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UNITED STATES NUCLEAR REGULATORY COMMISSION WASHINGTON, D. C. 20555

Docket Nos. 50-352/353

JUN 8 1981

Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464



Dear Ms. Zitzer:

This will confirm your telephone conversation of June 5, 1981 with Don Calkins. The meeting with Mr. Frank Romano is scheduled for 1:00 P.M. on June 18, 1981, at 7920 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Ergineers and Construction, Inc.

Sincerely,

Schwaller\_

A. Schwencer, Chief Licensing Branch No. 2 Division of Licensing

Enclosure: As stated This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

- #

October 29, 1980 Hollywood, Florida

# "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Supervising Structural Engineer United Engineers and Constructors Inc. & Ashok J. Desai, Structural Engineer United Engineers and Constructors Inc.

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"BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allea J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desai<sup>2</sup>, M.ASCE

### INTRODUCT ION

This paper summarizes the results of an extensive program carried on for the Seabrook Nuclear Station to increase blast-vibration limits for freshly placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect to any effect on design requirements. These "new" vibration limits allow for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

### BACKGROUND

Due to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vibration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscasset, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiate...

### DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated concrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

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## REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new hight, vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table L. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless based on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrook construction operation.

In addition to industry and literature searches, organization such as the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete companies and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibrating green concrete required various degrees of extrapolation to obtain useful parameters. It was, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect masonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

### SEABROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would have on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: more regular patterns). Since it is generally recognized that the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire test program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	<u>.</u>	92	-
Total	378	140	347	31

# FIELD TEST PROGRAM

Essentially the field test program was comprised of casting various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, namely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

### Field Cylinder Test Program

This program consisted of casting standard 6x12 inch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 20 foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Fads were equipped with hold down bolts and apparatus to hold four concrete mold cylinders firmly in place during the blast. Provisions were also made to bolt down a monitoring transducer on each pad and read remotely and a central station. (See Photograph No. 1)

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was deconated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad). The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the cont of cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-concrete age datum point (i.e.: cylinders subjected to the same blast vibrations) illustrates the fluctuating-oscillating changes in the concrete cylinder strengths for identically vibrated cylinders. The effect of differential curing time (7 days vs. 22 days) is considered to be of little consequences since no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which would offset any detrimental cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the variations actually lie in a relatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 98% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

### Field Beam Tes: Program

Reinforced beams measuring 4 x 8 inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bond failure it was necessary to minimize the embedded length to 4 inches so as not to fail the 4 x 8 inch concrete section in shear. Embedmeat length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam specimens were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test mads (See photograph No. 3). Two beams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. One set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast vibrations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beams were tested per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As loading was continued, the beam would ultimately fail by:

- Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond failure in the inchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediately by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering <u>unconfined</u> bond anchorage values and actual cylinder test values of the same age and material utilizer in the beam.

A summary of the test values is given in Table 2.

No signs or features were visible in the vibrated or unvibrated samples tested that could be related in any way to a less than sound concrete product.

Field Wall Test Program

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each wall was made up of two - 2 feet (0.61 m) wide by 8 foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with #6 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the test zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph No. 6).

Four-hour and fourteen-hour green concrete ages were chosen as sufficient to represent the varying spectrum of concrete set time characteristics.

Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transducer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

Twenty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27,210 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond failure load was determined to be the load at which continued pumping initially did not result in an increase in load. At this point, verification of movement



SAMPLING OF VIBRATION (WITS REPORTED TO ME SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

	NOMINAL AGE OF GREEN CONCRETE WITER PLACEMENT IN HOURS						
PLANT	0-3	2-11	11-24	-			
	*6		OCITY IN INCHES	we			
SEABBOOK (0)	007[6]	0.07 (4)	40	70			
MAINE - TANEEE	007	0.07	40	70			
OTHER	NOLIMIT	0.2	0.00	40			
U.M.	130	136	1 30	1 30 (0)			
PLANT	20	2.0	20	20(*)			
******	( <b>g</b> )	(.)	40	10			
DATA	NO LINE?	0.07	0.13				
	0.10	0.10	0.5	1.0 (*)			



- (a) Limits apacified (prior to Vibration of Green Concrete Test Progr (b) Limit raised to (Con Zuec for Line) hour of piecompet.
  (c) Limit roised to 0.14 m/sac for transporary structures.
  (d) Increase limit by 0.3 m/sec for transporary structures.
  (e) Maximum limit governed by anisting operating stant.
  (f) Limit non-piece to 3.0 m/sec films 7 days.
  (g) "approximate to 3.0 m/sec films 7 days. values available (h) curve uncreased to 2.0 m /sec after 38 mours

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120 .

AVERAGE SAFETT FACTOR

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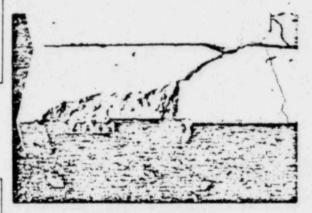
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2.68

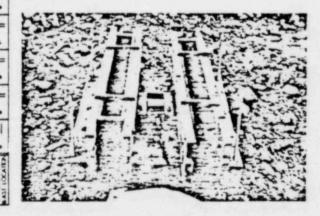
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Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

TEST ESISTER	CONC AGE AT BLAST	VELC	CITY IN	AFTICLE INCHES	/sec	SAFETY		SAFETY	ACTOR L/CALC	NEWLATION
~	HOURS		11.44	3 4.mm)		AVER	STO	AVER	STO	8
		1.95	4.18	5.82	16.47	145	613	2.52	0.22	11
	1		1	1		1 66	005	2.84	0.09	
710		1 57	1 42	615	1810	1.54	011	2 64	019	-
THO	24		1			148	0.05	2.59	0.04	
		0.01	4 20	0.99	14.12	2.02	0.12	3.12	0.19	-
712	- 14		-		1 × -	1.91	0 70	294	030	
		1.10	1.54	5.76	16 37	1.42	010	2.08	018	=
113	•					145	0.07	275	013	
		2.64	3.0		10 73	1 60	0.17	2.81	0.79	=
The	14	÷	-			2.05	0.14	347	0.74	
		2.68	4.81	10.27	10.66	1 50	0.09	7 54	0.16	=
115	•					1.27	0 13	216	0 22	
		2 00	3.31	. 50	. 10	1.30	0.11	240	0.19	11

VIMALED

CONTROL

I CONTROL AND & VIBRATED BEAMS PER SERIES

1.56

1.62

# TABLE 2 SUMMARY OF FELD BEAM TEST VALUES

ATTN

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitare jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was made between the ACI 318-77 <u>confined</u> anchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>confined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws or deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

## LABORATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker table. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

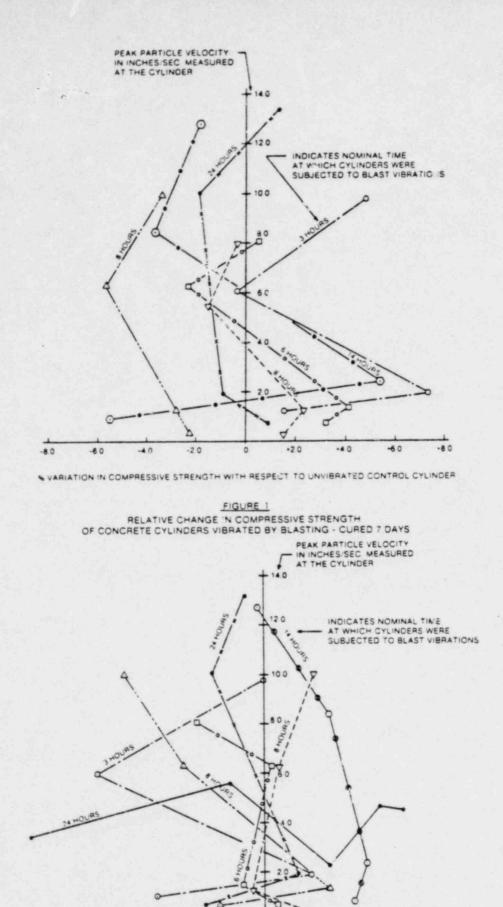
All testing work, except for load testing of the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hours was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

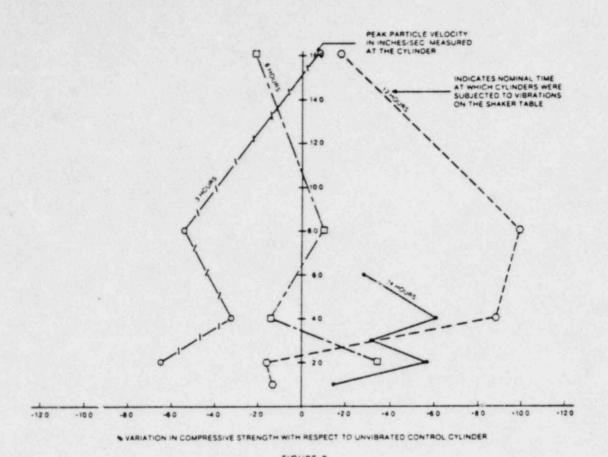
A C150 shaker manufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.

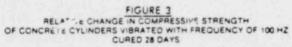


-80 -60 -20 0 -20 -40 -60 -80

N VARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

FIGURE 2 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS







Photograph 4 CYLINDER FIXTURE FOR VIBLATING GREEN CONCRETE MOLDS IN LABORATORY

Chotograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER TABLE

## LABORATORY TEST VELOCITIES AND FREQUENCIES (AND ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	AK PARTICI	E ACCELERA	ATION IN g	
50 hz	0.83	1.66	3.3	6.6	1 - 1	13.2
100 hz	1.66	3.3	6.6	13.2	•	26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 25.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

## Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be established in the change of cylinder strength with respect to any of the vibration levels introduced for any of the green concrete ages tested.

### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pill-out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting. Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, 1 whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 is to evaluate concrete strengths by comparate bond failures (not necessarily related to ACI 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. However, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

#### SUMMARY

- Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a less durable structure.
- 5. Results of the test were used to re-establish green concrete blast vibration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent strong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizontal lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

### CONCLUS IONS

- 1. The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

#### ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

### APPENDIX - DIRECT REFERENCES

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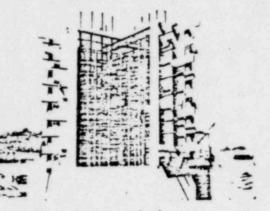
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Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING

CONC AGE AT BLAST IN HOURS	MEAR PARTICLE VELOCITY IN INCHES / SEC			MALOUT		NO LOAD ACTUAL/CALC	FACTOR			NO
			100		AVER LOAD	STD OEV TONS	AVER	STO	E Fi	
	• 1	5.02	127		25.0		2 51	0.087	4353	
14	1049	• \$ 7	• 50		26.3	0 00	273	0.067	3804	•
	7 48		700		26.1	0.70	7.55	0 377	1064	3
14	0.07		379	47	26.4	0 70	272	\$ 072	3851	
-					24 18	0.5#	2.55	0.057	4333	
VERA	-	ATED	ALLES		26 18		2.63	Г		
	4 14 14 14 14	Assi INK NURS Base 4 01 14 1049 4 7.44 14 0.97 NMD	A 4 1 5 2 A 4 1 5 2 A 2 44 - 14 0.97 - WERACE VIMATED 1	ATST INCHES / SEC INCHES / S	AST INCHES / SEC ARES INCHES / SEC ARES NATURES BASE MID TOP 4 01 592 127 46 14 1049 987 939 48 4 248 - 749 48 14 097 - 379 47 MID 1097 - 379 47 MID 14 14 097 - 379 47 MID 14 14 097 - 379 47	AST INCHES/SEC         RAES           INCHES/SEC         RAES           INA         AVER UDAD           BASE         MID         TOP           BASE         MID         TOP           A         A I         3.92         12.7           4         24.8         -         7.84           14         0.97         -         3.79         4.7           14         0.97         -         3.79         4.7         26.4           MMDL         -         -         -         4.8         26.1           MMDL         -         -         -         4.8         26.1	ALST INCINES / SEC NA NATS NA ALST NA NATS NA NA NA NA NA NA NA NA NA NA	AST INF         INCINES / SEC         BARES         INCIDED         AVER ICAD         STD ICAD         AVER           4         6         1         5.92         12.7         46         25.9         0.91         2.51           14         10.49         4.87         9.59         4.8         26.1         0.79         2.35           14         0.97         -         3.79         4.7         26.4         0.70         2.72           MEX         -         -         -         2.4         2.6 IF         0.39         2.55           VERAGE VIBARATED VALUES         26 IB         2.60         2.60         2.60	AST INCRES         INCRES         SEC INFRUES         AVER ICAD         STD ICAD         AVER ICAD         STD ICRES           84.5E         MID         TOP         TOPS         TOPS         AVER ICAD         STD ICRES         IS         ICAD         ICAD <td< td=""><td>AST INF         INCINES / SEC         AXES         Concentration           ASSE         MID         TOP         AVER IOAD         STD OEV         AVER DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD         AVER DEV         STD         STD         STD         STD         STD         STD         AVER DEV         STD         STD</td></td<>	AST INF         INCINES / SEC         AXES         Concentration           ASSE         MID         TOP         AVER IOAD         STD OEV         AVER DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD DEV         STD         AVER DEV         STD         STD         STD         STD         STD         STD         AVER DEV         STD         STD

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Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

TABLE & LABORATORY TEST PULLOUT LOADS IRRESPECTIVE OF GREEN CONCRETE AGE OR VERATION LEVEL

COIX MATCH	TEST DAT	NO	AVERAGE PULL-OUT LOAD POLNOS	STD DEV	NO.K	AVERAGE PULL-OUT IGAD POLNOS	STD OF Y
-	,	1	14.178	2053		17,106	7013
2	78	2	17 048	1413		18, 525	2452
	7	2	12.750	1725	10	12,925	1430
3	28	2	15.175	250	10	15,233	1330
-	7	2	12,213	738	12	13,924	1561
•	28	17	15,450	1075	12	15 160	2387

	TABLE	1		
LABORATO	TY TEST CTUR	YDER STRENK	THS	
ESSPECTIVE CA GRE				

		1	CONTRO	A		0	
CONC	nest Owr	NO	AVERAGE STRENGTH PSI	STO DEV PSI	NO	IVE BAGE STRENGTH PSI	STO DEV
	7	13	3340	53.5	37	3265	116.6
1	28	12	4007	67.4	1 21	4128	143.4
	,	1,	2740	49 7	10	2841	126.3
2	28	1,	3747	41.9	10	3-06	103 4
De l'HE TAL	,	11	2957	270	1 41	2820	100 7
3	28	1 3	3543	118	42	3010	153 8
	7	1,	2640	49	22	17 20	55 9
	28	1,	3767	728.8	22	3405	181.7

#### TABLES BASIC BLAST VIBRATION LIMITS FOR THE SEABBOOK STATION PERMANENT STRUCTURES

CONCRETE AGE	0-3	3-11	11-24	24-48	over 48
GROUND VELOCITY LIMITATIONS (2) INCHES FER SEC.	40	1.5	2.0	4.0	70

(1) CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VEIDCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES MER SECOND OR 0 5 INCHES MER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELT

> > ,

NSIC



UNITED STATES NUCLEAR REGULATORY COMMISSION WASHINGTON, D. C. 20555

Docket Nos. 50-352/353

JUN 8 1981



Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464

Dear Ms. Zitzer:

This will confirm your telephone conversation of June 5, 1981 with Don Calkins. The meeting with Mr. Frank Romano is scheduled for 1:00 P.M. on June 18, 1981, at 7920 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend.

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Engineers and Construction, Inc.

Sincerely,

Schwalter

A. Schwencer, Chief Licensing Branch No. 2 Division of Licensing

Enclosure: As stated This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

> October 29, 1980 Hollywood, Florida

# "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Supervising Structural Engineer United Engineers and Constructors Inc. & Ashok J. Desai, Structural Eugineer United Engineers and Constructors Inc.

Ape of # 8186110185

"BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allen J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desal<sup>2</sup>, M.ASCE

### INTRODUCT ION

This paper summarizes the results of an extensive program carried on for the Seabrook Nuclear Station to increase blast-vibration limits for freshly placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect to any effect on design requirements. These "new" vibration limits allow for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

### BACUGROUND

Due to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vooration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscashet, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiated.

### DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated concrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

<sup>1</sup>Supervising Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

Structural Engineer. United Engineers and Constructors Inc, Phila., PA.

## REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new higher vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table L. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless bas d on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrook construction operation.

In addition to industry and literature searches, organization such as the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete companies and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibrating green concrete required various degrees of extrapolation to obtain useful parameters. It ' as, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect masonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

# SEABROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would have on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: more regular patterns). Since it is generally recognized that the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire test program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	÷	92	-
Total	378	140	347	31

### FIELD TEST PROGRAM

Essentially the field test program was comprised of casting various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, ramely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

### Field Cylinder Test Program

This program consisted of casting standard 6x12 i.ch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 20 foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Pads were equipped with hold down bolts and apparatus to hole four concrete mold cylinders firmly i. place during the blast. Provisions were also made to bolt down a monitoring transducer on each pad and read remotely at a central station. (See Photograph No. 1).

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was detonated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad). The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-concrete age datum point (i.e.: cylinders subjected to the same blast vibrations) illustrates the fluctuating-oscillating changes in the concrete cylinder strengths for identically vibrated cylinders. The effect of differential curing time (7 days vs. 28 ays) is considered to be of little consequences sinc. no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which would offset any detrimental cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the variations actually lie in a elatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 98% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

### Field Beam Test Program

Reinforced beams measuring 4 x 8 inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bond failure it was necessary to minimize the embedded length to 4 inches so as not to fail the  $5 \times 8$  inch concrete section in shear. Embedment length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam speciment were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test pads (See photograph No. 3). Two beams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. One set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast vibrations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beams were tessed per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As loading was continued, the beam would ultimately fail by:

- Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond failure in the anchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediately by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering <u>unconfined</u> bond anchorage values and actual cylinder test values of the same age and material utilized in the beam.

A summary of the test values is given in Table 2.

No signs or features were visible in the vibrated or unvibrated samples tested that could be related in any way to a less than sound concrete product.

Field Wall Test Program

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each wall was made up of two - 2 feet (0.61 m) wide by 8 foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with #6 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the test zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph No. 6).

Four-hour and fourteen-hour green concrete ages were chosen as sufficient to represent the varying spectrum of concrete set time characteristics.

Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transcucer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

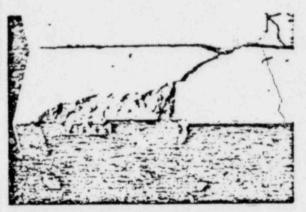
Twenty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27 ?10 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond failure load was determine. to be the load at which continued pumping initially did not result in an increase in load. At this point, verification of movement

SAMPLING	OF VIMATION	IMITS REPORTED	TO M SPECIFIED AT
1000	NUCLEAR PLAT	NT CONSTRUCT	ON SITES

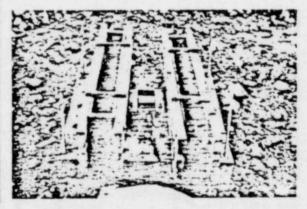
	NOMINAL AGE OF	GREEN CONCIE	TE AFTER MACEN	N1 IN HOU
PLANT	3-3	3-11	11-24	AFTER 24
	*1	AR PARTELE VEU	DEITY IN INCHES	sec
SEABBOOK (S)	007(6)	0.07 (0)	40	7.0
	0.07	0.07	40	70
	NOLIMIT	0.7	0 + 2 17 H#5 (#)	
OTHER	130	136	130	1 30 (0)
PLANT	26	20	20	20(*)
HITHNEL	(.)	1.	40	20
DATA	NOLIMIT	0.07	0 13	0 4 (N)
	0.10	0 10	0.5	10(1)



Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

(a) Limits specified		n of Groon Concrete Te	-
(b) Lover retrand to 1	Ca / we for for	n sour of piacoment	

(b) Lower choose to 10 m. Zwey, feer family-score of processing to 10 m. Zwey, feer family-score of processing to 10 m. Zwey, feer family-school (10 m. Zwey, feer 10 manual).
 (c) Maximum feers gar-anneal by constring operations (11 Lower increased to 30 m. Zwey, after 7 mark (21 magnetic to 30 m. Zwey, after 7 mark (21 magnetic to 30 m. Zwey, after 7 mark (21 magnetic to 30 m. Zwey, after 30 mark).
 (c) Lower exceeded to 20 m. Zwey, after 36 hours.

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1857 SERDES	CONC AGE AI BLAST	VELC	CITY IN	NT CLE	sec			SALETY ACTUAL	ND FALTOR FLALC	BEAM IENTATION
NC	HOURS		(1-12			AVER	STO	AVER	STO	2
19		1.95	4.18	3.62	16.42	1.45	013	2.52	0.22	1
	3		~			1.66	0.05	2.84	0.09	
		1 57	4.42	8.15	14.10	1	011	2 68	0 19	1
110	24	1.20				140	0.05	2.59	0.06	
		0.01	4 20		14 12	2.02	0.12	312	0.19	11
112	14					1.91	0 20	2.94	030	
	1956	1.10	1.54	\$76	16.37	1.42	010	2.68	0.18	-
103						145	0.07	275	013	
		2 64	5.0	+ 00	10.73	1.00	0.17	2 81	0.29	-
Tid			-			2.05	018	3.47	0.24	•
		2.08	4.81	10.27	10.60	1 50	0.09	2.54	0.16	=
115	•					1.27	0.13	216	0 22	
		2.00	2.31	* 50	9.10	130	0.11	240	0.19	ii
120				-		1 48	0.05	2 00	0.04	
	AVE	RAGE		-	ATED .	1.56		2.64		CHINA THE
	SAFETY	FACTOR	•	CON	-	1.62		2.77		132
		3 CON	-	CON				1		

# SUMMARY OF FIELD BEAM TEST VALUES

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitate jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was made between the ACI 318-77 <u>confined</u> anchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>con-</u><u>fined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws or deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

### LABOPATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker t-ble. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

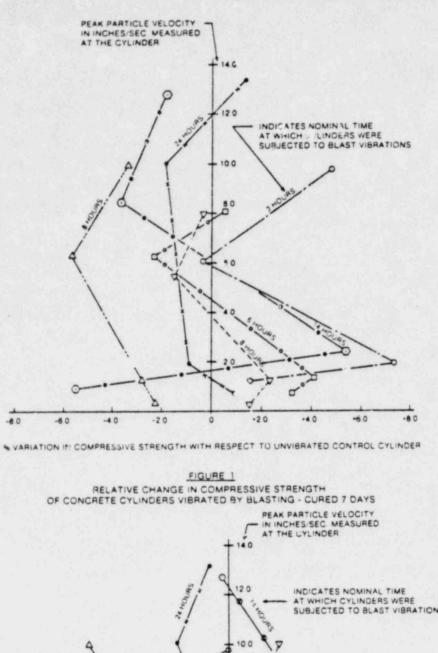
All testing work, except for load testing of the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

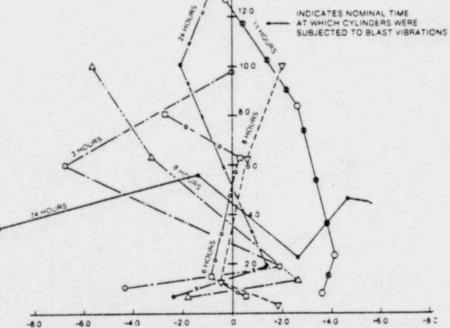
Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hour, was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

A C150 shaker manufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.





S VARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

FIGURE 2 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

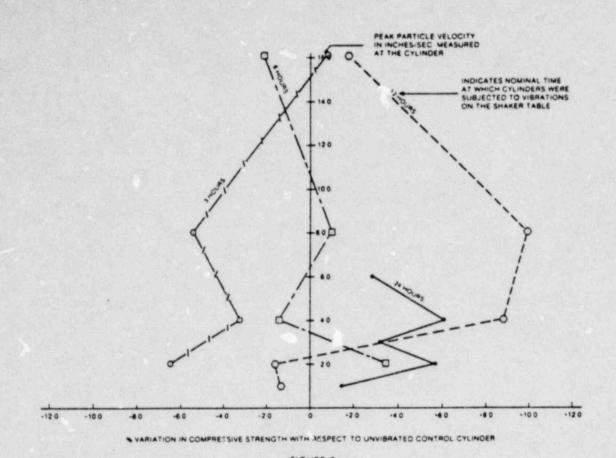


FIGURE 3 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ CURED 28 DAYS



\* 24 | 8

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C. 6

**6**)

Photograph 4 CYLINDER FIXTURE FOR VIBRATING GREEN CONCRETE MOLDS IN LABORATORY

Photograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER . ABLE

# LABORATORY TEST VELOCIATES AND FREQUENCIES (AJD ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	AK PARTICI	E ACCELERA	TION IN g	
50 hz	0.83	1.66	3.3	6.6	- `	13.2
100 hz	1.66	3.3	6.6	13.2		26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 25.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

### Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be established in the change of cylinder strength with respect to any of the vibration levels introduced for any of the green concrete ages tested.

#### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pull-out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting. Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, a whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 is to evaluate concrete strengths by comparate bond failures (not necessarily related to ACI 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. Sowever, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

### SUMMARY

- Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a less durable structure.
- 5. Results of the test were used to re-establish green concrete blast vibration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent strong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizontal lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

### CONCLUS IONS

- 1. The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- 2. If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

### ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

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COMPENDIUM - Relative Documents on the Effects of Vibration on Green Concrete

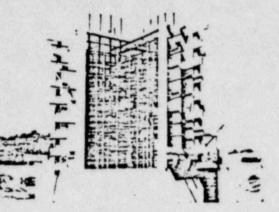
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Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING

TEST AT	CONC AGE AT BLAST	GE VELOCITY		PAL		LOUT SI		SAFETY FACTOR		NO	
*	Noves	BASE	MID	100		AVER LOAD	STD DEV TONS	AVER	STD Dev	(CK)	
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	14	1044	•#7	. 50		26.3	0.00	273	0 062	3804	•
24		2 48		7.64		20 1	0.79	2.55	0 077	4301	3
28	14	0.07		179	47	28.4	0 70	2 72	0 072	3851	
AL	-		•		4	26 18	0.59	2.55	0.057	4333	
	AVERA	-	AIED	ALLES		24 18		2.63			

\*...\*



Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

LABORATORY TEST PULL-OUT LOADS LABORATORY TEST PULL-OUT LOADS

			CONTROL		VIBRATED			
	CONC	NO	AVERAGE PULL-OUT LOAD POLNOS	STODEY	¥6	AVERACE AULI-OUT COAD FOLKES	STO DEV POUNDS	
	,	2	14,178	2053		17, 106	2013	
,	28	2	17.008	1413		18, 525	2482	
	,	2	12, 750	1225	10	12, 425	1430	
3 28	2	15 175	750	10	15.233	1330		
	,	2	12, 213	*75	17	12,979	1561	
	28	2	15,450	1075	12	15 160	2387	

1000 POUNDS + 453 & KILOGRAMS

IMALLA
LABORATORY TEST CYLINDER STRENGTHS
ESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

			CONTRO	ж		CETANELY				
CONC			AVERAGE STRENGTH PSI	STO DEV. PS1	NG	AVERAGE STRENGTH PSI	STO DEV			
	7	,	3340	53.5	32	3265	116.4			
21	28	3	4007	62.4	31	41 28	142.4			
1 -	,	1,	2740	49.7	10	2841	128.3			
	28	, ,	3747	41.9	10	3704	103.4			
1	,	1,	2957	270	41	7820	166 7			
3	28	1.	3543	138	42	3010	153.8			
	7	1,	2040	40	22	2720	155 +			
•	78	1,	1267	728.8	22	3405	181 7			

TABLES BASIC BLAST VIBLATION LIMITS FOR THE SEABROOK STATION PERMANENT STRUCTURES

CONCRETE AGE	0-3	3-11	11-24	24-48	44
GROUND VELOCITY LIMITATIONS (2) INCHES PER SEC.	•0	1.5	2.0	40	7.0

(1) CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VEUDITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES ME SECOND OR 0 5 INCHES ME SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELT

ONE INCH - 25 4 mm

NRC POR



### UNITED STATES NUCLEAR REGULATORY COMMISSION WASHINGTON, D. C. 20555

Docket Nos. 50-352/353

JUN 8 1981

Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464

Dear Ms. Zitzer:

ST NUCLAR RECRATORY COMMISSION

This will confirm your telephone conversation of June 5, 1981 with Don Calkins. The meeting with Mr. Frank Romano is scheduled for 1:00 P.M. on June 18, 1981, at 7920 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend.

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Ergineers and Construction, Inc.

incerely,

Schwalter

A. Schwencer, Chief Licensing Branch No. 2 Division of Licensing

Enclosure: As stated This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

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October 29, 1980 Hollywood, Florida

# "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Supervising Structural Engineer United Engineers and Constructors Inc. & Ashok J. Desai, Structural Engineer United Engineers and Constructors Inc. "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allen J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desai<sup>2</sup>, M.ASCE

## INTRODUCT ION

This paper summarizes the results of an extensive program carried e Seabrook Nuclear Station to increase blast-vibration limits

ily placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect to any effect on design requirements. These "new" vibration limits allow for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

### BACKGROUND

Lue to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vibration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscasset, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiated.

### DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated concrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

<sup>1</sup>Supervising Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

### REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new higher vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table L. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless based on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrock construction operation.

In addition to industry and literature searches, organization such as the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete companies and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibratir green concrete required various degrees of extrapolation to obtain useful parameters. It was, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect masonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

### SEALROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would have on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: more regular patterns). Since it is generally recognized that the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire test program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	÷	92	-
Total	378	140	347	31

#### FIELD TEST PROGRAM

Essentially the field test program was comprised of casting various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, namely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

# Field Cylinder Test Program

This program consisted of casting standard 6x12 inch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 2C foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Pads were equipped with hold down bolts and apparatus to hold four concrete mold cylinders firmly in place during the blast. Provisions were also made to bolt down a monitoring transducer on each pad and read remotely at a central station. (See Photograph No. 1).

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was detonated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad). The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-correcte a e datum point (i.e.: cylinders subjected to the same blast vibr. ions) illustrates the fluctuating-oscillating changes in the concrete c linder strengths for identically vibrated cylinders. The effect of differential curing time (7 days vs. 28 days) is considered to be of little consequences since no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which would offset any detrimental cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the variations actually lie in a relatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 98% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

### Field Beam Test Program

Reinforced beams measuring  $4 \times 8$  inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bond failure it was necessary to minimize the embedded length to 4 inches so as not to fail the  $4 \times 8$  inch concrete section in shear. Embedment length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam specimens were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test pads (See photograph No. 3). Two leams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. One set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast vibrations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beams were tested per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As .pading was continued, the beam would ultimately fail by:

4

- Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond failure in the anchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediately by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering unconfined bond anchorage values and actual cylinder test values of the same age and material utilized in the beam.

A summary of the test values is given in Table 2.

No signs or features were visible in the vibrated or unvibrated samples tested that could be  $r \epsilon$  ated in any way to a less than sound concrete product.

Field Wall Test Program

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each well was made up of two - 2 feet (0.61 m) wide by 8 foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with #6 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the tist zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph Nc. 6).

Four-hour and fourteen-hour green concrete ages were hosen as sufficient to represent the varying spectrum of concrete set time characteristics.

Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transducer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

Twenty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27,210 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond failure load was determined to be the load at which continued pumping inicially did not result in an increase in load. At this point, verification of movement

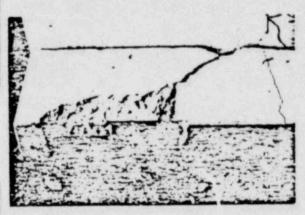


SAMPLING OF V PATION UNITS MEPOPTED TO BE SPECIFIED AT

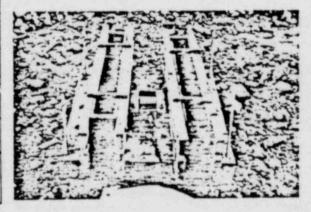
	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT . IN HOU					
PLANT	0-3	3-11	11-24	-		
	**	AS PARTICLE VEN		sec		
	0.07(%)	0.07 (4)	40	70		
	0.07	0.07	40	70		
	NOLIMIT	0 3	0.60 (d)	40		
OTHER	136	136	1.36	1 30 (0)		
RANT	20	20	30	20(*)		
IL! ITENCE	(.)	(.)	.0	70		
DATA	NOLMIT	0.07	0 13	0.4 (*)		
	0.10	0 10	0.5	1.0 (8)		



Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

25

(a) Lanets specified propr to V	Isbration of Green Concrete	ant Program
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(a) Luning specified gives to Vibertion of Green C. (b) Luning specified to 10 or /sace for first hear of an (c) Luning results (b) 14 or /sace for semporary shi (d) tenerosase lunit by (C) in / sace for end or re-(d) Maximum liner generated by easting agenetic (d) Lunin nervessed to 3.0 or / sace effort 7 days. (e) Responsed to 3.0 or / sace effort 7 days. (e) Responsed to 3.0 or / sace effort 7 days. (h) Lunin nervessed to 2.0 or / sace effort 7 days.

1851 SENES	CONE AGE AT BLAST	VELO		INCHES	sik			SAFETY ACTUAL	ACTOR	WEAM
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		1 95	4.18	3.82	18 42	1.45	0.13	2.52	0.22	-
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		1.37	4.42	.15	14.10	1.54	011	2.68	010	1
110	24			12		1.08	0.05	2.50	0.08	
		0+1	4 70		14 12	2.02	0.12	3.12	0.19	1
112	-				*	1.01	0 20	2.94	0.30	
			354	5.76	16.37	142	0.10	200	0.18	-
113	•	-	-		1.	145	0.07	275	01.	
		2.64	5.0	*	10 73	1 00	0.17	2 81	0.79	
754	14		× .			2.05	0.14	3.47	0.74	ŀ
		2.04		10 27	10.86	1.50	0.04	2.54	016	=
115	•				6. ¥.	1.27	013	210	0 22	
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	5	PACTO	•	CON	1101	1.82		2.77	. *	(CON)
		1 CON	-		DITAR			ES		. 94

# SUMMART OF HELD BEAM TOT VALUES

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitate jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was made between the ACI 318-77 <u>confined</u> unchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>confined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws or deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

### LABORATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker table. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

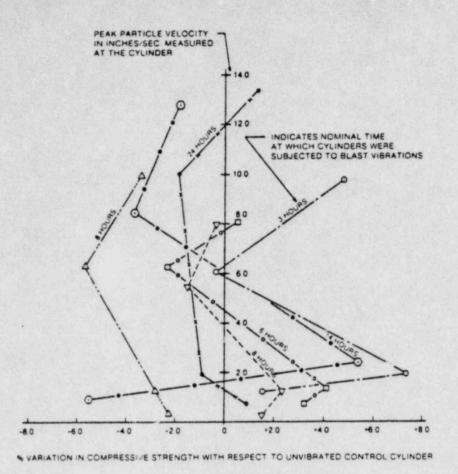
All testing work, except for load testing of the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

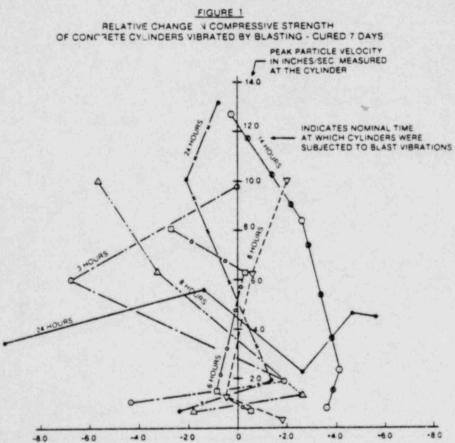
Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hours was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

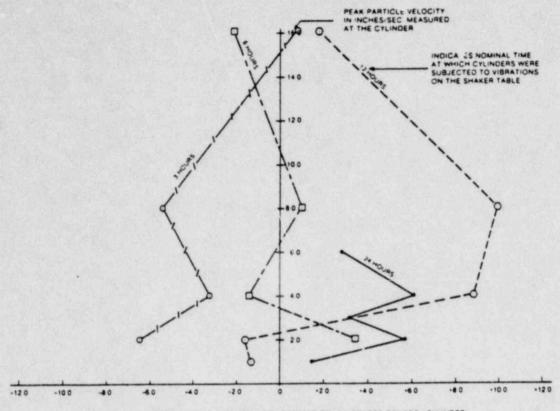
A C150 shaker menufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.





SVARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

EIGURE 2 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS



WARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

FIGURE 3 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ CURED 28 DAYS



Photograph 4 CYLINDER FIXTURE FOR VIBRATING GREEN CONCRETE MOLDS IN LABORATORY

Photograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER TABLE

# LABORATORY TEST VELOCITIES AND FREQUENCIES (AND ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	AK PARTICL	E ACCELER	ATION IN g	
50 hz	0.83	1.66	3.3	6.6	- '	13.2
100 hz	1.66	3.3	6.6	13.2	-	26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 5.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

### Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced  $pe^{z^*}$  particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be estab ished in the change of cylinder strength with respect to any of the vibra ion levels introduced for any of the green concrete ages tested.

### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pull-out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting. Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, a whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 is to evaluate concrete strengths by comparate bond failures (not necessarily related to ACI 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. However, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

### SUMMARY

- Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a less durable structure.
- 5. Results of the test were used to re-establish green concrete blast vibration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent strong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizonta! lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

### CONCLUS IONS

- The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- 2. If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

### ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

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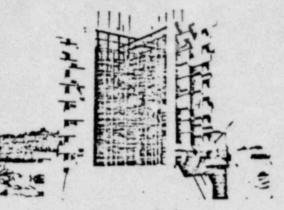
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Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING

TEST	CONC AGE AT BLAST	۷	IN CHES	NO LOAD	au	SAL	ND INCALC	AVER NO			
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34	ama	•		•	48	28.18	0.59	2.55	0.057	4333	
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	c	ONVER	SKOW P	ACTOR	ONE	TON	907 2	KILOGA	AMS		

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Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

TABLE & LABORATORY TEST AUL-OUT LOADS. IMESPECTIVE OF GREEN CONCRETE AGE OF VERATION LEVEL

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	,	1	12, 213	738	12	12.020	1561
	78	1	15,450	1075	12	15 160	2387

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KOO POUNDS + 453 & EROGRAMS

TABLED
BASIC BLAST VIBRATIO
THE SEABROOK STATION PER

			CONTRO	ж		VIBRATE	0	CONCRE
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•	28	1,	1267	228.8	122	3405	181.7	

#### LABLED BASIC BLAST VIBRATION UMITS FOR RE SEABBOOK STATION PERMANENT STRUCTURES

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GROUND VELOCITY LIMITATIONS (2) INCHES PER SEC	+0	1.5	2.0	4.0	7.0

(1) CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VEDICITY REQUIREMENTS.

(2) MEAK PURTICLE VELOCITY SMALL NOT EXCEED 2 INCHES ME SECOND OR 0.5 NCHES PER SECOND AT 1400 FEET OR 4050 FEET FROM THE BLAST LOCATION RESPECTIVELY

ONE INCH = 25 4 mm

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LOCAL POR.



### UNITED STATES NUCLEAR REGULATORY COMMISSION WASHINGTON, D. C. 20555

Docket Nos. 50-352/353

JUN B

1981

1981

S. NUCLEAR RECURATOR

Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464

Dear Ms. Zitzer:

This will confirm your telephone conversation of June 5, 1981 with Don Calkins. The meeting with Mr. Frank Romano is scheduled for 1:00 P.M. on June 18, 1981, at 7920 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend.

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Engineers and Construction, Inc.

Sincerely,

Shwaren

A. Schwencer, Chief Licensing Branch No. 2 Division of Licensing

Enclosure: As stated

This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

> October 29, 1980 Hollywood, Florida

# "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Supervising Structural Engineer United Engineers and Constructors Inc. & Ashok J. Desai, Structural Engineer

United Engineers and Constructors Inc.

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"BLASTING 'IBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allen J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desai<sup>2</sup>, M.ASCE

### INTRODUCT ION

This paper summarizes the results of an extensive program carried on for the Seabrook Nuclear Station to increase blast-vibration limits for freshly placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect "o any effect on design requirements. These "new" vibration limits allo for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

### BACKGROUND

Due to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vibration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscasset, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiated.

### DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated concrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

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Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

### REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new higher vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table L. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless based on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrook construction operation.

In addition to industry and literature searches, organization such as the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete compani 3 and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibrating green concrete required various degrees of extrapolation to obtain useful parameters. It was, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect misonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

### SEABROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would have on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: mor regular patterns). Since it is generally recognized that the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire tesc program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	÷	92	÷
Total	378	140	347	31

### FIELD LEST PROGRAM

Essentially the field test program was comprised of casting various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, namely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

# Field Cylinder Test Program

This program consisted of casting standard 6x12 inch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 20 foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Pads were equipped with hold down bolts and apparatus to hold four concrete mold cylinders firmly in place during the blast. Provisions were also made to bolt down a monitoring transduce: on each pid and read remotely at a central station. (See Photograph No. 1).

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was detonated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad). The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-concrete age datum point (i.e.: cylinders subjected to the same blast vibrations) illustrates the fluctuating-oscillating changes in the concrete cylinder strengths for identically vibrated cylinders. The effect of differential curing time (7 days vs. 28 days) i. considered to be of little consequences since no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which would offset any detrimental cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the ariations actually lie in a relatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 92% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

# Field Beam Test Program

Reinforced beams measuring 4 x 8 inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bend failure it was necessary to minimize the embedded length to 4 inches so as not to fail the 4 x 8 inch concrete section in shear. Embedment length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam specimens were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test pads (See photograph No. 3). Two beams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. Che set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast viltations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beams were tested per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As loading was continued, the beam would ultimately fail by:

- Bond failure of the 4 inch (102 mm) reber anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond follure in the anchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediately by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering <u>unconfined</u> bond anchorage values and actual cylinder test values of the same age and material utilized in the beam.

A summary of the test values is given in Table 2.

No signs or features were sible in the vibrated or unvibrated samples tested that could be related in any way to a less than sound concrete product.

# Field Wall Test Program

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each wall was made up of two - 2 feet (0.61 m) wide by & foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with 16 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the test zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph No. 6).

Four-hour and fourteen hour green concrete ages were chosen as sufficient to represent the ... in; spectrum of concrete set time characteristics.

Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transducer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

Twonty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27,210 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond fuilure load was determined to be the load at which continued pumping initially did not result in an increase in load. At this point, verification of movement

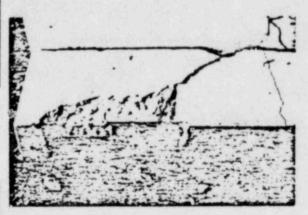


SAMPLING OF VIBRATION LIMITS REPORTED TO BE SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

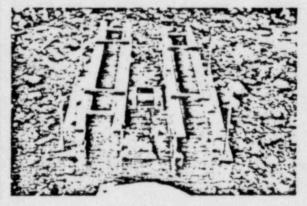
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Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

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112	14		1.5		-	1.93	0 20	2.94	0.30	•
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113					•	145	0.07	275	013	
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		2.08		10.27	10.80	1.50	0.09	2.54	016	-
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# SUMMARY OF PELO BEAM TEST VALUES

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitate jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was made tetween the ACI 318-77 <u>confined</u> anchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>confined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws or deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

### LABORATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker table. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

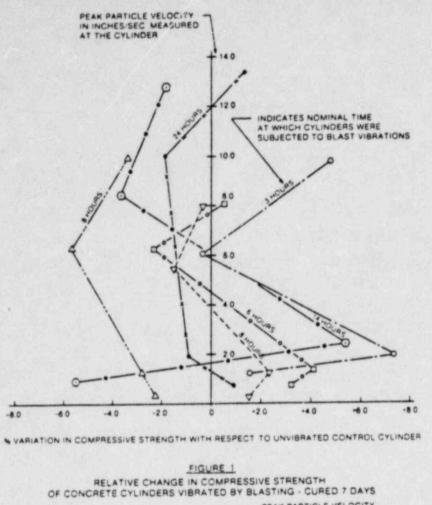
All testing work, except for load testing the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

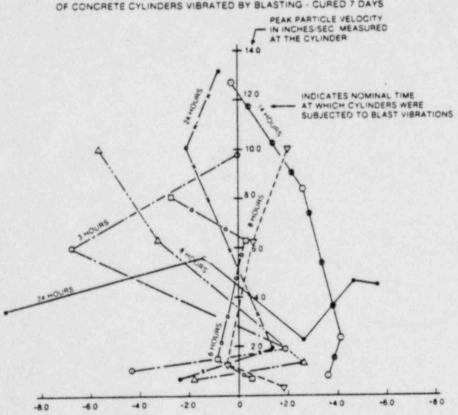
Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hours was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

A C150 shaker manufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.





SVARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

FIGURE 2 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

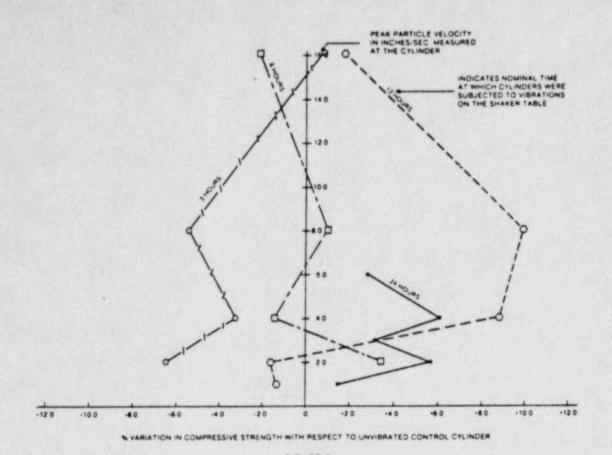
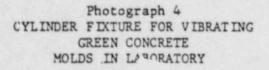


FIGURE 3 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ CURED 28 DAYS







Photograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER TABLE

# LABORATORY TEST VELOCITIES AND FREQUENCIES (AND ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	CAK PARTICI	LE ACCELER	ATION IN g	
50 hz	0.83	1.66	3.3	6.6	- 1	13.2
100 hz	1.66	3.3	6.6	13.2	-	26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 5.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

### Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be established in the change of cylinder strength with respect to any of the vibration levels introduced for any of the green concrete ages tested.

#### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pull out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting.

10

Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, a whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 's to evaluate concrete strengths by comparate bond failures (not necessarily related to ACI 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. However, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

## SUMMARY

- 1. Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a less durable structure.
- 5. Results of the test were used to re-establish green concrete blast vibration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent strong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizontal lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

### CONCLUS IONS

- 1. The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- 2. If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

### ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

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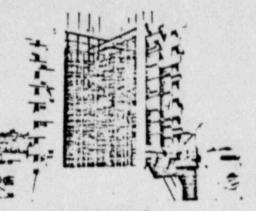
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Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING

EST NO	AGE		HAN MATCH VILOCITY IN INCHES/SEC		NO	ACTUAL PUAL OUT LOAD		SAVETY FACTOR			NO
	HOURS						-	STO	MI		
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24		2 48		7 60		26.1	0.74	2.55	0 077	4301	,
28	14	0.07		3.70	47	20.4	0 70	177	0 072	3851	
34	0-40					24.18	0.50	2.55	0.057	4333	•
	AVER	-	DITAS	ALLES		26.18		2.6.2			11

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a. 1.



Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

TABLE 4 LABORATORY 1531 MALOUT LOADS. BREAKCINE OF CREEN CONCRETE AGE OF VERATION LEVEL

			CONTROL	100	-	VIBANE	0
CONC BATCH	TEST DAT	NO	AVIENCE PULL-OUT (CAD POLHOS	STODEY	New York	AVERAGE NULL OUT IGAD NOLHOS	170 DEY
	,	1	14.178	2053		17,106	2013
3	28	1	17.048	1413		18, 525	2482
	7	1	12.750	1225	10	12, 025	1430
,	28	1	11.175	750	ю	15.233	1330
	7	1	12,213	738	12	17.654	1501
•	28	1	15.450	1075	12	15 100	2387

			14	ALE 1					
-	01	TOTA	TEST	CTLIN	DER	IN	NGTHS		
							VIBRATI	EVEL	

			CONTRO	х		VIBRATE	D
CONC.	TEST DAT	NO	AVERAGE STRENGTH PSI	STO DEV	NG	AVERAGE STRENGTH PSI	STO DEV
	,	3	3340	53.5	12	3285	118.4
1	20	>	6007	42.4	31	4128	141.4
1	,	1,	2740	40.7	10	2843	128.3
	28	1,	3747	41 *	10	3704	103 4
and the state of the	,	1,	2#57	270	41	2020	186.7
3	28	11	3543	118	42	3818	153 8
	,	1,	2000	49	22	27 20	155 *
•	28	1,	1247	724.8	111	3403	181.7

# TABLE & BASIC BLAST VIBATION LIMITS FOR THE SEABOOK STATION PERMANENT STRUCTURES

CONCRETE AGE	0-1	3-11	11-24	24-48	48
GROUND VELOCITY	40	1.3	2.0	40	70

(1) CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VELOCITY REQUIREMENT

(2) PEAK PARTICLE VELOCITY SHALL +C EXCEED 2 INCINES PER SECOND OR 0.5 INCINES PER SECOND AT 1. VO FEET OR 4000 FEET FROM THE BLAST LOCATION DESPECTIVELY

Docket Nos. 50- 2/353

JUN 8 1981

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DCalkins

MService

OI&E (3)

F. Schaner B. Jackson J. P. Knight BCCs:

NSIC

TERA

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ACRS (16)

Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464

Dear Ms. Zitzer:

This will confirm your telephone conversation of June 5, 1931 with Don Calkins. The meeting with Mr. Frank Romano is schedul of for 1:00 P.M. on June 18, 1981, at 7020 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend.

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Engineers and Construction, Inc.

Enclosure As stated	1: IST JUN L	Sincerely, Unginal signed by A. Schwencer, Chief Licensing Branch No. Division of Licensing	2	
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This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

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October 29, 1980 Hollywood, Florida

# "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Supervising Structural Engineer United Engineers and Constructors Inc.

> Ashok J. Desa., Structural Engineer United Engineers and Constructors Inc.

derpe of # 8176110185

"BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allen J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desai<sup>2</sup>, M.ASCE

### INTRODUCT ION

. . . .

This paper summarizes the results of an extensive program carried on for the Seabrook Nuclear Station to increase blast-vibration limits for freshly placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect to any effect on design requirements. These "new" vibration limits allow for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

## BACKGROUND

Due to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vibration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscasset, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiated.

### DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated concrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

<sup>1</sup>Supervising Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

<sup>2</sup>Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

# REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new higher vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table 1. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless based on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrook construction operation.

In addition to industry and literature searches, organization such is the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete companies and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibrating green concrete required various degrees of extrapolation to obtain useful parameters. It was, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect masonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

### SEABROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would have on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: more regular patterns). Since it is generally recognized that

2

the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire test program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	<u> </u>	92	-
Total	378	140	347	31

## FIELD TEST PROGRAM

Essentially the field test program was comprised of casting various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, namely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

Field Cylinder Test Program

This program consisted of casting standard 6x12 inch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 20 foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Pads were equipped with hold down bolts and apparatus to hold four concrete mold cylinders firmly in place during the blast. Provisions were also made to bolt down a monitoring transducer on each pad and read remotily at a central station. (See Photograph No. 1).

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was detonated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad).

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The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-concrete age datum point (i.e.: cylinders subjected to the same blast vibrations) illustrates the fluctuating-oscillating changes in the concrete cylinder strengths for identically vibrated cylinders. The effect of differential curing time (7 days vs. 28 days) is considered to be of little consequences since no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which would offset any detrimental. cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the variations actually lie in a relatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 98% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

# Field Beam Test Program

Reinforced beams measuring  $4 \times 8$  inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bond failure it was necessary to minimize the embedded length to 4 inches so as not to fail the  $4 \times 8$  inch concrete section in shear. Embedment length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam specimens were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test pads (See photograph No. 3). Two beams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. One set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast vibrations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beoms were tested per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As loading was continued, the beam would ultimately fail by:

- Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond failure in the anchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediately by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering <u>unconfined</u> bond anchorage values and actual cylinder test values of the same age and material utilized in the beam.

A summary of the test values is given in Table 2.

No signs or features were visible in the vibrated or unvibrated samples tested that could be related in any way to a less than sound concrete product.

Field Wall Test Program

+ + +

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each wall was made up of two - 2 feet (0.61 m) wide by 8 foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with #6 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the test zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph No. 6).

Four-hour and fourteen-hour green concrete ages were chosen as sufficient to represent the varying spectrum of concrete set time characteristics.

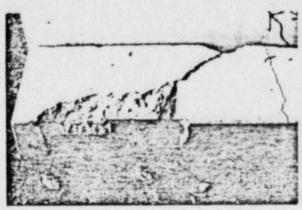
Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transducer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

Twenty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27,210 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond failure load was determined to be the load at which continued pumping initially did not result in an increase in load. At this point, verification of movement

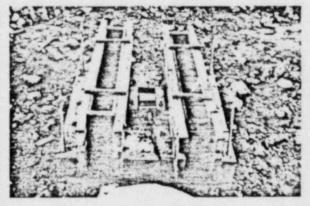


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Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

### TABLET

### SAMPLING OF VIBRATION LIMITS REPORTED TO BE SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

	NOMINAL AGE OF	GREEN CONCRE	TE AFTER PLACEME	NT, IN HOU
PLANT	0-3	3-11	11-24	A
	*1	AK PARTICLE VEU	DOITY IN INCHES	SEC.
SEABROOK (D)	007(6)	0.07 (*)	40	7.0
MAINE - TANKEE	0.07	1.07	40	70
OTHER	NOLIMIT	0 2	060 (d)	.0
UTHER	136	130	1 36	1 30 (*)
PLANT	20	20	20	20(*)
REFERENCE	(.)	(.)	40	7.0
DATA	NO LIMIT	0.07	013	0 . (h)
	0.10	0 10	0.5	10())

(a) Limits specified jarvar to Vibration of Green Concrete Test Program
(b) Limit raised to 1.0 in /sec. for Test hour of piecement.
(c) Limit raised to 0.14 in /sec. for Testporary structures.
(d) increase limit by 0.3 in sec. //r after 12 hours
(e) Assument feet powering by easing operating stent.
(f) Limit increased to 3.0 in /sec. after 2 days.
(g) Reported to be a modification of the "Weston Report values, not values available.
(h) Limit increased to 2.0 in /sec. after 36 hours.

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TEST SERIES	CONC AGE AT PLAST	VELC	-	ARTICLE INCHES	/sec	SAFETY ACTUA	AR ACTOR	SAFETY ACTUAL	HACTOR	BEAM DUTATION
~	HOURS			,		AVER	STD	AVER	STD	1 8
TO	,	1.95	4.18	5.82	16.42	1.45	0.13	2.52	0.72	11
14	,					1.66	0.05	2.86	0.09	
110		1.57	4.42	615	14.16	154	011	2.68	019	11
110	24			10	-	1.48	0.05	2.59	0.06	
		0.91	4.20	6.99	14.12	2.07	0.1.	3.12	01.	11
115	14		1.1			1.91	0 20	294	0.30	
		1.19	3.54	5.76	16.37	1.42	010	2.68	0.18	=
10				-	-	145	0.07	275	013	
		2.64	5.6	9.00	10.73	166	0.17	2.81	0.29	=
ты	14			-		2.05	0.14	3.47	0.24	•
		2.08		10.27	10.86	1.50	0.09	2.54	016	=
115			-			1 27	0 13	216	0 22	•
		3.00	3 31	. 50	9.19	1.36	0.11	2.40	G. 19	-
120			-			1 48	0.03	2 60	0.09	
	AVE	RAGE		VIB	NATED	1.50		2.68		· INCICATES
	SAFETY	FACTO		CON	TROL	1 62		2.77		12
		3 CON	TROL AP	4D . 11	GITAN	BE AMS P	ER SERIE	IS		

# TABLE 2 SUMMARY OF FIELD BEAM TEST VALUES

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitate jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was rade between the ACI 318-77 <u>confined</u> anchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>ccnfined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws ' deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

#### LABORATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker table. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

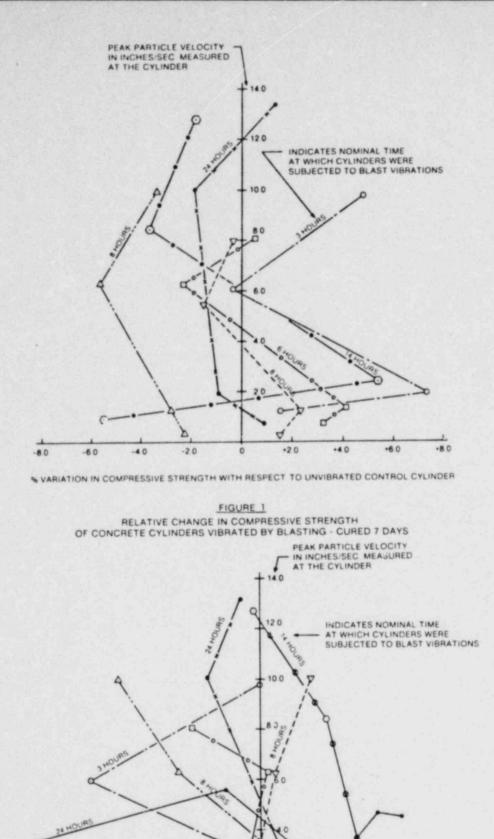
All testing work, except for load testing of the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hours was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

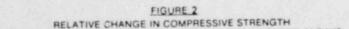
Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

A C150 shaker manufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.



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0

\* VARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

C

+40

.80

+60

Δ

+20

OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

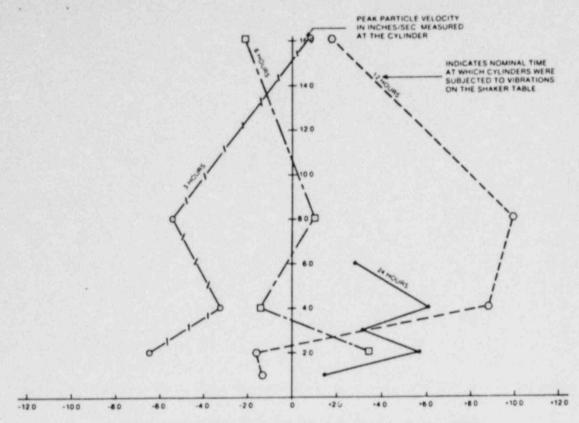
-20

-40

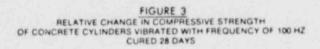
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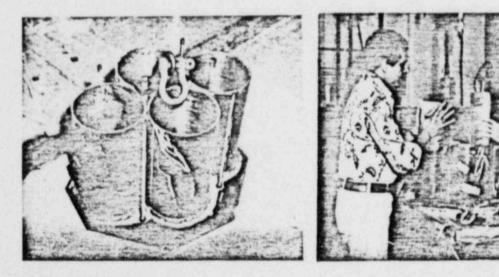
-8.0

-60



\* VARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER





Photograph 4 CYLINDER FIXTURE FOR VIBRATING GREEN CONCRETE MOLDS IN LABORATORY

1 × 1 × 1

Photograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER TABLE

## LABORATORY TEST VELOCITIES AND FREQUENCIES (AND ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	CAK PARTICI	E ACCELERA	TION IN g	
50 hz	0.83	1.66	3.3	6.6	1 - 1	13.2
100 hz	1.66	3.3	6.6	13.2	-	26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 25.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

#### Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be established in the change of cylinder strength with respect to any of the vibration levels introduced for any of the green concrete ages tested.

#### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pull-out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting. Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, a whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 is to evaluate concrete strengths by comparate bond failures (not necessarily related to ACI 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. However, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

## SUMMARY

- 1. Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a lass durable structure.
- 5. Results of the test were used to re-establish green concrete blast bration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent scrong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizontal lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

## CONCLUS IONS

- 1. The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- 2. If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

## ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

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COMPENDIUM - Relative Documents on the Effects of Vibration on Green Concrete

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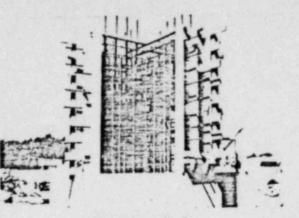
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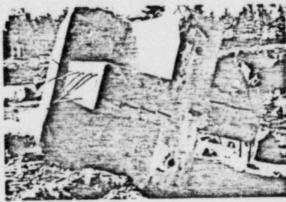
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TEST	CONC AGE AT BLAST	PEAK PARTICLE VELOCITY IN INCHES/SEC			NO	ACT PULL LO	OUT	SAI	ND HETY CROR L/CALC	AVER WALL 28 DAT	NO
~	HOURS	BASE	MID	100		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV	BI	
14		4.1	5 + 2	127	40	259	0+1	2 51	0.047	4353	
18	34	1049	*#7	<b>9</b> 59	40	26.3	0 60	273	0.062	3804	•
24		2 48		7.69		26.1	0.79	2.55	0 077	4301	3
28	14	0.07		3 79	47	76.4	0 70	272	0 072	3851	
34	COMICA.			•		26 18	0.59	2.55	0.057	4333	
	AVERA	GE VIS	RATED	ALUES	Channel and	26 18		2.63			



Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING



## Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

TABLE & LABORATORY TEST PAL-OUT LOADS IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

			CON! ROL		-	VIBRATE	0
CONC	TEST	NO. SPEC	AVERAGE PULL-OUT LOAD POUNOS	STO DEY	NO SPEC	AVERAGE PULL-OUT LOCD POUNDS	STO DEV POUNDS
	,	2	14,178	2053		17,106	2013
2	28	2	17.068	1413		18, 525	2482
	7	2	12,750	1225	10	12,925	1430
3	28	2	15,175	250	10	15,233	1330
	,	2	12, 213	738	12	13,929	1561
*	28	7	15,450	1075	12	15, 160	2387

	TR	NGTHS				
GE	0.	VIBRATION	LEVEL			
	-			 -	-	_

			CONTRO	н		VIBRATED			
CONC		NO	SVERAGE STRENGTH PS1	STO DEV PSI	NQ CYL	AVERAGE STRENGTH PSI	STD DEV		
	7	1,	3340	53.5	32	3265	116.4		
	28	3	4007	67.4	31	4128	141.4		
	,	1,	2740	49.7	10	2841	128.3		
2	28	1	3747	41.9	10	3706	103.4		
	,	1,	2957	270	41	2820	166 7		
3	28	13	3543	318	42	3616	153 8		
-	7	T,	2690	49	22	2720	155 9		
	78	1,	3267	228.8	22	3405	181.7		

TABLE S

#### TABLED BASIC BLAST VIBRATION LIMITS FOR THE SEABROOK STATION PERMANENT STRUCTURES

CONCRETE AGE IN HOURS (1)	0-3	3-11	11-24	24-48	OVER 48
GROUND VELOCITY LIMITATIONS [2] INCHES PER SEC	40	1.5	2.0	4.0	7.0

IT CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES MER SECOND OR D S INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY

> ONE INCH . 25 4 mm ONE FOOT = 0 305m



## UNITED STATES NUCLEAR REGULATORY COM MISSION WASHINGTON, D. C. 20555

Docket Nos. 50-352/353

JUN 8 1981

Ms. Phillis Zitzer Limerick Ecology Action P. O. Box 761 Pottstown, Pennsylvania 19464

Dear Ms. Zitzer:

This will confirm your telephone conversation of June 5, 1981 with Don Calkins. The meeting with Mr. Frank Pomano is scheduled for 1:00 P.M. on June 18, 1981, at 7920 Norfolk Avenue, Bethesda, Maryland. You are welcome to attend.

Enclosed is a document which was sent to Mr. Romano, relative to the meeting. It may not have reached the Local Public Document Room yet. It is a recent paper entitled, "Blasting Vibration Limits on Freshly Placed (Green) Concrete" by United Engineers and Construction, Inc.

Sincerely,

Schwalter

A. Schwencer, Chief Licensing Branch No. 2 Division of Licensing

Enclosure: As stated This Paper for Presentation at the ASCE 1980 ANNUAL CONVENTION AND EXPOSITION Session on Construction of Nuclear Facilities

. .

October 29, 1980 Hollywood, Florida

## "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By

Allen J. Hulshizer, Jupervising Structural Engineer United Engineers and Constructors Inc. & Ashok J. Desai, Structural Engineer United Engineers and Constructors Inc. "BLASTING VIBRATION LIMITS ON FRESHLY PLACED (GREEN) CONCRETE"

By Allen J. Hulshizer<sup>1</sup>, F.ASCE and Ashok J. Desai<sup>2</sup>, M.ASCE

## INTRODUCT ION

This paper summarizes the results of an extensive program carried on for the Seabrook Nuclear Station to increase blast-vibration limits for freshly placed concrete ("Green") without detrimental effect on its strength properties. In the absence of available data, a test program was carried out in both the laboratory and field to study a wide range of variables to insure the enveloping of various combinations of vibration characteristics and concrete ages.

Conclusions from the program have resulted in significantly raising previously utilized green concrete re-vibration limits while still providing conservative margins with respect to any effect on design requirements. These "new" vibration limits allow for more productive blasting work during concurrent concreting operations providing economies in both cost and schedule.

#### BACKGROUND

Due to long and various starting delays, it became necessary to reschedule excavation and concrete work concurrently in order to recover schedule losses. Blast vibration specification limits relating to green concrete, which did not hamper the previously time independent blasting and concreting efforts, became very restrictive and would have resulted in serious construction delays if necessarily maintained.

The original Seabrook specification blast vibration limits for green concrete was taken from work done for the Maine Yankee Atomic Power Plant, Wiscasset, Maine (1), herein after referred to as the "Weston Report." Apparently, these values have been used for other nuclear power plants in this country.

Examination of the Weston Report indicated that the parameters suitable to obtain vibration limits for the initial intended purposes did not establish conclusive limits and an apparent increase in these values could be substantiated.

## DEF IN IT IONS

Green concrete, as used within this paper, refers to concrete having an age within 24 hours after placement.

The term re-vibration or vibration of green concrete utilized within this paper refers to the vibrating of consolidated . oncrete during its early curing stage and <u>does not</u> refer to re-vibrating of fresh concrete to improve its properties.

Supervising Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

<sup>2</sup>Structural Engineer, United Engineers and Constructors Inc, Phila., PA.

## REVIEW OF HISTORICAL DATA

With the knowledge that green concrete vibration limits were not unique to the Seabrook work and that some margin was likely in the original Weston Report limits, a literature and industry practice search was undertaken to find quantitative data that would substantiate new higher vibration limits.

A survey was made of nuclear plants constructed on rock sites to ascertain what blast vibration limits were imposed to insure "safe" concrete work. A summary of the values as reported is given in Table L. Apart from vibration limits imposed to prevent tripping of on site operating nuclear plants, wide variations in specified peak particle velocities were found. The data used to establish the green concrete vibration limits was not available (unless based on the Weston Report) and in all cases the limiting values would have been restrictive to the Seabrook construction operation.

In addition to industry and literature searches, organization such as the American Concrete Institute, Portland Cement Association, Bureau of Reclaimation, blasting powder companies, cement and concrete companies and other sources even remotely related to the problem were contacted. An index of more salient related publications is provided in the Compendium.

Much of the experimental work and studies found were associated with consolidation during concrete placement and other information on re-vibrating green concrete required various degre of extrapolation to obtain useful parameters. It was, therefore, determined that testing work should be undertaken to obtain factual information specifically identified with raising green concrete re-vibration limits.

Of general note is that the normally cited blast damage criteria limits of 2 inches/sec. and lower appears to be established basically to protect masonry and plastered structures and to avoid public and legal struggles and does not directly relate itself to construction efforts removed from the public which involve engineered structures built of reinforced concrete. (See Compendium, Reference 1, Chapter 7, Paragraph 7-3, pgs. 7-5 to 7-10.)

## SEABROOK TEST PROGRAM

The Seabrook testing program was developed to evaluate what effect blast induced vibrations on green concrete would hav on structural properties of concrete with the goal of obtaining the critical damage limits. Concrete properties deemed most significant to structural performance and durability were that of compressive, shear and reinforcing bond strength. Since reinforced concrete is basically designed as a "cracked section", no effort was made to test or evaluate plain concrete flexural performance.

Because of the strong demand to have information related to actual conditions, one phase of the program was conducted in the field utilizing explosive blasting under controlled, monitored conditions. The other phase involved laboratory work which economically allowed for a more extensive and more controlled and monitored testing program but one which could be easily correlated with the field work and which could also be used to evaluate the effects of other than blast type vibrations (i.e.: more regular patterns). Since it is generally recognized that the first 24 hours of concrete set time will represent the most critical period, the program limited its study to concrete vibrated at various intervals within 24 hours after concrete placement.

The entire test program was carried out under fully implemented Quality Assurance procedures.

The following is a summary of the number of control and test samples utilized:

	Cylinder Compression Test	Shear & Bond Beam Test	Bond Pull Out Test	Cores
Field	120	140	255	31
Laboratory	258	÷	92	-
Total	378	140	347	31

#### FIELD TEST PROGRAM

Essentially the field test program was comprised of casing various types of concrete specimens and subjecting them, at specified concrete ages, to blast vibrations of differing magnitudes which were measured and recorded. Control (un-vibrated) specimens were cast from the same concrete batches. Field work was carried out in areas remote to heavy construction traffic and basically free from other blast induced vibrations so that the test vibrations introduced and monitored represent clean data free from background distortions. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

The field test program was divided into three areas, namely:

- 1. Cylinder Test
- 2. Beam Test
- 3. Wall Test

#### Field Cylinder Test Program

This program consisted of casting itendard 6x12 inch cylinders, subjecting them to blast vibrations (except for controls), curing the cylinders in accordance with ASTM C31 and then performing the standard ASTM C39 compressive load test. Reinforced concrete test pads were constructed on 20 foot (6.1 m) centers. Pads were founded on and anchored to rock by means of resin type rock anchors. Pads were equipped with hold down bolts and apparatus to hold four concrete mold cylinders firmly in place during the blast. Provisions were also made to bolt down a monitoring transducer on each pad and read remotely at a central station. (See Photograph No. 1).

A set of four cylinders were cast and rigidly fixed to the test pad. At the appropriate time the blast was detonated and the vibrations recorded for each of the four pads. The cylinders were then protected and cured in place for 24 hours after which they were removed (along with the remotely cast control cylinders), cured in the testing laboratory and compressive load tested after the 7 and 28 day curing time (two 7 day and two 28 day tests from each pad). The effect of blast vibrations on the cylinders was evaluated by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increase or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity. Comparative plots of 7 and 28 day cylinder compressive tests are shown in Figures 1 and 2 respectively.

As can be noted from the normalized test results plotted on Figures 1 and 2, no specific trend in the change of cylinder compressive strengths can be established since the relative variation in compressive strength increases and/or decreases randomly for any given age or curing or magnitude of induced vibration. A further comparison of corresponding 7 and 28 day relative compressive test for a specific vibration level-concrete age datum point (i.e.: cylinders subjected to the same blast vibrations) illustrates the fluctuating-oscillating changes in the concrete cylinder strengths for identically vibraced cylinders. The effect of differential curing time (7 days vs. 28 days) is considered to be of little consequences since no specific or general change in test values can be associated with the observed test results. (i.e.: Longer cure time did not apparently produce greater strength cylinders due to autogeneous healing which world offset any detrimental cracking effects produced by the induced vibrations. See Reference 3).

With respect to the magnitude of the increase or decrease in cylinder strengths it must be noted that the variations actually lie in a relatively tight band where 96% of the relative test values fall within a plus or minus 6% variation and 98% fall within a plus or minus 7% variation. This range of variation is considered to be within an acceptable level of variation that occurs in cylinder testing.

## Field Beam Test Program

Reinforced beams measuring  $4 \times 8$  inches and three feet (0.91 m)long were selected in order to utilize a standard cylinder testing machine and flexural beam testing apparatus. A typical beam was designed and reinforced with one No. 6 bar. To precipitate a reinforcing bond failure it was necessary to minimize the embedded length to 4 inches so as not to fail the  $4 \times 8$  inch concrete section in shear. Embedment length was controlled by installing plastic sleeves over the center portion of the reinforcing. (Photograph No. 2)

The beam specimens were cast, vibrated and cured in similar fashion to that of the cylinders utilizing the same test pads (See photograph No. 3). Two beams were cast on each pad. Two test sets of two beams each were made for each concrete age-vibration level datum point to be evaluated. One set was arranged so that the beams'long axes were aligned parallel to the direction to which the blast vibrations were originating and the other arranged with the beams'long axes perpendicular to the originating vibration direction. This approach was taken to be sure that there was no variation in results occurring from phenomenon relating to the difference between the blast wave propagation transverse to or along the axis of the beam. All beams were load tested 7 days after casting. Standard compressive cylinders were made to determine cylinder strength for analytical purposes.

Beams were tested per ASTM C293, center point loading. Due to the plastic sleeve the loading produced an early flexural crack in the beam center which did not effect its ultimate load capacity. As loading was continued, the beam would ultimately fail by:

- Bond failure of the 4 inch (102 mm) rebar anchorage thout splitting or shearing of the beam and sometimes followed by a shear failure.
- Bond failure in the anchorage zone resulting in splitting off concrete adjacent to the anchorage, usually followed immediate= ly by a shear failure of the beam. (Photograph 2)

The "Ultimate" load was recorded as the peak load capacity of the member (which occurred just prior to failure).

Since the mode of failure and the corresponding failure load varied, it was not possible to make a direct comparison between vibrated and unvibrated (control) beams as was done with the blast vibrated cylinders. An alternate means of evaluation was derived by calculating the safety factor between the "ultimate design capacity" and that of the "actual ultimate test capacity". The ultimate beam design capacity was determined from ACI 318-77 provisions considering <u>unconfined</u> bond anchorage values and actual cylinder test values of the same age and material utilized in the beam.

A summary of the test values is given in Table 2.

No signs or features were visible in the vibrated or unvibrated samples tested that could be related in any way to a less than sound concrete product.

Field Wall Test Program

The final stage in the field testing program was to "simulate a typical" concrete section and subject it to blasting and study the effects.

Five walls were constructed, four test walls were subjected to blasting and one control kept free of vibrations. Each wall was made up of two - 2 feet (0.61 m) wide by 8 foot high by 8 foot (2.44 m) long walls arranged as a cruciform to introduce longitudinal and transverse blast wave effects. Walls were typically reinforced throughout with #6 rebars at 12 inches (305 mm) on centers, each way.

Bond test dowels, #8 rebars, were placed into the walls at varying locations and depths. Plastic sleeves were used over the bars to control the test zone location and provide a 10 inch (254 mm) embedment length for pull testing of bond values (See photograph No. 6).

Four-hour and fourteen-hour green concrete ages were chosen as sufficient to represent the varying spectrum of concrete set time characteristics.

Each of the walls to be vibrated were instrumented at the foundation level and on the top of the wall at the intersection. The two closest walls to the blast also had a transducer located at the mid-height intersection. The higher transducers provided information relative to amplifications through the wall system.

Twenty eight days after casting the walls, pulling of the #8 test dowels commenced, utilizing a 30 ton (27,210 kg) hollow ram jack. Each bar was loaded until it began to pull out. The bond failure load was determined to be the load at which continued pumping initially did not result in an increase in load. At this point, verification of movement



SAMPLING OF VIBRATION LIMITS REPORTED TO BE SPECIFICD AT NUCLEAR PLANT CONSTRUCTION SITES

	NOMINAL AGE O	GREENCONCH		INT IN HOU					
PLANT	0-3	3-11	11-74	AF128 24					
	PEAR PARTICLE VELOCITY IN INCHES.SEC								
	007(6)	0.07 (4)	+0	20					
	9.07	0.07	40	70					
	NO LINET	0 2	12 1925 (4)	40					
O. MEN	136	136	1.36	1 36 (4)					
MANT	20	10	10	10 (*)					
-	(.)	(.)	.0	70					
DATA	NO LIMIT	0.07	013	0.4 (M)					
	0 10	0 10	0.5	1.0 (M)					

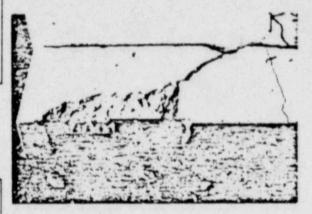


(a) Londs pascified prior to Vibration of Green Care (b) Lond randot to 10 m / sec. For first hear of peer (c) Lond researce (b) 14 m/sec. For first hear of peer (d) represent lond by 0.3 m/sec. For other 12 hears (d) represent lond by 0.3 m/sec. other 7 hears (d) permanent lond peer ned by exciting apertition (f) Lond more peer of the sec. other 7 hears (g) Resource to be a modulication of the "Western for restors eventsbin (h) Lond more peered to 2.0 m /sec. other 38 hears

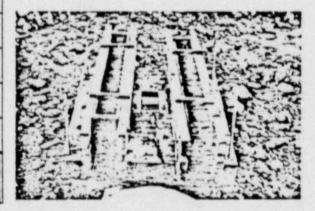
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Photograph 1 FIELD CYLINDER TEST PAD



Photograph 2 FIELD BEAM SPECIMEN AFTER LOAD TEST



Photograph 3 FIELD BEAM TEST PAD

1651	CONC AGE AT BLAST	VELC	-	-	/sec	SAPETY	MACTOR L/CALC	SAFETY	ND MACTOR /CALC	BEAM ENTATION
NO	HOURS		11.11	3.6000		AVER	STO	AVER	570 Dev	8
	,	1 95	4.18	5.82	16.42	1.45	0.13	2.52	0.27	-
				×		1 00	005	2.80	0.04	•
710	24	1.57	+ 42	#15	14.10	1 34	011	2.84	0 19	1
		1				148	0.05	2.59	2.04	
		0*1	A 20		14.12	3.07	0.12	3.12	0.19	11
112	14					1.01	0.10	2.44	0.30	
113		1.19	3.54	1.76	18.37	142	010	2.08	0.18	-
			1.4			143	0.07	2.79	013	
	1.50	2.64	5.0		10 73	1.00	017	2 81	0.79	-
714	u				-	2.03	0.14	3.47	0.24	•
		2.08		10.27	10.86	1 50	0.04	2.54	0.16	-
115						1 27	0 13	216	0 22	
		1.00	1.31	. 50		130	0.11	240	0.19	1
130						1.40	0.05	7 80	0.04	
	AVE	LAGE		-	CH LAN	1.36		7.88		SIL
	SAPETY	PACTO		CON	-	1.62		2 77	1.	PACACATES
		1 CON	-		OSTAN			5		

# SUMMARY OF HELD BEAM TEST VALUES

was made by measuring the "new" length of the extended bar. Essentially, the 10 inch embedment of the #8 bar was sufficient to develop a stress level in the average bar of 66,667 ksi (459.3 M Pa). In a few cases, the bars broke at a small notch put in the bar to facilitate jacking prior to breaking the bond.

Results of the pull-out values were very close and no significant difference can be observed between the vibrated and unvibrated values. A comparison was made between the ACI 318-77 <u>confined</u> anchorage values (for "other" bars) and the "actual" bond failure loads. A summary of these and other values are given in Table 3. Note, that the average unconfined bond safety factor from the beam test (Table 2) and the <u>confined</u> bond safety factor from the wall test are reasonably close, confirming a considerable margin of safety for bond values without any consideration for "top bar" allowances.

After completing the bond test, 4 inch (101.6 mm) dia. cores were taken from each of the walls. Visual examination indicated no signs of flaws or deterioration. Cores were load tested and gave results compatible with what would be expected from the load testing of cores.

Finally, one of the walls was blasted loose from the rock and pushed out of the way by bulldozing (See photograph No. 7). Examination of this wall externally and within the core holes did not reveal any blast induced cracking which would have been exaggerated by the extreme handling.

## LABORATORY TEST PROGRAM

Essentially, the laboratory phase of the testing program was comprised of casting cylinders and bond pull-out specimens and subjecting them, at specified concrete ages, to various fixed frequencies and velocities by means of a shaker table. All specimens were well monitored and vibration characteristics respectively recorded. Control (un-vibrated) specimens were cast from the same concrete batches. After the appropriate 7 or 28 day period had elapsed, the vibrated and control specimens were load tested and results evaluated.

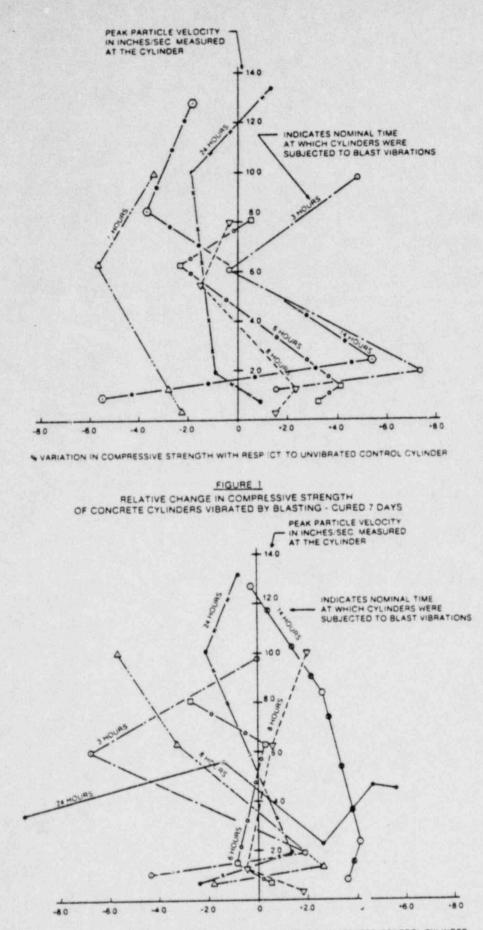
All testing work, except for load testing of the specimens, was carried out by The Franklin Institute Research Laboratories, utilizing the General Electric Company Space Center facilities at Valley Forge, Pennsylvania.

Nominal curing time from specimen casting to vibration of 3, 6, 12 and 24 hours was used.

The velocities and frequencies (and associated accelerations) given in the following Table were utilized. Test frequencies were chosen from the predominate frequencies associated with maximum velocities observed from the site blast monitoring records. (Table on next page.)

Vibrations were induced such that the profile of vibration had a rise and fall time of  $0.5 \pm 0.3$  seconds and remained at the peak level for  $5.0 \pm 0.5$  seconds. The specimens were subjected to excitation in one horizontal axis through the base. Vibration profiles were recorded for each of the three perpendicular axes.

A C150 shaker manufactured by M.B. Electronics, a Division of Textron Electronics, Inc., was used to energize the shaker table.



& VARIATION IN COMPRESSIVE STRENGTH WITH RESPECT TO UNVIBRATED CONTROL CYLINDER

FIGURE 2 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

68

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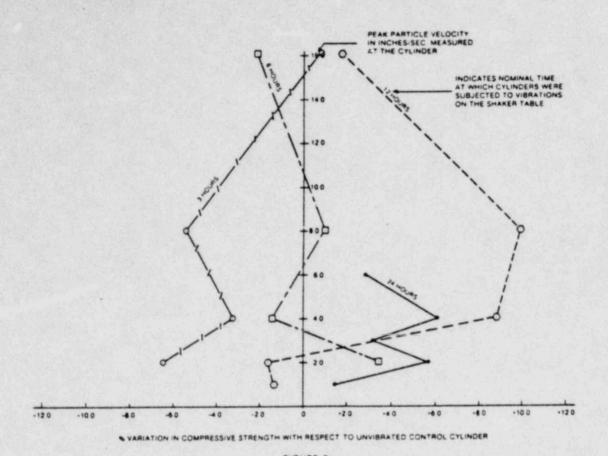


FIGURE 3 RELATIVE CHANGE IN COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ CURED 28 DAYS





Photograph 4 CYLINDER FIXTURE FOR VIBRATING GREEN CONCRETE MOLDS .IN LABORATORY

Photograph 5 INSERTING "GREEN" CONCRETE MOLDS INTO CYLINDER FIXTURE ON SHAKER TABLE

## LABORATORY TEST VELOCITIES AND FREQUENCIES (AND ASSOCIATED ACCELERATIONS)

FREQUENCY		MAX IMUM PE	AK PARTICI	LE ACCELERA	TION IN g	
50 hz	0.83	1.66	3.3	6.6	- `	13.2
100 hz	1.66	3.3	6.6	13.2	-	26.4
150 hz	2.5	5.0	10.0	20.0	30.0	-
PEAK PARTICLE VELOCITY INCHES/SEC.	1	2	4	8	12 One Inch=2	16 5.4 mm

The energy input into the laboratory vibrated specimens is considered to be comparatively more severe due to the longer period the specimen is subjected to the induced vibration.

#### Laboratory Cylinder Test Program

This program consisted of casting standard 6 X 12 inch (152.4 X 304.8 mm) cylinders and subjecting a group of 4 cylinders at a time to the selected vibrations by means of a rigid steel fixture fastened to the shaker table. (See photograph Nos. 4 and 5.) Cylinders were cast, cured and compressive load tested in accordance with ASTM C31 and C39. Control cylinders (unvibrated) were cast from respective concrete batches.

After the appropriate 7 or 28 day curing time, 2 cylinders from each group were load tested along with control specimens. The effect of vibration was evaluated in the same manner as the Field Program cylinders by normalizing the change in vibrated cylinder strengths by representing them as a percentage of increas, or decrease in strength from that of the control cylinders and plotting the variation with respect to the experienced peak particle velocity.

A representative plot is shown in Figure 3 and a table of test values, irrespective of vibration levels or green concrete age is given in Table 5.

Results of the laboratory cylinder test program were essentially the same as the field cylinder program. Specifically, no specific trend can be established in the change of cylinder strength with respect to any of the vibration levels introduced for any of the green concrete ages tested.

#### Laboratory Pull-Out Test Program

This program consisted of casting, curing and testing pull-out samples in accordance with ASTM C234. Pull-out specimens were 6 inch (152.4 mm) cubes with a 3 foot (0.91 m) long, #6 reinforcing bar extending to the specimen bottom. Specimens were cast in specially made molds, structurally strong enough to permit direct attachment to the shaker table. Specimens were subjected to the same basic age-vibration levels as that of the cylinders and tested 7 and 28 days after casting. Due to the nominal 30 inch (762 mm) extension of the #6 reinforcing bar, a whipping action was introduced during the shaking operation even though the top of the bar was relatively secured to the casting mold. This behavior created an added severity to the reinforcing bar bonding capability.

Although the ASTM C234 is to evaluate concrete strengths by comparate bond failures (not necessarily related to ACT 318 design values), the test did confirm information relative to the effect of the induced vibration on bonding characteristics.

Basically, all pull-out specimens failed by splitting of the concrete block prior to achieving a bond failure. However, the load developed by the 6 inch (152.4 mm) embedment of the #6 reinforcing bar was, again, significantly above the ultimate anchorage load calculated from ACI 318-77 for unconfined bars.

Values, irrespective of the green age or vibration level, are given in Table 4.

Essentially no reduction in concrete strength or bond capacity can be recognized as a result of the vibrations introduced to the various green concrete ages.

## SUMMARY

- Due to space limitations, detailed discussions of test and evaluation work and data, presentation has been greatly shortened. Data has been summarized in an attempt to provide sufficient overall information to establish the validity of the work.
- Test work was done for the most part with readily available resources, and there was no attempt to pursue a full scale research program outside the realms of establishing increased vibration levels for green concrete.
- Although the test program was aimed at finding a "critical" vibration intensity for green concrete, no vibration level was ever reached that could be associated with ultimate damage to the concrete tested.
- 4. Although many specimens of various types were subjected to input velocities up to and in the range of 8 to 12 inches per second and some subjected to velocities as high as 20 inches per second (1" = 25.4 mm), there has been no evidence to indicate that the revibrated green concrete tested would not structurally perform in accordance with its standard 28 day strength design values or would otherwise produce a less durable structure.
- 5. Results of the test were used to re-establish green concrete blast vibration limits as given in Table 6. The values listed are still conservative with respect to the test program results and even with respect to some of the "original Table 1" values. Provision for an increase in blast vibration levels above the Table 6 values was treated on a case-by-case basis, but essentially the Table 6 values allowed reasonable excavation efforts without schedule difficulties.
- Bond test results indicate an apparent strong conservatism in the ACI-318-77 anchorage provisions. This conservatism should be looked

at with respect to eliminating the 1.4 factor for horizontal wall laps which are currently identified as "top bars." This reduction in horizontal lap length would serve to reduce added congestion in heavily reinforced walls apart from any savings in reduced steel requirements.

## CONCLUS IONS

- The Seabrook Green Concrete Blast Vibration Limit Program has provided valuable data which conclusively supported increasing previous blasting vibration limits. Based on the observations of the Seabrook work, there is strong confidence to indicate that even higher vibration limits can be established if additional test work is performed.
- If no environmental, public structures, human tolerance or other safety considerations are involved, considerable margin still appears to exist in raising blasting vibration limits relative to the concurrent placement of concrete.

#### ACKNOWLEDGEMENTS

The Seabrook Station Power Plant is jointly owned by a number of utilities. Public Service Company of New Hampshire is the major shareholder and agent for the Owners. Yankee Atomic Electric Company is the Engineering Supervisor for the Owners.

United Engineers & Constructors Inc., is the Architect-Engineer and Construction Manager for the total facility.

Field work was carried on under the supervision and direction of United Engineers and Constructors Inc. Field Engineering Department by various on-site contractors.

Stephen A. Alsup served as blast monitoring consultant and advisory to vibration testing phases. (4)

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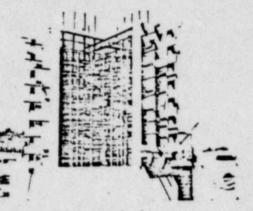
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Photograph 6 FIELD TEST WALL SHOWING REBARS EXTENDED FOR PULL-OUT TESTING

1651 Delation	CONE AGE AI MAST	۲	IN CHES / I			-	aut	SAI	NO HIY COR L/CALC		NO
~	-Curs		-	ret		AVER LOAD TONS	STD DEV TONS	AVER	STD Dev	e si	
1.4		•.1	3.*2	127		25.0	0+1	2 51	0.087	4353	
	14	1049	•#7	* 5*		26.3	0.00	273	6 0e2	3804	•
24		2 48		7.04		20.1	0.70	2.55	0 077	4301	J
28	14	0.07		370	47	26.4	0 70	2 72	0 072	3851	
AL	-					20 18	0.39	2.55	0.057	4333	
	AVERA	GE VIE	ATED	ALLES		26 18		2.63			

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Photograph 7 FIELD TEST WALL AFTER BEING BLASTED FROM FOUNDATION

TABLE & LABORATORY TEST PALLOUT LOADS WESPECTIVE OF GREEN CONCETTE AGE OF VERATION LEVEL

	1 day		CONTROL		-	VIBRATE	0
CONC	TEST	NO SPEC	AVELAGE PULL-OUT LOAD POUNDS	HONEY	NO.	AVERAGE PULL-OUT ICAD POLNOS	STO DEV
	,	1	14,178	2053		17,106	2013
1	78	2	17.068	1413		18, 525	2482
	,	2	12, 750	1225	10	12, #25	1450
3		2	15.175	250	ю	15,233	1330
	)	1	12, 213	738	12	13,929	1541
	28	1	15,450	1075	12	15 160	2347

			10	<b>a</b> (1.)				
LA	ORAT	OFT T	EST .	CILIN	DER	TRE	NGTHS	
RESPECTIVE								LEVEL

			CONTRO	ж	USRATED			
CONC.	TEST DAT	NO	AVERAGE STRENGTH PSI	STO DEV PSI	NQ. CTL	AVERAGE STRENGTH PSI	STO OF	
1	,	,	3340	53.5	32	3265	118.4	
	78	1,	4007		31	4128	142 4	
2 -	,	1,	2740	49.7	10	28.41	128.3	
	28	1,	3747	41.9	10	3704	103 4	
	,	1,	2957	270	1.	2020	166.7	
,	78	11	3543	118	42	3010	153 8	
		1,	2040	49	122	2720	155.0	
	78	1,	3267	224.8	122	3405	181.7	

#### TABLES BASIC BLAST VIBRATION LIMITS FOR THE SEABROOK STATION PERMANENT STRUCTURES

CONCRETE AGE	0-3	3-11	11-24	24-48	48
GROUND VELOCITY LIMITATIONS (2) INCHES PER SEC.	+0	1.5	2.0	40	7.0

(1) CONCRETE AGE SHALL BE CONSIDERED AS AGE OF ANY CONCRETE IN RESPECTIVE PLACEMENT GOVERNING THE MORE STRINGENT GROUND VELOCITY REQUIREMENTS.

(2) MAX PARTICLE VELOCITI SHALL NOT EXCEED 2 INCHES ME SECOND OR 0.5 INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELT