, and the additional first cost associated with the use of polymer-impregnated concrete rather than A4 concrete must be offset entirely by a reduction in maintenance costs.

RECOMMENDATIONS

To provide information needed to achieve the maximum reduction in material volume when specifying concrete polymers for a bridge deck, it is recommended that the following research be conducted.

1. Determine the appropriateness of methods other than "Working Stress" for concrete polymer design.

2. Establish minimum thickness criteria for concrete polymer slab decks.

3. Examine the feasibility of using concrete polymers in more sophisticated deck geometries.

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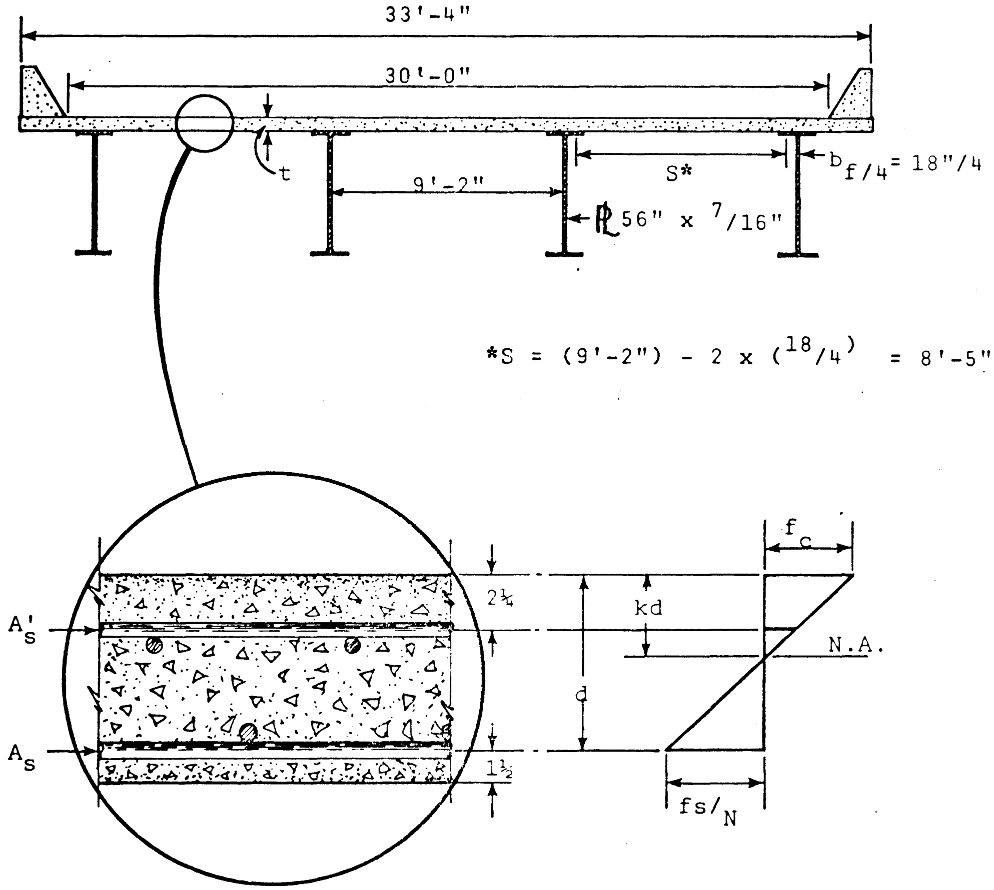
APPENDIX A

DESIGN INFORMATION

Design Method — "Working Stress"

Geometric Conditions and Notation — see figure below.



$A'_s = \frac{1}{2} A_s$

Span length	=	130'
E	=	modulus of elasticity
fy	=	yield stress
f_s	=	working stress
$M_{DL(1)}$	=	dead load moment (slab, str. steel, etc.)
$M_{DL(2)}$	=	dead load moment (parapets)
M_{LL}	=	live load moment
$M_{LL + I}$	=	live load + impact moment
$\overline{M}$	=	total moment
t	=	deck thickness
d	=	depth to bottom steel
B.F.	=	bottom flange
T.F.	=	top flange
T.C.	=	top concrete

Deck Design Information

Plan	A	B	C
E_s (psi)	29×10^6	29×10^6	29×10^6
fy (psi)	60×10^3	60×10^3	60×10^3
f_s (psi)	24×10^3	24×10^3	24×10^3
$\bar{\rho}_c$ (pcf)	145	159	159
Ec (psi)	3.12×10^6	6.24×10^6	6.24×10^6
f'c (psi)	4000	16000	16000
f_c (psi)	1200	4800	4800
n	9.2	4.6	4.6
W wearing surface (psf)	15	15	15
M_{DL}(ft-lbs) = $0.1\overline{W}S^2$	860	576	717
$I = \frac{50}{S + 125} \leq 0.3$	0.3	0.3	0.3
M_{LL}(ft.-lbs) = $(\frac{S + 2}{32}) \times (16000) \times (.8)$	4168	4168	4168
$M_{LL + I}$(ft-lbs)	5418	5418	5418
$\overline{M}$ (ft-lbs)	6278	5994	6135
f_s/n (psi)	2608.7	5217.4	5217.4
k_b	0.315	0.479	0.479
j_b	0.895	0.840	0.840
d_b(in)	6.09	2.49	2.49
t (in)	8.5	5.0	6.5
kd (in)	1.936	1.248	1.35
jd (in)	5.85	2.58	3.99
A_s (in^2)	0.54	1.16	0.77
A_s' (in^2)	0.27	0.58	0.38

Plate Girder Design Information

Plan	A	B	C
Es (psi)	29×10^6	29×10^6	29×10^6
fy (psi)	36×10^3	36×10^3	36×10^3
fs (psi)	20×10^3	20×10^3	20×10^3
$I = \frac{50}{130 + 125} \leq 0.3$	0.196	0.196	0.196
$D.F. = \frac{S}{2\ (5.5)}$	0.8334	0.8334	0.8334
M_{LL} @ 1/2 (ft.kips/lane)	2063.1	2063.1	2063.1
M_{LL} @ 1/4 (ft.kips/lane)	1590	1590	1590
$M_{LL + I}$ @ 1/2 (ft.kips)	2056.4	2056.4	2056.4
$M_{LL + I}$ @ 1/4 (ft.kips)	1585	1585	1585
M_{DL}(2)@ 1/2 (ft.kips)	540.8	540.8	540.8
M_{DL}(2)@ 1/4 (ft.kips)	405.6	405.6	405.6
M_{DL}(1)@ 1/2 (ft.kips)	2884.6	1980.6	2430.2
M_{DL}(1)@ 1/4 (ft.kips)	2152.6	1474.6	1811.8
n	9.2	4.6	4.6
effective slab width (ft)	8.0	4.5	6.0
eff.conc.area @ n(in^2)	83.49	52.83	93.91
eff.conc.area @3n (in^2)	27.83	17.61	31.30
steel area @ 1/2 (in^2)	114.5	96.5	105.5
steel area @ 1/4 (in^2)	92.0	74.0	83.0
stress T F@ 1/2 (ksi)	-19.34	-20.05	-18.52
stress B F@ 1/2 (ksi)	19.91	19.96	19.76
stress T C@ 1/2 (ksi)	-0.58	-0.13	-0.09
stress T.F.@ 1/4 (ksi)	-18.02	-19.73	-17.70
stress B.F.@ 1/4 (ksi)	19.43	20.64	19.81
stress T.C. @ 1/4 (ksi)	-0.50	-0.12	-0.08

Section Properties

Plan Sizes — (depth x width — in.)				Section Modulus (in^3)			
	T.F.	B.F.	Concrete	Type	T.S.	B.S.	T.C.
				Steel	2330.59	3094.51	0
A	2 x 18	3 x 18	8 x 96	Composite n = 27.6	4223.89	3401.37	3264.19
				Composite n = 9.2	8363.68	3622.84	5832.76
				Steel	1809.97	2371.0	0
A	1.5 x 18	2.25 x 18	8 x 96	Composite n = 27.6	3672.86	2658.09	2784.79
				Composite n = 9.2	7854.5	2838.72	5221.17
				Steel	1830.04	2578.96	0
B	1.5 x 18	2.5 x 18	4.5 x 54	Composite n = 13.8	2898.66	2772.54	2513.12
				Composite n = 4.6	5114.59	2936.56	4242.26
				Steel	1314.68	1851.96	0
B	1.0 x 18	1.75 x 18	4.5 x 54	Composite n = 13.8	2352.09	2044.81	2019.48
				Composite n = 4.6	4529.95	2183.92	3666.57
				Steel	2079.81	2837.5	0
C	1.75 x 18	2.75 x 18	6 x 72	Composite n = 13.8	4093.57	3134.47	3331.64
				Composite n = 4.6	8459.88	3321.59	6258.41
				Steel	1561.64	2112.77	0
C	1.25 x 18	2.00 x 18	6 x 72	Composite n = 13.8	3534.4	2392.38	2825.55
				Composite n = 4.6	7923.46	2541.88	5592.0