Physical Damage of Grain Caused by Various Handling Techniques

Douglas E. Fiscus, Assoc. Member ASAE **George H. Foster** Fellow ASAE **and Henry H. Kaufmann** Member ASAE

GRAIN often incurs physical damage from mechanical handling between the farmer's harvest field and the consumer, resulting in lower quality grain, lower farm prices and increased handling and storage problems.

If the grain industry is to reduce grain quality deterioration, greater knowledge is needed of the causes of grain damage from mechanical handling. To help meet this need, a study was conducted to investigate the extent and causes of physical damage to grain resulting from equipment used in marketing channels.

These investigations were conducted by Cargill, Inc., under Research Contract No. 12-14-100-8146(52), which was administered by the Transportation and Facilities Research Division, Agricultural Research Service, United States Department of Agriculture.

The types of grain used in the tests were yellow corn, yellow soybeans, hard red spring wheat and hard red winter wheat.

The handling equipment and procedures tested were drop tests (free fall and spouting), a grain thrower and a bucket elevator.

In addition, the grain test parameters included two levels of moisture and temperature. Handling techniques were varied in regard to such matters as drop heights, belt speeds, impact surfaces, types of spout ends, types of elevator buckets and feeding methods.

Previous Work

Researchers have investigated the different aspects of grain damage from mechanical causes. Byg and Hall (1968), Schmidt, Saul and Steele (1968) and Waelti and Buchele (1969) determined corn kernel damage was caused by the harvesting machine. Perry and Hall (1965 and 1966), found relationships between pea bean damage and drop height. Clark, Welch and Anderson (1967) and Kirk and McLeod (1967) found relationships between impact velocity and cottonseed rupture. Bilanski (1966) investigated the damage resistance of corn, soybeans, wheat, barley and oats. Agness (1968) investigated breakage, using laboratory grain breakage devices. No work was reported concerning the grain damage that results from commercial handling practices.

Test Procedure

Selected grain lots for testing were obtained from commercial marketing channels in Minneapolis, Minnesota. Corn was obtained at 17 to 22 percent moisture and artificially dried to lower moisture contents. A continuous flow grain drier was used in which corn temperatures did not exceed 140 F. Soybeans and wheat were not artificially dried. All three grains were judged to have typical physical properties of grains in commercial trade.

These grain lots were precleaned with commercial grain cleaners to remove weed seeds, chaff, straw and other extraneous material. Next this grain was passed over a series of vibrating wire mesh screens to remove all broken kernels prior to testing.

After testing, vibrating screens were used to remove the broken kernels from the entire test lot of from 2,000 to over 13,000 lb of grain. Commercial wire mesh screens were used which approximated the sieve sizes prescribed by United States Department of Agriculture grain grading standards (16). Screen sizes used were as follows:

Grain	Screen opening In.	Screen wire diameter In.
Corn	0.159 sq	0.041
Soybeans	0.158 x 0.5 rectangle	0.072
Wheat	0.065 x 0.25 rectangle	0.035

The free fall drop tests simulated dropping grain into a storage bin. The test grain was loaded into a 350-bu holding bin. The bin bottom was fitted with a trap door discharge that was either fully open or fully closed. Streams from interchangeable 8- and 12-in. diameter round orifices were tested at drop heights of 40, 70 and 100 ft. To simulate dropping into an empty bin, a concrete impact surface at a 45-deg angle was used (Fig. 1A). To simulate dropping into a partially filled bin, a grain-on-grain impact surface was used (Fig. 1B), provided by filling a 36 in. diameter cylinder, 18 in. high with grain.

To simulate dropping grain down a spout such as that used when filling a railroad car, the 350-bu drop bin discharge orifice was fitted with an 8-in. diameter spout and slide gate. The spout discharge was fitted with either a bifurcated end or a flexible single spout end (Fig. 2). The flexible spout test was modified by adding a ¾ by 2 in. steel bar in the spout end to simulate the attachment of a grain thrower, as is sometimes used in ship loading. The ¾-in. dimension was perpendicular to the grain flow. Nominal drop heights of 40 and 100 ft were used. The grain impacted on a steel vertical bulkhead 20 ft away from the spout centerline, such as would occur in railroad car loading. For free fall and spouting drop, the 0 ft distance was defined as the lower edge of the discharge orifice.

A grain thrower (Fig. 3) is often installed at the discharge end of a ship loading spout to load the far corners of a cargo hold. Tests were made using

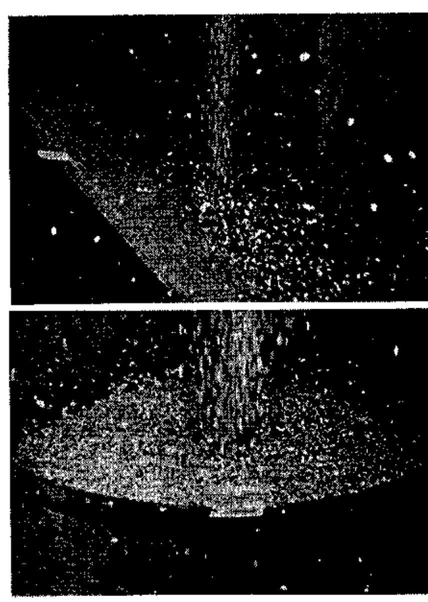

Fig. 1 Impact surfaces used in free fall tests. (Top) Corn flow from 8-in. diam orifice impacting concrete slab. (Bottom) Corn flow from 8-in. diam orifice impacting grain

Paper No. 69-853 was presented at the Winter Meeting of the American Society of Agricultural Engineers at Chicago, Ill., December 1969, on a program arranged by the Electric Power and Processing Division.

The authors are: DOUGLAS E. FISCUS, Research Engineer, Cargill, Inc., Minneapolis, Minn.; GEORGE H. FOSTER, Field Station Leader, TFRD, ARS, USDA, Purdue University, Lafayette, Ind.; and HENRY H. KAUFMANN, Manager, Grain Research Lab., Cargill, Inc., Minneapolis, Minn.

* Mention of a trademark or proprietary product in this article does not constitute a guarantee or warranty of the product by he U. S. Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

This article is reprinted from the TRANSACTIONS OF THE ASAE (vol. 14, no. 3, pp. 480, 481, 482, 483, 484, 485, and 491, 1971), the Transactions of the American Society of Agricultural Engineers, Saint Joseph, Michigan

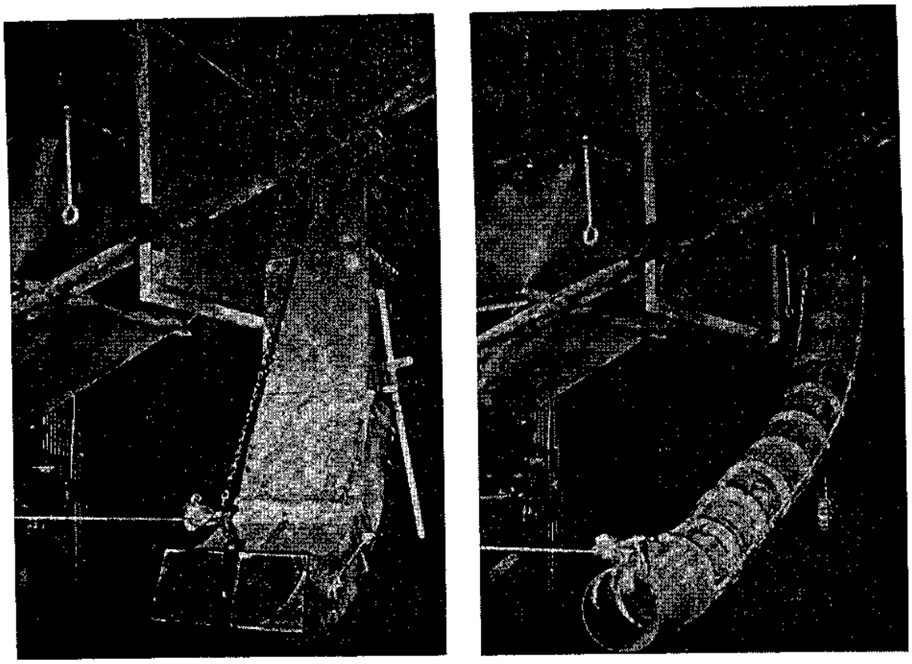

Fig. 2 Spout ends used in drop tests. (Left) Bifurcated spout. The two discharges from this spout are normally directed 180 deg apart to load both ends of a rail car. They were positioned parallel in this test to save space. (Right) Flexible turn spout

a Stephens-Adamson Swivel Piler* to throw grain against bulkheads at distances of 10, 25 and 40 ft from the centerline of the thrower tail pulley. The bulkheads were vertical wood, vertical steel and horizontal steel bulkheads. Thrower belt speeds of 4,030, 3,030 and 1,889 fpm were used.

A conventional bucket elevator (leg) was used, but the discharge head was not enclosed (Fig. 4). Discharge was therefore free and unrestricted. Screw Conveyor Corporation Nu-Hy 9 x 6 in. buckets and Link-Belt Company High Speed 9 x 6 in. buckets were tested at 650 and 940 fpm belt speeds. The buckets were spaced 8 in. apart on the belt. Head pulley diameter was 60 in. and tail (boot) pulley diameter was 30 in. Both front and back boot feeding and full and half-full buckets were tested.

Description of the grains tested by the above handling techniques are shown in Tables 1 through 3.

Analysis Procedure

The dependent variable in all tests was grain breakage. The independent variables were handling method, grain type and condition. Each test "run" was replicated three times and the mean breakage for each condition calculated. The data were analyzed statistically for significant differences between mean breakages. Two statistical treatments were used: Analysis of variance and Q test. A library computer program (6) was used for the analysis of variance. The Q test was used as specified by Snedecor (14). Significance or no sig-

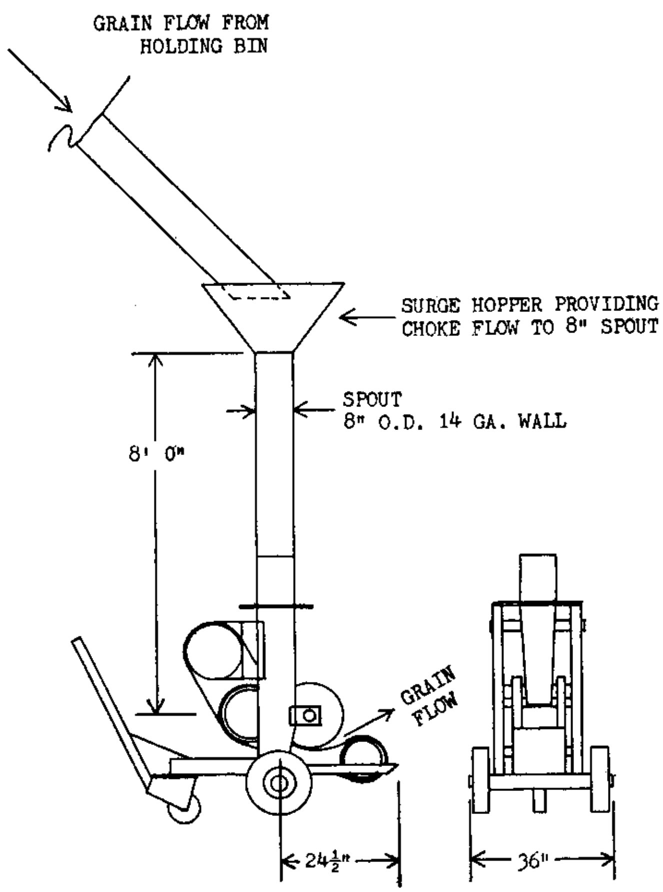

Fig. 3. Grain thrower used for breakage tests (Stephens-Adamson 16-in. swivel piler)

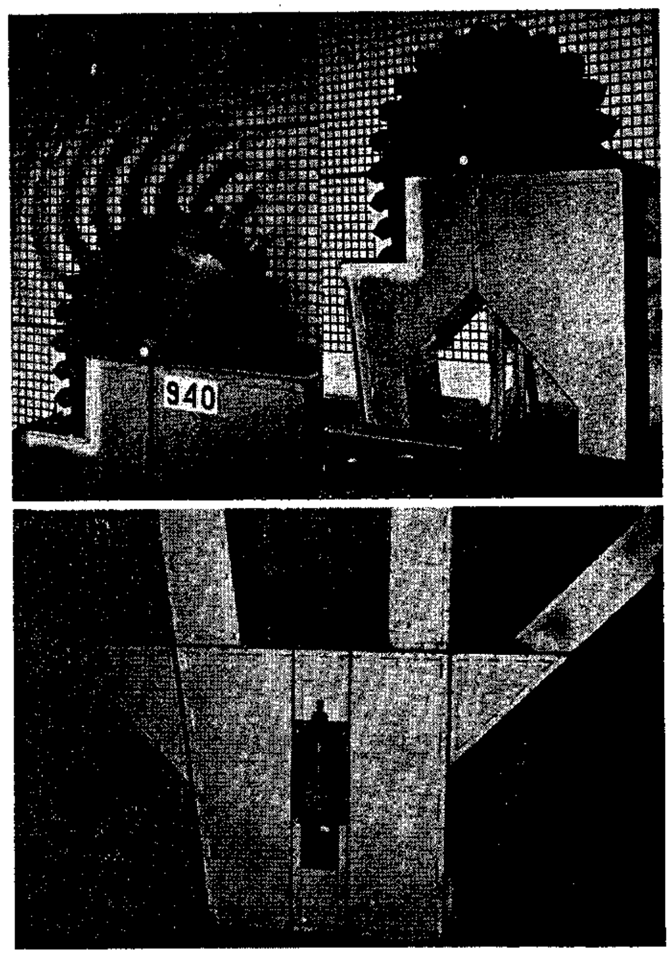

Fig. 4 Bucket elevator used in the tests. Top shows discharging corn at 940 fpm belt speed. Bottom shows elevator boot

nificance was declared, using 95 per cent confidence level.

Results

Tables 1, 2 and 3 summarize the results of tests for the three principal handling methods studied.

For each grain, drop tests caused the greatest breakage and bucket elevator tests the least breakage. The difference between drop, thrower and bucket elevator tests were greatest for corn and least for wheat. Increased breakage has a magnification effect. Generally, the higher the absolute magnitude of breakage caused by grain type, moisture and temperature, the greater the breakage differences between handling methods tested.

Corn had the highest breakage. The broken particles of corn ranged in size from dust to the largest particles that would pass the screen opening. As compared with wheat and soybeans, corn is a structurally weak kernel that fragmentizes into random particle sizes during the breakage process.

Soybean breakage was practically all splits, where the kernel broke into two halves. Compared with corn and wheat, a soybean is composed of two structurally strong halves, held together by a weak bond.

Wheat had the lowest breakage. Wheat breakage was mainlv dust and small kernel particles, apparently caused by an abrasion process.

The variability of the data is shown in Table 4. The means and variances of all tests with one grain and one han-

TABLE 1. BREAKAGE IN GRAIN DROPPED IN FREE-FALL AND THROUGH SPOUTING

			Grain	Corn		Soybeans			Spring wheat		Winter wheat
			Moist. percent	12.6	15.2	11.0	10.7	12.6	11.2	12.9	11.1
			Temp. deg F	25	31	32	46	50	27	34	45
			T.W. lb per bu	55.0	54.0	58.2	57.9	57.9	61.1	61.3	63.6
Drop height, ft	Discharge orifice, in.	Impact surface	Impact angle, degrees	Mean percent breakage							
(FREE FALL TESTS)											
100	12	Concrete	45	12.01	6.87	4.01	3.2	1.40	0.36	0.15	0.21
71	12	Concrete	45	7.07	2.54	1.82	1.23	0.56	0.19	0.11	0.18
40	12	Concrete	45	3.59	0.27	0.89	0.62	0.24	0.16	0.12	0.15
100	8	Concrete	45	13.82	9.55	5.63	5.72	2.18	0.34	0.16	0.29
71	8	Concrete	45	10.83	5.03	2.99	2.22	0.97	0.20	0.11	0.18
40	8	Concrete	45	5.86	0.86	1.69	1.15	0.37	0.16	0.12	0.18
103	8	Grain	90	12.53	7.11	4.06	4.11	1.39	0.29	0.16	0.14
72	8	Grain	90	7.74	4.00	1.89	1.68	0.62	0.22	0.11	0.08
43	8	Grain	90	4.35	0.25	1.05	0.74	0.27	0.16	0.13	0.11
(SPOUTING TESTS—8-in. dia. spout)			Spout end								
100	8	Steel	Bifurcated	8.32	2.22	1.82	1.57	0.59	0.23	0.14	0.14
40	8	Steel	Bifurcated	2.97	0.26	0.82	0.50	0.21	0.19	0.14	0.09
100	8	Steel	Flex Turn	7.02	1.53	1.45	1.32	0.41	0.21	0.10	0.12
41	8	Steel	Flex Turn	2.37	0.15	0.67	0.53	0.22	0.14	0.15	0.12
100	8	Steel	Flex w/bar	7.99	2.72	2.07	2.28	0.65	0.24	0.14	0.13
41	8	Steel	Flex w/bar	3.07	0.33	0.94	0.75	0.29	0.16	0.13	0.13
			Average	7.30	2.91	2.12	1.84	0.69	0.22	0.13	0.15

TABLE 2. BREAKAGE IN GRAIN HANDLED WITH A GRAIN THROWER

		Grain		Corn				Soybeans			Spring wheat		Winter wheat
		Moist., percent		13.2	12.8	15.4	15.0	11.1	12.5	10.7	11.1	12.9	10.8
		Temp., deg F		49	78	34	76	39	41	61	36	47	44
		T.W. lb per bu		54.1	54.5	53.6	53.7	58.0	58.0	58.1	61.9	58.6	63.9
TEST CONDITION													
Belt speed, fpm	Thrower distance, ft	Bulkhead		Mean percent breakage									
4030	10	Steel	Vert.	5.53	1.98	1.66	0.94	1.49	0.84	0.77	0.15	0.13	0.14
4030	10	Steel	Horz.	4.52	2.57	1.18	0.83	1.43	0.77	0.64	0.20	0.14	0.18
4030	10	Wood	Vert.	5.34	2.27	1.41	0.97	1.47	0.67	0.51	0.27	0.14	0.22
4030	25	Steel	Vert.	3.32	1.78	1.16	0.60	1.62	0.64	0.77	0.23	0.15	0.10
4030	25	Steel	Horz.	3.54	1.59	0.88	0.52	1.28	0.69	0.66	0.23	0.17	0.08
4030	25	Wood	Vert.	2.86	1.79	0.74	0.60	1.21	0.74	0.60	0.15	0.13	0.13
4030	40	Steel	Vert.	2.88	2.08	1.04	0.61	1.08	0.67	0.60	0.23	0.17	0.09
4030	40	Steel	Horz.	3.60	2.45	0.78	0.58	1.20	0.64	0.61	0.20	0.21	0.11
4030	40	Wood	Vert.	2.00	1.51	0.65	0.57	1.01	0.60	0.51	0.14	0.12	0.11
3030	10	Steel	Vert.	2.81	1.80	1.07	0.76	1.09	0.57	0.29	0.12	0.14	0.10
3030	10	Steel	Horz.	2.53	1.65	1.30	0.58	0.98	0.60	0.35	0.15	0.10	0.15
3030	10	Wood	Vert.	2.90	1.69	1.07	0.70	0.95	0.50	0.29	0.22	0.17	0.20
1889	10	Steel	Vert.	1.56	0.75	0.55	0.39	0.61	0.40	0.40	0.13	0.14	0.08
1889	10	Steel	Horz.	1.67	0.67	0.43	0.32	0.56	0.38	0.27	0.16	0.08	0.12
1889	10	Wood	Vert.	1.47	0.79	0.58	0.35	0.60	0.37	0.23	0.21	0.15	0.18
			Average	3.10	1.69	0.97	0.62	1.11	0.61	0.50	0.19	0.14	0.13

TABLE 3. BUCKET ELEVATOR PERCENT BREAKAGE

			Grain	Corn				Soybeans		Spring wheat		Winter wheat
			Moist., percent	13.3	12.7	15.1	14.8	10.8	12.6	10.9	12.9	11.5
			Temp., deg F	43	85	28	84	58	43	28	36	48
			T.W., lb per bu	54.3	54.4	54.2	53.6	57.8	57.9	61.1	61.1	63.5
TEST CONDITION												
Belt speed, fpm	Boot feeding method	Bucket loading	Bucket style	Mean percent breakage								
650	Front	½ Full	Nu-Hy	3.18	1.06	1.17	0.30	0.42	0.43	0.11	0.11	0.13
650	Front	Full	Nu-Hy	2.74	0.68	0.92	0.21	0.22	0.25	0.11	0.16	0.13
940	Front	½ Full	Nu-Hy	2.89	1.06	1.30	0.33	0.43	0.34	0.17	0.15	0.12
940	Front	Full	Nu-Hy	2.68	0.95	0.80	0.26	0.53	0.37	0.15	0.16	0.13
650	Back	½ Full	Nu-Hy	2.21	1.03	0.78	0.20	0.32	0.27	0.11	0.17	0.11
650	Back	Full	Nu-Hy	1.64	0.81	0.28	0.19	0.22	0.24	0.11	0.14	0.12
940	Back	½ Full	Nu-Hy	2.01	0.90	0.41	0.24	0.42	0.27	0.12	0.12	0.10
940	Back	Full	Nu-Hy	2.67	0.82	0.29	0.29	0.51	0.28	0.33	0.11	0.20
650	Front	½ Rull	Link	2.95	1.06	1.00	0.21	0.37	0.36	0.15	0.15	0.11
650	Front	Full	Link	2.81	0.79	0.35	0.18	0.37	0.32	0.17	0.13	0.14
940	Front	½ Full	Link	3.03	0.96	0.39	0.32	0.46	0.40	0.18	0.13	0.10
940	Front	Full	Link	2.36	0.89	0.82	0.35	0.40	0.33	0.22	0.12	0.08
650	Back	½ Full	Link	2.48	0.67	0.24	0.38	0.29	0.24	0.15	0.12	0.13
650	Back	Full	Link	2.26	0.65	0.20	0.22	0.30	0.24	0.16	0.12	0.10
940	Back	½ Full	Link	2.67	1.38	0.79	0.28	0.68	0.33	0.18	0.12	0.18
940	Back	Full	Link	1.98	0.92	0.83	0.31	0.51	0.26	0.19	0.12	0.20
			Average	2.54	0.91	0.66	0.27	0.40	0.31	0.16	0.13	0.13

dling method were averaged together to arrive at the pooled values shown in the table. The pooled standard deviation is the square root of the pooled variance. The trend is increasing variability with increasing breakage. The coefficient of variation normalizes the data for differences in the absolute values of breakage and is of the same order of magnitude for each grain.

When analyzing results, statistical significance can be declared on very small differences. The purpose of this research was to investigate damage in commercial grain handling. It would be impractical to make a point of small differences that would not normally be detected in commercial practice. In grain grading standards (16), 0.1 percent is the smallest unit of measure. Therefore, the criteria used for significance were: The variable must be statistically significant at the 95 percent level, and it must cause greater than an average 0.1 percent breakage difference. Table 5 shows the significant variables.

Wheat breakage was so low that there were no significant breakage differences caused by wheat class or any of the handling techniques. Wheat was therefore eliminated from further consideration; only corn and soybeans are considered in the following discussions of the drop tests and tests with a grain thrower and a bucket elevator.

TABLE 4. BREAKAGE VARIABILITY

Grain	Test	Grain breakage: Pooled mean	Pooled standard deviation	Confidence interval*	Coefficient of variation
		Percent	Percent	Percent	Percent
Corn	Drop	4.11	0.420	1.04	10.2
Corn	Thrower	1.60	0.127	0.31	7.9
Corn	Bucket elevator	1.10	0.148	0.37	13.5
Soybeans	Drop	1.55	0.073	0.18	4.7
Soybeans	Thrower	0.74	0.051	0.12	6.9
Soybeans	Bucket elevator	0.36	0.046	0.12	12.8
Wheat	Drop	0.17	0.016	0.04	9.4
Wheat	Thrower	0.15	0.019	0.05	12.7
Wheat	Bucket elevator	0.14	0.018	0.04	12.9

* At 95 percent confidence level.
† Coefficient of variation is the standard deviation expressed as a percent of the mean.

TABLE 5. SIGNIFICANT VARIABLES*

Handling Technique	Variable	Corn	Soybeans	Wheat
Drop	Drop height	yes	yes	no
	Orifice size	yes	yes	no
	Impact surface	yes	yes	no
	Spout end	yes	yes	no
Thrower	Belt speed	yes	yes	no
	Thrower distance	yes	no	no
	Bulkhead	no	no	no
Bucket elevator	Belt speed	no	no	no
	Boot feeding	yes	no	no
	Bucket loading	yes	no	no
	Bucket style	no	no	no
	Grain moisture	yes	yes	yes
	Grain temperature	yes	yes	yes
	Wheat class	—	—	no

* Yes = significant. No = not significant.

Drop Tests

All of the variables in the drop tests were significant. Drop height had the greatest effect on breakage, as shown in Figs. 5 and 6 and in Table 6. Breakage increased rapidly at drop heights greater than 40 ft.

Fig 5 demonstrates that breakage caused by grain falling on other grain was consistently less than that caused by grain falling on concrete. The lower breakage rate was observed at all drop heights and all grain temperatures and moistures tested. This suggests that grain is a more elastic impact surface than concrete.

Fig. 6 shows the grain stream from the 8-in. orifice had consistently greater

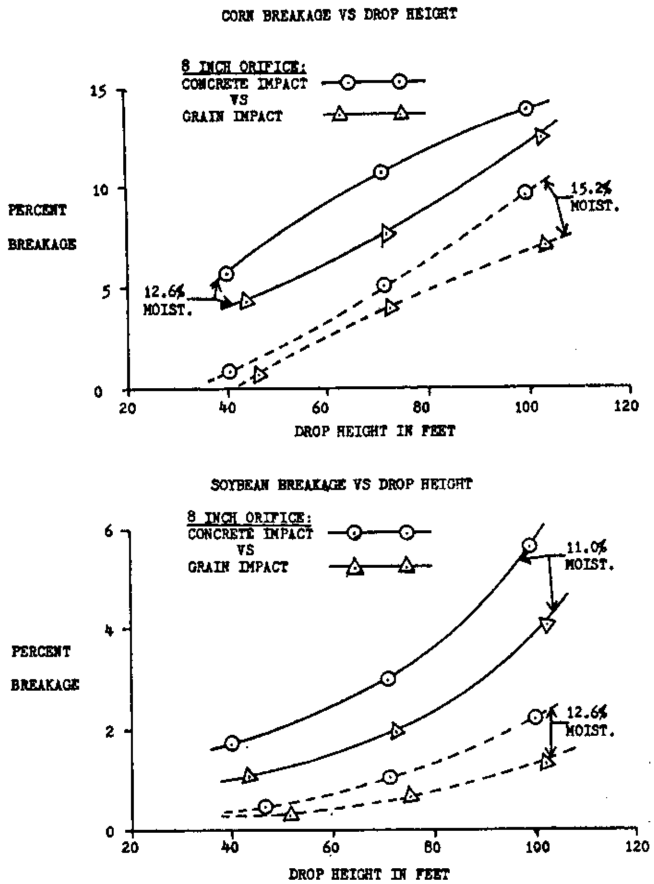

Fig. 5 Breakage versus drop height

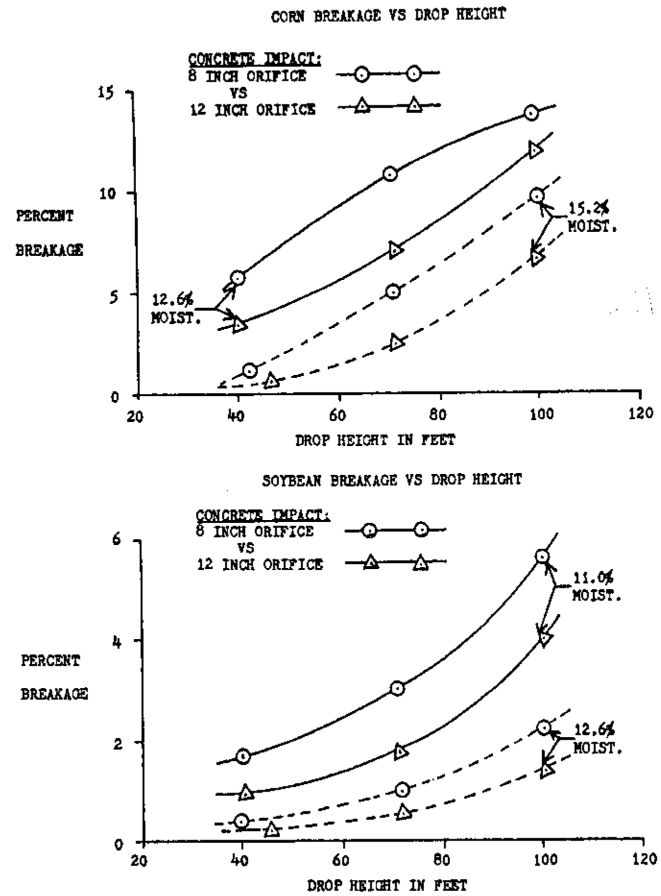

Fig. 6 Breakage versus drop height

breakage than from the 12-in. orifice. The larger diameter grain stream had more cushioning effect upon impact because of its larger mass. There was more kernel interaction and less stream dispersion, which resulted in more grain-on-grain impact and less grain-on-concrete impact. More tests using a variety of stream sizes would be needed to substantiate this theory.

Dropping grain through spouting with a 90-deg turn on the end and impacting it against a vertical steel bulkhead caused about one-third less breakage than free fall tests at the same drop heights. In the spouting tests with soybeans, a flexible turn with a bar across the spout end caused more breakage than the bifurcated spout end, which in turn caused more breakage than a flexible turn without the bar. Corn was the same, but there was no difference between the flexible turn with a bar and the bifurcated spout end. Table 6 shows these relationships.

Both the bifurcated spout end and the flexible turn with a bar had a metal projection in the middle of the spout, causing part of the dropping grain to impact on steel. This impact caused higher breakage.

TABLE 6. BREAKAGE FROM DROPPING CORN AND SOYBEANS THROUGH AN 8-IN. SPOUT

Grain	Drop height	Breakage by types of spout ends (a) Flexible turn w/bar	Bifurcated	Flexible turn
	Ft	Percent	Percent	Percent
Corn	100	5.4	5.3	4.3
Corn	40	1.7	1.6	1.3
Soybeans	100	1.7	1.3	1.1
Soybeans	40	.7	.5	.5

(a) Average of tests at all grain moistures and temperature levels.

Grain Thrower Tests

Thrower belt speed had the largest effect on breakage. Fig. 7 shows breakage increased with increasing belt speed. Breakage was almost lineal with belt speed except in the tests with low-moisture and low-temperature corn. The data in Fig. 7 were averaged for all bulkheads, since bulkhead type and position were not significant factors.

Vertical or horizontal wood or steel bulkheads caused no significant difference in breakage in the grain thrower tests. Thrower distance was significant only for corn. The breakage with the bulkhead at 10 ft was slightly higher than at 25 and 40 ft. There was no difference in breakage results between distances of 25 and 40 ft. The grain stream had a curvilinear trajectory and hit the bulkhead less squarely at distances of 25 and 40 ft than at 10 ft.

Bucket Elevator Tests

No bucket elevator variables were significant except the bucket loading and the method of boot feeding, and then only for corn. Half-full buckets caused an average increase of 0.2 percent breakage over that with full buckets. This increase meets the significant criteria, but it is a small difference. Presumably this higher breakage is caused by a larger percentage of kernels impacting grain on steel when the buckets fill. Once the bucket is partially full, much of the filling impact is grain on grain. Drop tests confirmed that the impact of grain on grain caused less breakage than grain on concrete.

Feeding the elevator on the front or up-leg side caused an average of 0.3 percent more breakage than feeding on the down-leg side. This difference is small. With front feeding, the falling grain impacted empty buckets traveling upward. With down-leg feeding, both the empty bucket and the grain were

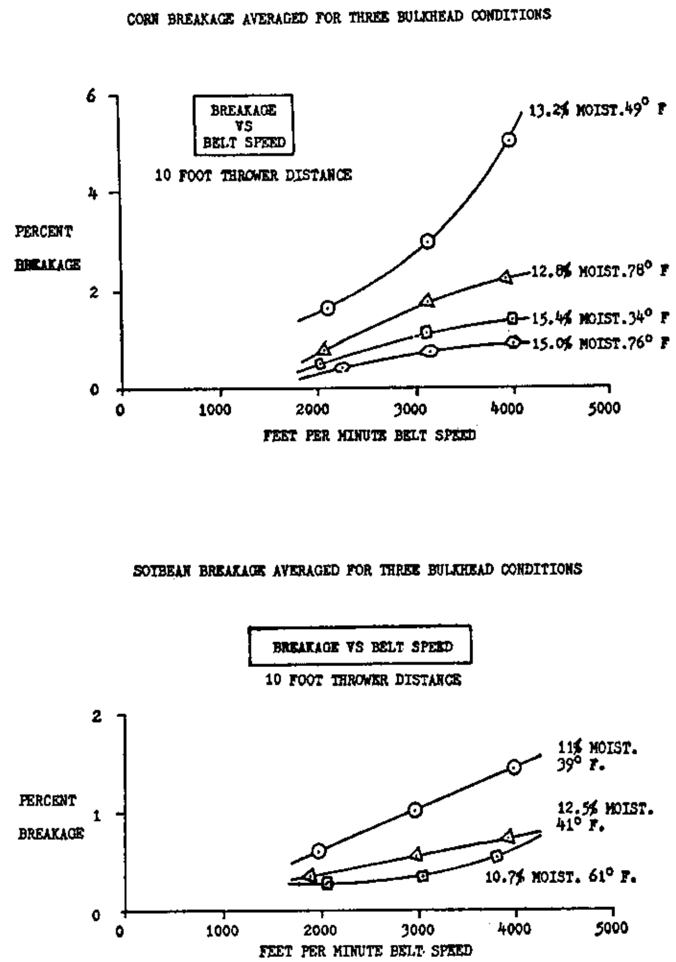

Fig. 7 Breakage versus grain thrower belt speed

traveling downward. The bucket filled as it moved around the tail pulley. Since the relative velocity between grain and bucket was less in down-leg feeding, the impact force and grain breakage were less.

Temperature and Moisture

The effect of grain temperature and moisture on breakage was significant in all tests. Fig. 7 shows that breakage was greater at the low temperatures and moisture contents. Moisture had a greater effect than temperature. As an example, the average breakage in 15 grain thrower tests with corn was 3.1 percent in the corn at 13.2 percent moisture content and 49 F temperature and only 0.6 percent in the corn at 15.0 percent moisture and 76 F temperature.

TABLE 7. A DROP INDEX* FOR CORN AND SOYBEANS

Handling technique	Test condition	Drop index				
		Corn		Soybeans		
		12.6 percent M 25 F †	15.2 percent M 31 F	11.0 percent M 32 F	10.7 percent M 40 F	12.6 percent M 50 F
Free fall	12-in. orifice concrete impact	3.3	25.4	4.5	5.2	5.8
	8-in. orifice concrete impact	2.4	11.1	3.3	5.0	5.9
	8-in. orifice grain impact	2.9	28.4	3.9	5.6	5.1
Spouting‡	bifurcated spout end	2.8	8.5	2.2	3.1	2.8
	flex turn spout end	3.0	10.2	2.2	2.5	1.9
	flex turn w/bar spout end	2.6	8.2	2.2	3.0	2.2

* The number of times grain may be dropped 40 ft without exceeding the breakage in a single drop of 100 ft.
† Grain moisture and temperature at time of the test.
‡ 8 in. diameter spout.

Remedial Measures

To reduce breakage, handle grain at as high a temperature and moisture content as possible. However, this contradicts the recommendations for storing grain. Storage life is increased at low grain temperatures and moisture contents.

Reducing drop height showed the greatest potential for breakage reduction in commercial grain handling. Dropping grain from heights over 40 ft—either in free fall or down a spout—caused greater breakage than either the grain thrower or bucket elevator.

Often the breakage from three or more drops of 40 ft was less than the breakage from a single drop of 100 ft. Table 7 gives an index which was calculated to relate the breakage in drops of 40 and 100 ft for all the corn and soybean conditions tested. Because 100 ft is not an even multiple of 40 ft, breakage was linear in drops of from 0 to 40 ft. Any value in the table larger than 2.5 (100 divided by 40) suggests that breakage could be reduced by limiting the drop height to 40 ft. The data in Table 7 suggest that reducing the drop height was more effective with grain at the higher moisture levels, since a greater number of drops of 40 ft were required to equal one drop of 100 ft. For dry grain that is very brittle, drop heights should be less than 40 ft, the minimum drop distance in these tests.

Conclusions

1. Corn incurred more breakage than soybeans, and soybeans more breakage than wheat.
2. Wheat breakage was less than 0.4 percent in all tests.
3. Dropping grain from heights greater than 40 ft caused more breakage than any other handling method tested.
4. Impact of the grain on concrete caused more breakage than grain on grain.
5. The grain stream from an 8-in. diameter orifice incurred more breakage than the grain stream from a 12-in. diameter orifice.
6. Breakage was greater at low grain moistures and temperatures.

References

1 Agness, J. B. Measuring mechanical damage to corn kernels. ASAE Paper No. 68-620, American Society of Agricultural Engineers, St. Joseph, Mich., 1968.

2 Bilanski, W. K. Damage resistance to seed grains. *Transactions of the ASAE* 9:(3)360, 1966.

3 Burington, R. S. and May, D. C. Handbook of probability and statistics. Handb. Publishers, Inc., Sandusky, Ohio, 1958.

4 Byg, D. M. and Hall, G. E. Corn losses and kernel damage in field shelling of corn. *Transactions of the ASAE* 11:(2)164, 1968.

5 Clark, R. L., Welch, G. B. and Anderson, J. H. The effect of high velocity impact on the germination and damage of cottonseed. ASAE Paper No. 67-822, 1967.

6 Gouwens, D. W. Statistical computer program S55—least squares analysis of variance. Eli Lily and Co., Indianapolis, Ind., 1968.

7 Harvey, W. R. Least squares analysis of data. Agricultural Research Service, USDA Pub. ARS 20-8, 1960.

8 Kiker, C. F. and Ross, I. J. An equation of motion for multiple granular particles in free fall in enclosed vertical ducts. *Transactions of the ASAE* 9:(4) 468, 1966.

9 Kirk, I. W. and McLeod, H. E. Cottonseed rupture from static energy and impact velocity. *Transactions of the ASAE* 10:(2) 227, 1967.

10 Neter, J. and Wasserman, W. Fundamental statistics for business and economics. 2nd edition Ally and Bacon, Inc., Boston, Mass., 1964.

11 Perry, J. S. and Hall, C. W. Evaluating and reducing mechanical-handling damage to pea beans. *Transactions of the ASAE* 9:(5) 696, 1966.

12 Perry, J. S. and Hall, C. W. Mechanical properties of pea beans under impact loading. *Transactions of the ASAE* 8:(2) 191, 1965.

13 Schmidt, J. L., Saul, R. A. and Steele, J. L. Precision of estimating mechanical damage in shelled corn. Agricultural Research Service, USDA, Pub. ARS 42-142, 1968.

14 Snedecor, G. W. and Cochran, W. G. Statistical methods. 6th edition Iowa State Univ. Press, Ames, Iowa, 1967.

15 Waelti, M. and Buchele, W. F. Factors affecting corn kernel damage in combine cylinders. *Transactions of the ASAE*, 12:(1) 55, 1969.

16 Waelti, M. and Buchele, W. F. Official grain standards of the United States. Agricultural Marketing Service. Grain Div., USDA Pub. SRA-AMS-177. May 1964.

17 Proceedings: A Symposium on grain damage. Grain Harvesting Com. PM 53, ASAE. Agr. Eng. Dept., Iowa State Univ. April 17-18, 1968.