Analysis of Pathological Manifestations in Grain Storage Steel Silo Foundations

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Resumo

A Grain storage silos, as well as other buildings, are susceptible to structural pathologies that can compromise their performance and reduce life cycle. The study of pathological manifestations in these constructions can contribute to prevent structural problems and accidents. This work shows the main pathological manifestations that appear in foundations of steel silos for grain storage. It analyzes characteristics such as design, flowchart, operation, and maintenance of silo foundations. The survey and analysis of pathological manifestations were conducted with the objective of identifying the most frequent causes of these problems. There was a high occurrence of settlements, which appeared in 62% of all constructions inspected. There were a significant number of cases of corrosion on reinforcement or on the union with the metal-based structure, found in 77% and 69% of units, respectively. There were concrete fissures and cracks in 38%, and other pathologies with lower incidence. A few recommendations are presented at the end of this work.

Palavras-chave: Grain storage. Pathological manifestations. Silo foundations. Steel silos.

1 Introduction

In most countries, grains are among the most important staple foods, and therefore they have a great economic importance. However, they are produced on a seasonal basis, and in many places there is only one harvest a year, which may be subject to failure. This means that for feeding the world's population, most of the global production of maize, wheat, rice, and soybean must be held in storage for periods varying from one month to more than a year. Grain storage therefore occupies a vital place in the economies of both developed and developing countries.

Brazil, a country with continental dimensions, has a large agricultural potential with more than 376 million hectares and a favorable weather for grain production, Weber (1995). With the mechanization of farming, Brazil became one of the biggest producers of grains. In this scenario, the region on the western border of Rio Grande do Sul state has an important role because it is one of the biggest producers of rice in Brazil.

Rice production requires, by its market characteristics, a large volume of storage structures such as silos and warehouses, but Brazilian storage capacity is still lower than its production. Brazil's national supply company, CONAB (2010), recommends that storage capacity be at least two years of production.

Containers used for storing bulk solids are usually called bins, bunkers, silos or tanks. Although there is no agreement for these terms, shallow structures containing coal, coke, ore, crushed stone, gravel and similar materials are often called bins or bunkers, and tall structures containing materials such as grain are usually called silos, Li (1994) *apud* Dogangun *et al*. (2009).

Silos are considered, among storage structures, the most viable solution due to a low physical space necessary to its construction, manpower, and transportation costs, as well as the possibility of pre-

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serving a product (grains) by maintaining its quality. On the western border of Rio Grande do Sul state, silos are the main storage structures used.

According to Calil and Cheung (2007), a technically designed and well-conducted storage unit has advantages such as:

- Product is kept away from attacks of insects and rats;
- Rational, secure, and mostly economical storage, considering that a producer that stores in bulk also sells in bulk, saving moneyand handwork for packing;
- Transportation economy, since freight rates increase during the harvest period;
- Formation of a stock to regulates market prices;
- Small areas needed to store large amounts of grains.

According to Cogo (2011), Brazilian government wants to increase, from 15% to 30%, the total capacity of private storage in five years. Currently, Brazilian storage capacity is 123 million tons, while the current grain harvest is 147 million tons.

In Rio Grande do Sul state (RS), according to its official institute for rice business, IRGA (2010), rice production reached 8,047,897 million tons in 2008/2009 harvest, an increase of 24% relative to 2006/2007 harvest, Figure 1.

Grain storage silos, as well as other buildings, are susceptible to structural pathologies that can compromise their performance and reduce life cycle. These structures are subjected to many different unconventional loading conditions, which result in unusual failure modes. Failure of a silo can be devastating as it can result in loss of container, contamination and loss of material, material replacement cost, cleanup costs, environmental damage, and possible injury. The study of pathological manifestation in these constructions can contribute to prevent structural problems and accidents, Picchi (1993).

According to Nascimento *et al.* (2013), with the increasing global industrialization, the use of silos has become important, because it represents the possibility of storage of products originating in the industries of spinning, mining, construction, food, pharmaceutical, among other. In this aspect, functionality problems, such as obstructions in the flow, tube effect and incomplete unloading became more frequent, while structural problems became responsible for many accidents resulting in loss of life and enormous economic damage.

Most silos are steel or reinforced concrete cylindrical structures built on mat foundations. Sometimes they could be elevated and supported by frames or reinforced concrete columns. The design of silos is primarily governed by the type and properties of the stored material. As the density, flow and friction properties of grains, cement, coal, carbon black, and other bulk materials vary widely, the loads applied on a silo structure and the associated load carrying system are different from the traditional building type structures, Dogangun *et al.* (2009).

Foundations of storage structures, called silo bases, are also structures where pathological manifestations appear in large scale and, depending on economic losses that may result from agricultural industry, must be studied more carefully.

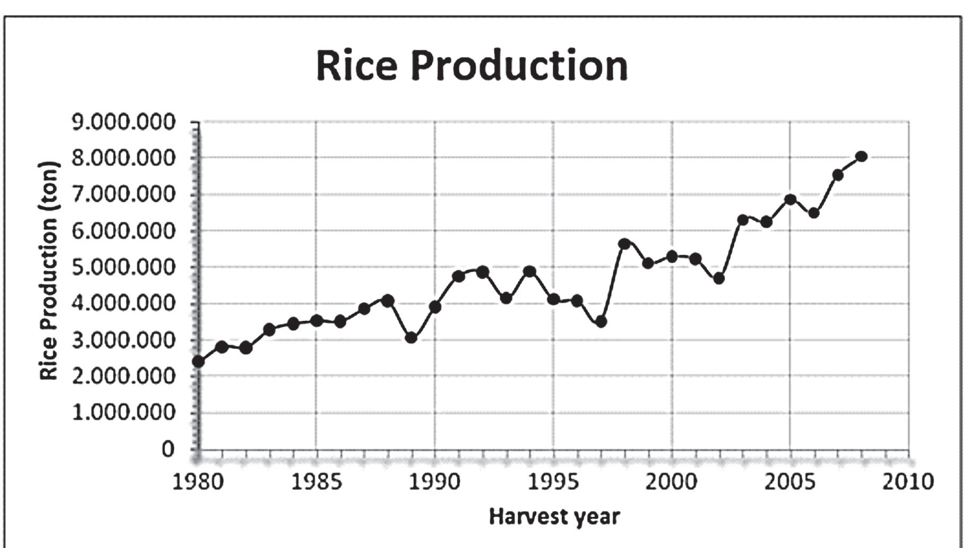


Figure 1 *– Increase on rice production in RS, IRGA (2010).*

According to Dogangun *et al.* (2009), silos are relatively slender structures with a small floor area or diameter compared with their height. As a result, considerably large axial stresses are produced at the base of the structure due to the weight of the bulk material and structure. The supporting soil is typically subjected to uniform compressive pressure due to applied gravity loads. The foundation of silos should be designed more carefully than that for standard building structures. For example, nonuniform placement of bulk material during filling can result in nonuniform pressure distribution at the base and cause problems. When the vertical load from the weight of the stored material is off center, the pressure bulb under the silo will be distorted. Lateral loads due to earthquakes or strong winds can also produce similar effects. The local overstressing of the soil beneath the foundation may cause tilting, differencialsettlement, and collapse.On western border of Rio Grande do Sul state there are two common types of silo bases. A circular-beam supported by piles or columns and a slab on the ground. Both systems need a slab on the ground to receive most of the grain load. The difference is that in a circular-beam system, steel walls are supported by a beam and not directly over a slab. Figure 2(a) shows a circular-beam base during its construction and Figure 2(b) shows a circular slab on the ground before placing concrete.

This work shows the main pathological manifestations that appear in those concrete bases for grain storage. It analyzes characteristics of design, workflow, operation, and maintenance of silo bases. The survey and analysis of pathological manifestations were conducted with the objective of identifying the most frequent causes of these problems.

(a) (b)

Figure 2 *– (a) A circular-beam base during its construction; (b) Circular slab on the ground during construction.*

Table 1 – List of industries inspected and types of silo bases found.

Industry	City	Number of silos analyzed	Base type
1	Alegrete	12	Circular-beam over piles
2	Alegrete	25	Circular-beam over piles
3	Alegrete	23	Circular-beam over piles
4	Alegrete	12	Circular-beam over piles
5	Dom Pedrito	20	Circular-beam over piles
6	Itaqui	6	Circular-beam over piles
7	Maçambara	8	Circular-beam over piles
8	Rosário do Sul	10	Circular-beam over piles
9	São Borja	56	Circular-beam over piles
10	São Gabriel	24	Circular-beam over piles
11	Uruguaiana	33	Slab on the ground
12	Uruguaiana	10	Slab on the ground
13	Uruguaiana	1	Slab on the ground

2 Methodology

This research was conducted in cities of the western border of Rio Grande do Sul state, due to the great number of grain storage units in this region. The aiming of this work was to analyze the main pathological manifestations occurring on silo bases, as well as describe possible related causes.

This study evaluated 13 industries, in eight different cities, totalizing 240 bases evaluated. All cities are small (country side), with less than 140,000 inhabitants, and far from the ocean, where environmental aggression is reduced. Table 1 shows all units inspected, city, and kind of concrete base.

To limit the search scope, this analysis was restricted to silo foundations, and only concrete elements were verified. Inspections were restricted to the outside of these bases and followed a methodology proposed by Souza and Ripper (1998), divided into three basic steps: collecting data, analysis, and diagnosis. With this data, it was possible to diagnose and map all main problems, also looking for a history of maintenance and usage of all inspected elements, aiming to understand these pathologies observed.

3 Results

Table 2 shows all pathological manifestations found in grain storage silo bases, as well as the number of industries with that problem.

Figure 3 shows, by using data from Table 2, the percentage of each pathological manifestation found, relative to the number of bases inspected.

It can be observed that there is a high occurrence of settlements, about 61.5% of all inspected storage units, that may be caused by errors in both design or construction phases. It is important to emphasize that

Table2 – Summary of pathological manifestations found in Grain Storage silo bases.

Pathological Manifestations	Probable cause	Number of occurrences
Cracking Caused by Corrosion of Reinforcement	Design and material failure	10
Corrosion at the Concrete Joint and Steel Wall	Maintenance	09
Cracking Caused by Wind Stress	Design and material failure	05
Excessive Deformation	Design and construction	06
Biological Agents	Maintenance	10
Cracking on Concrete Walls	Design and material failure	02
Settlement	Design and construction	08
Cracking Caused by Thermal Movement	Design	07

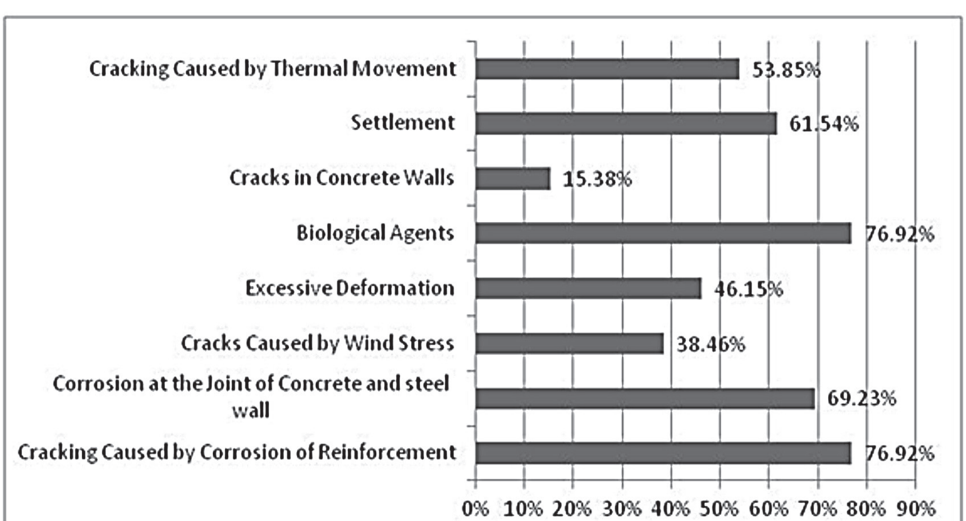


Figure 3 – *Ratio between pathologies found and the total amount of concrete bases inspected.*

during design phase soil tests must be performed, since most of these pathological occurrences happen due to problems with soil-structure interaction.

In these structures, loads are distributed almost uniformly over the bottom slab, causing the bulb stress to reach greater depths, along with the silo diameter. Thus, preparing the soil to receive these loads is important to reach a perfect soil-structure interaction.

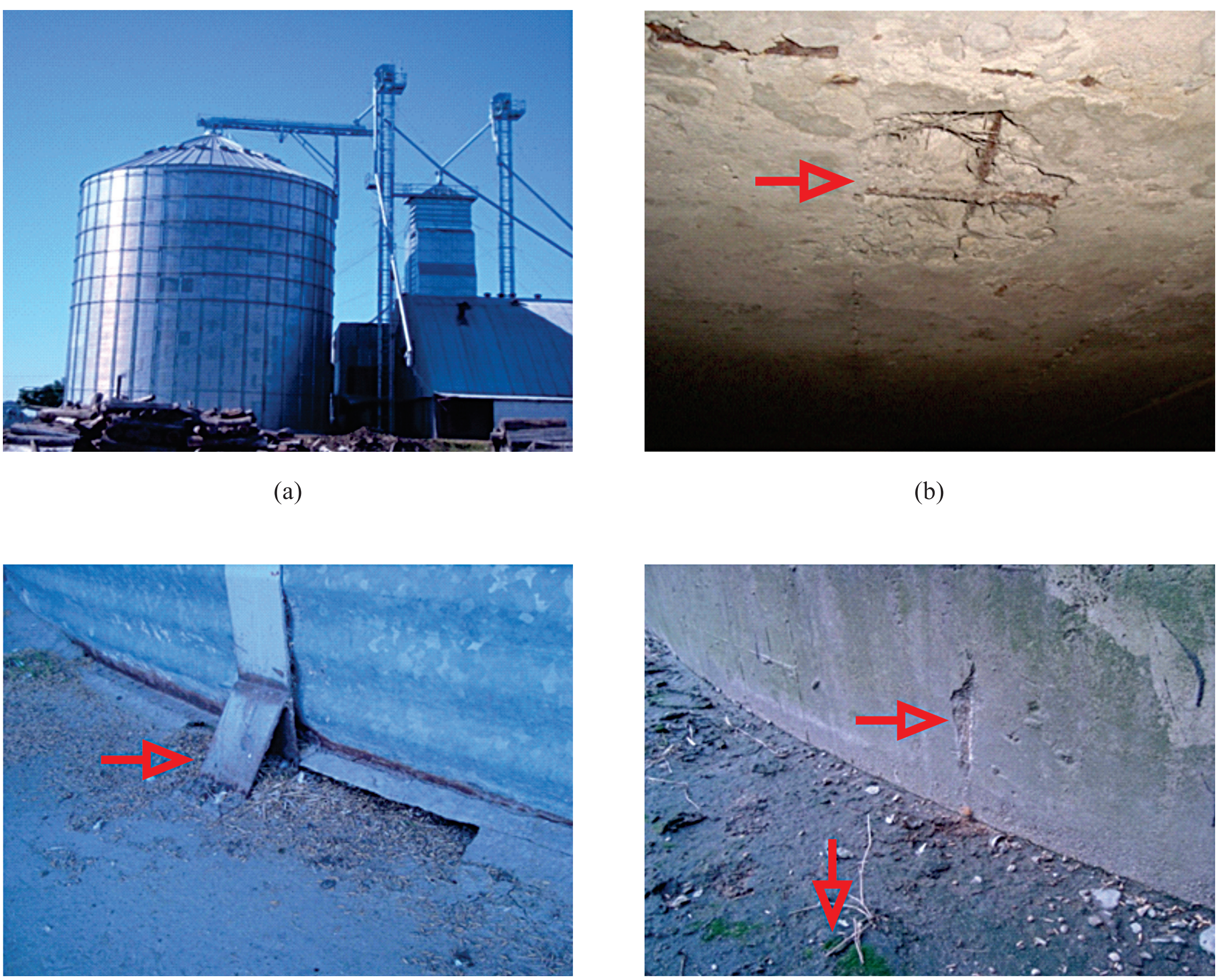
It can be observed, in Figure 4(a), that this silo suffered a great inclination caused by settlement of the base, behaving as a rigid body. According to Velloso and Lopes (2004), differential settlements are caused by a presence of regions of low-resistance ground. In this case, it is possible that during the construction of this base, the superficial organic layer of the soil was not completely removed, thus causing the settlement.

In circular-beam systems, we observed settlement of the bottom slab without apparent damage to steel walls. However, the aeration system was completely compromised, reducing the capacity of keeping the quality of grain storage. These cases were still treated as a settlement of the base.

In 77% of these industries, we found cracks caused by corrosion of reinforcement. That was due to small concrete cover, high porosity, and presence of moisture. Figure 4(b) shows a corrosion crack observed.

This cracking is caused by steel oxidation, which produces hydrated iron oxide ($Fe_2O_3nH_2O$) that occupies a volume greater than the original steel, which breaks the concrete cover and leaves the reinforcement exposed.

Corrosion was also observed in the union of concrete and steel walls in 69.2% of all bases inspected, caused by design problems and ineffective maintenance. Such conditions are common in regions with humid weather and lack of sun incidence. According to Ripper



(a) (b)

(c) (d)

Figure 4 *– (a) Settlement of the base; (b) Cracking caused by corrosion of reinforcement; (c) Corrosion at a joint between a concrete base and a metal wall; and (d) Biological agents on the base of the silo and sidewalk.*

and Souza (1998), corrosion on bolts and other metal parts embedded in concrete accelerate this process when they are not properly protected with oil or anti-corrosive products. Figure4(c) shows a point of corrosion at a joint between a steel wall and a concrete base.

It is well known that if preventive measures are not taken, corrosion causes deterioration of the metal components of structures. Steel silos are especially susceptible to corrosion and subsequent deterioration and failure. Such failures indicate the importance of frequent regular inspections for the structural integrity of metal silos.

Biological agents were found in 76.9% of all units inspected. It is possible that this has been caused by accumulating a lot of dust, seed remains, and moisture, thus being an ideal place for growing fungi, bacteria, and vegetation, in addition to the presence of rodents and other pests.

Pathological manifestations caused by biological agents require attention, as well as deterioration of structures may affect the quality and integrity of grains, which need to be kept away from moisture and microorganisms that can cause partial or total deterioration.

This type of pathology is usual in all buildings that are unprotected and exposed to weather conditions. The appearance of those pathologies may lead to chemical degradation. According to Medeiros (2005), such condition problems are easy to avoid but difficult and expensive to fix.

Figure4(d) shows a silo base without a sidewalk to protect its structure, and its beam in direct contact with the ground. This forms a layer of lichens and fungi at the surface of concrete, damaging its appearance and creating organic and inorganic acids that can attack it, in addition to accumulating moisture that can promote corrosion of reinforcement, Palermo *et al.* (1997), cited by Hausenstein (2009).

Cracking caused by thermal movement were observed in 53.8% of all industries (Figures 5 (a) and (b)). It was found in slabs on the ground bases, widely used in this region of the state. These bases are characterized by a flat slab with a thickness ranging from 15 to 30 cm. Souza and Ripper (1998) attribute this type of cracking to the existing temperature gradient between different regions of the structure, resulting in the appearance of natural concrete joints. In the case of foundation slabs, the temperature gradient is between the upper face, exposed to direct sunlight, and the lower face in contact with the ground.

In this case, the pathological manifestation can be attributed to the large area exposed to direct sunlight, because the circular concrete slab extends beyond the contour of silo's metal wall. It can be noticed that these cracks are approximately spaced evenly and usually appear on the west side, where the sun is more intense in the summer, as it is the case of the region studied.

Excessive deformation appears in 46.2% of all units inspected. It was observed, as shown in Figure 5(c), in some concrete bases built with circular-beam over piles, deformations above the limits established by Brazilian Code NBR 6118 (2003) at the span of the discharge tunnel.

There are some possibilities for this problem: wrong considerations during design, mistakes in loading, which is not acceptable since these loads are provided by the silo manufacturer, or construction mistakes using wrong thickness or wrong reinforcement.

Cracks and fissures on silo walls are important indicators of structural problems and may compromise safety. It is worth noting that cracks can serve as a gateway for moisture, exposing grains to degradation.

As seen on Figure 5(d), the silo's reinforced concrete wall presents cracks at 45o, characterizing a structural failure.

Cracks caused by wind stress were observed in 38.5% of all industries analyzed. In some bases, wind action resulted in cracking. In others, anchor stretches were observed. Figures 5 (e) and (f) give an example of wind action. In all wind problem cases, cracks are located near to anchors, since these are responsible for transmitting tension from steel walls to the concrete structure.

The authors had access to steel structure designs of some Brazilian manufacturers, and it was observed disrespect to national standardization. Lower wind speed and wind pressure than specified in NBR 6123 (1988) were adopted. Brazilian manufacturers adopted for this design a wind speed of 120 km/h, below the specified speed for this region of the country, which is 162 km/h.

According to Blessmann (2001), some wind-caused accidents were generally due to deficiencies in anchorage. In some cases, however, the problem is an inadequate size or design of foundations, which do not have the weight or depth needed.

4 Conclusions

This paper presented the main pathological manifestations that appear in foundations of steel silos for grain storage.The survey and analysis of pathological manifestations were conducted with the objective of identifying the most frequent causes of these problems.

In all storage units inspected, some bases had high levels of degradation, requiring maintenance to ensure its performance and life cycle.

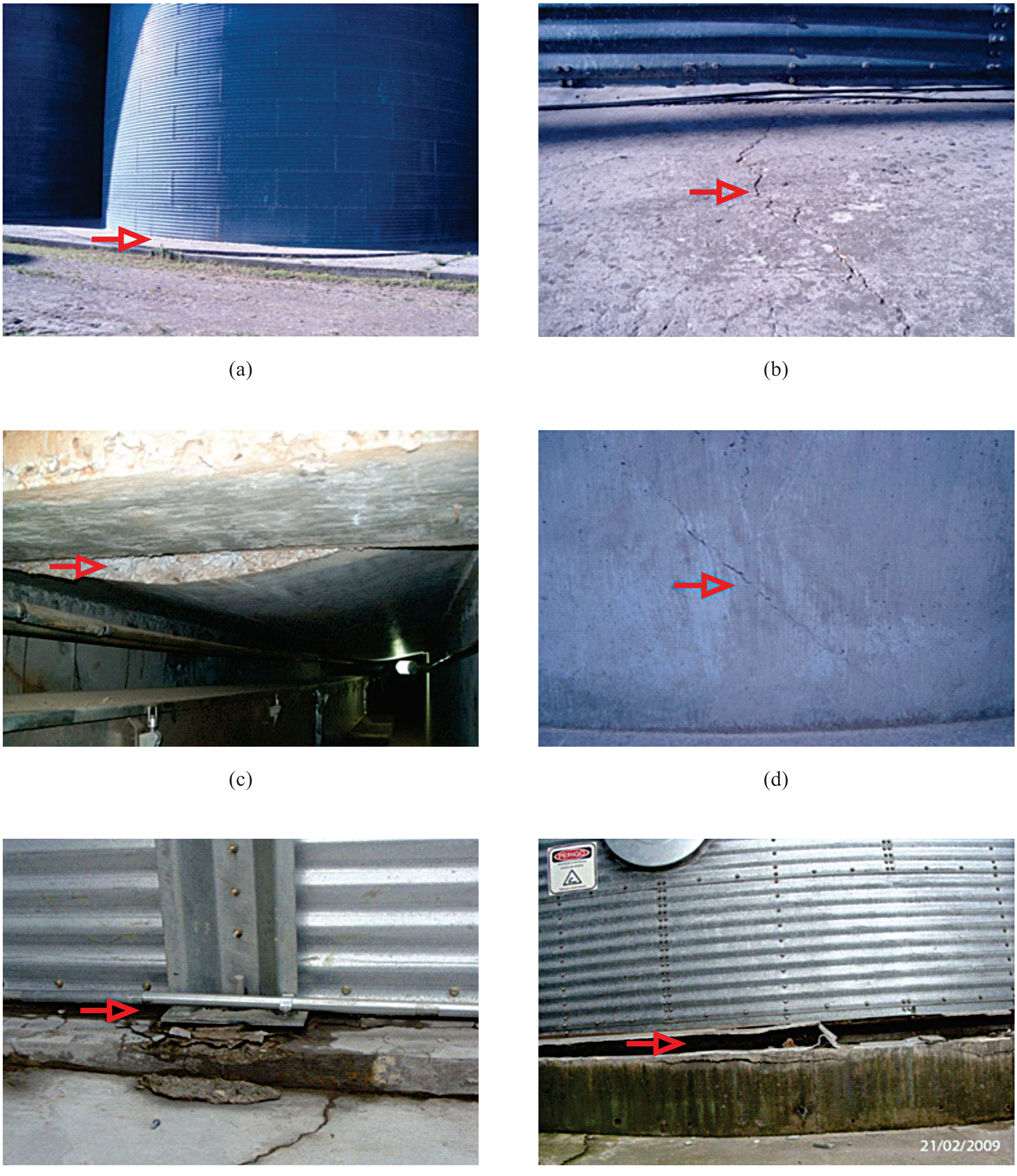


Figure 5 *– (a) Cracks caused by thermal movement- slab on the ground under sun incidence; (b) Crack observed caused by thermal movement; (c) Excessive deformation at the span of a discharge tunnel; (d) Reinforced concrete wall with a crack at 45º; (e) Cracks caused by wind stress in anchor stretch; and (f) Cracks caused by wind stress.*

The majority of pathological manifestations observed were cracking caused by corrosion of reinforcement, biological degradation, corrosion at concrete joint and steel walls, settlements, cracking caused by thermal movement, excessive deformation, cracking caused by wind stress, and cracking on concrete walls.

This research noticed that even with advances in the technology used for grain storage, much more advancements in qualification of the workforce employed when implementing and maintaining these systems are still needed. In addition, the design quality of these structures did not follow this progress.

Moreover, as intended for food storage, these industries require a plan for ongoing maintenance to avoid compromising their life cycle structure, while not affecting the quality of stored grains.

Cracks and deformations in such structures can serve as a gateway to pests or contaminants, so there is a need to reduce the number of pathologies in these bases.

5 References

ABNT. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6118. Projeto de Estruturas de Concreto – Procedimentos. Rio de Janeiro, 2003.

ABNT. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6123. Forças Devido ao Vento em Edificações. Rio de Janeiro, 1990.

BLESSMANN, J. Acidentes Causados pelo Vento. Porto Alegre: Editora Universidade/UFRGS, 2001.

CALIL, C. J.; CHEUNG, A. B. Silos: Pressões, Fluxo, Recomendações para o Projeto e Exemplos de Cálculo. USP/EESC/SET: São Carlos, 2007.

COGO, C. Capacidade Estática de Armazenamento do País. Consultoria Agra econômica. Acessado em: 13 mai. 2011. Online. Disponível em: <http://www.carloscogo.com.br>.

CONAB. Companhia Nacional de Abastecimento. Acessado em: 02 out. 2010. Disponível em: <www.conab.gov.br>.

DOGANGUN, A.; KARACA, Z.; DURMUS, A.; SEZEM, H. Cause of Damage and Failures in Silo Structures Journal of Performance of Constructed Facilities, v. 23, n. 2, april, 2009.

HAUENSTEIN, C. A. Análises Microbiológicas de Amostras de Concreto Deteriorado da Estação de Tratamento de Esgoto 3. Beira-Rio. 2009. Trabalho de Conclusão do Curso. Curso de Graduação em Engenharia Ambiental. UDC.

IRGA. Instituto Rio Grandense do Arroz. Arquivos publicados. Acessado em: 05 out. 2010. Disponível em: <www.irga.rs.gov.br/arquivos>.

MEDEIROS, B. L. Estruturas Subterrâneas de Concreto: Levantamento de manifestações patológicas na região Metropolitana de Curitiba e Análise de sistema de Reparo. 2005. Dissertação/Mestrado. Curso de Mestrado em Engenharia Civil, Universidade Federal do Paraná.

MILMAN, J. M. Equipamentos para pré-processamento de grãos. Ed. UFPel: Pelotas, 2002.

NASCIMENTO, J. W. B.; LOPES NETO, J. P.; MONTROSS, M. D. Horizontal Pressures in Cylindrical Metal Silos and Comparison with Different International Standards.Engenharia Agrícola, Jaboticabal, v. 33, n. 4, p. 601-611, jul./ago. 2013.

PICCHI, F. A. Sistemas da Qualidade: uso em empresas de construção de edifícios. 1993. 462f. Tese/Doutorado. Curso de Pós-Graduação em Engenharia de Construção Civil e Urbana, Universidade de São Paulo.

SOUZA, V. C. M.; RIPPER, T. Recuperação e Reforço de Estruturas de Concreto. Pini: São Paulo, 1998.

VELLOSO, D. A.; LOPES F. R. Fundações. Volume 1 – Critérios de projeto: investigação de subsolo: fundações superficiais. Oficina de Textos: São Paulo, 2004.

WEBER, E. A. Armazenagem Agrícola. La Salle: Porto Alegre, 1995.