Proposed Design Expressions for Nominal Shear Transfer Strength for use in Design

Based on the basic equation for total shear stress v_t in equation 12, namely,

$$v_t = c' + \mu' I$$

and introducing the constants of experiment derived for the two materials and age levels, the following expressions are presented. They are applicable for the design of concrete structural composite sections made of two-layered concretes in sub-freezing temperatures having a precast parent regular concrete of strengths up to and exceeding 12,000 psi.

(i) for early loading conditions based on 1 day test results

$v_t = 248 + 0.68\ I$, for magnesium phosphate concrete
and $v_t = 890 + 0.54\ I$, for MMA Polymer concrete

(ii) for long term loading conditions based on 7 day test results

$v_t = 278 + .88\ I$, for magnesium phosphate concrete
and $v_t = 1015 + .89\ I$, for MMA Polymer concrete

A minimum of $I = 250$ psi is recommended for magnesium phosphate concrete.

Comparison with ACI code provisions for Shear Transfer Strength

Section 11.7 of the ACI Building Code, ACI 318-89 (17) lists methods for the design of cross sections subjected to shear transfer at interfaces between dissimilar materials. These provisions allow design for shear transfer based on the shear friction theory proposed by Birkeland (3) and Mast (5). A comparative study of ACI expression 11.26 for ultimate shear transfer strength, $v_t = 0.85\ \phi\ \rho f_y \mu$ ($\mu = 0.6$ to 1.4) with the experimental results is presented in figure 11 for both the cold jointed surfaces of cold weather concretes ($\mu = 0.6$) in test specimens and monolithically cast regular concretes ($\mu = 1.4$) in control specimens. In this expression 0.85 is the shear strength reduction factor. Also presented in this Figure is the comparison of the test results with the ACI Commentary equation (1b) under section R 11.7.3, $v_t = 0.85\ (0.8\ A_s f_y + bdK_1)$ where, 0.8 is the coefficient of friction, 0.85 is the shear strength reduction factor and $K_1 = 400$ psi for normal concrete.

Shear transfer strengths predicted by the ACI equation 11-26 of the code are conservative at both early and late ages for both the types of cold weather concretes. This is because ACI seems to disregard the contribution of apparent cohesive shear transfer strength. At higher values of shear reinforcing index strength I, the ACI values are conservative for polymer concretes. The control concrete specimens cast under normal weather conditions developed stresses much higher than the ACI expressions. From this discussion, it is very clear that MMA polymer concrete can develop shear stresses just by shear and bond in excess of the ACI upper limit of 800 psi even at early ages, whereas the magnesium phosphate concrete can develop the same at early ages with shear reinforcement strengths of 700 psi and more.

The above comparison also validates the previous findings of the second author on polymer concrete layered systems cast under normal weather conditions that the ACI code underestimates the shear transfer strength.

CONCLUSION

1. This experimental investigation has identified two types of high strength cold weather concretes suitable for repairing at early age structural components in sub-freezing temperatures and subjected to shearing loads. The two types of concretes are (i) Magnesium phosphate concrete (water activated) and (ii) MMA (Methyl Methacrylate) polymer concrete. The study has shown that the shear transfer capacity in such concrete elements can be expressed as follows:

   $$v_t = I\mu' + c'$$

   For a composite element of magnesium phosphate concrete or polymer concrete cast at sub-freezing temperatures against a 12,000 psi conventional precast concrete, constants μ' and c' at 24 hours and 7 days age of concrete have been developed.

   A maximum shear transfer strength for polymer concrete can be taken as high as 2200 psi and for magnesium phosphate concrete as high as 1100 psi

2. At an early age of 24 hours, shear transfer strength of 900 psi and 1400 psi can be obtained for magnesium phosphate and polymer concretes respectively with a reinforcing index of 965 psi.

3. A minimum shear reinforcing index of 250 psi is recommended for magnesium phosphate concrete in order to take advantage of contribution of shear reinforcement to shear transfer strength.

4. Comparison of the derived expressions and constants from the experimental investigation with the section 11.7 of the ACI 318-89 Building code provisions for ultimate shear transfer strength shows that the ACI code underestimates the shear transfer strength at early ages even for cold weather concretes. Shear stresses in excess of the ACI upper limit of 800 psi can be developed even at early ages with appropriate concrete strengths and reinforcement for the cold weather concretes.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of the FHWA and The New Jersey Department of Transportation in funding the main phase of the project. This work was done by the first author under the directions of the second author in partial fulfillment of requirements for the Ph.D. This project was conducted at the Concrete Research Laboratory of Rutgers, The State University of New Jersey.

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NOTATIONS

A_s area of transverse shear reinforcement, in^2 (or mm^2)

q bond strength per unit bond area, psi (or KPa)

f_y steel yield stress, psi (or KPa)

f_s actual steel stress, psi (or KPa)

I shear reinforcing index = ρf_y

k_1 ratio of the bond area to the total area

k_2 ratio of projected area of aggregate to the total shear plane cross sectional area

k_3 ratio of the area unoccupied by the aggregates to that of the total shear at the shear plane

V_t total shearing load, lb (or kg)

V_b, V_d, V_f & V_i shear resisting loads due to bond, dowel action, friction and aggregate interlock respectively, lb (or kg)

μ coefficient of friction

μ' apparent coefficient of friction

v_b, v_d, v_f & v_i intensity of shear resistances due to bond, dowel action, friction and aggregate interlock respectively, psi (or KPa)

v_t total shear resistance, psi (or KPa)

ρ shear reinforcement ratio = nA_s/bd

U.S. CUSTOMARY TO SI (METRIC) CONVERSION FACTORS

1 in	=	25.4 mm	1 in^2	=	645.16 mm^2
1 in^3	=	16,387.06 mm^3	1 in^4	=	416,231 mm^4
1 ft	=	0.3048 m	1 ft^2	=	0.092903 m^2
1 ft^4	=	8.360975×10^{-3} m^4	1 ksi	=	6.895 MPa
1 kg f	=	9.80665 N	1 lb	=	4.448 N
1 kip	=	4448 N	1 lb/ft	=	14.594 N/m
1 kip/ft	=	14.594 kN/m	1 kip in	=	113 N m
1 kip ft	=	1356 N m			

TABLE 1 -- PUSH OFF SPECIMEN TEST RESULTS FOR MAGNESIUM PHOSPHATE CONCRETE SPECIMENS

Specimen Identification Code	Shear Reinforcing Strength (psi)	Shear Transfer Capacity (psi) 'τ'	Number of Test Specimens	Failure Mode
PN1	-	303	2	vertical movement along the shear plane
PN3	-	313	1	
PN7	-	321	2	
PL1	258	321	2	same as above with yielding of transverse
PL3	258	429	1	steel
PL7	258	446	2	
PM1	644	750	2	light diagonal cracking, vertical movement
PM3	644	786	1	along the shear plane, light spalling of
PM7	644	839	2	magnesium phosphate concrete
accompanied				by yielding of steel
PH1	965	893	2	light diag. cracking, vert. movement along
PH3	965	1036	1	the shear plane, moderate spalling of
magnes-				
PH7	965	1143	2	ium phosphate concrete plus steel yield

Notations:

P = Magnesium Phosphate concrete
N = Specimens without any transverse shear reinforcement
L,M,H = Specimens with light, moderate and heavy transverse shear reinforcement respectively
1,2,3 = Specimens cured for 1, 3 and 7 days respectively at 15-20^0 F.

TABLE 2 -- PUSH OFF SPECIMEN TEST RESULTS FOR MMA POLYMER CONCRETE SPECIMENS

Specimen Identification Code	Shear Reinforcing Strength (psi)	Shear Transfer Capacity (psi) 'T'	Number of Test Specimens	Failure Mode
TN1	-	857	2	vertical slip along the shear plane
TN3	-	857	1	
TN7	-	1036	2	
TL1	258	1071	2	same as above with yielding of steel
TL3	258	1071	1	
TL7	258	1286	2	
TM1	644	1250	2	light diagonal tension cracking accompanied
TM3	644	1357	1	by regular concrete spalling plus yielding
TM7	644	1429	2	of steel
TH1	965	1393	2	light diag. tension cracking accompanied
TH3	965	1571	1	by regular concrete spalling plus yielding
TH7	965	1964	2	of steel

Notations:

T = Methyl methacrylate based polymer concrete

N = Specimens without any transverse shear reinforcement

L,M,H = Specimens with light, moderate and heavy transverse shear reinforcement respectively

1,2,3 = Specimens cured for 1, 3 and 7 days respectively at 15-20^0 F.

TABLE 3 -- PUSH OFF SPECIMEN TEST RESULTS FOR CONTROL SPECIMENS

Specimen Identification Code	Shear Reinforcing Strength (psi)	Shear Transfer Capacity (psi) 'I'	Number of Test Specimens	Failure Mode
CN	-	1536	2	light to heavy diag. tension cracking,
CL	258	1571	2	compression spalling, typical shear failure,
CM	644	1964	2	yielding of steel in CL, CM & CH w/concrete
CH	965	2286	2	plus specimens

Notations:

C = Control specimens
N = Specimens without any transverse shear reinforcement
L,M,H = Specimens with light, moderate and heavy transverse shear reinforcement respectively

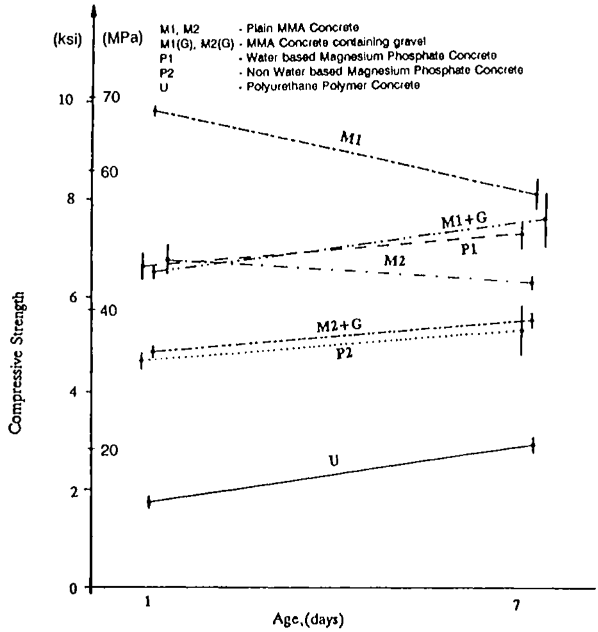

Fig. 1--Cylinder compressive strength test results

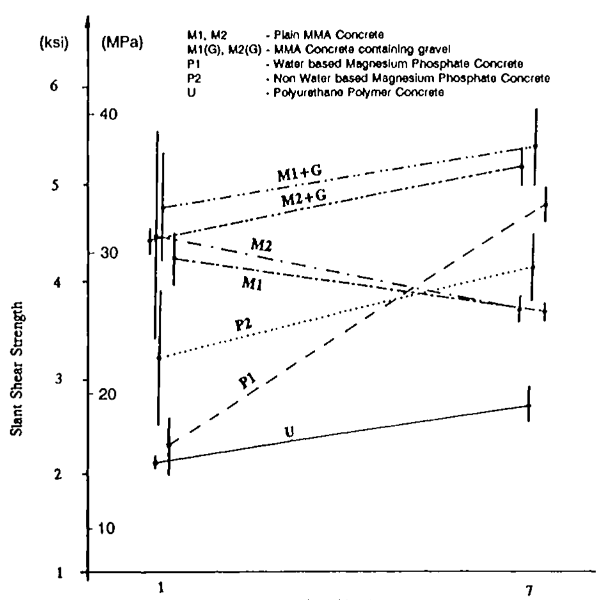

Fig. 2--Cylinder slant shear strength test results