PROGRESS REPORT ON THE RELATIONSHIP BETWEEN LABORATORY AND FIELD PERFORMANCE OF LIGHTWEIGHT AGGREGATE CONCRETE

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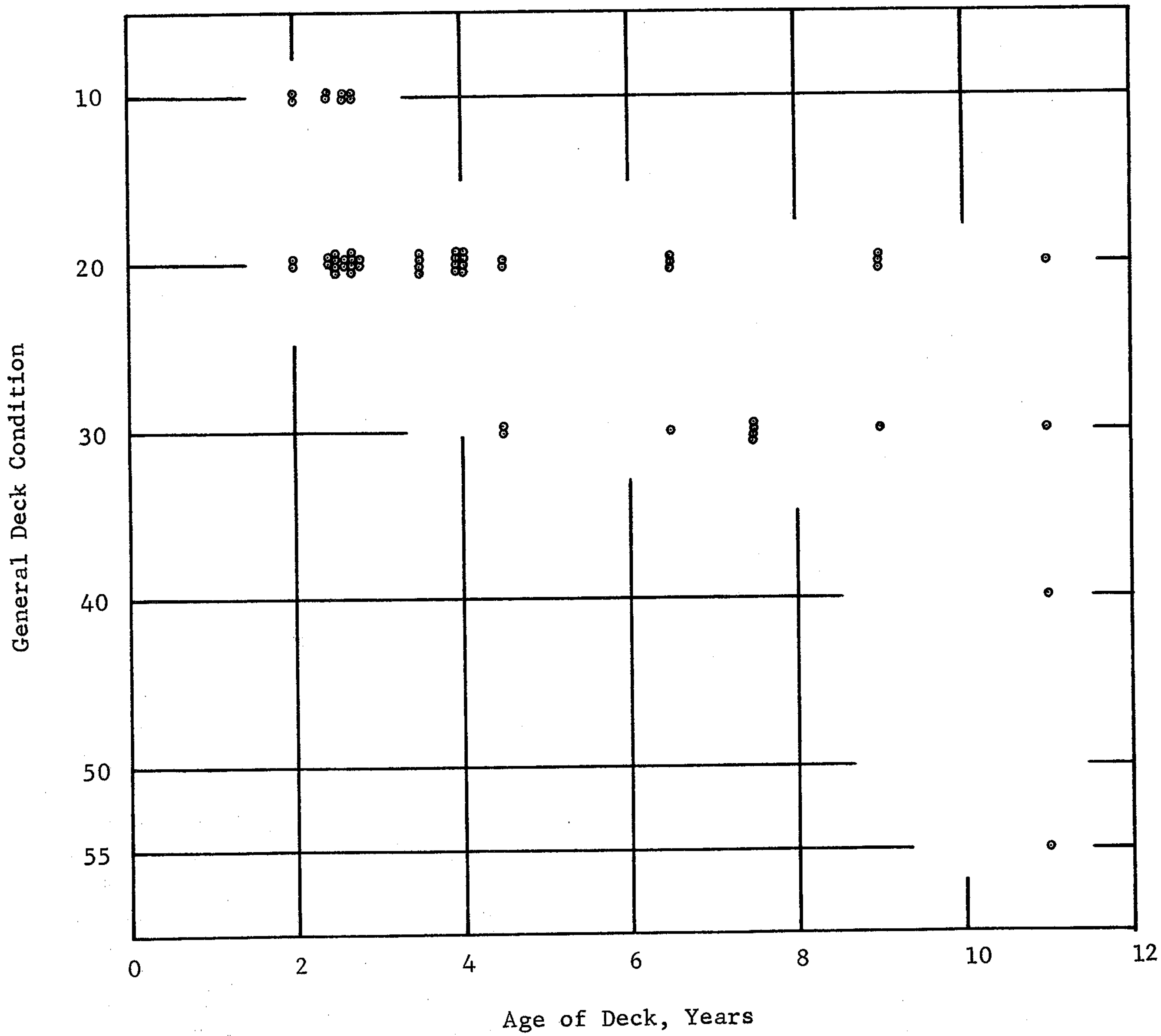

Fig. 1. Relationship Between General Deck Condition and Age of Deck.

Construction records showed that the deck was cast using a six-sack-per-cubic-yard mix with Haydite lightweight aggregate and 350 lbs. of sand admixture to provide workability. The gross water-cement ratio of the mix was 7.1 gallons per sack, (0.63 by weight). Air content of the fresh concrete averaged eight percent.

As stated earlier, the quality of the concrete varied considerably from pour to pour--two being of relative good quality and two of relatively poor quality. A plan view showing the deterioration is given in Figure 2. It should be pointed out here that the pour numbers are arbitrary and do not represent construction sequence. Pour number one showed only slight surface scaling and minor random cracking and in general showed no serious distress. Pour number two had extensive scaling and moderate cracking with 15 percent of the area delaminated. Pour number three had minor random cracking and scaling and minor delamination. Pour number four was in the worst condition and showed minor cracking and severe scaling with several large areas of open delamination. One area of open delamination had severe cracks causing loss of structural integrity. Three months after the survey was made, the badly cracked and delaminated area failed completely leaving a two-foot hole in the deck. A 7- by 40-foot section of the slab has since been replaced.

Study of Cores. Twenty-one, four-inch cores were taken from seven locations on the bridge deck. Each core was subjected to visual and low magnification examination, load deformation determinations and impact hammer readings. Thin sections were made from cores from each location and studied under the petrographic microscope. Some of the larger pieces of aggregate were removed from the cores and subjected to differential thermal analysis.

To supplement information obtained from the cores, laboratory specimens were cast from three concrete mixes using lightweight aggregate from the same source as that used in the bridge deck but manufactured 11 years later. Two of these mixes were made to conform as closely as possible to the mix design used in the bridge deck.

Visual Examination. All but six of the twenty-one cores contained at least one vertical crack. For the most part, these cracks extended from the bottom upward, a distance of 1/2 to 2/3 the height of the core. Three of the 11 cores incorporating reinforcing bars were cracked from the top down to and parallel to the steel, but the steel did not show excessive rusting.

Load Deformation. Each of the cores were subjected to load deformation determinations with an Instron testing machine. The total load and deformation between loading heads was recorded continuously for zero load to 1,630 psi (20,000 lbs.

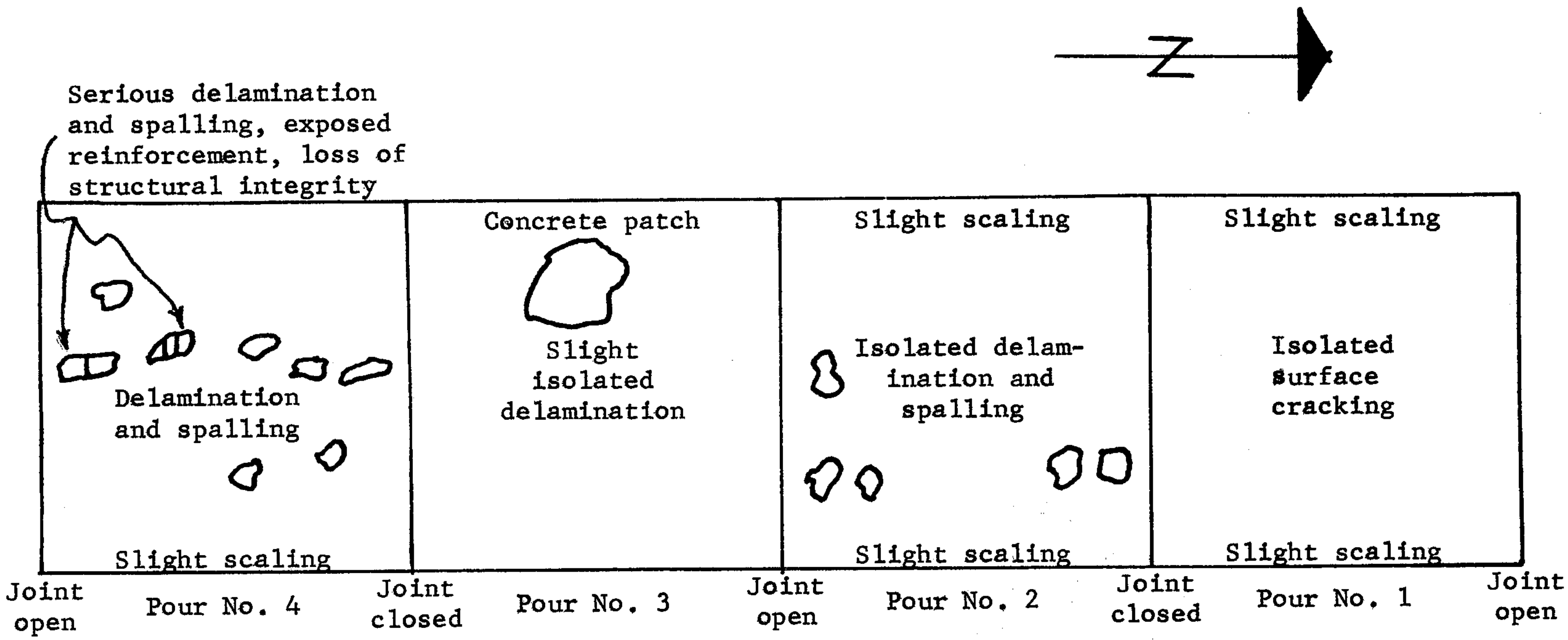

Fig. 2. Plan View of Deer Creek Bridge Deck Showing Deterioration.

total load). The indicated modulus of elasticity between 14,000 and 18,000 lbs. total load was calculated for each core. These values of indicated modulus of elasticity are given in Table 1.

Impact Hammer. Determinations of impact hammer readings were made on each of the cores and on specimens from the laboratory mixes. Comparisons of compressive strength with hammer reading and indicated modulus of elasticity with hammer readings are given in Figure 3 and 4. Using Figure 3 in conjunction with Table 1, it can be seen that these data indicate sufficient compressive strength was obtained in the deck.

As indicated by Figure 4 or by Table 1, the cores were very flexible--an average indicated modulus of elasticity of only 0.92 million psi was obtained from the 11-year-old concrete while 28-day specimens from the laboratory mixes had an average indicated modulus of elasticity of 1.26 million psi. This tends to point out a significant difference between the materials used in the deck and those used in the laboratory mixes.

Petrographic Analysis. This study was conducted by Dr. Horace R. Blank, Research Geologist. From visual and low-magnification observation, he reports:

> "Most of the pieces of synthetic coarse aggregate are light gray, but some are olive, orange, red, or black. A few pieces have darker rinds. All pieces have a rather earthy or chalky luster. Under the stereoscopic microscope at high magnification most pieces prove to be very minutely vesicular, but not greatly expanded."

Petrographic thin sections from at least one core from each location on the bridge deck were prepared and studied under the petrographic microscope. Dr. Blank reports:

> "Considerable difficulty was experienced in obtaining sections of the concrete thin enough to determine the nature of the synthetic aggregate, because of the dark color and fragile nature of many of the pieces. In every section studied under the petrographic microscope most of the aggregate pieces were isotropic and were glass, even though not thoroughly expanded to glass sponge. However, in every section at least one piece was found that was anisotropic and incompletely vitrified, and should be considered clay or shale."

Differential Thermal Analysis. DTA was performed on some of the larger pieces of aggregate removed from the cores. In order to discount any peaks caused by the cement that may have been included, a DTA pattern for cement mortar (Ottawa sand)

Table 1

Indicated Modulus of Elasticity of Cores

Pour No.	Core No.	Indicated $(E \times 10^{-6})$ psi
4	1	.50
	2	.43
	3	1.11
	4	1.06
	5	1.06
	6	.39
	7	.91
	8	1.37
	9	
	10	.79
	11	.89
3	12	.80
	13	.85
2	14	.88
	15	.49
	16	.69
	17	.68
	18	1.93
	19	1.17
1	20	.91
	21	1.59

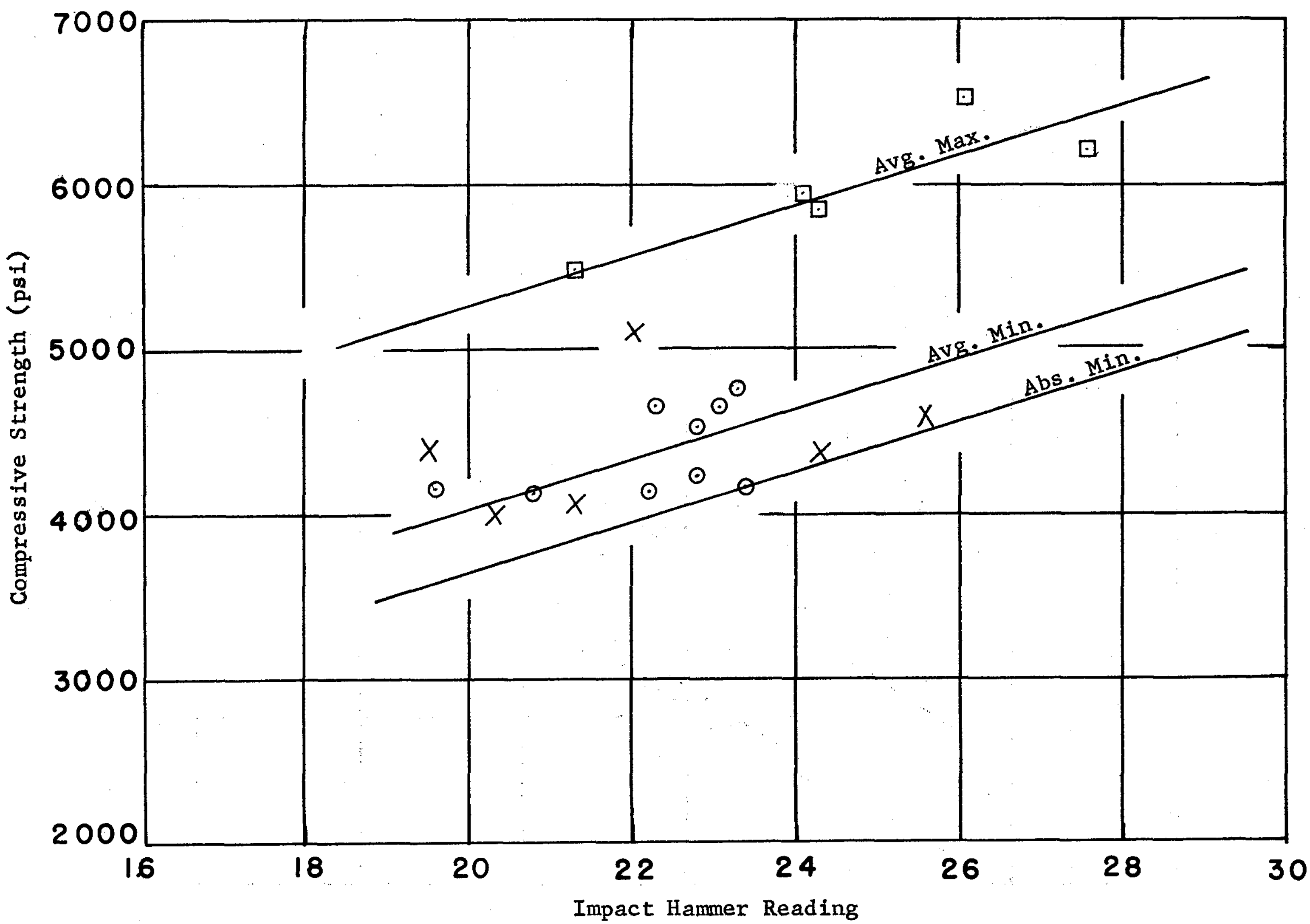

Fig. 3. Relationship Between Compressive Strength and Impact Hammer Reading.

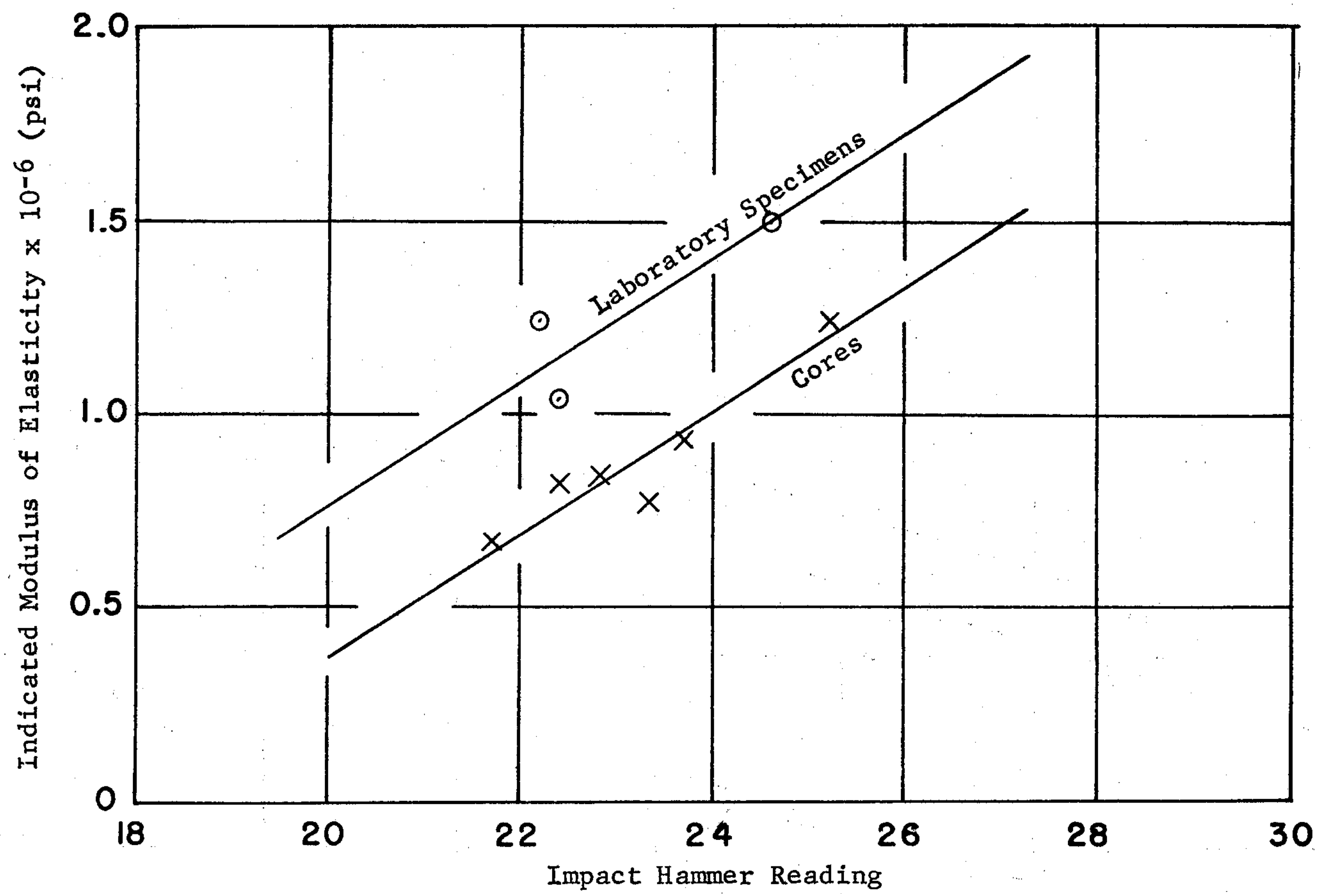

Fig. 4. Relationship Between Modulus of Elasticity and Impact Hammer Readings.

was obtained and compared to the pattern for the lightweight aggregate. A comparison of these patterns show an endothermic peak of about 1620^{O}F for the lightweight aggregate. This temperature is within the range of vitrification temperatures for shale and indicates that the vitrification process had not been completed. These data verify the finding previously obtained by petrographic examination.

Summary. A small but significant amount of the lightweight aggregate proved to be incompletely vitrified. Concrete made with this aggregate is sound and durable so long as an aggravating condition does not exist. But, where a crack happens to intersect an underburned particle or one of those particles happen to be in a zone of excessively high water concentration caused by restraint by the steel or plastic settlement, volume change and disruption will occur. This in turn will cause more cracking allowing water to penetrate the concrete and come in contact with more underburned particles. The relatively high flexibility (low modulus of elasticity) of the bridge deck could contribute also to this cracking, thus further aggravating the problem.