THE UNIVERSITY OF MANITOBA

DESIGN OF TEMPORARY GRAIN STORAGES

by

G. L. Gamby

A Thesis

Submitted to the Faculty of Graduate Studies

in partial fulfillment of the requirements

for the Degree of Master of Science

Department of Agricultural Engineering
University of Manitoba
Winnipeg, Manitoba

May, 1974

DESIGN OF TEMPORARY GRAIN STORAGES

by

G.L. Gamby

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

Master of Science

ABSTRACT

DESIGN OF TEMPORARY GRAIN STORAGES

by

G. L. Gamby

Temporary structures are required by the Western Canadian grain farmer to store his surplus grain. Design requirements of temporary structures for storing grain were formulated from pervious research work. Various bin configurations utilizing plastic as a structural component were designed and structurally tested. Results of the tests indicated that a cylindrical bin with composite wall and conical roof was structurally sound. The bin had a yearly storage cost of \$1.07 per m^3 (1973 material cost index) based upon a two-year design life of all components. This compared favourably with a yearly storage cost of approximately \$1.00 per m^3 for permanent storage structures in Western Canada.

Three bins with different venting techniques were constructed and filled with wheat from the fall harvest of 1973. Temperature monitoring of the grain bulk revealed the presence of hot spots on the floors of two bins. The bins were unloaded after a storage period of four months duration.

Unloading of the bins revealed that a deteriorated layer of grain approximately 2.5 cm thick had occurred at several areas on the floor of each bin. The grain

deterioration was affected by moisture which had entered the bin through small puncture holes on the bin floors. Entrance of moisture at the roof-to-wall joints in each bin also caused small localized pockets of deterioration to occur.

ACKNOWLEDGEMENTS

The author wishes to express his deepest appreciation to Dr. W. E. Muir for his guidance, counsel, and patience during the course of this project. Thanks are due to Dr. M. G. Britton, Dr. R. N. Sinha, and Dr. G. E. Laliberte for their interest and assistance in the project.

I am grateful to the Canada Department of Agriculture and the National Research Council of Canada for their financial support of this project.

I am indebted to Bonar and Bemis, Winnipeg; Curry Industries, Winnipeg; Grace Construction Materials, Winnipeg; and Sto-Cote Industries, Chicago for their extreme generosity in donations of construction materials for the bins.

Messrs. M. Caron, A. Gamby, G. Kabernick, B. Parker, and V. Parker deserve special consideration for the donation of their facilities and grain for structural and long-term storage tests.

Appreciation is extended to Professor H. A. H. Wallace and the Canada Grains Commission for analysis of the grain samples.

I would like to sincerely thank my fellow graduate students (in particular, Glen Bergson) and the Agricultural Engineering staff (permanent and summer) for their assistance, ideas, and encouragement over the course of this project. I also express my thanks to Lena McAlinden for her diligence in typing of the manuscript.

TABLE OF CONTENTS

SECTION PAGE

SECTION	PAGE

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

In recent years the grain farmer in Western Canada has been faced with the serious problem of storing surplus grain. Surplus grain is defined as production exceeding a farmer's long-term average production. The problem has been further aggravated by variable markets which cause large amounts of farm stored grain to be held over from one year to the next. This reduces the amount of storage capacity available for the following year's production. Thus, most of the farmers in Western Canada invariably have surplus grain during some years. To maintain the quality of stored grain and hence its high dollar value, surplus grain should be protected in a storage structure.

It is uneconomical to build a permanent type of storage structure for surplus grain. Friesen (1971) found that the average storage cost per year in 1971 was \$1.03 per m^3 of stored grain on prairie farms. Fixed costs such as depreciation, interest on investment, and insurance amounted to \$0.74 per m^3 per year. Variable costs such as insurance, grain loss in storage, and repairs were estimated to be \$0.29 per m^3 per year. Thus, if the grain storage structure is only used to store surplus grain in one year out of every three years then the fixed costs increase by a factor of three to \$2.22 per m^3 per year. Assuming variable costs to be the same for each year of storage, the total storage cost is \$2.51 per m^3 per year. For utilization in one year out of every five years fixed costs increase to \$3.70 per m^3 year and variable costs remain the same at \$0.29 per m^3 per year. The total storage cost then becomes \$3.99 per m^3 per year. These figures are much greater than the average farm storage cost of \$1.03 per m^3 per year. In years of surplus grain the erection of a structure to store grain for only one year may be less expensive than maintaining a large number of empty permanent bins in years of no surplus grain.

A structure which could be used for storage of surplus grain during years of high production or depressed markets or both would be feasible. The structure should have a design life equal to the duration of a normal grain storage period, one year, to minimize capital investment. A fixed cost of \$0.70 per m^3 would be required to realize a yearly storage cost of approximately \$1.00 per m^3 of stored grain per year. This assumes that variable costs such as insurance, grain loss, and repairs remain the same at approximately \$0.30 per m^3 per year. The structure will be referred to as a temporary structure for storing grain due to its short design life.

Temporary grain storage structures are already in widespread use in Western Canada. In 1968 to 1969 it was found that 60% of 2,522 elevator agents in Western Canada reported the use of temporary grain bins in their districts (R.N. Sinha, unpublished). In 1970 temporary grain storage accounted for 5.6% of the total farm storage in Western Canada (Friesen, 1971). This is equivalent to approximately 32,500 temporary bins of 71 m^3 capacity assuming farm storage capacity is equal to the grain production on the prairies in 1970.

Although temporary farm bins are being used to store surplus grain, the structures presently available do not appear to be well designed. Research work by Muir, Sinha, and Wallace (1973) has shown that most temporary grain bins do not adequately preserve the grain quality over the first winter of storage.

Because of the need for improved temporary grain storage structures, the objectives of this project were:

1. To design a temporary grain storage structure which adequately preserves grain quality for at least one year.
2. To structurally test the grain storage structure.
3. To study the effectiveness of the bin in maintaining grain quality for at least one year.

2. LITERATURE REVIEW

2.1 Temporary Grain Storage Structures

Muir, Sinha, and Wallace (1973) have studied problems of storing grain in the temporary grain bins that are now in use in Manitoba. Two replicates of open-topped and polyethylene-covered bins containing the main cereal crops --wheat, oats, and barley were studied. Grain was placed into the bins by co-operating farmers in the fall of 1969, overwintered and sampled by the researchers in the spring of 1970. Four of the bins still in use were sampled a second time in the fall of 1970 to determine deterioration of the stored grain during the summer months. The variables measured at each sampling were moisture content, temperature, seed viability, fungal infection, and insect and mite populations.

The study revealed that most types of temporary grain bins now in use in Western Canada do not adequately protect the grain quality over the first winter of storage. During the summer storage period deterioration of the grain was quite excessive. This is mainly due to the fact that as length of storage time increases deterioration of the grain also increases.

The researchers determined that deterioration and increases in moisture content of the grain during winter storage may be reduced with a polyethylene cover. Venting the cover reduced moisture accumulation as well as fungal infection and insect and mite infestations along the top surface of the cone.

Bins which were covered with loose or baled straw were of little benefit compared with open-topped bins. The use of open-topped bins during the summer storage period was recommended. Moisture which entered the bin through holes in the polyethylene cover was prevented from evaporating to the outside air by the cover. Any moisture entering the open-topped bins evaporated. Hence, in the summer months deterioration of the grain due to wet spots was greater in the polyethylene-covered bins than in the open-topped bins.

2.2 Bin Pressure Research

2.2.1 Lateral pressures in flexible plastic containers

Gupta (1971) determined the lateral pressures exerted by hard red spring wheat on the walls of small cylindrical polyethylene containers, 25-cm diameter to 90-cm diameter, and compared them with those predicted by Janssen's equation. Janssen's equation was found to be inapplicable in predicting lateral pressures in flexible containers.

A dimensional analysis equation was developed to predict lateral pressures in flexible containers. However, the equation was applicable only to containers of height, diameter, and wall thickness tested.

2.2.2 Rankine's formula

To predict grain pressures in shallow bins (in shallow bins the plane of rupture passes through the upper grain surface before it meets the opposite wall) the Canadian Code for Farm Buildings (National Research Council, 1970) recommends the use of Rankine's formula.

Rankine made the following assumptions in the development of his theory on lateral pressures in granular materials (Taylor, 1948):

1. A semi-infinite cohesionless mass is being supported by a rigid, frictionless wall.
2. Active stage in which the wall moves away from the backfill is the minimum condition of loading.
3. Passive stage in which the wall moves toward the backfill is the maximum condition of loading.
4. The resultant pressure of the material on the wall acts in a horizontal direction.

Rankine's equation for the active stage is:

$$P_a = \frac{1 - \sin \phi}{1 + \sin \phi} wh \quad \ldots (2.1)$$

where:

P_a = horizontal pressure on the wall in the active stage, kg/m^2,

ϕ = angle of internal friction, degrees,

w = bulk density of granular material, ton/m^3, and

h = depth of granular material, m.

The Canadian Code for Farm Buildings (National Research Council, 1970) recommends that ϕ equals the angle of repose of the grain in Eq. (2.1). For the case of surcharge, the horizontal pressure is increased by a factor of 1.25 (National Research Council, 1970). Eq. (2.1) becomes:

$$P_a = 1.25 \frac{1 - \sin\phi}{1 + \sin\phi} wh \qquad \ldots (2.2)$$

2.2.3 Résal's formula

To predict lateral pressures imposed by granular materials upon inclined walls Résal modified Rankine's formula by considering the influence of wall friction (Cain, 1916). By graphically solving a statics problem Résal determined that the stress at any point on an inclined wall is:

$$E_a = 2K\ wh \qquad \ldots (2.3)$$

where:

E_a = active horizontal pressure on the wall, kg/m^2,

K = a constant for given inclinations of the wall and surface,

w = bulk density of granular material, ton/m^3, and

h = depth of granular material, m.

The constant, K, can be determined by:

$$K = \frac{1}{2}\left[\frac{\cos(\phi + \alpha)}{(1 + n)\cos\alpha}\right]^2 \frac{1}{\cos(\phi' - \alpha)} \qquad \ldots (2.4)$$

where:

n = a dimensionless ratio,

ϕ = angle of repose of granular material, degrees,

α = angle made by inner face of wall with the vertical, degrees, and

ϕ' = angle of friction of granular material on the wall, degrees.

The dimensionless ratio, n, is given by:

$$n = \sqrt{\frac{\sin(\phi + \phi')\ \sin(\phi - i)}{\cos(\phi' - \alpha)\ \cos(\alpha + i)}} \qquad \ldots (2.5)$$

where:

i = angle made by free surface with the horizontal, degrees.

For a wall with $\alpha > 10°$ Résal suggested the use of λ to replace ϕ' in Eq. (2.4) and Eq. (2.5). He defined λ by the equation:

$$\lambda = \tan^{-1} \frac{\sin\phi\ \cos(2\alpha + \phi)}{1 - \sin\phi\ \sin(2\alpha + \phi)} \qquad \ldots (2.6)$$

3. DESIGN REQUIREMENTS

3.1 Granary Structure and Its Interrelations

A grain bulk is a multivariate system composed of a number of biotic and abiotic variables. It is important that most, if not all the variables be considered in the design of a temporary grain storage structure. The main variables which can be influenced by the design are abiotic variables such as temperature, moisture content, and oxygen content and external biotic agents which include insects, mites, micro-organisms, rodents and birds.

Temperature and moisture content are the most important variables in a grain bulk. They are interrelated and affect the agents of deterioration in a grain bulk. As an example, mites will not develop below 5 C and insects will not develop below 15 C (Sinha, 1973). A moisture content less than 13% arrests the growth of most micro-organisms and mites (Sinha, 1973). Hence, the grain bin design should maximize heat and moisture loss but minimize heat and moisture uptake.

Insects, mites, and micro-organisms, if present in the grain bulk, normally do not grow and reproduce initially throughout the grain bulk. Rather, they develop in micro- and macro-environmental pockets caused both by uneven distribution of moisture at the time of initial storage and also by subsequent moisture migration. This moisture migration is normally caused by convective air currents resulting from temperature gradients in the grain bulk. Since moisture migration within the bin is variable from season to season elimination of micro- and macro-environmental pockets cannot be readily achieved. A structure that is designed to minimize this problem would probably not be economical at the present time.

3.2 Cost Requirements

The structure should have a cost of approximately \$1.00 per m^3 of storage space per year. This is in accordance with the 1970 average of \$1.03 per m^3 of storage capacity per year (Sec. 1.1). This figure has been selected to encourage farmers to use temporary grain storage bins. If the yearly storage cost per m^3 is equal to or greater than the storage cost of permanent bins used for temporary storage (i.e. \$1.03 to \$3.99 per m^3 per year) some farmers may not utilize any type of storage for their surplus grain. If conditions (temperature, moisture content, and oxygen content) within an open grain bulk are ideal this grain may become heavily infested by insects, mites, and micro-organisms (Sinha, 1973). Hence, deterioration will be high and dollar value low. Since cost is the most important variable with respect to the structure, the design life of the structure is to be based upon the bin design, materials selection, and cost.

3.3 Structural Requirements

Moisture is an important variable in a grain bulk. It is necessary that the bin structure minimizes increases of moisture content of the grain during the storage period. As recommended in Sec. 2.1 the bin design should incorporate a roof (cover). The cover will prevent any increases in moisture content of the grain due to rain or snow during the one year storage period. A floor should also be used to prevent moisture from entering the bin at ground level.

The wall and roof structure of the bin must withstand grain loads, snow and wind loads, and resist bird and rodent damage. Vertical and horizontal forces exerted by the grain on the vertical wall of the structure can be calculated using Rankine's formula (Sec. 2.2.2). Horizontal forces exerted by the grain on the roof of the structure can be calculated from Résal's formula (Sec. 2.2.3). Snow and wind loads on the structure can be determined by methods in the Canadian Code for Farm Buildings (National Research Council, 1970).

Venting of the structure is also required. A vent in the cover should reduce moisture accumulation as well as related fungal infections, and insect and mite infestations along the top surface of the grain bulk.

3.4 Material Requirements

The bin must be constructed of materials which will resist weathering for a period equal to the design life of the structure.

Materials for the wall and roof structure should minimize heat flow into the bin from solar radiation or high ambient air temperatures. The material should also allow rapid grain cooling as the ambient air temperature decreases in autumn. Materials with low shortwave absorptivities would minimize radiant heat uptake while materials with high long-wave emissivities would maximize radiant heat loss (Kreith, 1969).

Materials with low water vapour transmission rates are required to minimize moisture movement into the bin.

The bin should be constructed from materials which are light in weight. This will contribute to ease of erection without reliance upon heavy equipment.

4. SELECTION OF MATERIALS

4.1 Selection Requirements

Materials were selected according to the following criteria which were developed from the design requirements presented in Section 3:

1. Low cost per unit area to minimize storage cost.
2. High strength-to-weight ratio to minimize the weight of the structure and enable easier erection.
3. Low water vapour permeability to minimize moisture migration into the bin from the environment.
4. Low deterioration of material during exposure to weathering for one year.
5. Low shortwave absorptivities and high longwave emissivities to reduce radiant heat uptake.
6. Materials must be available in large sizes (lengths and widths) to minimize joining during the construction phase.

An initial concept of a temporary grain storage structure was formulated to develop the general material requirements for such a structure. In the design concept it was considered that the grain bulk was completely enclosed by the structure. The structure would minimize the entrance of moisture, birds, rodents, and microflora into the bin. Grain deterioration would then be reduced.

The enclosure could be fabricated utilizing two major types of materials; self-supporting and non-self-supporting materials.

Self-supporting materials are classified as materials which exhibit inherent rigidity. An example of a self-supporting material is plywood. Self-supporting materials could be used effectively in the wall structure of a temporary grain bin. No external or internal support system would be required and costs could be minimized.

Non-self-supporting materials are classified as materials with non-inherent rigidity. They may be either films or light-gauge materials with sufficient strength to withstand the pressures imposed by the grain bulk. A support system would be required to support the structure during filling.

Both self-supporting and non-self-supporting materials may not be of sufficient strength to withstand pressures imposed by the grain bulk. Hence, for some materials it is necessary that additional materials be utilized to withstand the loads. These materials are referred to as reinforcing materials.

Fastening systems were also studied because materials had to be selected that could be readily fastened together.

4.2 Material Class

4.2.1 Self-supporting materials

Materials considered in this class are:

1. Fibreglas sheeting - reinforced polyester laminate,
2. CB-TUFF* board - polyethylene coated paper product,
3. Rhinocor* board - polyethylene coated paper product,
4. Polyflute* - extruded copolymer sheeting,
5. Plywood - laminated wood veneer sheeting,
6. Aspenite - sheeting fabricated from compressed wood chips and glue, and
7. Zicon* - polyethylene coated chicken wire.

Properties and major disadvantages of the self-supporting materials are presented in Table 4.1. Only materials with a relatively low cost were considered. This is warranted by the low yearly storage cost requirement of \$0.70 per m^3 per year. Hence, materials such as steel and glass were not considered. Cost comparisons are based upon 1973 material prices.

4.2.2 Non-self-supporting materials

Materials studied in this class were:

1. TU-TUF* - cross-laminated poly sheeting,

---

*Trade name.

Table 4.1

Physical properties of self-supporting materials.

MATERIAL*	MANUFACTURER	SIZE AVAILABILITY	COLOUR	WEATHERING, ONE YEAR	TENSILE STRENGTH, kg/m	PERMEANCE, METRIC PERMS**	FASTENING	COST, $/m^2$	DISADVANTAGE
Fibreglas	Structural Glass	0.476 cm thick	White	Little effect	30.1	Low	Glue	18.30	High cost
CB-TUFF Board	Consolidated Bathurst	N.A.	Brown	Rapid deterioration	N.A.	N.A.	Staple, glue	N.A.	Rapid deterioration
Rhinocor Board	Consolidated Bathurst	N.A.	Brown	Rapid deterioration	N.A.	N.A.	Staple, glue	N.A.	Rapid deterioration
Polyflute	Kruger Pulp and Paper	Sheets 125.5 cm x 227 cm	White	Little effect	N.A.	Low	Staple, glue	3.23	High cost
Plywood 0.794 cm	MacMillan Bloedel	Sheets (0.794 x 122 x 244) cm	Brown	Little effect	36.08	Low	Nail, bolt	1.97	High cost
Plywood 0.953 cm	MacMillan Bloedel	Sheets (0.953 x 122 x 244) cm	Brown	Little effect	36.08	Low	Nail, bolt	2.19	High cost
Aspenite 0.635 cm	MacMillan Bloedel	Sheets (0.635 x 122 x 244) cm	Brown	Little effect	Not uniform	Low	Nail, bolt	1.46	High cost
Aspenite 0.794 cm	MacMillan Bloedel	Sheets (0.794 x 122 x 244) cm	Brown	Little effect	Not uniform	Low	Nail, bolt	1.81	High cost
Corrugated Paper (waxed)	MacMillan Bloedel	Sheets 150 cm x 267 cm	Brown	60% reduction in properties	32.5	Low	Staple	0.62	Fastening
Corrugated Paper	MacMillan Bloedel	Sheets 150 cm x 267 cm	Brown	Short life due to moisture	32.5	Low	Staple	0.34	Short life, Fastening
Zicon	Flexipane, England	Rolls 183 cm x 4572 cm	Clear	Polyethylene may deteriorate	Low	Nil	Wire splice	1.12	Polyethylene deterioration, High cost

N.A. - Data not available.
* - Commercial terminology and trade names where applicable are used.
** - Units of metric perms - $g(m)^{-2}(24h)^{-1}torr^{-1}$.

2. Fabrene* - woven polyolefin fabric,
3. Milrol* - polyethylene sheeting,
4. Butyl rubber,
5. Nylon reinforced vinyls,
6. Waterproof cotton duck canvas,
7. Asphalt-impregnated building paper, and
8. Aluminum foil.

Properties and major disadvantages of the non-self-supporting materials are given in Table 4.2. Due to similarities between materials only one material in a category (e.g. woven polyethylene fabrics) was considered.

4.2.3 Reinforcing materials

Materials studied in this class included:

1. Wire mesh - concrete reinforcing mesh, and
2. Snow fence.

The materials and their pertinent properties are presented in Table 4.3. Wire mesh, 6 x 6 - 10/10 gauge (British wire gauge) and 6 x 6 - 8/8 gauge were selected as optimum reinforcing materials due to their high strength, long life and low cost.

4.2.4 Fastening systems

Fastening systems for the non-self-supporting materials include Polyzip*, Polykan tape*, and TU-TUF* tape. Polyzip consists of an extruded polythene channel and tape. The materials to be fastened are placed in the channel. The

---

*Trade name.

Table 4.2

Physical properties of non-self-supporting materials.

MATERIAL*	MANUFACTURER	SIZE AVAILABILITY	COLOUR	WEATHERING, ONE YEAR	TENSILE STRENGTH, kg/m	PERMEANCE, METRIC PERMS**	FASTENING	COST, $/m^2$	DISADVANTAGE
TU-TUF-2 2.5 mil TU-TUF-4 4.0 mil	Sto Cote	Rolls 197 cm to 1219 cm in width	White	Little reduction in properties	2.48 3.97	0.0184 0.0136	Tape	0.31 0.40	Low tensile strength
Fabrene P C TA TM	DuPont	Rolls 137 cm wide Rolls 152 cm wide Rolls 152 cm wide Rolls 152 cm wide	Clear	50% reduction in strength	11.16 14.88 18.60 24.80	Low	Stitch	0.19 0.34 0.42 0.50	Size availability
Milrol UV4 Milrol 2, 4 6, 8, 10 mil	CIL	Rolls (183, 244, 305, 366, 488, 610, 732, 1219 cm) x 3048 cm	Clear	Little reduction in properties, Six-month life	1.55 0.89 39.70	0.143 after ageing	Tape, Heat, Sealing	0.11 0.04- 0.22	Six-month life
Buryl Rubber	N.A.	N.A.	Black	Little reduction in properties	N.A.	Low	Heat, Seal	11.84	High cost
NRV (nylon resistant vinyl)	Snyder Mfg.	Rolls 54 cm x 11,430 cm	White	Brittle at low temperatures	N.A.	Low	Heat, Seal	1.08	Bittle at low temperatures
Waterproof cotton duck canvas 8 oz 10 oz 12 Oz 14 oz	Manta Ind.	Rolls 114 cm wide Rolls 91 cm wide Rolls 91 cm wide Rolls 91 cm wide	Brown	Little effect on properties	9.55 12.65 17.86 N.A.	High	Stitch	3.23 1.53 1.20 2.03	High cost
Building paper, 60 lb	Building Products	Rolls 91 cm in width	Black	Little reduction in properties	4.34	Low	Staple	0.11	Black, Toxic to grain consumer
Aluminum 0.04 cm	Alcan	Sheet 91.44 cm x 244 cm	Silver	No reduction in properties	19.84	Low	Rivet	1.38	High cost

N.A. - Data not available
* - Commercial terminology and trade names where applicable are used.
** - Units of metric perms = $g(m)^{-2}(24h)^{-1}torr^{-1}$.

Table 4.3

Physical properties of reinforcing materials.

MATERIAL	MANUFACTURER	SIZE AVAILABILITY	TENSILE STRENGTH, kg/m	COST, $/m^2
Wire Mesh:		Rolls:		
6 x 6 - 6/6*	Irving Wire	152 cm wide	31.0	$0.75
6 x 6 - 4/4*	Irving Wire	152 cm wide 214 cm wide	48.9	$0.99
6 x 6 - 8/8*	Irving Wire	122 cm wide	26.3	$0.56
6 x 6 - 10/10*	Irving Wire	152 cm x 6100 cm	17.6	$0.48
Snow Fence	Fulco Metals	Roll: 122 cm x 1525 cm	9.5	$1.13

*Material description: 6 x 6 - grid size (in).
6/6 - British wire gauge of vertical wire and horizontal wire.

tape is snapped into the channel by a special tool to form a tight joint. This system may be used for fastening various combinations of materials together. Cost of the Polyzip is approximately $0.65 per m.

Polykan adhesive tape and TU-TUF adhesive tape are also used as fastening systems for Milrol polyethylene and TU-TUF poly sheeting. Clear Polykan tape costs $3.50 for a roll 5 cm by 30.5 cm. White TU-TUF tape costs $6.75 for a roll 5 cm by 55 m.

5. DESIGN AND STRUCTURAL TEST PROCEDURE

5.1 Selection of Bin Capacity

A bin capacity of approximately 70 m^3 was chosen for the study. The capacity was selected as the maximum for a structure of this type based upon the average storage capacity on Western Canadian farms in 1970 of 45 m^3 (Friesen, 1971). Hence, design stresses are maximum. If smaller structures are required, they may be fabricated utilizing the same materials without re-design and structural testing.

A restricting dimension of 3.2 m was chosen as the maximum horizontal distance from the wall of the structure to the filling spout. This is the reach of a medium-length grain auger which was assumed to be 9.1 m long (Agricultural Machinery Administration, 1961).

5.2 Spray-on-Foam

Spray-on-foam was considered as a means of protecting the grain bulk from the environment. The concept utilizes a ureaformaldehyde foam which would be applied in a thin layer to the surface of the grain bulk. The foam would prevent moisture from entering the bin. Snow loads would be supported internally by the grain bulk itself. Plastic film could be utilized as a floor for the grain bin.

The main advantage of the system is the ease and speed of application. Little time is required to completely enclose a large grain bulk. Also, the system may be utilized for any volume of grain.

The main disadvantage of the system is cost. The cost at present for this system is approximately \$4.85 per m^2 of surface area. A conical grain bulk with a 70 m^3 capacity would cost approximately \$975.00 or \$13.93 per m^3. Work was not continued on this system due to the excessive costs involved.

5.3 Conical Bin

A conical bin was next considered for study. A bin with a radius of 3.2 m, an overall height of 5.5 m, and a wall angle of 60° yields a capacity of approximately 60 m^3 (Fig. 5.1). The advantage of this type of structure is that it requires only two separate sections of material for fabrication of the structure. The floor is fabricated from a section of material with a diameter of 6.4 m. The roof is fabricated from a piece of material with a diameter of 12.8 m.

Good material utilization is obtained with this bin since the wall angle of 60° requires a piece of material in the form of a semi-circle to obtain the conical shape (Appendix A).

The structure could be fabricated from non-self-supporting materials available in large sheets. Both the floor and wall structures could then be fabricated from single sheets of material minimizing the number of joints.

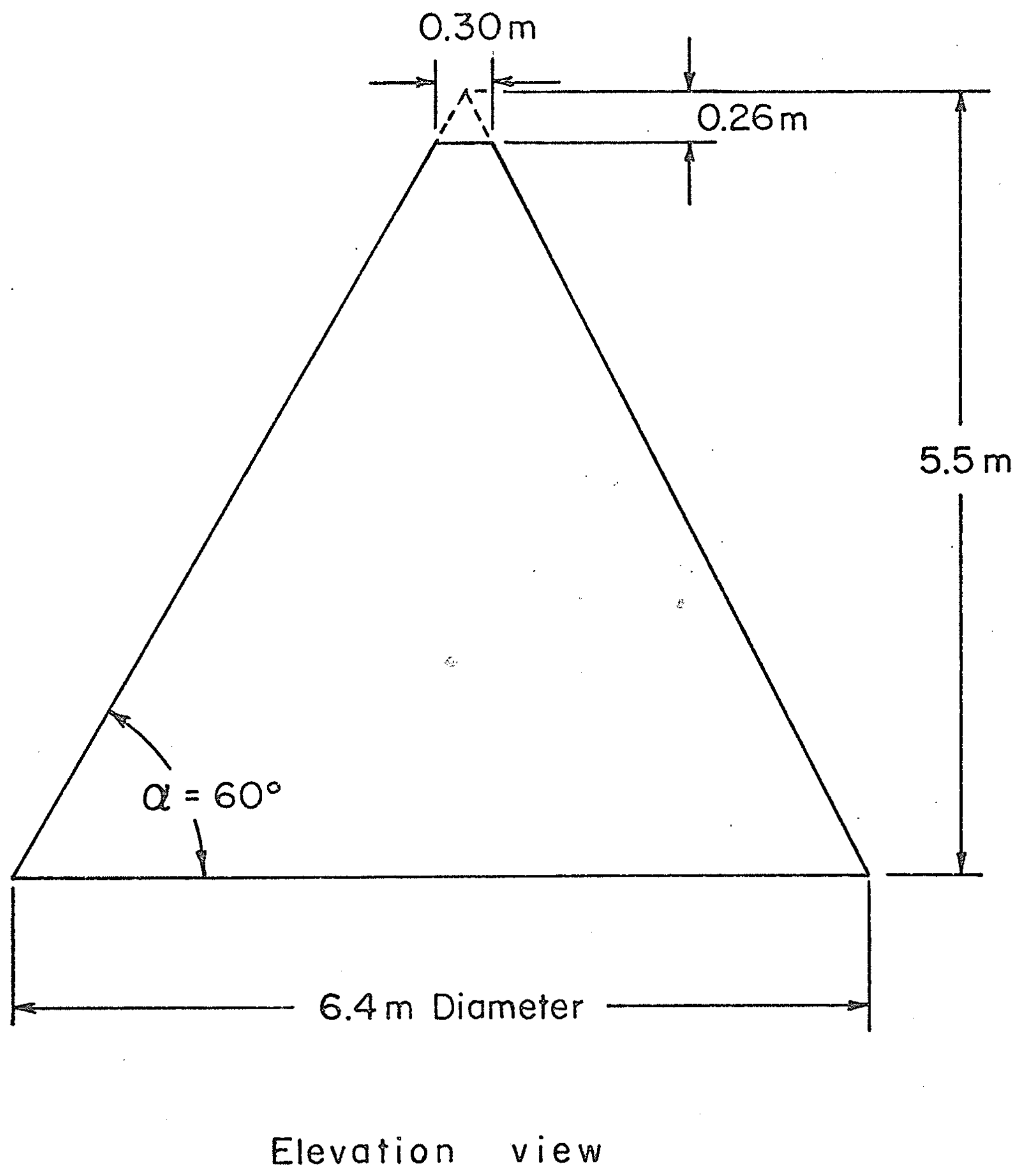


Fig. 5.1 Conical grain bin.

The structure could be fastened together using Polyzip for the bottom joint between the wall and floor. Polyzip or Polykan tape could be used to complete the seam on the walls which forms the semi-circular piece of material into the conical shape.

During filling, the structure requires either an internal or an external support system. Internal support systems include removable frames, permanent frames, and inflation systems. Installation of frames inside the completed bin before loading is extremely difficult. An inflation system, however, could be easily set up to support the structure. The inflation system is advantageous due to the uniform support exerted by the air on the structure during loading and unloading. The inflation system could also be utilized for more than one bin to amortize the cost of the inflation system over several structures.

External support systems include removable frames and the use of the grain auger as a support. The removable frame is disadvantageous since a high-strength, light-weight structure is required to span the grain bin (diameter equals 6.4 m). Attachment of the bin to the framework is also a difficult problem since the bin is 5.5 m high during loading. Suspension of the grain bin on the grain auger spout is advantageous since cost of this system is negligible. Difficulties with this support system include grain auger stability which could be exceeded by the extra weight of the bin which is attached to the spout. Attachment of the bin to the auger outlet is also a problem since the bin is on the ground and must be attached to the spout of the auger which is approximately 3 m above ground at its lowest point (Agricultural Machinery Administration, 1961). Difficulty in unloading would also be experienced since no support for the structure could be provided during the unloading procedure.

A conical bin was designed with the dimensions given in Fig. 5.1. Wheat was used as the grain bulk with the following properties: density = 0.882 metric ton/m^3, angle of repose, $\phi = 21.7°$, and coefficient of friction on polyethylene, $\mu' = 0.366$ (Gupta, 1971). Maximum lateral pressures in the bin were predicted using Résal's formula (Eq. (2.3)) and stresses in the walls corresponding to predicted lateral pressures were calculated using the following equation:

$$T = L_p D/2 \qquad \ldots (5.1)$$

where:

T = circumferential tension in bin wall, kg/m (load per unit width of material),

L_p = lateral pressure on bin wall, kg/m^2, and

D = bin diameter, m.

A tension value of 31.9 kg/m on the bin wall was predicted. This value exceeds the tensile strength of the strongest non-self-supporting material, Fabrene TM grade, which has a tensile strength of 24.8 kg/m (Table 4.2). Hence, the design was not feasible.

A small bin of approximately 17.7 m^3 capacity was constructed for structural testing to determine the effect of the high tensile forces on the structure. The bin had a radius of 2.1 m, a wall angle of 60°, and an overall height of 3.6 m. A maximum tension on the bin wall of 14.1 kg/m was predicted using Eq. (2.3) and Eq. (5.1). The bin was constructed entirely of UV4 polyethylene with a tensile strength of 1.55 kg/m (Table 4.2). Joints were secured using Polykan tape. An interior wooden frame was constructed to support the structure during filling. Wheat was used for the test.

Upon filling of the bin, there was excessive elongation of the wall due to the high stresses (Fig. 5.2). Filling was discontinued upon buckling of the interior wooden frame. Failure was induced by the high forces which were transferred from the wall to the frame.

Results of the test indicated that no further work could proceed in this area until non-self-supporting materials with high tensile strengths and low elongation were made available at low cost.

5.4 Cylindrical Bin with Monolithic Wall and Conical Roof

A cylindrical bin with monolithic wall and conical roof was next considered for study. A circular bin with a

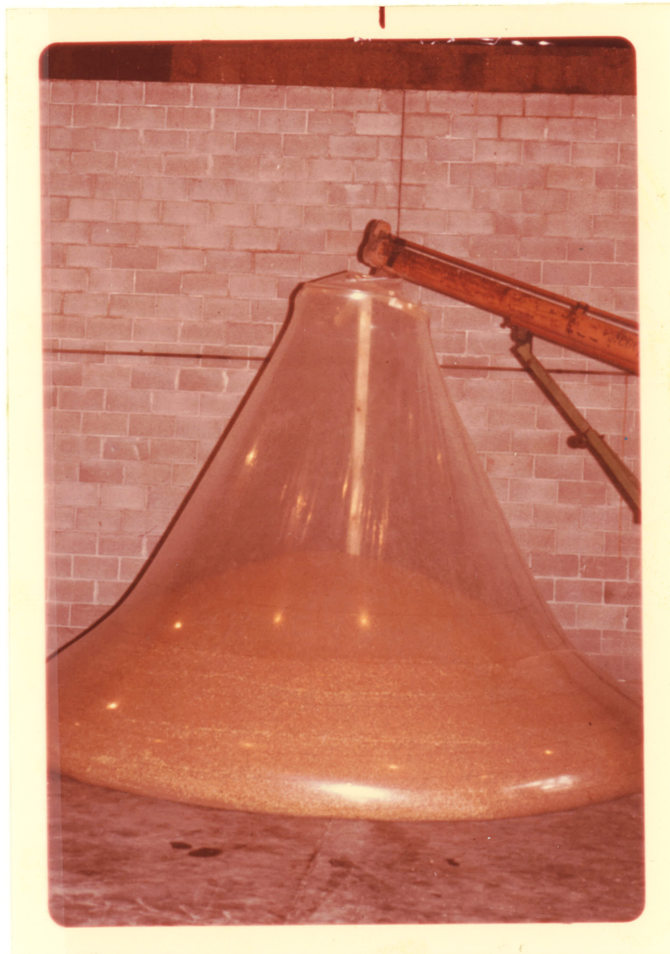


Fig. 5.2 Conical bin under structural test.

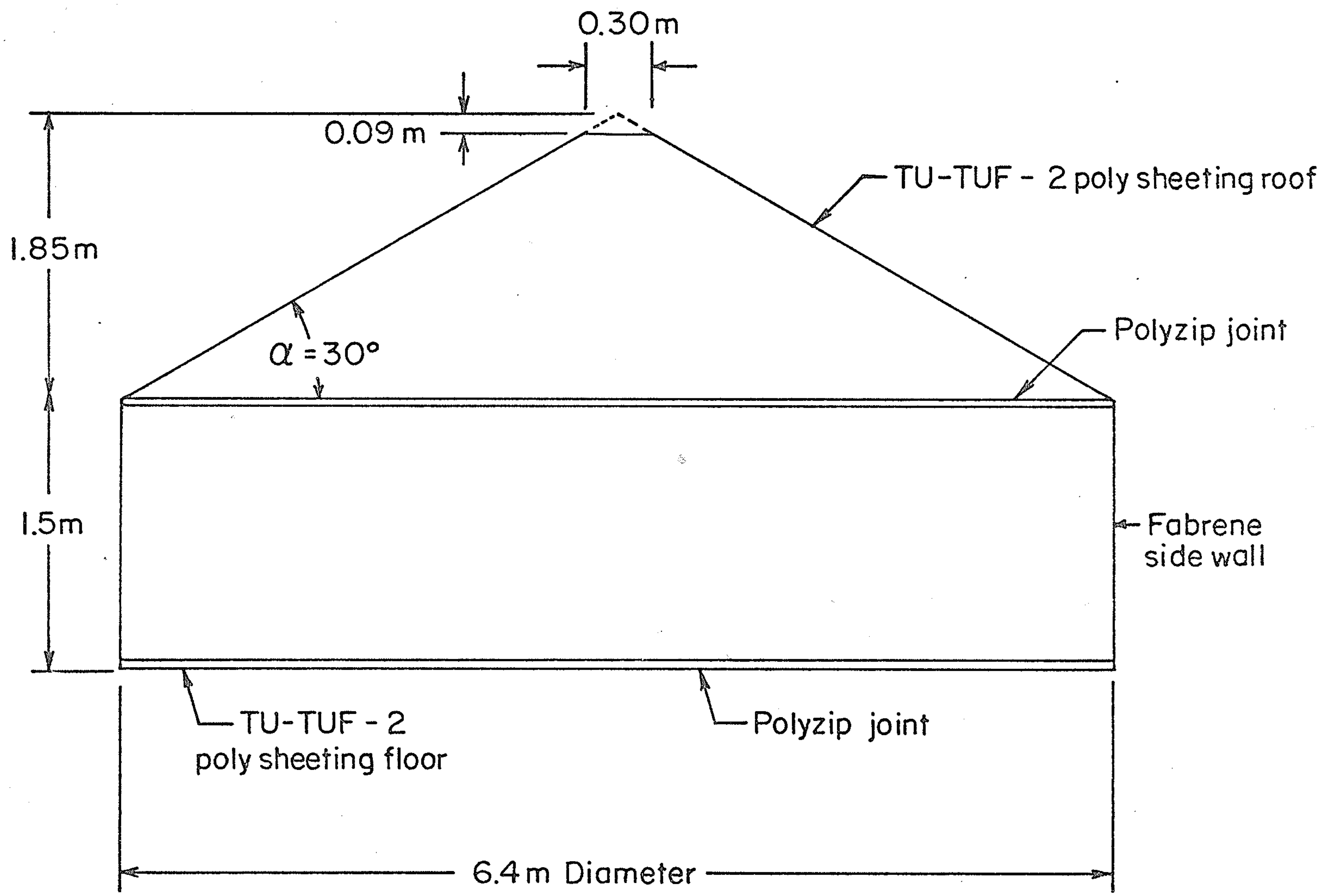
radius of 3.2 m, sidewall height of 1.5 m, and a conical roof with a roof angle of 30° has a capacity of 69 m^3 (Fig. 5.3). The roof angle of 30° was selected on the premise that the roof would be structurally loaded by cereal grains which normally have an angle of repose less than 30°. This was expected to minimize damage to the roof caused by wind flutter.

A design stress of 17.2 kg/m on the bin wall was calculated using Eq. (2.2) and Eq. (5.1). Fabrene TM grade with a tensile strength of 24.8 kg/m was selected for the wall structure of the bin. Available in 1.5 m widths, good materials utilization is obtained as a piece of Fabrene 1.5 m x 20.4 m is required for the wall.

TU-TUF-2 poly sheeting was used for the floor and roof of the structure. Its high puncture strength and large widths make it ideal for this application. The white colour should also minimize heat uptake on the roof due to radiation.

The floor of the structure was fabricated from a piece of TU-TUF-2 poly sheeting 6.4 m in diameter. The roof was fabricated from a piece of TU-TUF-2 poly sheeting 7.7 m in diameter (allows 0.3 m overlap). A segment of 48.2° was removed from the roof section to obtain the conical roof with a 30° slope (Appendix A).

Polyzip was chosen as the fastening system for the floor-to-wall joint and roof-to-wall joint. Polykan tape was used for the roof joint. The wall joint was completed



Elevation view

Fig. 5.3 Cylindrical bin with monolithic wall and conical roof.

by using two metal strips each 1.4 m in length. The ends of the Fabrene wall strip were wound around each metal strip which were then bolted together. Polyzip was not used for this joint due to the high tensile forces present in the wall membrane.

A support system for the bin was required during the loading procedure due to the non-self-supporting materials utilized in the design. An inflation system consisting of a 0.19-kW furnace fan and an air duct made from polyethylene was selected for this purpose. The air entered the bin through a hole placed in the roof near the grain filling spout. Two one-way flap valves each consisting of a piece of TU-TUF-2 poly sheeting were taped inside the bin over the air entrance spout and the grain filling spout. The function of the valves was to prevent loss of air during filling. Hence, the fan need not operate continuously.

A bin of the given dimensions was constructed and structurally tested. Barley with a density of 0.770 metric tons/m^3 was used for the test.

The bin did not perform as expected. Great difficulty was experienced with the air inflation system. Over-inflation of the bin occurred resulting in an unstable structure. Any slight breeze caused the structure to move a large amount both laterally and vertically. Stakes had to be provided along the base of the structure to prevent movement. When the fan was stopped, the bin did not remain inflated.

Rather, air escaped rapidly from the air duct spout and grain filling spout. The rapid deflation (approximately 2 min) indicated that the air valves were not functioning.

Filling of the structure with grain was also a problem. Any small eccentricities in loading resulted in the structure leaning over. This leaning further aggravated the eccentric loading. Concentric loading is important in this type of structure to balance the wall stresses induced by the grain bulk.

The monolithic wall constructed of Fabrene did not function properly. High elongations in the Fabrene resulted in sagging of the wall (Fig. 5.4). This resulted in an increase of the bin diameter which would require an auger reach in excess of 3.2 m, the reach of a medium-length grain auger.

The roof did not load as expected. The roof angle was too shallow which resulted in no lateral loading of the roof membrane. Hence, wind flutter would probably be a problem.

Unloading of the structure was relatively easy. The Polyzip joint between the wall and roof was unfastened. The roof was then removed and a grain auger inserted into the grain bulk (Fig. 5.5). The bin had to be unloaded evenly to prevent wall sagging. Easy clean-up was facilitated by the TU-TUF-2 floor which did not puncture under severe abuse.

The results of the structural test indicated the

Fig. 5.4 Cylindrical bin with monolithic wall and conical roof under structural tests.

Fig. 5.5 Unloading of cylindrical bin with monolithic wall and conical roof.

following requirements:

1. A better inflation method.
2. A steeper roof angle.
3. A wall structure with low elongation.
4. A better filling method to permit concentric loading.

5.5 Cylindrical Bin with Composite Wall and Conical Roof

Based upon the previous test results, a new design was formulated which incorporated a composite wall. Steel mesh was used as a wall reinforcement to resist the horizontal and vertical loadings imposed upon the wall structure by the grain bulk. The mesh allows a low tensile strength material to be used as a wall membrane.

The composite-wall bin had a radius of 3.2 m, wall height of 1.5 m, and a roof angle of 35°. A steeper roof angle was chosen to provide loading of the roof membrane. A capacity of 70 m^3 is obtained in this structure.

TU-TUF-2 poly sheeting was selected as the membrane for the roof, wall, and floor. Wire mesh, 6 x 6 - 10/10 gauge was selected as a wall reinforcement to encircle the bin. The wire mesh has a tensile strength of 17.6 kg/m - which is greater than the calculated design stress of 17.2 kg/m (Sec. 5.4).

The floor and roof structure were fabricated from TU-TUF-2 poly sheeting 6.4 m in diameter and 7.9 m in diameter, respectively. The wall was fabricated from sections of material 1.5 m x 20.1 m.

Fastening of the TU-TUF was accomplished using Polyzip for the roof-to-wall joint and floor-to-wall joint. Joints on the roof and sidewall were fastened together using Polykan tape. The ends of the steel mesh were fastened together by overlapping the ends of the wire and twist-tying them.

An air inflation system was used to support the structure during loading and unloading. A combination grain filling spout and air valve was taped to the top of the bin (Fig. 5.6). Air entered the spout from a duct which was attached to a hole in the side of the spout.

During inflation, the valve was closed by air pressure. When filling began the grain flow opened the valve which then blocked the air duct to prevent over-inflation of the bin. The resultant increased backpressure on the fan caused a reduction in the air volume.

The valve was constructed from a cardboard tube with an outer diameter of 25.4 cm. TU-TUF-2 poly sheeting attached to Polyzip tape was used for the valve diaphragm. The Polyzip tape provided a flexible valve which conformed to the curved surface of the tube during grain loading. Polyzip channel attached to the tube prevented the valve from opening outwards during inflation.

Steel stakes were driven into the ground every 1.8 m around the bin circumference to anchor the bin firmly to the

Fig. 5.6 Combination grain filling spout and air valve shown in the loading position.

ground during inflation (Fig. 5.7). The stakes locked over the tape section of the Polyzip.

A bin was built and structurally tested using barley with a density of 0.770 metric tons/m^3. From a structural standpoint, the test was successful. The bin had an actual capacity of approximately 70 m^3. The bin wall withstood the horizontal and vertical stresses imposed by the grain bulk. There was little elongation of the bin wall due to the forces acting upon it.

The roof did not load as expected. Only the lower roof section was internally loaded by the grain. It was not practical to continue filling and load the upper roof section as there was little clearance between the grain bulk and the roof.

The roof eave did not occur at the top Polyzip joint (roof-to-wall joint). Rather, a "climbing" effect of the roof on the steel mesh was exhibited (Fig. 5.8). This phenomenon is advantageous because then the top Polyzip joint is not directly exposed to run-off water from the roof. There was no danger of the roof structure sagging over the top of the steel mesh since the steel mesh is 1.5 m high while the actual height of the wall membrane is 1.4 m. Fastening overlap of 10 cm caused this reduction in wall height.

Inflation of the bin was a problem. The combination filling spout and air valve did not function properly. The filling spout flexed with the roof membrane and tilted

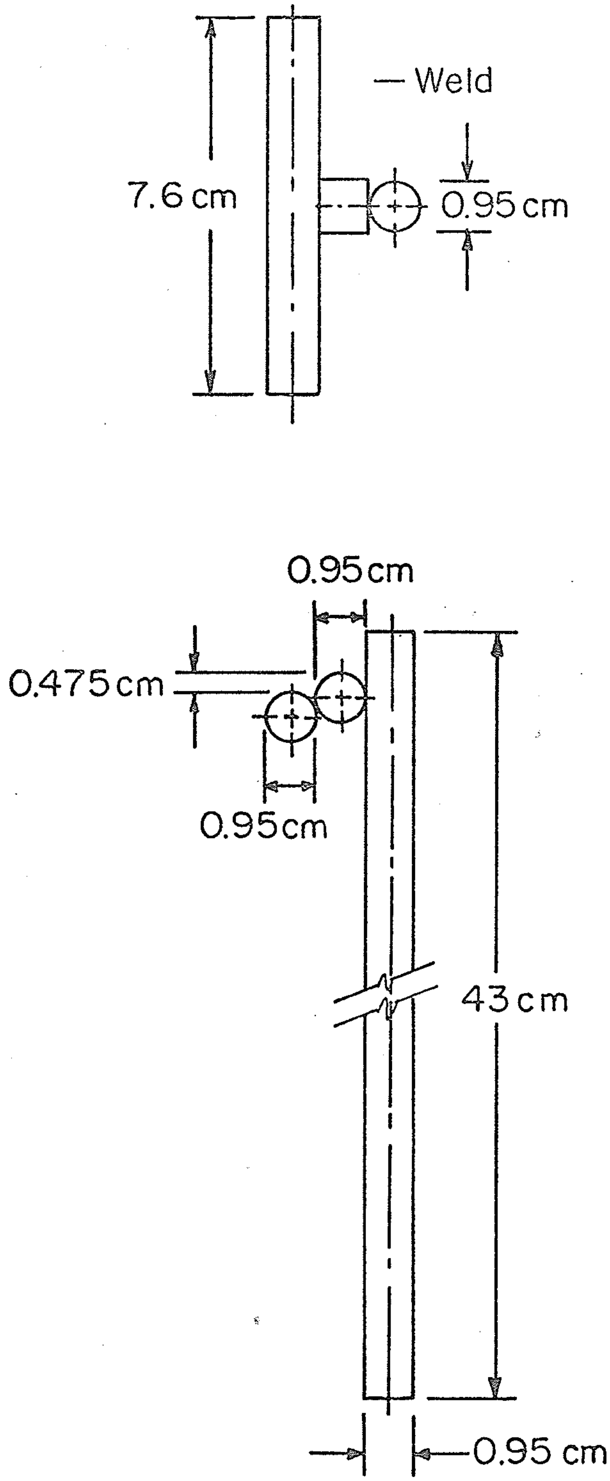


Fig. 5.7 Anchor stake.

Fig. 5.8 "Climbing" effect of bin roof on the steel mesh wall.

preventing easy entrance of the grain auger spout. Also, over-inflation of the bin occurred. The fan had to be turned on and off to prevent this phenomenon.

The inflation problem was rectified by removing the valve from the roof. A hole was punctured near the top of the roof and the air duct inserted. Air was allowed to escape through the grain filling spout at the apex of the roof. Inflation time was slightly longer (from 15 min to 20 min) but an air release was provided for the structure. Hence, over-inflation was not as critical as with the air valve.

Uniform loading of the bin posed a difficulty. Eccentric loading was still present although the composite wall withstood some of the uneven loading.

Cost of the structure, as calculated in Appendix B, was \$1.07 per m^3. This was assuming a two-year design life on all components. However, the fan, steel mesh, and Poly-zip may be used five or six times. Therefore, the yearly storage cost was over-estimated to predict a realistic cost figure.

Results of the test indicated:

1. The design was structurally sound.
2. Uniform loading of the bin was a problem. Concentric circles painted on the bin floor could aid the loading procedure.
3. The air inflation system (no valve) was adequate, but could be improved.

6. LONG-TERM STORAGE TESTING

6.1 Initial Plan

Based upon the results of the structural tests, the cylindrical bin with composite wall and conical roof design was chosen for a storage test of one-year duration. Three bins of similar design but different venting systems were to be built. The purpose of the different venting systems was to determine their effect on the grain quality during the storage period. A different length of wall reinforcement was used for each bin to determine its effect on bin capacity and location of the top Polyzip joint ("climbing" effect). Two different taping techniques were used for fastening the TU-TUF-2 poly sheeting wall joint and roof joint. The purpose of the different taping techniques was to determine the life of the two tapes (Polykan and TU-TUF) under extreme environmental conditions.

During the storage period, temperatures were to be continually monitored to determine the presence of any hot spots in the bins resulting from localized biological activity. Moisture contents and protein contents were to be taken periodically to determine any loss of grain quality over the storage period. Insect, mite, and mould counts were to be taken at the termination of the storage period to determine the cause of any grain deterioration which occurred.

6.2 Test Bins

6.2.1 Structural features

Three bins, referred to as bins A, B, and C, with a capacity of 35 m^3 were built. Bins with a capacity of 70 m^3 each were preferred, however, the unavailability of large wheat stocks from the fall harvest made this impractical. The diameter, sidewall height, and roof angle of each bin was 4.9 m, 1.5 m, and 35°, respectively. The floor was fabricated from pieces of TU-TUF-2, 4.9 m in diameter. Roofs were fabricated from pieces of TU-TUF-2, 6.1 m in diameter. This allowed for an overlap of 10 cm on the roof-to-wall joint. The sidewalls were fabricated from sections of TU-TUF-2 1.5 m x 15.3 m (includes 10-cm overlap). Wire mesh, 6 x 6 - 10/10 gauge, 1.5 m in width was used for the wall reinforcement. The length of the wire mesh for test bin A was 15.5 m; for test bin B, 15.2 m; and for test bin C, 14.9 m.

Fastening of roof-to-wall and floor-to-wall was accomplished with Polyzip. The wire mesh ends were fastened together by overlapping the wire ends and twist-tying them together. Polykan tape was used for fastening the TU-TUF-2 wall joint and roof joint on bins A and B. TU-TUF tape was used for fastening these joints on bin C.

6.2.2 Venting

Different venting systems were constructed for each of the bins. The vent on bin A consisted of a section of 10-oz brown waterproof canvas duck 46-cm square. A TU-TUF-2 poly sheeting edge, 5 cm in width, was stapled to the canvas perimeter to permit easy taping. The vent was taped over the grain bin filling spout upon completion of the filling procedure. Theoretically, the canvas duck breathes which allows the escape of moisture from the bin to the environment.

The vent on bin B was constructed from a section of cardboard tubing (Sonotube) with an outer diameter of 25.4 cm and a length of 75 cm (Fig. 6.1). Three holes, 15 cm x 15 cm, with equal circumferential spacing were cut in the tube 5 cm from the bottom. Two holes, 15 cm x 15 cm, were cut diametrically opposite, 10 cm from the top of the tube. Upon completion of loading the bin, the vent was inserted through the grain bin filling spout to a depth of approximately 30 cm. The vent was then taped to the roof. A 22.7-ℓ container 30 cm x 40 cm was placed over the top of the vent to prevent snow and rain from entering the bin, yet providing for air circulation (Fig. 6.2).

Bin C did not incorporate a vent. TU-TUF-2 poly sheeting was taped over the grain bin filling spout upon completion of loading.

6.3 Loading and Unloading Procedure

Loading of all three bins occurred in September, 1973. An air inflation system similar to that described in Sec. 5.4 was used. Air entered the structure through a hole near the

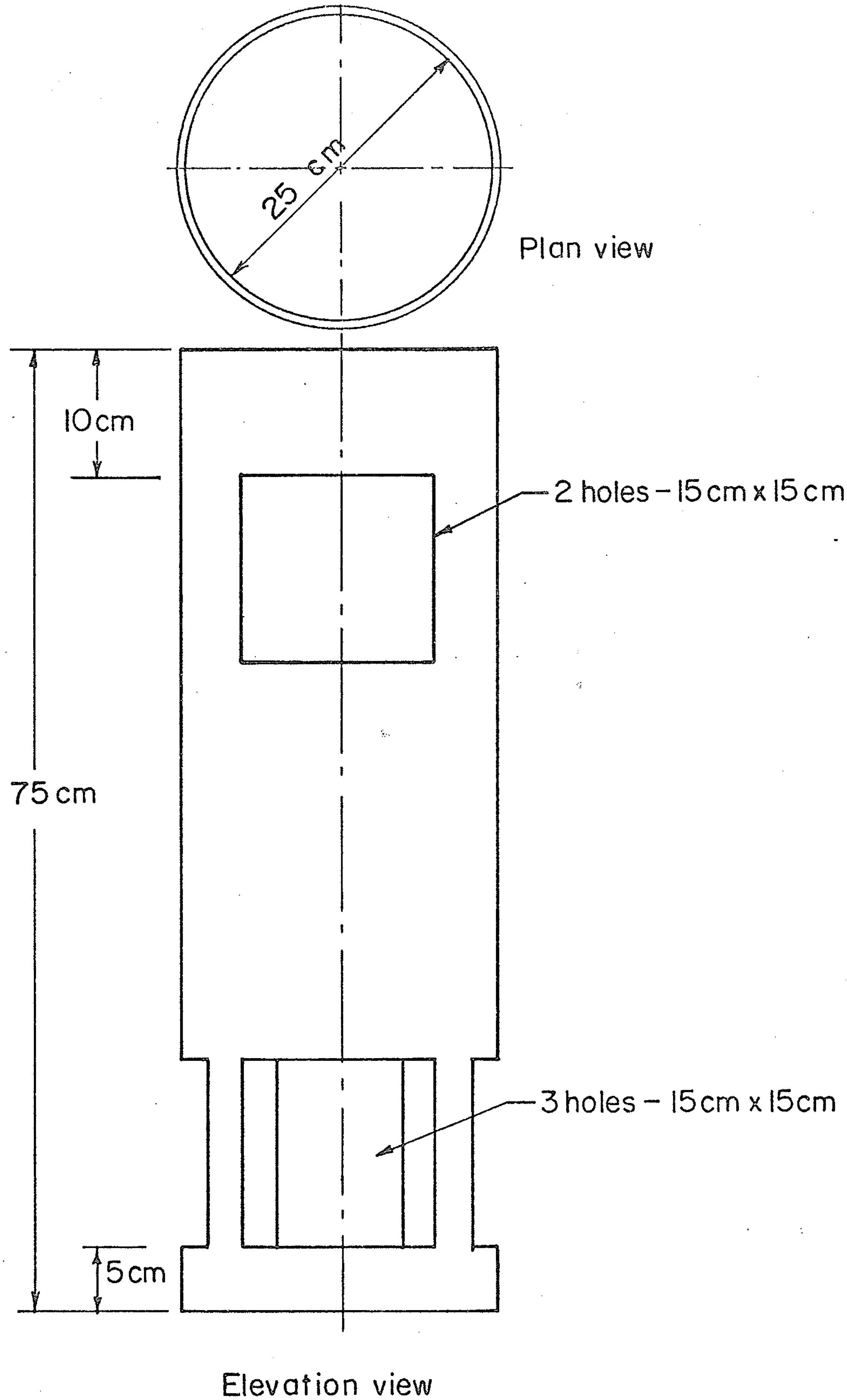


Fig. 6.1 Sonotube vent.

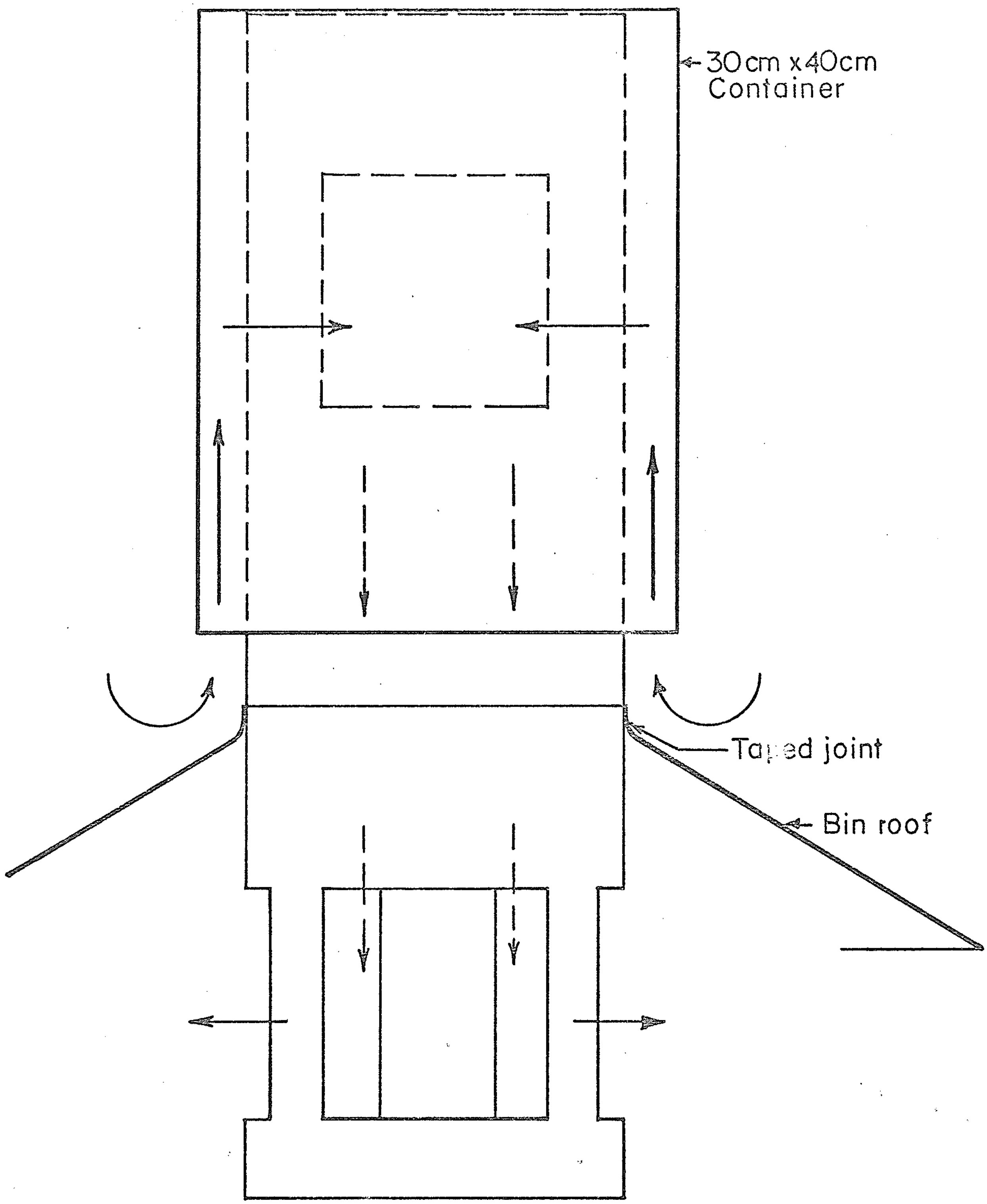


Fig. 6.2 Air flow through Sonotube vent.

apex of the roof (Fig. 6.3). Anchor stakes were provided every 1.5 m around the periphery of the bin to constrain the structure prior to filling.

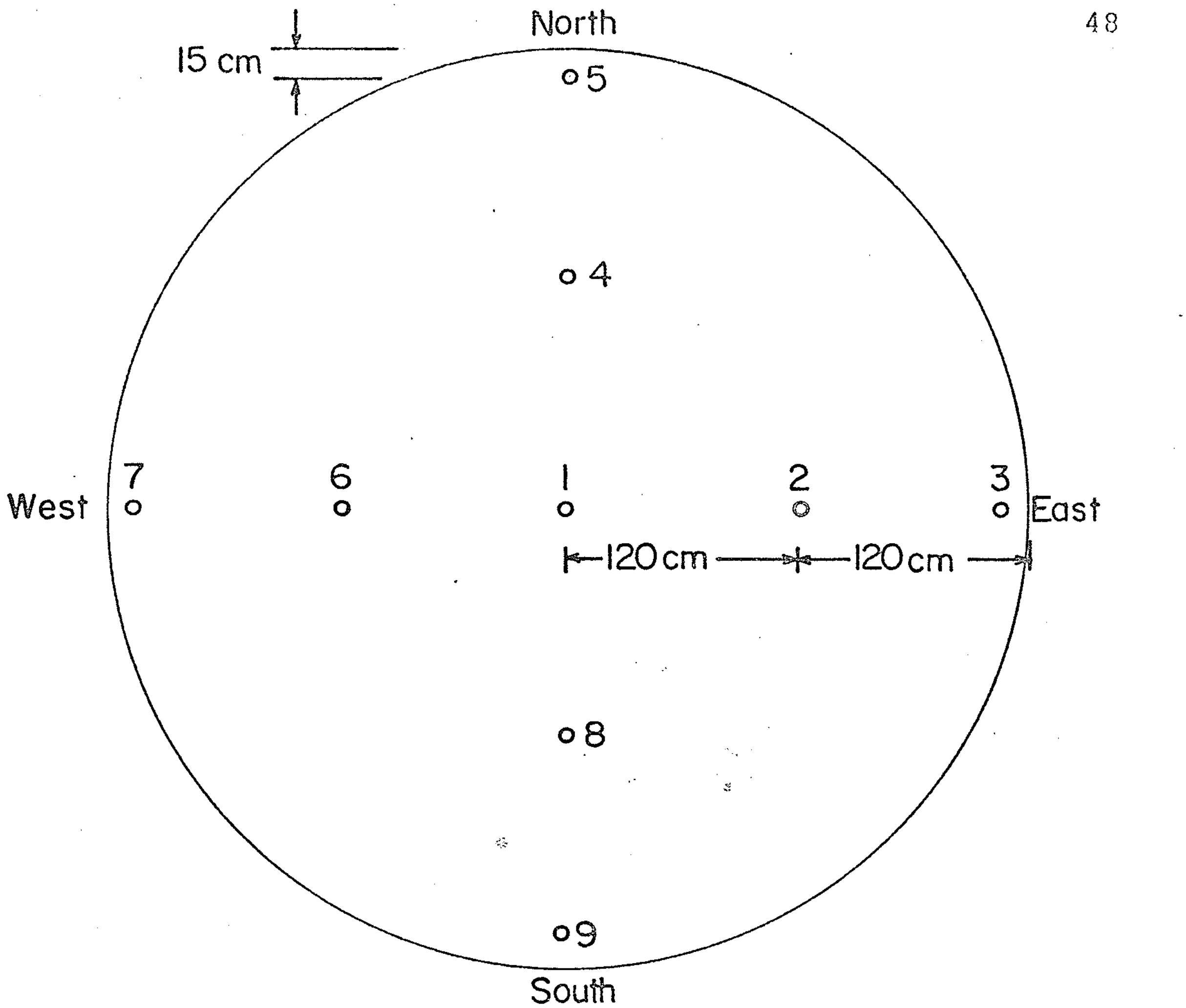
To permit uniform loading of the bins, concentric circles were drawn on the floor of each bin. A small plastic window 30.5-cm square was provided on the roof of each bin to view the loading. Any eccentricities in loading could be easily corrected. A movable grain auger spout was provided for this purpose.

Unloading of bins A and B occurred in January, 1974 while bin C was unloaded in November, 1973 due to a moisture problem. The bins were unloaded in the manner described in Section 5.3.

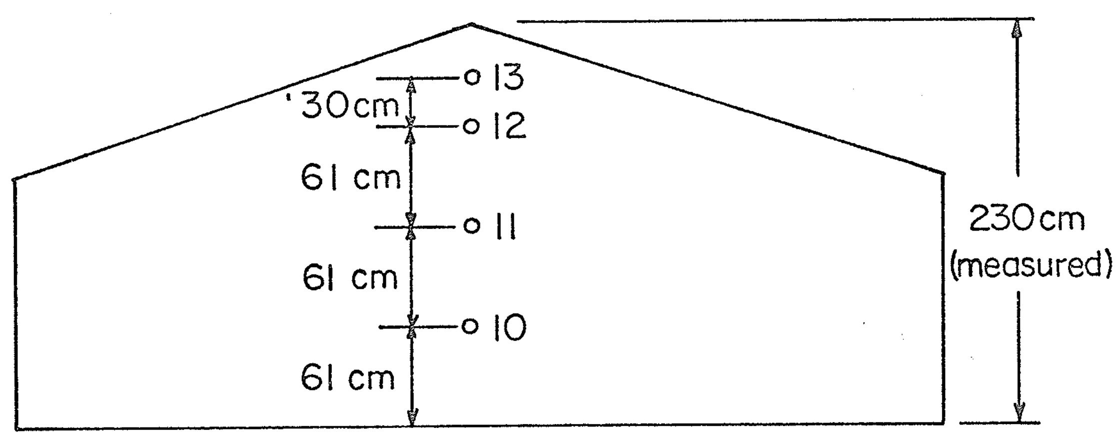
6.4 Measurement Techniques

6.4.1 Temperature

Temperature measurements were taken in each bin at 13 locations (Fig. 6.4). Temperatures on the floor of each bin were measured with 18-gauge (B&S) copper-constantan thermocouples taped to the floors before filling. Temperatures down the centre of each bin were measured with 22-gauge (B&S) copper-constantan thermocouples. The thermocouples were attached together at their respective distances to form a harness. This harness was pushed to the bottom of the bin with a 1.8-cm diameter wooden rod. A nail was placed at an incline 61 cm from the bottom of the rod. The harness



Plan view (all locations are on bin floor)



Elevation view (all locations are at the center of the bin)

Fig. 6.4 Thermocouple locations.

Fig. 6.3 Air inflation system in operation.

was attached to this nail to ensure that the harness was located 61 cm from the floor. The rod was removed after inserting the thermocouples. The thermocouple temperatures were read on a thermocouple indicator with minimum graduations of 0.25 C. Temperatures were taken every two days initially. As the temperatures in the bins stabilized, frequency of measurement was decreased.

6.4.2 Sampling procedure

Bins A, B, and C were sampled in September, 1973 (start of test period) and November, 1973. Bins A and B were sampled in January, 1974. Bin B was only partially sampled at this time due to unexpected unloading by the farmer.

Grain samples were taken at the centre of each bin at depths of 30 cm, 61 cm, 122 cm, and 183 cm using a 250-g torpedo probe. Samples were also taken at areas of suspected high moisture content during the unloading of each bin (Table 6.1).

The samples were stored in plastic bags in a cool room (0 C) until testing could be done in the laboratory. Moisture content of each sample was determined by oven drying whole kernels at 130 C for 19 h (ASAE, 1972). Protein content and grade of each sample were measured by the Canada Grains Commission.

At the termination of the test period for bins A and B, seed viability, fungal flora infection, and insect and mite infestations were determined from the samples taken from the locations shown in Table 6.1. Viability (germination) of cereal seeds and their associated fungal flora were determined by randomly selecting 25 seeds from each sample. The seeds were incubated for one week at room temperature (17 C to 24 C) on filter paper saturated with sterile water. Insects and mites were extracted from each sample (245-g) by placing the sample in Berlese funnels under 100 W incandescent electric bulbs for 24 h. (Sinha, 1964).

Table 6.1

Description of additional sample locations in bins A, B, and C during unloading.

BIN	CODE	LOCATION
A	A-NT	North side of bin, roof-to-wall joint
	A-ST	South side of bin, roof-to-wall joint
	A-ET	East side of bin, roof-to-wall joint
	A-WT	West side of bin, roof-to-wall joint
	A-NB	North side of bin, floor-to-wall joint
	A-SB	South side of bin, floor-to-wall joint
	A-EB	East side of bin, floor-to-wall joint
	A-WB	West side of bin, floor-to-wall joint
	A-Floor	Centre of bin floor
B	B-FN	North side of bin, floor
	B-FS	South side of bin, floor
	B-ST	South side of bin, roof-to-wall joint
	B-(ST-.5)	South side of bin 15 cm below roof-to-wall joint
	B-(ST-2.)	South side of bin, 61 cm below roof-to-wall joint
C	C-FN	North side of bin, floor
	C-FW	West side of bin, floor
	C-NT	North side of bin, roof-to-wall joint
	C-WT	West side of bin, roof-to-wall joint

7. RESULTS AND DISCUSSION

7.1 Filling Technique

Difficulty was experienced in loading the bins. Gusts of wind caused lateral movement of the bin roofs and walls. The lateral movement resulted in several anchor stakes on the windward side of each bin to lift out of the ground. The bins began to overturn within the confines of the steel mesh making insertion of the grain auger spout into the bins difficult.

Eccentric loading of the bins was a problem. With the aid of the concentric circles painted on the floor of each bin and the roof window, the grain auger spout was initially adjusted to load the grain directly in the centre of each bin. However, during loading the grain would load one side of the bin more than the other. To compensate the grain auger spout was continually adjusted to provide uniform loading.

The roof membrane of each bin was only partially loaded by the grain. As the lower section of the roof (portion above the eave) was loaded the clearance between the upper roof section and the grain bulk decreased. At this point, the air filling duct was removed from the bin and the air hole was taped closed to prevent loss of grain through the air filling spout. Since there was now no support system for the remaining roof section, sagging of the roof occurred and filling had to be discontinued.

Upon completion of loading the roof-to-wall joint had a different location in each of the bins. In test bin A (15.5-m steel-mesh circumference, 15.2-m wall-membrane circumference) and in test bin B (15.2-m steel-mesh and wall-membrane circumference) the roof joints were 10 cm and 15 cm below the eaves of the bins, respectively. The roof-to-wall Polyzip joint was loaded laterally (tensile loading perpendicular to the joint) due to the elongation of the wall and roof membrane. The bin roof sagged over the joint and protected it from run-off water. The capacity of each bin was approximately 35 m^3. Although bin C had a larger diameter than bin B, the wall height (floor to eave) was 5 cm less than in bin B resulting in similar capacities. Hence, there appeared to be no advantage in utilizing a steel mesh circumference greater than the circumference of the wall membrane.

The roof-to-wall joint in test bin C (14.9-m steel-mesh circumference and 15.2-m wall-membrane circumference) was located at the eave of the bin. Hence, the joint was not protected from water run-off. The top Polyzip seam was not laterally loaded to any extent. Due to the excess of wall and roof membrane materials, the bin sagged over the top of the steel mesh causing slight tearing of the material at that point. The tears were taped closed with Polykan tape to prevent the entrance of moisture. Capacity of the bin was approximately 35 m^3. Although bin C had a smaller diameter than bin B, the greater wall height in bin C accounted for similar capacities.

7.2 Weathering Effects

Weathering effects on the steel mesh and wall membranes of the test bins were negligible. However, the test period was relatively short and more damage could occur during a longer test period. There was no difference in the weathering effects on TU-TUF tape and Polykan tape. Minor damage to the roofs was effected by the wind. Small pin holes developed in the roof membranes of all three bins. The pin holes were probably fatigue failure of the material resulting from wind flutter. High winds tore the roof membrane joints on test bin B and test bin C. The joints were repaired with their respective tapes. Difficulty, however, was experienced with tape adhesion at temperatures less than 0 C.

7.3 Moisture Content

No correlation could be made between the change of moisture content in each bin over the storage period and its corresponding venting (Table 7.1). This was mainly due to the short storage period. If the bins had remained for the summer storage period more conclusive results might have been obtained.

Moisture contents as high as 25% (wet weight basis)

Table 7.1

Moisture contents along the centre axis of each bin.

TEST BIN	SAMPLE DEPTH, cm	MOISTURE CONTENT, % WET WEIGHT BASIS		
		SEPTEMBER, 1973	NOVEMBER, 1973	JANUARY, 1974
A	30	12.0	12.8	12.8
	61	12.0	12.4	12.4
	122	11.9	12.2	12.8
	183	11.9	12.4	12.3
	Mean	12.0	12.5	12.6
B	30	12.3	12.9	
	61	12.5	13.4	
	122	12.9	12.5	
	183	14.7	12.2	
	Mean	13.1	12.8	
C	30	12.5	12.8	
	61	13.3	12.7	
	122	11.5	12.6	
	183	12.2	12.3	
	Mean	12.4	12.6	

were obtained in many areas along the roof-to-wall Polyzip joint in test bin C (Appendix C). In test bins A and B there was little deterioration along the roof-to-wall Polyzip joint. An average moisture content of 12.4% was obtained for the roof-to-wall Polyzip joint in test bin A. Data were not available for the joint in test bin B because the bin was unloaded by the farmer before samples could be obtained.

The poor sealing characteristics of the top joint in test bin C resulted from the low lateral loading of the Polyzip. An inherent characteristic of the Polyzip fastening system is that a high lateral loading results in a closer fit between the tape and channel components of the system. Since a high lateral load was not present, moisture migrated into the bin through the joint. The location of the joint at the eave of the bin also contributed to the moisture problem. Water was trapped in the joint after a rain and could not run off the bin. In test bins A and B, the joints were below the eave and were afforded protection by the overlapping roof section.

There was a layer of deteriorated grain approximately 2.5 cm thick in many areas on the floors of all the test bins. Moisture contents in the range of 15.1% to 54.5% with a mean of 24.7% were measured. However, the moisture did not appear to enter the bins through the floor-to-wall Polyzip joints which were laterally loaded. Rather, moisture entered the structure through several small holes in the floors. The holes were likely caused by debris under the bins which punctured the floors.

7.4 Temperature

Average initial temperatures of the grain in test bins A, B, and C were 16.1 C, 14.0 C, and 20.7 C, respectively. As the average temperature of the ambient air (average of the mean daily temperatures over a ten-day span taken at the Winnipeg International Airport) decreased during the storage period the temperatures at the majority of thermocouple locations also decreased.

Early in the storage period, however, hot spots developed at thermocouple location 1 in bin A and at thermocouple location 4 in bin B (Fig. 6.4). The temperature at location 1 was approximately 11 C greater than the average temperature of the four thermocouples located on the floor a radial distance of 120 cm from location 1 (Fig. 7.1). The hot spot occurred two weeks after filling the bin and lasted for approximately two weeks. The temperature at location 4 in bin B was also approximately 11 C greater than the average temperature of the other three thermocouples locations on the floor a radial distance of 120 cm from the centre of the bin floor (Fig. 7.2). The hot spot occurred three weeks after filling the bin and lasted for approximately three weeks. The above normal temperatures

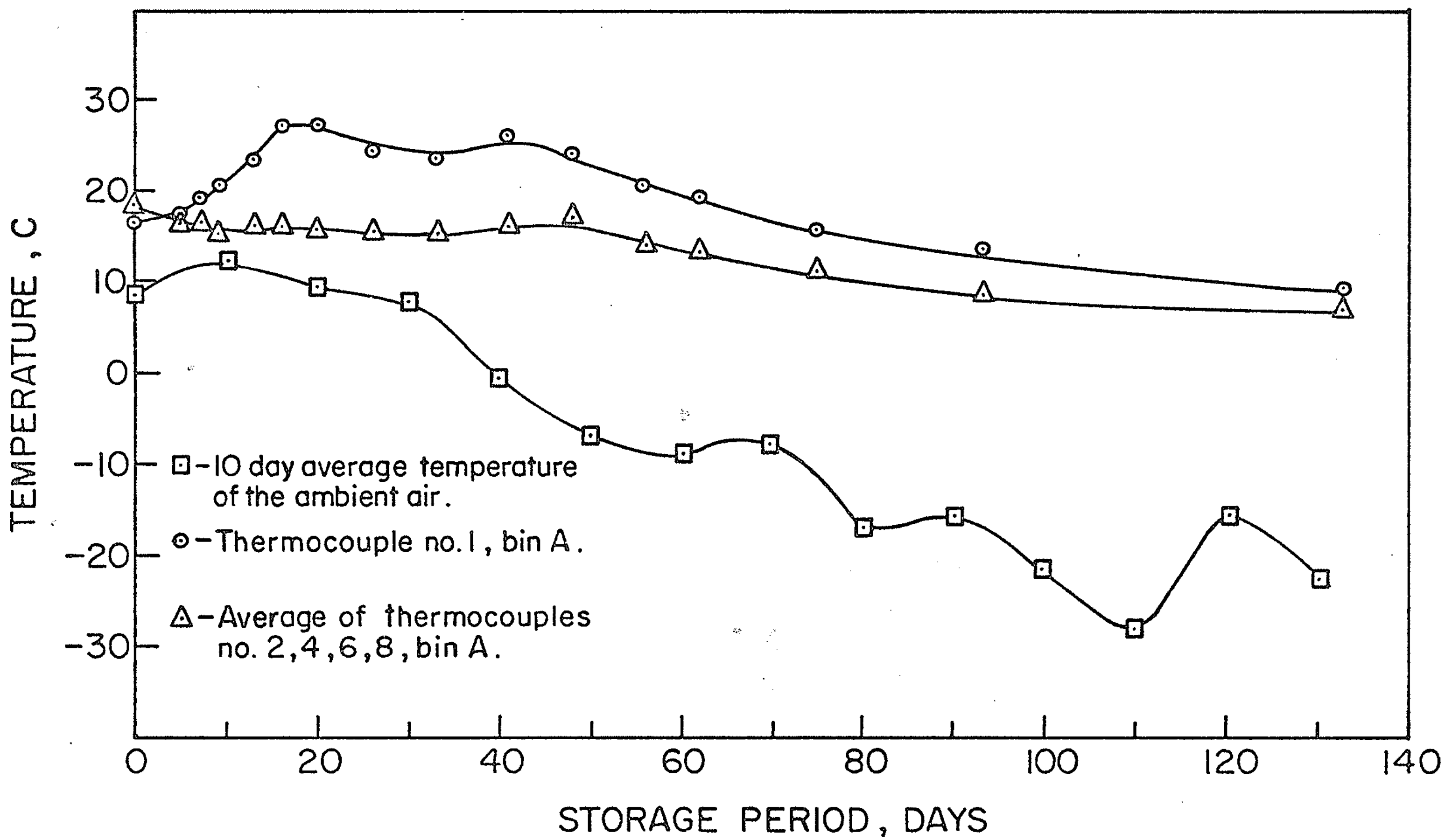


Fig. 7.1 Temperature of hot spot in bin A.

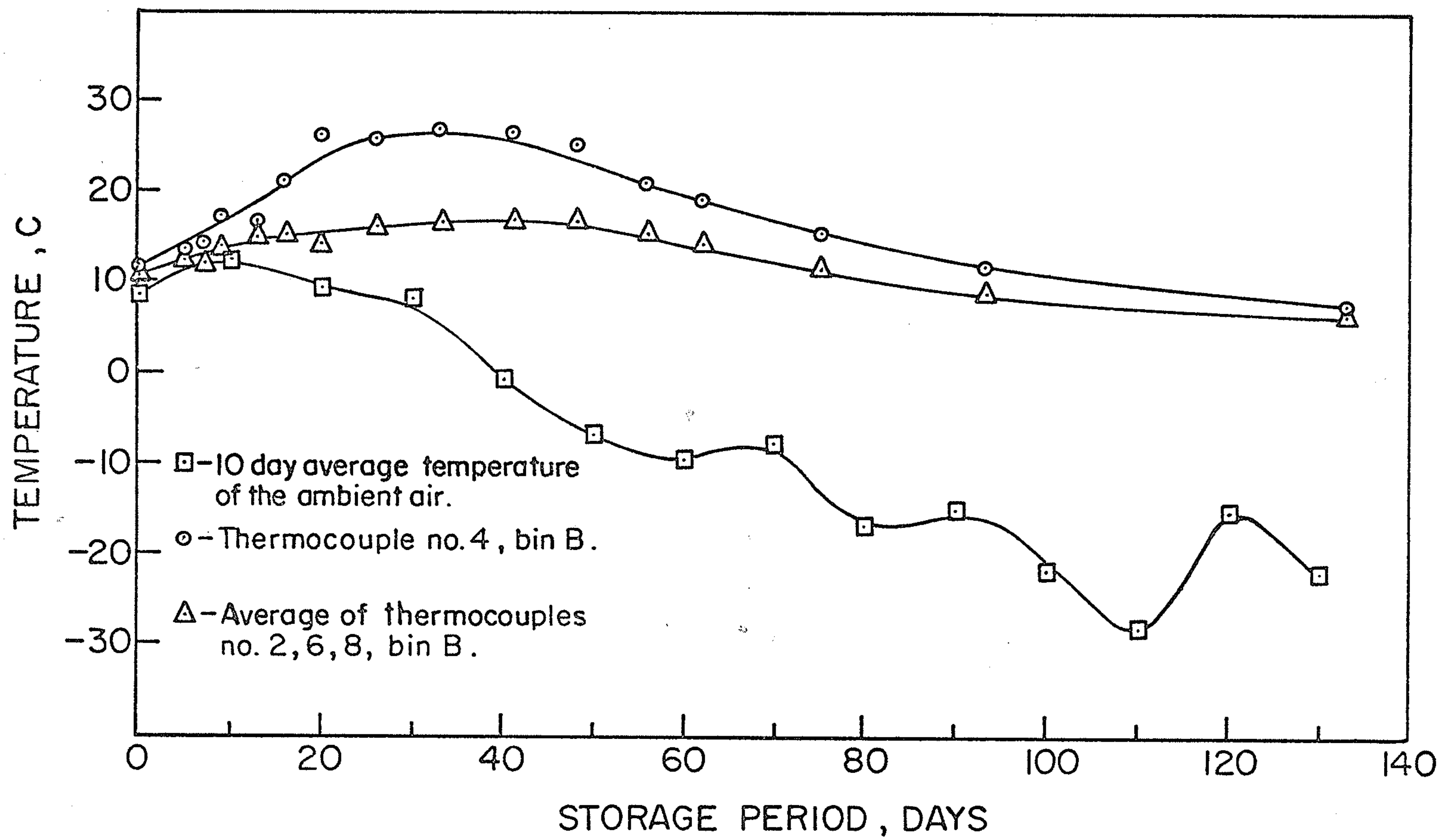


Fig. 7.2 Temperature of hot spot in bin B.

indicated that deterioration was taking place at these localized areas (Sinha and Wallace, 1965). Unloading of the bins confirmed that deterioration had occurred at the localized hot spots.

7.5 Grain Condition

Protein content of the wheat along the centre axis of each bin did not change appreciably during the storage period (Table 7.2) as would be expected from previous work (Zeleney, 1954). Protein contents taken at additional sample locations in each bin (Appendix C) were in accordance with their respective center values.

The commercial grade of the wheat in bin A at a depth of 183 cm decreased (Table 7.3). This decrease may have been caused by grain deterioration near the floor of the bin although the grain at this location appeared normal during unloading. A grade discrepancy was also noted at the 122-cm sample depth. The discrepancy at this location is attributed to sampling and grading techniques. It is highly probable that the probe did hot sample from exactly the same point. No grade discrepancies were observed in bin B. In bin C the grade at all sample points decreased from No. 2 C.W. Red Spring to No. 3 C.W. Red Spring. This drop of grade is unexplainable. Wheat grades at additional sample locations are given in Appendix C.

Table 7.2.

Protein contents along the centre axis of each bin.

TEST BIN	SAMPLE DEPTH, cm	% PROTEIN CONTENT		
		SEPTEMBER, 1973	NOVEMBER, 1973	JANUARY, 1974
A	30	13.0	13.3	13.2
	61	13.2	13.6	13.4
	122	13.5	13.8	13.4
	183	13.5	12.8	12.6
	Mean	13.3	13.4	13.2
B	30	12.0	12.0	
	61	11.9	11.4	
	122	12.1	12.1	
	183	13.1	13.4	
	Mean	12.3	12.2	
C	30	12.0	12.1	
	61	11.6	11.4	
	122	11.5	11.3	
	183	11.4	11.2	
	Mean	11.6	11.5	

Table 7.3

Grade of wheat along the centre axis of each bin.

TEST BIN	SAMPLE DEPTH, cm	GRADE*		
		SEPTEMBER, 1973	NOVEMBER, 1973	JANUARY, 1974
A	30	No. 1	No. 1	No. 1
	61	No. 1	No. 1	No. 1
	122	No. 1	No. 2	No. 1
	183	No. 1	No. 3	No. 3
B	30	No. 3	No. 3	
	61	No. 3	No. 3	
	122	No. 3	No. 3	
	183	No. 3	No. 3	
C	30	No. 2	No. 3	
	61	No. 2	No. 3	
	122	No. 2	No. 3	
	183	No. 2	No. 3	

*All grades are Canada Western Red Spring Wheat.

7.6 Agents of Deterioration

7.6.1 Microflora[1]

High infection of *Alternaria*, a field fungus, occurred at most sample locations in the bins except for locations near the bin floors and also at location A-NT (Table 7.4). The presence of high *Alternaria* infection indicated healthy grain at these locations.

Aspergillus infection was negligible and *Penicillium* relatively light. The high infection of *Scopulariopsis* (location B-FN and B-FS) was probably responsible for the zero germination at these points. As a consequence, these two samples were surface sterilized with 10% Javex for 2 min and plated on Czapek's agar and on Malt Salt agar.

On both of these agars a high presence of *Scopulariopsis*, 94% infection at location B-FN and 100% infection at location B-FS, was found. In addition, the Czapek's agar produced 100% bacteria infection at location B-FS and 36% bacteria infection at location B-FN. On the Malt Salt agar 25% of all the seeds at both locations produced fungi of the *Aspergillus glaucus* group.

Normally, one would expect *Aspergillus* to be the primary cause of deterioration, *Scopulariopsis* a secondary cause, and bacteria a tertiary cause. As moisture content

---

[1]Sec. 7.6.1 was written in conjunction with Mr. H.A.H. Wallace, Winnipeg.

Table 7.4

Microflora on seed stored in test bins A and B
(frequency of occurrence of kernels plated on saturated filter paper, %).

CODE	Germination	Alternaria	Aspergillus	Epicoccum	Fusarium	Gonatobotrys	Hormodendrum	H. Sativum	Paecilomyces	Penicillium	Scopulariopsis	Streptomyces	Trichothecium	Bacteria
A-NT	92	42	0	0	0	0	0	0	0	0	0	0	0	0
A-ST	100	96	0	0	4	0	0	4	0	0	0	0	0	0
A-ET	92	92	0	0	0	0	0	4	0	4	0	0	0	0
A-WT	100	100	0	0	0	4	8	4	0	0	0	0	0	0
A-NB	96	84	0	0	8	0	4	0	0	0	0	0	0	0
A-SB	100	100	0	0	0	0	0	0	0	4	0	0	0	0
A-EB	100	92	0	4	0	0	4	0	0	0	0	0	0	0
A-WB	96	92	0	0	0	0	8	4	4	4	0	0	0	0
A-Floor	44	60	8	0	0	0	0	4	0	28	0	16	72	4
Bin A:														
30 cm depth	96	96	0	0	0	0	16	0	0	0	0	0	0	0
61 cm depth	100	96	0	0	0	0	0	8	0	0	0	0	0	0
122 cm depth	92	96	0	0	0	0	4	8	0	8	0	0	0	0
183 cm depth	96	92	0	0	0	0	4	0	0	0	0	0	0	0
B-FN	0	0	12	0	0	0	0	0	0	24	100	56	40	42
B-FS	0	0	0	0	0	0	0	0	0	20	88	8	20	8
B-ST	68	96	0	0	0	0	4	0	0	0	0	0	0	0
B-(ST-.5)	80	88	0	0	0	0	12	0	0	0	0	0	0	0
B-(ST-2.)	96	96	0	0	0	0	4	0	0	0	0	0	0	0

of the grain increased, these agents would normally invade the grain in the above order. Because the infection with Scopulariopsis is much higher than for the Aspergillus species it is difficult to conclude whether the Scopulariopsis is inhibiting the Aspergillus on the agar plates or whether it in itself was the actual fungus that caused the deterioration of the seed. It is probable that the sudden increase in the moisture content of the grain on the floor of test bin B raised the moisture content of the seed to conditions suitable for the growth of Scopulariopsis.

7.6.2 Mites

A large infestation of mites occurred in bin A at the floor sampling location, A - Floor (Table 7.5). *Tyrophagus zachvatkini* Volgin was the predominant species at this location with 449 mites occurring in a 245-g sample. A moisture content of 17.7% wet weight basis and a temperature range of 5 C to 27 C (Fig. 7.1) provided an ideal environment for growth (Sinha, 1973). Although the mites did not appear to have caused heavy deterioration, they are bio-indicators of impending deterioration.

7.6.3 Other agents of deterioration

Other agents of deterioration; insects, rodents, and birds were not present in the bins. Several rodent trails had been made in the snow around the bottom of bins A and B, but no damage to the bins occurred.

Table 7.5

Location, number, and species of mites in test bins A and B.

LOCATION	MITE COUNT	SPECIES
A-Floor	449	*Tyrophagus zachvatkini* Volgin
A-WB	2	*Tyrophagus zachvatkini* Volgin
A-EB	1	*Stigmaeidae*
A-SB	2	*Proctolaeps scolytyi* Evans
B-FN	1	*Proctolaeps scolytyi* Evans

8. SUGGESTIONS FOR FUTURE STUDY

Structural tests indicated that a conical grain bin and a cylindrical bin with a monolithic wall and conical roof were not adequate for grain storage. The main reason for their unsatisfactory performance was that materials with high tensile strengths and low elongation are not presently available at low cost.

The cylindrical bin with composite wall and conical roof withstood structural loads imposed by the grain bulk. The bin, however, was not effective in preventing grain deterioration during a four-month winter storage period. Although the amount of grain deterioration was minimal, continuation of the test during spring and summer would have probably resulted in more grain spoilage.

Grain deterioration was affected by the entrance of moisture into the bin through the roof-to-wall Polyzip joint and through the floor membrane. The problem could be eliminated through the use of more puncture-resistant materials for the floor membrane. A fastening system with closer tolerances would minimize moisture migration through the roof-to-wall joint.

Problems with the roof section were also encountered. The bin could not be filled so as to structurally load the complete roof section. Damage to the roof membrane was inflicted by wind flutter. The use of stronger materials for the roof membrane could alleviate the problem. An improved loading system which allows structural loading of the roof would also provide a solution to the problem.

Development of better unloading systems is also required. The unloading procedure which was used for the test bins was adequate. However, to permit partial unloading of the structure, an unloading hatch or spout would be desirable.

Estimated costs of storing grain in the cylindrical bin with composite wall and conical roof was \$1.07 per m^3 per year based upon a two-year design life of all components. This was in accordance with the estimated yearly storage cost of \$1.00 per m^3. However, based upon the inability of the structure to prevent grain deterioration during the four-month storage period future work should consider a cost greater than \$1.00 per m^3. This would allow better materials to be utilized in the design and hence maintain grain quality over a one-year storage period.

REFERENCES

Agricultural Machinery Administration. 1961. Report on test of Brandt grain loader. Province of Saskatchewan, Department of Agriculture, Regina. Publication No. 1860. 6 p.

American Society of Agricultural Engineers. 1972. Agricultural engineers yearbook. ASAE, St. Joseph, Michigan. 384 p.

Cain, W. 1916. Earth pressure, retaining walls and bins. John Wiley and Sons, Inc., New York. 287 p.

Friesen, B. 1971. Farm stored grain on the prairies--a cost study. Canada Grains Council, Winnipeg. 33 p.

Gupta, D.K. 1971. Lateral grain pressures in flexible plastic containers. Unpublished M.Sc. thesis. University of Manitoba, Winnipeg. 76 p.

Kreith, F. 1969. Principles of heat transfer. International Textbook Co., Scranton. 620 p.

Muir, W.E., R.N. Sinha and H.A.H. Wallace. 1973. Abiotic and biotic characteristics of grain stored in temporary farm bins. Canadian Agricultural Engineering. 15:35-42.

National Research Council. 1970. Canadian code for farm buildings. National Research Council of Canada, Ottawa. 218 p.

Sinha, R.N. 1964. Mites of stored grain in Western Canada --ecology and methods of survey. Proc. Entomol. Soc., Manitoba. Vol. 20. 14 p.

Sinha, R.N. 1973. Interrelations of physical, chemical, and biological variables in deterioration of stored grain. Chap. 2. p. 15-47. In Grain storage--part of a system. R.N. Sinha and W.E. Muir (Editors). Avi Publishing Co., Westport, Conn.

Sinha, R.N. and H.A.H. Wallace. 1965. Ecology of a fungus-induced hot spot in stored grain. Can. J. Plant Sci. 45:48-59.

Taylor, D.W. 1948. Fundamentals of soil mechanics. John Wiley and Sons, Inc., New York. 568 p.

Zeleny, L. 1954. Chemical, physical, and nutritive changes during storage. Chap. 2. p. 46-76. In Storage of cereal grains and their products. J.A. Anderson and A.W. Alcock (Editors). Am. Assoc. Cereal Chemists, St. Paul.

APPENDIX A

COMPUTATION OF MATERIAL SECTION REQUIRED TO FORM A CONE

Formation of a cone (Fig. A.1) from a circular sheet requires that a segment of the sheet be removed. The remaining section is then fastened together to form a cone.

From Fig. A.2:

$$\beta = S/R \qquad \ldots (A.1)$$

For circumferences to be equal:

$$2\pi r = 2\pi R - S \qquad \ldots (A.2)$$

or

$$S = 2\pi(R - r) \qquad \ldots (A.3)$$

Substituting Eq. (A.3) into Eq. (A.1) and converting to degrees:

$$\beta = \frac{2\pi(R - r)}{R} \frac{(180)}{\pi} \qquad \ldots (A.4)$$

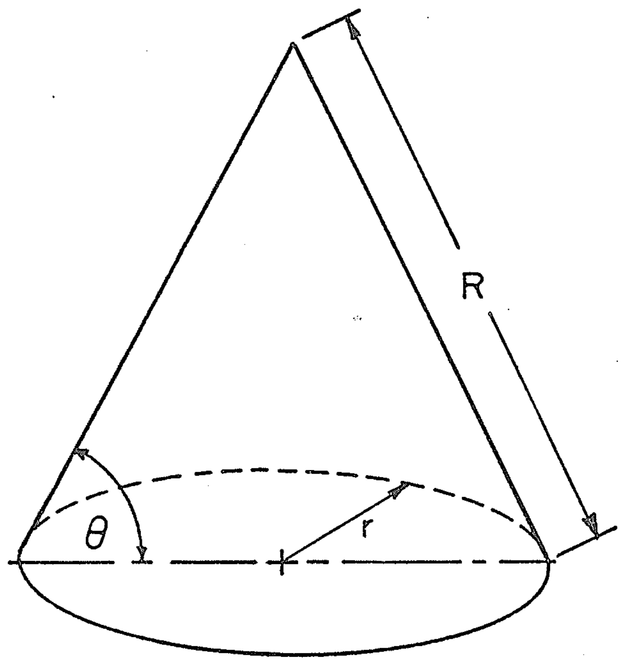
or

$$\beta = 360\left(1 - \frac{r}{R}\right) \qquad \ldots (A.5)$$

But $\quad r/R = \cos\theta \qquad \ldots (A.6)$

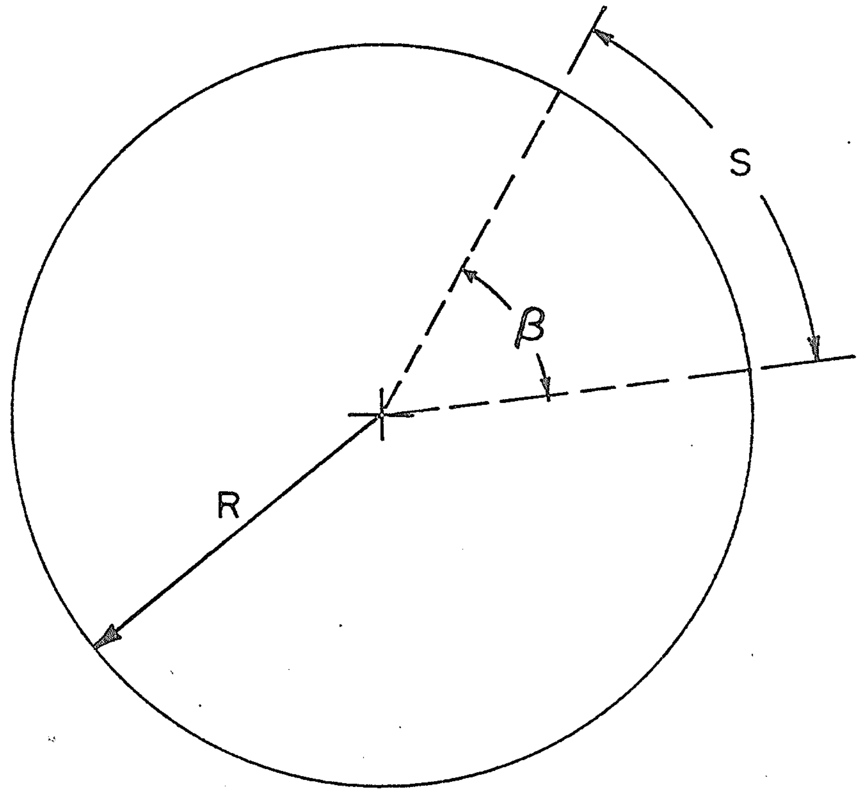
Substituting Eq. (A.6) into Eq. (A.5):

$$\beta = 360(1 - \cos\theta) \qquad \ldots (A.7)$$



where: θ = wall angle of cone, radians
r = radius of the base, m
R = length of the conical sidewall, m

Fig. A.1 Conical wall.



where: R = radius of the material section, m
S = arc length of the segment, m
β = segment angle, radians

Fig. A.2 Material section.

APPENDIX B

BIN MATERIALS AND COST

Based on volume discounts on the material for 300 bins and excluding federal sales tax, the cost of material for one cylindrical bin with composite wall and conical roof is:

Polyzip Fastening - 40.8 m @ 45.9¢/m		$ 19.00
Wire Mesh 6 x 6 - 10/10 - 1.5 m x 20.7 m @ 44.1¢/m^2		13.75
Polykan Tape - 5 cm x 30.5 m		2.50
TU-TUF-2 Poly Sheeting - 2 1/2 mil		
Floor - 6.4 m x 6.4 m Wall - 1.5 m x 20.4 m Roof - 7.9 m x 7.9 m Air Duct - 1.2 m x 9.2 m	145 m^2 @ 21.5¢/m^2 + 17 1/2% duty	37.00
Used Furnace Fan and Motor		20.00
Polyzip Tool		3.00
Stakes (10 required) and Miscellaneous		4.75
TOTAL		$100.00
Handling Charges and Profit		50.00
TOTAL		$150.00

Design Life = Two Years

$$\therefore \text{ Yearly Cost*} = \frac{75.00}{70 \text{ m}^3} = \$1.07/\text{m}^3$$

*Based on 1973 material cost index.

APPENDIX C

DATA AT ADDITIONAL SAMPLING LOCATIONS

Table C.1

Moisture content, protein content, and grade at additional sample locations in bins A, B, and C during unloading.

CODE	MOISTURE CONTENT, % WET WEIGHT BASIS	% PROTEIN CONTENT	GRADE*
A-NT	12.2	13.1	No. 1 C.W.
A-ST	12.3	12.7	No. 1 C.W.
A-FT	11.8	13.0	No. 1 C.W.
A-WT	13.1	14.1	No. 1 C.W.
A-NB	12.6	13.8	No. 1 C.W.
A-SB	12.3	13.2	No. 1 C.W.
A-EB	11.8	13.8	No. 1 C.W.
A-WB	51.5	13.8	No. 1 C.W.
A-Floor	17.7	12.6	Heated sample
B-FN	24.2	Sample size too small	Heated sample
B-FS	22.9	Sample size too small	Heated sample
B-ST	27.5	11.3	No. 3 C.W. (damp)
B-(ST-.5)	12.3	12.3	No. 3 C.W.
B-(ST-2.)	14.1	12.1	No. 3 C.W.
C-FN	54.3	Rotted sample	Rotted sample
C-FW	15.1	11.0	No. 3 C.W. (tough)
C-NT	25.5	11.9	No. 3 C.U.** (damp)
C-WT	17.1	11.4	No. 3 C.W. (tough)

*Red Spring Wheat.
**Canada Utility.