REPORT 1965 - 01

VERMONT DEPARTMENT OF HIGHWAYS

Materials Division
Research Report

A STUDY OF THE VALUE OF FRACTURED AGGREGATE IN CONCRETE

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A STUDY OF THE VALUE OF FRACTURED AGGREGATE IN CONCRETE

In our little state of Vermont, we are blessed with many deposits of good quality glacial gravel, also a few deposits of excellent granite and good hard limestone.

However, many of the gravel deposits have a large percentage of small stones which go through the processing plants with little or no crushing. In rewriting the concrete specifications, consideration was given to increasing the required percentage of fractured faces in gravel. This met with the immediate disapproval of the gravel producers. It was decided that tests with different percentages of fractured and non-fractured gravel in concrete mixtures were necessary to determine the best direction in which to proceed.

An amount of gravel aggregate was procured, representative of that supplied ready-mix producers, to make enough cylinders and beams to show an accurate picture, relative to aggregate bond and strength, by both compression and flexure. The aggregate was obtained in two sizes. No. 1 stone being 100% smaller than 1½", 90-100% smaller than 1¼", 0-10% smaller than 5/8", and 0-5% smaller than No. 4. No. 2 stone being 100% smaller than 3/4", 90-100% smaller than 5/8", and 0-5% smaller than No.4. all of the crusher fractured aggregate was separated from the non-fractured, the requirement being that at least one face show fracture.

The large stone mixes were proportioned using two thirds No. 1 stone and one third No. 2 stone. All mixes had a cement factor of 6½ sacks per cubic yard and a water-cement ratio of 5¼ gallons per sack. Each mix was tried previously to be sure that the yield was correct. Many studies have been conducted in which all factors have not been kept uniform which make for controversy as to what the results would have been if such and such had been correct.

A total of eight different mixes were made in a 1⅓ cubic foot laboratory mixer. this was sufficient to cast three 6" x 12" cylinders for compression and one 6" x 6" x 36" beam for flexure. One end of the beam was broken at 9 days, the other at 28 days. All specimens, immediately after casting, were placed in the curing room at 72 degrees F. and at 100% relative humidity.

A STUDY OF THE VALUE OF FRACTURED AGGREGATE IN CONCRETE (2)

There has been some speculation as to how much more water is required to maintain slump and workability in a mix using small or No. 2 stone. We hoped to find an answer.

The mixes are described as follows:

Mix #1:- Gravel with no fractured faces, using 1½" & 5/8" stone, 6½ bags of cement, 5¼ gal. of water, slump 3" ±¼".

Mix #2:- Gravel with 50% fractured faces, balance non-fractured using 1½" & 5/8" stone, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼".

Mix #3:- Gravel with 100% fractured faces, using 1½" & 5/8" stone, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼".

Mix #4:- Gravel with no fractured faces, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼", using 5/8" stone only.

Mix #5:- Gravel with 50% fractured faces, balance non-fractured using 5/8" stone only, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼".

Mix #6:- Gravel with 100% fractured faces, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼", using 5/8" stone only.

Mix #7:- Crushed limestone ledgerock, using 1½" & 5/8" stone, 6½ bags of cement, 5¼ gal. of water, slump 3" ± ¼".

Mix #8:- Crushed limestone ledgerock, using 5/8" stone only, 6½ bags of cement, 5½ gal. of water, slump 3" ± ¼". (Note. This mix required an additional ¼ gal. of water to maintain the same slump and workability as the other mixes.)

Test results.

	Cylinders. Comp. strength in lb. per sq. in.		Beams. Modulus of Rupture in lb. per sq. in.		Equiv. comp. strength in lb. per sq. in.	
	10 days	28 days	10 days	28 days	10 days	28 days
Mix #1	2030	3050	593	786	3113	4126
Mix #2	1884	2910	593	821	3113	4310
Mix #3	2345	3260	646	786	3391	4126
Mix #4	2662	3905	681	821	3575	4310
Mix #5	2740	4115	681	786	3575	4126
Mix #6	2740	4240	681	803	3575	4216
Mix #7	2260	3885	611	978	3208	5134
Mix #8	2515	3745	541	838	2840	4399

4" x 4" x 4" cubes were cut from the remaining sections of test beams with the following results relative to compressive strength and absorption.

	Comp. strength in lb. per sq. in. ave. of 2 cubes	% Absorption 3 samples of each
Mix #1	4609	4.8 - 4.7 - 5.2
Mix #2	4180	5.6 - 4.1 - 4.7
Mix #3	3922	4.6 - 5.7 - 5.8
Mix #4	4542	3.4 - 3.4 - 3.6
Mix #5	5188	5.2 - 5.5 - 5.1
Mix #6	5409	5.4 - 5.4 - 5.5
Mix #7	4758	4.1 - 4.8 - 3.9
Mix #8	4953	5.0 - 4.1 - 4.6

Conclusions.

From the tests results, it is apparent that crushed gravel aggregate with 75% having at least one fractured face, concrete with good strength, good bond, low absorption, low water-cement ratio and good durability may be produced. However, good quality crushed ledge rock will still remain a superior aggregate for concrete.

In the gravel aggregate mixes with non-fractured and 50% fractured faces, there were many pieces of aggregate with smooth surfaces which pulled away from the mortar instead of breaking the aggregate. This was not nearly as evident on the mixes with 100% at least one face fractured or with ledge rock. It is also evident that crushed ledge rock as aggregate produces concrete stronger in flexure than does crushed gravel.

This would mean that bridge superstructures would suffer less damage due to flexural movement if built with crushed ledge rock rather than crushed gravel. There does not seem to be as much difference in compression as in flexure but seldom is any damage done to concrete in compression.

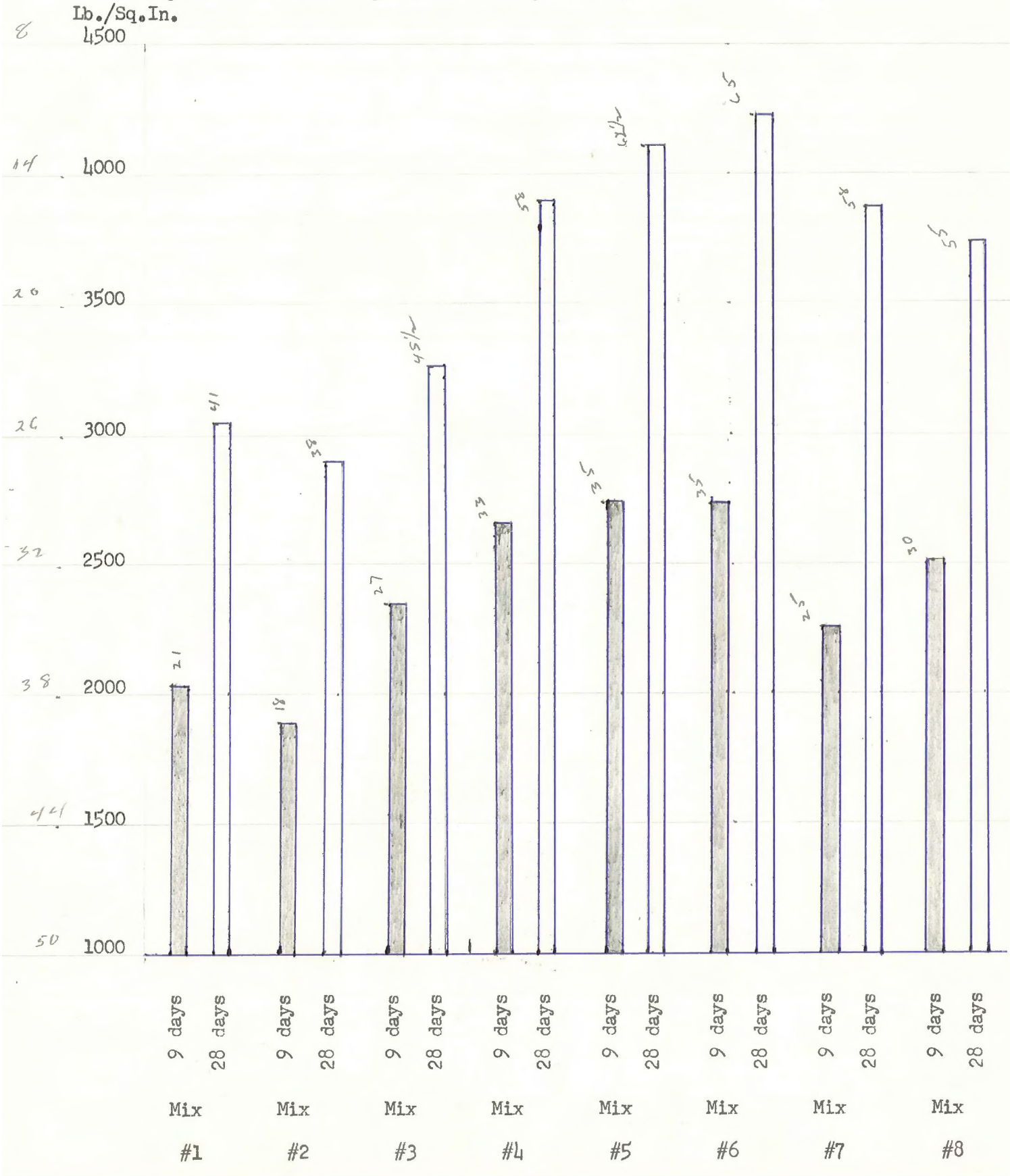
Cost.

One other interesting factor is the cost of raw materials, crushed gravel versus crushed ledge rock. The prices quoted here are delivered prices per ton at two ready-mix concrete plants who have supplied the state with a large quantity of concrete for Interstate bridges.

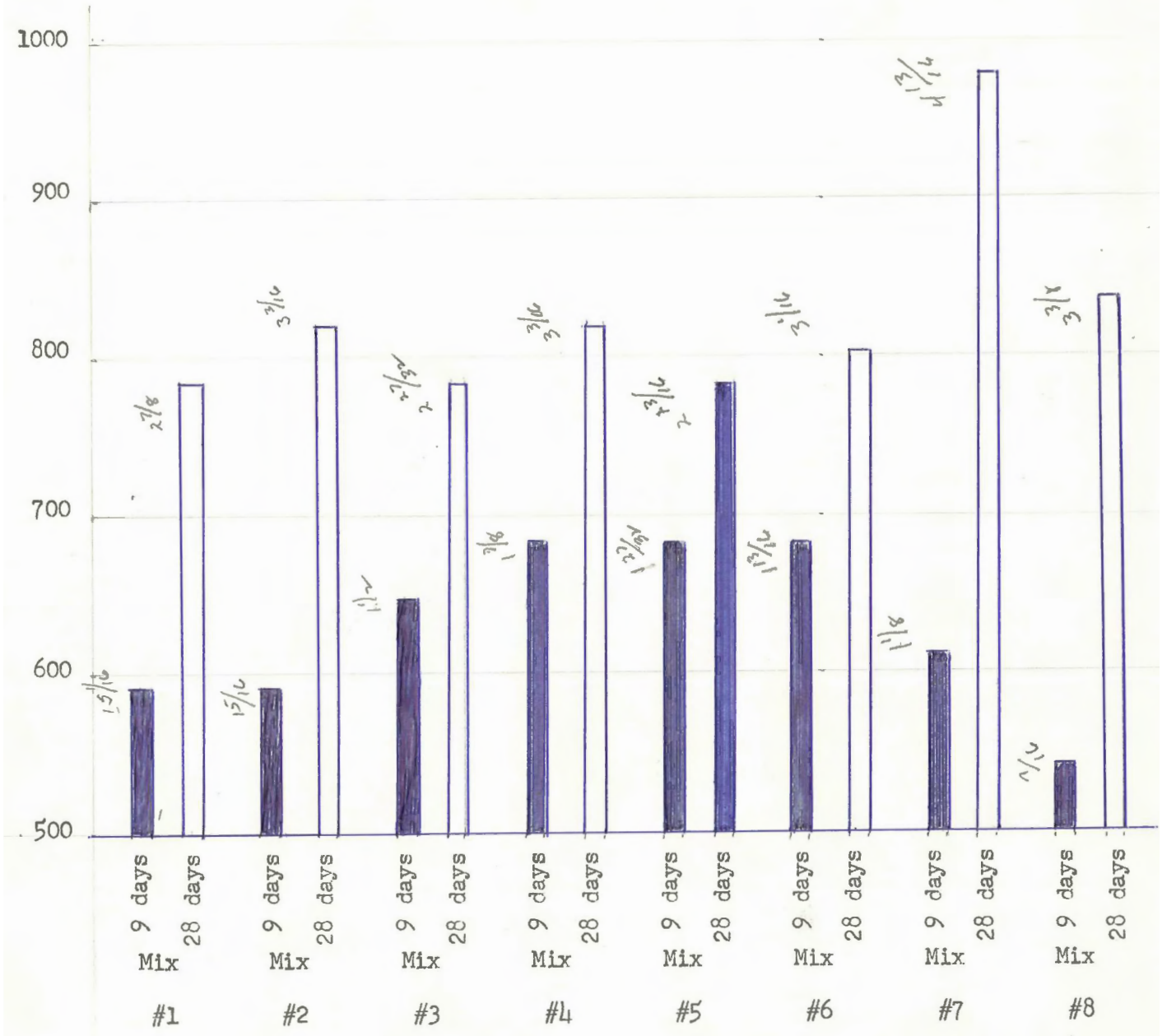
	Crushed Gravel	Crushed ledge rock
1½" - 5/8"	$ 2.15	$ 1.65
3/4" - #4	$ 2.25	$ 1.85
1" - #4	$ 2.25	$ 1.60

The approximate amount of stone per cubic yard of concrete is just under one ton, so the cost is about 40¢ per cubic yard cheaper for crushed ledge rock than it is for crushed gravel aggregate.

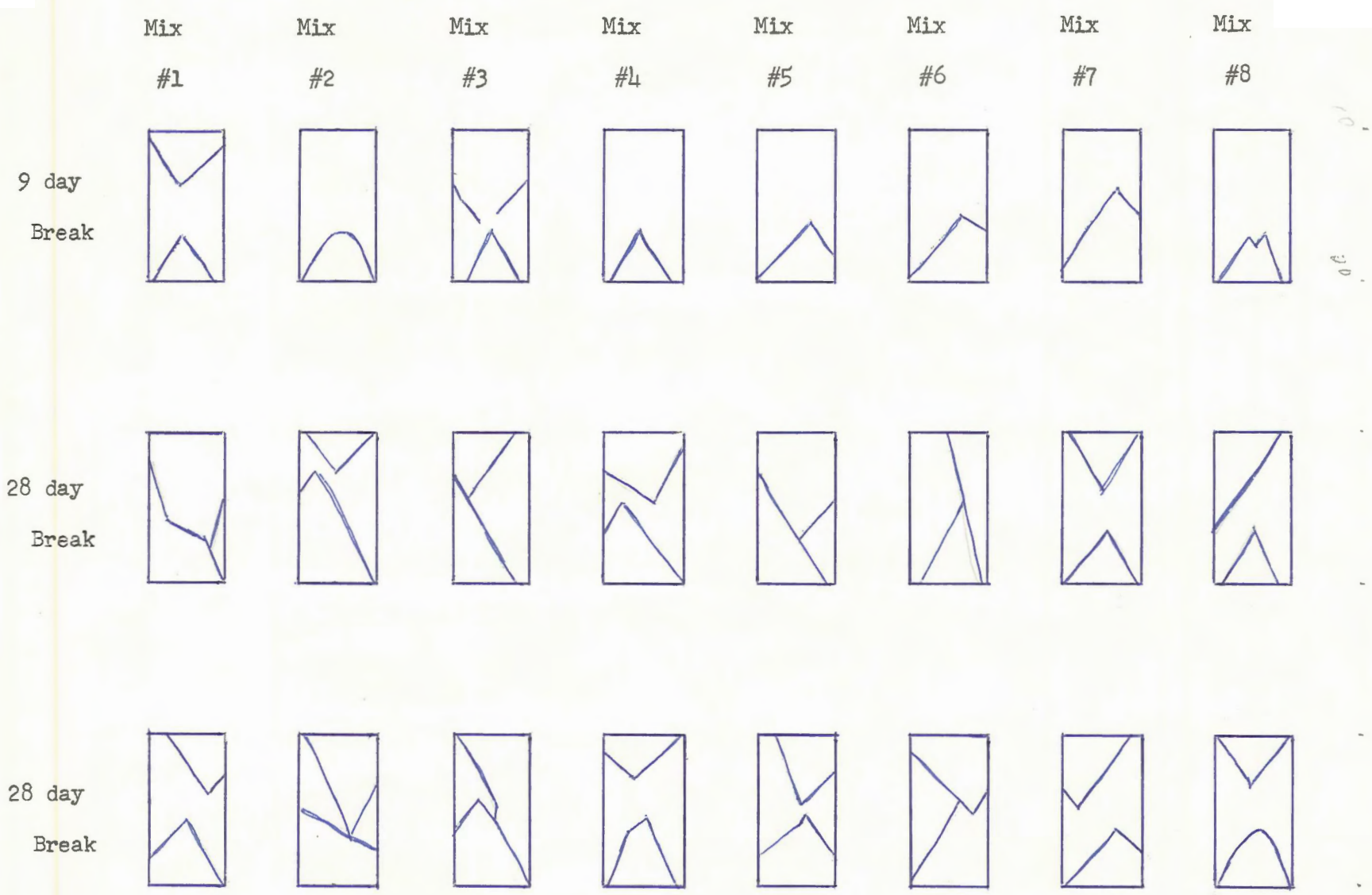
Graphic results of Compression Test Cylinders.



Graphic results of flexural test beams.
Modulus of rupture, lb./sq. in.



Fracture pattern of cylinders under compression.



Note. Mixes #1, #4 (non-fractured gravel), #2, #5 (50% fractured gravel) showed numerous smooth, rounded surfaces of aggregate that had pulled away from the mortar instead of breaking the aggregate. Mixes #3, #6 (100% fractured gravel), #7 and #8 (crushed ledge rock) showed very few "pull-outs". This shows that aggregate with a high percentage of fractured faces has much better bonding qualities than non-fractured aggregates.