Experimental Determination of Janssen's Stress Ratio K. By Four Methods

A.O. Atewologun, G.L. Riskowski,
A.J. Muehling (1)

ABSTRACT

The stress ratio (K) used in design formulas of grain storage bins was determined by four different methods. Static stresses from soybeans were measured in a 0.91 m diameter x 2.74 m high model galvanized steel bin. For the first method, the vertical loads on the floor and the wall were determined separately and K-ratio calculated from Janssen's equation. The second method involved the measurement of vertical and hoop strains in the walls of the model bin. Six two-element rosette gages were spaced at equal distances around the outer circumference of the bin at 15.2 cm above the floor. The strains were reduced to stresses using Hooke's law for biaxial stress and membrane theory for thin-walled cylindrical shells. The third method was the use of dynamometric ring load cells to measure horizontal and shear loads at the bin wall, simultaneously. Three wall ring cells were placed at different heights on the model bin wall (15.2 cm, 61.0 cm, and 106.7 cm above the floor). The fourth method was by direct measurement of vertical and horizontal stresses within the grain mass using in-mass transducers (IMTs). These IMTs were used at four different heights at the center of the bin (15.2 cm, 61.0 cm, 106.7 cm, and 152.4 cm above the floor). A total of 18 runs was performed. The K-ratio decreased with increasing depth of material at shallow depths. At depths of three times the diameter of bin, K-ratio approached a constant value that may be approximated by-Ko = 1 — sine where is the angle of friction of grain to grain.

RÉSUMÉ

La rapport K utilisé dans les formules de calcul des silos à grain était déterminée par quatre méthodes différentes. Les chargements statiques du Soya était mesurés dans un modèle cylindrique en métal galvanisé, 0,91 m de diamètre x 2,74 m de hauteur. Pour la première méthode, le chargement vertical sur l'aire et l'espalier était déterminé séparément et le rapport K était calculé d'équation de Janssen. La deuxième méthode a impliqué la mesure verticale et un cercle aux tensions de l'entourage de l'aire et de l'espalier modèle à l'extérieur autour de la circonférence du silo. Les six deux-éléments gage rosette étaient espacés à des distances égales à 15,2 cm au-dessus de l'aire. Les tensions étaient réduites par la loi de Hooke pour deux axes tension et membrane théorie d'un espalier mince corps cylindrique.

La troisième méthode a usé d'un dynamométrique charge cellule pour mesurer la charge horizontale et la charge en cisailles du silo et l'espalier, simultanément. Trois cercles en cisailles étaient placés à différente hauteur sur le modèle du silo (15,2 cm, 61,0 cm et 106,7 cm au-dessus de l'aire. Pour la quatrième méthode on a mesuré directement la tension verticale et horizontale à l'intérieur de la masse de grains avec masse transducer (IMTs). Les IMTs étaient usés à quatre hauteurs différentes au centre du silo (15,2 cm, 61,0 cm, 107,0 cm et 152,4 cm au-dessus de l'aire). Un total de dix-huit rampes étaient accomplies. Le rapport K a diminué quand la hauteur du grain a augmenté pour les petites hauteurs. Pour des hauteurs de trois fois le diamètre de silo, la proportion K s'était approchée une valeur constante Ko = 1 — sin approximativement, où est l'angle de frottement interne du grain.

INTRODUCTION

Janssen's equation (Janssen, 1895) is used extensively for calculating grain loads. The accuracy of Janssen's equation is greatly dependent on the accuracy of the K-ratio, However, current K-ratio values are subject to controversy due to differences in definitions and questionable measurement methods (Sundaram and Cowin, 1979; Glastonbury and Bratel, 1966).

The experimental method of determining K-ratio on storage bins can be subdivided into three approaches according to the location of pressure measurement sensors :

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1. The authors are : ADENUGA O. ATEWOLOGUN, Graduate Research Assistant, GERALD L. RISKOWSKI, Assistant Professor, and ARTHUR J. MUEHLING, Professor, Agricultural Engineering Dept., University of Illinois, Urbana, IL.

- on the bin wall
- on a separately supported floor
- in the mass of the granular material

Wall pressure measurements have been taken using strain gages on steel reinforcement in concrete bins (Pieper, 1969). Pressure diaphragms mounted flush to bin walls have also been used to give direct stress values (Williams et al. 1987), and outward wall deflections have been measured with linear variable differential transformers (LVDTs) or dial gages. Wall pressure measurements give direct information about the response of the designed structural member and the material and installation costs for prototypes are reduced. However, the flexibility of the wall distorts the results of model bin tests. There are also problems in dealing with wall friction values that are not accurately kjnow and there are problems with very small strain ranges. Erratic results are thus common.

Floor pressure measurements involve the weighing of a floor that is supported separately from the bin walls (Janssen, 1985; Reimbert and Reimbert 1976; and Jamieson, 1903). Though this provides little information on the local response of bin sections, it has the advantage of averaging out local irregularities for determining the average K-ratio of the grain mass. Material and installation costs are reduced for model testing and there is less need for statistical evaluation.

Few investigators have taken pressure measurements within the mass of a granular material for many reasons :

- design focuses on bin walls
- introducing a foreign body within a granular mass may change the existing stress pettern
- special sensors are needed
- calibration of sensors is difficult
- the need for statistical evaluation increases

Terzaghi (1920) used three vertical steel tapes in sand and he pulled the middle sandwiched tape out through a groove. The force to pull the center tape out was related to the horizontal force on the outer tapes. Perry and Jangda (1970) used a cylindrical diaphragm sensor sensitive to radio waves to monitor flow patterns of glass beads. Clower et al. (1973) investigated the variation in K-ratio for sugar beet pulp, cornmeal, wheat and soybean meal by drawing horizontally and vertically oriented blades through the confined mass. Moysey (1983) used diaphragm sensors in model bins and Nichols et al. (1987) designed and tested six-faced transducer embedded in soil to measure normal stresses in six predetermined directions under tractor load. Lee (1987) pulled thin plates coated with a monolayer of particles out of a plexiglass model bin filled with steel spheres to measure interior stresses.

EXPERIMENTAL PROCEDURE

A model bin was constructed and instrumented to measure the K-ratio by four methods. It was an open-ended cylinder, 0.91 m in diameter by 2.74 m high and was fabricated from 0.93 mm thick smooth galvanized steel. The four methods were; 1) bin floor method; 2) wall strain method; 3) ring transducer method; and 4) in-mass transducers method. The arrangement of all the components of the apparatus is shown in figure 1. A dial gauge was mounted to measure the wall deflection at 38 cm from the bin floor to determine if the model bin was stiff enough to ensure at rest conditions.

Bin Floor Method

The bin floor was supported separately from the wall so the weight carried by the floor alone could be determined. A clearance of 3 mm between the floor and the wall prevented load transfer from wall to floor. The floor loads were measured with three cantilever load cells spaced evenly around the floor circumference. These load cells were calibrated on a Tinus Olsen universal testing machine prior to the grain load tests. A 10 cm diameter opening was cut in the center of the wooden floor and equipped with a sliding gate for unloading grain. The wall loads were transferred directly to the laboratory floor without being measured. The grain was weighed before it was loaded into the model bin. Wall loads were determined by subtracting the floor load from the total weight of the grain in the bin.

Wall Strain Method

Two-element strain-gage rosettes were fixed on the outside wall of the model bin at a height of 15.2 cm from the bin floor. Six rosettes were evenly spaced around the bin circumference at the same height to get an average strain at that height. Each rosette was bonded onto the bin so one strain gage was oriented in the horizontal axis and the other in the vertical axis of the bin to measure the hoop and meridional strain, respectively. The rosette system was not calibrated prior to the test runs. The strains were reduced to stresses using Hook's law for biaxial stress and membrane theory for thin walled cylindrical shells.

Ring Transducer Method

Ring load cells were developed for the simultaneous measurement of normal and shear stresses which were based on the principles suggested by Smid and Novosad (1971). Each circular ring was designed as a thin curved bar, having a radius of curvature at least ten times the thickness of the ring. This constraint ensured that linear distribution of bending stresses could be assumed in the perpendicular cross section of the bar. Applied normal and shear stresses cause bending stresses in the ring which, in turn, cause deformations on the outer and inner periphery of the ring. These deformations are combined in pairs of equal positive and negative values by special wiring in a wheatstone full bridge circuit. This corresponds to the stresses exerted on the outer fibers of bent beams on opposite sides of the neutral axis. The sensitivity is amplified due to larger relative deformations. A detailed description of the design is given in Atewologun (1990). Normal and shear loads were transmitted to the ring by a 64 mm sensing plate. It was desirable to have a pressure sensing area of at least twenty times the maximum dimension of the grains (Perry and Jangda, 1967).

On one side of the model bin, three 6.4 cm diameter holes were cut out along the same vertical axis at 15.2 cm, 61.0 cm, and 106.6 cm heights above the bin floor to fit the sensing plates of the three wall ring load cells. A steel post held the three wall ring load cells in place. The wall ring load cells were mounted to the post with a bracket that could be adjusted in three directions. The sensing plates were adjusted to be flush with the inside of the wall and so they were free to deflect without touching the wall.

Each ring load cell was calibrated in radial and tangential directions using known weights. There was a small gravity effect, wich was subtracted from strain readings to obtain the actual strain values that correspond to applied loads. The performance of each transducer circuit was very good because the calibration curves were linear and interference between the tangential circuit and the radial circuit was negligible.

In-Mass Transducers

Two in-mass transducers (IMTs) were designed to measure pressures within the soybean mass. Each IMT had three diaphragm sensors arranged to measure normal stresses in three planes (Figure 2). The three sensors were held in the desired orientation by a rigid wire frame. Each diaphragm sensor was designed as a circular thin plate with fixed all-around support. A detailed description of the diaphragm sensor design is in Atewologun (1990). Grains were glued to cloth which was fixed to the diaphragm of each sensor, which greatly reduced variation in data due to orientation of grains in contact with the diaphragm

On the opposite side of the bin from the ring load, four 12.7 cm diameter holes were cut to allow the placement of the in-mass transducers. These four opening, located at 15.2 cm, 106.7 cm, and 152.4 cm from the bin floor were covered with plates after the IMTs were put in place.

The IMTs were calibrated in a special bin with an air inflatable diaphragm on top of a soybean mass which exerted uniform overburden pressures on the grain mass. This calibration bin was made of the same steel and diameter as the model test bin. The IMTs were embedded in the grain mass at the central axis of the bin.

A Measurement Group Inc. P-3500 strain indicator and two SB-10 switch and balancing units were used to measure strains of all cells, transducers, and strain gages. A Hamilton Baldwin ST-340 strain indicator and its accessory switch and balancing unit were used for measuring the strain readings from the cantilever load cells and the hopper weighing load cell.

Test Runs

Soybeans were used as the test grain in this study. Their average water content was 9.2 % (wet basis) and the average density was 7 KN/m^3. A triaxial test done at Iowa State University gave an internal friction angle of 32° for the soybeans.

Soybeans were loaded into two hoppers and weighed with a 22,000 N ring load cell. After filling the bin, the hoppers were weighed again to determine the weight of grain in the bin. The hopper was lifted with a forklift to a height of 15.2 cm above the model bin and a gate was opened allowing the grain to empty into the bin. The hopper gate was located over the center of the bin for axisymmetric loading. Loading was stopped intermittently as required to place IMTs.

There were a total of eighteen runs. Grain was removed and reloaded for each experimental run. The same soybeans were used for all the runs. Readings were taken for the floor, wall rosette, and wall ring load cell methods for each of the eighteen runs with the bin full of soybeans which provided eighteen replicates for each of these three methods. Readings were taken immediately after filling the bin, one hour later, and again four hours after the original filling. The one-hour readings were used for analysis because they were essentially the same as those of the four-hour readings.

For the first twelve runs, the two IMTs were always placed in the concentric center of the bin and the heights of the IMTs varied randomly among the four given heights from run to run. The order of runs and the location of the IMTs was randomized for the test runs. This provided six replicates for the

IMT reading for each of the four heights. The final six runs were done exactly as the first twelve, except the IMTs were located only at the two bottom heights and on the bin floor. This set of runs was performed to investigate the radial variation of the horizontal and vertical stresses within the grain mass from the center to the bin wall. Readings were taken at grain height intervals of around 55 cm while loading and after the bin was full.

RESULTS AND DISCUSSION

Bin floor method

Bulk density was determined throughout the study by using total grain weight loaded into the bin and the known bin volume. The bulk densities remained essentially constant at around 7 KN/m^3. The vertical stress. S. at the bottom of the bin was calculated by dividing the grain weight carried by the floor by the floor area. This value was substituted into Janssen's equation to solve for K. A value for of 0.25 was assumed (which corresponds to a friction angle u of 14°) which is for soybeans at 9.2 % moisture content on galvanized steel (Mohsenin, 1986; Sitkei, 1986). The average K-ratio from the eighteen runs of the floor method was 0.55 with a standard deviation of 0.05, Table 1.

Wall strain method

Strain data were reduced to horizontal and vertical stresses by

- averaging the six strains in each direction
- calculating the magnitudes of the hoop (circumferential) stress and the meridional stress in the bin wall from the average strains, using Hooke's law for biaxial stress (Young, 1989).
- Calculating horizontal and vertical stresses using the membrane theory for thin circular shells (Billington, 1982).

The average K-ratio from the rosette strain gage method was 0.40 with a standard deviation of 0.08, Table 1. This K-ratio was computed without a need to assume any value for the coefficient of wall friction.

Ring transducer method

The horizontal stress at each load cell location was calculated using a sensing plate diamter of 64 mm. The resulting horizontal stresses were substituted into into Janssen's equation to solve for K-ratio. A value of 0.25 was assumed for. The K-ratio a the bin wall was found to increase with height above the bin floor which means that it decreased as grain depth increased, figure 3. The average K-ratio at the 15.2 cm height above the bin floor was 0.44 with a standard deviation of 0.10; for the 61.0 cm height, the average K-ratio was 0.69 with a standard deviation of 0.15, and at the 106.7 cm height, the K-ratio average increased to 0.80 with a standard deviation of 0.23 (Table 1).

In-mass transducer (IMT) method

The IMT method was a direct measurement procedure of obtaining K-ratio values. The observed strains were converted to pressures using the in-grain calibration curves for the IMTs which were obtained in a previous study (Atewologun, 1990). The results at each of the four heights are in Table 1. The average vertical (Sz) and horizontal (S) stresses both increased with grain depth. The vertical stress increased more rapidly than the horizontal stress, Figure 4. Therefore, the K-ratio at the center of the bin also decreased as grain depth increased, Figure 3.

In this study, three normal stresses were measured on different planes with the IMTs (horizontal, plane, 45° angle to the horizontal plane, and vertical plane). The 45° angle diaphragm was used as a check for the readings from vertical and horizontal planes. The vertical shear stress. Srz is theoretically zero at the center of the bin and maximum at the wall because when grain is loaded into a bin, the vertical stress, Sz, tends initially to be the major principal stress. The shear stress Srz was computed from :

Srz = S45° - 0.5SM, - 0.5Sz

As expected, the IMT placed at the center of the bin gave shear stresses nearly equal to zero for all experimental runs. The readings from the diaphram a a 45° plane thus confirmed the dependability of the readings from the vertically and horizontally oriented diaphrams. Future measurements of K-ratio in a grain mass with in IMT would only need the vertical and horizontal diaphrams.

Comparaison of K-ratio Values From All Four Methods

Average K-ratio values obtained for the different load measuremnt methods and at the various heights is summarized in Table 1. There was close agreement between the Rosette strain gage method, the wall ring cell method at the 15.2 cm height, and the IMT method at the 15.2 cm height (0.40 to 0.46). An unpaired « t » test for these methods at the 15.2 cm height showed no difference in the K-ratio mean values (P 0.05). However, as the height from the bin floor increased.

the agreement between the wall ring cell method and the IMT method diverged, Figure 3. Although the K-ratio increased with height from the bottom of the bin in both cases, the shapes of the curves differed.

An unpaired « t » test showed the means for all heights other than 15.2 cm to be statistically different (P 0.05). The IMTs measured K-ratio at the center of the bin and the ring load cells measured it at the walls, so K-ratio may vary radially from the center of the bin at shallow grain depths.

For both the wall ring and IMT methods, the the K-ratio was found to decrease with depth. Regression analysis of the wall ring and IMT data showed a strong variation with height (P 0.01) in both cases. This trend corresponds with the results of Caughey et AL. (1951), Reimbert and Reimbert (1976) and Pleissner (1906). Amundson (1945), Clower et al. (1973) and Pleissner (1906). Amundson (1945), Clower et al. (1973) and Lenczner (1963) found K-ratio to be constant with depth of grain while Ketchum ans Williams (Ketchum, 1919) and Kramer (1944) reported that K-ratio increases with depth of grain in a storage bin.

The floor-load method gave an average K-ratio for the entire grain mass of 0.55. Interestingly, the average K-ratio for the four heights of IMTs was 0.53. An unpaired « t » test showed that the difference between these two means was not statistically different (P 0.05). This suggests that the floor method corresponds to the average K-ratio with height along the central axis of the bin.

In the shallow bin range, wall ring cells gave higher K-ratio than the IMTs which suggests that the measurement of K-ratio values at the wall by the piston-type sensor mounted flush to the wall will consistently yield higher K-ratio values than the IMT method.

The K-ratio values that have been obtained by some past investigators for soybean range from 0.38 to 0.54 (Table 2). The K-ratio values measured in this work by the floor method (K = 0.55) and the average of the IMTs over all heights (K = 0.53) were similar to the value of 0.543 reported by Sundaram and Cowin (1979) who used the floor method. The K-ratio value of 0.43 from wall pressure diaphragms (Sundaram and Cowin, 1979) agreed closely with the values from the rosette method and the wall ring cell method (K = 0.40 and K = 0.44, respectively) of the present study. Consistent differences in K-ratio therefore exist because of different measuremnt methods.

CONCLUSIONS

1. The floor method gave an average of the K-ratio for the entire height of grain above the floor at the bin center. Reproducibility of the results was very good. The main objection to using the floor load method is that the K-ratio values depend on the choice of the coefficient of friction (u'). Thus, unless u' is known accurately, the K-ratio values obtained from the floor method may be erroneous.

2. Wall load meassurements obtained with wall load cells are good when combined with other methods. Improper alignement of the ring sensing plates with respect to the bin wall would alter the readings of the wall ring load cells substantially. It is recommended that special care be exercised in the alignment of wall diaphragms so that they are completely free from and flush with the wall of the grain bin. An accurate value for u' is needed for the wall load cell method.

3. The rosette strain gage method is good if several measurements are taken around the circumference of the bin. There was a wide variation of readings from one gage to another. Therefore an average of at least six measurements must be considered. Another limitation of the rosette strain gage method is that if the strain levels are small, the readings are subject to external interference from temperature, humidity, or vibration.

4. In-mass measurements revealed a definite decrease in the K-ratio as the depth of grain increased. In the shallow bin range, K-ratio as high as 0.67 was obtained. At depths greater than twice the diameter of the bin, the K-ratio approached the value 0,47. The measurements of the K-ratio at the deep bin range (15.2 cm and 61 cm above the floor) of the bin were not statistically different.

The IMT method of measurement was successful. It has the advantage that measurements made away from the wall of the bin were not dependent on a choice of coefficient of friction of grain on the wall (u'). It compared favorably to the floor load method if averaged over the height of the bin.

5. Of all the four methods, only the floor method gave a different K-ratio at deep bin range. The floor method K-ratio corresponded to the average of K-ratios at all heights of the IMT method at the center of the bin. Regression analysis of data from the wall ring and IMT methods showed a strong variation with depth (P 0.01) in the shallow bin depths. Although K-ratio decreased with

increassing depth of material for methods, the wall ring method gave higher K-ratios than the IMT method.

6. It can be concluded from the results of this study that the K-ratio is not a material property, because a true material property will not be affected by depth of material (or overburden pressure) or diameter of the bin. Therefore the use of the Rankine coefficient

$$Ka = (1 - \sin p)/(1 + \sin p)$$

for the design of grain storage bins cannot be justified. Using an angle $s = 32°$ in the above equation for the soybean material of the present study gave $Ka = 0.307$, a value much below the K-ratio values obtained at deep bin depths from all four measurement methods. However the static earth pressure coefficient commonly used in soil mechanics ($Ko = 1 - \sin p$) applied to the test materiel used for this research becomes $Ko = 0.470$, which coincides with the K-ratio results of the IMT measurement method at deep bin depths of grain. The use of the Rankine active coefficient for design in the case of the storage of the material used in the present study would underestimate the vertical compression in the bin wall.

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Table 1. Average K-ratio values from all four measurement methods.

		Heights from bin floor (cm)			
Method	Replicates	15.2	61.0	106.7	152.4
Floor Load	18	0.55 (0.05)	*	0	0
IMT	6	0.46 (0.13)	0.47 (0.07)	0.52 (0.07)	0.67 (0.15)
Rosette Gages	18	0.40	*	*	*
Wall Ring Cells	18	0.44 (0.10)	0.69 (0.15)	0.80 (0.23)	—— ——

* Height irrelevant to method

(standard deviation in parentheses)

Table 2. K ratio for soybeans as reported by some past investigators.

Reference	Methods	K ratio
Caughey et al (1951)	Floor load and wall pressure diaphragms	0.383
Sundaran and Cowin (1979)	Wall pressure	0.430 diaphragms alone
Sundaran and Cowin (1979)	Floor load alone	0.543

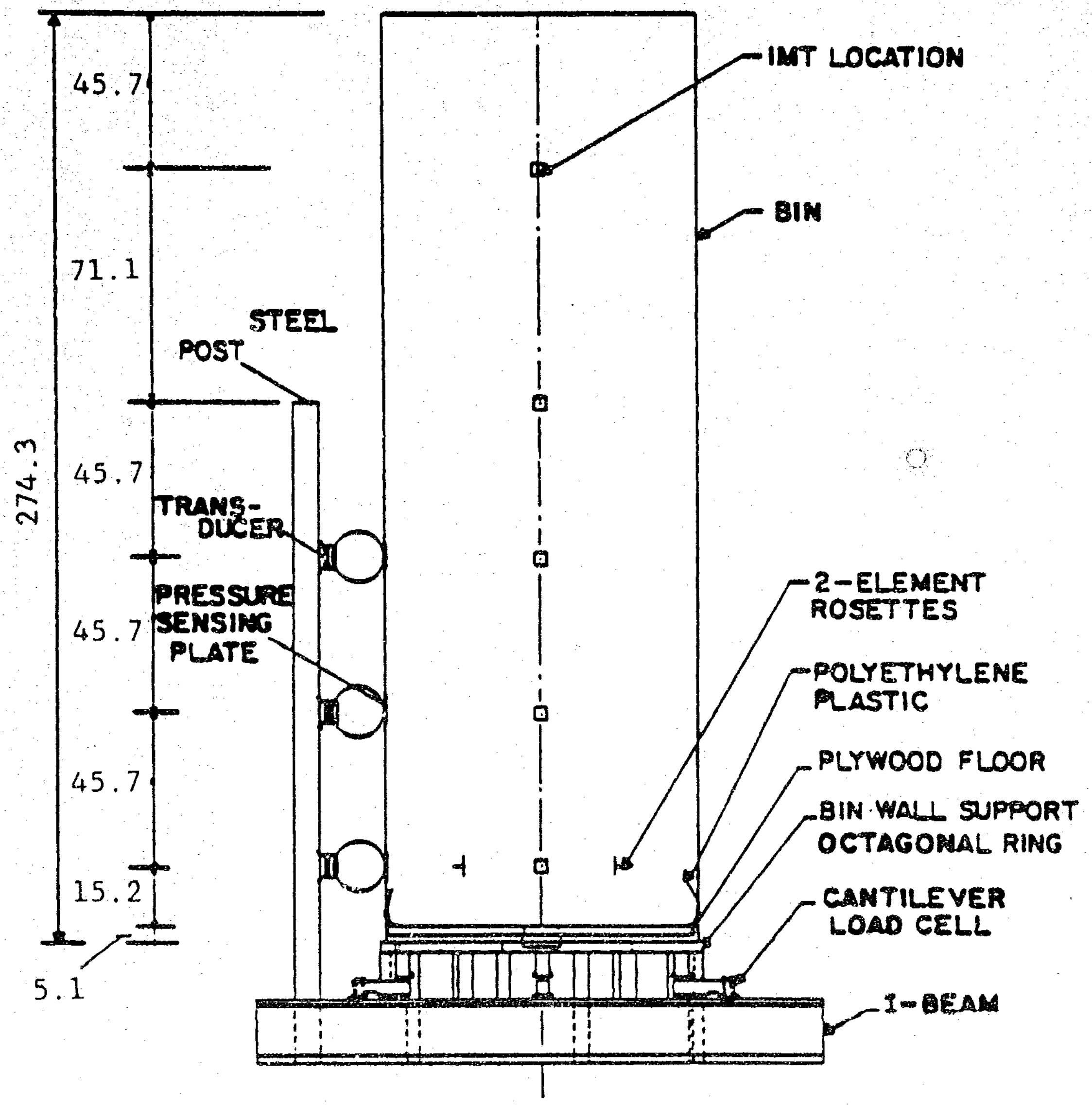
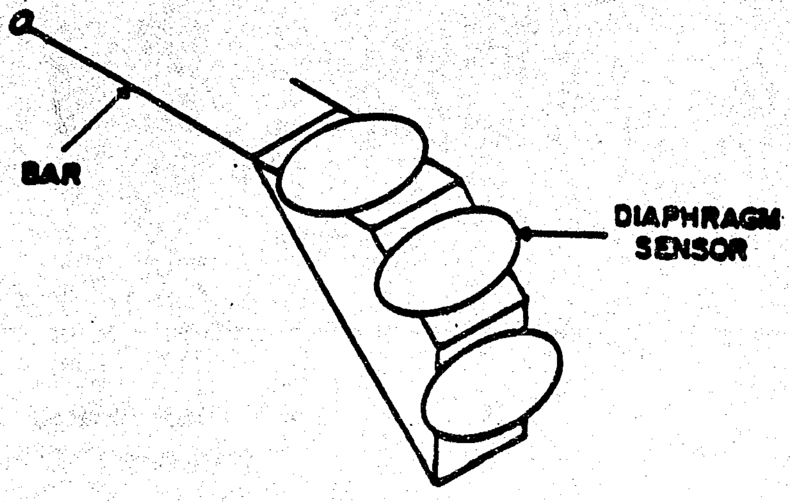
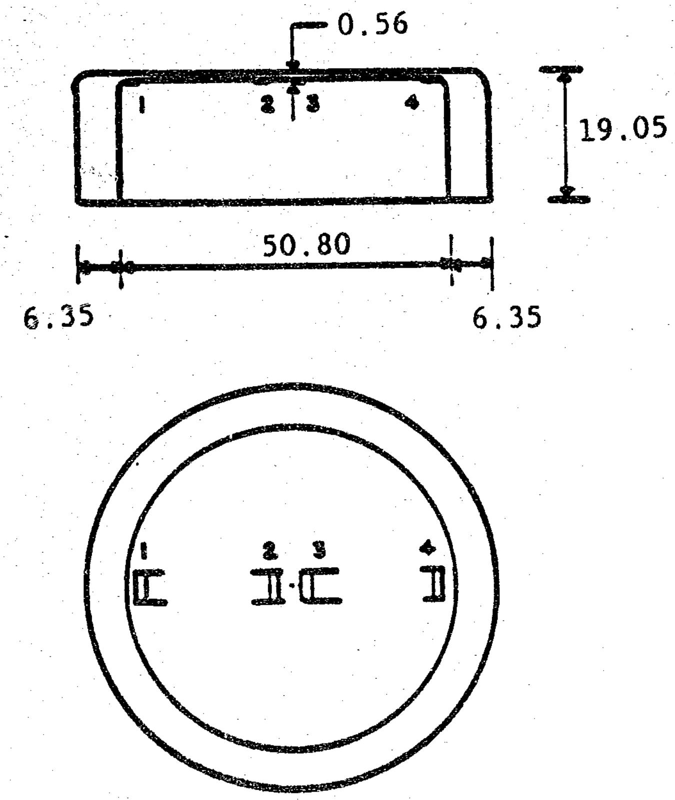


Figure 1. Model grain bin (all dimensions in cm)



In-mass transducer



Diaphragm sensor

Figure 2. In-mass transducer and its diaphragm sensor detail (all dimensions in mm)

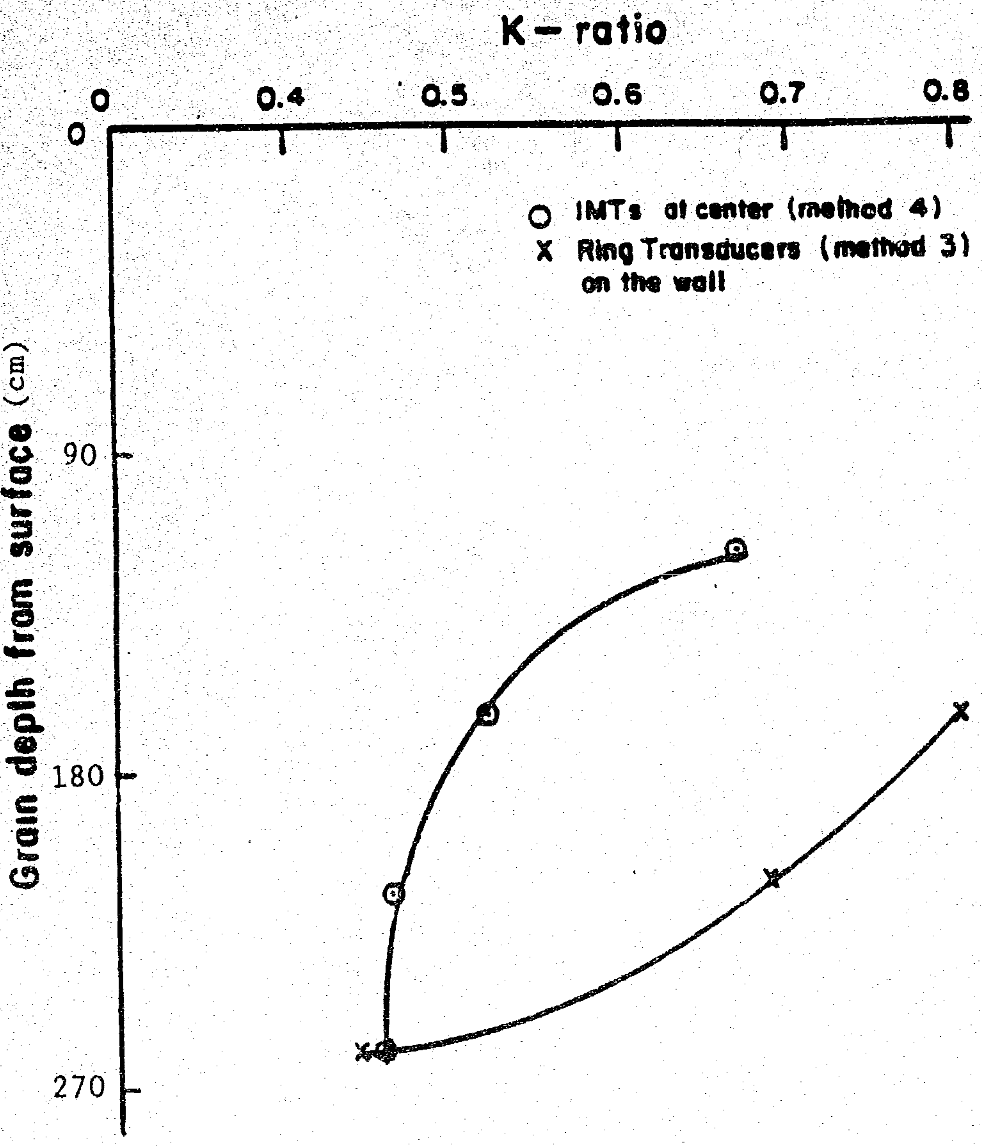


Figure 3. K-ratio variation with depth of grain at full load

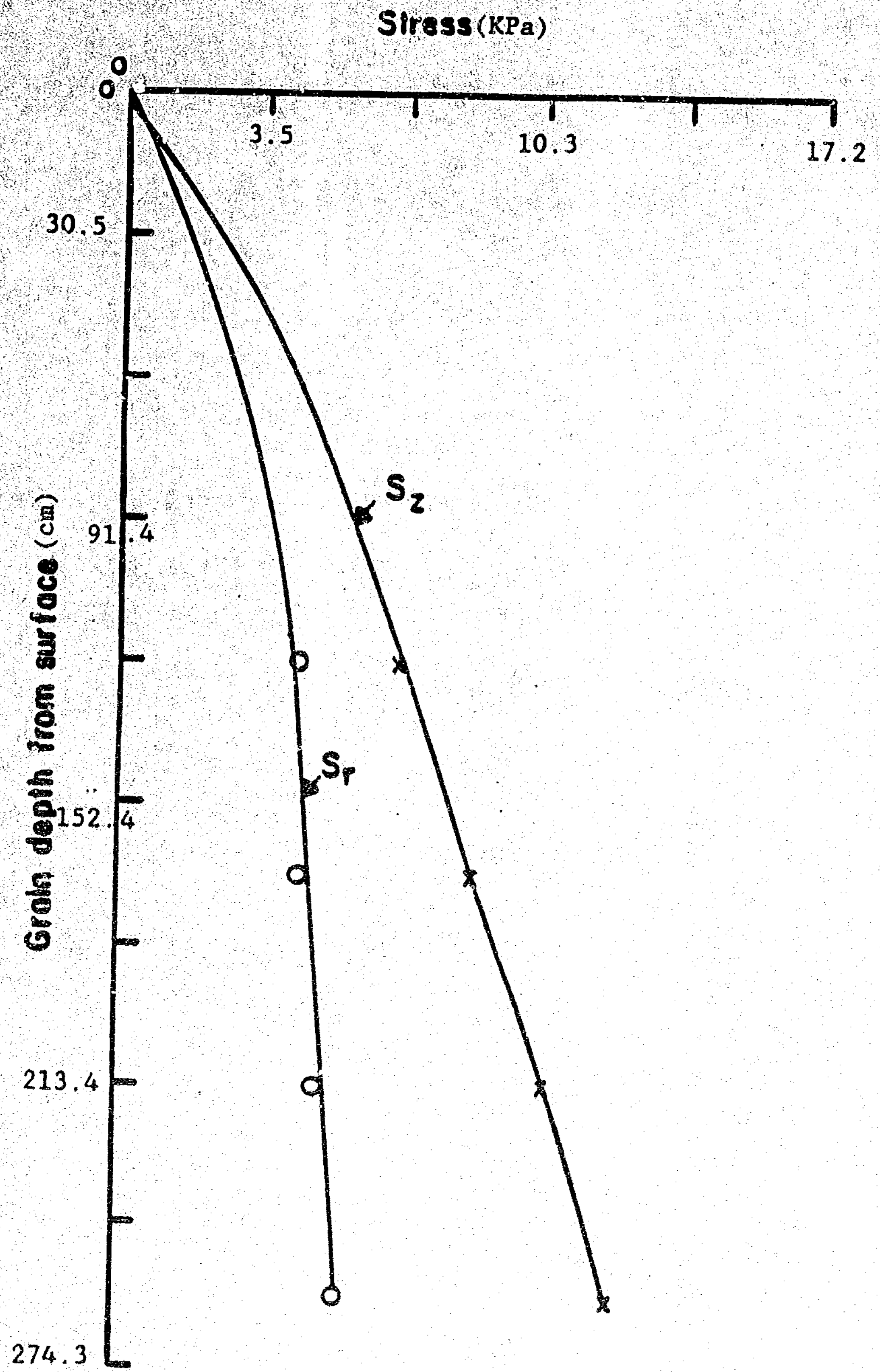


Figure 4. Variation of vertical and horizontal stresses with depth of grain (IMT method at center of bin)

239

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INDICATEUR BIBLIOGRAPHIQUE: / [✓ REUNION K] | DICTIONNAIRE L | DONNEES NUMERIQUES N | THESES OU DISSERTATION U | LEGISLATION W | [✓ BIBLIOGRAPH. Z] | CARTE (S) INCLUSE (S) Y | [✓ RESUME E] | NON CONVENTION. V | SYNTHESE BIBLIOGR. R

1 009 A NIVEAU

Utiliser un bordereau pour chaque niveau bibliographique A, M ou C, cerclé en 008, en partant du niveau le plus spécifique (c'est à dire la gauche) et reporter le code correspondant en 009. Pour le niveau bibliographique S, utiliser la section 2 du bordereau. Pour les descripteurs AGROVOC, les termes d'indexation du vocabulaire local et les résumés utiliser les sections 3 à 5 au verso.

		Etiquette	Données (à dactylographier)
Auteur (s) Personne physique (Affiliation (s))		100	Atewologun, A.O.; Riskowski, G.L.; Muehling, A.J. (Univ. of Illinois, Urbana (Etats-Unis). Agricultural Engineering Dept.)
Collectivité(s) auteur(s)		110	
Titre universitaire		111	
Titre anglais	Titre principal	200	Experimental determination of Janssen's Stress Ratio K. by four methods
	Eléments secondaires	201	
Réunion	Nom	210	Stockage des Cereales et des Legumineuses
	Lieu	211	Rabat (Maroc)
	Date	213	28-30 Nov 1990
Titre original (Translit.)	Titre principal	230 2	[Determination experimentale du rapport K par quatre methodes]
	Eléments secondaires	231	
Edition (N°)		250	
No. Rapport/brevet		300	
Nos. secondaires		310	
ISBN/IPC		320	
Adresse bibliographique	Lieu de publication	401	
	Editeur	402	
	Date de publication	403	
Collation		500	
Langue (s) du texte		600	(En) | 601 | Resumes (En, Fr)
Notes		610	2 tableaux. 4 figs. 26 ref

2 009 S NIVEAU

Titre de publication en série	Titre principal	230	Hommes Terre et Eaux (Maroc)
	Eléments secondaires	231	Revue Mar. des Sci. Agronomiques et Veterinaire
ISSN		320	ISSN 0393-9554
Date de publication		403	(Mar-Jun 1991)
Collation		500	v. 21(82-83) p. 135-145
Notes		610	

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Sections 3 à 5 au verso

3 009 | 9 | / | EN | 009 | 9 | / | ES | 009 | 9 | / | [✓ FR]

Code de langue des descripteurs (cercler obligatoirement celui qui convient)

	Eti-quette	Données (à dactylographier)
Descripteurs AGROVOC pour l'index matières dans Agrindex	**800**	SILO; PRESSION; MESURE (PRIMAIRE) (Séparer les descripteurs par un point virgule (;) et un espace. Faire précéder les propositions de nouveaux descripteurs par un point d'interrogation (?))
Autres descripteurs AGROVOC		/ (laisser un espace après la barre oblique (/))
Commentaires sur les descripteurs existants ou proposés	**810**	

4 009 | 9 | / | | |

Code de langue des termes d'indexation

Termes d'indexation du vocabulaire local	**820**	

5 009 | X | / | FR |

Code de langue du résumé

Langue du résumé en clair	**850**	
Résumé	**860**	Quatre méthodes differentes ont ete utilisee pour la determination du rapport K qui est utilise dans les formules de calcul des silos a grain. les chargements statiques du soja etaient mesures dans un modele cylindrique en metal galvanise, 0,91 m de diametre x 2,74 m de hauteur

FIN **النهاية**

15

VUES **مشاهد**