dirt, and, lastly, to cleanse the grain from any adhesive dirt, etc. The first lot are removed by the truck hopper screens, and the second by the cleaning machines. Cleaning removes useless material, upon which freight would have to be paid, and at the same time increases the selling price of the grain. The clean grain is spouted to an elevator boot, whence it is elevated and distributed in the main storage bins.

The storage bins are usually in a separate annex, connected from the top to the working house by covered bridges carrying the distributing conveyors, and below by tunnels containing the reclaiming conveyors. The bins are usually circular and of large diameter (up to 20 feet), and 90 to 100 feet deep, and are built in contiguous rows, the interspaces also being used for storage. All bins, of whatever size, have self-cleansing hoppered bottoms. Each distributing belt over the bins has a self-propelling tripper, so that it may deliver into the fixed spout of each bin of two or three rows wide.

The distributing conveyors are housed in a light structure of steel covered with corrugated iron. In a similar manner the reclaiming conveyors in the tunnels below the bins are fed by spouts from several rows of bins. Grain for shipment is drawn off from the storage bins, conveyed underground to the working house, elevated, weighed, and then spouted to cars, or into the holds of vessels along the quay. At the lake fronts the vessels take whole cargoes of grain and come along the quay at the elevator; but at the sea ports they may take mixed cargoes, and may be berthed some distance away. It is therefore necessary to provide long-distance conveyors in elevated galleries to take the grain to the various berths.

The velocity of the spouted grain is usually sufficient to carry it to the farthest part of each hold, so that little or no hand trimming is required.

Terminal elevators are provided with a unit for drying wet and damaged parcels of grain, as it is essential that all oversea shipments be quite dry to prevent spoiling in transit. A limited accommodation for bagging is also usually installed.

Many of the seaport terminal elevators are provided with a marine tower for unloading barges and steamers. The towers are fixed, or, despite the great weight, movable, so as to accommodate the spacing of steamer holds. They contain telescopic or movable elevating legs, which may be lowered into the holds.

Materials of Construction.—Formerly most of the elevators in America were made of wood, there being an abundant supply of cheap timber. Dry grain is inflammable. Fires were frequent, the buildings and contents being destroyed with startling rapidity. Insurance rates, both on such buildings and their contents, were very high, and became a serious addition to working costs. Specially low rates are charged for structures and contents when the former are constructed to meet the stringent requirements of the fire insurance companies.

The buildings are made as fireproof as human ingenuity can arrange, the structure, including roof, being of structural steel and corrugated iron, or reinforced concrete, structural steel and corrugated iron, doors are of steel, the windows have iron frames and are glazed with wired glass. The buildings are fitted with very complete fire services. The use of rising forms has greatly reduced the cost of reinforced concrete, which is now almost invariably used, except for the superstructures.

Pressure of Grain.—It is necessary to know the nature and magnitude of the pressure exerted by grain before Grain Silos can be designed to be both safe and economical in construction. Ignorance or disregard of these forces has led to many disastrous failures of silo bins.

The problem is somewhat similar to that of retaining walls, but is not so simple. The solution for retaining walls will apply for shallow bins where the angle of rupture cuts the surface of grain, but it will not apply for deep bins.

There are two formulae which give results which agree very closely with the results of experiments: (1) Jansen's Formula, (2) Airy's Formula.

Jansen's Formula.—This is based on the results of experiments.

$$V = \frac{WR}{k\mu^1}\left(1 - \epsilon^{-\frac{k\mu^1 h}{R}}\right)$$

$$L = kv = \frac{WR}{\mu^1}\left(1 - \epsilon^{-\frac{k\mu^1 h}{R}}\right)$$

V = vertical pressure of grain in lbs. per sq. ft.
L = lateral pressure of grain in lbs. per sq, ft.
W = Weight of grain in lbs. per cubic foot.
μ = Co-efficient of friction of grain on grain.
μ^1 = Co-efficient of friction of grain on bin walls.
R = Hydraulic radius of Bin.
h = Depth of grain to any point.
ϵ = Base of Naperian System of Logarithms.

Various experimenters have measured the pressure of grain at various depths, and have determined the value of μ, μ^1 and k. In 1900 Jamieson, in Canada, made extensive experiments on model and full sized bins, and confirmed the correctness of Jansen's Formula. Jamieson found by experiment that for wheat k.0.6, and found the following values for μ^1 with wheat weighing 50 lbs. per cubic foot:—

Wheat on steel trough plate bin .	μ^1 =	0.468
Wheat on steel flat plate sweated to the bars	μ^1 =	.375 to .400
Wheat on cement concrete smooth		
Wheat on steel cylinder rivetted	μ^1 =	.365 to .375
to rough	μ^1 =	.400 to .425
Wheat on brick, smooth to rough	μ^1 =	.400 to .425
Wheat on cribbed wooden bin . .	μ^1 =	.420 to .450

Airy's formula is a very heavy and complicated one to use. It is given in a paper on Pressure of Grain in the Proceedings of Institute of Civil Engineers, Volume CXXXI.

Airy determined the co-efficients of friction of various kinds of grain on bin walls. His results are of great value, and are given in the above paper, and are as follows:—

Table No. 8.

TABLE OF COEFFICIENTS OF FRICTION OF VARIOUS KINDS OF GRAIN.

	Weight of a Cubic Ft. loosely filled into Measure.	Coefficients of Friction.				
		Grain on Grain u	Grain on Rough Board u'	Grain on Smooth Board u'	Grain on Iron u'	Grain on Cement u'
Wheat ..	49 lbs.	0·466	0·412	0·361	0·414	0·444
Barley ..	39 ,,	0·507	0·424	0·325	3·376	0·452
Oats	28 ,,	0·532	0·450	0·369	0·412	0·466
Maize .	44 ,,	0·521	0 344	0·308	0·374	0·423
Beans ..	46 ,,	0·616	0·435	0·322	0·366	3·442
Peas ..	50 ,,	0·472	0·287	0·268	0·263	0·296
Tares ..	49 ,,	0·554	0·424	0·359	0·364	0·394
Linseed ..	41 ,,	0·456	0·407	0·308	0·339	0·414

If the measure is well shaken, and the grain is closely pressed into the measure, the weight of a cubic foot of grain will, in all cases, be about 4 lbs. greater than the weights given in the above table.

Ketchum, in "Walls, Bins and Grain Elevators," draws the following conclusion from the results of many experimenters:—

The pressure of grain on bin walls and bottoms follows a law (which, for convenience, will be called the law of "semi-fluids"), which is entirely different from the law of pressure of fluids.

The lateral pressure of grain on bin walls is less than the vertical pressure (0.3 to 0.6), depending on the grain, etc., and increases very little after a depth of 2½ to 3 times the width or diameter of the bin is reached.

The ratio of lateral to vertical pressures, K, is not a constant, but varies with different grains and bins. The value of K can only be determined by experiment.

The pressure of moving grain is very slightly greater than the pressure of grain at rest (maximum variation for ordinary conditions is probably ten per cent.).

Grain bins, designed by the fluid theory, are in many cases unsafe, as no provision is made for the side walls to carry the weight of the grain, and the walls are crippled.

The pressures on the floor and sides of concrete bins of 10ft., 20ft. and 30ft. diameter, filled with wheat, are shown graphically on the accompanying diagram.

It will be noted that below a depth of about 3 diameters there is very little increase of pressure, either on the sides or on the bottom. If the pressure on the bottom does not increase with the increase in depth of grain, it follows that the grain is being partially sustained by friction by the side walls.

Steel bins designed on the fluid theory have failed by crippling of the side plates, as they were not designed to withstand the compression due to the transferred weight of the grain. The percentage of weight carried by the walls and the bottom have been calculated for concrete bins of 10ft., 20ft. and 30ft. diameter filled with wheat, and shown graphically on the accompanying diagram.

It will be noticed that for bins 10ft. diameter and 100ft. deep, only 10 per cent. of the total weight is carried by the bottom, the rest being transferred by friction to the side walls.

Grain Elevators are usually very tall buildings, and therefore exposed to strong winds. Many failures have occurred owing to the super-structure not being strong enough to withstand heavy gales or cyclones.

Grain elevators of all types and sizes exert great pressure on their foundations. Ignorance or neglect of this fact, or failure to properly proportion the footings to give an even settlement, has caused many disastrous failures.

PRESSURE OF WHEAT IN BINS

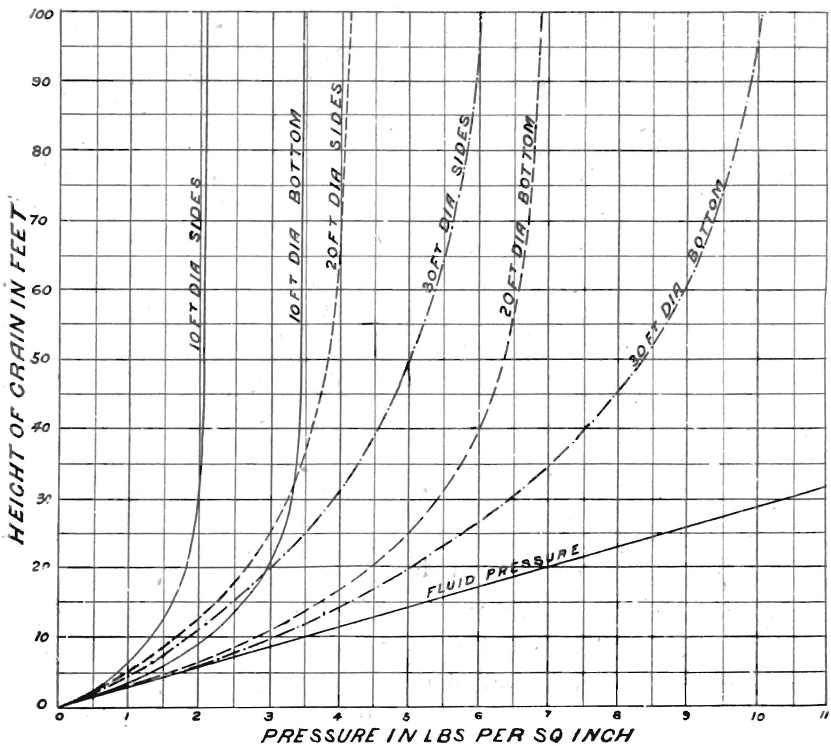


Fig 5.

Grain elevators may meet disaster from several causes:

(a) Destruction by fire.
(b) Bursting of the bins.
(c) Destruction by cyclone.
(d) Failure of foundations.
(e) Destruction by dust explosion.

The first four causes have already been discussed.

PERCENTAGE OF TOTAL WEIGHT OF WHEAT CARRIED BY BOTTOM AND SIDES

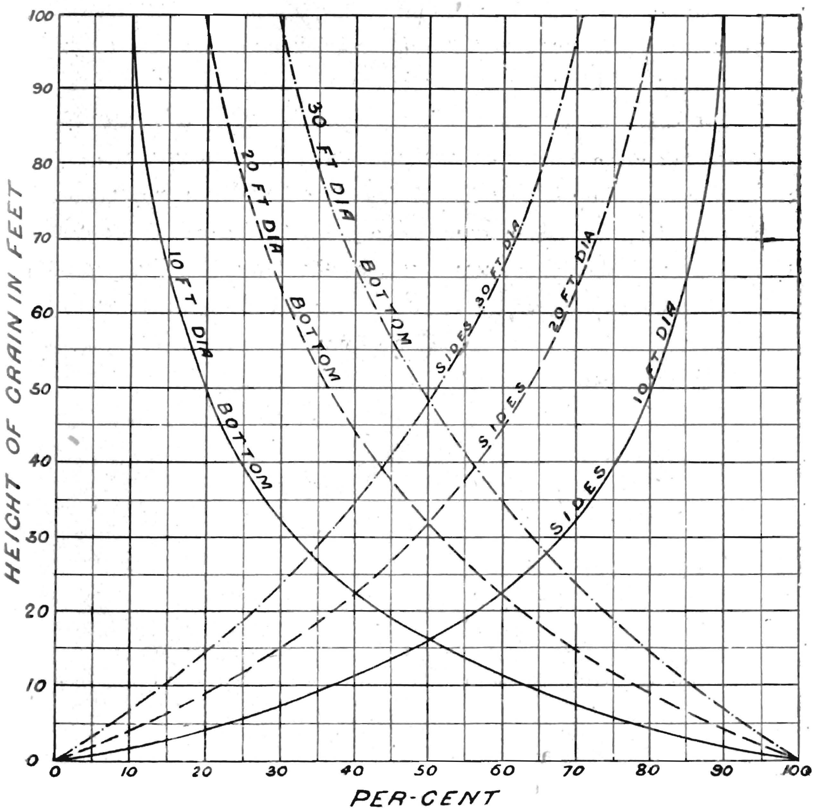


Fig. 6.

It is now well known that finely divided dry carbonaceous matter floating in the air forms, if in sufficient quantity, a very explosive mixture. Most of the recent disastrous explosions in Coal Mines have been due to coal dust as the main agent. In like manner numerous flour-mills and grain elevators have been wrecked or badly damaged by explosions of fine flour or grain dust. Complete systems of dust extractors are now applied to all places where dusting takes place, thus removing a danger to the safety of the structure and employees, and, at the same time, improving the hygenic conditions and comfort of the employees. The extracted dust may be used in firing the boilers, or sold as feed. Naked lights are a danger in flour mills and grain elevators. Electric lighting is now universal.

All machinery is electrically driven, each unit or set with its own motor. The current is generated in a separated power plant, or is purchased from an outside supply company. In the latter case boilers are only provided for working the drying plant or for heating the buildings.

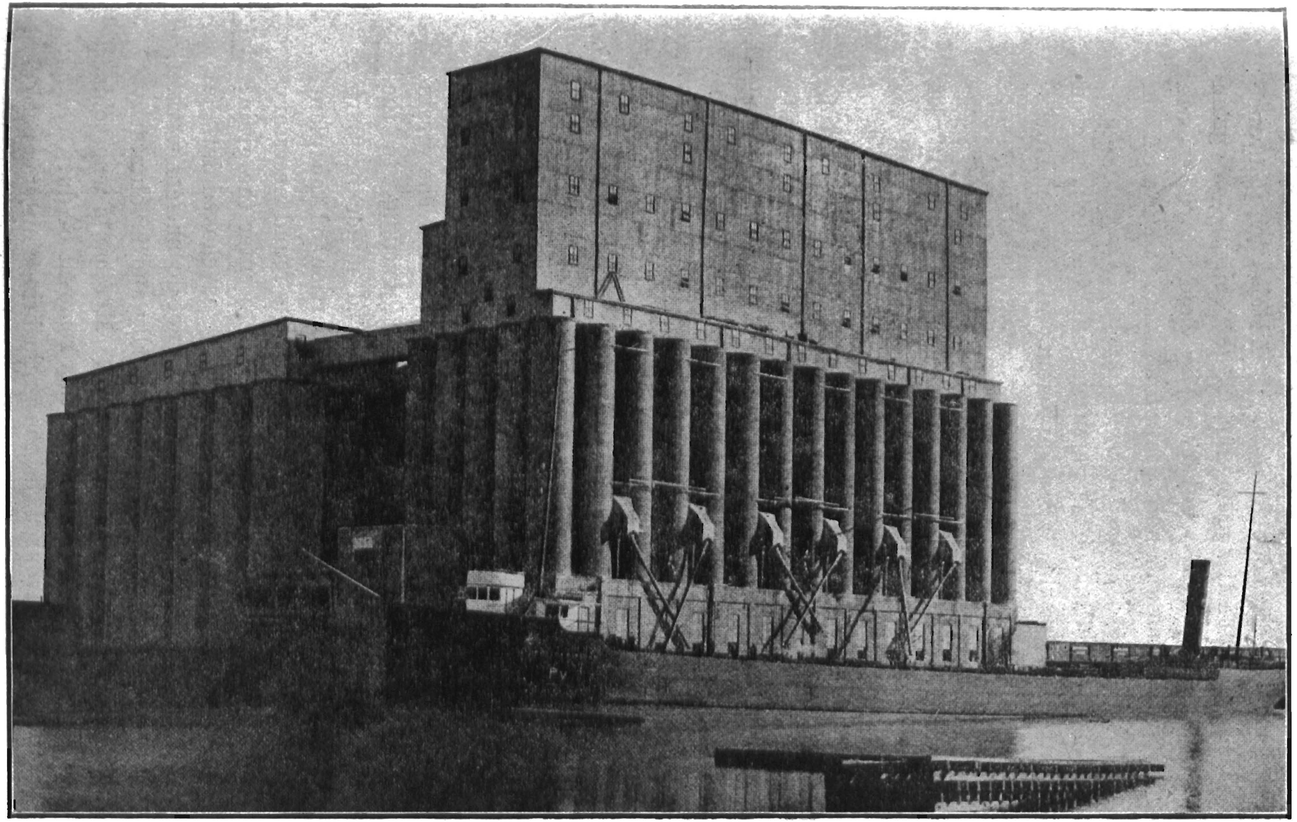
Modern elevators are provided with very extensive systems of telephone, signalling and control apparatus. These are so arranged that the Superintendent may, for the whole plant, and the Foreman for each department, know what bins, appliances, etc., are being operated. The controlling apparatus enables each electrically driven appliance of any section to be stopped in proper rotation.

The electric distribution of power has greatly assisted in developing large elevator plants.

SHIPPING GRAIN IN BULK BY VESSELS.

Vessels which receive their cargoes at Lake Ports in America usually take a whole cargo of grain. The vessels are brought alongside the shipping quay of the large Elevators, and the whole cargo run in in a few hours. Vessels which load at the seaports, on the other hand, usually ship a mixed cargo. There is a disinclination to shift a large vessel from wharf to wharf to receive its cargo. The cargo has, therefore, to be brought to the vessel.

Long distributing conveyors run from the storage bins, and convey the wheat to the various wharves, where it is spouted into the holds. General cargo may also, at the same time, be loaded into the vessels. Stringent



First Section of the 40,000,000 Bushel Grand Trunk Pacific Elevator, Fort William, Ont.

precautions are adopted by law, and also by Insurance Companies, for the prevention of the shifting of grain during the roughest voyage. The chief provisions are that where loose or bulk grain forms more than a certain portion of the vessel's cargo, it shall be divided by longitudinal and transversal partitions and properly stowed or trimmed, or that a certain amount in bags shall overlie the loose grain, so that it is impossible for any substantial alteration in the centre of gravity to be occasioned by any mischance so as to affect the stability of the ship.

Grain in bulk is unloaded at London Docks by fixed and floating elevators, the elevating appliances consisting of grab hoists, elevator legs which may be lowered into the hold, or by pneumatic elevators. Grain stowed in bunkers and other confined spaces cannot be reached by grabs or telescopic elevators, whereas the suction ends of pneumatic elevators may be taken into any place used for stowage. They also have the further advantage that they occupy so little space that the hatchways may be simultaneously used for the discharge of other cargo.

Pneumatic systems on the vacuum, pressure, and vacuum-cum-pressure methods have been employed. The last mentioned is now preferred. The grain is removed from the hold by partial vacumm to the vacuum box, weighed and then forced under pressure to the various bins. In the lower portion of the plant air under partial vacuum is used. It is found necessary to allow a fairly large amount of air to enter the grain; if too little air is admitted the pipe is choked by the grain; if too much, the machine does not do efficient work. This method of elevation automatically and involuntarily removes dust and lighter particles. Merchants who sold on weight at first objected to this removal of dust, etc., but it is now favoured, as the grain brings an enhanced selling price. The grain is discharged from the vacuum chamber by means of an air lock. It has a twin box, so that one may be unloaded while the other is filling.

The amount of power required to elevate a given quantity of grain is greater for a pneumatic plant than for ordinary bucket elevating and belt conveying machinery, but the former possesses the working advantages already mentioned, besides cleaning, aerating and brightening the grain in transit.

Cost of Operating the System.—Mr. G. T. Burrell, of Chicago, U.S.A., in his report to New South Wales Government on the Bulk Handling of Wheat in New South Wales, examined the cost and losses of the present system, and also gave an estimate for handling in bulk. The writer will, therefore, not attempt to make estimates of his own.

He makes the following comparison, omitting charges common to both systems, such as freight, insurance, etc., though the latter would probably be less for the bulk handling system.

Total cost of handling, and loss to 1000 bags during transport from farmer to vessel:—

Damage in field	£1	5	0
Loading and unloading at Railway Station	4	10	0
Damage from weather at Railway Station	5	0	0
Re-bagging at Railway Station	0	10	0
Handling at Darling Island	4	1	0
Power at Darling Island	0	12	0
Waste through dribbling	4	17	0
Bags	29	1	0
Covering stacks and railway waggons ..	0	12	0
	£50	8	0

This will amount to a little more than fourpence per bushel.

His costs for bulk handling may be summarised as follows:—

Cost at country elevators.	**pence per bus.**
Labour	.3
Power	.025
Repairs, depreciation of plant, etc.	.075
	.400

Cost at terminal elevator.	**pence per bus.**
Labour	.083
Power	.008
Repairs, depreciation, etc.	.020
	.111
Total	.511

That is a little more than one half-penny per bushel. Deducting this amount from the cost given above for the present system, there is a saving of about 3½ pence per bushel. This rate applied to the exportable quantities of wheat for the present harvest would be a saving of £700,000 for New South Wales (of which over £400,000 would be for bags alone), and for the Commonwealth £1,750,000. At the present high rate for bags, the saving for N.S.W. would be £200,000 more, and for the Commonwealth would be £500,000 more than the above figures based on Mr. Burrell's data.

In round figures it may be taken that the saving in operating cost, of an amount equal to one man's wages, warrants the investment of £1000 in capital expenditure in providing appliances and plant, for a new and improved system of work.

It is announced that the Government intends to seek Parliamentary sanction to instal a bulk handling scheme estimated to cost £2,000,000. The scheme provides for the construction of 100 elevators. There will be a big terminal elevator in Sydney, with a capacity of 3,000,000 bushels, and another terminal elevator at Newcastle, with a capacity of 500,000 bushels. Both of these elevators will be so constructed that they will be capable of considerable expansion in their holding space. For instance, when the Sydney elevator is completely built, it will hold 8,000,000 bushels. The elevators that will be built at the more important railway sidings in the country, will range in capacity from 50,000 to 300,000 bushels. These will also be built with a view to further development, and will be capable of great expansion. Provision will also be made for the purchase of 800 box waggons.

The first cost of a grain handling plant should not be the controlling element. More consideration should be given to convenience and economy of operation, flexibility of arrangement, provision for possible extension, and standard construction, all of which assure efficiency in operating, low cost in maintenance, freedom from breakdowns and costly delays.

The terminal elevator charges at Montreal for bulk wheat are .8 to .9 cents per bushel (1/4 to 1/6 per ton). This charge covers the whole operation from the time the grain arrives at the elevators, 20 days storage, and delivery into the holds of ocean steamships (See Proceedings of the Institute of Civil Engineers, Volume CCVIII.).

The cost of bagging and loading wheat at the same place into ship's hold is about 5 cents per bushel (8/4 per ton). This cost, however, does not include cost of storage and unloading from barges or railway trucks.

The unloading charge at London Docks for wheat in bulk is 14.5 pence to 23.5 pence per ton. The charges for wheat in bags is higher.

The principal advantages of bulk handling may be summarised as follows:—

Great saving in time and cost of handling the grain.

Saves the cost of providing bags every season.

Greater reduction in the quantity of lost and damaged grain.

Greater expedition in loading and unloading railway trucks, thus increasing the effective capacity of the rolling stock.

Greater expedition in loading and unloading ships, thus reducing shipping charges.

Less Fire Insurance Rate if stored in proper fireproof structures.

Greater ease in cleaning and grade, thus saving freight and increasing selling price.

Discussion

MR. A. J. HART said: Mr. President and gentlemen, I am particularly pleased to be able to propose a vote of thanks to Mr. Poole for his paper, because the subject of grain storage and construction of silos, the handling of wheat, and that sort of thing, has always been of very great interest to me. I remember that I often used to watch the boats on the river, where I was brought up, discharging grain, filling silos, and, in later years, the fascination of the subject for me has ever increased.

One does not know where to begin to discuss this paper of Mr. Poole's: it is all extremely interesting. With regard to the tables, and the summary they give us of grain production in Australia, they are most enlightening, as is the striking way in which the graphs illustrate the effects of drought on the production of any crop. I was particularly surprised to notice, in looking into the table, that the yield of wheat grown in the British Isles is about 57,000,000 bushels. Very often out here one hears an expression of