Attachment

U.S. Department of Energy
Office of River Protection
Mr. R. J. Schepens
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P.O. Box 450, MSIN H6-60
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CCN: 057740

MAY 0 8 2003

Dear Mr. Schepens:

CONTRACT NO. DE-AC27-01RV14136 – CONCRETE SUBSIDENCE

Attached for your information is the High Level Waste (HLW) Concrete Subsidence Study Phase B (Final Report), Revision 1. Phase B of the study addresses the technical issues relating to surface cracking in the HLW vitrification facility basemat. This revision of the final report addresses the comments received during the HLW Concrete Subsidence meeting held May 1, 2003 with the U. S. Department of Energy, Office of River Protection.

If you have any questions, please contact Don Scribner, Civil, Structural, and Architectural Discipline Engineering Manager, at 371-3072.

Very truly yours,

R. F. Naventi
Project Director

DTS/las

Attachment: HLW Concrete Subsidence Study Phase B (Final Report), Revision 1

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HLW Concrete Subsidence Study
Phase B (Final Report)

Contents

1 Introduction

1.1 Purpose

The purpose of this study is to:

1. Document the results from the planned actions identified in Phase A of this report (Ref. 1).

   - Confirm development and lap length within placements HLW-0006B and HLW-0008 are adequate assuming a conservatively derated bond strength, as follows:

     1. Determine embedment and rebar splice locations from the rebar shop drawings for the affected areas.
     2. Identify specific demand/capacity ratios at these embed/splice locations and determine if adequate capacity exists based on a Top Bar Factor conservatively set at 2.0.
     3. Identify if and how much margin is impacted.

   - Repeat for other placements where similar conditions conducive to potentially excessive subsidence existed during concrete placement.

2. Address the following 5 additional points requested by the U.S. Department of Energy (DOE), Office of River Protection (ORP) in their letter 03-AMWTP-016, dated March 13, 2003.

   - Include the field procedure revibration criteria and other documentation ensuring adequate direction has been provided to the field for revibration for placements.
   - Provide rational for not changing mix design as an alternative method for addressing subsidence.
   - Provide criteria that establish which placements may have experienced a potential for significant subsidence. Document the rationale. Also, provide rational for eliminating wall placements as areas of concern.
   - Document why a 50% derating of bond strength is conservative for basemat placements where potential subsidence is a concern. Also, evaluate reduced bond strength under horizontal steel in deep wall placements.
   - If it becomes necessary to use the design margin (i.e. demand/capacity (D/C) ratio = 0.85) to accommodate the derated bond strength, document how this utilization will be communicated to all impacted design elements in order for them to accommodate reduced design margin in these areas.

1.2 Background

On January 13, 2003, NCR 24590-WTP-NCR-CON-03-003 was written to document the observance of surface cracking at EL (-) 21' 0" for concrete placements in the HLW building basemat identified as HLW-0006B and HLW-0008. The cracks were approximately 1/8" maximum in width and 1" maximum in depth.

The two areas exhibiting surface cracking are located in a horizontal joint and therefore only received a float surface finish. Although all design drawing and specification requirements were met, the field considered the condition "indeterminate" and referred it to engineering for disposition.

The surface cracking was attributed to concrete subsidence. The ACI 318 and 349 Design Codes consider the effects of concrete subsidence in the design allowables, but do not provide criteria for an acceptable subsidence level – i.e. the extent of concrete subsidence after which the code provisions are no longer conservative. In order to evaluate the detrimental effects of the surface cracking, BNI consulted with a number of concrete specialists. Technical opinions varied – there were points of agreement and conflicting views.

Points of Agreement:

- Conditions existed in the 2 HLW placements conducive to cracks forming from concrete subsidence (low temperature, finishing method, slab thickness, set time, rebar details, fly ash content, etc.,).
- The surface cracks do not jeopardize the structural integrity of the concrete or mat foundation.
- The ACI 318 and ACI 349 codes contain provisions that accommodate subsidence.
- The HLW basemat was designed and constructed consistent with the ACI Code Provisions.
- The extent of concrete subsidence is an unknown – and a field determination may not be feasible.
- Revibration prior to initial concrete set is effective for preventing subsidence cracking and densifies the surface and improves the bond around the top reinforcement.

Conflicting Views:

- Subsidence in the affected HLW areas is within the limitations of the ACI Code Provisions (i.e. bond strength reduction factor)
- Excessive subsidence is not necessarily limited to the affected HLW areas.

The specialists' qualifications, opinions, and recommendations are summarized in Phase A of this report. Phase A also outlines the path forward for addressing the conflicting views and demonstrating the adequacy of the existing WTP concrete design. The Phase B report documents the final conclusions.

1.3 Definitions

BSR (Bond Strength Reduction) – the loss of concrete bond strength expressed as a percentage. BSR is related to TBF by: BSR = 1 – (1/TBF)

TBF (Top Bar Factor) – the factor applied to the basic development length of a reinforcement bar to account for BSR around the top layer of reinforcement.

2 Results and Conclusions

2.1 Results

2.1.1 Placement HLW-008B and 008 Evaluation

Review of rebar drawings and the calculations performed for this study show that the actual reinforcement bar length vs. required length is greater than 2.8 (ref. 5). Since the results exceed more than twice the code provisions for bond strength reduction, design margin does not need to be utilized to accommodate any additional bond strength reduction.

2.1.2 Revibration Criteria

Starting in February 2003, revibration has been performed on all structural concrete placements over 24" in depth. Revibration, identified in Section 7.4 of ACI 309R, was implemented to minimize the influences of concrete subsidence. Subsidence related surface cracking has not been identified in any concrete placements that have implemented revibration. Similarly, concrete placements made prior to cold weather conditions did not experience any signs of subsidence related cracking.

Field direction for revibration has been provided through Special Instructions. These instructions are developed, reviewed and documented for each concrete placement. The requirements are discussed in detail with the Construction Supervision, Craft Supervision, Field engineering and Field Quality Control during the Pre-placement meeting to ensure adequate direction and understanding has been provided. The applicable section from the Special Instruction form is shown in Attachment A1. In addition, training sessions specifically for the revibration operation was conducted for appropriate field personnel.

A draft of the complete revibration requirements and criteria, including warm weather provisions is shown in Attachment A2. This draft is currently being coordinated with construction. The final version will be incorporated into the field procedure for Concrete Operations (Ref. 7).

2.1.3 Mix Design

BNI considered changing the concrete mixture design to decrease set time during cold weather placements. There are a number of ways concrete set time can be influenced. Reducing the fly ash replacement, increasing the portland cement content, decreasing the water/cementitious materials (w/cm) ratio and/or introducing a set-accelerating admixture would all effectively decrease the set time. After reviewing these options and considering the current performance of the concrete, it was decided not to change the mix design for the following reasons:

- Fly ash is beneficial for large placements. It serves to minimize the peak hydration temperature, thus minimizing routine thermal related cracking. Additionally, fly ash reduces the permeability of the hardened concrete thus enhancing the concrete's durability. A reduction in ash content may potentially increase permeability. Although reducing the fly ash content would shorten the set time, there is no need to lose the benefits from the fly ash content. Revibration and final finishing more than adequately mitigate any detrimental effects from subsidence.
- According to the Aggregate Petrographic Analysis Test Report provided by CTL conclusions, the project aggregate particles contain constituents, specifically strained quartz, microcrystalline silica (chert), and trace amounts of siliceous volcanic rock that may be susceptible to deleterious alkali-silica reaction (ASR) with the alkalis in the portland cement. It is common practice to proportion concrete with fly ash for mixtures containing potentially reactive aggregate (Ref. 6).
- According to Section 2.1.6 of ACI 305R, the degree to which concrete bleeds is related to the amount of fly ash present in the concrete mixture. In general, fly ash provides control over excessive bleeding and subsequent subsidence. (subsidence is directly proportional to the amount of bleed water that is free to move to the concrete surface) (Ref. 10)
- Increasing the cement content (reducing the w/c+p) to improve set time changes the behavior of the paste making it sticky and difficult to properly finish. As mentioned briefly above, high levels of cement would adversely influence thermal curing and protection of the as-placed concrete placements.
- While effective at changing the time of set, the behavior of set-accelerating admixtures are influenced by changes in mix temperature and routine variations in cement chemistry. Many of

the concrete placements are large and time consuming, the behavior of the accelerating add-mixture will change throughout the placement making prediction of mix behavior difficult.

- With the large amount of concrete already in place, the craft are very familiar with the behavior and performance of the current concrete mixtures; this includes pumpability, response to vibration, set time characteristics, and finishability. Changes to the mixture will alter its behavior when placed, and such changes may potentially have adverse affects on future concrete operations.

2.1.4 Evaluate Other Potentially Affected Placements

An evaluation of reduced concrete bond strength in potentially affected placements was performed by determining the equivalent TBF at each critical location. Equivalent TBF was calculated by dividing the actual splice or development length by the calculated length based on reinforcement details for each placement (cover, spacing, bar diameter, transverse steel). The resulting ratio is the maximum TBF value that can be applied at each location without changing any of the existing reinforcement details. This maximum was compared to a conservative value of 2.0 to demonstrate that the current splice and development lengths provided on WTP bounds any increase needed to account for excess subsidence. Two case were considered.

Case 1: Retaining the existing design margins as measured by the demand over capacity ratio (D/C ratio)

Case 2: Reducing the existing design margins to a minimum level of D/C = 0.85 and thereby increasing the maximum TBF.

Evaluations were performed on both concrete basemats and walls. The results of both evaluations are described below. Summary results are listed on Table 1.

2.1.4.1 Basemat Evaluations

HLW – based on actual splice lengths and the ACI 408 Design Equation the equivalent TBF in the critical placements is 2.80 without reducing any of the existing design margin.

LAW – based on actual splice lengths and the ACI 408 Design Equation the equivalent TBF in all basemat placements is 3.2 without reducing any of the existing design margin.

PTF – based on actual splice lengths and the ACI 408 Design Equation the equivalent TBF in the critical pit mat placements is 2.3 without reducing the existing design margin.

2.1.4.2 Wall Evaluations

LAW – based on actual splice lengths and the ACI 408 Design Equation the equivalent TBF in the critical wall placements is 2.2 without reducing any of the existing design margin.

PTF – based on actual splice lengths and the ACI 408 Design Equation the equivalent TBF in the critical pit wall placements is 2.3 without reducing any of the existing design margin.

TABLE 1 – SUMMARY
CASE 1 & 2 EQUIVALENT TOP BAR FACTORS FOR
ACI 318/349 & ACI 408

PLACEMENT	TBF w/ NO CHANGE IN DESIGN MARGIN D/C<0.85 CASE 1 ACI 318/349	TBF w/ DESIGN MARGIN REDUCED TO D/C=0.85 CASE 2 ACI 318/349	TBF w/ NO CHANGE IN DESIGN MARGIN D/C<0.85 CASE 1 ACI 408	TBF w/ DESIGN MARGIN REDUCED TO D/C=0.85 CASE 2 ACI 408
HLW				
Basemat – HLW-006B Basemat – HLW-008 Basemat – other critical placements(1)	1.5 1.5 1.5	4.2 2.9 2.8	2.8 2.8 2.8	7.7 5.4 5.2
Walls – no placement affected	N/A	N/A	N/A	N/A
LAW				
Basemat – all placements	2.0	2.0	3.2	3.2
Walls – all critical placements (1)	1.3	3.0	2.2	5.1
PTF				
Pit mats – all critical placements (1)	1.6	2.0	2.3	3.9
Basemat – no placements affected	N/A	N/A	N/A	N/A
Walls – all critical placements (1)	1.6	1.7	2.3	2.5

Notes:
(1) See section 3.1 for identification of critical placements
(2) See Tables A1 through A4 for detailed results

2.2 Conclusions

Comparing actual lengths provided to the calculated lengths required from Case 1, ACI 408 it is shown that the top bar factor can be increased from 1.3 to over 2.0 without reducing the existing design margins for any of the critical placements. This increase relates to a doubling of the bond strength reduction factor from 0.25 to 0.50. This 100% increase in reduced bond strength bounds any additional 'Top Bar Factor' required for excessive subsidence – see section 3.4. Therefore, the splice lengths and reinforcement details provided for WTP are acceptable.

In addition, it is unnecessary to utilize any additional design margin (i.e. design margin in excess of D/C ratio of 0.85) in order to accommodate the derated bond strength for any placement. No existing design elements are impacted.

Planned Actions:

All future design will be performed using the conservative method for calculating reinforcement developments and splice lengths based on ACI 318-99 / ACI 349-01 and a 1.3 TBF.

Incorporate revibration criteria into the Construction Procedure for Concrete Operations (Including Supply), 24590-WTP-GPP-CON-3203.

3 Study Basis

This section describes the bases used for establishing the results, conclusions and planned actions presented in Section 2.

3.1 Basis for Revibration Criteria

A number of studies have been conducted to better understand the mechanism of concrete subsidence; research has shown that a number of physical parameters may influence the extent of concrete subsidence and its' resultant effects (cracking over horizontal reinforcement). The extent to which subsidence occurs is largely controlled by the degree of initial consolidation, height of concrete, and the amount of bleed water that is free to travel through the concrete.

Initial consolidation of concrete at the WTP River Protection Project is performed by mechanical internal vibration in accordance with the recommendations of ACI 309R, Consolidation of Concrete. In general, consolidation is described in ACI 309R as being completed in two stages, initial slumping of the concrete, followed by deaeration of entrapped air bubbles. Proper initial consolidation of the concrete mass will greatly reduce the degree and potential for delayed consolidation and/or subsidence. Further deaeration and densification of the concrete surface may occur during the finishing of the concrete surface. Experience has confirmed that revibration is "largely accomplished by the finishing operations in flatwork" (ref. 9).

The amount of bleed water that is free to travel through the concrete is largely influenced by the concrete mixture proportions, rate of slump loss, and the time to initial set. During cold-weather placement conditions, concrete slump loss and subsequent initial set of the concrete may extend as long as 2 to 3 hours after final lift placement. This period of time is influenced by concrete temperatures, ambient temperatures, cement content, as well as the type and quantity of chemical and/or mineral admixtures present in the concrete (fly-ash). During this period of time, concrete is free to bleed as solid materials (cement, sand, and stone) settle to a position of stability within the concrete matrix, thereby pushing bleed water to the surface. As the concrete losses slump and begins to reach initial set, the solid materials in suspension reach a position of stability and the bleed rate slows to nearly zero.

The practice of revibration that has been instituted on cold weather placements at the WTP River Protection Project has been successful in removing bleed water and air along horizontal concrete surfaces. The action of revibration has eliminated signs of excessive subsidence over construction joints (reflective cracking over top bars) by removing bleed water that may be trapped under reinforcement bars and/or aggregate particles in normal slump concrete.

During recent normal weather placement operations, it has been identified that concrete revibration procedure is interfering with the normal finishing operations and may affect floor flatness. This interference will become more detrimental on flat work (mats and slabs) as the average ambient temperatures increase and the time between strike-off and final finishing decreases. During normal to hot-weather placement conditions, concrete slump loss and initial set may take place as early as 1 to 2 hours after final lift placement. As concrete loses workability, the concrete becomes exceedingly more difficult to work, complicating the process of strike-off, primary float, revibrate, final float, and then steel trowel finishing. Finishing over wall construction joints however are not a concern as construction joints are more readily accessible and require minimal finishing requirements.

3.2 Criteria for Significant Subsidence

BNI worked directly with Dr. David Darwin, Chairman of the ACI Committee 408 on Bond and Development of Reinforcement in establishing the criteria for significant subsidence. Dr. Darwin's input is directly reflected in this report. In addition, Dr. Darwin will submit an independent report endorsing the criteria for significant subsidence.

The first step in establishing a criteria was determining the significant factors that led to the surface cracking observed in the HLW placements. An examination of the pour cards and field data revealed that finishing method and low temperature were common to the affected areas.

Finishing method

Research has shown that trowel finishing reduces the 'top bar effect'. Working the surface consolidates the surrounding concrete and releases trapped bleed water and air. In some studies finishing was reported to result in top bars with higher bond strength than lower cast bars (ref. 12 & 14).

The top surface of WTP basemats receive a steel trowel finish with the exception of the wall / mat construction joints, those areas directly below concrete walls. These areas receive a float finish and are left rough to receive the additional concrete lift from the placements above. The widths of the construction joints vary from 3 ft to as much as 20 ft for the large placements below the process and handling tunnels. The construction joints for the HLW basemat / walls are shown on Figure A1.

For relatively narrow walls, the finishing operation on the concrete floor directly adjacent to the wall dowels also consolidates the unfinished concrete beneath the construction joints. As the wall width increases, the additional consolidation from floor finishing decreases. In the case of the very wide construction joints in the HLW basemat – trowelling the floor has very little benefit. The two affected areas in placements HLW-006B and HLW-008 were both in a very wide construction joint.

TABLE 2

TEMPERATURE DATA FOR HLW BASEMAT PLACEMENTS W/WIDE CONSTRUCTION JOINTS

	General						Temperature			
Wall/Slab	Thick., ft	Placement I.D.	Duration Placmt., (Hrs)	Quantity, CY	Date	Cracks Y/N	Ambient max (deg F)	Ambient min (deg F)	Ambient Avg (deg F)	Avg. Conc Temp
Non-Cold Weather Placements:										
Mat Foundation	6	HLW-4B	8	1101	8/29/2002	N	98	64	81	66
Mat Foundation	6	HLW-4A	7	1052	9/10/2002	N	90	57	74	66
Mat Foundation	6	HLW-7A	12	1857	9/26/2002	N	74	43	59	64
Cold Weather Placements:										
Mat Foundation	6	HLW-6A		927	10/15/2002	N	73	34	54	59
Mat Foundation	6	HLW-5B	13	1985	11/21/2002	N	58	44	51	58
Mat Foundation	6	HLW-6B		1678	12/3/2002	Y	34	31	33	56
Mat Foundation	6	HLW-8	18	2029	12/17/2002	Y	38	26	32	57

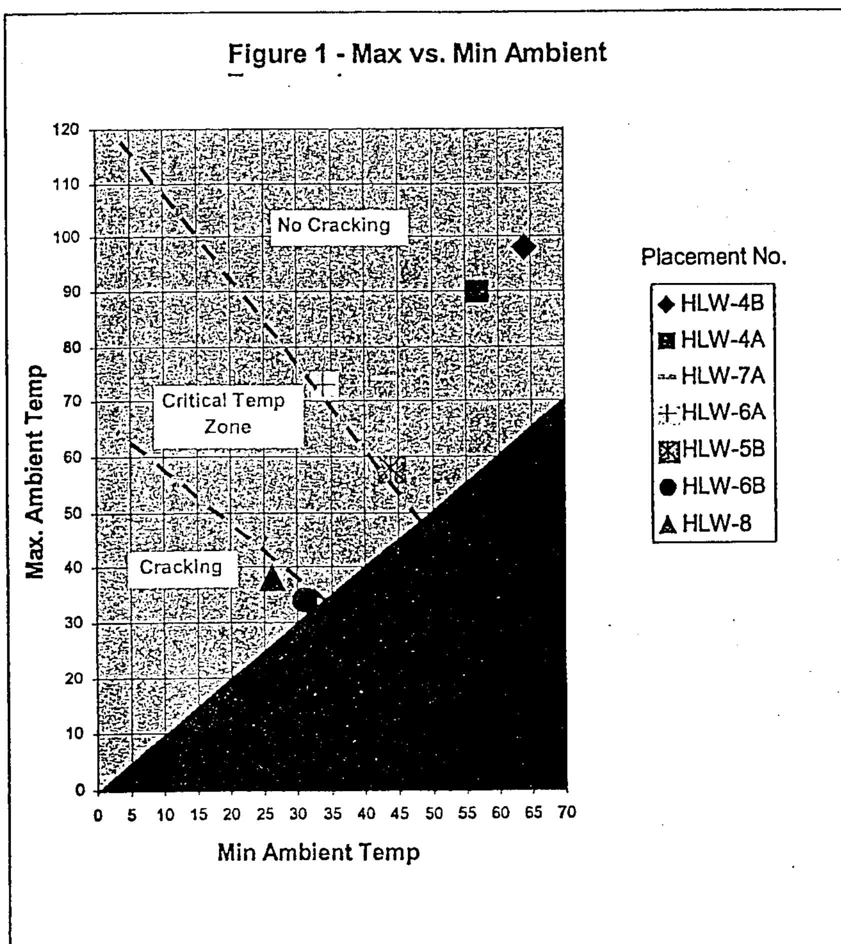
Low Temperature

There were 5 other placements with wide construction joints where no subsidence cracks occurred. These areas had similar concrete cover, rebar, concrete mix, and placement operations to the 2 areas exhibiting surface cracking. The only difference was temperature condition. Table 2 lists the temperature data for the 7 placements in the HLW basemat containing a wide construction joint. For a complete summary of the field data, see Table A5.

The data shows that ambient temperature was the primary variable for the subsidence cracking observed in the HLW slab. There is very little variance in concrete temperature. The concrete temperature range is only 10 deg F while the ambient temperatures' ranges are 60 deg F, 39 deg F, and 49deg F for max, min and average ambient temperatures.

Criteria

To establish the critical temperature criteria, minimum ambient temperature was plotted against maximum ambient temperature for the 7 HLW placements. From the locations of the HLW-6B and HLW-8 data points (placements w/ subsidence cracks) and the data points from the 5 placements exhibiting no cracking, boundary lines were drawn dividing the graph into three temperature zones: no cracking, critical temperatures, and cracking.



The criteria for excessive subsidence was set to placements with minimum / maximum ambient temperatures in either the Cracking zone or the Critical Temperature Zone. By conservatively including temperatures in the critical zone, the criteria includes all placements with conditions conducive to excessive subsidence. In addition, the criteria was extended to both basemats and walls as well as finished and unfinished surfaces. The screening criteria was not applied to placements where revibration was performed.

Table 3 shows all placements meeting the criteria.

TABLE 3
Placements with Conditions Conducive to Excessive Subsidence

LAW Cold Weather Placements

Wall/Slab	Thick., ft	Placement I.D.	Date	Ambient max (deg F)	Ambient min (deg F)	Average Ambient (deg F)	GNN Avg. Conc.Temp.	Quantity, CY
Exterior Wall	3	LAW-16	12/9/2002	42	36	39	56	190
Mat Foundation	.75 to 5	LAW-1B&D	1/14/2003	44	35	39.5	56.4	350
Mat Foundation	.75 to 3	LAW-1C	1/16/2003	39	36	37.5	59.2	155
Exterior Wall	3 to 5	LAW-10	1/23/2003	57	33	45	57.4	510
Exterior Wall	3	LAW-12	2/12/2003	51	32	41.5	59.7	196
Exterior Wall	3	LAW-17	2/20/2003	58	38	48	55.7	177

HLW Cold Weather Placements

Wall/Slab	Thick., ft	Placement I.D.	Date	Ambient max (deg F)	Ambient min (deg F)	Average Ambient (deg F)	GNN Avg. Conc.Temp.	Quantity, CY
Mat Foundation	6	HLW-2B	10/2/2002	70	34	52	58.7	688
Mat Foundation	6	HLW-6A	10/15/2002	73	34	53.5	58.6	927
Mat Foundation	6	HLW-5B	11/21/2002	58	44	51	58.4	1985
Mat Foundation	6	HLW-6B	12/3/2002	34	31	32.5	56	1678
Mat Foundation	6	HLW-8	12/17/2002	38	26	32	56.9	2029
Mat Foundation	6	HLW-5A	1/7/2003	33	24	28.5	56.7	1496

PTF Cold Weather Placements

Wall/Slab	Thick., ft	Placement I.D.	Date	Ambient max (deg F)	Ambient min (deg F)	Average Ambient (deg F)	GNN Avg. Conc.Temp.	Quantity, CY
Mat Foundation (center pit)	6	PTF-2	12/4/2002	34	32	33	58.2	1207
Mat Foundation (FW Pit)	6	PTF-3	12/9/2002	40	36	38	57.5	402
Mat Foundation (S. tunnel)	6	PTF-5	12/12/2002	42	37	39.5	57	933
North Tunnel Walls	6	PTF-10-1	1/22/2003	34	30	32	55.7	187
Firewater Pit Walls	6	PTF-C-6	1/31/2003	52	39	45.5	58	246
North Tunnel Walls	6	PTF-C-10-2	2/4/2003	50	31	40.5	57	185
Firewater Pit Walls	3 to 6.25	PTF-C-7	2/13/2003	44	37	40.5	56.7	188
South Tunnel Walls	6	PTF-11-1	2/19/2003	52	38	45	58.5	385

3.3 Basic Development Length

The ACI codes recognize the presence of subsidence in all concrete placements in excess of 12-inch depths. This condition is accounted for by applying a 1.3 factor to top bar embedment length and an additional 1.3 factor for Class B splices. This factor has been applied in the WTP design process per the Code requirements.

For the purpose of this study, the basic development length is calculated using the ACI 408 design equation (Ref. 16, equation 7) as a special system of design under the provisions of ACI 318-99 / 349-01, Section 1.4. The 408 Design Equation is the state of the art design provision for development length recommended by ACI Committee 408 on Bond and Development of Reinforcement and approved by the ACI Technical Activities Committee at the Fall 2002 ACI Conference in Phoenix, AZ.

The 408 design equation yields more accurate development lengths than other development design equations (Ref 17). When compared to 318-99, the 408 equation results in longer lengths for certain bar sizes, spacing, and covers and shorter lengths for others. In the case of the WTP mat and wall reinforcement, the ACI 408 equation yields noticeably shorter development lengths. The shorter length is attributable to the actual values of cover and spacing and the greater accuracy of the ACI 408 equation (Ref 16).

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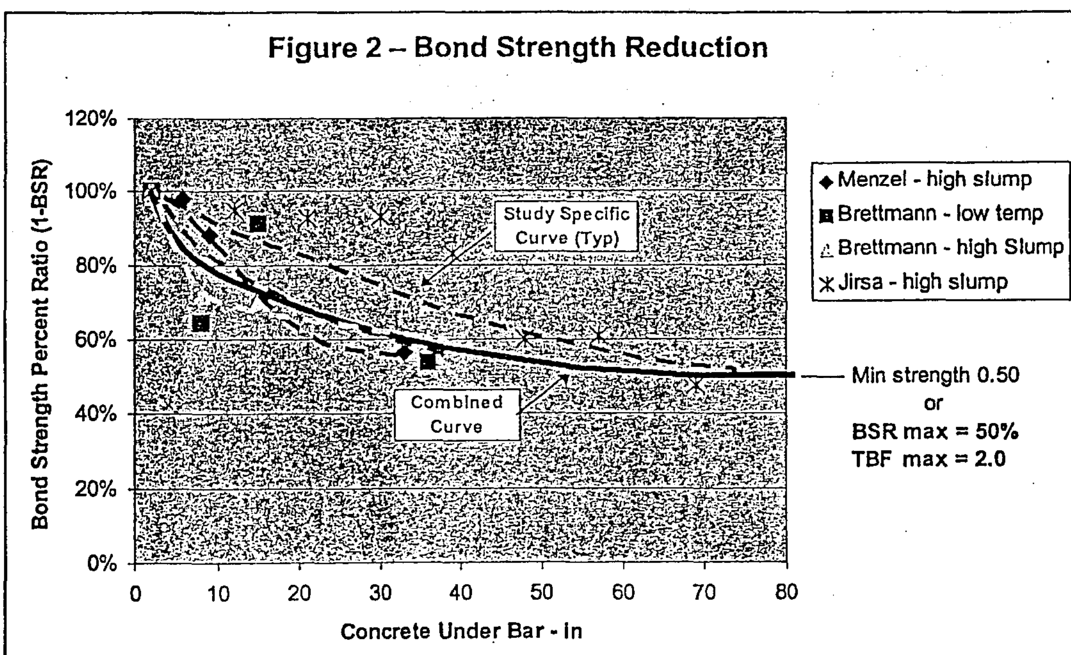
3.4 Bond Strength Reduction (BSR)

Existing Research

A number of studies have been performed over the years relating concrete subsidence to a reduction in bond strength, the reduction being most apparent for top-cast bars. The research is limited, however, for excessive subsidence (i.e. subsidence resulting in bond strength reductions outside the limitations of the ACI code). A literature search found 3 studies with data indicating top bar factors in excess of 1.3 – research performed by Menzel for the Portland Cement Association, by Jirsa and Breen at the University of Texas, and by Brettmann, Darwin, and Donahey at the University of Kansas. The research showed that high top bar factors (i.e. > 1.4) were measured in a small number cases for bars placed under special conditions. The special conditions include high slump, low temperature, low cover, no consolidation, and the presence of superplasticizers in the concrete (ref. 12, 13, 15). Of these, only low temperature is present in the WTP mat and wall placements.

Using the research, BNI established an upper limit for BSR by plotting the reported bond strength reductions against depth of concrete placed under the reinforcement. Results were considered for tests with similar characteristics to the WTP placements (cover & consolidation) having low temperature or high slump. Although not directly applicable the WTP placements, BNI included the high slump condition since high slump acts similar to cold weather in delaying set time and increasing the detrimental effects of subsidence. The results are fairly consistent showing a max BSR of 50% or TBF of 2.0 for deep concrete placements – see Figure 2.



Engineering Judgement

A Top Bar Factor of 2.0 doubles the bond strength reduction from the code provision of 25% to 50%. A 50% BSR is equivalent to having a bond strength of zero over the entire bottom half of the bar for the full length of the splice. Although tests have shown bond strength reductions greater than 50%, these are determined for relatively short embedment lengths – 10" to 12" (ref. 12 & 13) not for the entire length of a fully developed bar (89" min for a #11 splice). Zero bond strength for more than half the circumference over the full length is a worst case scenario and not a credible event. Therefore, a BSR = 50% max is reasonable and conservative based on engineering judgement.

Potential Field Testing

There are no current test instruments or methods for establishing the extent of subsidence below cast-in-place bars. In discussions with technical experts, it was suggested that the project develop a first-of-a-kind destructive test program to examine concrete cores through top reinforcement in the cracked zone and measure any gaps below the bar. BNI did not proceed with the tests due to the lack of a recognized test procedure and validated baseline. This would be the first time coring is performed for this purpose. BNI's position is that an unverified test is neither conclusive nor defendable and sees no merit on embarking on a research project with an undefined outcome.

Max Bond Strength Reduction

A max BSR = 50% (max TBF = 2.0) is reasonable and conservative based on bounding research data augmented with engineering judgement.

3.5 Calculations and Results

Calculations were prepared for the critical placements in the major facilities – HLW, PT, and LAW buildings (Ref. 3, 4, 5). These calculations consider the particular reinforcement configurations and actual design margins at the splice locations in the critical placements. In some locations, actual design margins were not calculated at the splice. In these cases, the design margin from the critical section closest to the splice was conservatively used. These calculations demonstrates that the effective top bar development and lap splice lengths (computed by using conservative loading parameters and adjusted for potential loss of bond strength) exceeds the minimum length required for all load conditions in the areas under consideration.

The calculated Top Bar Factors (Bond Strength Reduction) based on actual lengths with no reduction in Design Margin (D/C) Ratio are shown in tables A1 and A3.

The calculated Top Bar Factors (Bond Strength Reductions) adjusted for Design Margin (D/C) Ratio = 0.85 are calculated and tabulated in tables A2 and A4.

4 References

1. BNI letter from R.F. Naventi to R.J. Schepens, ORP, "High Level Waste Concrete Subsidence Study," CCN: 050351, February 27, 2003

2. ORP letter from R. J. Schepens to R. F. Naventi, BNI, "Contract No. DE-AC27-01RV14136 – Concrete Subsidence," 03-AMWTP-016, March 13, 2003

3. Calculation 24590-PTF-DGC-S13T-00030, "PT Concrete Subsidence Evaluation"

4. Calculation 24590-LAW-S0C-S15T-00012, "Concrete Subsidence Splice Lengths Evaluation"

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5 Appendix A – Tables, Figures, and Attachments

Table A1 – Calculated Top Bar Factors (Bond Strength Reductions); ACI 318-99 / 349-01 with no change in Design Margin (D/C < 0.85)

Table A2 – Calculated Top Bar Factors (Bond Strength Reductions); ACI 318-99 / 349-01 with current Design Margin reduced to D/C = 0.85

Table A3 - Calculated Top Bar Factors (Bond Strength Reductions); ACI 408 with no change in Design Margin (D/C < 0.85)

Table A4 - Calculated Top Bar Factors (Bond Strength Reductions); ACI 408 with Current Design Margin reduced to D/C = 0.85

Table A5 – Concrete Subsidence Study; Field Data Summary

Figure A1 – Plan: HLW Basemat Concrete Placement Numbers with Slab/Wall Construction Joints

Attachment A1 – Special Instruction for Construction Work Package; Form for Revibration Requirements

Attachment A2 – Revibration Requirements and Criteria

Attachment A3 – Meeting notes from Case Study on Top Bar Effects for Large Mat Foundations presented to the ACI 318-B subcommittee on Rebar and Development at the 2003 ACI Spring Conference.

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Table A1 - Calculated Top Bar Factors (Bond Strength Reductions)
ACI 318-99 / 349-01 with no change in Design Margin (D/C < 0.85)

Placement	Thick ft	Placement I.D.	LENGTH PROVIDED Lp (in)	DEVELOPMENT LENGTH ACI 318/349[1] l_d (in)	TOP BAR FACTOR TBF [2]	BOND STRENGTH REDUCTION (%) BSR [2]
HLW						
Foundation						
Mat Fdn - EW splice	6	HLW-2B	102	66.6	1.5	35%
Mat Fdn - NS splice	6	HLW-2B	98	66.6	1.5	32%
Mat Fdn - EW splice	6	HLW-5A	100	66.6	1.5	33%
Mat Fdn - NS splice	6	HLW-5A	102	66.6	1.5	35%
Mat Fdn - EW splice	6	HLW-5B	100	66.6	1.5	33%
Mat Fdn - NS splice	6	HLW-5B	104	66.6	1.6	36%
Mat Fdn - EW splice	6	HLW-6A	102	66.6	1.5	35%
Mat Fdn - NS splice	6	HLW-6A	100	66.6	1.5	33%
Mat Fdn - EW splice	6	HLW-6B	101	66.6	1.5	34%
Mat Fdn - NS splice	6	HLW-6B	100	66.6	1.5	33%
Mat Fdn - EW splice	6	HLW-8	101	66.6	1.5	34%
Mat Fdn - NS splice	6	HLW-8	102	66.6	1.5	35%
LAW						
Foundation						
Mat Fdn - EW splice	5	all placements	117	58.0	2.0	50%
Mat Fdn - NS splice	5	all placements	117	53.0	2.2	55%
Mat Fdn - EW devlp bar	5	all placements	120	45.0	2.7	63%
Walls						
Exterior Wall - Hor. splice	3 to 5	LAW-10	89	68.0	1.3	24%
Exterior Wall - Hor. splice	3	LAW-12	89	68.0	1.3	24%
Exterior Wall - Hor. splice	3	LAW-16	89	68.0	1.3	24%
Exterior Wall - Hor. splice	3	LAW-17	89	68.0	1.3	24%
PTF						
Foundation						
Mat Fdn (center pit) - EW splice	6	PTF-2	94	59.8	1.6	36%
Mat Fdn (center pit) - NS splice	6	PTF-2	94	59.8	1.6	36%
Mat Fdn (FW Pit) - EW splice	5	PTF-3	94	59.8	1.6	36%
Mat Fdn (FW Pit) - NS splice	5	PTF-3	94	59.8	1.6	36%
Mat Fdn (S. tunnel) - EW splice	6	PTF-5	94	59.8	1.6	36%
Mat Fdn (S. tunnel) - NS splice	6	PTF-5	94	59.8	1.6	36%
Walls						
Firewater Pit Walls - Hor. Splice	6	PTF-C-6	94	59.8	1.6	36%
Firewater Pit Walls - Hor. Splice	3-6.25	PTF-C-7	94	59.8	1.6	36%
North Tunnel Walls - Hor. splice	6	PTF-10-1	94	59.8	1.6	36%
North Tunnel Walls - Hor. splice	6	PTF-C-10-2	94	59.8	1.6	36%
South Tunnel Walls - Hor. Splice	6	PTF-11-1	94	59.8	1.6	36%

Notes:
(1) Includes 1.3 factor for Class B splice where applicable
(2) TBF calculated with no reduction in Design Margin (D/C ratio)

Table A2 - Calculated Top Bar Factors (Bond Strength Reductions)
ACI 318-99 / 349-01 with current Design Margin reduced to D/C = 0.85

Placement	Thick ft	Placement I.D.	LENGTH PROVIDED Lp (in)	DEVELOPMENT LENGTH ACI 318/349[1] l_d (in)	CURRENT DESIGN MARGIN D/C ratio	REDUCED DESIGN MARGIN D/C ratio	TOP BAR FACTOR TBF [2]	BOND STRENGTH REDUCTION (%) BSR [2]
HLW:								
Foundation								
Mat Fdn - EW splice	6	HLW-2B	102	66.6	0.43	0.85	3.0	67%
Mat Fdn - NS splice	6	HLW-2B	98	66.6	0.26	0.85	4.8	79%
Mat Fdn - EW splice	6	HLW-5A	100	66.6	0.45	0.85	2.8	65%
Mat Fdn - NS splice	6	HLW-5A	102	66.6	0.39	0.85	3.3	70%
Mat Fdn - EW splice	6	HLW-5B	100	66.6	0.32	0.85	4.0	75%
Mat Fdn - NS splice	6	HLW-5B	104	66.6	0.30	0.85	4.4	77%
Mat Fdn - EW splice	6	HLW-6A	102	66.6	0.21	0.85	6.2	84%
Mat Fdn - NS splice	6	HLW-6A	100	66.6	0.45	0.85	2.8	65%
Mat Fdn - EW splice	6	HLW-6B	101	66.6	0.31	0.85	4.2	76%
Mat Fdn - NS splice	6	HLW-6B	100	66.6	0.26	0.85	4.9	80%
Mat Fdn - EW splice	6	HLW-8	101	66.6	0.44	0.85	2.9	66%
Mat Fdn - NS splice	6	HLW-8	102	66.6	0.39	0.85	3.3	70%
LAW:								
Foundation								
Mat Fdn - EW splice	5	all placements	117	58.0	0.85	0.85	2.0	50%
Mat Fdn - NS splice	5	all placements	117	53.0	0.85	0.85	2.2	55%
Mat Fdn - EW devlp bar	5	all placements	120	45.0	0.85	0.85	2.7	63%
Walls								
Exterior Wall - Hor. splice	3 to 5	LAW-10	89	68.0	0.0[3]	0.85	n/a	n/a
Exterior Wall - Hor. splice	3	LAW-12	89	68.0	0.0[3]	0.85	n/a	n/a
Exterior Wall - Hor. splice	3	LAW-16	89	68.0	0.37	0.85	3.0	67%
Exterior Wall - Hor. splice	3	LAW-17	89	68.0	0.37	0.85	3.0	67%
PTF:								
Foundation								
Mat Fdn (center pit) - EW splice	6	PTF-2	94	59.8	0.66	0.85	2.0	50.6%
Mat Fdn (center pit) - NS splice	6	PTF-2	94	59.8	n/a [3]	0.85	n/a [3]	n/a [3]
Mat Fdn (FW Pit) - EW splice	5	PTF-3	94	59.8	0.58	0.85	2.3	56.6%
Mat Fdn (FW Pit) - NS splice	5	PTF-3	94	59.8	n/a [3]	0.85	n/a [3]	n/a [3]
Mat Fdn (S. tunnel) - EW splice	6	PTF-5	94	59.8	0.54	0.85	2.5	59.6%
Mat Fdn (S. tunnel) - NS splice	6	PTF-5	94	59.8	n/a [3]	0.85	n/a [3]	n/a [3]
Walls								
Firewater Pit Walls - Hor. Splice	6	PTF-C-6	94	59.8	0.62	0.85	2.2	53.6%
Firewater Pit Walls - Hor. Splice	3-6.25	PTF-C-7	94	59.8	0.62	0.85	2.2	53.6%
North Tunnel Walls - Hor. splice	6	PTF-10-1	94	59.8	0.59	0.85	2.3	55.8%
North Tunnel Walls - Hor. splice	6	PTF-C-10-2	94	59.8	0.59	0.85	2.3	55.8%
South Tunnel Walls - Hor. Splice	6	PTF-11-1	94	59.8	0.80	0.85	1.7	40.1%

Notes:
(1) Includes 1.3 factor for Class B splice where applicable
(2) TBF calculated based on Demand/Capacity = 0.85
(3) Indicates there is no structural demand load on reinforcment - e.g. temperature steel

Table A3 - Calculated Top Bar Factors (Bond Strength Reductions)
ACI 408 with no change in Design Margin (D/C < 0.85)

Placement	Thick ft	Placement I.D.	LENGTH PROVIDED Lp (in)	DEVELOPMENT LENGTH (ACI 408) l_d (in)	TOP BAR FACTOR TBF [2]	BOND STRENGTH REDUCTION (%) BSR [2]
HLW						
Foundation						
Mat Fdn - EW splice	6	HLW-2B	102	36.1	2.8	65%
Mat Fdn - NS splice	6	HLW-2B	98	26.8	3.7	73%
Mat Fdn - EW splice	6	HLW-5A	100	36.1	2.8	64%
Mat Fdn - NS splice	6	HLW-5A	102	26.8	3.8	74%
Mat Fdn - EW splice	6	HLW-5B	100	36.1	2.8	64%
Mat Fdn - NS splice	6	HLW-5B	104	34.4	3.0	67%
Mat Fdn - EW splice	6	HLW-6A	102	36.1	2.8	65%
Mat Fdn - NS splice	6	HLW-6A	100	26.8	3.7	73%
Mat Fdn - EW splice	6	HLW-6B	101	36.1	2.8	64%
Mat Fdn - NS splice	6	HLW-6B	100	26.8	3.7	73%
Mat Fdn - EW splice	6	HLW-8	101	36.1	2.8	64%
Mat Fdn - NS splice	6	HLW-8	102	26.8	3.8	74%
LAW						
Foundation						
Mat Fdn - EW splice	5	all placements	117	36.1	3.2	69%
Mat Fdn - NS splice	5	all placements	117	36.1	3.2	69%
Mat Fdn - EW devlp bar	5	all placements	120	36.1	3.3	70%
Walls						
Exterior Wall - Hor. splice	3 to 5	LAW-10	89	40.3	2.2	55%
Exterior Wall - Hor. splice	3	LAW-12	89	40.3	2.2	55%
Exterior Wall - Hor. splice	3	LAW-16	89	40.3	2.2	55%
Exterior Wall - Hor. splice	3	LAW-17	89	40.3	2.2	55%
PTF						
Foundation						
Mat Fdn (center pit) - EW splice	6	PTF-2	94	31.0	3.0	67%
Mat Fdn (center pit) - NS splice	6	PTF-2	94	40.3	2.3	57%
Mat Fdn (FW Pit) - EW splice	5	PTF-3	94	31.0	3.0	67%
Mat Fdn (FW Pit) - NS splice	5	PTF-3	94	40.3	2.3	57%
Mat Fdn (S. tunnel) - EW splice	6	PTF-5	94	31.0	3.0	67%
Mat Fdn (S. tunnel) - NS splice	6	PTF-5	94	40.3	2.3	57%
Walls						
Firewater Pit Walls - Hor. Splice	6	PTF-C-6	94	40.3	2.3	57%
Firewater Pit Walls - Hor. Splice	3-6.25	PTF-C-7	94	40.3	2.3	57%
North Tunnel Walls - Hor. splice	6	PTF-10-1	94	40.3	2.3	57%
North Tunnel Walls - Hor. splice	6	PTF-C-10-2	94	40.3	2.3	57%
South Tunnel Walls - Hor. Splice	6	PTF-11-1	94	40.3	2.3	57%

Notes:
(1) not used
(2) TBF calculated with no reduction in Design Margin (D/C ratio)

Table A4 - Calculated Top Bar Factors (Bond Strength Reductions)
ACI 408 with Current Design Margin reduced to D/C = 0.85

Placement	Thick ft	Placement I.D.	LENGTH PROVIDED Lp (in)	DEVELOPMENT LENGTH (ACI 408) l_d (in)	CURRENT DESIGN MARGIN D/C ratio	REDUCED DESIGN MARGIN D/C ratio	TOP BAR FACTOR TBF [2]	BOND STRENGTH REDUCTION (%) BSR [2]
HLW								
Foundation								
Mat Fdn - EW splice	6	HLW-2B	102	36.1	0.43	0.85	5.6	82%
Mat Fdn - NS splice	6	HLW-2B	98	26.8	0.26	0.85	12.0	92%
Mat Fdn - EW splice	6	HLW-5A	100	36.1	0.45	0.85	5.2	81%
Mat Fdn - NS splice	6	HLW-5A	102	26.8	0.39	0.85	8.3	88%
Mat Fdn - EW splice	6	HLW-5B	100	36.1	0.32	0.85	7.4	86%
Mat Fdn - NS splice	6	HLW-5B	104	34.4	0.30	0.85	8.6	88%
Mat Fdn - EW splice	6	HLW-6A	102	36.1	0.21	0.85	11.4	91%
Mat Fdn - NS splice	6	HLW-6A	100	26.8	0.45	0.85	7.0	86%
Mat Fdn - EW splice	6	HLW-6B	101	36.1	0.31	0.85	7.7	87%
Mat Fdn - NS splice	6	HLW-6B	100	26.8	0.26	0.85	12.2	92%
Mat Fdn - EW splice	6	HLW-8	101	36.1	0.44	0.85	5.4	81%
Mat Fdn - NS splice	6	HLW-8	102	26.8	0.39	0.85	8.3	88%
LAW								
Foundation								
Mat Fdn - EW splice	5	all placements	117	36.1	0.85	0.85	3.2	69%
Mat Fdn - NS splice	5	all placements	117	36.1	0.75	0.85	3.7	73%
Mat Fdn - EW devlp bar	5	all placements	120	36.1	0.28	0.85	10.1	90%
Walls								
Exterior Wall - Hor. splice	3 to 5	LAW-10	89	40.3	0.0[3]	0.0[3]	n/a	n/a
Exterior Wall - Hor. splice	3	LAW-12	89	40.3	0.0[3]	0.0[3]	n/a	n/a
Exterior Wall - Hor. splice	3	LAW-16	89	40.3	0.37	0.85	5.1	80%
Exterior Wall - Hor. splice	3	LAW-17	89	40.3	0.37	0.85	5.1	80%
PTF								
Foundation								
Mat Fdn (center pit) - EW splice	6	PTF-2	94	31.0	0.66	0.85	3.9	74.4%
Mat Fdn (center pit) - NS splice	6	PTF-2	94	40.3	n/a [3]	n/a [3]	n/a [3]	n/a [3]
Mat Fdn (FW Pit) - EW splice	5	PTF-3	94	31.0	0.58	0.85	4.4	77.5%
Mat Fdn (FW Pit) - NS splice	5	PTF-3	94	40.3	n/a [3]	n/a [3]	n/a [3]	n/a [3]
Mat Fdn (S. tunnel) - EW splice	6	PTF-5	94	31.0	0.54	0.85	4.8	79.0%
Mat Fdn (S. tunnel) - NS splice	6	PTF-5	94	40.3	n/a [3]	n/a [3]	n/a [3]	n/a [3]
Walls								
Firewater Pit Walls - Hor. Splice	6	PTF-C-6	94	40.3	0.62	0.85	3.2	68.7%
Firewater Pit Walls - Hor. Splice	3-6.25	PTF-C-7	94	40.3	0.62	0.85	3.2	68.7%
North Tunnel Walls - Hor. splice	6	PTF-10-1	94	40.3	0.59	0.85	3.4	70.2%
North Tunnel Walls - Hor. splice	6	PTF-C-10-2	94	40.3	0.59	0.85	3.4	70.2%
South Tunnel Walls - Hor. Splice	6	PTF-11-1	94	40.3	0.80	0.85	2.5	59.6%

Notes:
(1) not used
(2) TBF calculated based on Demand/Capacity = 0.85
(3) Indicates there is no structural demand load on reinforcment - e.g. temperature steel

Table A5
Concrete Subsidence Study - Field Data Summary

	General						Temperature					Consolidation			
Wall/Slab	Thick., ft	Placement I.D.	Duration Placmt., (Hrs)	Quantity, CY	Date	Cracks Y/N	Ambient max (deg F)	Ambient min (deg F)	Ambient Avg (deg F)	Avg. Conc Temp	Greatest CJ Width	Finish Method @ C.J.	Revib Y/N	No. of Vibr.	Placement Rate
LAW															
Cold Weather Placements:															
Exterior Wall	3	LAW-16	5.5	190	12/9/2002	N	42	36	39	56	3	Vib. G.C.	N	9 and 3	26 (26 Max)
Mat Foundation	.75 to 5	LAW-1B&D	2 and ?	350	1/14/2003	N	44	35	40	56	5	Vib. G.C.	N	5 and 3	35 (35 Max)
Mat Foundation	.75 to 3	LAW-1C	5	155	1/16/2003	N	39	36	38	59	5	Vib. G.C.	N	5 and 3	40 (60 Max)
Exterior Wall	3 to 5	LAW-10	8	510	1/23/2003	N	57	33	45	57	5	Vib. G.C.	N	9 and 3	65 (80 Max)
Exterior Wall	3	LAW-12	6	196	2/12/2003	N	51	32	42	60	3	Vib. G.C.	N	5 and 2	30 (33 Max)
Exterior Wall	3	LAW-17	6	177	2/20/2003	N	58	38	48	56	3	Vib. G.C.	N	5 and 2	30 (33 Max)
HLW															
Non-Cold Weather Placements:															
Mat Foundation	6	HLW-2C	5	517	8/22/2002	N	86	54	70	66	4	Vib. G.C.	N	5 and 3	160 (210 Max)
Mat Foundation	6	HLW-4B	8	1101	8/29/2002	N	98	64	81	66	26	Float	N	5 and 3	160 (210 Max)
Mat Foundation	6	HLW-4A	7	1052	9/10/2002	N	90	57	74	66	16	Float	N	5 and 3	160 (210 Max)
Mat Foundation	6	HLW-3	10	1577	9/12/2002	N	96	55	76	65	8	Vib. G.C.	N	5 and 3	160 (300 Max)
Mat Foundation	6	HLW-7A	12	1857	9/26/2002	N	74	43	59	64	9	Float G.C.	N	9 and 3	160 (300 Max)
Mat Foundation	6	HLW-2B	6	688	10/3/2002	N	62	52	57	59	4	Vib. G.C.	N	9 and 3	130 (160 Max)
Cold Weather Placements:															
Mat Foundation	6	HLW-6A	No SI	927	10/15/2002	N	73	34	54	59	14	Float	N	No SI	No SI
Mat Foundation	6	HLW-5B	13	1985	11/21/2002	N	58	44	51	58	22	Float	N	9 and 3	160 (300 Max)
Mat Foundation	6	HLW-6B	No SI	1678	12/3/2002	Y	34	31	33	56	30	Float	N	No SI	No SI
Mat Foundation	6	HLW-8	18	2029	12/17/2002	Y	38	26	32	57	14	Float	N	9 and 3	120 (150 Max)
Mat Foundation	6	HLW-5A	10	1496	1/7/2003	N	33	24	29	57	4	Vib. G.C.	N	9 and 3	160 (300 Max)
PTF															
Mat Foundation (N. tunnel)	6	PTF-4	5	587	11/21/2002	N	58	44	51	62	6	Float	N	3 and 3	140 (220 Max)
Mat Foundation (center pit)	6	PTF-2	10	1207	12/4/2002	N	34	32	33	58	6	Float	N	9 and 3	180 (240 Max)
Mat Foundation (FW Pit)	6	PTF-3	6	402	12/9/2002	N	40	36	38	58	6	Vib. G.C.	N	6 and 3	100 (160 Max)
Mat Foundation (S. tunnel)	6	PTF-5	8	933	12/12/2002	N	42	37	40	57	6	Float	N	9 and 3	140 (220 Max)
North Tunnel Walls	6	PTF-10-1	7	187	1/22/2003	Y	34	30	32	56	6	Vib. G.C.	N	1 and 3	30 (50 Max)
Firewater Pit Walls	6	PTF-C-6	8	246	1/31/2003	N	52	39	46	58	6	Vib. G.C.	Y	5 and 3	35 (70 Max)
North Tunnel Walls	6	PTF-C-10-2	6	185	2/4/2003	N	50	31	41	57	6	Vib. G.C.	Y	2 and 2	35 (50 Max)
Firewater Pit Walls	3 to 6.25	PTF-C-7	7	188	2/13/2003	N	44	37	41	57	6.25	Vib. G.C.	Y	2 and 2	35 (50 Max)
South Tunnel Walls	6	PTF-11-1	No SI	385	2/19/2003	N	52	38	45	59	6	Vib. G.C.	Y	No SI	No SI

S.B. - Sand blast
G.C. -Green Cut
S.I. Special Instructions
Float - Bull flaot and/or magnesioum float
Vib. G.C. - Vibrated surface finish, then Green Cut

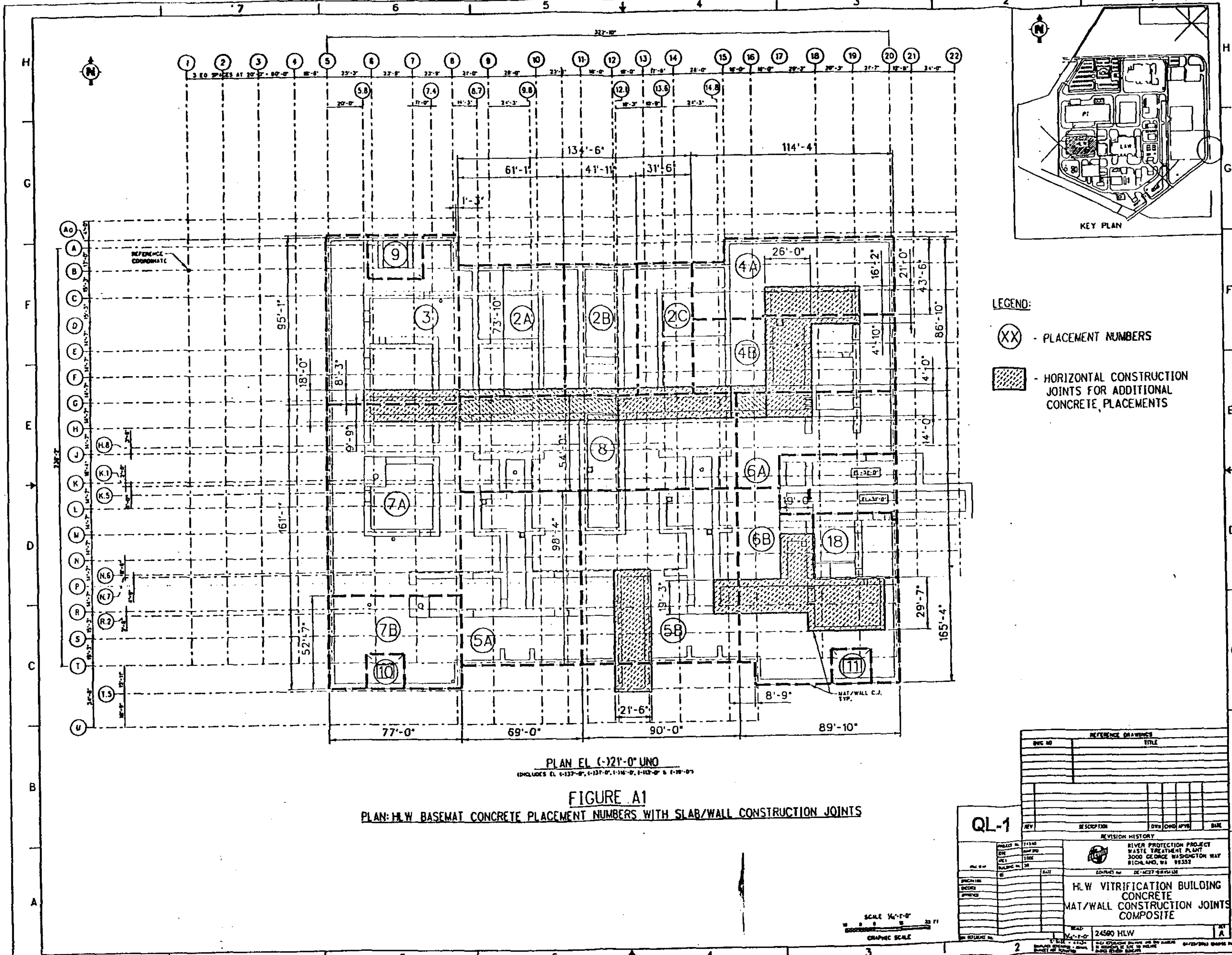


FIGURE A1

PLAN: HLW BASEMAT CONCRETE PLACEMENT NUMBERS WITH SLAB/WALL CONSTRUCTION JOINTS

Special Instructions for Construction Work Packages

Item ID No.: N/A	Special Instruction Number: 24590-PTF-SI-C-03-

5.0 *Placement Requirements for Normal Weather Concrete*

- An FE or QCE designee will monitor concrete mixer truck discharge into the hopper/augermax and determine acceptability of concrete.
- The minimum pre-placement temperature for forms/ reinforcing steel/ embeds shall be 35°F or greater when placement is initiated.
- To decrease the possibility of subsidence cracking, revibration of the final lift of concrete shall be employed. The revibration should be performed on the top portion of the placement and the vibrator should be inserted to a depth between about 6" and 24" as indicated on the Concrete Pour Card. The revibration should be performed as close to the time of initial set as possible without interfering with the finishing activities. The field engineer and construction supervision shall monitor the concrete placement to estimate the reasonable time to perform the revibration. Attributes to consider in determining the time of revibration including:
  1) Concrete Temperature
  2) Slump of concrete being placed
  3) Ambient Conditions (including humidity, temperature, wind, sun, etc.)
  4) Placement Rate
  5) Placement configuration and finish requirements
  6) Observation of the condition of as-placed concrete

6.0 *Post Placement Requirements for Normal Weather Concrete*

A. The FE and/ or QCE shall monitor the exposed concrete surface temperature a minimum of 1 time daily. Subject thermometers shall be calibrated via the M&TE program. Document cure temperatures on Concrete Pour Card.

ATTACHMENT A2
REVIBRATION REQUIREMENTS AND CRITERIA

The following revibration criteria is currently being coordinated with construction. A final version will be formally included in Concrete Operations (Including Supply) Procedure, 24590-WTP-GPP-CON-3203:

3.10.2.14 *As directed by the engineer, structural concrete elements (walls, slabs, foundations) over 24" in vertical dimension may require revibration to help eliminate the potential for subsidence cracking by removing air voids and bleed water that may have been trapped. The Field Engineer (FE) shall indicate on the Placement Card if revibration is required and the required depth of revibration.*

3.10.2.15 *The revibration should be performed:*

- *Over entire surface of horizontal construction joints (walls and mats)*
- *Over the entire surface of <u>finished</u> areas during cold weather placement conditions or any other condition where concrete temperatures are less than 55 degrees. (walls and mat)*
- *As close to the time of initial set as possible without interfering with the finishing activities.*
- *With a minimum vibrator head diameter of 2-1/2" except for highly congested areas where a smaller vibrator would be appropriate.*
- *Revibration of finished surfaces may be discontinued when cold weather placement conditions are no longer applicable as determined by Civil Field Engineering Supervision.*
- *Revibration of unfinished construction joint surfaces shall be continued unless directed otherwise by Engineering.*

3.10.2.16 *It is not necessary to extend the depth of revibration into the previous lift. The revibration depth should be as follows:*

- *For section 36" or more in depth, the depth of revibration should be between about 6" to 24" below the top surface.*
- *For sections over 24" but not greater than 36" the depth of revibration should be between about 6" to 14".*
- *In general, tip of vibrator must penetrate below top mat of reinforcement to remove trapped air and water.*

3.10.2.17 *The FE and CS (Concrete Superintendent) shall monitor the concrete placement to estimate the reasonable time to perform the revibration so as to revibrate as late as possible without interfering with the finishing activities. Attributes to consider in determining the time of revibration include:*

a.) Concrete Temperature
b.) Slump of Concrete being placed
c.) Ambient Conditions (humidity, temperature, wind, sun, etc)
d.) Placement Rate
e.) Placement Configuration and finish requirements
f.) Observation of the condition of the as-placed concrete (i.e. rate of slump loss and the amount of bleed water appearing at the surface)

"Cold-Weather Placement Conditions" as referenced above is defined in the Construction Procedures as the following, in accordance with the definition identified in ACI 306R.

3.1.11 Cold Weather: Per ACI 306.1, Standard Specification for Cold Weather Concreting, it is a period when, for more than three (3) consecutive days, the average daily temperature is less than 40°F and the air temperature is not greater than 50°F for more than half of any 24 hour period within this time frame.

ATTACHMENT A3
MEETING NOTES FROM CASE STUDY ON TOP BAR EFFECTS FOR LARGE MAT FOUNDATIONS

Date of Presentation: 01Apr03
Location: ACI Spring Conference - Vancouver, B.C.
Recorded by: Bruce Bitner, BNI

Subject: Top Bar Effects of Large Mat Foundations: A Case Study - Presentation made by Bechtel National Inc. (BNI) to the ACI 318B Code Subcommittee on Reinforcement and Development

Attendees:

BNI	ACI 318B Subcommittee (partial list)	ACI 408 Committee
Bruce Bitner	Dr. Steven McCabe (chairman)	Dr. David Darwin (chairman)
Jeff White	J. Breen	
	R. Eligehausen	
	David Gustafson	
	Leroy Lutz	
	Dennis Mitchell	

Attachment: Presentation slides

Notes:

1.0 Existing Condition

1.1 BNI is currently designing and constructing a major Waste Treatment Plant in Washington State. The project consists of 3 major reinforced concrete and steel structures and over 256,000 CY of concrete. BNI has placed approximately 30,000 CY of concrete to date.

1.2 Recently, surface cracks appeared on two separate concrete placements in the basemat foundation on one of the major structures. The basemat dimensions are 300 ft x 200 ft x 6 ft thick. The cracks run in a regular grid pattern directly above the top layer of reinforcement. The crack pattern is fairly uniform over the unfinished portion of the placements. The max crack dimensions are approx. 1/8" wide and 1" deep.

1.3 The top reinforcement mat consists of 2 layers of #11 bars at 12" center to center spacing in each direction. The top reinforcement is layered as follows: E-W (top), N-S (2nd), E-W (3rd), and N-S (4th). Cover over the top bar is 2 1/2". The top mat reinforcement is supported from rigid rebar chairs made from welded structural trusses.

1.4 The concrete is a basic 4,000 psi mix w/ 20% fly-ash, normal range water reducing agent, and excellent 28 day break strengths (over 6,000 psi). The field estimates that set up times vary from 1-2 hrs in the summer and 2-3 hrs in the winter.

1.5 An examination of the pour cards and field data revealed that low temperature and finish method where common factors for the two cracked placements. The ambient and concrete surface temperature for both placements were below 40 deg F and 60 deg F respectively. Also, neither placement received a final trowel finish. No other concrete placed above these temperatures or that received a steel trowel finish showed any signs of cracking.

2.0 Initial Conclusions - Seven concrete specialists (two Bechtel specialists and five outside consultants) examined the cracks, placement records, and other field data. In general they agreed that:

2.1 The cracks were caused by concrete subsidence. Concrete settling around the top layer(s) of reinforcement prior to initial set opened up the cracks directly above the top 2 layers of reinforcement. The 2 cracked areas are designed to have an additional concrete lift placed above the entire area. As such, they were float finished and did not receive a final steel trowel finish. A final trowel finish would have prevented the cracking.

2.2 Concrete design and placement were performed in accordance with ACI provisions. Development lengths were calculated using the 'Top Bar Factor' prescribed by the ACI 318. Reinforcement details conformed to the code requirements. Concrete placement followed all requirements and recommended industry practices for cold weather placements.

2.3 Cracking causes no detrimental effects on structural integrity of basemat concrete. The specialists could not reach consensus as to the effect on localized bond strength of the reinforcing steel.

2.4 Revibrating upper 8"-16" prior to initial set is a recognized method for preventing subsidence cracking. BNI has used this method for all placements since the cracking occurred. There have been no additional cracks since implementing the new method.

3.0 Technical bases needed - The specialists could not agree on conclusions related to the effects of subsidence on the bond strength of the reinforcement. Specifically they disagreed on 2 points.

1. whether the subsidence exhibited at the two cracked areas reduced the bond strength of the concrete beyond the limit considered by the 'Top Bar Factor' in ACI 318 (i.e. the 1.3 development length factor for reinforcing bars where more than 12" of fresh concrete is cast below).

2. whether other factors of large mat foundations cause excessive subsidence (i.e. outside the provisions considered by ACI 318), irrespective of surface cracking.

The second point of disagreement, suggests the code's 1.3 'Top Bar Factor' may not be sufficient for all concrete placed under similar conditions (i.e. 6 ft thick, #11 rebar, rigid chairs, 20% fly ash, cold weather conditions, 2 1/2" cover).

There is no direction given by the code on these two points nor can BNI find any definitive research. BNI asked if any of the committee members could provide documented direction or identify specific research on the following issues:

3.1 Criteria for conditions where subsidence is outside the range considered by the ACI 318 code provisions - criteria should be in terms of critical factors: depth of placement, temperature, set time, rebar size, etc.,.

3.2 Method and acceptance criteria for measuring excessive subsidence - there are no current methods for determining whether subsidence is in excess of the code allowable. One proposal is to core drill through a series of top reinforcing bars and measure any gaps below the rebar in the core. There is not a validated test method or compatible acceptance criteria currently available. These would need to be established.

3.3 Bond Strength Reduction Factor for excessive subsidence ('Top Bar Factor' greater than 1.3) - an arbitrary increase of 100% (from 0.25 to 0.50) was suggested based on the alternate calculation results - see item 4.0.

3.4 Bond Strength Reduction in horizontal wall reinforcement - there is no indication of excess subsidence on any of the wall placements.

4.0 Alternate Method - Calculation & Results

4.1 BNI calculated the development length derived from ACI 318-99 (and ACI 349-01) and the development length produced using an alternate method from ACI Title 97-S65, based on the publication by Zuo and Darwin.

4.2 The results showed that the bond strength reduction could be doubled from 25% to 50% (i.e. 'Top Bar Factor' increased from 1.3 to 2.0) using the same development and splice lengths provided in the large mat foundations based on ACI 318-99 (349-01).

4.3 BNI believes the 100% increase in bond strength reduction bounds any additional 'Top Bar Factor' needed to account for excessive subsidence and, therefore, the splice lengths and reinforcement details based on ACI 318-99 are acceptable.

5.0 Feedback / Recommendations from Committee

5.1 **Cause of Cracking** - Several committee members zeroed in on temperature as the cause of the cracking. One member said there were cases where fly ash combined with some admixtures (super-plasticizers, etc.,) delayed initial concrete set as much as 12 to 24 hrs. BNI stated average set time for this specific mix is affected by cold weather but it's in the order of 2 - 3 hrs. However, BNI does believe delayed set was the cause of the cracking.

5.2 **Horizontal Wall Reinforcement** - BNI asked whether they should consider increasing the top bar effect for horizontal wall reinforcement even though there has been no cracks in the wall placements. One committee member recommended BNI check the older versions of the code. Previously, the code did not consider top bar effect for horizontal wall reinforcement. In his opinion, you don't need to increase it.

5.3 **Finishing Method vs. Top Bar Effect** - Prof. R. Eligehausen cited results from research in Germany relating finishing method to top bar effect. He indicated top bars in finished concrete exhibit a much higher bond strength (as much as 2 times) over unfinished concrete when the reinforcement is detailed for a pull out failure (i.e. concrete does not split). This is the case for the mat foundations in this study.

5.4 **Top Bar Factor** - BNI asked if there is a need for updating the code to increase the 'Top Bar Factor' for large mats or other placements where subsidence potentially causes the existing code provisions to be inadequate and if so, by how much. The committee members acknowledged there was no consideration in the code for increasing the 'Top Bar Factor' (1.3) in any event. No one was aware of specific research or structural failures relating subsidence cracks to reduced development strength nor special factors for large placements leading to detrimental subsidence outside the range considered by ACI 318. The committee did not see the need to increase the current 'Top Bar Factor' for large placements.

5.5 Comment on BNI Approach - BNI asked for comments on it's approach of using the ACI Title 97-S65 method for recalculating basic development length and showing the resulting 'Top Bar Factor' of 2.0 bounds any additional bond strength reduction potentially caused from subsidence in large mats (items 4.2 and 4.3). The committee was in general agreement that BNI's approach and conclusions were reasonable.

5.6 Additional Comments: Dr. McCabe asked committee members with any further suggestions, comments, recommendations, or relevant data to forward them to him and he would pass them along to BNI. BNI will also pass along any new information on this case to the subcommittee through Dr. McCabe.

Top Bar Effect for Large Mat Foundations

Case Study for ACI 318B Technical Committee

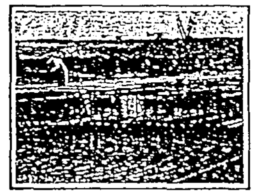
Bruce Bitner / Jeff White – Bechtel National Inc.

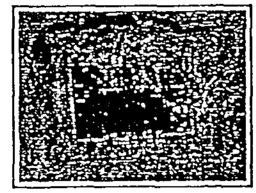
Agenda:
- Existing Condition
- Initial Conclusions
- Technical bases needed
- Alternate Provisions – calculation & results
- Feedback / Recommendations from Committee

Top Bar Effect for Large Mat Foundations

Existing Condition:

Mat Size: 300' x 200' x 6'thk
Rebar Size: #11 @ 12" ctc – e.w.
Rebar Chairs: rigid



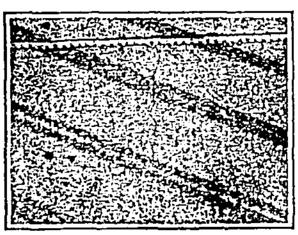


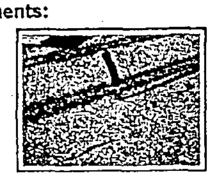
Technical Committee 318-B
Code-Reinf./Development

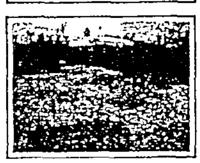
Top Bar Effect for Large Mat Foundations

Subsidence Cracks at 2 Placements:

Ambient Temp: < 40°F
Concrete Temp: < 60°F
Finish Method: Float only







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Top Bar Effect for Large Mat Foundations

Initial Investigation – 7 Concrete Specialists

Consultants in Agreement on:
- Cracks caused by subsidence of concrete prior to initial set
- *Concrete design and placement in accordance w/code*
- No effect on structural integrity (bond strength notwithstanding)
- Revibrating upper 8"-16" will prevent future cracking

Differences of Opinion:
- Subsidence within code provisions for 'top bar effect'
- Investigation should be limited to cracked areas

Technical Committee 318-B
Code-Reinf./Development

Top Bar Effect for Large Mat Foundations

Subsidence & Bond Strength Reduction

Critical Placement Factors → Concrete Subsidence → Bond Strength Reduction / Casting Position Factor

CURRENT CODE PROVISIONS:

- Pour Height > 12"
- Mix Design
- Temperature
- Rebar Size
- Cover
- Finishing Method

↕ ?

25% / CPF = 1.3

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Code-Reinf./Development

Top Bar Effect for Large Mat Foundations

Subsidence & Bond Strength Reduction:

Critical Placement Factors → Concrete Subsidence → Bond Strength Reduction / Casting Position Factor

LARGE MATS: NOT COVERED BY CODE

- Pour Height 72"
- Mix Design 20% fly ash
- Temperature < 40°F (ambient)
- Rebar Size # 11
- Cover 2 ½"
- Finishing Float only

↕ CRACKS ↕ ?

Technical Committee 318-B
Code-Reinf./Development

Top Bar Effect for Large Mat Foundations

Alternate Provisions for Development Length

[illegible]

Calculate development length using ACI Title 97-S65

[illegible equation]

[illegible]

[illegible equation]

L_d = 36.1" for #11, 2 ½" cover, 12" spacing

Top Bar Effect for Large Mat Foundations

Compare to:

Calculate development length using ACI 318-89

[illegible equation]

L_d = 47.4" for #11, 2 ½" cover, 12" spacing

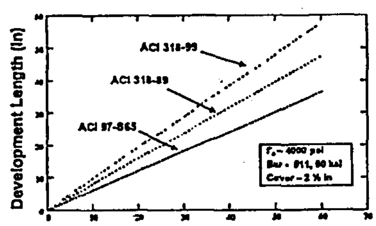
Calculate development length using ACI 318-99

[illegible equation]

L_d = 57.5" for #11, 2 ½" cover, 12" spacing

Top Bar Effect for Large Mat Foundations

Results:



New design expressions reduce development length by 37% over '99 code and 18% over '89 by taking account of pull out failure mode.

Top Bar Effect for Large Mat Foundations

Alternate Provisions (cont.)

For our case, reducing basic development length allows increase in CFP while maintaining current 75" top bar development length and design margins...

1.3 x L_d ACI 318-99 = CFP Increase x L_d ACI 97-S65

AND

0.65 x L_d ACI 318-99 = L_d ACI 97-S65

Substitute and Solve for CPF increase... CPF Increase = 2.0

...or 50% BSRF – reasonable and conservative

Top Bar Effect for Large Mat Foundations

Results & Recommendations

Process and Workmanship:

- New Code provisions or commentary are needed for placements made in conditions that tend to produce subsidence (e.g. revibrate, reduce slump, etc.). These provisions should address the principle factors such as temperature and depth of placement.

Development Length:

- Current research reveals that the Code versions examined contain considerable conservatism for relatively typical applications for most bar sizes. Adopt new method for calculating basic development length.
- Additionally the research indicates that the factor of 1.3 normally used for Class B splices may not be required.

Top Bar Effect for Large Mat Foundations

Technical Bases Needed:

- Criteria for conditions where subsidence is outside the range considered by the ACI code.
  - cracked areas
  - uncracked areas
2. Measuring Excessive Subsidence (if answer to 1. is yes)
   - test method
   - acceptance criteria
3. Bond Strength Reduction Factor for excessive subsidence
4. Bond Strength reduction in horizontal wall bars – Issue?
5. Feedback / Recommendations from Committee...