R-389

QUANTITY AND DISTRIBUTION OF CHLORIDE IN AGGREGATE AS PLACED IN THE STOCKPILE AND ON THE ROAD

E. C. Novak, Jr.
R. C. Mainfort

Research Laboratory Division
Office of Testing and Research

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Synopsis

This report describes the continuation of studies performed to determine the distribution of chloride in aggregate mixtures as used for highway base course construction, with emphasis on conditions at the time of production.

Samples representing thirteen different aggregate producing operations were obtained and analyzed in a statistically significant manner. Some operations were sampled more than once and some were sampled both as produced and as subsequently placed on the roadway. Results of this study indicate that:

1. The distribution of chloride throughout the aggregate, as produced, varies widely and in some cases this variation is extreme.

2. Little or no attempt is made to mix the chloride and aggregate at the time of production. Chloride is merely applied to the aggregate with the hope that subsequent handling and manipulation will uniformly distribute the admixture.

3. The quantity of chloride and its distribution can vary from day to day within the same operation. Some of this is intentional so that erratic quantities obtained from previous operations can be balanced out.

4. None of the basic methods used for adding chloride were sufficiently outstanding to warrant recommendation of their use in all operations. The higher efficiencies obtained appear to be due to greater care taken in adjusting and handling the equipment.

5. Although quantities of chloride were often erratic, the overall amount in most cases met specification requirements.

6. Aggregate as placed on the road after stockpiling was consistently lower in chloride content than specifications require. However, the road samples were much more uniformly mixed than were samples taken at production. This indicates that due to mixing and handling subsequent to production, the original variation in mixing efficiency may not be too critical.

QUANTITY AND DISTRIBUTION OF CHLORIDE IN AGGREGATE AS PLACED IN THE STOCKPILE AND ON THE ROAD

Work described in this report covers another phase in the overall scope of Research Project R-59 E-19, "Concentration and Distribution of Calcium Chloride Within Stockpiles of Treated Aggregates." This project was initiated in 1959 at the request of R. L. Greenman, Assistant Testing and Research Engineer, for the purpose of studying the efficiency and effectiveness of present methods of treating and storing aggregates as used for highway base construction.

The first phase of this work was described in Research Report No. 339, "Quantity and Distribution of Calcium Chloride Within Stockpiles of Treated Aggregate," which described the wide variations of chloride content determined by sampling a large number of stockpiles. As a result of this work it was decided to study, in more detail, the variation in chloride content of the aggregate as it was produced and delivered to the stockpile, or other required location. In this way the mixing efficiency of different operations could be determined, and the cause for wide variations of chloride in stockpiles could be isolated. Such information could also be used to determine: 1) the most efficient methods of adding chloride, 2) whether chloride is being lost during stockpiling and placing on the road, and 3) if there is a relationship between how well the chloride is originally mixed with the gravel and its uniformity when placed on the road.

This work was conducted during the summer of 1961 under the immediate supervision of E. C. Novak, Jr., assisted by L. D. Searcy.

TESTING PROCEDURES

Thirteen gravel producing sites were included in this study. These were widely distributed throughout the lower peninsula of Michigan and represented wide variations in methods of adding admixtures. Most of the stockpiles met MSHD specifications for a 22A mixture but some were 23A and 24A. Most were treated with 6 lb of chloride per ton of aggregate but some were treated with 9 lb per ton. The dry form of chloride was used at three of the sites. At all others, the solution form was used.

Twenty-five representative samples were taken for each operation. These consisted of 1- to 2-lb samples, of which five were taken from each of five different truck-loads as deposited on the stockpile. All samples were obtained during a 1-hr period and were selected in a statistically random manner. The quantity of chloride in each aggregate sample was determined in the laboratory using a modified form of the procedure described in ASTM Designation D1411-56T.

In order to obtain a measure of efficiency of chloride dispersion for the field mixes, special mixtures were prepared under controlled laboratory conditions and their uniformity measured. In this test, 200-lb samples of a 22A gravel were placed in a concrete mixer and water in the amount of 3 percent added to bring the mixture to an average moisture content representative of field conditions. After thoroughly mixing the aggregate and water (for 5 min) the required amount of calcium chloride was added and mixing continued for an additional 2 min. The chloride used was in the form of a 36-percent solution with quantities of 2, 6, and 12 lb of calcium per ton of aggregate. These values covered the range of normal field applications. After mixing, the material was sampled in a manner similar to that used for the field samples. Results obtained by the controlled laboratory tests were used as a measure of the efficiency of the different field operations.

In addition to the samples obtained at the production site, tests were also made on samples taken from the roadway where the aggregate was finally placed. These were obtained in approximately the same manner as the stockpile samples. Five samples were selected at random from five stations of freshly placed gravel. Each sample weighed from 1 to 2 lb each. Sampling was performed at various times subsequent to placing the aggregate.

A. Belt feed directly to truck.

B. Belt feed to hopper. Drops to truck.

C. Belt feed to hopper. Drops to second belt for feeding to truck.

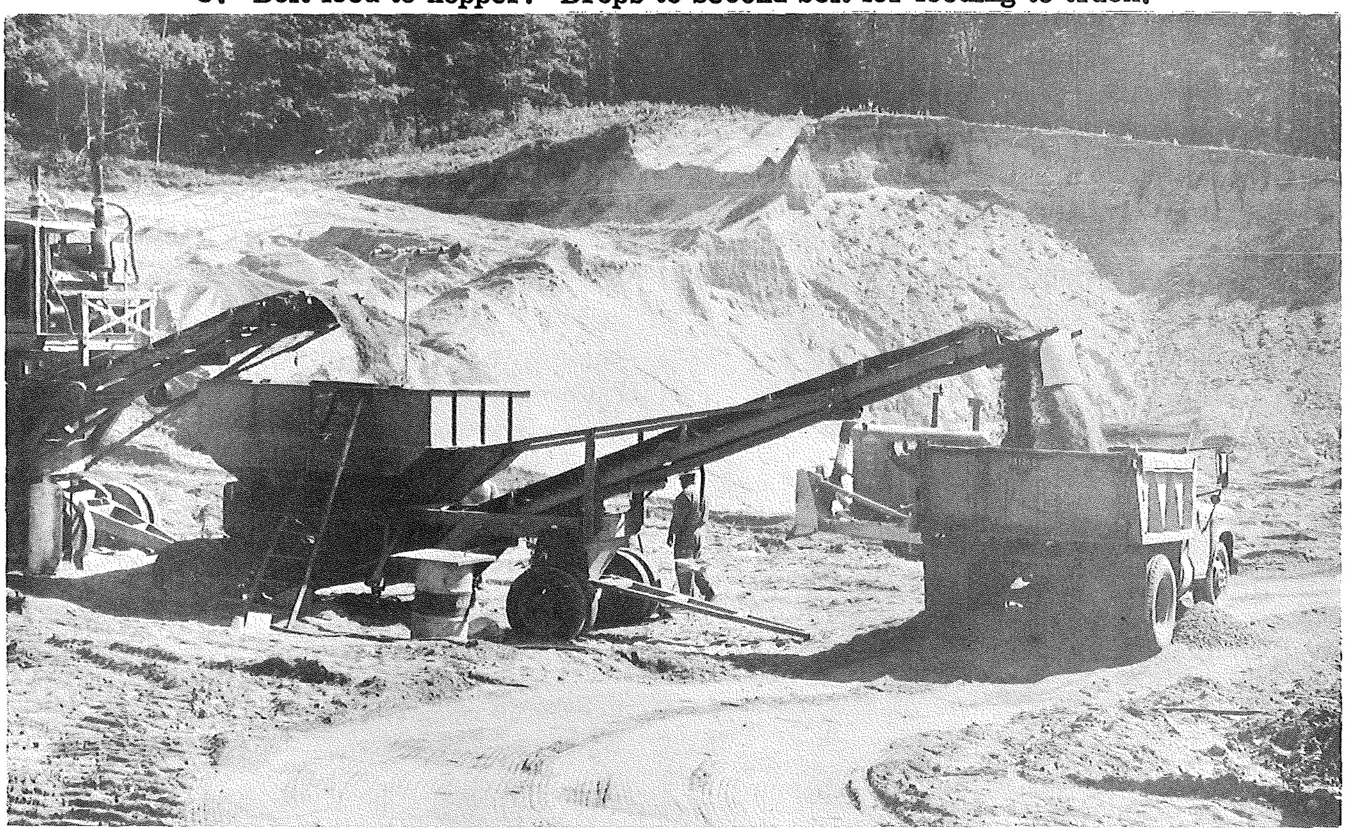


Figure 1. Three basic methods used to move aggregate from the crusher to the haul truck.

METHODS USED TO MIX CHLORIDE AND AGGREGATE

At present, MSHD specifications do not require any particular method for mixing chloride with aggregates nor is a specific form of admixture required. There are almost as many different methods of adding the chloride as there are producers. Most of these methods represent honest attempts to obtain the most efficient mixture, but others appear to be based primarily on economic considerations and convenience of operation.

Practically all of the gravel producers use the liquid form of chloride treatment. Eleven out of the thirteen producers included in this study used this form of application. This preference is due to the lower initial cost of the liquid material and the ease of applying and storing the solution. When the solid form is used it must be stored in a dry place or specially protected from moisture. When delivered, bagged chloride must be unloaded and stacked, during which time production usually stops. Furthermore, during the operation, at least one man is required to feed dry forms of chloride to the gravel. All of these problems are minimized by the use of liquid chloride. The main reason given for using the bagged form of calcium chloride is that less equipment needs to be moved if frequent changes of operation sites are expected.

Three basic methods were used for handling the aggregate between the crusher and the haul trucks. Each of these methods, shown in Fig. 1, could influence the chloride-aggregate mixing process. None of the producers used a specific mixing device during their operation, so that any mixing obtained depended upon the loading and handling operations.

In the method shown in Fig. 1A the aggregate is carried from the crusher directly to a waiting truck by means of a travelling belt. Three or four trucks are required if continuous operation is to be maintained.

In Fig. 1B the gravel is carried from the crusher to a surge bin by means of a travelling belt. The gravel then drops from the surge bin into a waiting truck. Depending upon the distance of the stockpile, only one or two trucks are required for continuous operation.

Fig. 1C shows an arrangement in which the aggregate is moved from the crusher by a travelling belt to a surge bin from which it emerges onto another travelling belt for moving into the truck. One or two trucks can handle this operation efficiently.

Liquid Application

For the liquid chloride application, all producers handle storage, measuring of quantities, and pumping in substantially the same way. Chloride solution is delivered by the supplier in the concentration desired.

A constant head centrifugal pump is used to provide pressure and a water meter and gate valve are placed in the system to measure and regulate the flow of solution. The weight of gravel produced is determined by counting the number of truckloads during a given time interval. Meter readings at the start and end of this period indicate the quantity of chloride used. From these values the treatment in pounds of chloride per ton of aggregate can be computed. Variation can be corrected by the control valve. Meters are checked daily and require periodic adjustment.

The main variables between different operations are how and at what stage of the operations chloride is added to the aggregate. These are listed as part of Table 1 and are illustrated throughout this report.

The spray bar is the most popular method for applying liquid chloride to aggregate. Other methods used consist of one or more hoses which apply the chloride to the aggregate in concentrated streams.

Dry Application

Only two producers included in this study used chloride in the dry form. One of them used rock salt instead of calcium chloride but the methods of handling the two were similar. The dry material was added to the belt from a mechanically operated hopper as the gravel was carried from the crusher to the truck. In one case the chloride was added about midway along the belt; in the other it was added at the very bottom of the belt inside the crusher. This allowed some mixing as the gravel left the crusher. The quantity of chloride applied was controlled by the speed of the belt. Control of quantities was obtained by comparing the bags of chloride used per day with the quantity of aggregate produced. If too little chloride was added the deficit was made up by spreading the required number of bags of chloride over the stockpile as shown in Fig. 2. If too much chloride was added during a day's operation the excess was recorded and deducted from the next day's run.

TABLE 1
SUMMARY DATA--BASED ON 25 SAMPLES FOR EACH CONDITION

	Pit Designation	Aggregate Type	Admixture			Operation	Distribution of Chloride, lb per ton				Mixing Efficiency, percent (SL/SF x 100)	Aggregate Gradation	
							Field			Laboratory			
			Type	Form	Lb/Ton		Average	Standard Deviation (SF)	Range of Average (99.73% Probability)	Standard Deviation (SL)		Average Percent Passing 3/8-in. Sieve	Standard Deviation, percent
Samples as Produced	Bruce Gee	22A	$CaCl_2$	Solution	6	3 sprays at top of belt feeding to hopper - drops to truck	5.7	2.0	4.5- 6.9	1.8	90	68.9	4.5
	Wier	24A	$CaCl_2$	Solution	9	3 sprays at bottom of belt feeding to hopper - drops to truck	12.3	4.2	9.9-14.7	3.3	79	68.1	11.0
	Heistand	22A	$CaCl_2$	Solution	6	2 spray bars with 9 nozzles each at top of belt feeding to truck	2.6	1.3	1.7- 3.5	0.9	69	72.5	11.5
	Robbins	23A	$CaCl_2$	Solution	9	4 sprays at bottom of belt feeding to truck	11.8	5.5	8.5-15.1	3.3	60	64.5	10.6
	Webster	24A	$CaCl_2$	Solution	6	15 sprays at top of belt feeding to truck	4.9	3.0	3.1- 6.7	1.7	57	81.0	6.7
	Stanley	22A	$CaCl_2$	Solution	9	16 sprays at top of belt feeding to truck	10.7	5.7	7.4-14.0	3.0	53	68.2	----
	Mangus	22A	$CaCl_2$	Solution	6	9 sprays at top of belt feeding to hopper - drops to truck	6.3	4.3	3.6- 9.0	2.0	47	68.1	8.7
	Paul	24A	$CaCl_2$	Solution	9	Belt feed to hopper - 2 sprays at top of second belt as it feeds to truck	7.3	5.0	4.3-10.0	2.3	46	67.3	14.3
	Knibbs	22A	$CaCl_2$	Solution	6	7 sprays at top of belt feeding to hopper - drops to truck	5.2	3.7	3.1- 7.3	1.7	46	73.3	21.3
	Hicks	23A	$CaCl_2$	Dry	9	Added dry as gravel leaves crusher - conveyed by belt to truck (some mixing in crusher)	6.5	5.1	3.5- 9.5	2.1	41	74.5	2.6
	Almon	22A	$CaCl_2$	Solution	6	7 sprays at top of belt feeding to hopper - drops to truck	4.5	3.8	2.1- 6.9	1.5	39	64.8	13.4
	Conservation	22A	$CaCl_2$	Solution	6	Belt feed to hopper. 3 spray bars with 4 nozzles each at top of belt from hopper as it feeds into truck	9.7	7.3	5.2-14.2	2.8	38	68.1	8.5
	Smith	22A	$CaCl_2$	Dry	6	Added dry at midpoint of belt leading directly to truck	11.6	9.4	5.9-17.3	3.2	34	54.7	13.8
	Conservation	22A	$CaCl_2$	Solution	6	7 sprays at top of belt feeding to hopper - drops to truck	11.7	9.5	6.0-17.4	3.2	34	63.8	8.5
	Wier	22A	$CaCl_2$	Solution	6	3 sprays at bottom of belt leading to hopper - drops to truck	4.5	4.7	2.7- 6.3	1.5	32	71.3	----
	Smith	22A	NaCl	Dry	6	Added dry at midpoint of belt leading directly to truck	5.1	9.3	0-10.8	1.7	18	67.0	7.4
	Herbst	22A	$CaCl_2$	Solution	6	Belt to hopper. Single spray added 3/4 distance up the belt feeding to truck	18.1	28.9	0-36.1	3.8	13	64.5	6.3
Road Samples	Bruce Gee	22A	$CaCl_2$	Solution	6	Stockpiled 6 weeks. Tested immediately after grading	3.6	1.02	3.0- 4.2	1.2	118	63.1	5.1
	Smith	22A	NaCl	Dry	6	Stockpiled 6 weeks. Tested immediately after grading	3.4	1.05	2.8- 4.0	1.14	108	63.1	18.7
	Stanley	22A	$CaCl_2$	Solution	9	Stockpiled 1 day. Tested immediately after grading	7.0	2.3	5.5- 8.5	2.2	96	62.4	10.2
	Stanley	22A	$CaCl_2$	Solution	9	Stockpiled 1 day. Tested 7 days after grading	4.0	1.4	3.1- 4.9	1.3	93	60.6	----
	Wier	24A	$CaCl_2$	Solution	9	Stockpiled 3 months. Tested immediately after grading	4.7	1.8	3.5- 5.9	1.55	86	73.1	5.9

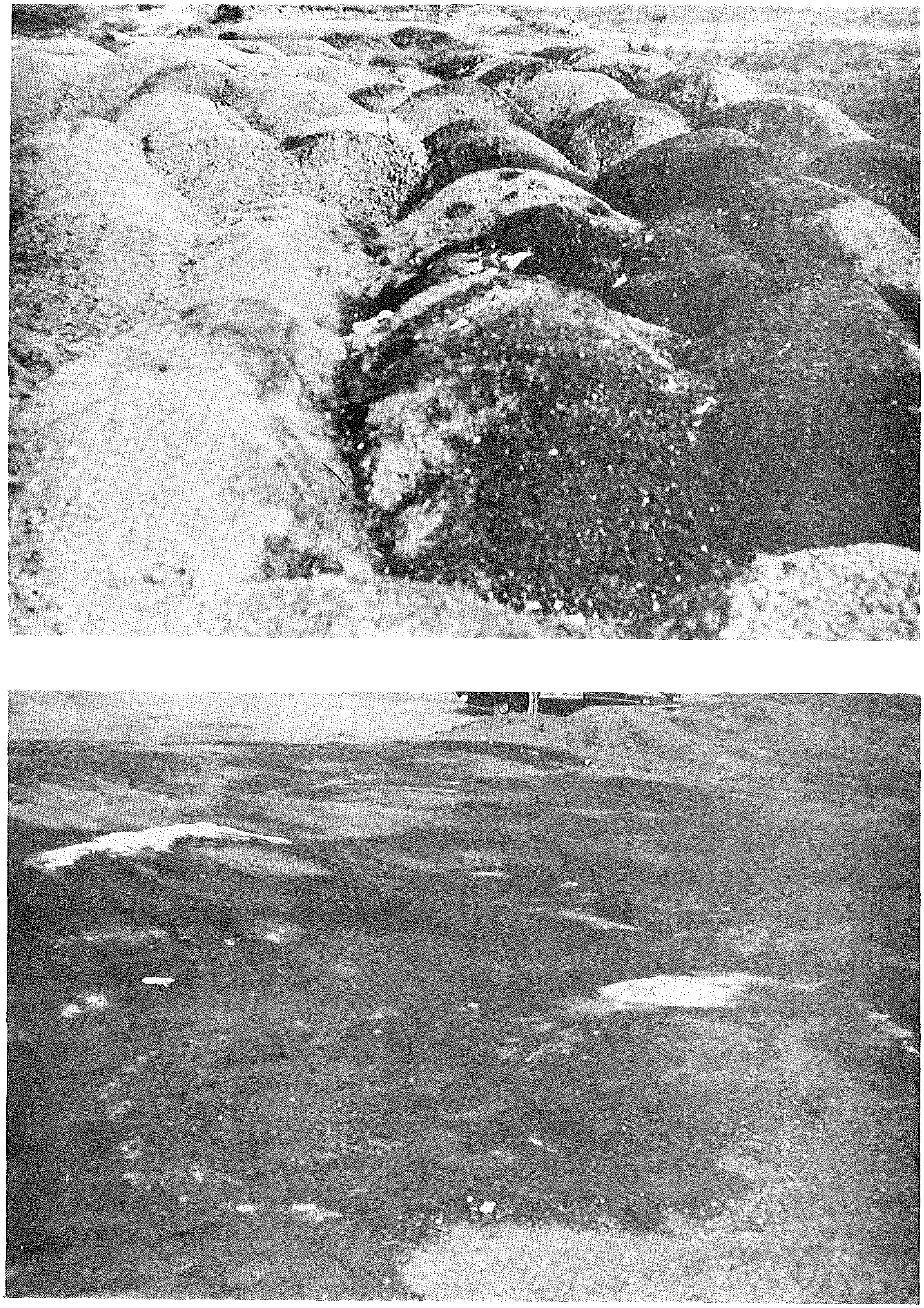


Figure 2. Appearance of stockpiles after surface addition of calcium chloride. Darker areas indicate recently dissolved chloride.

FACTORS AFFECTING UNIFORM DISTRIBUTION

None of the producers studied had a rapid or accurate method for determining and adjusting the quantity of chloride added to the gravel. Because these controls were lacking, the average chloride content of the aggregate varied during a daily run. Typical daily averages ranged from 5 to 6.4 lb of chloride per ton of aggregate. The target or specified amount in these cases was 6 lb per ton. This indicates that in addition to sample variations, the overall chloride content for a day's run (representing a large portion of a stockpile) can also show a considerable variation.

Another important cause of variable mixing is segregation of the aggregate as it is handled. The finer portion of the mixture (say, the minus 10 fraction) has a much greater surface area for a given volume or weight than does the coarse, or plus 10, fraction. This causes a greater acceptance and retention of chloride solution by the finer particles. Therefore, if gravel is badly segregated, the fine aggregate is capable of holding much greater concentrations of chloride than is the coarse fraction. Fig. 3 shows typical examples of segregation as aggregate is fed from a belt to a truck. In these photographs the finer gravel is being deposited to one side while the coarser material falls to the other.

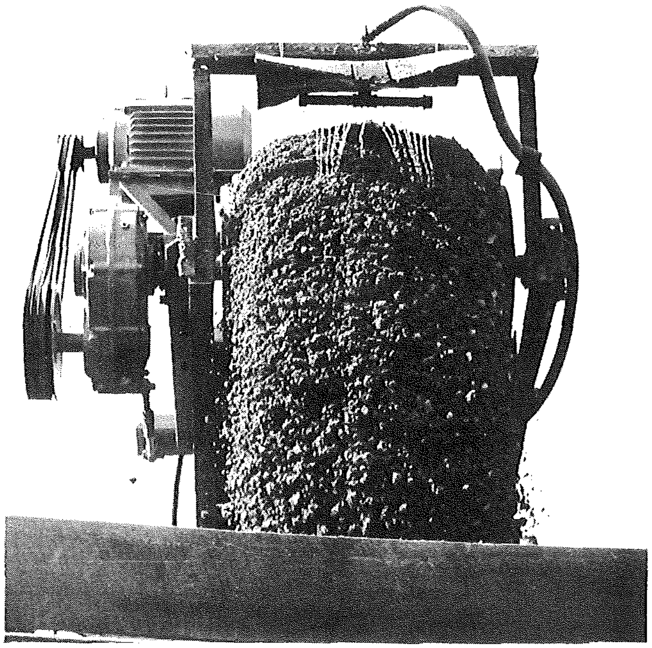
Moisture content of the gravel as it comes from the crusher may also affect the distribution of chloride throughout the mixture. Wetter gravels tend to aid the flow of chloride throughout their mass, resulting in more uniform distribution. On the other hand, dry gravel tends to hold the chloride solution in one area. Thus, should only a small percentage of a dry gravel receive chloride, the solution will not tend to distribute itself throughout the aggregate mass.

If water contents are too high, the finer screens tend to clog so that the rate of gravel production often varies. Under such conditions, however, chloride addition often continues at a constant rate, resulting in a non-uniform treatment. A typical non-uniform gravel flow is shown in Fig. 4. In this particular operation, although the rate of chloride application remained constant, the flow of gravel could be seen to vary considerably.

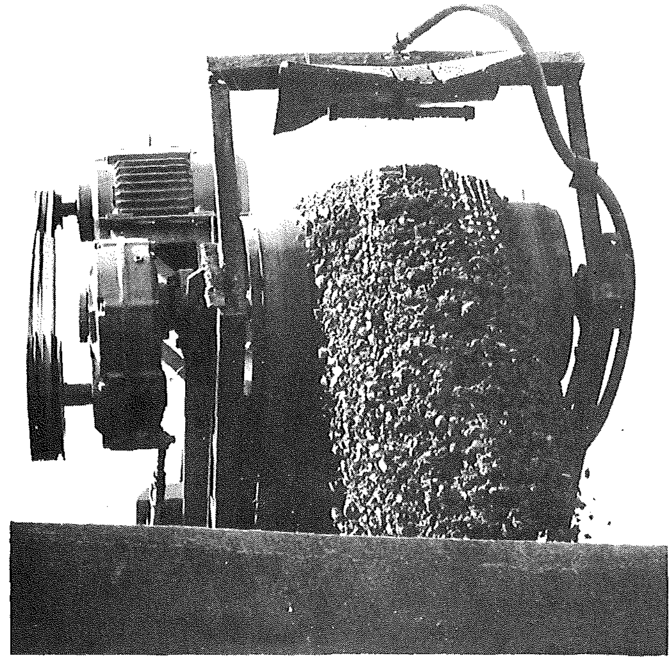
A. As fed to truck.

B. As fed to belt.

Figure 3. Segregation of aggregate during loading.



A. High gravel flow.



B. Low gravel flow.

C. Non-uniform flow of gravel.

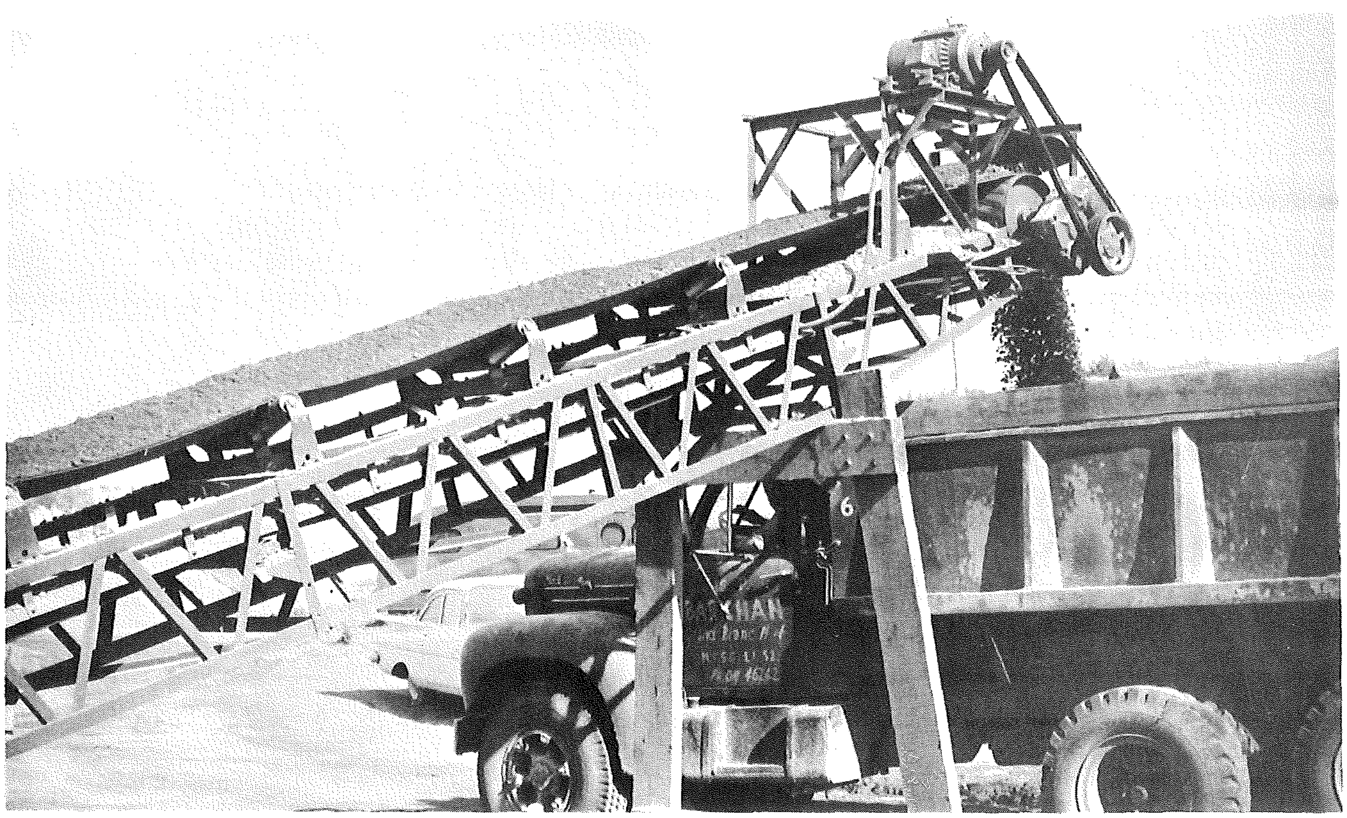


Figure 4. Variation in gravel flow with constant rate of chloride application.

Two very poor methods of applying liquid chloride are illustrated in Figs. 5 and 6. In Fig. 5 a heavy stream is applied only to the center of the aggregate width and only about 15 percent of the aggregate is being treated, resulting in uneven distribution. Fig. 6 shows how a poor spray bar arrangement can result in non-uniform distribution of the chloride. Instead of hitting the gravel as it falls, the stream of chloride merely drops to one side of the gravel as it piles up in the surge bin. Only about 20 percent of the gravel is treated in this case. When the surge bin is empty the gravel drops through directly into the truck, untouched by chloride, until the solution trickles from the bin into the truck.

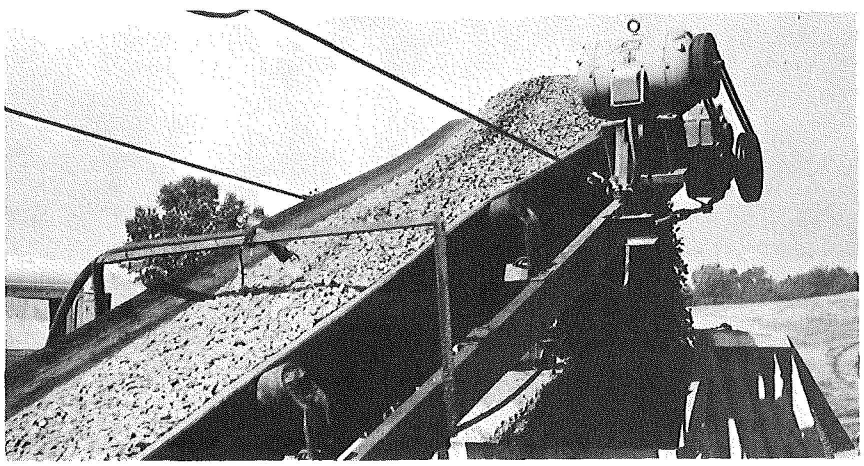
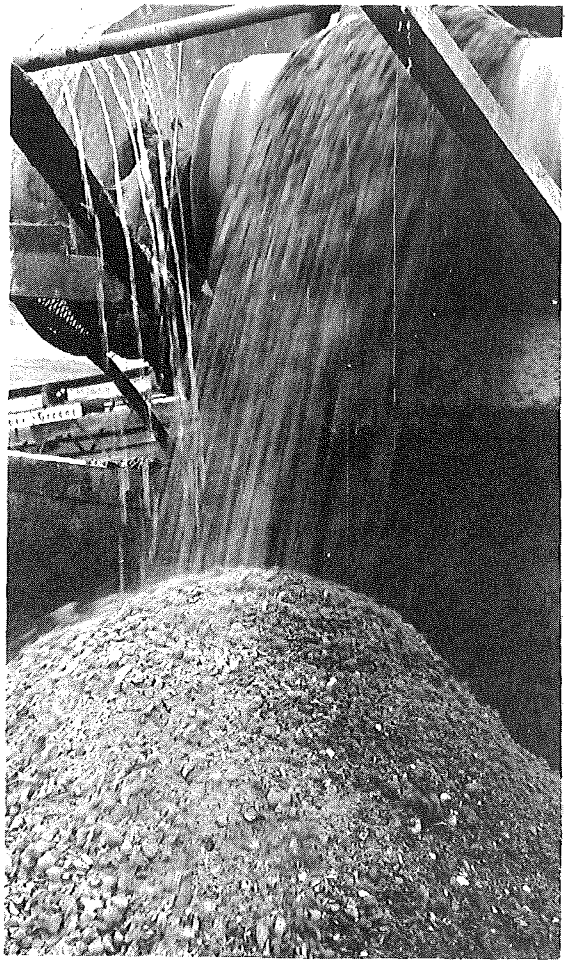


Figure 5. Application of chloride by a single spray.

The result of such non-uniform mixing of chloride is shown in Figs. 7 and 8. Dark areas in the stockpile (Fig. 7) averaged about 30 lb of chloride per ton, the light areas about 1 lb per ton. In Fig. 8 the chloride content varied from 25 to 30 lb per ton in the dark area as compared with from 2 to 4 lb in the light.

Mixing problems were also encountered when the dry form of chloride was used. Generally the dry chloride was placed to one side of the belt and when fed into the truck tended to fall to one side of the mixture. Fig. 9 shows an example of this form of segregation as the mixture is placed in the truck.

Some producers have used a wheel, rolling on the gravel supply, to control the rate of liquid or solid chloride flow in proportion to the height of aggregate treated. Most had abandoned this method of control, however, because the wheel continually picked up fine wet material, thereby altering its calibration.



A. Arrangement.

B. Surge bin filling.

C. Surge bin empty.

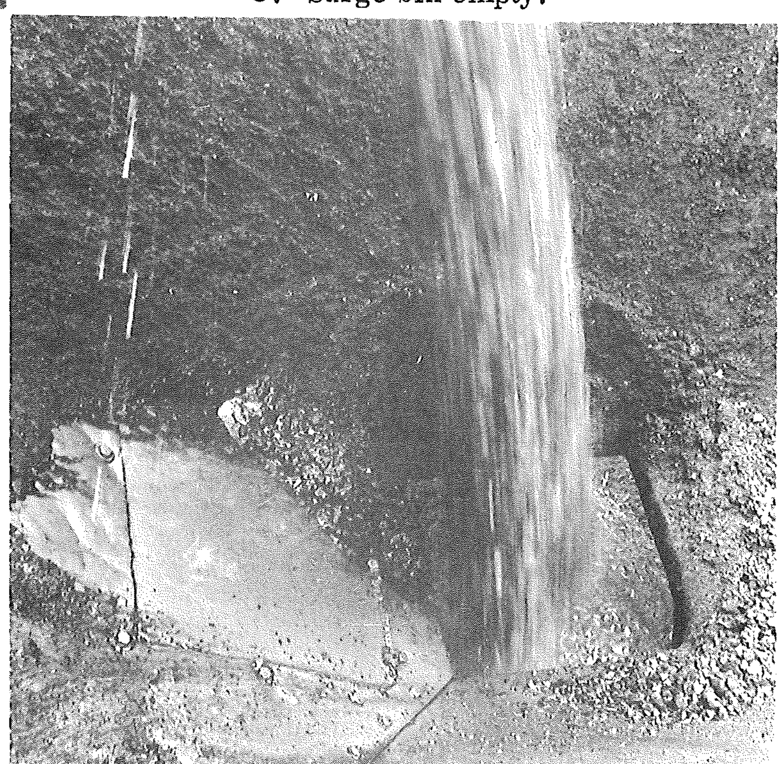


Figure 6. Non-uniform distribution of chloride due to poor spray bar arrangement.

Figure 7. Surface of newly prepared stockpile showing non-uniform distribution of chloride.

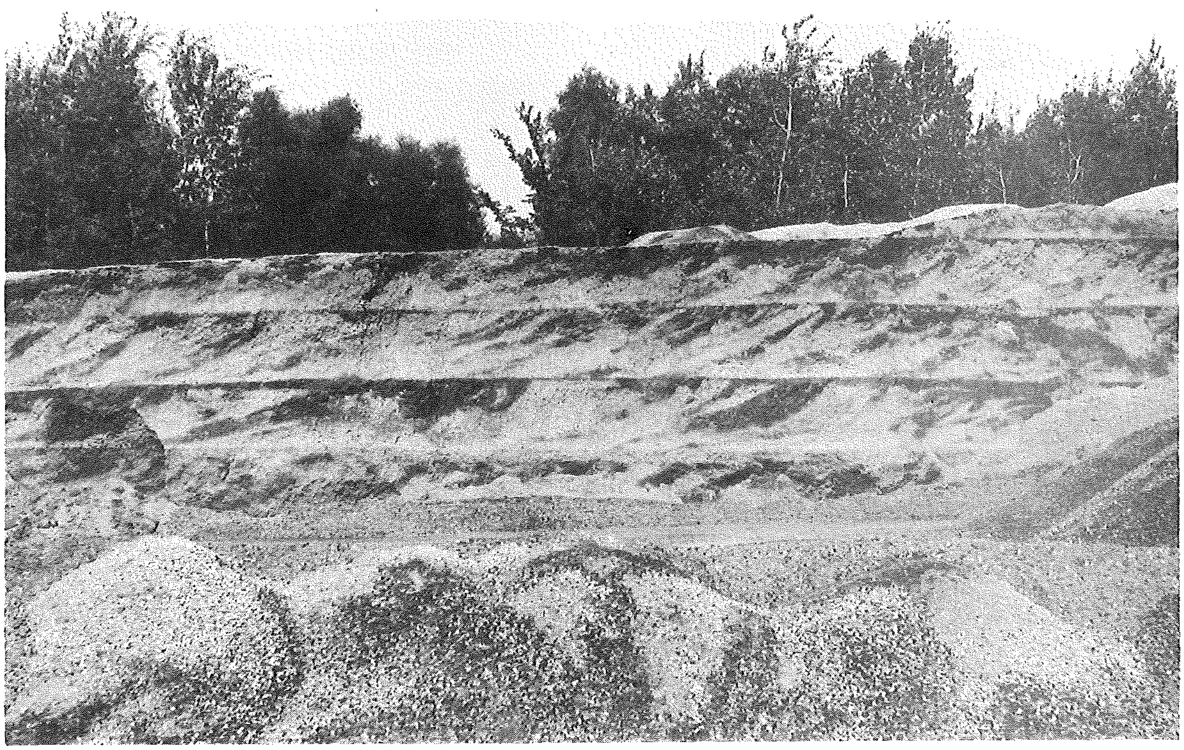


Figure 8. Cross-section of one-day-old stockpile showing variation in chloride content.

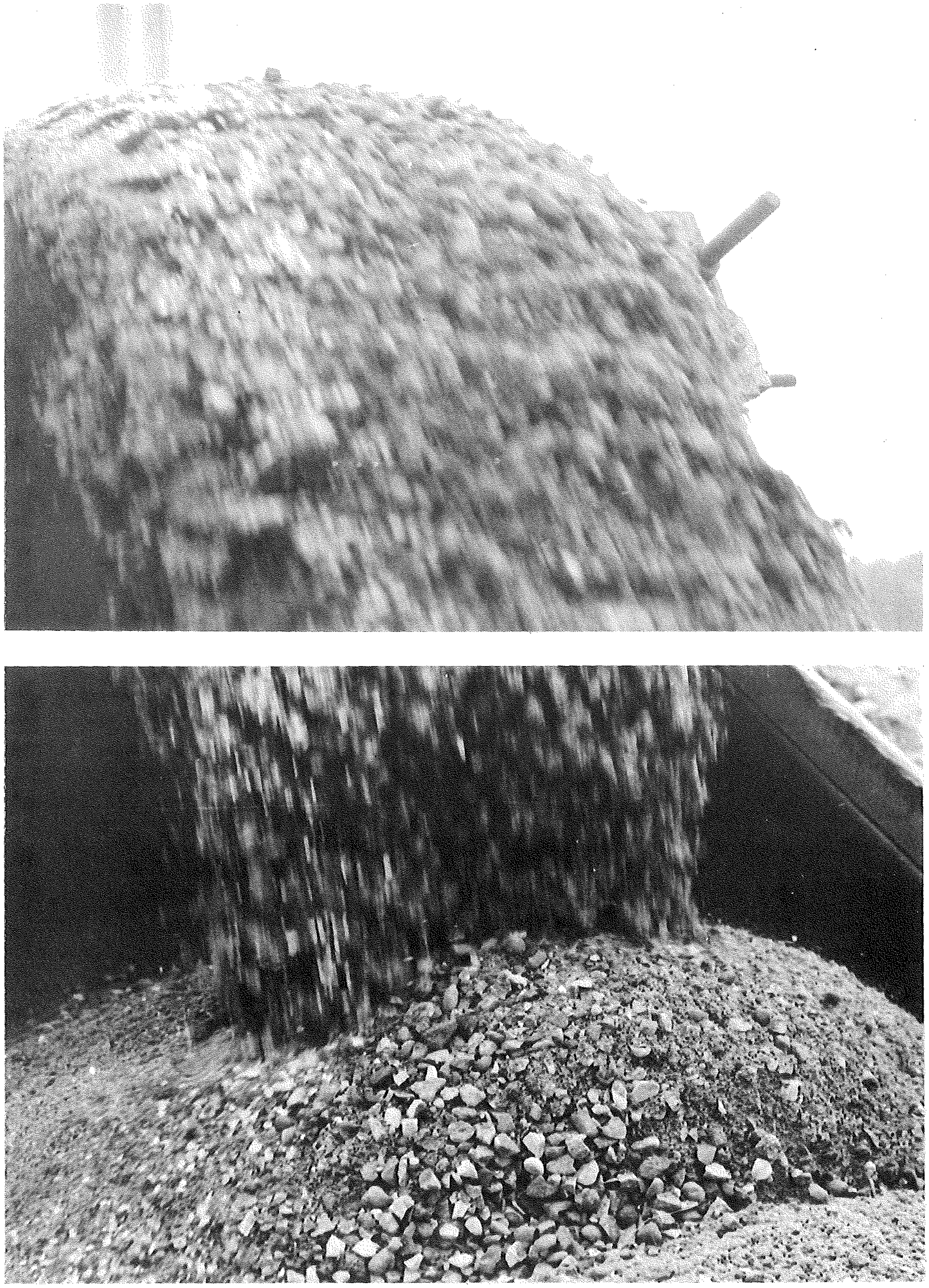


Figure 9. Segregation of rock salt as it falls into truck (salt falls to left).

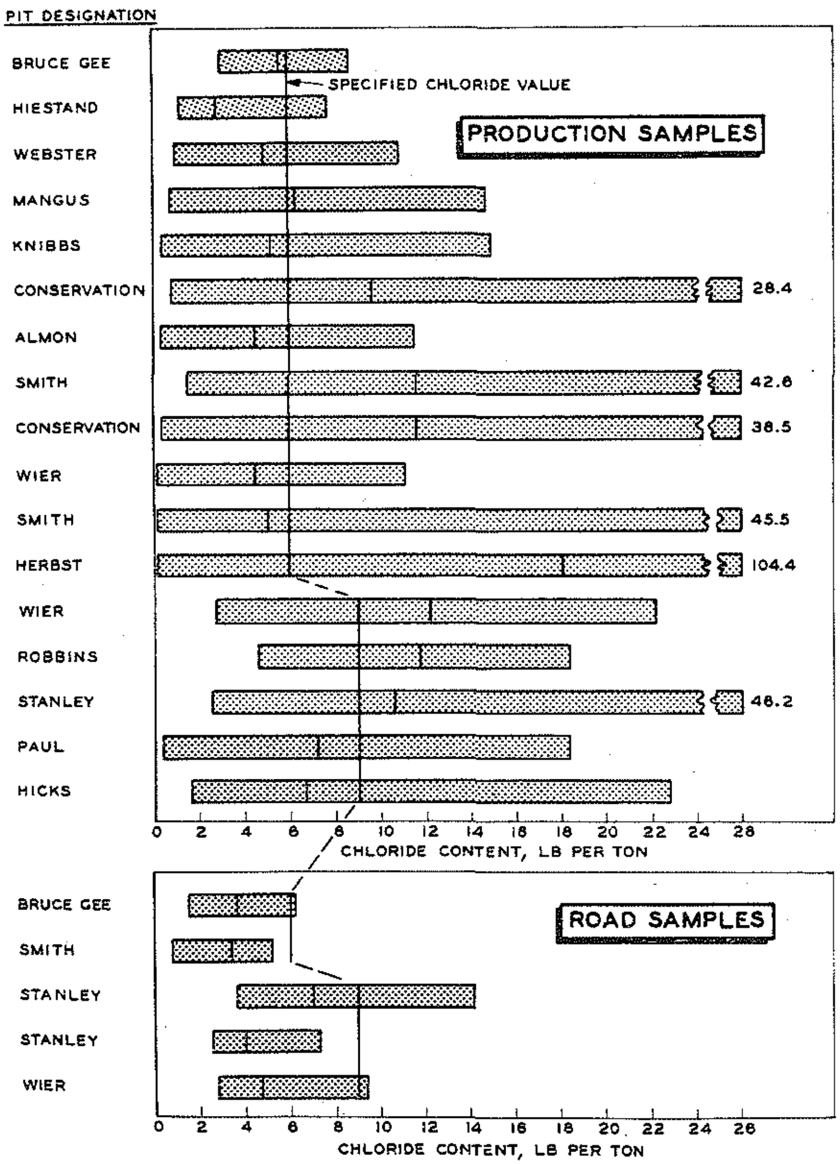


Figure 10. Chloride contents of aggregate mixtures (range and average of values).

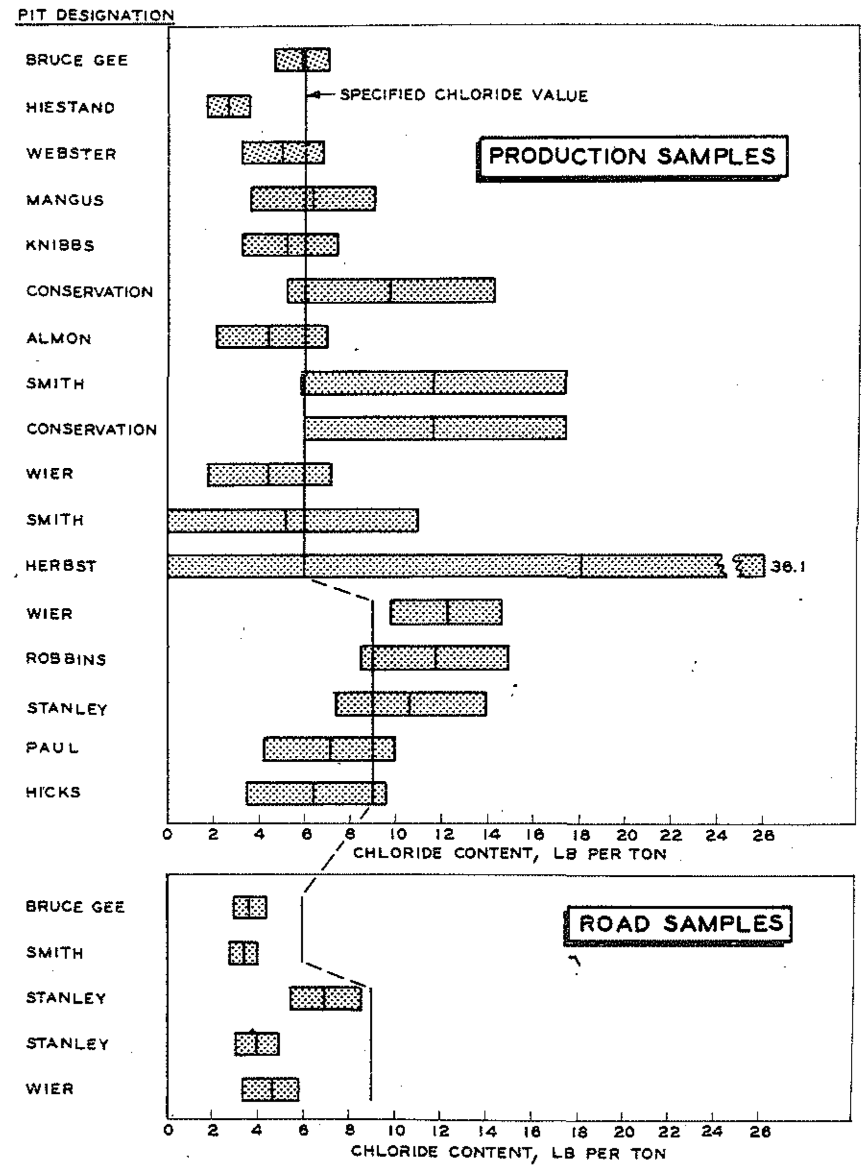


Figure 11. Distribution of chloride in aggregate samples based on range of average values (99.73-percent probability level).

TEST RESULTS

Table 1 summarizes all of the important information obtained concerning the gravel production methods included in this study. Seventeen conditions, involving thirteen different producers, were tested. Four of these were sampled on two different occasions. The results are expressed in terms of average quantity of treatment, their standard deviation from the average, the probable range of their averages, and a mixing efficiency ratio in which field results are related to controlled laboratory values.

These data show two important phases of the mixing process: 1) quantity of chloride added to the aggregate, and 2) uniformity of mixing. Both of these factors are inter-related.

Fig. 10 shows the maximum, minimum, and average chloride contents obtained from the 25 samples taken at each operating site. These results show that thirteen out of the seventeen operations studied are at least 1 lb per ton of aggregate too high or too low in chloride content, indicating that most of the producers are having difficulty controlling the rate at which they add chloride to the stockpile. Nearly all of the stockpiles varied from the specified amount of chloride. However, a study of the mean or average values showed that in many cases the extreme variations were exceptions rather than the rule.

The ranges of the data shown in Fig. 10 can be considered as an index of how much the average chloride content might vary if another group of random samples were taken. For example, the average chloride content of the Bruce Gee operation (small range) should not vary as much as that of the Herbst operation (wide variation), when other groups of 25 samples are taken.

Using statistical analysis it is possible to predict the range through which the average chloride content will vary for any group of samples taken from a particular stockpile. The values included by such ranges are an index of both the quantity and the distribution of the chloride added. Fig. 11 shows the average chloride content of the samples taken and the range through which 99.73 percent of all possible sample averages will fall. These data show, for example, that the Bruce Gee operation is receiving chloride

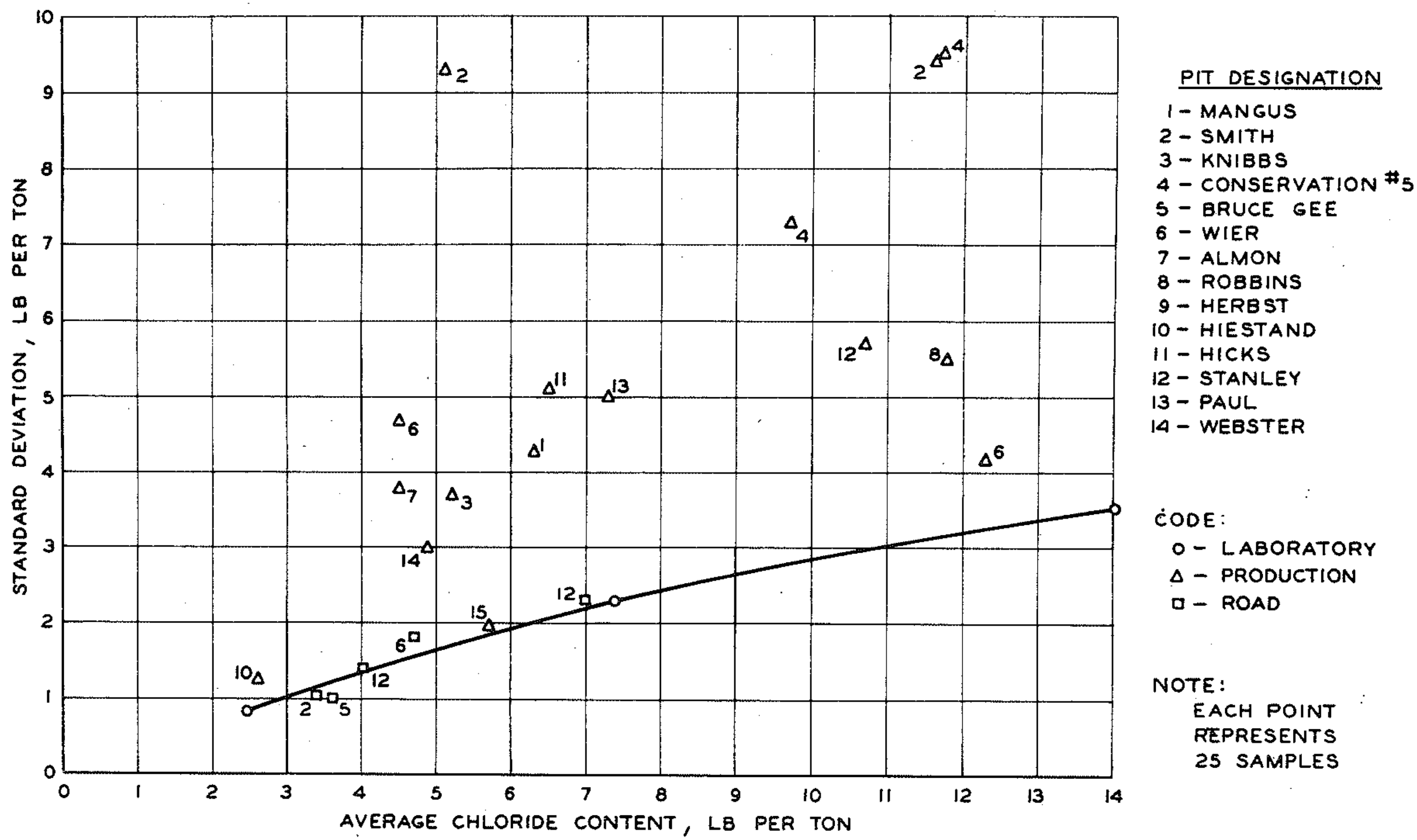


Figure 12. Comparison of field site and laboratory mixing at the different average chloride contents.

close to the specified amount. In 99.73 percent of the time average chloride contents will vary between 4.6 and 7.0 lb per ton---which includes the specified value of 6 lb per ton. On the other hand, the average chloride content of the Hiestand operation, 99.73 percent of the time, will range between 1.7 and 3.5 lb per ton, which does not even approach the required amount. Only in about one-quarter of one percent of the time would this operation have a chance of receiving the specified 6 lb of chloride per ton if operating in the same manner as when tested.

Fig. 11 also indicates the efficiency of the mixing for different operations. Wide spans of variation such as shown for the Smith, Conservation, and particularly the Herbst operation, indicate poor distribution of chloride throughout the stockpile. The Hiestand operation, although low in chloride content, proved to be one of the most efficiently mixed.

Fig. 12 shows a comparison between the uniformity of controlled laboratory mixing and that found in the field. The comparison was made on the basis of a range of chloride treatments prepared in the laboratory which included all values found in the field. The standard deviations of 25 samples representing each condition were used as a means for comparison and indicate both the quantity and distribution of the chloride. The closer the field values come to the laboratory curve the more uniform is the mix. This figure indicates that only the Bruce Gee operation performed satisfactorily for both uniformity and quantity of chloride. The Hiestand pit and the road samples showed good distribution of chloride but were too low in chloride content.

An efficiency ratio, in which the standard deviation of the laboratory and field mixes are compared, is included in Table 1. These data indicate that the operation of a given stockpile can vary from day to day. The Wier pit, for example, showed a variation in mixing efficiency from 80 to 32 percent at different times of sampling.

In order to check the uniformity of the gradation of the aggregate, a sieve analysis was made using the 3/8-in. sieve. These data are also included in Table 1. The standard deviation of the minus 3/8-in. fraction indicates a wide variation in values at each test site. Variations in the mixtures were not reflected by corresponding variations in mixing efficiency, however, indicating that gradation does not exert a primary effect on chloride distribution.

In general the data obtained indicate that wide variations exist in both quantity and distribution of chloride as delivered to the trucks.

CONCLUSIONS

Based on 17 gravel producing operations tested during this study, the following conclusions are made:

Mixing Efficiency. The chloride content of aggregate as furnished by all producers varied considerably. In many cases, these variations were extreme. Three operations were so bad that 25 samples were insufficient for obtaining a meaningful statistical analysis of conditions. Only one operation out of the 17 studied could be considered satisfactory with respect to both chloride content and uniformity of mixing.

In spite of poor mixing characteristics, however, all producers except one met or exceeded the total quantity of chloride required by specifications for their aggregate.

Methods of Adding Chloride. No attempt was made by producers to mix the chloride and aggregate at the time of production. The admixture is merely added, with the hope that subsequent handling will improve uniformity. None of the methods included in this study appear to be good enough to warrant their adoption as a standard. Higher efficiencies can be obtained by more careful handling and adjusting of the equipment, and this should be insisted upon by inspectors.

Both the amount and the distribution of chloride varied for a given producer at different times of testing. Some of these variations were caused by deliberate attempts to balance out previous variations in chloride content.

Loss During Stockpiling. As in previous studies it was found that there was a significant loss in chloride content between the time of stockpiling and placing on the roadway. Chloride was also lost from the roadway itself within a week after placing.

Uniformity on Roadway. Aggregate and chloride were much more uniformly mixed when placed on the road than at the time of production, indicating that handling operations improve the distribution of chloride throughout the aggregate and that original non-uniformity may not be too important, provided the specified quantity of chloride is present and some mixing takes place.

RECOMMENDATIONS

Based on 17 gravel producing operations tested during this study, the following recommendations are made:

1. More rigid control by inspectors should be exerted when the chloride is added to the aggregate. Many flagrant and obvious faults could be corrected, resulting in more uniform mixing.

2. The time that an aggregate remains in a stockpile should be kept to a minimum. High chloride losses from stockpiles, now quite common, could be reduced by reducing the time of storage.

3. Aggregate should be handled as much as possible between the stockpiles and the location of intended use. This allows more uniform distribution of chloride throughout the aggregate and may substantially correct poor initial mixing.

4. A supplemental study should be made to determine more fully the quantity and uniformity of the admixture that actually reaches the roadway. This would better establish the importance of thorough mixing at the source and also show how effective the overall chloride treatment is as a moisture control for the job.