

Stored grain compaction factor

Accurate factors are necessary because volume measurements will not give exact measure of grain

by Rumela Bhadra

It is well known that grain undergoes compression when subjected to cumulative weight exerted from the overlying material in a storage unit. The extent of compression depends on several factors associated with the stored materials (crop type, test weight, moisture content) and bin characteristics (type of bin wall material, size and geometry of the grain bin).

Compression of grain leads to packing and thus adjusts the bulk density of the material. Therefore, accurate compaction factors are necessary, because volume measurements of the stored grain alone will not allow us to determine the exact amount of grain in the bin.

COMPACTION HISTORY

One of the earliest compaction factor data collections in the U.S. was performed by the U.S. Department of Agriculture (USDA)-United States Warehouse Examiner's group. The current U.S. Warehouse Licensing and Examination Division deals with issuing licenses to elevators and records bin inventory and storage data.

The USDA-FSA warehouse examiners use a handbook, known as "Warehouse Examiner's Handbook Grain Pack Data WS-3, Exhibit 9" for determining grain compaction factors. This book presents a detailed method for determining compaction factors for grain bins based on bin shape (round or interstice concrete bins) and average test weight of the grain bin. The exact publication date of this book is not known, but it appears that it was published in the 1950s.

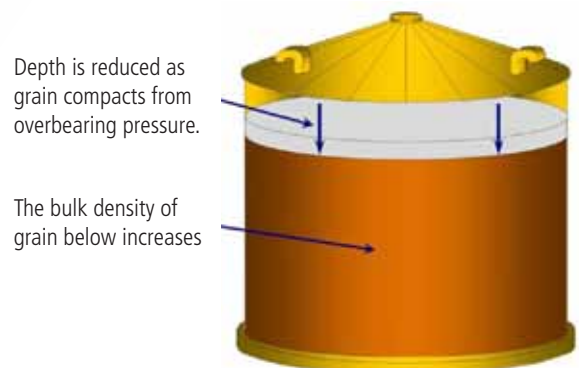
According to the original documentation and communication letters that led to the development of the handbook, approximately 95 bins were analyzed to measure compaction factors. These bins were primarily located in Kansas, Texas and Oklahoma. Most of the bins (95%) were constructed out of concrete although a few of them were wooden warehouses. Clearly the latter storage structures were very outdated as per modern industry design.

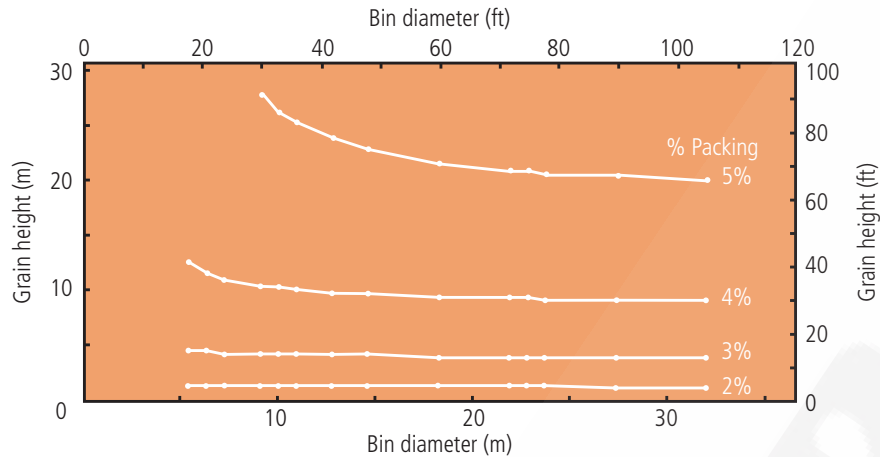
Some of this field data dates back to 1939. The bins had an average diameter of 18 feet. USDA-FSA warehouse examiners closely followed the procedure outlined in the handbook to collect this initial field data. In order to meet the needs of the modern grain industry (increased bin size, varying shapes and grain capacity), the Federal Warehouse group has made slight adjustments over the years, but its primary compaction factor data remains unchanged. However, many of these updates are not widely known among researchers and grain industry stakeholders.

Grain producing states in the U.S. all have their own state agricultural warehouse control officials that license elevators similar to the USDA-FSA warehouse examiners and use compaction factor tables from Warehouse Examiner's Handbook. And, it is believed that their procedure is very similar to that of the USDA-FSA warehouse examiners for most of the crops.

The USDA-Risk Management Agency (RMA) is associated with operating and managing crop insurance programs through the Federal Crop Insurance Corporation (FCIC). RMA through FCIC develops and approves insurance pre-

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mium rates and regulates subsidies for American farmers and ranchers. Hence, USDA-RMA also needs accurate compaction factors for grain inventory measurements. USDA-RMA and County USDA-Farm Service Agency (FSA county offices) used two different sets of compaction factor databases based

on empirical approaches to estimate the amount of grain in bins.

Around 2005, USDA-RMA started using FSA county office's compaction factor database based on capacity (bushel per foot) and test weights, but these values are much different than compaction factors listed in "Warehouse Exam-

iner's Handbook Grain Pack Data WS-3, Exhibit 9." However, the source of these compaction factors is not known.

ACADEMIC STUDIES

Studies related to compaction factors have been done in academia. These studies often use a scientific-based approach rather than just empirical data. The most widely recognized early study on grain compaction and correlating it with a granular science models was found in a published paper by H.A. Janssen in 1885.

Janssen derived the pressure caused by a column of corn in a bin. Based on a given height of corn, Janssen could determine the bottom pressure in the column. Even though his experiments were done in a square profile chamber, the pressure results were considered equivalent to grain contained in a circular structure with the same equivalent area to that of the square profile.

He also postulated that arching within the grain systems prevented measuring bottom pressures at various points. Since 1978, Janssen's research work has been cited 375 times, according to Matthias Sperl. Janssen derived the grain compaction model based on forces surrounding a differential element of grain inside the bin. The basic differential equation of Janssen is given as:

$$\frac{\partial P}{\partial y} = gD - \left(\frac{kP\mu}{R} \right)$$

Dy is the grain height, D is the bulk density or test weight of the stored material, P is the overbearing pressure, g is gravitational constant, μ is the coefficient of friction of grain on bin wall, R is the hydraulic radius of the structure (hydraulic radius = bin area/bin diameter) and k is a lateral to vertical pressure coefficient (varies with storage structure).

The solution by Janssen assumed μ , k and D to be constant. Because of this assumption, the above model is not accurate in large grain storage bins where the density of the stored material changes with a change in grain depth.

In order to develop and test this model

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for grain bins, a research group from the University of Kentucky (Ross et al.) in 1979 published a paper modeling the effect of pressure and moisture content on D , k and μ . Also, they showed how change in bin diameter can be related to bulk density changes.

Soon after, subsequent studies by S.A. Thompson and his group (in the 1980s and 1990s) led to the development of a user friendly program known as WPACKING that could generate much more reliable packing factors for varying bin sizes and shapes, bin material, crops types, moisture and test weights.

This WPACKING model used a more accurate revision of Janssen's equation and verified the model using laboratory data for HRW wheat, corn, soybeans and sorghum and a small amount of field data from commercial storage bins. The science and procedures behind WPACKING is readily available through journal publications, unlike the empirical-based compaction factor data used by government agencies.

The WPACKING could predict the compacted test weight of the grain, packing factor of the grain for any bin shape and size, and finally the amount of grain in the bin. Eventually, this method and, hence, the WPACKING

model was published by the American Society of Agricultural and Biological Engineers (ASABE) Standards in 1992 and later on it was again revised and reclassified as Engineering Practice in 2010 by ASABE.

DEVELOPING NEW FACTORS

Recently, there has been some mistrust and confusion around the existing packing factor data used by government agencies like USDA-RMA and the Federal Warehouse examination group. It was desired by some stakeholders in the grain industry to develop more accurate packing factor data for inventory control.

An article by Malm and Backer related to compaction factor in 1985 stated that compaction factors used by government agencies are not adequate for the grain industry and stated that compaction factors used by the Federal Crop Insurance Corporation (FCIC) at USDA-RMA appear to over-predict storage mass of grain bins.

This article stated the mistrust that was prevalent regarding FCIC compaction factor data. In 2001, the Association of American Warehouse Control Officials (AAWCO) approached researchers at the Quality Grains Research Consortium (NC-213 – Marketing and Delivery

of Quality Cereals and Oilseeds) annual conference about developing new packing factor data that would be more reliable with modern grain bin designs. NC-213 is a consortium formed by multiple universities and USDA-ARS research laboratories. AAWCO is now renamed AGRO (Association of Grain Regulatory Officials). Also, from 1994 to 2005 USDA-RMA did not use any pack factor database as they felt the existing pack factors were not accurate enough.

Finally, in 2009 USDA-RMA began a partnership with USDA-ARS at Manhattan, Kansas, U.S., funded through an interagency agreement, to carry out a large-scale packing factor project for six major crops (wheat, corn, soybean, sorghum, oats, and barley) in the U.S.

USDA-ARS is collaborating with Kansas State University, the University of Georgia, and the University of Kentucky to deliver this work. This project will be based on the scientific work and model development of Ross and Thompson's research group and thus will improve the WPACKING program to fit the current industry standards.

The scale and scope of this project is larger than previous packing factor studies. Crop samples are taken from the entire U.S. and include multiple varieties

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and regional composites. The WPACKING program will be refined with new data simulating varying bin sizes, shapes, material and bin wall types. Additionally, the program will be updated to grain quality factors such as moisture, test weight, dockage, damage, foreign material, and broken kernels.

Unlike empirical methods of determining packing factor, mostly used by governmental agencies, the WPACKING model uses detailed laboratory compressibility measurements for all included grain types. Thus, WPACKING model calibration and validation requires a manageable amount of field data from storage bins representing the range of sizes and types in use in the U.S. grain industry.

Measurement of a few hundred bins is currently being conducted to validate and calibrate the WPACKING model. Using a science-based approach in the WPACKING program will help avoid excessive cost of obtaining massive amounts of commercial bin data and at the same time will provide more accurate and reliable predictions of the mass of grain in the bin. It is hoped that this model will generate confidence intervals for the prediction of grain compaction and in-

ventorying of grain that has not previously been available.

CONCLUSIONS

Quality management is becoming extremely important to the grain industry, both in domestic and international markets. It requires careful and accurate documentation of the amount of grain stored in bins, and this can only be achieved if there are reliable and accurate compaction factors. Climatic uncertainties also beg for more accurate inventory control. Abnormal climatic situations like drought will alter the test weight and other quality parameters of grain kernels. This variable in grain quality will yield different packing scenarios than those normally observed. Hence, reliable and accurate compaction factors are necessary to estimate the exact amount of grain in the bin.

Inventory control (which is the ability to measure accurately the amount of grain in a bin at any given time) is extremely crucial for insurance agencies, auditors, elevator managers and farmers. It is needed for various financial and operational purposes. Thus, again we see reliable compaction factors are needed to predict the exact amount of grain in storage bins based

on volume measurements.

The compaction factor project undertaken by USDA-ARS and its collaborators will be able to provide reliable, updated information to the modern grain industry and user-friendly software for predicting compaction factors and, hence, the amount of grain in any storage unit. It is the hope of researchers that this software will find greater acceptance among the grain industry, governmental agencies and elevator managers, and also that it will be considered “the tool” for performing grain inventories. Getting a single uniform compaction factor database, i.e., the WPACKING program, is the long-term vision of this research group. **WG**

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