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Docket Nos. 50-352/353

JUN 8 1981

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U.S. NUCLEAR REGULATORY COMMISSION

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,

A. Schwencer

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

Enclosure:
As stated

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PDR ADOCK 05000352
A PDR

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

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United Engineers and Constructors Inc.
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United Engineers and Constructors Inc.

Encl. of
8106110185

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

By Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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.

DEFINITIONS

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 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 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	-	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 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) 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 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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

TABLE 1

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

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK [a]	0.07 [b]	0.07 [c]	4.0	7.0
MAINE-YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.2	0.6 @ 12 HRS [d]	4.0
	1.36	1.36	1.36	1.36 [e]
	2.0	2.0	2.0	2.0 [f]
	[g]	[g]	4.0	7.0
	NO LIMIT	0.07	0.13	0.4 [h]
	0.10	0.10	0.5	1.0 [h]

(a) Limits specified prior to Vibration of Green Concrete Test Program.
(b) Limit raised to 1.0 in./sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) Increase limit by 0.3 in/sec./hr after 12 hours.
(e) Maximum limit governed by existing operating plant.
(f) Limit increased to 3.0 in/sec after 7 days.
(g) "Reported to be a modification of the "Weston Report" values, no specific values available.
(h) Limit increased to 2.0 in./sec. after 36 hours.

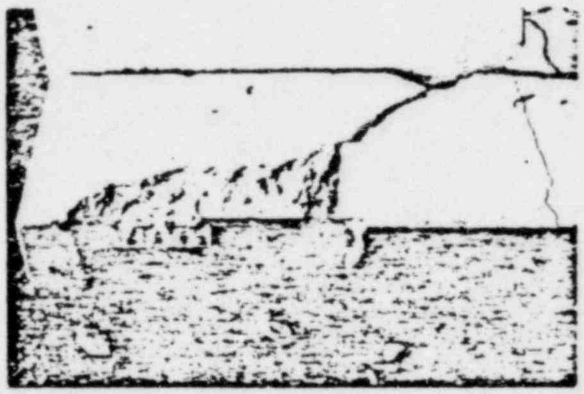
ONE INCH = 25.4 mm

TABLE 2

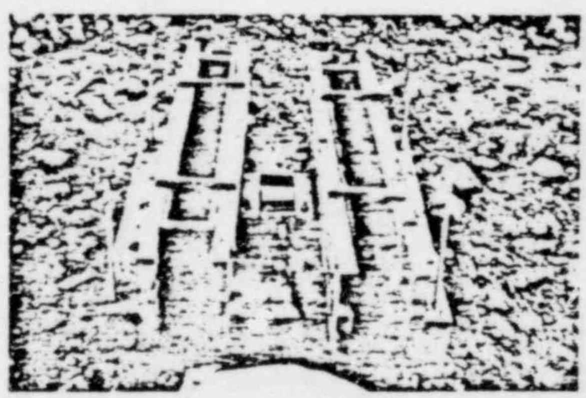
SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR SAFETY FACTOR ACTUAL/CALC STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND SAFETY FACTOR ACTUAL/CALC STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	5.82	16.42	1.45	0.13	2.52	0.22	||
		-	-	-	-	1.66	0.05	2.88	0.09	•
T10	24	1.57	[illegible].42	6.15	14.16	1.54	0.11	2.68	0.19	||
		-	-	-	-	1.48	0.05	2.59	0.08	•
T12	18	0.91	4.20	6.99	14.12	2.02	0.12	3.12	0.19	||
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	1.19	3.54	5.76	16.37	1.42	0.10	2.68	0.18	=
		-	-	-	-	1.45	0.07	2.75	0.13	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	=
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	7.54	0.16	=
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.31	8.50	9.19	1.36	0.11	2.40	0.19	||
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR		VIBRATED				1.56	-	2.68	-	• INDICATES BLAST LOCATION
		CONTROL				1.62	-	2.77	-	
3 CONTROL AND 8 VIBRATED BEAMS PER SERIES										

Photograph 1
FIELD CYLINDER TEST PAD



Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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.

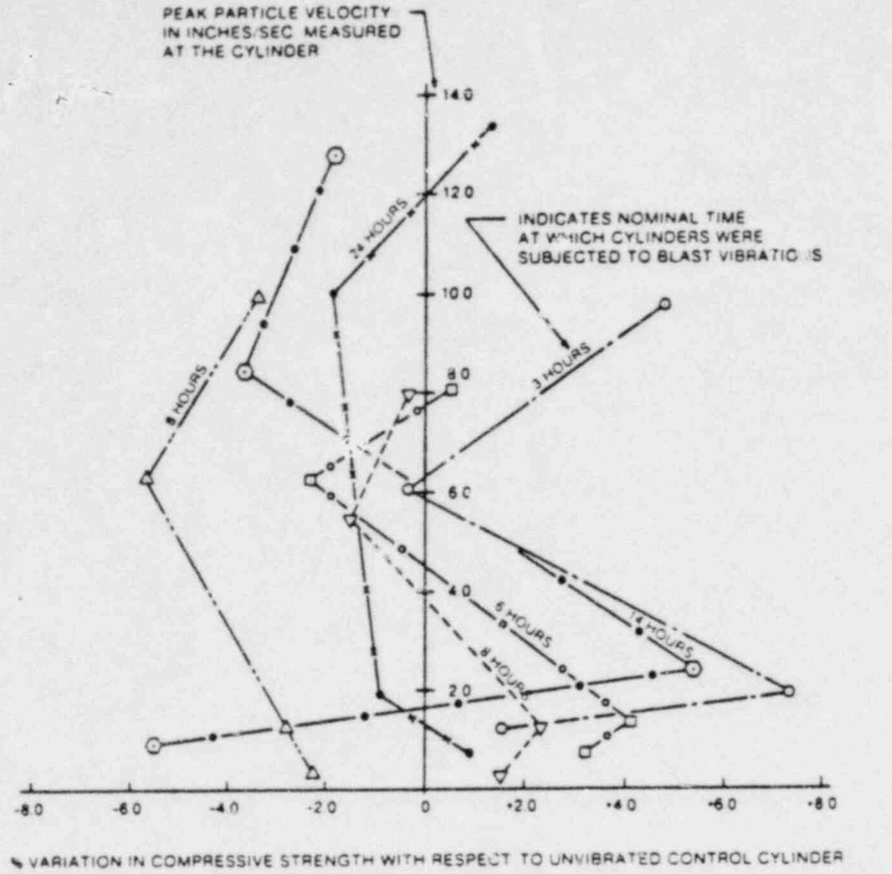


FIGURE 1
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

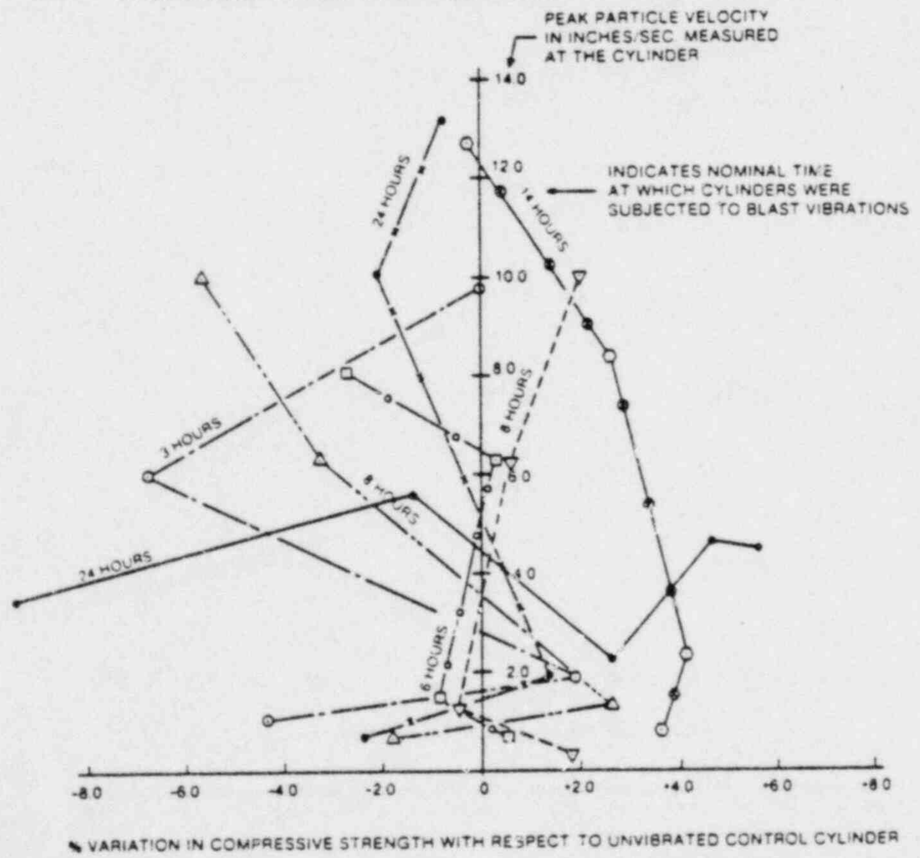


FIGURE 2
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

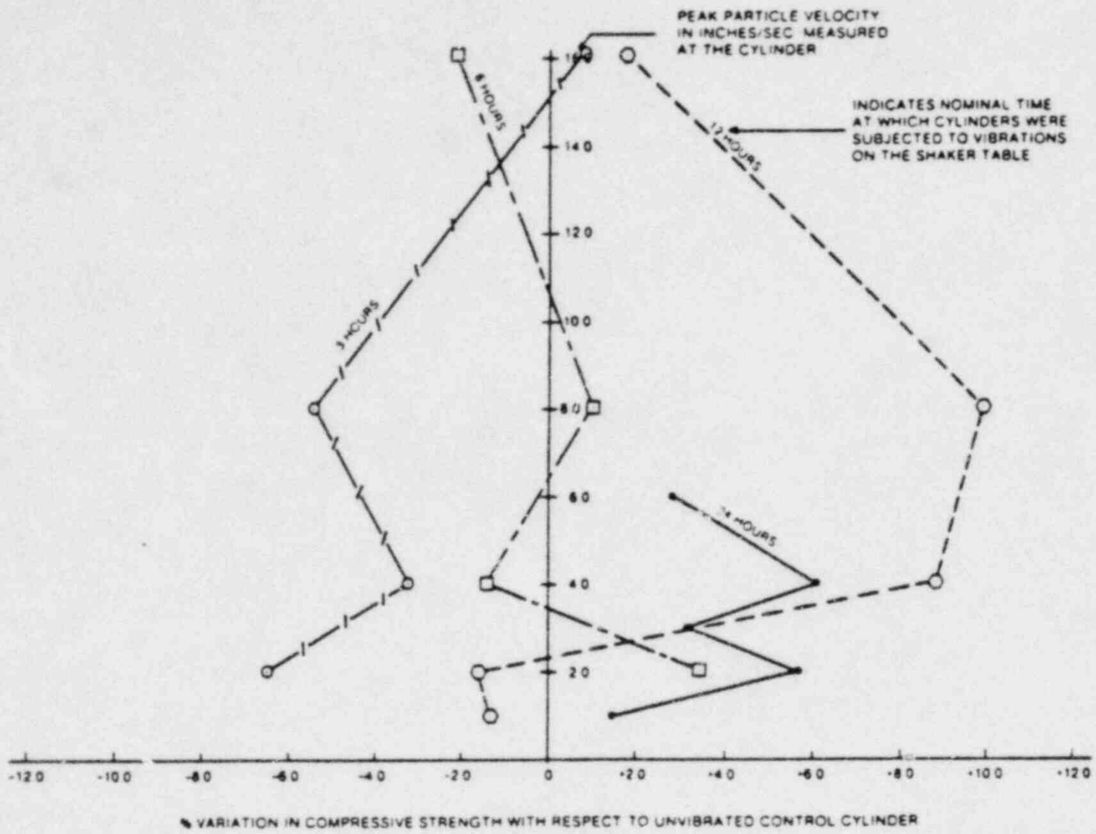
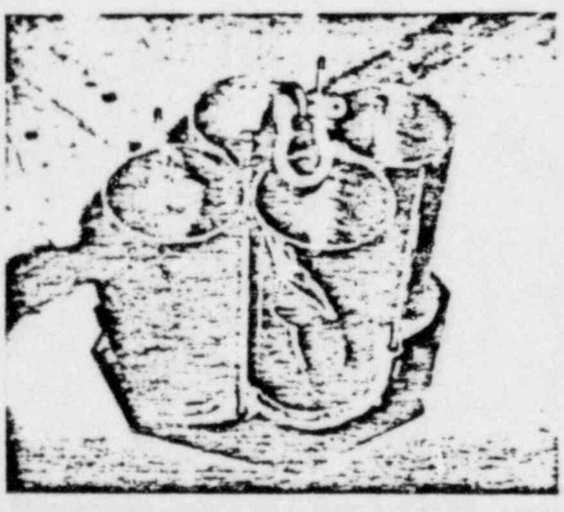
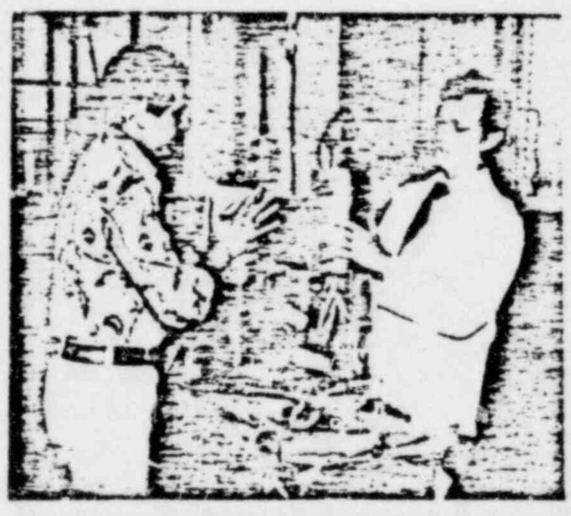


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS



Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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.

2. 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.

3. 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 re-vibrated 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.

6. 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.

CONCLUSIONS

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)

APPENDIX - DIRECT REFERENCES

1. "In-SITU Dynamic Elastic Moduli of Concrete During Curing Process for Maine Yankee Atomic Power Plant, Wiscassett, Maine", Weston Geophysical Research, Inc., Weston, Mass.

2. "Measurements of Vibrations Caused by Construction Equipment and Blasting Report RR172", April 1971 Department of Highways, Ontario, Canada.

3. Waddell, Joseph J. "Practical Quality Control for Concrete", McGraw-Hill Book Company, 1962, par. 7-8, Autogenous Healing.

4. "Measured Vibration Levels, Blast Shock Testing on Curing Concrete-Final Summary Report," S.A. Alsup & Associates, Inc., August 12, 1977 (Prepared for Public Service Company of New Hampshire.)

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

1. US Corps of Engineers, Engineering and Design Manual, EM 1110-2-3800 dated March 1972, "Systematic Drilling and Blasting for Surface Excavations", Chapter 7 - Damage Prediction and Control.

2. Bastian, CE, "The Effect of Vibrations on Freshly Poured Concrete."

3. Portland Cement Association, "The Effect of Jarring on Fresh Concrete."

4. Popovics, S, "A Review of the Concrete Consolidation by Vibration," Materiaux Et Constructions, Vol. 6, No. 36, 1973, pgs. 453-463.

5. Voina, N.I and Mirsu, O "Some Aspects Concerning the Influence of Vibration (Revibration) and Retarders on Concrete Workability and Strength."

6. Wiss, John F, "Damage Effects of Pile Driving Vibration," paper presented at the 45th Annual Meeting of the Committee on Construction Practices-Structures.

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8. Larnach, W.J., "Changes In Bond Strength Caused By Revibration of Concrete and Vibration of Reinforcement," Magazine of Concrete Research, July 1952.

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Post Program Documents

11. Krell, William C., "The Effect of Coal Mill Vibration on Fresh Concrete", Concrete International, December 1979, pgs. 31-34.

12. MacInnis, Cameron, Kosteniuk, Paul W., "Effectiveness of Rivibration and High-Speed Slurry Mixing for Producing High-Strength Concrete," ACI Journal, December 1979, Technical Paper Title No. 76-51, pgs. 1255-1265.

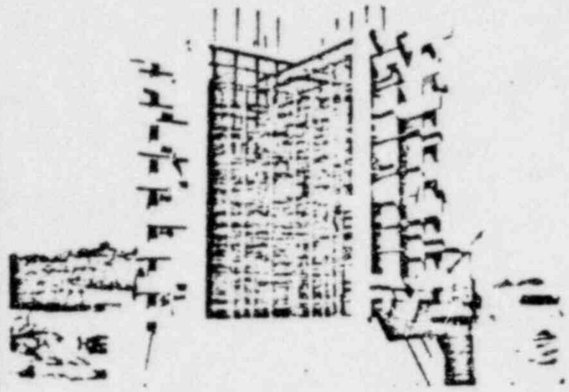
13. Akins, Kenneth P. Jr., Dixon, Donald E., "Concrete Structures and Construction Vibrations," ACI SP 60-10, pgs. 213-247.

14. Chae, Yong S., "Design of Excavation Blasts to Prevent Damage," Civil Engineering, April, 1978, pgs. 77-79.

TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL/CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	5.92	12.7	46	25.9	0.91	2.51	0.087	4353	8
1B	16	10.69	9.87	9.59	46	26.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.55	0.077	4301	3
2B	16	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.19	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.18		2.63			
CONVERSION FACTORS: ONE INCH = 25.4 MILLIM... ONE TON = 907.2 KILOG... ONE PSI = 6.89 KILOPASCALS											

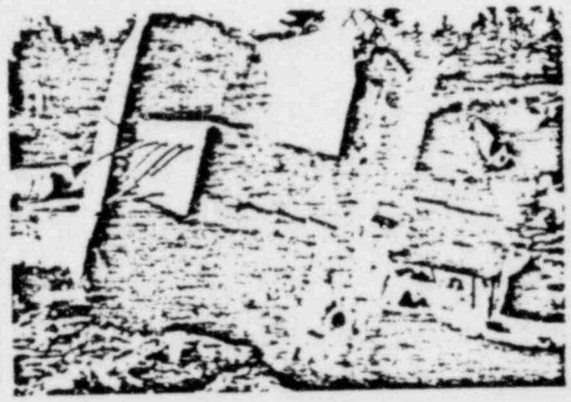


Photograph 6
FIELD TEST WALL SHOWING
REBARS EXTENDED FOR
PULL-OUT TESTING

TABLE 4

LABORATORY TEST PULL-OUT LOADS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	3013
	28	2	17,088	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	250	10	15,233	1330
4	7	2	12,213	738	12	13,929	1561
	28	2	15,450	1075	12	15,160	2387
CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6 — 1000 POUNDS = 453.6 KILOGRAMS							



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIB...TED		
		NO CTL	AVERAGE STRENGTH PSI	STD DEV PSI	NO CTL	AVERAGE STRENGTH PSI	STD DEV PSI
1	7	3	3340	53.5	32	3265	116.4
	28	3	4007	62.4	31	4128	141.4
2	7	3	2740	49.7	10	2841	128.3
	28	3	3747	41.9	10	3?06	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.8
4	7	3	2690	49	22	2720	155.9
	28	3	3267	228.8	22	3405	181.7
ONE PSI = 6.89 KILOPASCALS							

TABLE 6

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.	4.0	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 VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES PER SECOND OR 0.5 INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY.

ONE INCH = 25.4 mm
ONE FOOT = 0.305 m

NSIC

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

RECEIVED
JUN 12 1981
U.S. NUCLEAR REGULATORY COMMISSION

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,

A. Schwencer

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.

dupe of
#8106110185

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

By Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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.

DEFINITIONS

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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[2]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 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	-	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 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) 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 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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

TABLE 1

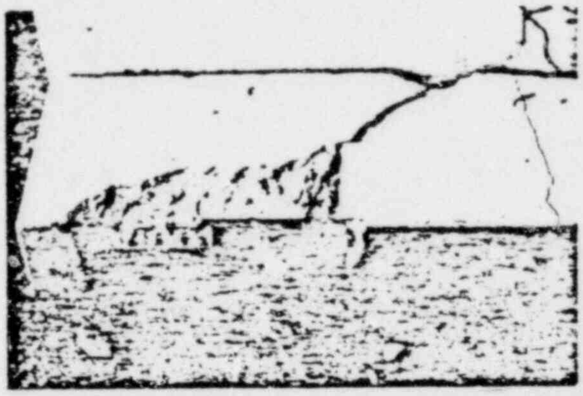
SAMPLING OF VIBRATION LIMITS REPORTED TO BE SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT, IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK (a)	0.07 (b)	0.07 (c)	4.0	7.0
MAINE-YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.2	0.6 @ 12 HRS (d)	4.0
	1.36	1.36	1.36	1.36 (e)
	2.0	2.0	2.0	2.0 (f)
	(g)	(g)	4.0	7.0
	NO LIMIT	0.07	0.13	0.4 (h)
	0.10	0.10	0.5	1.0 (h)

(a) Limit specified prior to VIbration of Green Concrete Test Program.
(b) Limit raised to 1.0 in./sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) increase limit by 0.3 in/sec./hr after 12 hours.
(e) Maximum limit governed by existing operating plant.
(f) Limit increased to 3.0 in/sec after 7 days.
(g) Reported to be a modification of the "Weston Report" values, no specific values available.
(h) Limit increased to 2.0 in./sec. after 36 hours.

ONE INCH = 25.4 mm

Photograph 1
FIELD CYLINDER TEST PAD

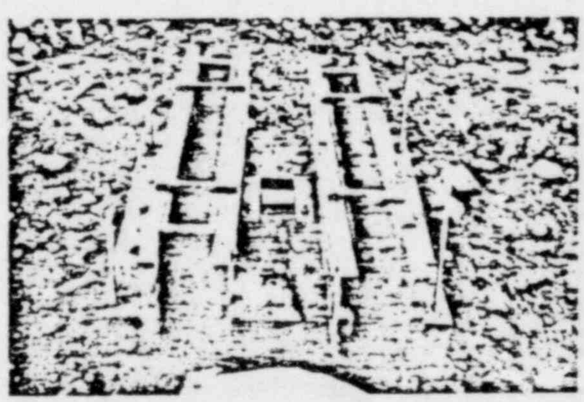


Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST

TABLE 2

SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO.	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR SAFETY FACTOR ACTUAL/CALC STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND SAFETY FACTOR ACTUAL/CALC STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	5.82	16.42	1.45	0.13	2.52	0.22	||
		-	-	-	-	1.66	0.05	2.88	0.09	•
T10	24	1.57	4.42	6.15	14.16	[illegible]	0.11	2.68	0.19	||
		-	-	-	-	1.49	0.05	2.59	0.08	•
T12	14	0.91	4.20	6.99	14.12	2.02	0.12	3.12	0.19	||
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	1.19	3.54	5.76	16.37	1.42	0.10	2.68	0.18	=
		-	-	-	-	1.45	0.07	2.75	0.13	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	=
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	2.54	0.16	=
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.31	8.50	9.19	1.36	0.11	2.40	0.19	||
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR		VIBRATED				1.56	-	2.64	-	• INDICATES BLAST LOCATION
		CONTROL				1.62	-	2.77	-	
3 CONTROL AND 8 VIBRATED BEAMS PER SERIES										



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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 ± 0.3 seconds and remained at the peak level for 5.0 ± 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.

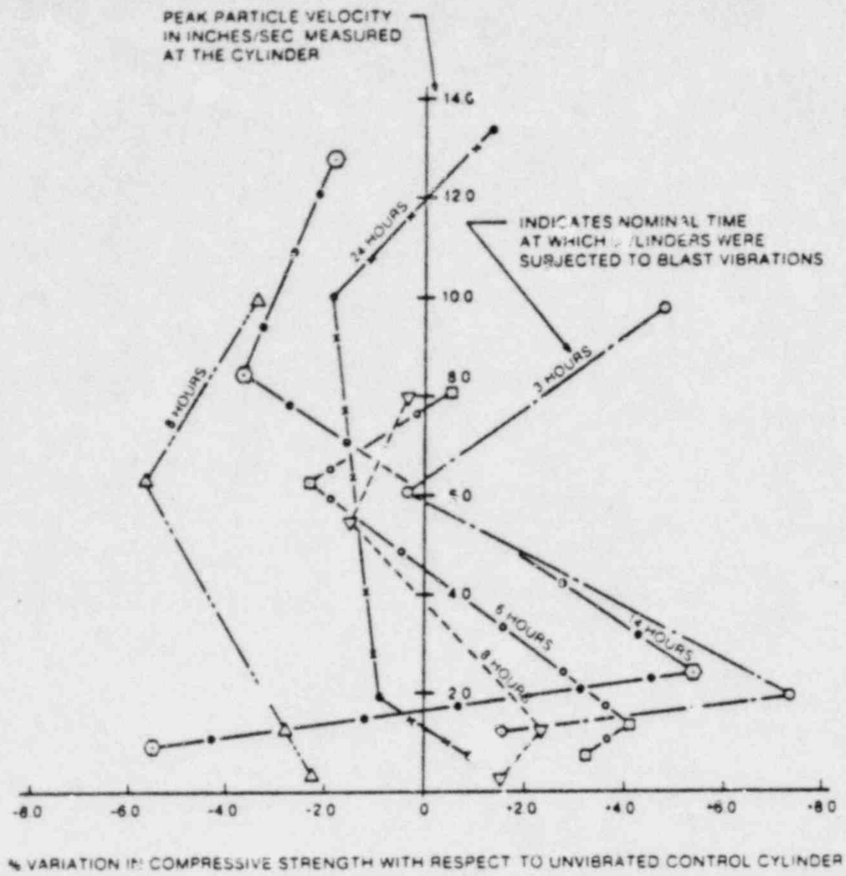


FIGURE 1
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

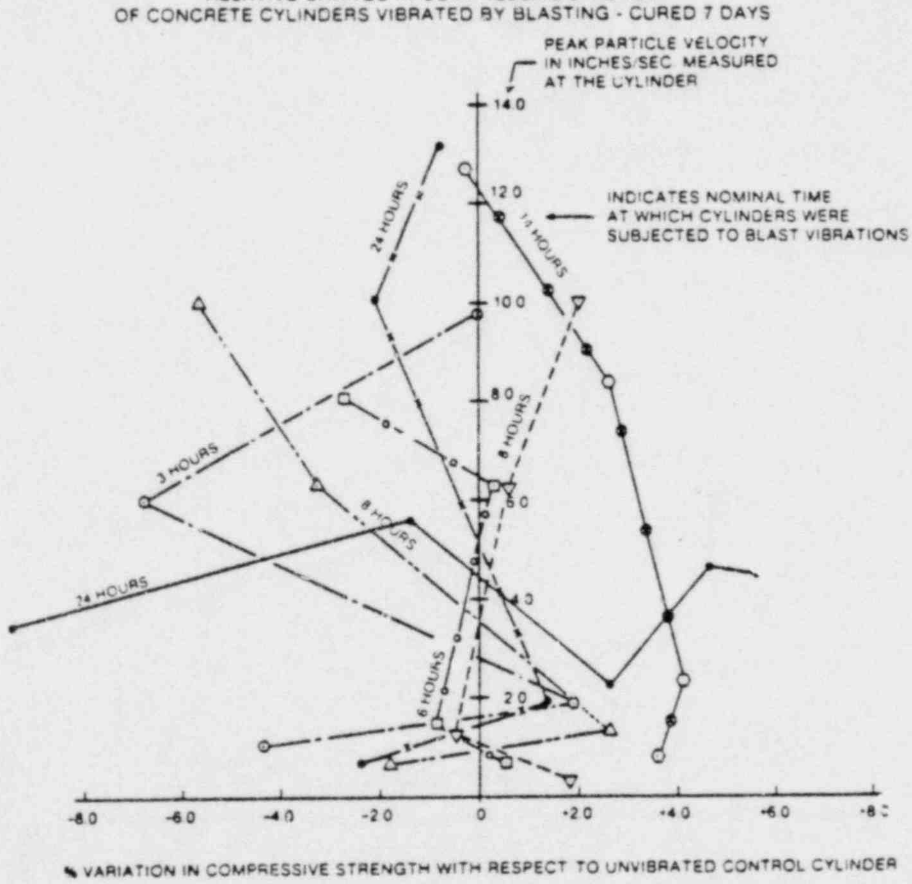


FIGURE 2
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

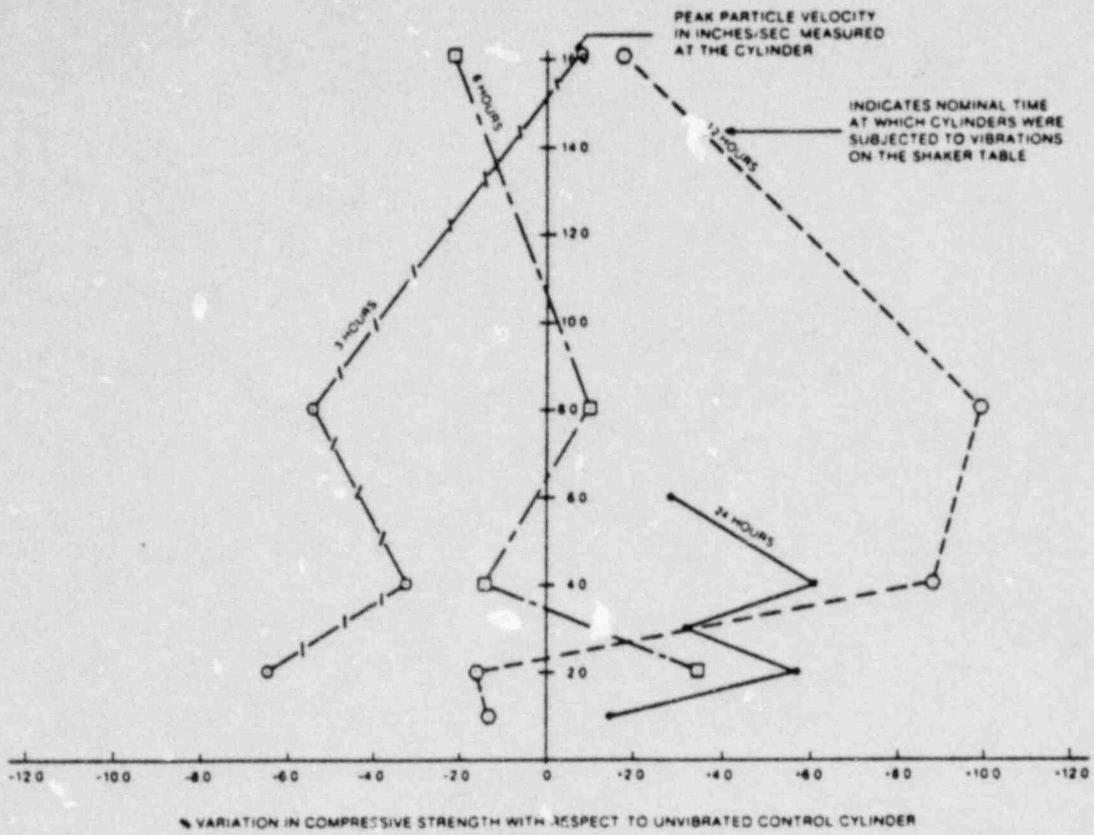
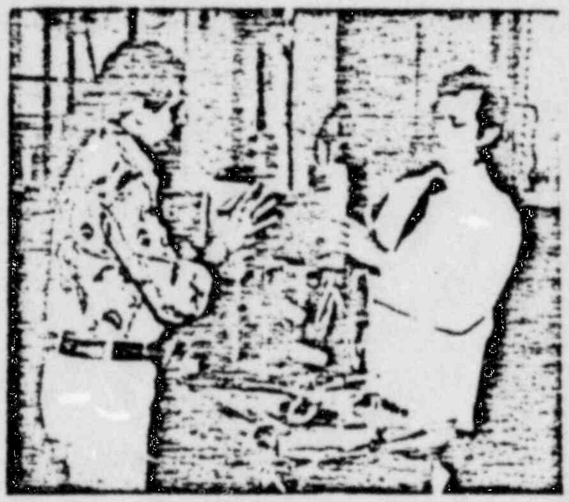


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS

Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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 <u>unconfined</u> 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.

2. 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.

3. 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), <u>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</u>.

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.

6. 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.

CONCLUSIONS

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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13. Akins, Kenneth P. Jr., Dixon, Donald E., "Concrete Structures and Construction Vibrations," ACI SP 60-10, pgs. 213-247.

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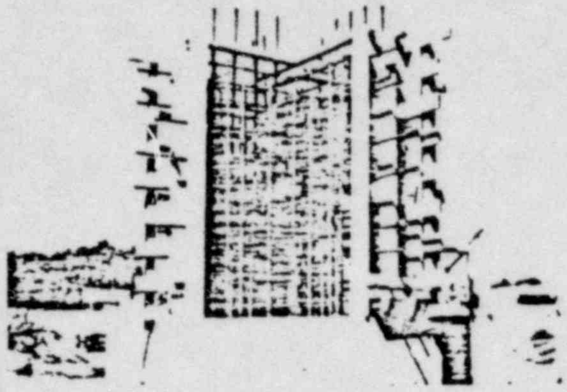
TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL / CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	5.92	12.7	46	25.9	0.91	2.51	0.087	4353	8
1B	14	10.69	9.87	9.50	46	26.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.55	0.077	4301	3
2B	14	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.18	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.18		2.63			

CONVERSION FACTORS: ONE INCH = 25.4 MILLIMETERS
ONE TON = 907.2 KILOGRAMS
ONE PSI = 6.89 KILOPASCALS



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

TABLE 4

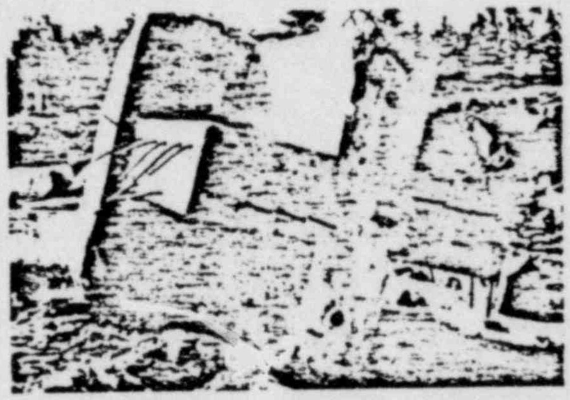
LABORATORY TEST PULL-OUT LOADS

IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	2013
	28	2	17,088	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	250	10	15,233	1330
4	7	2	12,213	[illegible]	12	13,929	1561
	28	2	15,450	1075	12	15,160	2387

CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6

1000 POUNDS = 453.6 KILOGRAMS



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS

IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI	NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI
1	7	3	3340	53.5	32	3265	116.4
	28	3	4007	62.4	31	4128	141.4
2	7	3	2760	49.7	10	2641	128.3
	28	3	3747	41.9	10	3706	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.8
4	7	3	2690	49	22	2720	155.9
	28	3	3267	228.8	22	3405	181.7

ONE PSI = 6.89 KILOPASCALS

TABLE 6

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.	4.0	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 VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES PER SECOND OR 0.5 INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY.

ONE INCH = 25.4 mm
ONE FOOT = 0.305 m

NRC PDR

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

Docket Nos. 50-352/353

JUN 8 1981

RECEIVED
JUN 12 1981
U.S. NUCLEAR REGULATORY COMMISSION

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, "Blas ng Vibration Limits on Freshly Placed (Green) Concrete" by United E ineers and Construction, Inc.

incerely,

A. Schwencer

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.

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

By Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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

DEFINITIONS

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.

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

[2]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 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	-	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 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) 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 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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

TABLE 1

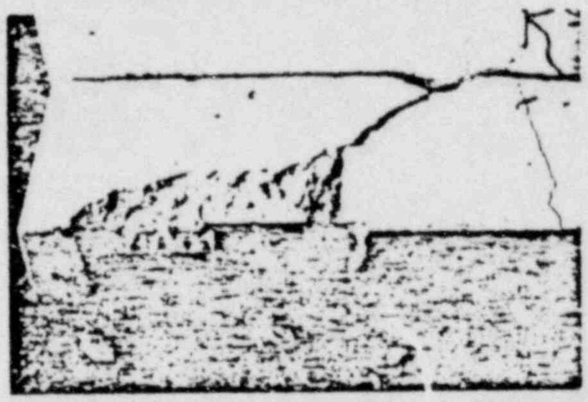
SAMPLING OF V. RATION LIMITS REPORTED TO BE SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT, IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK (a)	0.07 (b)	0.07 (c)	4.0	7.0
MAINE-YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.2	0.6 @ 12 HRS (d)	4.0
	1.36	1.36	1.36	1.36 (e)
	2.0	2.0	2.0	2.0 (f)
	(g)	(g)	4.0	7.0
	NO LIMIT	0.07	0.13	0.6 (h)
	0.10	0.10	0.5	1.0 (h)

(a) Limits specified prior to Vibration of Green Concrete Test Program.
(b) Limit raised to 1.0 in./sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) increase limit by 0.3 in/sec./hr after 12 hours.
(e) Maximum limit governed by existing operating plant.
(f) Limit increased to 3.0 in/sec after 7 days.
(g) Reported to be a modification of the "Weston Report" values, no specific values available.
(h) Limit increased to 2.0 in./sec. after 36 hours.

ONE INCH = 25.4 mm

Photograph 1
FIELD CYLINDER TEST PAD

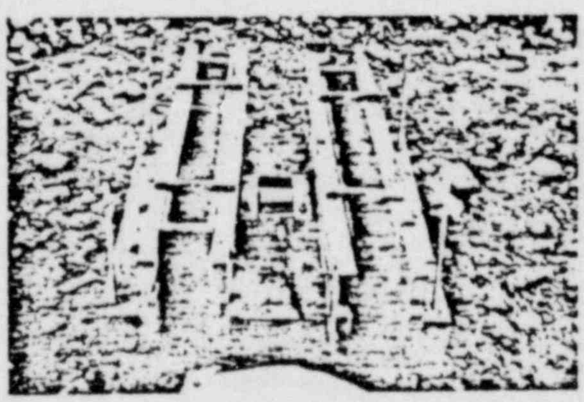


Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST

TABLE 2

SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO.	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	3.82	16.42	1.45	0.13	2.52	0.22	||
		-	-		-	1.66	±0.05	2.88	0.09	•
T10	24	1.57	4.42	6.15	14.16	1.54	0.11	2.68	0.19	||
		-	-	-	-	1.48	0.05	2.59	0.08	•
T12	4	0.91	4.20	6.99	14.12	2.02	0.12	3.12	0.19	|
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	-	3.54	5.76	16.37	1.42	0.10	2.62	0.18	≡
		-	-	-	-	1.45	0.07	2.75	0.1.	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	≡
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	2.54	0.16	≡
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.31	8.50	9.19	1.36	0.11	2.40	0.19	||
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR		VIBRATED				1.56	-	2.68	-	• INDICATES BLAST LOCATION
		CONTROL				1.62	-	2.77	-	
3 CONTROL AND 8 VIBRATED BEAMS PER SERIES										



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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 ± 0.3 seconds and remained at the peak level for 5.0 ± 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.

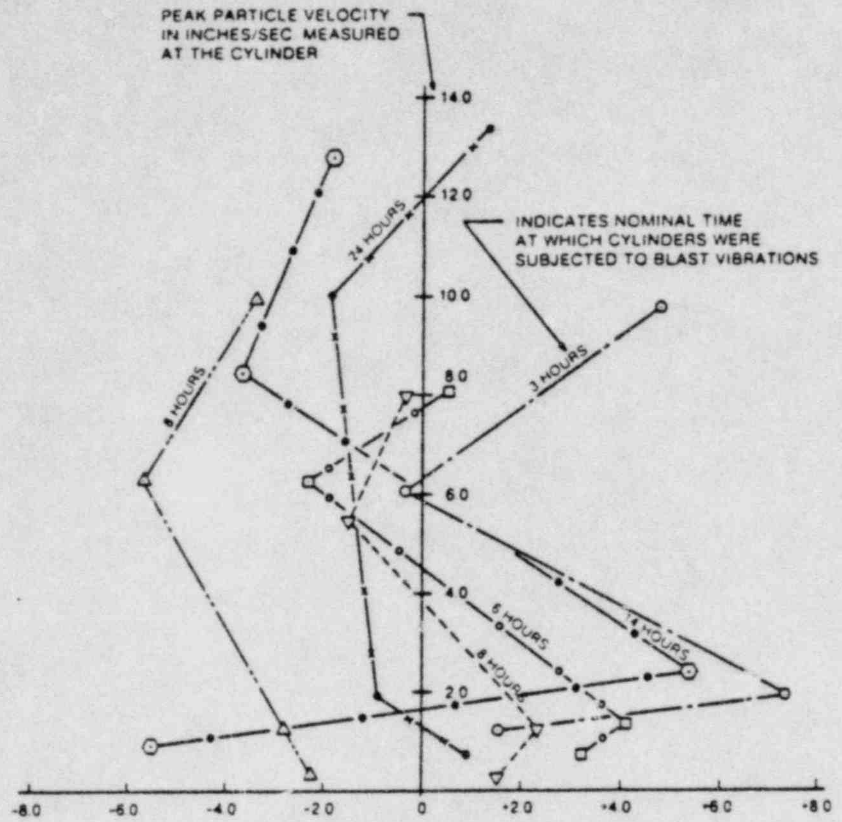


FIGURE 1
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

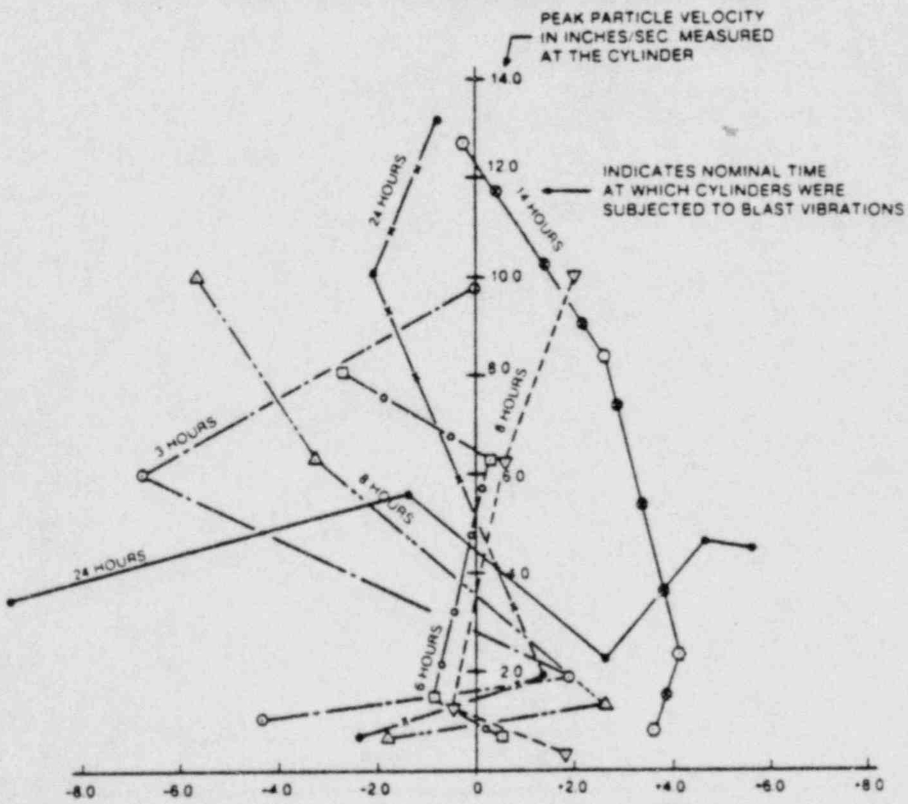


FIGURE 2
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

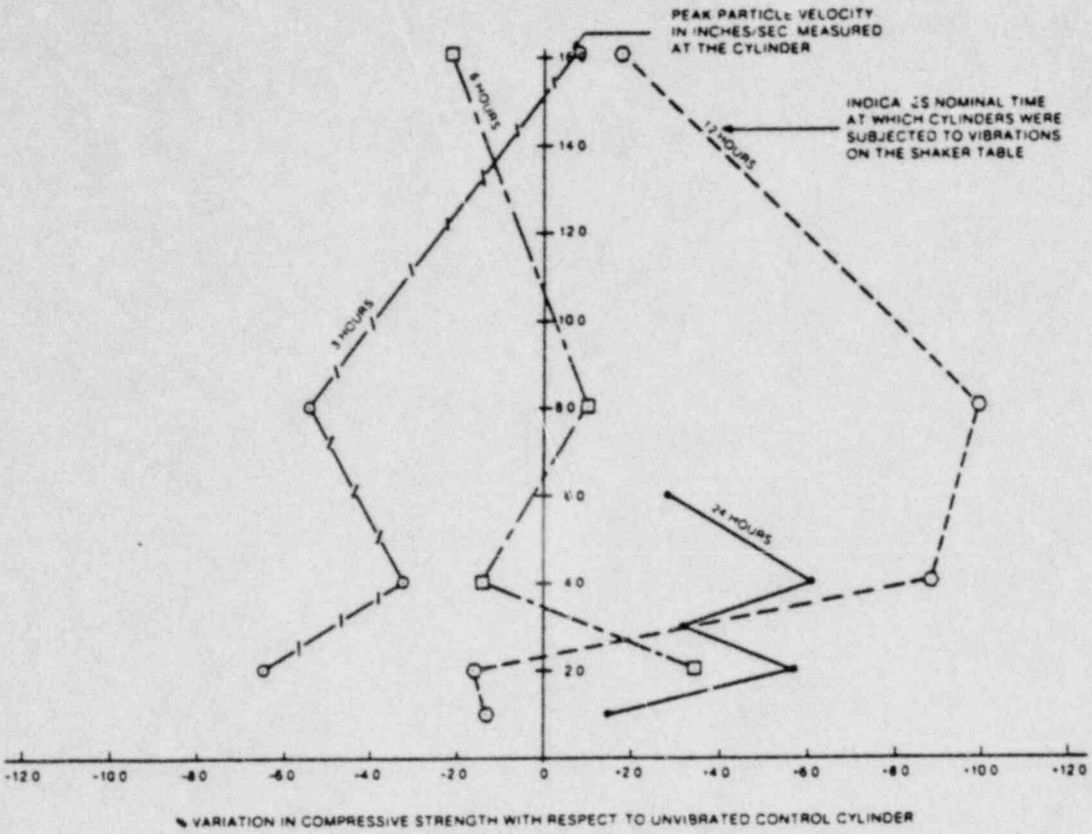
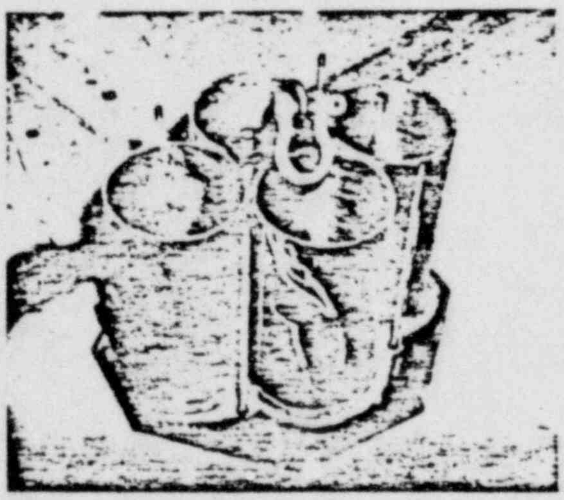


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS



Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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 <u>unconfined</u> 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.

2. 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.

3. 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), <u>there has been no evidence to indicate that the re-vibrated 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</u>.

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.

6. 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.

CONCLUSIONS

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)

APPENDIX - DIRECT REFERENCES

1. "In-SITU Dynamic Elastic Moduli of Concrete During Curing Process for Maine Yankee Atomic Power Plant, Wiscassett, Maine", Weston Geophysical Research, Inc., Weston, Mass.

2. "Measurements of Vibrations Caused by Construction Equipment and Blasting Report RR172", April 1971 Department of Highways, Ontario, Canada.

3. Waddell, Joseph J. "Practical Quality Control for Concrete", McGraw-Hill Book Company, 1962, par. 7-8, Autogenous Healing.

4. "Measured Vibration Levels, Blast Shock Testing on Curing Concrete-Final Summary Report," S.A. Alsup & Associates, Inc., August 12, 1977 (Prepared for Public Service Company of New Hampshire.)

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

1. US Corps of Engineers, Engineering and Design Manual, EM 1110-2-3800 dated March 1972, "Systematic Drilling and Blasting for Surface Excavations", Chapter 7 - Damage Prediction and Control.

2. Bastian, CE, "The Effect of Vibrations on Freshly Poured Concrete."

3. Portland Cement Association, "The Effect of Jarring on Fresh Concrete."

4. Popovics, S, "A Review of the Concrete Consolidation by Vibration," Materiaux Et Constructions, Vol. 6, No. 36, 1973, pgs. 453-463.

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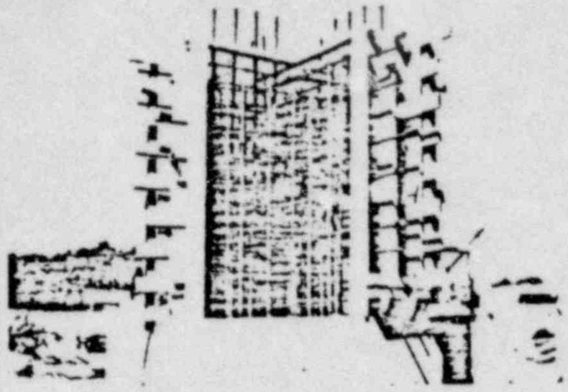
TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL/CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	5.92	12.7	46	25.9	0.91	2.51	0.087	4253	8
1B	14	10.69	9.87	9.59	46	26.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.55	0.077	4301	3
2B	14	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.18	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.10		2.63			

CONVERSION FACTORS ONE INCH = 25.4 MILLIMETERS
ONE TON = 907.2 KILOGRAMS
ONE PSI = 6.89 KILOPASCALS



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

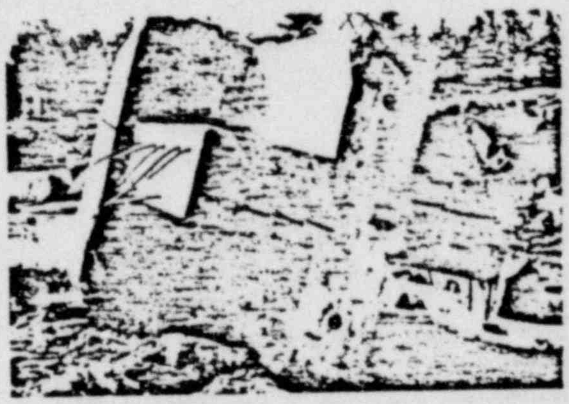
TABLE 4

LABORATORY TEST PULL-OUT LOADS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	2013
	28	2	17,088	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	750	10	15,233	1330
4	7	2	12,213	738	12	12,929	1561
	28	2	15,450	1075	12	15,160	2387

CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6

1000 POUNDS = 453.6 KILOGRAMS



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC. BATCH	TEST DAY	CONTROL			VIBRATED		
		NO CYL	AVERAGE STRENGTH PSI	STD. DEV. PSI	NO CYL	AVERAGE STRENGTH PSI	STD. DEV PSI
1	7	3	3340	53.5	32	3265	116.4
	28	3	4007	62.6	31	4128	141.4
2	7	3	2740	49.7	10	2841	128.3
	28	3	3747	41.9	10	3706	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.6
4	7	3	2690	49	22	2720	155.9
	28	3	3267	228.8	22	3405	181.7

ONE PSI = 6.89 KILOPASCALS

TABLE 6

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.	4.0	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 VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES PER SECOND OR 5.5 INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY.

ONE INCH = 25.4 mm
ONE FOOT = 0.305 m

LOCAL PDR

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

Docket Nos. 50-352/353

JUN 8 1981

RECEIVED
JUN 12 1981
U.S. NUCLEAR REGULATORY COMMISSION

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,

A. Schwencer

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 Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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.

DEFINITIONS

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.

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

[2]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 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.: 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 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 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 vibration 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) 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 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 6 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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 [illegible]ing 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

TABLE 1

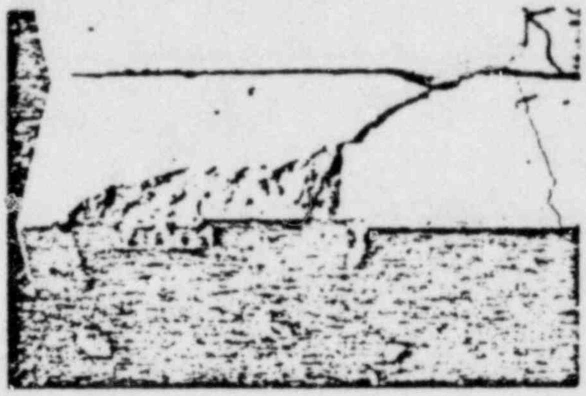
SAMPLING OF VIBRATION LIMITS REPORTED TO BE SPECIFIED AT NUCLEAR PLANT CONSTRUCTION SITES

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT, IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK (a)	0.07 (b)	0.07 (c)	4.0	7.0
MAINE-YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.3	0.6 @ 12 HRS (d)	4.0
	1.36	1.36	1.36	1.36 (e)
	2.0	2.0	2.0	2.0 (f)
	(g)	(g)	4.0	7.0
	NO LIMIT	0.07	0.13	0.4 (h)
	0.10	0.10	0.5	1.0 (h)

(a) Limits specified prior to Vibration of Green Concrete Test Program.
(b) Limit raised to 1.0 in./sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) Increase limit by 0.3 in/sec./hr after 12 hours.
(e) Maximum limit governed by existing operating plant.
(f) Limit increased to 3.0 in/sec after 7 days.
(g) Reported to be a modification of the "Weston Report" values, no specific values available.
(h) Limit increased to 2.0 in/sec after 36 hours.

ONE INCH = 25.4 mm

Photograph 1
FIELD CYLINDER TEST PAD



Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST

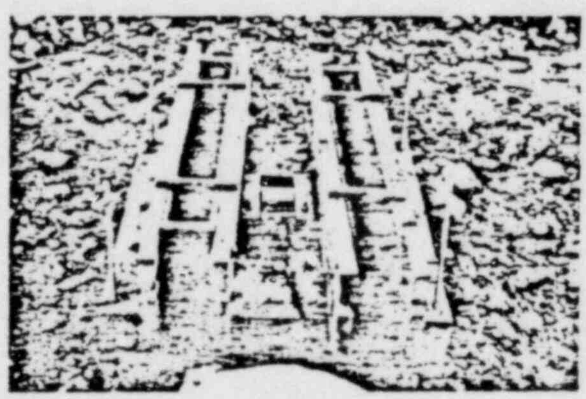
TABLE 2

SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR SAFETY FACTOR ACTUAL/CALC STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND SAFETY FACTOR ACTUAL/CALC STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	5.82	16.42	1.45	0.13	2.52	0.22	||
		-	-	-	-	1.66	0.05	2.88	0.09	•
T10	24	1.57	4.42	6.15	14.16	1.34	0.11	2.68	0.19	||
		-	-	-	-	1.48	0.05	2.59	0.08	•
T12	14	0.91	4.20	6.99	14.12	2.02	0.12	3.12	0.19	||
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	1.19	3.54	5.76	16.37	1.42	0.10	2.66	0.18	=
		-	-	-	-	1.45	0.07	2.75	0.13	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	=
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	2.54	0.16	=
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.21	8.50	9.19	1.36	0.11	2.40	0.19	||
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR				VIBRATED		1.56	-	2.68	-	
				CONTROL		1.62	-	2.77	-	

3 CONTROL AND [illegible] VIBRATED BEAMS PER SERIES

• INDICATES BLAST LOCATION



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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.

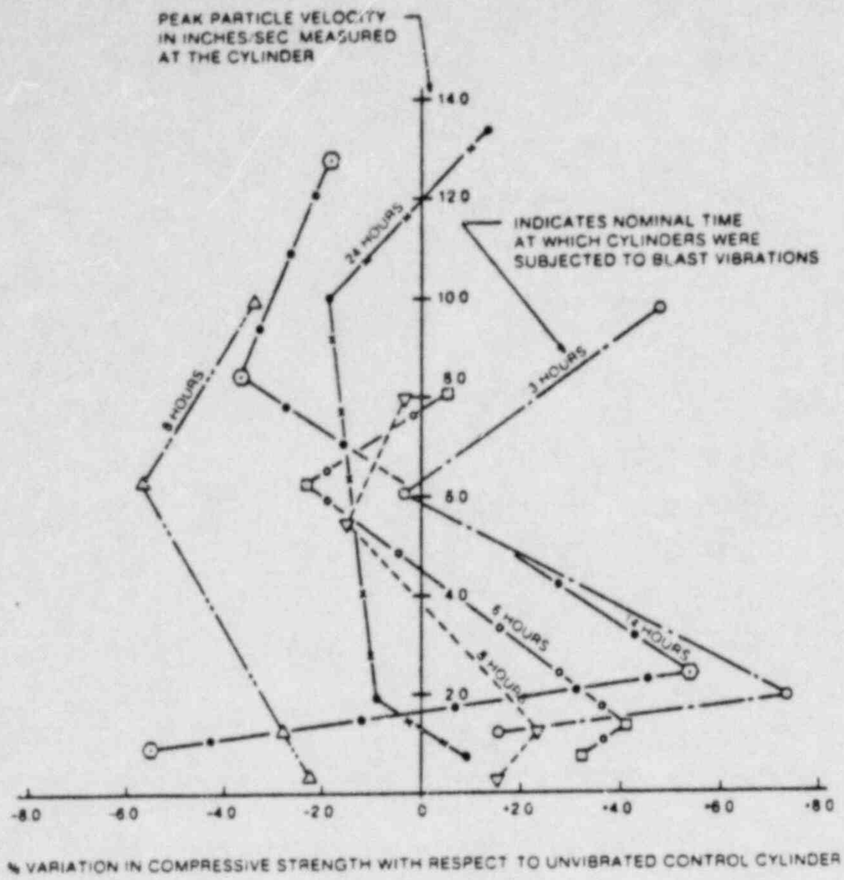


FIGURE 1

RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

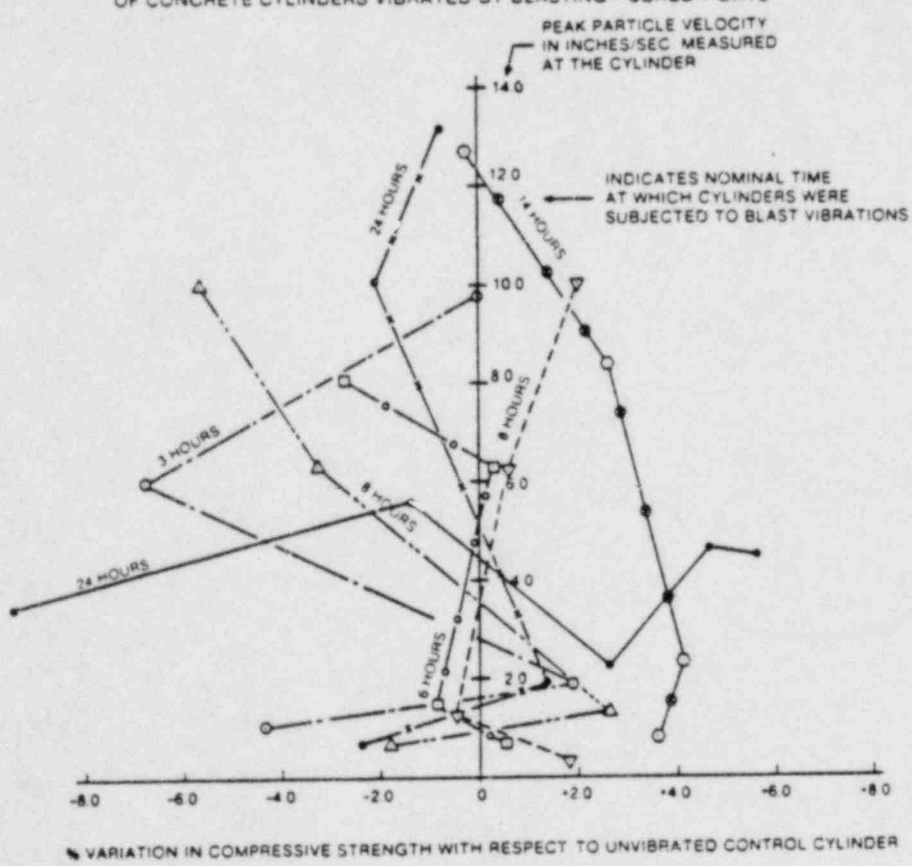


FIGURE 2

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

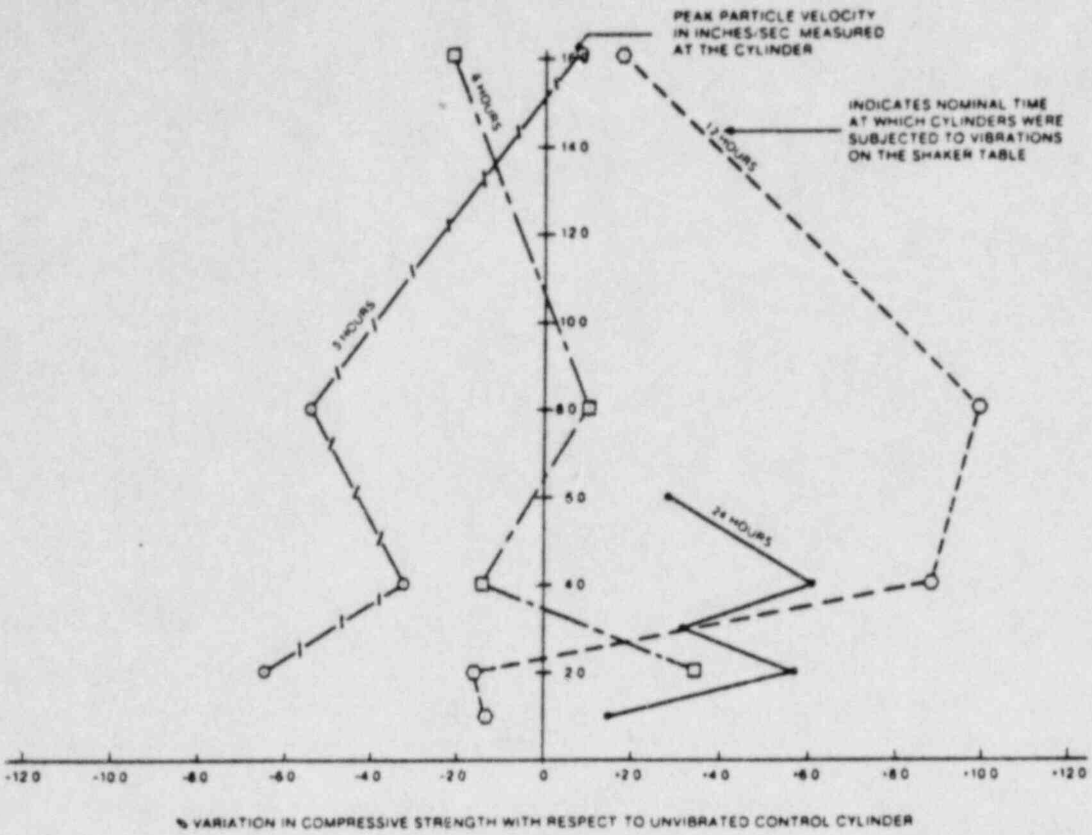


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS

Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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.

2. 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.

3. 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.

6. 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.

CONCLUSIONS

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)

APPENDIX - DIRECT REFERENCES

1. "In-SITU Dynamic Elastic Moduli of Concrete During Curing Process for Maine Yankee Atomic Power Plant, Wiscassett, Maine", Weston Geophysical Research, Inc., Weston, Mass.

2. "Measurements of Vibrations Caused by Construction Equipment and Blasting Report RR172", April 1971 Department of Highways, Ontario, Canada.

3. Waddell, Joseph J. "Practical Quality Control for Concrete", McGraw-Hill Book Company, 1962, par. 7-8, Autogenous Healing.

4. "Measured Vibration Levels, Blast Shock Testing on Curing Concrete-Final Summary Report," S.A. Alsup & Associates, Inc., August 12, 1977 (Prepared for Public Service Company of New Hampshire.)

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

1. US Corps of Engineers, Engineering and Design Manual, EM 1110-2-3800 dated March 1972, "Systematic Drilling and Blasting for Surface Excavations", Chapter 7 - Damage Prediction and Control.

2. Bastian, CE, "The Effect of Vibrations on Freshly Poured Concrete."

3. Portland Cement Association, "The Effect of Jarring on Fresh Concrete."

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6. Wiss, John F, "Damage Effects of Pile Driving Vibration," paper presented at the 45th Annual Meeting of the Committee on Construction Practices-Structures.

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Post Program Documents

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12. MacInnis, Cameron, Kosteniuk, Paul W., "Effectiveness of Rivibration and High-Speed Slurry Mixing for Producing High-Strength Concrete," ACI Journal, December 1979, Technical Paper Title No. 76-51, pgs. 1255-1265.

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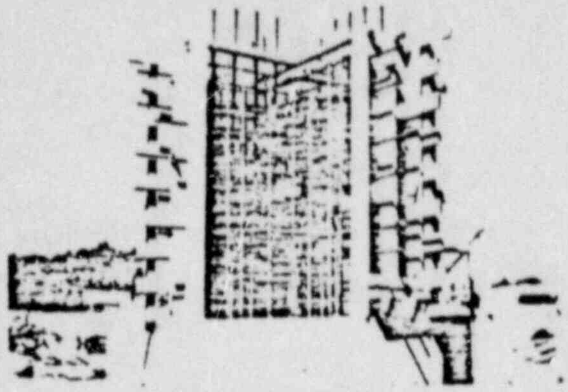
14. Chae, Yong S., "Design of Excavation Blasts to Prevent Damage," Civil Engineering, April, 1978, pgs. 77-79.

TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL/CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	5.92	12.7	46	25.9	0.91	2.31	0.087	4353	8
1B	14	10.69	9.87	9.59	46	36.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.35	0.077	4301	3
2B	14	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.18	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.18		2.63			

CONVERSION FACTORS: ONE INCH = 25.4 MILLIMETERS
ONE TON = 907.2 KILOGRAMS
ONE PSI = 6.89 KILOPASCALS



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

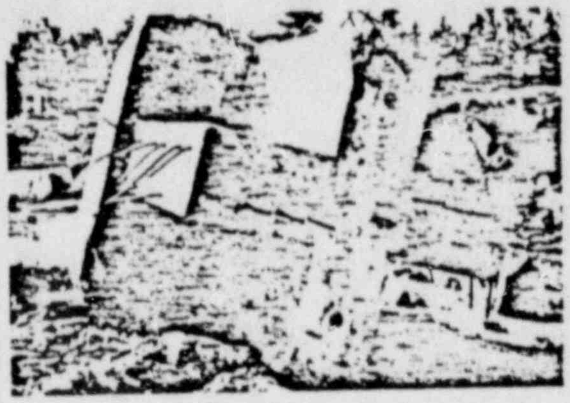
TABLE 4

LABORATORY TEST PULL-OUT LOADS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	3013
	28	2	17,088	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	250	10	15,233	1330
4	7	2	12,213	738	12	13,929	1561
	28	2	15,450	1075	12	15,160	2387

CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6

1000 POUNDS = 453.6 KILOGRAMS



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI	NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI
1	7	3	3340	53.5	32	3263	116.4
	28	3	4007	62.4	31	4128	141.4
2	7	3	2740	49.7	10	2841	128.3
	28	3	3767	41.9	10	3706	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.8
4	7	3	2690	69	22	2720	155.9
	28	3	3267	228.8	22	3403	181.7

ONE PSI = 6.89 KILOPASCALS

TABLE 6

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.	4.0	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 VELOCITY REQUIREMENT.

(2) PEAK PARTICLE VELOCITY SHALL [illegible] EXCEED 2 INCHES PER SECOND OR 0.5 INCHES PER SECOND AT [illegible]0 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY.

ONE INCH = 25.4 mm
ONE FOOT = 0.305 m

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Docket Nos. 50-[illegible]/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 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.

Sincerely,
Original signed by

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

Enclosure:
As stated

add Docket Nos to letterhead.

OFFICE	DL:LB#2	DL:LB#2					
SURNAME	DCalkins:ph	ASchwencer					
DATE	06/ 08 /81	06/ 8 /81					

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. Desa., Structural Engineer
United Engineers and Constructors Inc.

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

By Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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.

DEFINITIONS

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 does not refer to re-vibrating of fresh concrete to improve its properties.

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

[2]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 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	-	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 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) 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 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage without splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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

TABLE 1

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

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT, IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK[a]	0.07[b]	0.07[c]	4.0	7.0
MAINE-YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.2	0.6 @ 12 HRS[d]	4.0
	1.36	1.36	1.36	1.36[e]
	2.0	2.0	2.0	2.0[f]
	(g)	(g)	4.0	7.0
	NO LIMIT	0.07	0.13	0.4[h]
	0.10	0.10	0.5	1.0[h]

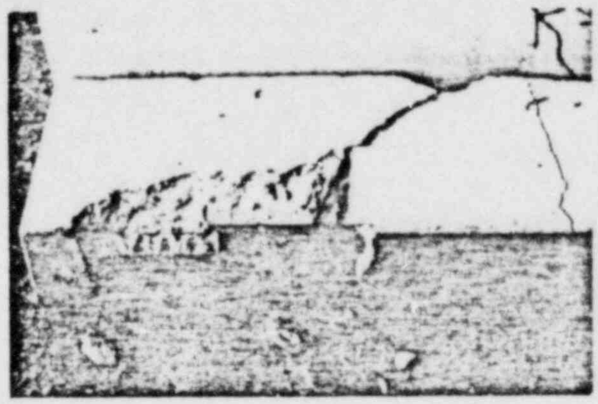
(a) Limits specified prior to Vibration of Green Concrete Test Program.
(b) Limit raised to 1.0 in/sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) increase limit by 0.3 in/sec/hr after 12 hours
(e) Maximum limit governed by existing operating plant
(f) Limit increased to 3.0 in/sec after 7 days.
(g) Repo:ted to be a modification of the "Weston Report" values, no specific values available
(h) Limit increased to 2.0 in/sec after 36 hours

ONE INCH = 25.4 mm

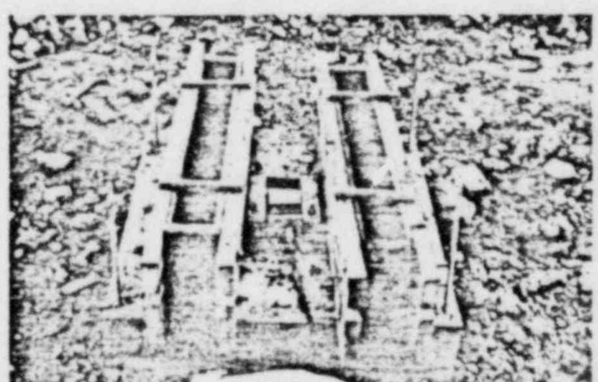
TABLE 2
SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO.	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	5.82	16.42	1.45	0.13	2.52	0.22	‖
		-	-	-	-	1.66	0.05	2.88	0.09	•
T10	24	1.57	4.42	6.15	14.16	1.54	0.11	2.68	0.19	‖
		-	-	-	-	1.48	0.05	2.59	0.08	•
T12	14	0.91	4.20	6.99	14.12	2.02	0.1[illegible]	3.12	0.1[illegible]	‖
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	1.19	3.54	5.76	16.37	1.42	0.10	2.68	0.18	═
		-	-	-	-	1.45	0.07	2.75	0.13	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	═
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	2.54	0.16	═
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.31	8.50	9.19	1.36	0.11	2.40	0.19	‖
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR				VIBRATED		1.56	-	2.68	-	• INDICATES BLAST LOCATION
				CONTROL		1.62	-	2.77	-	
3 CONTROL AND 8 VIBRATED BEAMS PER SERIES										

Photograph 1
FIELD CYLINDER TEST PAD



Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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.

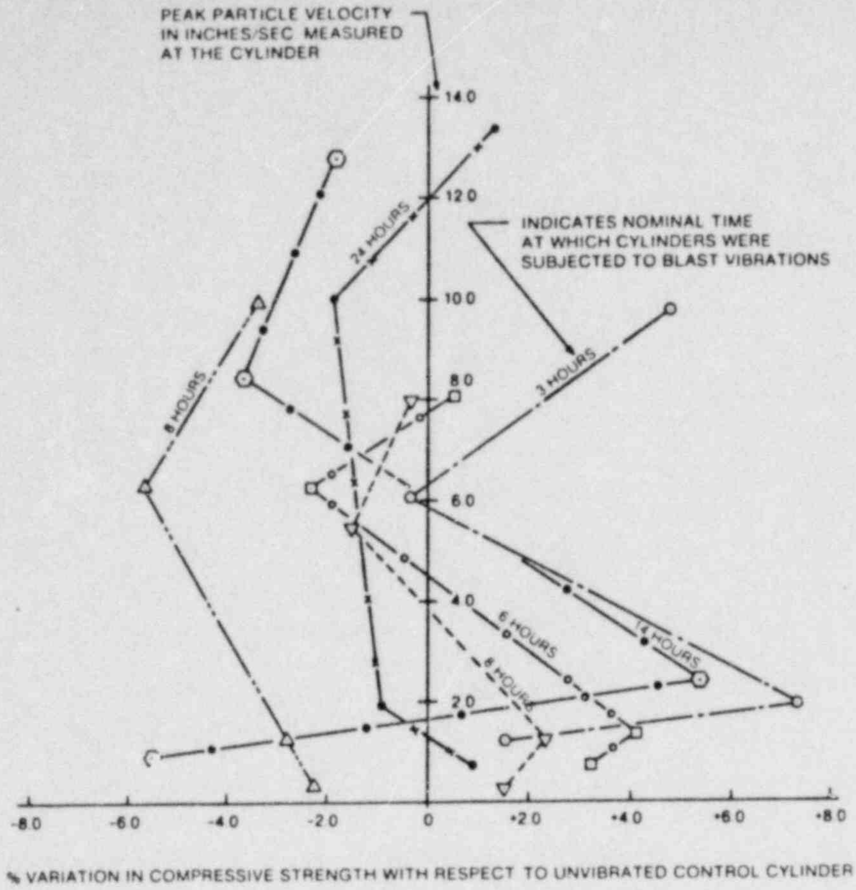


FIGURE 1

RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

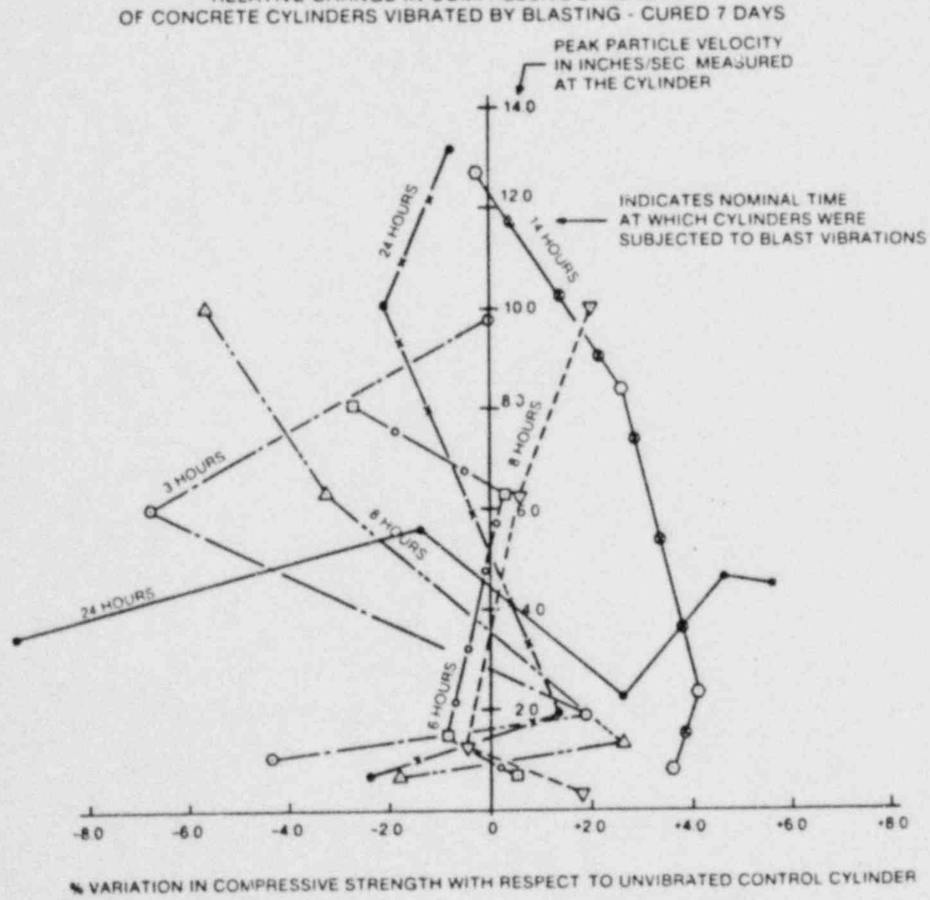


FIGURE 2

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

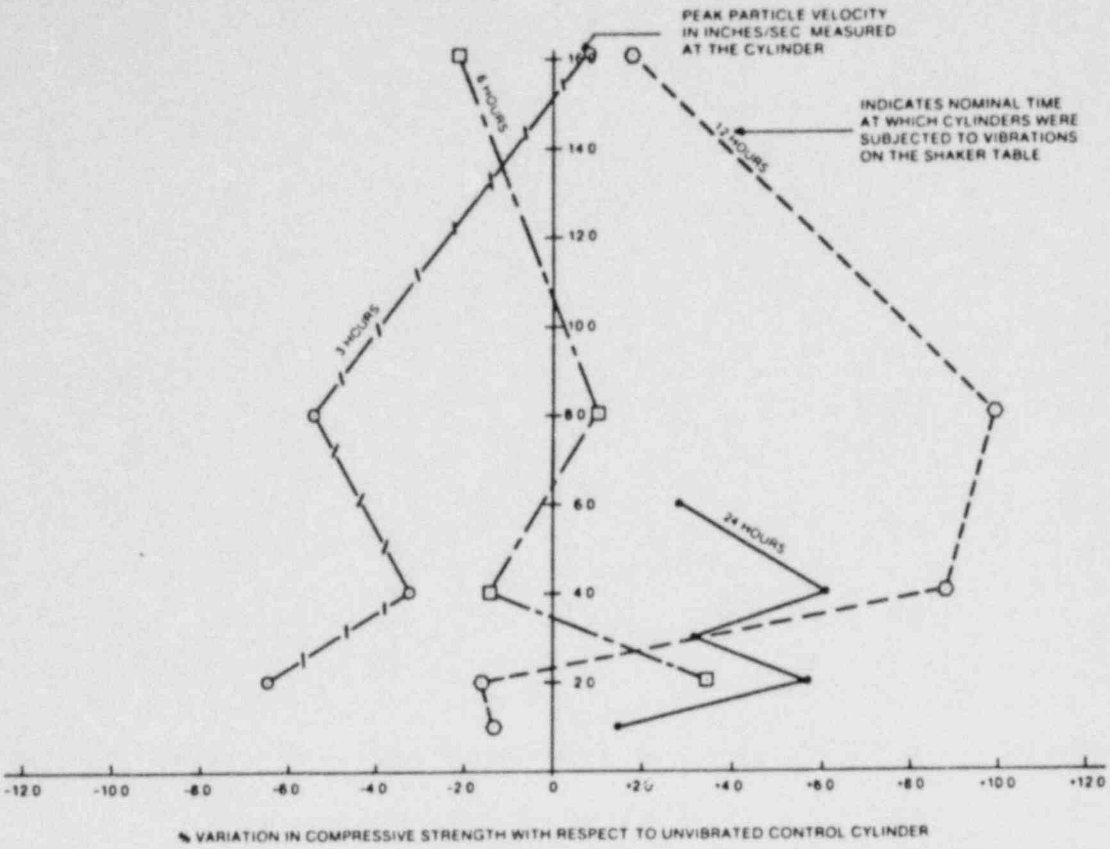
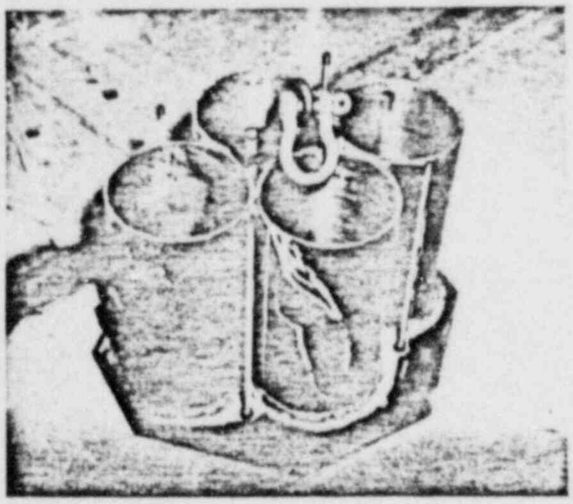


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS



Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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.

2. 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.

3. 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.

6. 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.

CONCLUSIONS

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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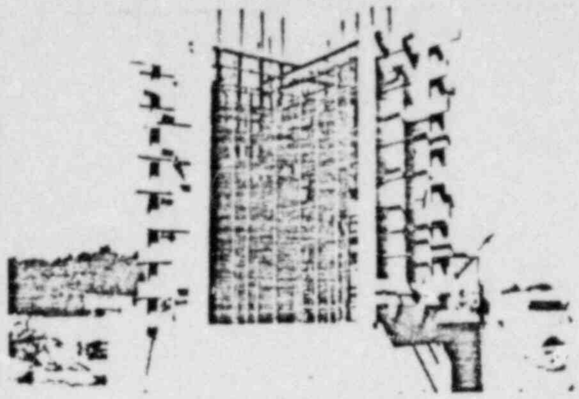
TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL / CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	5.92	12.7	46	25.9	0.91	2.51	0.087	4353	8
1B	14	10.69	9.87	9.59	46	26.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.35	0.077	4301	3
2B	14	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.18	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.18		2.63			

CONVERSION FACTORS : ONE INCH = 25.4 MILLIMETERS
ONE TON = 907.2 KILOGRAMS
ONE PSI = 6.89 KILOPASCALS



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

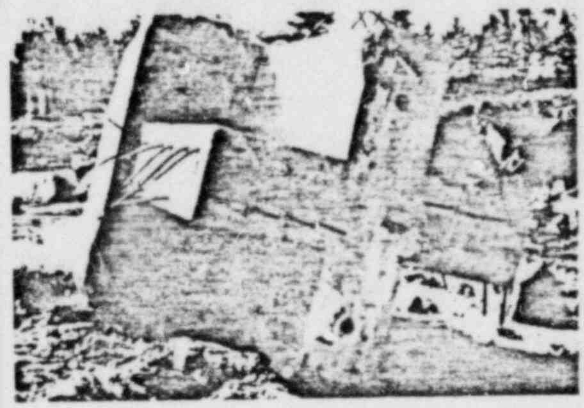
TABLE 4

LABORATORY TEST PULL-OUT LOADS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO. SPEC.	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO. SPEC.	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	2013
	28	2	17,068	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	250	10	15,233	1330
4	7	2	12,213	738	12	13,929	1561
	28	2	15,450	1075	12	15,160	2387

CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6

1000 POUNDS = 453.6 KILOGRAMS



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS
IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI	NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI
1	7	3	3340	53.5	32	3265	116.4
	28	3	4007	62.4	31	4128	141.4
2	7	3	2740	49.7	10	2841	128.3
	28	3	3747	41.9	10	3706	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.8
4	7	3	2690	49	22	2720	155.9
	28	3	3267	228.8	22	3405	181.7

ONE PSI = 6.89 KILOPASCALS

TABLE 6

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	4.0	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 VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES PER SECOND OR 0.5 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 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,

A. Schwencer

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

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

By Allen J. Hulshizer[1], F.ASCE and Ashok J. Desai[2], M.ASCE

INTRODUCTION

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.

DEFINITIONS

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 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 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 cas[illegible]g 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 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) 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 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. 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:

1. Bond failure of the 4 inch (102 mm) rebar anchorage thout splitting or shearing of the beam and sometimes followed by a shear failure.

2. 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 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

TABLE 1

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

PLANT	NOMINAL AGE OF GREEN CONCRETE AFTER PLACEMENT, IN HOURS			
	0-3	3-11	11-24	AFTER 24
	PEAK PARTICLE VELOCITY IN INCHES/SEC			
SEABROOK (a)	0.07 (b)	0.07 (c)	6.0	7.0
MAINE YANKEE	0.07	0.07	4.0	7.0
OTHER PLANT REFERENCE DATA	NO LIMIT	0.2	0.6 @ 12 HRS (d)	4.0
	1.36	1.36	1.36	1.36 (e)
	2.0	2.0	2.0	2.0 (f)
	(g)	(g)	4.0	7.0
	NO LIMIT	0.07	0.13	0.4 (h)
	0.10	0.10	0.5	1.0 (h)

(a) Limits specified prior to Vibration of Green Concrete Test Program.
(b) Limit raised to 1.0 in./sec. for first hour of placement.
(c) Limit raised to 0.14 in/sec. for temporary structures.
(d) increase limit by 0.3 in/sec./hr after 12 hours.
(e) Maximum limit governed by existing operating plant.
(f) Limit increased to 3.0 in/sec after 7 days.
(g) Reported to be a modification of the "Weston Report" values, no specific values available.
(h) Limit increased to 2.0 in./sec. after 36 hours.

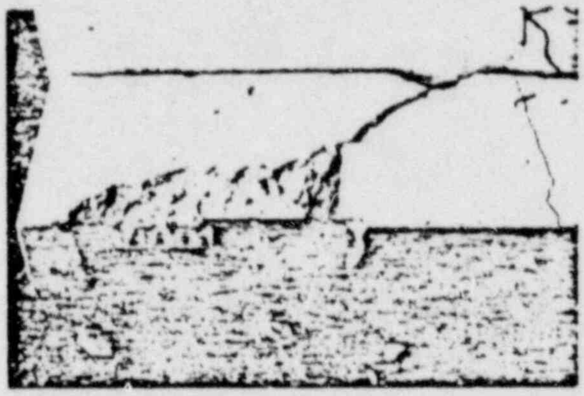
ONE INCH = 25.4 mm

TABLE 2

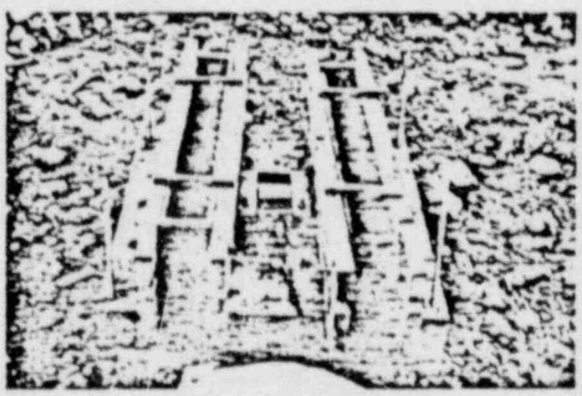
SUMMARY OF FIELD BEAM TEST VALUES

TEST SERIES NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES/SEC (1" = 25.4mm)				SHEAR SAFETY FACTOR ACTUAL/CALC AVER	SHEAR STD DEV	BOND SAFETY FACTOR ACTUAL/CALC AVER	BOND STD DEV	BEAM ORIENTATION
T9	3	1.95	4.18	3.82	16.42	1.45	0.13	2.52	0.22	‖
		-	-	-	-	1.66	0.05	2.88	0.09	•
T10	24	1.57	4.42	6.15	14.16	1.54	0.11	2.68	0.19	‖
		-	-	-	-	1.48	0.05	2.59	0.08	•
T12	14	0.91	4.20	6.99	14.12	2.02	0.12	3.12	0.19	‖
		-	-	-	-	1.91	0.20	2.94	0.30	•
T13	6	1.19	3.54	5.76	16.37	1.42	0.10	2.68	0.18	=
		-	-	-	-	1.43	0.07	2.75	0.13	•
T14	14	2.64	5.6	9.66	10.73	1.66	0.17	2.81	0.29	=
		-	-	-	-	2.05	0.14	3.47	0.24	•
T15	8	2.68	4.81	10.27	10.86	1.50	0.09	2.54	0.16	=
		-	-	-	-	1.27	0.13	2.16	0.22	•
T20	8	2.00	3.31	8.50	9.19	1.36	0.11	2.40	0.19	‖
		-	-	-	-	1.48	0.05	2.60	0.09	•
AVERAGE SAFETY FACTOR				VIBRATED		1.56	-	2.68	-	
				CONTROL		1.62	-	2.77	-	
3 CONTROL AND 8 VIBRATED BEAMS PER SERIES										• INDICATES BLAST LOCATION

Photograph 1
FIELD CYLINDER TEST PAD



Photograph 2
FIELD BEAM SPECIMEN
AFTER LOAD TEST



Photograph 3
FIELD BEAM TEST PAD

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 confined 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 confined 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.

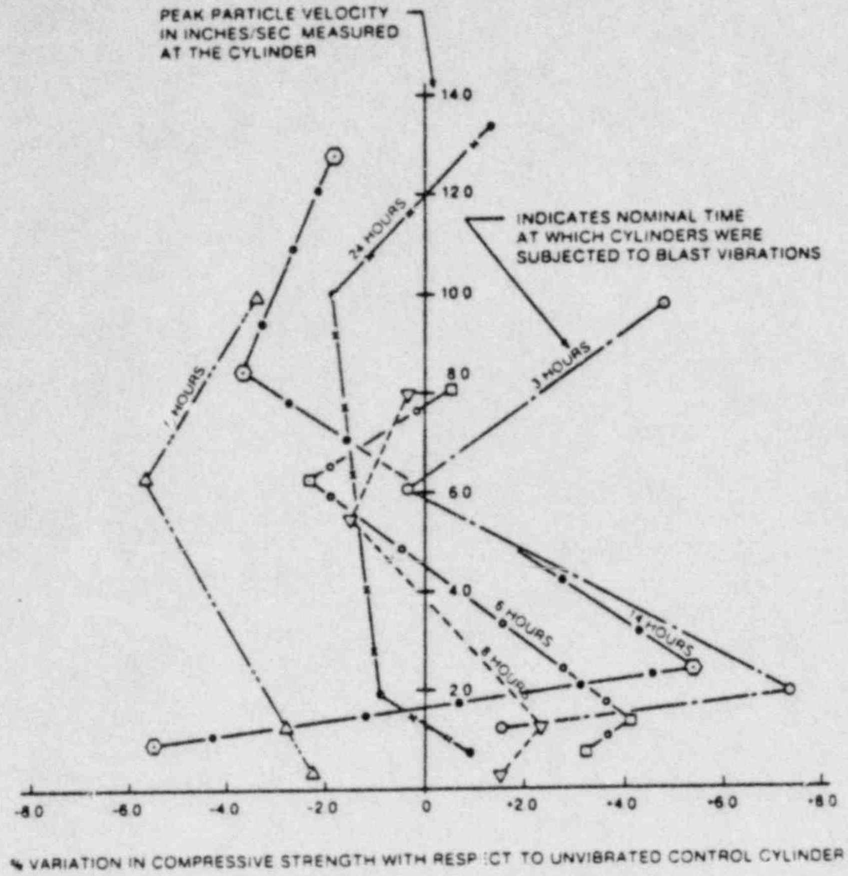


FIGURE 1
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 7 DAYS

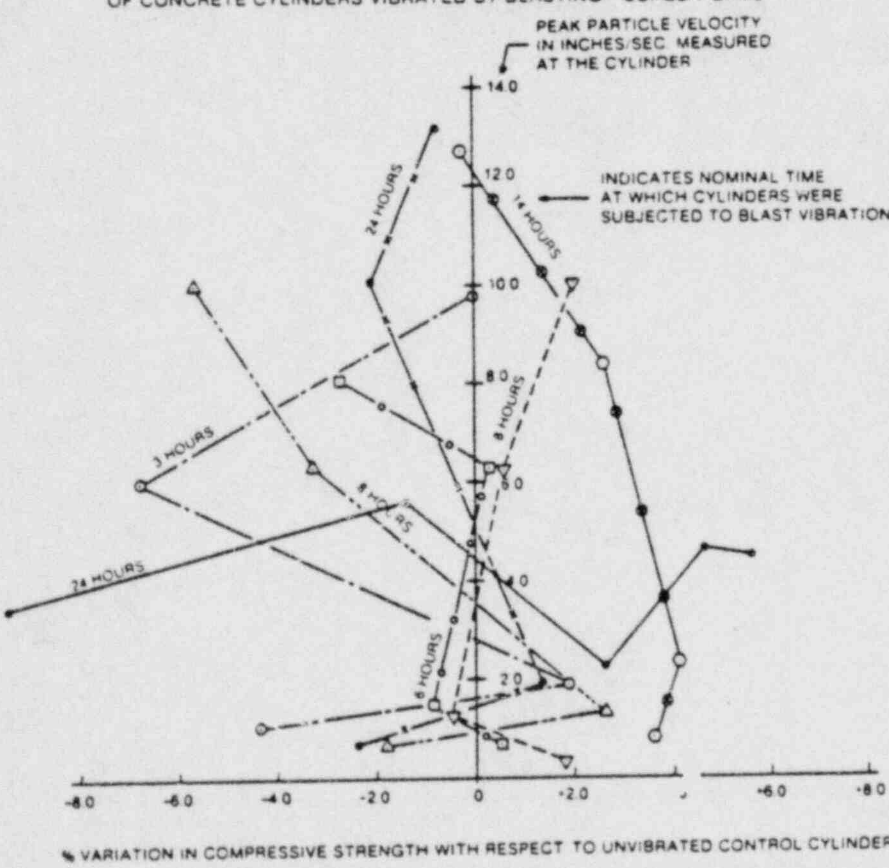


FIGURE 2
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED BY BLASTING - CURED 28 DAYS

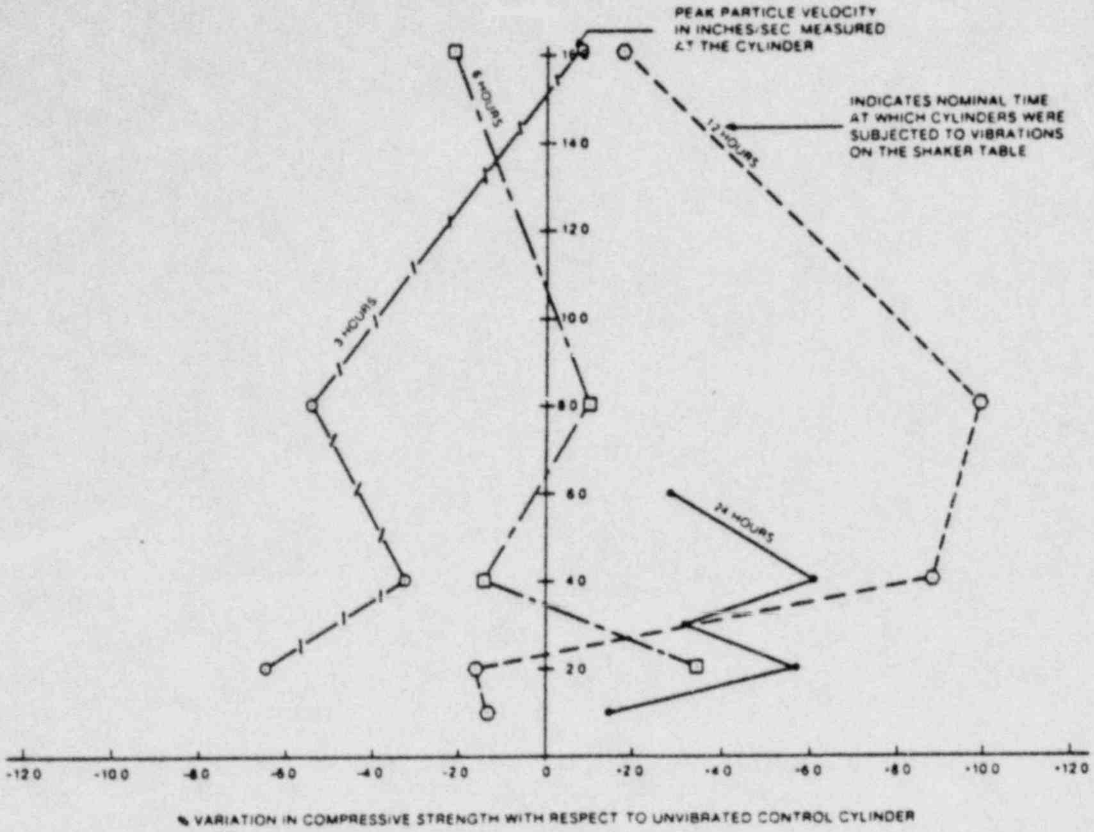
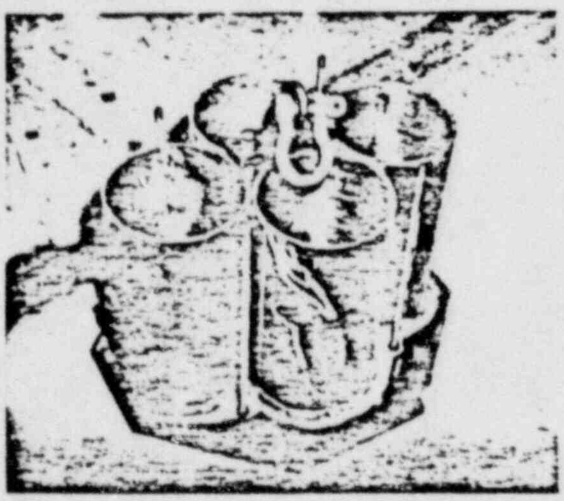
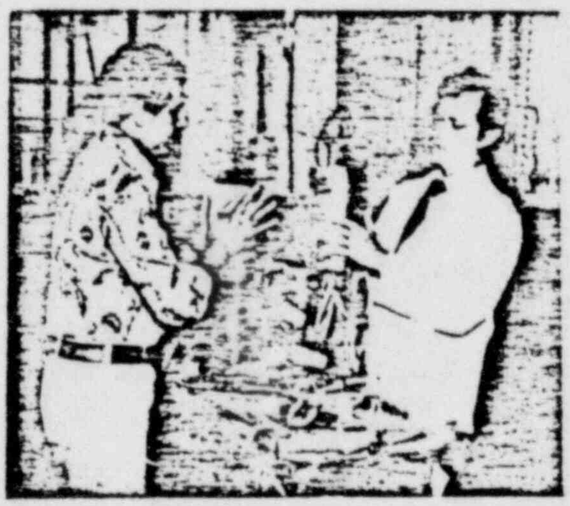


FIGURE 3
RELATIVE CHANGE IN COMPRESSIVE STRENGTH
OF CONCRETE CYLINDERS VIBRATED WITH FREQUENCY OF 100 HZ
CURED 28 DAYS



Photograph 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	MAXIMUM PEAK PARTICLE ACCELERATION 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	16

One Inch=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.

2. 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.

3. 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.

6. 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.

CONCLUSIONS

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)

APPENDIX - DIRECT REFERENCES

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_ Waddell, Joseph J. "Practical Quality Control for Concrete", McGraw-Hill Book Company, 1962, par. 7-8, Autogenous Healing.

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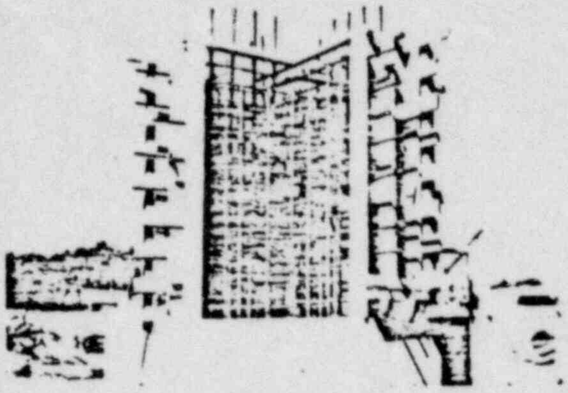
TABLE 3

SUMMARY OF FIELD WALL TEST VALUES

TEST WALL NO	CONC AGE AT BLAST IN HOURS	PEAK PARTICLE VELOCITY IN INCHES / SEC			NO BARS	ACTUAL PULL OUT LOAD		BOND SAFETY FACTOR ACTUAL/CALC		AVER WALL 28 DAY CONC PSI	NO CORES
		BASE	MID	TOP		AVER LOAD TONS	STD DEV TONS	AVER	STD DEV		
1A	4	6.1	3.92	12.7	46	25.9	0.91	2.51	0.087	4353	8
1B	14	10.69	9.87	9.59	46	26.3	0.60	2.73	0.062	3804	6
2A	4	2.48	-	7.69	48	26.1	0.79	2.55	0.077	4301	3
2B	14	0.97	-	3.79	47	26.4	0.70	2.72	0.072	3851	6
3A	CONTROL	-	-	-	48	26.18	0.59	2.55	0.057	4333	8
AVERAGE VIBRATED VALUES						26.18		2.63			
CONVERSION FACTORS ONE INCH = 25.4 MILLIMETERS ONE TON = 907.2 KILOGRAMS ONE PSI = 6.89 KILOPASCALS											



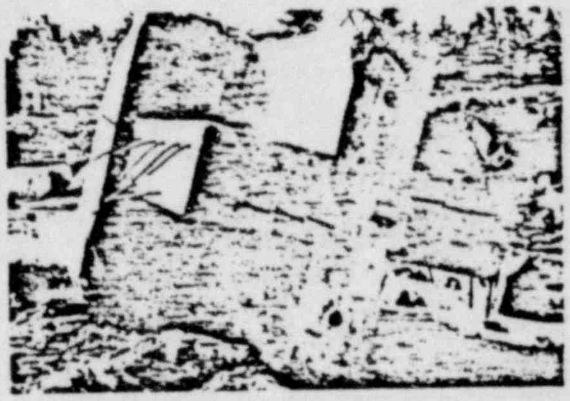
Photograph 6
FIELD TEST WALL SHOWING
REBARS EXTENDED FOR
PULL-OUT TESTING

TABLE 4

LABORATORY TEST PULL-OUT LOADS

IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS	NO SPEC	AVERAGE PULL-OUT LOAD POUNDS	STD DEV POUNDS
2	7	2	14,178	2053	8	17,106	2013
	28	2	17,088	1413	8	18,525	2482
3	7	2	12,750	1225	10	12,925	1430
	28	2	15,175	250	10	15,233	1330
4	7	2	12,213	738	12	13,929	1561
	28	2	15,450	1075	12	15,160	2387
CONCRETE CYLINDER STRENGTHS GIVEN IN TABLE 6 1000 POUNDS = 453.6 KILOGRAMS							



Photograph 7
FIELD TEST WALL AFTER
BEING BLASTED FROM FOUNDATION

TABLE 5

LABORATORY TEST CYLINDER STRENGTHS

IRRESPECTIVE OF GREEN CONCRETE AGE OR VIBRATION LEVEL

CONC BATCH	TEST DAY	CONTROL			VIBRATED		
		NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI	NO CYL	AVERAGE STRENGTH PSI	STD DEV PSI
1	7	3	3340	53.5	32	3265	116.4
	28	3	4007	62.4	31	4128	141.4
2	7	3	2740	49.7	10	2841	128.3
	28	3	3747	41.9	10	3706	103.4
3	7	3	2957	270	41	2820	166.7
	28	3	3543	118	42	3616	153.8
4	7	3	2690	49	22	2720	155.9
	28	3	3267	228.8	22	3405	181.7
ONE PSI = 6.89 KILOPASCALS							

TABLE 6

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.	4.0	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 VELOCITY REQUIREMENTS.

(2) PEAK PARTICLE VELOCITY SHALL NOT EXCEED 2 INCHES PER SECOND OR 0.5 INCHES PER SECOND AT 1400 FEET OR 4000 FEET FROM THE BLAST LOCATION RESPECTIVELY.

ONE INCH = 25.4 mm
ONE FOOT = 0.305m