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Analysis and Design Issues in Liquid-Containing Structures

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ACI WEB SESSIONS

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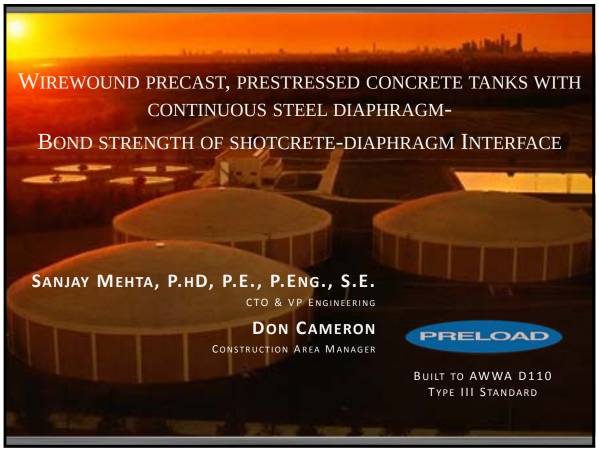
ACI WEB SESSIONS



Wirewound precast, prestressed concrete tanks with continuous steel diaphragm- Bond strength of shotcrete-diaphragm interface

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PRELOAD
Built to AWWA D110 Type III Standard

Presentation Outline

1. Design and construction of AWWA D110- Type 3 tanks
2. Seismic load path at wall base joint
3. Pull out tests for shotcrete-diaphragm interface
4. Theoretical basis for "development surface"
5. Pull test for shotcrete-diaphragm-base cable system
6. Conclusions

AWWA D110- Type III- Tank Cross Section

Mechanically Seaming Steel Diaphragm

Benefits of Pre Cast Wall Panels

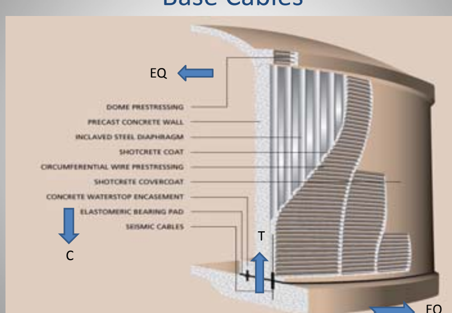
- Low concrete slump & water-cement ratio possible
- Better concrete compaction
- Concrete test results available before placing panel on footing
- Steel diaphragm ensures watertightness

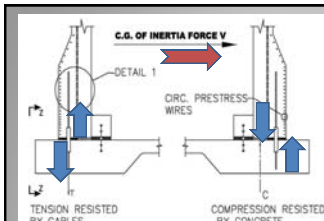
Waterstop Encasement

Tank Prestressing

Shotcrete Cover on Prestressed Wire

Seismic Load Path: Diaphragm-Shotcrete-Base Cables

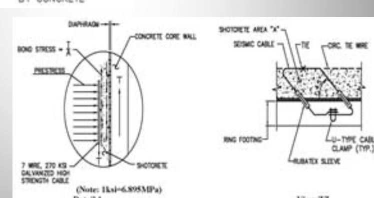




CONCERN:

CAN PLAIN VERTICAL SURFACE OF DIAPHRAGM TRANSFER SEISMIC UPLIFT FORCE TO THE BASE CABLE THROUGH SHOTCRETE?

AWWA D110-04 TABLE 2: DIAPHRAGM-SHOTCRETE BOND STRESS= $2.5\sqrt{f_c'}$= 158 psi (4000 psi Conc).



CONCERN….

AWWA D110-04 TABLE 2 SPECIFIES VALUE FOR BOND STRESS

IT IS MORE APPLICABLE IN HORIZONTAL DIRECTION WHERE DIAPHRAGM RIBS PROVIDE MECHANICAL INTERLOCK WITH SHOTCRETE

WHAT IS APPROPRIATE VALUE OF BOND STRESS IN VERTICAL DIRECTION?

IS THERE ANY NEED TO CHANGE DIAPHRAGM FABRICATION PROCESS TO FURTHER INCREASE THE BOND STRENGTH IN VERTICAL DIRECTION?

NOT ENOUGH INFORMATION AVAILABLE IN THE LITERATURE- UNIQUE SITUATION FOR THIS TYPE OF STRUCTURE IN HIGH SEISMIC ZONES

PRELOAD CONDUCTED SOME TESTS TO ANSWER THESE QUESTIONS

BOND STRENGTH
REINF. STEEL v/s DIAPHRAGM SHEETS

FACTORS THAT INFLUENCE THE BOND STRENGTH OF REBAR HAVE BEEN STUDIED FOR WELL OVER 100 YEARS- ACI 408R IS THE STATE-OF-THE-ART REPORT

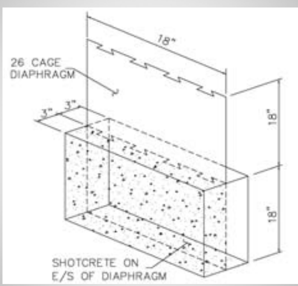
REBAR IS A LINE ELEMENT

DIAPHRAGM FABRICATED PER ASTM A 1008 IS A THIN SURFACE ELEMENT- 26 GAGE (0.017in).

EVEN #3 BAR (0.375" DIAMETER) IS 22 TIMES THICKER THAN DIAPHRAGM

BOND STRENGTH OF DIAPHRAGM SHEET IS NOT STUDIED AS RIGOROUSLY AS REINFORCEMENT BECAUSE SUCH A SITUATION OCCURS ONLY IN TYPE III TANKS

TEST SPECIMENS



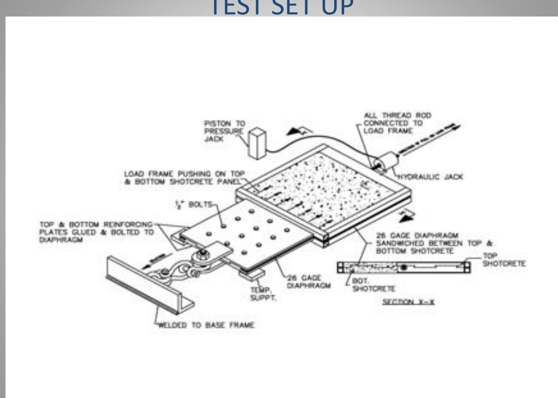
TWO SPECIMENS AS SHOWN WERE FABRICATED AT A JOB SITE

TEST SPECIMENS…

REINFORCEMENT PLATE

SPECIMEN WITH BOTTOM REINFORCEMENT PLATE IN POSITION

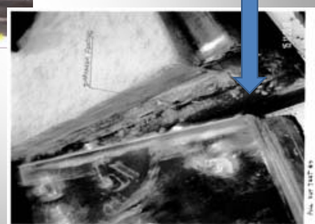
TEST SET UP



TEST SET UP….

RESULTS- FAILURE MODES

TEST SPECIMENT 2-
DIAPHRAGM TENSION FAILURE



TEST SPECIMEN 1-
DIAPHRAGM SLIP / PULL OUT

RESULTS.....

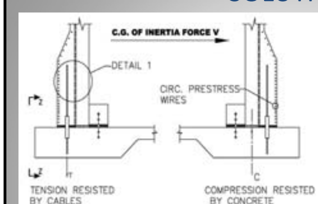
Test	Load	Stress	Failure Mode
1	16,967Lbs	26.2psi	Diaphragm slip/ bond failure
2	20,938Lbs	32.3psi	Diaphragm tension failure

Bond strength is in the same range as tensile strength of diaphragm.

Increasing diaphragm bond strength by introducing deformation in vertical direction will simply change the failure mode from diaphragm slip to diaphragm fracture.

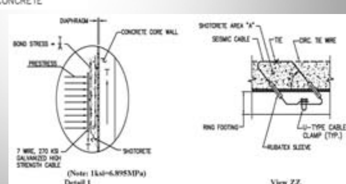
What should be the design approach for seismic load path from diaphragm to shotcrete to base cables?

SOLUTION….



MOBILIZE SUFFICIENT SURFACE AREA OF DIAPHRAGM- SHOTCRETE INTERFACE SUCH THAT FAILURE MODE IS GOVERNED BY YIELDING OF BASE CABLES.

RESPONSE REDUCTION FACTOR (R=3.25) SPECIFIED IN CODES IS BASED ON ENERGY DISSIPATION ASSOCIATED WITH DUCTILE YIELDING OF BASE CABLES ASSUMING OTHER FAILURE MODES ARE PRECLUDED.



EQUATION FOR DEVELOPMENT SURFACE

The tensile strength of the diaphragm:

$$F_T = A_D \times W \times f_Y$$

A_D = cross section area of diaphragm per unit width
W = width of the diaphragm= 1'-6" in this case
f_Y = yield strength, maximum of 40ksi per ASTM A 1008

The bond strength of the diaphragm:

$$F_B = W \times L \times \tau$$

τ = ultimate bond stress per unit surface area.

L = Diaphragm embedded in shotcrete=1'-6" in this case

DEVELOPMENT SURFACE..

EQUATING $F_T = F_B$

DEVELOPMENT LENGTH $L_d = (A_D \times f_Y)/(144 \times \tau)$

$L_d = 2.83 ft$

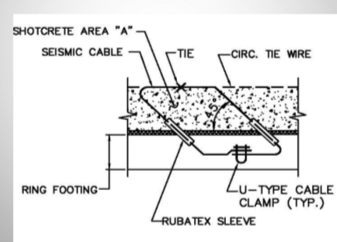
FOR
$\tau = 26.3 psi$
$f_Y = 40 ksi$
$A_D = 0.267 sq.in/FT$

DEVELOPMENT SURFACE= L_d X W

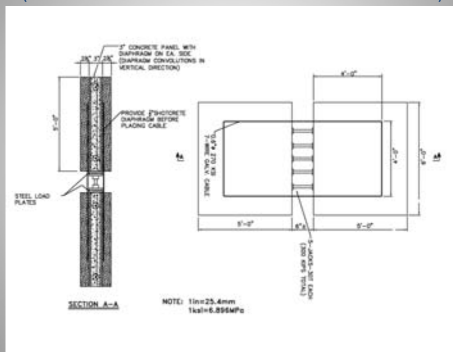
DUCTILE FAILURE MODE

SO LONG AS BOND STRESS OVER L_d X W IS MOBILIZED BY BASE CABLES, DIAPHRAGM PULL-OUT OR TENSION FAILURE WILL NOT GOVERN

EQUATING TENSILE STRENGTH OF BASE CABLES TO BOND STRENGTH OVER SURFACE AREA "A" (L_d X W) WILL ENSURE DUCTILE FAILURE MODE



FULL-SCALE TEST
(WITHOUT BENEFIT OF PRESTRESS AND CURVATURE)

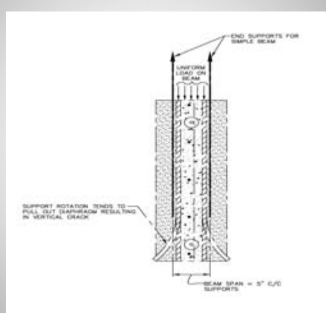


FULL SCALE TEST SETUP

0.65*5*30=97.5T=195KIPS

BOND= $\frac{195KIPS}{(2*4*4*144)}$ =42.3psi

FAILURE MODE



FAILURE MODE…

RESULTS OF FULL SCALE TEST

AVAILABLE BOND STRENGTH OF 42.3PSI IN VERTICAL DIRECTION
EVEN WITHOUT CONFINEMENT AND PRESTRESSING EFFECTS

ACTUAL CONSTRUCTION MORE ROBUST THAN TEST SET UP:
- WALLS POURED VERTICALLY FOR THE TEST SET UP
- NO PRESTRESS AND CONFINEMENT FOR THE TEST SET UP
- NO CURVATURE OR REDISTRIBUTION EFFECTS

ALL THESE ADD TO STRENGTH/DUCTILITY OF THE SYSTEM

CONCLUSIONS

PULL OUT OF DIAPHRAGM IN CASE OF A SEISMIC UPLIFT CAN BE AVOIDED BY PROPER DETAILING

ANY ATTEMPT TO INCREASE BOND STRENGTH (WITHOUT INCREASING TENSILE STRENGTH) WILL NOT IMPROVE SYSTEM DUCTILITY BECAUSE THE FAILURE MODE WILL SIMPLY SHIFT FROM DIAPHRAGM PULL OUT TO DIAPHRAGM TENSION FAILURE

PROPER DETAILING TO MOBILIZE SURFACE AREA OF SHOTCRETE IS THE BEST METHOD TO ENSURE THAT FULL STRENGTH AND DUCTILITY OF BASE CABLE IS MOBILIZED