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Systems of Farm-level Storage of Food Grains and Use of Ferrocement for making Silos: A Review

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Abstract: In India, agriculture is considered as backbone for its economic development in view of the facts that agriculture and allied sectors have significant share on revenue and employment generation. Therefore, in the era of industrial development, agriculture still holds a place of pride for the national development. According to the Department of Food & Public Distribution of India, it aims to ensure food security for the country by monitoring its production and facilitating sufficient food grain storage systems. The focus is on incentivizing farmers through fair value of their produce by way of Minimum Support Price mechanism. To fulfill the aforementioned policy, along with sufficient production of food grains, proper storage facilities should be ensured. Ferrocement is a strong, versatile, light weight, durable building material which is simple in composition, requires almost no formwork, labour intensive with minimum skill and of low overall construction cost. Ferrocement may prove to be an effective and overall economic material for the construction of grain storage silos. Thus, the review covers the food grain storage systems in India, study of response of ferrocement as a structural material and pressure computation in silos.
Keywords: Ferrocement, Silos, Food grains storage, Finite Element Method, Hoop Stresses, Longitudinal Stresses, Janssen's Theory, Wall pressures

I. INTRODUCTION

The present study aims to explore a domestic structure for the storage of food grains at farm – level using ferrocement as a construction material. From that perspective, the literature review has been entitled under the following three heads:

A] Food Grain Storage System in India
B] Ferrocement Technology
C] Silos

II. LITERATURE REVIEW

A. Food Grain Storage System in India

M. Thimma Reddy studied different types of storage structures used in India. Straw Storage Structures are mostly outdoor structures and are constructed of Straw ropes. Their capacity ranges from 3 – 20 tons and have a service life of 5 months to 2 years, depending upon the rainfall. This structure has the biggest advantage of low cost of construction and provides proper aeration during storage. Bamboo Storage Structures is basically a basket type of store, made of split bamboo plaited together and plastered with mud. It can be placed inside a house or may be outside. Its storage capacity varies from 0.75 – 1.00 tons for indoor structures & 1 to 25 tons in case of outdoor structures. Its life varies from 4 – 15 years depending upon the way of maintenance. Susceptibility to moisture and rodent attack are the drawbacks of this structure.

Masonry Storage Structure is constructed of bricks or stones in rectangular shape as a part of a house with mud or lime or cement as a binding material. It has a capacity ranging from 7.5 to 30 MT. In spite of durability, structure has inadequate protection against rodents and moisture and can subject to infestations due to resident infestation in cracks and crevices.

Mud Storage Structures are like a drum and made up of locally available clay, hence prove economical. The storage capacity is 1 to 2 qt with 10 – 15 years of service life. It is light weight, so also fragile.

Underground Storage Structures are constructed where water table is low. Their floor is made up of straw and paddy husk and sealed with straw and mud. They are sometimes lined with bricks or stones. They are of 1 – 2 MT capacity. They are safe against theft as well as fire, but they demand yearly maintenance work. Also, it is difficult to empty and clear out and may prove dangerous, due to accumulation of carbon dioxide gas in the free board. Although, they do not allow the growth of aerobic insects, moisture may find out a way to spoil the grains stored in.

Modern techniques of grain storage include use of small metallic bins, silos, go – downs and ware houses. Food Corporation of India (FCI) offers such modern techniques of storage fulfilling price support expectation for the farmers as well as distribution and maintenance of buffer stock throughout the country. Thus, to cater the increasing demand of population, an economically viable and long-lasting option of storage is to be explored[1].

Naik et al. studied different Indigenous storage structures, advantages & disadvantages associated with them and categorized them into three categories i.e. traditional, improved and scientific storage structures. The traditional storage structures are made up of paddy straw, wheat straw, wood, mud, bricks or stones although prove economical from their construction point of view, but they need regular maintenance. The Improved storage structures are basically enhanced form of traditional storage structures like small storage bins made up of metal sheets or bricks and mud supplemented with polythene sheets for moisture prevention. The scientific storage structures are ware houses and silos which are constructed, rented and maintained by government. This type of storage structure not only maintains the quantity, but also quality of food grains which in turn provide proper nutritional value to the consumers. Still, in India, post-harvest losses in food grains either due to improper or insufficient storage facility has been estimated to be Rs. 50,000 crores per year which could feed one third of India's poor. Thus, it's a need to introduce scientific storage structures which will reduce the avoidable losses and provide a cheaper option for the food grain storage[2].

Shukla el al. explained that a major contributor in post-harvest loss of food grains is irrational way of storing a large portion of farm produce by the farmers. The authors mentioned an engineering aspect of the traditional storage structures keeping in view social and economic condition of the Indian farmers. They classified storage structures into four major categories viz. Indoor metallic and non – metallic structures and Outdoor metallic and non – metallic structures. They emphasized on the use of scientific design method to optimize the quantities of construction materials especially, cement and steel required for building up the storage structure [3].

Dhuri observed that about 1 ton of food grains are retained and stored by Indian farmer at farm level which results into loss of grains. Therefore, to prevent the losses, the author suggested a fumicover, which is a multi-layered cross laminated sheet, along with 10 gm Celphos which can be used for covering stored food grains. It can fumigate 1 ton of food grains. The test has been carried out at five places across the country and found user friendly, economical and durable for farmers in developing countries like India [4].

Mishra studied different indigenous methods of food grain storage systems. In the study, the author pointed out various factors like moisture content of grains, temperature control and storage environment which affect the quantity as well as quality of food grains that would be available to consumers and need to be scientifically addressed. To monitor and improve quality of food grain stored by traditional storage methods, timely visual inspection of food grains, use of machine vision system, Near – Infra Red system (NIR) and Chemical and Microbiological Analysis, these four quality measurement methods have been suggested [5].

B. Ferrocement Technology

Desayi et al. put forward semi empirical mathematical expressions for predicting shear strength of ferrocement elements. Two series of experiments were conducted on ferrocement beam elements with 600 mm clear span under four-point load system. The design of experiment was done by considering five variables, number of mesh layers, layout of mesh layers, strength of mortar, shear span to depth ratio and provision of skeletal steel. 155 specimens were tested and shear force was computed using various equations available in the referred literature for flexure – shear cracking, web – shear cracking, flexure – shear failure and web – shear failure and compared with the results obtained from the tests. In the layout of wire meshes, in few specimens meshes were distributed uniformly throughout the thickness, whereas in some specimens, wire meshes were lumped near top and bottom faces. In some specimens, wire meshed were tied to skeletal steel using binding wires. Since, guidelines were not available in ACI code for shear strength determination of ferrocement elements; ACI and BS code for reinforced concrete were referred. The important findings of the research were as follows:

• The empirical equations available and semi – empirical expressions suggested by the authors showed quite comparable results for predication of shear strength for ferrocement elements.

• Based on two types of models, viz. flexure – shear and web – shear models, the critical shear forces were found by flexure – shear model.

• Due to non – availability of codal methods for predicting shear strength of ferrocement, ACI and BS codes of reinforced concrete were found to be conservative and underestimate the shear force at flexure – shear and web – shear failure [6].

Debs and Naaman focused on flexural response of ferrocement reinforced using mesh as a primary reinforcement and polymeric fibers as secondary reinforcement. Thin ferrocement beam specimens were cast in the size of 127mm x 457 mm x 12.7 mm thick and reinforced with two types of wire meshes, one with 25.4 mm x 25.4 mm aperture and another with 50.8 mm x 50.8 mm aperture.

The parameters under investigation were type of mesh, type of fibers and positioning of meshes in the ferrocement specimen cross – section. The fibers used were Polyvinyl alcohol fibers (PVA) and Polypropylene fibers (PP). The specimens were tested under four-point flexure tests. The important observations were as follows:
• PVA fibers reinforced ferrocement specimens showed better behavior as compared to PP fiber reinforced ferrocement specimens in terms of cracking and yielding.
• Addition of PVA fibers increased the cracking load by 30% and decreased crack spacing and crack width by 80%.
• Presence of mesh layer on compression and tension faces of the ferrocement beam specimens did not show any significant change in the behavior as compared to ferrocement specimens reinforced only on tension face in terms of load – deflection and cracking [7].
Skudra et al. suggested an analytical approach to predict elastic modulus and shear modulus of a ferrocement element reinforced with hexagonal woven mesh. They considered hexagonal woven wire mesh as if made up of repeating grid elements. Therefore, only single grid element of the mesh was considered to develop a mathematical approach. Using volume fraction concept and Hooke's law, the authors recommended equations to determine elastic modulus and shear modulus. Dependence of shear modulus on volume fraction content was represented graphically [8].
Arif et al. determined elastic properties of ferrocement experimentally and compared them with the existing available equations. The researchers cast total 36 ferrocement test specimens under in – plane tension, in – plane compression and flexure condition. Two types of wire mesh were used as reinforcement in ferrocement specimens. One was machine woven galvanized steel mesh with 7.5 mm x 6.0 mm opening and 0.72 mm average wire diameter and another was square welded galvanized steel mesh with 1.44 mm average diameter and 15 mm x 15 mm opening size. Test specimens included plain cement mortar specimens i.e., without reinforcing meshes and specimens reinforced with woven and welded mesh at different orientation or angle with the direction of loading and mesh layers. The specimens were tested under tension, compression and flexure. The test results showed following salient outputs:
• Plain Cement Mortar Test specimens showed brittle failure under tension, compression and flexure as compared to those which were reinforced with mesh layers.
• Ferrocement specimens tested under in – plane tension showed increase in failure load with the increase in the numbers of layers of wire meshes. But no significant variation in Young's modulus was observed due to simultaneous change in thickness and number of layers
• Ferrocement specimens reinforced with woven wire mesh showed better performance in tension test than those with square welded wire mesh due to less spacing between the wires in case of woven wire mesh.
• Ferrocement specimens reinforced with wire meshes at 300 to 600 orientations showed weak performance due less volume fraction in the direction of loading.
• Ferrocement specimens showed cracking, chipping and spalling in case of compression test.
• In flexure, the specimens showed better behavior with the increase in number of mesh layers with best performance at 00 and poorest at 450 orientation of wire mesh.
• Elastic modulus obtained from the conventional expressions available was found to be higher than that obtained experimentally [9].
Kubaisy et al. studied behavior of reinforced concrete slabs under flexure when provided with additional ferrocement cover on tension face. 12 slab specimens under five groups were made as conventional reinforced concrete slab specimens, specimens with additional ferrocement cover reinforced with different volume fraction, specimens with different thickness of ferrocement layer on tension face of the conventional reinforced concrete slab, specimens depending upon method of connection of wire mesh with conventional reinforcement in the slab specimens and specimens having cold joint ferrocement layer. The slabs were tested as simply supported over 1400 mm clear span with central loading condition. It was observed that additional ferrocement cover in tension face reduced crack width and crack spacing as compared to control specimens. Thus, the study proved use of ferrocement cover provided on tension face of reinforced concrete slab as an advisable method of improving its tensile characteristics [10].
Masood et al. investigated flexural behavior of ferrocement panels when prepared and cured with potable and saline water. The authors used cement, fly ash as partial replacement, sand, layers of woven and hexagonal wire mesh, potable water and water with NaCl for mixing and curing. Two mortar mixes were used, first with cement to sand ratio as 1:2.5 and second with cement: fly ash: sand mixed in 0.8:0.2:2.5 proportion by weight. Water to cement ratio was kept 0.4. The slab panels were moist cured for 28 days and air – dried for 4 days before testing. The specimens were tested under uniformly distributed load. The test observations indicated following results:
• There was increase in the load carrying capacity of the panels with the increase in number of layers of wire meshes.

• The specimens with fly ash mixed and cured with potable water showed poor flexural capacity as compared to those without fly ash.

• Increase in the load carrying capacity was observed in the specimens mixed and cured in saline environment as compared to normal environment for fly ash content ranging from 0% to 20%.

• The ratio of ultimate load to deflection was higher for specimens reinforced with woven mesh as compared to hexagonal mesh irrespective of environmental conditions [11].

Moita et al. used ferrocement as material for the construction of a water tank in a water treatment plant at Brazil. A water tank of 20 m diameter and 2.68 m in height was constructed with 8 cm wall thickness. The tank wall was reinforced with two kinds of welded wire meshes to have volume fraction as 1.08% to 2.03% horizontally to cater hoop tension and 1.08% to 1.62% vertically. Hoop tension variation was recorded using 40 strain gauges pasted on the wire mesh under tank full condition. To compare experimental results, finite element modeling was done using two approaches, one with axis symmetric solid finite element model and second with Semi-loof shell element and concluded that homogeneous or axis symmetric solid finite element modeling gives more conservative results than experimental [12].

Nassif and Najm13 investigated feasibility of ferrocement laminate when used as a shoring plank at the soffit of a deck beam to obtain composite action of the reinforced concrete beam with the ferrocement layer. The authors prepared 24 composite beams for testing under two – point loading. The composite beams of 152 mm x 152 mm cross – section and 915 mm in length were cast with various combinations of layers and type of meshes in ferrocement laminate with variable thickness. The ferrocement laminates were connected to reinforced concrete beams through four techniques. First technique was using hooks (H) as shear connector, second with L – shaped studs (L) as shear connector, third with U –shaped shear connectors (U) and fourth by simple roughening of interface of reinforced concrete beams and ferrocement laminates (RS). The composite beams were also analyzed using Finite Element Method to compare ultimate moment carrying capacity, load – deflection relation and stress – strain relation. From the investigation, it was concluded that

• The composite beams with square welded mesh showed better flexural behavior as compared to hexagonal mesh.

• In case of specimens belonging to RS group, proper composite action was not observed as those were with shear connectors.

• Composite beams with Hooks showed higher stiffness as compared to those with L – shaped connectors.

• The FEM analysis gave agreeable results for load – deflection relation and ultimate moment carrying capacity [13].

Hago et al. studied bending behavior of ferrocement roof panels under symmetric two-point loads condition. Total Six ferrocement slab specimens were prepared with 2100 mm x 470 mm x 20 mm dimensions in two groups; one with flat cross – section and another with edge beams of 50 mm depth along the length of the specimens forming a channel cross – section. The test results showed that a slab specimen undergone three stages up to its failure viz. a) First crack initiation, b) multiple cracking and c) Failure. Channel section slab specimens gave higher value of loads at failure than that of flat slab specimens. All the slab specimens indicated large deflections and better ductile behaviour [14].

Shannag et al. investigated effect of the use of discontinuous fibers on flexural strength of ferrocement specimen reinforced with woven mesh. The fibers used were brass coated steel fibers and glass fibers. For investigation, 72 ferrocement plates of 300 mm x 75 mm x 12.5 mm size reinforced with two and four layers of woven galvanized steel mesh were prepared and tested for centre point load. The important outcome of the investigation is summarized as below:

• Increase in the flexural strength was observed with the increase in the number of layers of wire meshes.

• For the equal number of wire meshes, those with smaller wire spacing showed better strength.

• The specimens with 2 % brass coated steel fibers showed 2.6 times increase in the flexural strength and 3.85 times more energy absorption up to failure, whereas, the specimens with glass fibers showed marginal increment in flexural strength and 2.6 times increase in the energy absorption as compared to control specimens. Thus, addition of fibers in ferrocement effectively controlled the spalling of mortar cover under bending action [15].

Shannag investigated flexural response of ferrocement plate specimens when immersed in Sodium and Magnesium Sulphate solutions for 1 year and compared with those immersed in tap water for the same duration. 54 specimens of Ferrocement plates of 300 mm x 75 mm x 12.5 mm size reinforced with two and four layers of woven galvanized steel square mesh were prepared. The mix proportion was 1:1:0.5:0.02 by weight of Ordinary Portland cement, sand, water and super plasticizer respectively. The specimens were tested for central point load bending on Universal Testing Machine. The test results indicated that

• Test specimens in Sodium Sulphate solution and reinforced with two layers of wire mesh with the smallest wire spacing showed 24 % increase in flexural strength and 178 % increase in energy absorption as compared to control specimens.

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• Test specimens in Sodium Sulphate solution and reinforced with four layers of wire mesh with the smallest wire spacing showed 28 % decrease in flexural strength and 11 % decrease in energy absorption as compared to control specimens.

• Magnesium sulphate solution showed higher damaging effect as compared to Sodium Sulphate solution causing decrease in flexural strength and energy absorption [16].

Greepala investigated effect of volume fraction of wire mesh and mortar cover of ferrocement specimens when exposed to fire. Post – fire investigation related to flexural characteristics and damage to ferrocement was carried out. Total 21 ferrocement specimens were prepared under three groups A, B and C. Group A had plain mortar, steel reinforced mortar and ferrocement specimens to investigate their performance under fire. Group B investigation was conducted to observe influence of volume fraction of wire mesh and group C was for investigation of effect of mortar cover. Seven specimens were prepared in each group, out of which three were tested without exposure to fire and remaining four were tested after exposure to gradual temperature increase to 1060o C during three hours. Sandwich ferrocement samples with 3 mm air gap for providing thermocouples were prepared and two thermocouples were provided to study the effect of fire on exposed ferrocement surfaces and one was provided to record temperature inside the furnace. After exposure to fire, the specimens were allowed to cool down to room temperature before testing. The salient observations of the tests were as follows:

• Incorporation of wire mesh improved post – fire mechanical properties of ferrocement as compared to plain cement mortar and concrete cover.

• After fire exposure, increase in volume fraction of wire mesh did not affect flexural strength and toughness of ferrocement significantly.

• A given mortar cover also had no significant impact on flexural strength and toughness of ferrocement both before and after fire exposure, but more damage was observed for specimens with thinner cover [17].

Kondraivendhan and Pradhan investigated conventional concrete circular columns of different grades for their axial compressive load carrying capacity with and without ferrocement jacketing. The circular columns were 150 mm in diameter and 600 mm in height. A total 42 plain cement concrete cylinders including 21 as controlled and 21 as jacketed with 15 mm thick ferrocement external layer were casted with different grades of concrete as M25, M30, M35, M40, M45, M50 and M55. Following are the observations of the researchers:

• Due to better confinement of jackets, there was substantial increase in ultimate load carrying capacity of P.C.C. columns when jacketed with ferrocement. It is 78 % for M25 grade concrete column and for other grades it varies between 45 to 60 %.

• There was enhancement in axial and radial strains by 4 to 50 % for jacketed column specimens because of better ductile nature of the ferrocement jacket as compared to conventional concrete [18].

Thanoon et al. investigated semi – fabricated composite ferrocement – brick floor slab system for flexural behavior under two line loads. Red bricks were laid with various combinations of their placements (continuous and discontinuous) over 60 mm thick ferrocement slabs. To have composite action between the bricks and ferrocement slab panels, truss type continuous shear connectors were provided at the time of casting at the joints between the bricks filled with cement mortar. The ferrocement slabs were reinforced with two layers of square wire meshes. After 28 days of curing, the four slab specimens were tested for two line loads in the middle third of 3 m simply supported span and structural response was observed. The results indicated that

• The specimens showed good composite action between the ferrocement layer and brick layer due to the presence of shear connectors.

• The specimens with discontinuous arrangement of bricks showed better flexural behavior than those with continuous due to the presence of intermediate cement mortar joints which acted as grid system.

• Strain distribution along the depths of the specimens showed full integrity between the layers up to yielding.

• The ductility ratio was observed to be greater than 2 for all the specimens.

With the increase in the number of truss type shear connectors, structural response became better [19].

Sakthivel et al. studied various structural applications of ferrocement and found ferrocement as a unique prospective building material for construction of new structures and repair of existing structures because of its simplicity from preparation as well application point of view. The authors also studied a new construction material called Engineered Cementitious Composite (ECC) in which fibres (Poly-Vinyl Alcohol Fibres) are used instead of wire meshes. It has high tolerance in damage, energy absorption and deformation behavior in case of shear in seismic condition. It has applications in construction and repair of roads, bridge decks, columns, retaining walls and dams. Authors emphasized on research on ferrocement with fibres to promote ferrocement as a better alternative construction material [20].

Ibrahim investigated punching load capacity of cementitious slabs, when reinforced with wire meshes of square and diamond shaped openings. Total 27 slab samples of variable thickness were tested for square patch load and rectangular patch load applied at the central portion of the slabs. Following are the important findings of the investigation:

• Ductility of plain cementitious slabs reinforced with diamond shaped was observed to be four times more than that of control specimens.

• Slab specimens reinforced with diamond shaped wire meshes showed higher ultimate load and deflection as compared to square wire meshes for similar thickness and volume fraction.

• Under line rectangular loading, slabs reinforced with diamond shaped wire meshes showed 60 % higher ultimate load and 288 % higher deflection as compared to square wire mesh reinforced slabs.

• With the increase in thickness of the slab specimens, change in failure mode was observed from punching to flexure [21].

Ibrahim investigated shear capacity of ferrocement deep beams with respect to wire mesh type, its volume fraction and load configuration. A total of 18 ferrocement plates/deep beams were reinforced with three types of wire meshes placed at the centre of 20 mm thickness of the beams. The meshes used were expanded metal, square meshes and chicken wire mesh. Under group A, the specimens were tested for bending for concentrated patch load and for group B the load applied was uniform load with 400 mm clear span. The salient observations of the research were as follows:

• Increase in the shear capacity was observed in case of specimens reinforced with chicken wire mesh as compared other two types of meshes.

• Ductility of the ferrocement deep beams was observed to be higher in case of uniform load as compared to concentrated patch loads.

• Shear capacity of group A specimens predicted by codes were well comparable with those obtained experimentally as compared to group B specimens.

• Shear behavior of ferrocement deep beams and concrete deep beams were observed to be similar [22].

Anitha et al. studied the toughness of hybrid ferrocement slabs of variable thickness reinforced with two and three layers of square welded wire mesh. The materials for casting of the slabs consisted of cement, sand (passing through 4.75 mm I.S. sieve) and coarse aggregates (4.75mm < particle size < 6.00 mm I.S. sieve) mixed in 1:1.2:0.8 proportion. 25 % cement by weight was replaced by micro silica. Total 12 square slabs were prepared of 25 mm 30 mm thickness. After 28 days of curing, the slab specimens were tested under the blows of 3.5 kg hammer dropped from 1.185 m height for 25 mm thick slabs and 1.18 m height for 30 mm thick slabs. The number of blows required for the initiation of the first crack and ultimate failure were counted and energy absorption capacity along with ductility index was computed. The results indicated that

• Around 21 % and 16 % increase in the initial energy absorption were observed respectively for 25 mm and 30 mm thick slabs with increase in the layers of wire meshes from 2 to 3.

• Increase in the number of layers improved ductility index of hybrid ferrocement slabs by 3 % and 21 % respectively for 25 mm and 30 mm thick slabs.

• Variation of thickness enhanced the ductility index by 39 % and 18 % respectively for 25 mm and 30 mm thick slabs. Thus, the slabs failed in punching shear without any indication of brittleness nearby the location of impact [23].

Sasiekalaa et al. focused on making ferrocement technology eco – friendly by using silica fumes and fly ash as partial replacement of cement. As per the study, the blend of these three materials takes care of penetration of chlorine ions, reduction in water demand of silica fumes, high early as well as long term strength development. Following are the observations based on the study:

• Tensile strength is not much affected by the matrix, but depends on the type of wire mesh, number of mesh layers and their orientation.

• For compressive strength of ferrocement elements, cement mortar with 1:2 ratio, water binder ratio of 0.35 with silica fume content 5%, fly ash content 20% and superplastisizer content ranging 0.2% to 0.6% found suitable. It also improved flow ability, early and long term strength of ferrocement along with improvement in energy absorption capacity of ferrocement [24].

Shannag et al. investigated application of thin ferrocement laminates made up of usual cement, sand and mesh in addition to cementitious materials like silica fumes and fly ash, for structural repairs and rehabilitation. The authors casted six plain cement concrete cylinders of M25 grade. Out of six, two were control specimen, two were jacketed with two welded wire meshes and remaining two were jacketed with four welded wire meshes. The ferrocement jacket was 20 mm thick of one of the best mix proportions of ingredients. The specimens were tested after 14 days of curing under pure axial compression. The researchers have observed that

• With the increase in number of layers in ferrocement jacket, there was enhancement in load carrying capacity, axial compressive strain and lateral displacement of concrete cylinders.
• The matrices with appropriate proportion of cement, sand, silica fume, fly ash and superplasticizers can provide strength as well as flowability to form high strength ferrocement jackets suitable for structural repairs and retrofitting depending upon the nature of the damage, cost of repair and practicality [25].

Azad et al. studied ferrocement elements under tensile stress and flexural condition. Similar to Brazilian Spilt Cylinder test on concrete, the ferrocement discs of 152 mm diameter and 25 mm thickness reinforced with 3 and 6 layers of welded galvanized steel wire fabric were tested. The test specimens were cured for 28 days and allowed to air dry for another 14 days before testing. The researchers developed a tensile stress – strain relation from the test results and suggested an equation to determine ultimate tensile strain of ferrocement element at failure. The applicability of the suggested equation was ascertained by analyzing ferrocement beams and slab strips with different span to depth ratio. The authors concluded that tensile strength of ferrocement governed by the combined tensile strength of matrix and reinforcing wire mesh. Thus, the tensile stress – strain model so developed was accurately and safely applicable to predict load – deflection characteristics of ferrocement beams and slabs for span to depth ratio smaller than 22 [26].

Kaish et al. studied effect of external ferrocement jacketing on load carrying capacity of existing square columns. The authors investigated scaled models of square RC columns by using four different techniques. Total 41 scaled square RC columns of 100 mm cross – section and 600 mm length were casted under four heads as conventional sharp edged columns jacketed with regular single layer of 12 mm thick ferrocement, rounded edge columns jacketed with single layer of 12 mm thick ferrocement, conventional sharp edged columns jacketed with single layer of 12 mm thick ferrocement accompanied by shear keys in the form of nails and conventional sharp edged columns jacketed with single layer of 12 mm thick ferrocement accompanied by two additional mesh layers at the corners. The specimens were tested for concentric and eccentric loading. The results indicated improvement in axial compressive load carrying capacity and ductility of the square columns. Also rounded edge columns and columns with ferrocement jacket reinforced with three layers at the corners showed better performance under concentric and eccentric loads [27].

Deepa Shri et al. focused on performance of ferrocement slabs prepared from self-compacting micro concrete using discontinuous fibers. The slab specimens were prepared with 25 mm 30 mm thickness. Those were reinforced with 2 and 3 layered bundles of wire meshes. The mix proportion was 1:1.2:0.8 for cement, sand and coarse aggregates less than 6 mm particle size with water – cement ratio 0.40 and partial replacement (25 %) of cement with silica fumes. Polypropylene fibers 0.3% by weight of cementitious materials were added. The specimens were tested for two-point symmetric load system. The salient findings of the work were as follows:
• Increase in the load carrying capacity was observed with increase in the content of fibers.
• Increase in the thickness enhanced the load at failure.
• Stiffness of the slab specimens with a bundle of 2 layers of wire mesh found to be less as compared to those with 3 layers.
• Narrowing of crack widths was observed in the specimens additionally reinforced with discontinuous fibers [28].

Mahyuddin et al. studied load – deflection characteristics, first crack load, crack width and crack spacing of polymer – modified ferrocement panels exposed to air and salt water environment and compared with unmodified ferrocement panels. In this investigation, three commercial polymers namely, Styrene – Butadiene Rubber (SBR), Polyacrylic Ester (PAE) and Vinyl Acetate Ethylene (VAE) were used. The specimens were prepared of 500 mm x 100 mm x 25 mm in size reinforced with three layers of square welded wire meshes. The exposure conditions for the specimens were the combinations of wet curing, air drying and contact with 4 % Sodium Chloride solution for 28 days and 9 months. The specimens were tested for flexure under four-point loading. The salient findings in the research were as listed below:
• Increase in the flexural strength was observed to be 13 % more in case of saltwater exposed specimens as compared to air exposed specimens at the age of 9 months.
• Marginal enhancement in compressive strength and Young's Modulus was observed for saltwater exposed specimens.
• Specimens with 15 % polymer showed 25 % higher flexural strength for air exposure and 32 % increase in flexural strength for saltwater exposure.
• Polymer modified ferrocement specimens showed 16 % higher load at first crack for 28 days saltwater exposure.
• Narrower cracks and higher first crack loads were observed for polymer modified specimens [29].

Navid et al. investigated contribution of specific surface of mesh reinforcement to tensile strength of ferrocement composite. The authors studied behavior of ferrocement under direct axial tension. Three stages were observed regarding behavior of ferrocement under increasing tensile stress; a) elastic stage, b) crack formation stage and c) crack widening stage. From the experimentation carried out, it was concluded that with the increase in specific surface of wire mesh in the mortar, increase in the tensile strength of ferrocement was observed. Also cracks in ferrocement were much finer than those in conventional reinforced cement concrete [30].

Gangadharappa et al. emphasized on making ferrocement as eco – friendly material by replacing sand with blast furnace slag in certain percent. The sand component of cement mortar was replaced by blast furnace slag by 0 %, 20 %, 35 % and 70 %. The experimentation was done on dumb bell shaped ferrocement specimens reinforced with 0, 2, 4 and 6 layers of wire meshes for axial tension carrying capacity. Total 16 test specimens and 48 control cubes were casted and respectively tested for axial tensile and compressive loading. From the study, the researchers concluded that ultimate strength had got increased at 20 % replacement of sand by blast furnace slag and further decreased with 35 and 70 % blast furnace slag. Also, increase in number of mesh layers increased tensile strength of the ferrocement specimens [31].

Parande et al. studied the effect of number of wire mesh layers and effect of steel fibers on the tensile strength of ferrocement composite for a constant thickness of an element. Dumb – bell shaped test specimens with 40 mm thickness and 700 mm length; reinforced with wire mesh layers varying from 1 to 6 with and without steel fibers were prepared. The specimens were tested on Universal Testing Machine of 200 kN capacity for axial tensile load carrying capacity. The researchers observed increase in the axial load carrying capacity and elongation with the increase in the volume fraction i.e., number of layers of wire mesh in the specimens. With the addition of steel fibers, 10 to 17 % increase in the tensile strength was observed [32].

Kamanuru et al. researched behavior of ferrocement slab panels using self compacting mortar made up of various water cement ratios, fly ash and polypropylene fibres. Ferrocement slab panels of 600 mm x 200 mm x 25 mm were casted. The specimens were tested for the deflection and ductility. The specimen made with water cement ratio of 0.45 showed better response to deflection and exhibited better ductility as compared to the specimens casted using water cement ratio as 0.40 and 0.50. The ultimate bending moment and deflection for the specimen with water cement ratio 0.45 was 170 Nmm and 11.65 mm respectively [33].

C. Silos

Singh et al. compared experimental values of lateral pressures on bin wall and hopper due to stored material with the prevailing theories of lateral pressure calculation for filling (static) and emptying condition of the bins. The factors under consideration were method of filling the bins and method of spreading the material to be stored. The theoretical values of lateral pressures on the bin wall and hopper were calculated using Janssen's and Lvin's theory for filling and emptying condition of the bin and compared with the experimental results. The bin which was tested had diameter as 7 m and height 46 m. The stored material was barley. The results reported following salient findings:

- Deviation in pressures on bin wall and hopper observed experimentally and calculated theoretically was due to variation in method of filling and spreading the grains.
- Emptying Pressures were found to be comparable with those calculated by Lvin's theory.
- Use of grain spreader increased pressure on hopper and reduced lateral pressure on bin wall.
- Eccentric filling of bin increased lateral pressure on one side of the bin wall than opposite side of the bin wall [34].

Yong Hong Wu established boundary element technique and finite element method and their computer programs for the prediction of pressure distribution on silo wall under static (filling) and dynamic (initial discharging) condition of the flow of bulk materials. The author developed three models of silos made of Perspex material with height to diameter ratio as 5.00 first model with flat bottom, second model with hopper of 300 angle and third model with hopper of 750 angle with horizontal to investigate flow phenomenon and pressure distribution on silo walls. Following are the important findings of the author:

- Pressure distribution on the vertical wall and hopper wall under silo filling condition observed experimentally were very close to prediction by Jenike's theory.
- For dynamic condition, numerical prediction of pressure distribution on vertical silo wall was in between the prediction by Janssens' theory and recommendations by Institute of Engineers, Australia.
- Increase in the discharge pressure was observed just above the outlet followed by decrease in the pressure at outlet and increase in the transition zone.
- Pressure and the internal stresses developed in silo walls were governed by wall friction, wall flexibility and material stored in the silo [35].

Schwab et al related to wheat loads and its pressure distribution in a full – scale storage bin. A cylindrical steel bin of 4.1 m diameter and 12.3 m height was fabricated with smooth galvanized steel. Four compressive load cells were installed at the bottom of the silo wall for measuring vertical pressure at the bottom of the silo due to wheat as a stored material.

The complete height of the silo was divided into seven levels at which two vertical and two horizontal metallic strain gauges at 154o angle, were provided to measure vertical and horizontal strains in bin wall. The physical properties of the wheat which was used as stored material were determined. The authors reported following findings from the test:

- Theories recommended by Janssen and Walker showed comparable values of lateral pressure in the bin wall with the experimental values, with slight overestimation by Reimbert's theory.
- Vertical pressure distribution was the function of radial location and not uniform at a section.
- Total vertical load measured at the floor level due to stored material and predicted by the models were coinciding.
- Total vertical load transferred to the bin wall increased with the increase in height to diameter ratio [36].

Thilakrathna et al investigated performance of small scale airtight ferrocement bins with respect to quality and mass loss of rice paddy stored for six months. The authors constructed conical shaped ferrocement bins of 2.5 t capacity and 25 mm wall thickness. The diameter of the bin at the bottom of the cone was 2.30 m with total height of 3.00 m from the ground. The bin was simply placed on ferrocement hopper which was thereafter supported on 0.75 m high three pillars. The bin was covered by a metal cone over which 25 – 50 mm thick layer of rice – straw was provided for thermal insulation. The bin was coated with cement slurry to reduce its permeability. Using appropriate equipments and accessories temperature variation, gas concentration and mass loss were evaluated. The results indicated that

- Rice straw layer proved sufficient enough for heat insulation.
- Quality of rice paddy was unaffected, but air tight storage completely inhibited germination.
- Mass loss during the storage was observed negligible as compared to prevailing method of storage [37].

Jianbao et al analyzed large diameter silo for static wall pressure and pressure at the end of filling, using 3-dimensional finite element models. The authors also studied influence of scaling of dimensions of silo, change in wall material properties and stored material properties on wall pressures. Wall pressure was computed using Rankine's method and finite element analysis was done to compare the results of scaling of silo and changing various parameters related to material properties. The results indicated that

- Wall pressure on large diameter silos could not be predicted by simply scaling the pressures computed for small diameter silos for the same wall height.
- Young's modulus of wall material and properties of stored material influenced the magnitude of static wall pressure.
- Wall pressures at the end of filling of large diameter silos were higher than the static wall pressure at the bottom of silo [38].

Zhu et al studied effect of eccentric discharge of stored material on the wall pressures of a squat R.C.C. silo and compared with finite element analysis results. The authors considered three cases related to supine surface and variation in height of stored material stored in a reinforced concrete squat flat bottomed silo with an eccentric outlet. Expressions were derived for the respective cases on the basis of Janssen's theory. For finite element analysis, eight – noded shell and solid elements were modeled respectively for wall and stored material. Circumferentially normal and vertical pressure curves were obtained theoretically and using FEA. The comparison showed close fitting of circumferentially normal pressures and deviation in vertical pressures which were obtained theoretically and using FEA [39].

Rahim analyzed seven models of cylindrical silos supported on columns, with different height to diameter ratio used for wheat storage for seismic loads. The silos were analyzed for pressures when fully filled; with and without earthquake loads and compared with the theoretical values. The analysis results indicated that

- Ensiled material increased pressures by 3 – 5 times for tall silos.
- Pressures developed in silo full condition due to ground motion were higher than those computed for discharging condition.
- In case of large diameter silos, significant increase in normal, shear forces and bending moments at the supports was observed [40].

Patel et al. analyzed ferrocement silos for various height to diameter ratios and capacities using ANSYS. The finite element models using tetrahedral elements were developed for three storage capacities 400 m3, 500 m3 and 600 m3 each with height to diameter ratios of 3, 4 and 5. The pressure calculations were done using Janssen's theory static equilibrium approach. The hoop stress in the silo wall was designated by normal stress in the radial direction and vertical compressive stress was considered as longitudinal stress. The analysis output showed that hoop stresses went on increasing with the increase in the depth of a silo wall for a storage capacity and decreasing with the increase in the height to diameter ratio even for the same storage capacity. In case of longitudinal stresses, the values went on increasing along the depth of the silos with the increase in the storage capacity and height to diameter ratio as well [41].

I.S. 4995 (Part I) – 1974 deals with general requirements and assessment of bin loads for reinforced concrete silos. It is limited to silos of circular and polygonal shapes. Different methods of assessment are provided for granular and powdery materials. The code is based on Janssen's theory to determine pressures on the silo walls due to stored material.

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The code specifies Horizontal pressure (Ph), Vertical Pressure (Pv) on the plan area of bin filling and Vertical pressure on the silo walls due to friction between the stored material and wall (Pw). The code considers values of pressure ratio, wall friction and bulk density of the stored material to be constant along the silo wall depth. The code does not cover mass or funnel flow characteristics of the stored material in emptying condition.

These pressures on silo wall along the depth of silo is computed in terms of corresponding maximum pressures Phmax, Pvmax and Pwmax. The code does not account for the effect of moisture and increase in pressure due to consolidation [42].

I.S. 4995 (Part II) – 1974 deals with design criteria for reinforced concrete silos, permissible stresses in concrete and reinforcement. The code also recommends permissible crack width of 0.1 mm for water tight structure, otherwise 0.2 mm. The expression used for the calculation of crack width for a reinforced concrete silo is as mentioned below [43]:

$$w_{cr} = 10\text{-}6\ [4+\rho\ (\varphi'/p_0)]\sigma_{sa}\{1–[6/(\ p_0\ \sigma_{sa})^2]\}$$

EN1991 – Part 4 deals with the actions on silo taking into account the silo structure, properties of stored material and discharge flow patterns. The code classifies silos into three assessment classes according to their capacities to consider an effect silo size on pressures. It also includes effect of eccentricity during filling and discharging of silos in the form of patch loads.

Depending upon the height to diameter ratio of silos and action assessment class, pressure and force calculations on silo walls change. The code suggests a rule to calculate upper and lower characteristic values of each parameter related to stored material properties. Accidental pressures due to asymmetric filling, variation in the properties of stored material and geometric imperfections related to silo are dealt in terms of patch loads. The code recommends for ignoring patch loads due to filling in case of silo with less than 100 t capacity [44].

III. SUMMARY

The literature study is summarized as follows:

1) In the first part, various grain storage methods have been studied and observed that the traditional methods of grain storage systems have limitations regarding environmental hazards and service life of the storage structures which cause food grain losses during storage. Although modern techniques like ware houses, fumicover have positively contributed to prevent losses at post – harvest level, still there is a gap in the storage capacity available and required for food grains storage. This ultimately creates a gap in the income and expenditure of farmers. Thus, alternative approach needs to be explored to prevent on – farm post – harvest storage losses of food grains.
2) Mechanical properties of ferrocement have been investigated by many researchers. Silica fumes and fly ash when added to cement mortar have improved energy absorption capacity of ferrocement. In ferrocement, cement mortar in combination with silica fumes and fly ash with wire meshes has shown improved flow ability and strength which make it suitable for rehabilitation and retrofitting of structures.
3) Increase in tensile strength has been observed with the increase in specific area of wire mesh reinforcement in ferrocement.
4) Ferrocement when investigated for external jacketing of plain and reinforced concrete columns, remarkable improvement in the compressive load carrying capacity of the columns has been observed. This is due to better confinement and ductile nature of ferrocement jackets.
5) Increase in number of layers of wire meshes has shown increase in tensile strength under direct tension as well as better flexural behavior of ferrocement.
6) Ferrocement when investigated for its application for flexural structural members, it has improved flexural strength of beams and slabs, showed smaller crack width and crack spacing on the surface.
7) Enhancement in deflection characteristics of ferrocement has been observed when modified with polymeric fibers.
8) Improvement in the shear capacity and ductility index has been observed with the increase in number of layers of wire meshes. Chicken wire mesh has imparted better impact strength as compared to expanded metal and square welded wire mesh.
9) Ferrocement showed better post – fire mechanical behaviors as compared to plain cement mortar which is generally provided as plaster.
10) Silos are subject to various pressures due to stored material. Pressures calculated by Janssen’s theory and observed experimentally when compared, showed agreeable values under static filled condition, whereas, Reimbert’s theory slightly overestimate the pressure values.

11) Air tight conical shaped ferrocement silos of 2.5 t capacity has been investigated for quality and mass loss of rice paddy and observed that after six months of storage, quality of the paddy remained unaffected with only 2 % mass loss which is comparative less than the conventional method of storage.
12) Effect of variation in material properties of silo wall and scaling of large diameter silos has been observed to be influential for the same wall height of silos.
13) I.S. code follows Janssen's theory for pressure calculation which assumes pressure ratio to be constant along the depth of the silo and does not consider geometric imperfections the silo structure. European code considers flow pattern of stored material, capacity of a silo and its geometric imperfections while computing the pressures on silo wall due to stored material.

Irrational way of storing food grains at farm level is observed as one of the reasons for losses which can be prevented by using on – farm storage structures. Ferrocement is known for its better crack resistance, mould ability, light weight and ease in construction. Hence, the feasibility of ferrocement as a construction material for grain storage silos is required to be investigated.

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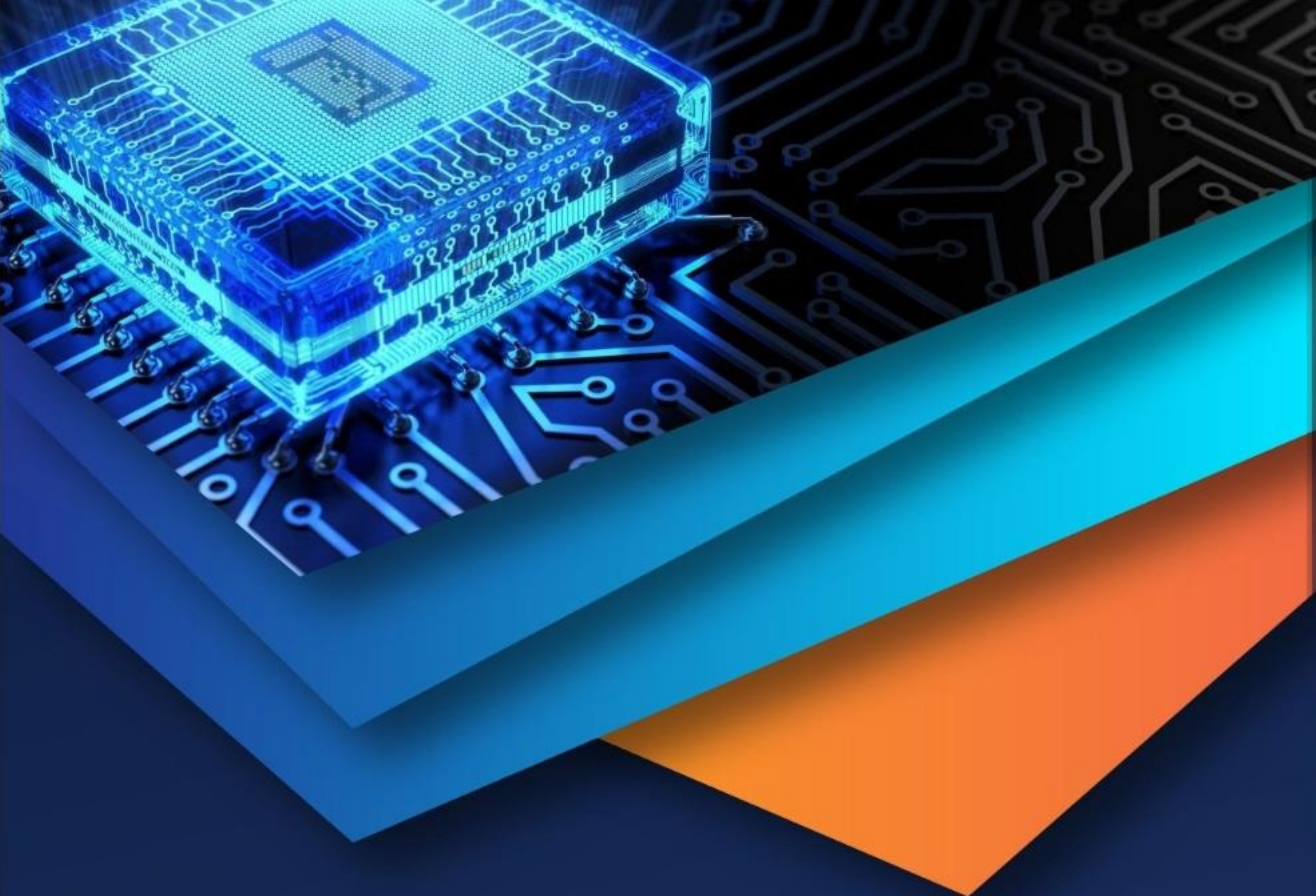

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