Investigation of the Impact-Type Concrete Test Hammer

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This work describes a series of tests designed to determine the reliability of results, the feasibility of use, and the practical applications of the test hammer in construction control. Test results are compared to the published findings of other investigators and the reliability of calibration curves under various test conditions is carefully investigated. Indicated strengths are significantly affected by specimen size, restraint or clamping in testing machine, surface texture, mix proportions, and type of aggregate. Coefficient of variation over a wide variety of specimens average 18.8 percent and exceeded 30 percent for some groups of specimens. It is recommended that special calibrations be provided for each mix or change of aggregate, and that use of the test hammer on weak or young concrete be kept to a minimum because such testing may produce significant surface blemishes.

●THE first test series consisted of obtaining hammer rebound values for concrete cylinders selected at random from those being tested during the routine testing program. This series consisted of two hundred 6- by 12-in. and twenty-six 18- by 36-in. concrete cylinders, ranging in age from 28 days to 1 year and older, and varying in weight, curing conditions, water-cement ratios, air contents, cements contents, pozzolans, and aggregates. All cylinders were tested for compressive strength; thirty-two of the 6- by 12-in. and six of the 18- by 36-in. cylinders were also evaluated for modulus of elasticity.

Test hammer readings were obtained with the specimen in an upright position and the hammer held horizontal and normal to the surface of the specimen. The instrument was held firmly as the pressure was gradually increased until impact. Readings were taken within the center two-thirds portion around the cylinder. Care was taken so as to avoid obvious air pockets, honeycomb, and the immediate areas of previous impacts. Specimens were free from restraining load during the hammer testing, but were supported by hand immediately behind the impact area (Fig. 1).

The average rebound value "R" for each specimen was determined from the best suited 10 of 15 readings, (as per manufacturer's instructions, 10 readings nearest average of 15) as recommended in the booklet of operating instructions furnished by the manufacturer of the test hammer.

The second test series consisted of obtaining hammer rebound values on four 6- by 12-in. concrete cylinders under restraining load conditions. An average "R" was determined for each cylinder in an unrestrained condition in the same manner as outlined in the first test. Each cylinder was then placed in the compression machine, and a constant load was maintained while another average "R" determination was made. Average "R" values were determined for each cylinder at five successively increasing constant loads (Figs. 1 and 2).

The third test series was designed to determine the possible use of the test hammer on concrete at early ages, and to measure variations in the rebound value due to different

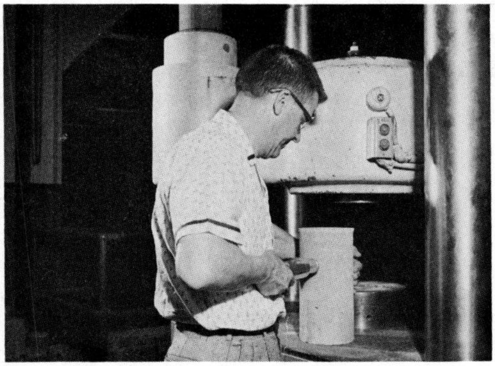

Figure 1. Testing an unrestrained specimen with the concrete test hammer.

aggregate, surface textures, restraining load, and surface shapes. Two types of aggregates were used in similar mixes (Table 1); (a) local river coarse aggregate and sand, and (b) crushed limestone coarse aggregate and river sand. One slab, 14 by 26 by 6 in., was made from each mix. One-half of this slab was cast against plywood, the other half was cast against a steel liner. Fifteen companion cylinders were also made from each mix; five in steel molds, five in tin can molds, and five in paper carton molds.

Slabs were stored in the mix room, stripped at 8 hr, and covered with plastic film to prevent loss of moisture. The cylinders to be tested at 8, 16, and 24 hr were stored in 100 percent relative humidity at 73.4 F and stripped at time of testing. The 3- and 7-day cylinders were stored in the mix room with the slabs, stripped at 24 hr, and covered with plastic to prevent loss of moisture.

Both types of surfaces of each slab and one cylinder from each mix and surface texture were read in an unrestrained condition with the hammer at each time interval. The cylinders were also read while under an axial restraining load.

The fourth series of tests was made to determine if there was any difference between curved and flat surfaces when both were restrained. The mix using river coarse aggregate and sand was the same as in series 3. Four 5- by 5- by 10-in. prisms were cast against plywood so that specimens having flat test surfaces could be restrained (Fig. 3). Four 6- by 12-in. cylinders were cast in steel molds, four in tin can molds, and four

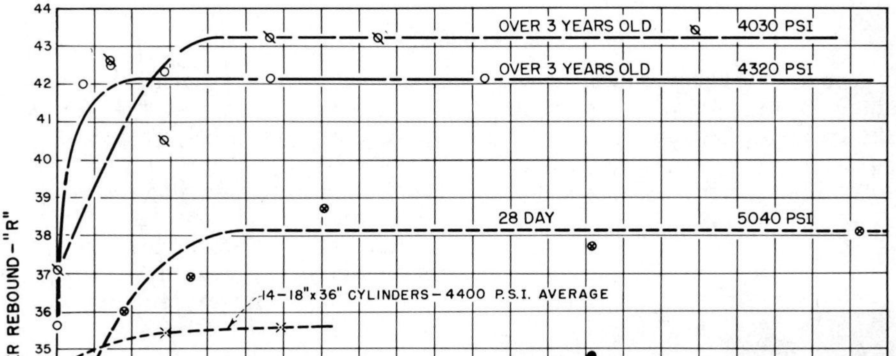

Figure 2. Restraining load vs rebound readings 6- by 12-in. cylinders—test series No. 2.

TABLE 1

CONCRETE PROPERTIES—SERIES 3, 4, AND 5
(Cubic Yard Batch)

Property	Mix No. 1 River Aggregate	Mix No. 2 Crushed Limestone
W/c ratio	0.50	0.52
Water content, lb	261	272
Cement content, lb	519	526
Percent sand	34	38
Slump, in.	3.2	2.7
Percent air	3.0	2.4
Unit weight, pcf	147.3	149.1
Maximum size aggregate, in.	1½ in.	1½ in.

in paper carton molds. The prisms were stored in the mix room, stripped at 8 hr, and covered with plastic. The cylinders to be tested at ages of 8, 16, and 24 hr were stored in 100 percent relative humidity at 73.4 F until they were stripped at time of testing. The 72-hr cylinders were stripped at 24 hr, moved from the fog room to the mix room with the prisms, and covered with plastic to prevent loss of moisture. All specimens were evaluated in both a restrained and unrestrained condition.

Because of the difference in hammer readings for prisms and cylinders, it was thought that the initial curing condition might be affecting the results, so the fifth test series was conducted to eliminate this difference. This series was identical to the fourth series except all specimens were placed in 100 percent relative humidity at 73.4 F, stripped at 8 hr, and stored in the fog room until time of testing.

The difference in readings between loaded and unloaded specimens (Fig. 2) raised the question as to whether this could be caused by the stress condition or be simply a question of effective mass or restraint. This led to the testing under load of 14 heavy 18- by 36-in. cylinders containing 6-in. maximum size aggregate.

DISCUSSION

The purpose of this investigation was to evaluate the rebound readings obtained with the hammer on miscellaneous specimens and on specially prepared specimens by comparing the indicated compressive strength obtained from these readings with compressive strength results obtained by conventional test methods.

Since the instructions furnished with the test hammer recommend the best 10 out of 15 readings to determine "R" and N. G. Zoldners (1) recommends the best 9 out of 15 readings, a calculation was made to determine any appreciable difference between the two methods which might affect the results of this investigation. Information furnished with the test hammer states that the mean value of "R" can be assumed to be reliable when 10 readings of the 15 deviate not more than ±2.5 with an "R" of 15, ±3 with an "R" of 30 and ±3.5 with an "R" of 45. The principal difference between the two methods seems to be that the manufacturers require only 10 reliable readings while Zoldners recommends the use of the middle 9 of 15 reliable readings. Only 15 readings were taken on each specimen; and while the "best 10"

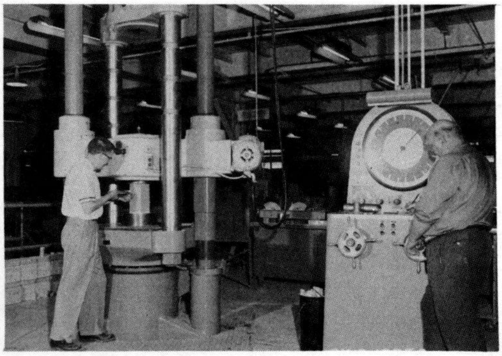

Figure 3. Testing a restrained specimen with the concrete test hammer.

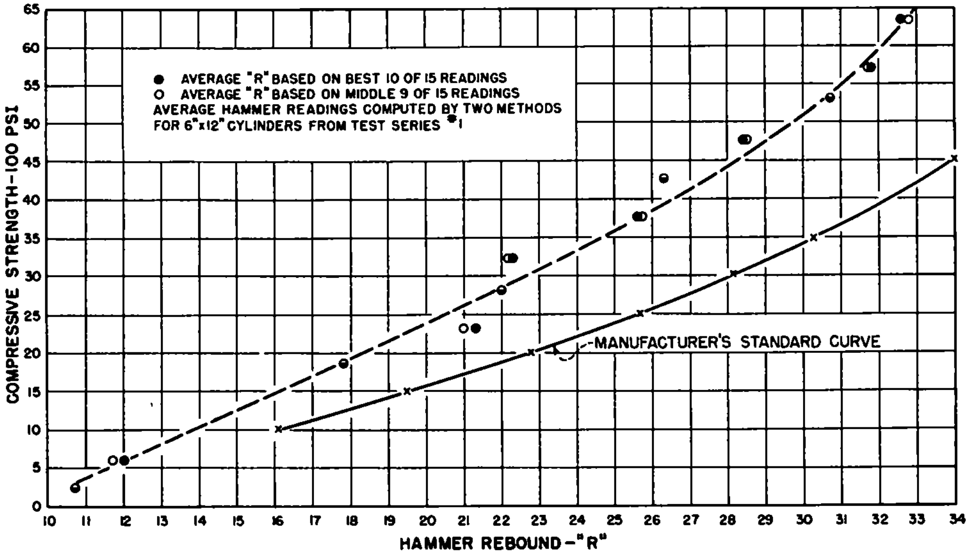

Figure 4. Compressive strength vs hammer rebound readings.

TABLE 2

DEVIATION OF COMPRESSIVE STRENGTH VALUES AT SAME AVERAGE REBOUND READINGS FOR ALL CONCRETE CYLINDERS— TEST SERIES 1, 2, 3, 4, and 5

R	Avg Strength (psi)	No. of Specimens	Standard Deviation (psi)	Coefficient of Variation (%)
10	200	2	40	20.0
11	533	6	140	26.3
12	723	4	179	24.8
13	759	7	212	27.9
14	1,205	4	157	13.0
15	1,103	4	35	3.2
16	1,697	7	526	31.0
17	1,604	7	387	24.1
18	1,833	7	498	27.2
19	2,513	4	509	20.3
20	2,820	15	604	21.4
21	2,885	11	604	20.9
22	3,037	12	713	23.5
23	3,499	17	548	15.7
24	3,554	9	780	21.9
25	3,769	15	519	13.8
26	4,029	16	596	14.8
27	4,045	23	732	18.1
28	4,723	21	642	13.6
29	4,493	17	728	16.2
30	5,075	20	597	11.8
31	4,955	13	1,014	20.5
32	5,579	13	911	16.3
33	5,575	8	495	8.9
34	4,679	2	1,121	24.0
Avg		10	531	18.8

of the 15 readings seldom exceeded the manufacturers' recommended limits, the deviation of all 15 readings was seldom within the proposed limits for reliability.

In determining the best 10 of 15 readings, the 15 readings were averaged and then the 5 readings with the greatest deviation from this average were eliminated. The remaining 10 readings were then averaged to obtain "R". Zoldners' method was modified due to the fact that only 15 readings were taken on each specimen and not all of these 15 readings were within reliable limits. The highest three and the lowest three readings were discarded, and the middle nine averaged to determine "R". These middle nine readings were well within the limits of reliability.

This comparison of methods was made on the first 124 cylinders evaluated in test series 1. While it was found that there may or may not be a slight difference in "R" values for each specimen, the difference is negligible for the average of a number of specimens. These data are shown in Figure 4, and it can be seen that the resulting curve by either method would coincide at the majority of points.

No valid results can be obtained by indiscriminate use of the test hammer. This is shown in Figure 5 where "R" values are plotted against the corresponding compressive strengths for the specimens from test series 1, 3, 4, and 5. The standard deviation of compressive strengths at the same average hammer reading for these specimens fluctuates from 25 lb per sq in. to 1, 121 lb per sq in. and the coefficients of variations range from 3 to 31 percent (Table 2).

"R" values for the 18- by 36-in. cylinders are higher within any strength range than for corresponding 6- by 12-in. cylinders (Fig. 5). The methods employed in casting the large cylinders make it improbable that the higher readings are due to striking large aggregate near the surface. Both the 6- by 12-in. and 18- by 36-in. cylinders were evaluated in an unrestrained condition. Since the specimens with the greater weights have the higher readings, it can be assumed that some of the energy of the hammer impact on the smaller specimen displaced the cylinders and resulted in lower rebound readings. When this possible displacement was restricted by a restraining load on the specimens in test series 2, 3, 4, and 5, the "R" values obtained were higher than those obtained on the same specimens in an unrestrained condition (Figs. 2 and 6).

Grieb (2) found that 6- by 12-in. cylinders did not have enough mass or rigidity to give reliable rebound readings unless restrained. However, the rebound values obtained in this investigation on unrestrained cylinders were within the limits of reliability mentioned earlier in the discussion. Further, the standard deviations and coefficients of variation (Table 5) for specimens both unrestrained and effectively restrained are of the same order when the specimens are in the same weight and size category (Fig. 6). Thus, it can be concluded that "R" values determined from the unrestrained condition are no less valid than those obtained in the restrained condition. However, "R" values determined from different conditions or different weight and size specimens cannot be compared. From these facts, it is evident that structural mass might even affect results in field applications.

The wide deviation in strength for the same "R" values (Table 2) can be narrowed considerably by segregating the different specimens according to common factors such as age, aggregate, size, surface, etc. This is shown in Figure 5 and given in Tables 2 and 3 where the average standard deviation is reduced from 531 lb per sq in. to 106 lb per sq in. and the average coefficient of variation is reduced from 18.8 to 9.6 percent by separating the specimens according to aggregate only.

As the restraining load on a specimen increases, the average rebound reading also increases until a maximum is reached, after which an increase in load does not appreciably affect the rebound value (Fig. 2). The restraining load at which the "R" value remains constant appears to vary with the individual specimen; however, from these tests, the effective restraining load for consistent results appears to be about 15 percent of the breaking strength of the specimen. This does not correlate closely with the 250-lb per sq in. effective restraining load indicated by Green (3) or with the 300-lb per sq in. effective restraining load indicated by Grieb (2). Note the inconsistency in the relationship of rebound reading to compressive strength for the specimen shown in Figure 2.

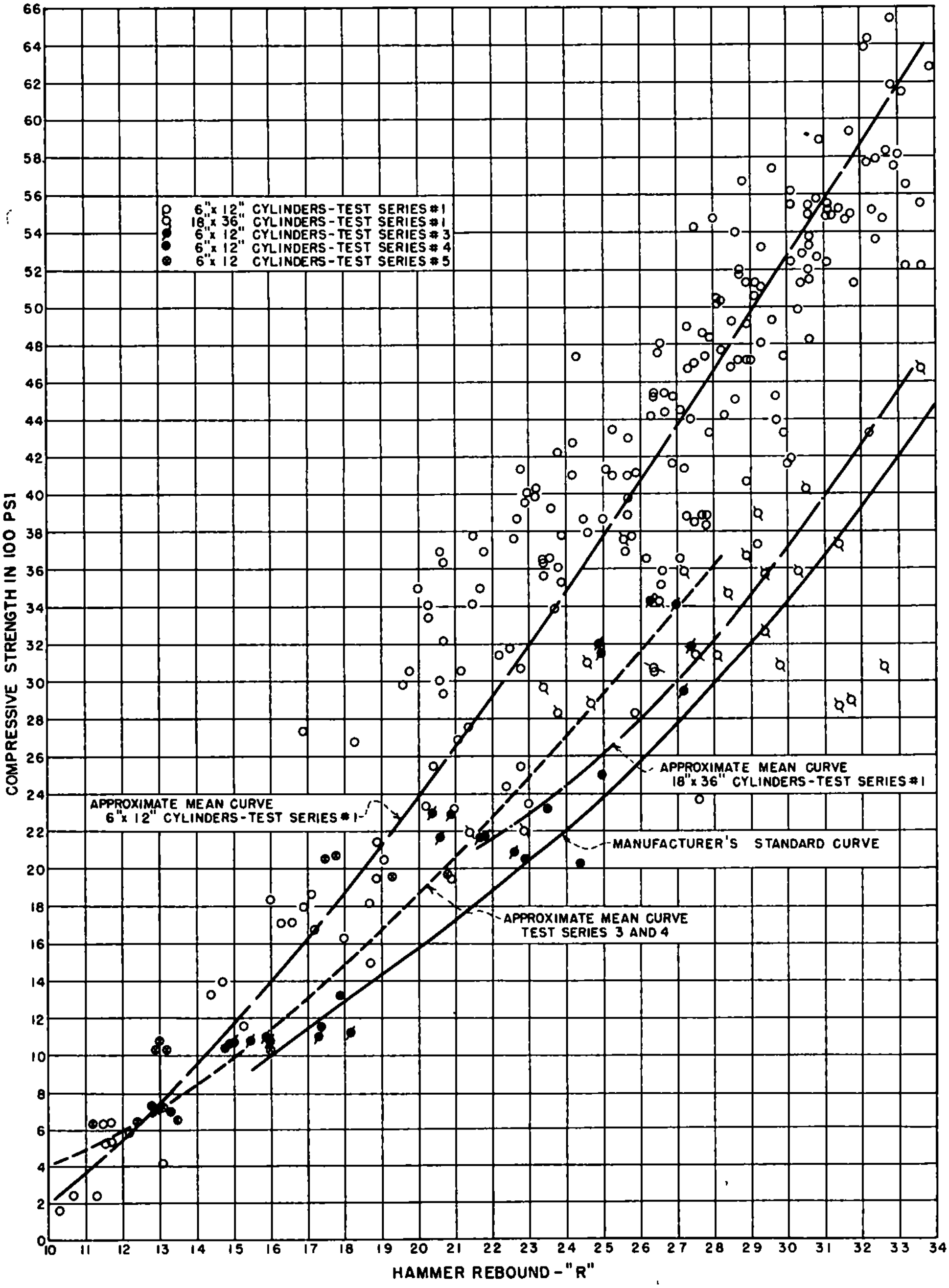

Figure 5. Compressive strength vs rebound reading for unrestrained cylinders.

The restrained 18- by 36-in. specimens exhibited the same tendency to give higher "R" readings under load, but to a lesser degree than did the 6- by 12-in. cylinders (Fig. 2). These data clearly indicate that the "R" reading is a function of the size and rigidity of the test mass. It is probable that the stress condition contributes slightly toward the higher readings in restrained specimens. The size of unsupported areas of a thin structure or the backfilled condition of field structures would probably make a significant difference in the readings obtained.

The impact hammer should be specially calibrated for the conditions of field use, including the size and type structure, aggregate source, mix proportions, and concrete age.

It was determined from the third test series that the rebound readings are affected by the types of aggregate in the concrete. This series showed "R" values for the concrete containing local river aggregate were consistently higher than those for the specimens containing crushed limestone aggregate (Fig. 8).

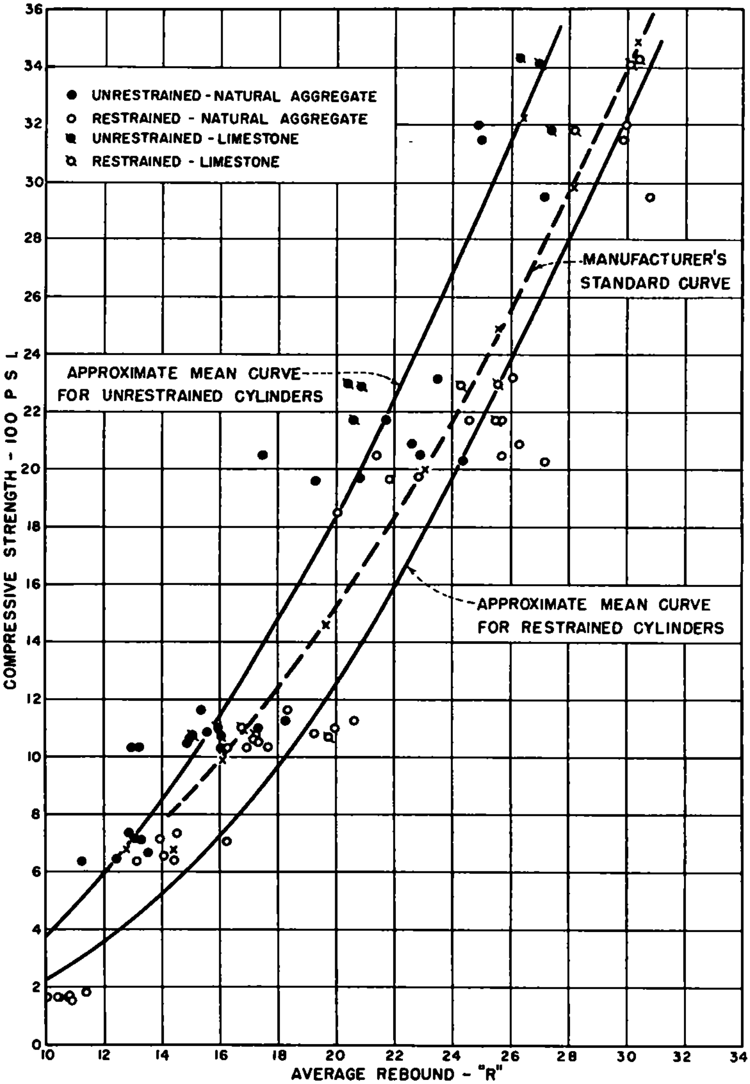

Figure 6. Comparison of rebound readings for 6- by 12-in. cylinders with and without restraining load—test series No. 3, 4, and 5.

TABLE 3

DEVIATION OF COMPRESSIVE STRENGTH VALUES AT SAME AVERAGE REBOUND READINGS FOR ALL CONCRETE SPECIMENS WITH LOCAL RIVER AGGREGATE—TEST SERIES 3, 4, AND 5

R	Avg Strength (psi)	No. of Specimens	Standard Deviation (psi)	Coefficient of Variation (%)
10	169	3	5	3.0
11	183	3	6	3.3
12	245	3	99	40.4
13	700	4	36	5.1
14	689	4	38	5.5
15	720	1	-	-
16	922	3	152	16.5
17	1,046	3	12	1.1
18	1,160	1	-	-
19	1,028	5	155	15.1
20	1,014	4	168	16.6
21	2,005	2	45	2.2
22	1,645	2	325	19.8
23	-	0	-	-
24	2,121	2	51	2.4
25	2,123	3	51	2.4
26	2,183	3	97	4.4
27	2,029	1	-	-
28	-	0	-	-
29	2,824	2	324	11.5
30	3,076	2	125	4.1
31	3,100	1	-	-
32	3,100	1	-	-
Avg		3	106	9.6

Results from the third, fourth, and fifth test series show that flat surfaces give higher hammer readings than cylindrical surfaces (Fig. 7). Companion cylinders cast in steel, tin can, and paper carton molds showed no significant difference between the steel-molded and tin can-molded specimen, but the paper-molded specimens gave higher readings (Fig. 8). This was true even though the steel-molded and tin-molded specimens had a smoother surface and might indicate that the paper form withdraws moisture from the concrete, thus lowering the water-cement ratio at the surface and resulting in a higher strength in this area. Since the hammer primarily tests the surface, it could be possible for the hammer to reflect a nonexistent high strength from a hardened surface.

The third, fourth, and fifth test series showed that the test hammer has no value in testing concrete at very early ages because the hammer rebounds were not great enough to be read accurately on the scale, and further, that the hammer severely scarred the concrete, thus prohibiting its use on green concrete anywhere that it might be exposed to view (Fig. 9). Surface texture causes little significant difference in "R" values at early ages (Fig. 10). This is probably due to the fact that the concrete is still so soft that any difference due to texture is overshadowed by the effect caused by the crushing and displacing action of the hammer on green concrete.

A check was made to correlate "R" with the modulus of elasticity of the concrete specimens tested in series 1. As shown in Figure 11, no valid correlation can be made directly between "R" and elasticity. However, a satisfactory relationship between "R" and elasticity might be obtained if the hammer were to be calibrated for each individual mix tested. Further tests would be required to draw any valid conclusions, and the value of this information is questionable in relation to its applicability and to the expense of deriving it.

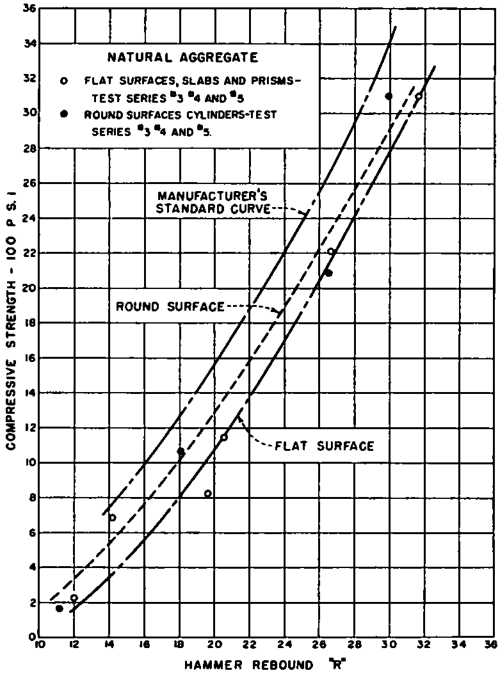

Figure 7. Comparison of surfaces.

Investigations by the Corps of Engineers (4) were extensive enough to conclude that hammer readings taken on dry concrete surfaces will be generally higher than readings taken on wet surfaces, and that hammer readings taken with the hammer held in a horizontal position are generally higher than those obtained with the hammer in a vertical position.

From observations in this and other previously published investigations, it appears that the impact-type concrete test hammer gives a correlation between compressive strength of concrete and rebound values. However, indiscriminate use of the hammer will give misleading results. The deviation in strengths indicated by any rebound value can be narrowed from wide limits to reasonable limits by calibration of the test hammer. A calibration should be made for each mix being used on a job under both wet and dry surface conditions and with the hammer both vertical and horizontal. Correction factors should be derived to compensate for use of the

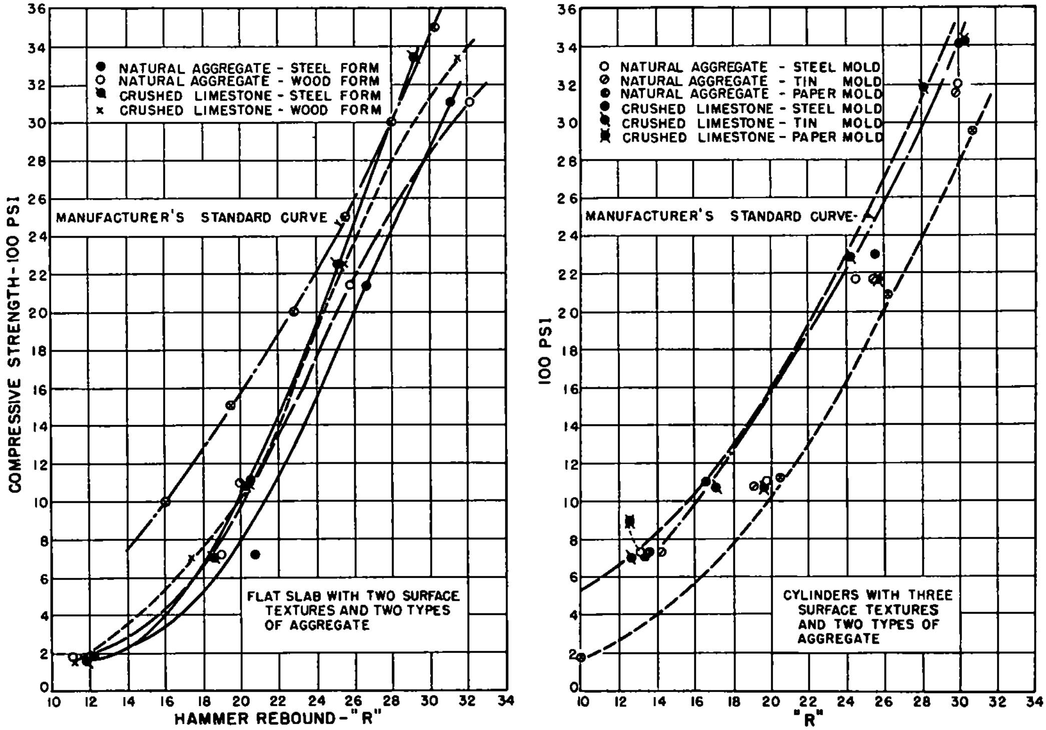

Figure 8. Comparison of shapes, surface textures and aggregates—test series No. 3.

TABLE 4

DEVIATION OF AVERAGE OF REBOUND READINGS WITHIN NARROW STRENGTH RANGES FOR CONCRETE CYLINDERS— TEST SERIES 1

Strength Range 100 Psi	No. of Specimens	Avg, R	Standard Deviation	Coefficient of Variation
0- 5	7	10.7	1.1	10.3
5-10	5	11.7	0.2	1.7
10-15	3	15.9	2.0	12.6
16-18	4	17.0	1.3	7.6
18-20	6	18.1	1.6	8.8
20-22	4	20.6	1.7	8.3
22-24	4	23.0	2.9	12.6
24-26	3	24.8	3.3	13.3
26-28	4	19.4	1.9	9.8
28-30	8	25.2	4.2	16.7
30-32	12	24.8	3.9	15.7
32-34	4	23.5	3.6	15.3
34-36	14	25.7	4.1	16.0
36-38	17	24.5	2.8	11.4
38-40	15	25.7	2.0	7.8
40-42	14	26.3	2.6	9.9
42-44	9	27.0	2.6	9.6
44-46	12	27.5	1.1	4.0
46-48	12	28.4	2.1	7.4
48-50	10	28.5	1.2	4.2
50-52	12	29.2	1.1	3.8
52-54	12	31.0	1.4	4.5
54-56	17	30.8	1.5	4.9
56-58	6	31.1	1.7	5.5
58-60	6	32.6	1.1	3.4
60-65	6	32.8	0.6	1.8

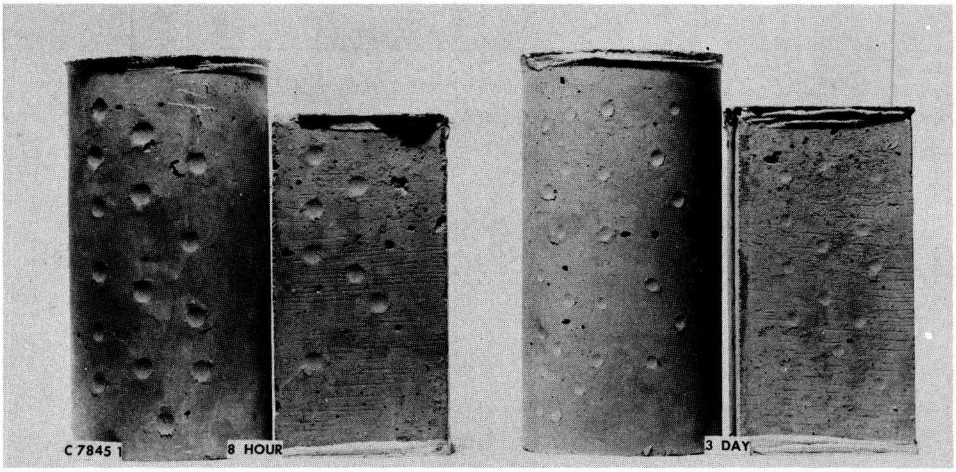

Figure 9. Early age specimens showing pocking due to concrete test hammer impact. Eight-hour specimens on left, and 3-day specimens on right.

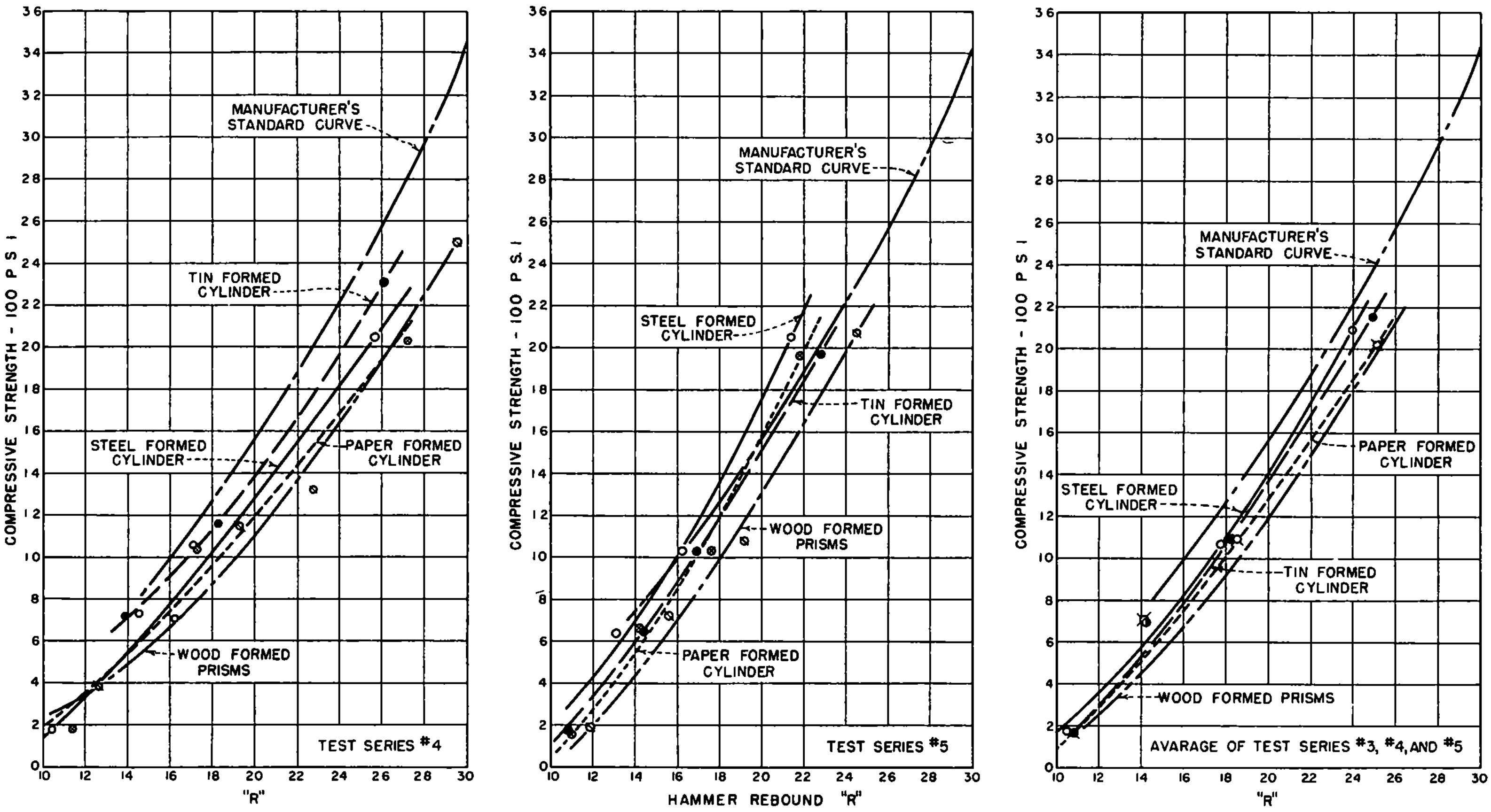

Figure 10. Comparison of surface textures and shapes—test series, 3, 4 and 5—natural aggregate.

TABLE 5

DEVIATIONS OF COMPRESSIVE STRENGTH TESTS AND HAMMER REBOUND READINGS ON RESTRAINED AND UNRESTRAINED 6- BY 12-IN CYLINDERS—TEST SERIES 3, 4, AND 5

		Compressive Strength			Unrestrained Condition			Restrained Condition		
No. of Cylinders	Age (hr)	Psi	Standard Deviation (psi)	Coefficient of Variation (%)	Avg, R	Standard Deviation	Coefficient of Variation	Avg, R	Standard Deviation	Coefficient of Variation
5	8	172	6	3.5	Too low to be read	-	-	10.7	0.4	3.7
6	16	682	36	5.3	12.7	0.8	6.3	14.4	0.9	6.3
12	24	1,076	39	3.6	15.4	1.4	9.1	18.1	1.4	7.7
12	72	2,131	120	5.6	21.4	1.8	8.4	24.8	1.8	7.3
6	7-day	2,221	163	5.1	26.3	1.0	3.8	29.9	0.8	2.7

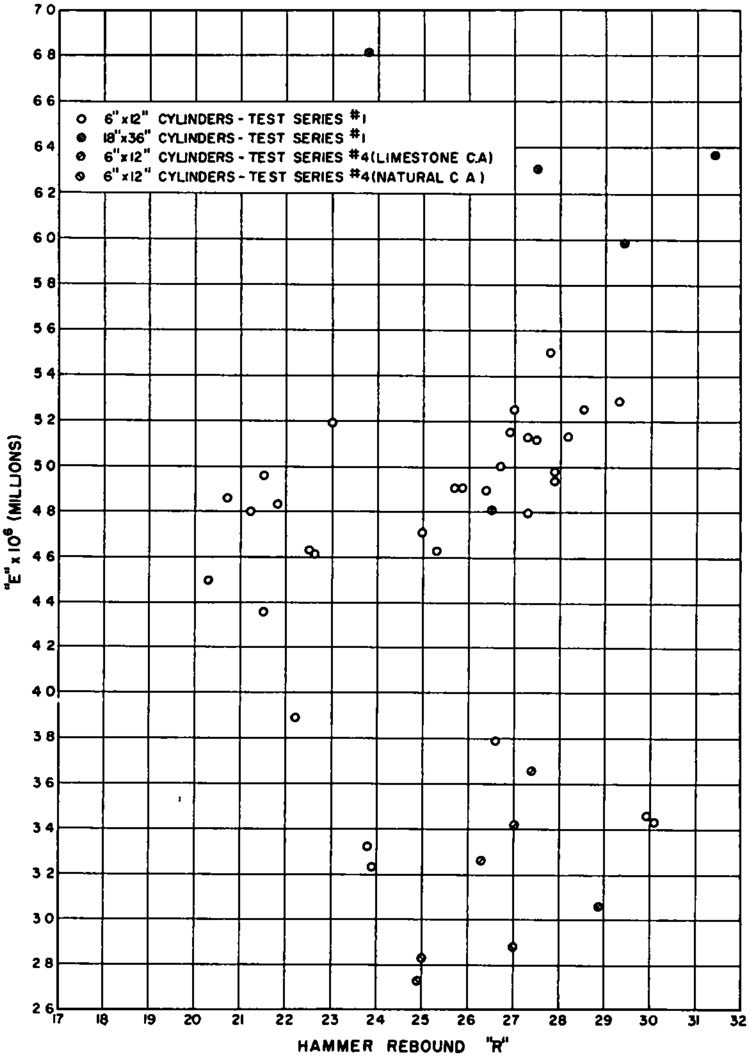

Figure 11. Comparison of hammer readings and modulus of elasticity.

hammer on other than flat surfaces, for use of the hammer at angles other than horizontal and vertical, and to compensate for deviations due to surface textures from forming materials other than those used for the original calibrations. The curves furnished by the manufacturer should not be used. Grieb found that the manufacturer's curve was conservative in practically every instance which the investigation verifies so long as the specimen is small and young or unrestrained. However, the data shown in Figures 2 and 6 indicate that for either old concrete, heavy specimens, or restrained specimens, the reverse is likely to be true.

At this time, there have been no investigations involving the use of the test hammer on reinforced concrete. It is likely that very heavily reinforced concrete will cause erratic hammer readings which would preclude its use for testing in this type of construction.

The test hammer, when calibrated properly, could be an effective aid to field testing of concrete, but no amount of calibration will be sufficient for it to replace the conventional test methods.

The expense of calibration should be weighed against its value as a simple and rapid check for concrete quality. Above all, its limitations and its proper use should be understood by all concerned prior to its acceptance as a testing tool.

CONCLUSIONS

1. A usable relationship exists between readings (R) obtained from the impact-type concrete test hammer and the compressive strength of concrete (Tables 2, 3, 4, and Figs. 2, 4, and 5). This relationship will be closer if special calibration curves are provided for each particular application.
2. The test hammer is not suitable for either very early age tests or where concrete strength is less than 1,000 lb per sq in., (Fig. 9).
3. Different surface shape, texture, aggregate types, condition of cure, or moisture content cause measurable variation in rebound readings.
4. Rebound readings increase with restraining loads up to about 15 percent of specimen strength, indicating that the hammer readings are a function of the size or rigidity of the test mass (Fig. 2).
5. The use of a test hammer on concrete specimens selected at random is not reliable due to the extreme variations of strengths obtained from concretes having the same "R" value (Tables 2 and 4 and Fig. 5).
6. Other factors being equal, flat surfaces produce higher hammer readings than rounded surfaces (Figs. 7 and 10).
7. The "R" value cannot be directly correlated to the modulus of elasticity of concrete (Fig. 11).

REFERENCES

1. Zoldners, N.G., "Calibration and Use of Impact Test Hammer." ACI Journal Proc., Vol. 54, p. 161 (Aug. 1957).
2. Grieb, William E., "Use of the Swiss Hammer for Estimating the Compressive Strength of Hardened Concrete." Public Roads 30:2, p. 45 (June 1958).
3. Green Gordon W., "Test Hammer Provides New Method of Evaluating Hardened Concrete." Also a discussion by six authors, ACI Journal Proc., Vol. 51, p. 249 (Nov. 1954).
4. "Investigation of the Schmidt Concrete Test Hammer." U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper No. 6-267 (June 1958).

Discussion

W.H. CAMPEN, Omaha Testing Laboratories—Although the test hammer is not an accurate instrument for determining the compressive strength of concrete, it is a fine qualitative instrument. As such it can be used for a number of purposes. I wish to mention two cases in which it proved very useful.

One case involved a large number of pedestals in an electrical sub-station. Due to cracking and spalling when the superstructures were being placed, the concrete in the pedestals was questioned by the engineer. The writer was engaged to investigate. He eventually tested all the pedestals with the hammer and classified the strengths as good, doubtful, and poor. Cores were then taken from the representative groups and tested for strength and cement content. The results confirmed the indications of the hammer.

Another case involved an exposed floor in a power plant. Soon after the floor was poured, a cold wave came along and although the floor had been covered and provided with heat, parts of it failed to set properly. The hammer identified the parts which had set properly as well as those which had not. Eventually, during additional curing, the hammer was used to indicate when the concrete in all of the floor attained uniform strength.