Damageability Analysis of Industrial Building Structures

Daria Tupitsyna and Albert Baiburin

Abstract The article is devoted to the study of defects and damages of industrial objects. Reports on inspections of industrial facilities are analyzed. Types and frequency of damages of various building structures are given. According to the results of damage analysis the most significant, statistically justified, damages and defects of building structures have been singled out. The ranking of damage types according to the frequency of their occurrence has been carried out. The obtained results make it possible to expand the information on the types, frequencies and causes of damages of standard structures of industrial buildings, which is important for ensuring their safe operation, substantiating the maintenance and repair plans and increasing the production efficiency.

Keywords Industrial buildings · Defect · Damage · Criticality analysis · Building structures

1 Introduction

The service life of industrial buildings operating under normal conditions must be at least 50 years, the service life of structures exposed to highly aggressive media at least 25 years. These figures are specified in accordance with the recommendations of code of practice SP 255.1325800.2016 [1]. However, the actual service life of a building may be reduced if the structures suffer various damages or defects.

There are many causes of damage to building structures. The following main classes of defects and damages can be identified: manufacturing defects in the factory, construction and installation defects on the construction site, operational damage, repair work defects. Possible operational causes of damage to building structures: atmospheric effects, ageing of materials, foundation settlement, increased

D. Tupitsyna · A. Baiburin (✉)
South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, Russian Federation
e-mail: baiburinak@susu.ru

N. Vatin et al. (eds.), *Proceedings of MPCPE 2022*, Lecture Notes in Civil Engineering 335, https://doi.org/10.1007/978-3-031-30570-2_7

loads, effects of workshop aggressive environment, increased humidity and temperature, roof leaks, operation of lifting devices, accidental impacts, cut-outs due to technological needs, etc.

Quantitative analysis of criticality of damages (defects) is a very time-consuming procedure requiring considerable expenses related to accumulation of statistics, mathematical processing of inspection results, and selection of criticality criteria. Classification of defects in construction by significance given in [2] is rather conventional and does not take into account the frequency of observation and probability of detection of defects.

The aim of the work was to analyse the types of damage and defects in industrial buildings on a large body of data from their inspections and industrial safety assessments. Many works of domestic and foreign researchers [3–8] have been devoted to the study of damage to buildings and structures.

According to [9], the following are the most common defects in building structures:

1. Defects in metal structures: cracks in the base metal, welded joints; deviations from the design position, geometric dimensions and non-design cut-outs contributing to weakening of elements and off-centre application of loads; local and general deformation of elements; disorder of bolted and riveted connections; defects of welded connections (undercuts, rough scales etc.); destruction of protective coatings and metal corrosion.
2. Defects in reinforced concrete structures: destruction and spalling of concrete; baring and corrosion of reinforcement; cracks in concrete; damage to reinforcement and embedded parts; bulging of compressed reinforcement; longitudinal cracks and destruction of compressed concrete; rupture or displacement of transverse reinforcement in the area of inclined cracks; deflections and deviations from the design position; oiling, damping and corrosion of concrete.
3. Defects in masonry structures: cracks in the masonry; violation of the geometry of structural elements; delamination of masonry due to failure to tie the rows together; destruction of masonry materials from erosion; bulging, bowing and other deformations.

In order to carry out an objective assessment of the condition of the metal framing elements, according to [10], attention must be paid to the following defects: displacement of columns and supports axes relative to the axis breakdown axes in the support section; columns deviation from vertical; difference in marks of support surfaces of neighbouring columns in a row and span; deflection arrow (curvature) of columns, framework struts, links on columns; cutouts of branches and gratings of through columns; loosening of anchor bolts fastening, etc.

According to [11], the following characteristic damages of concrete and reinforced concrete structures can be identified: cracking in various structures, destruction of the protective layer of concrete, denudation and corrosion of reinforcement, corrosion of concrete. We also gathered statistics on the occurrence of the above damage with an indication of the percentage of defective structures. The most frequently occurring defects are corrosion of the concrete of the wall cladding, corrosion of the reinforcement of the cover slabs as well as failure of the concrete protection layer.

The following characteristic defects are observed in steelwork [12]: cracks in truss and sub-truss elements, reduced depth of structural support, cracks in welded joints, and general bending of structures.

From the analysed sources it is difficult to draw meaningful conclusions specifically for industrial buildings due to the lack of heterogeneous data, methods of classification and assessment of defects and damages. In order to identify the main damages and defects of industrial building structures and to study their frequency and causes it is necessary to process a large amount of data. Such data was obtained after processing the results of survey of industrial facilities (workshops) of various structural systems.

2 Methods

In order to perform quantitative assessment of defects and damages, inspection and examination reports from more than 100 industrial facilities were analysed. Single-storey industrial buildings from the metallurgical, mechanical engineering, energy and building materials industries were considered as objects of research. Years of commissioning ranged from 1902 to 2016: 1902–1940 - 10 objects; 1941–1970 - 61 objects; 1971–1990 - 21 objects; 1991–2016 - 9 objects.

In terms of structural design, the workshops investigated were divided into frame, wall and frame-wall buildings. In terms of structural design and materials used: full reinforced concrete frame; full metal frame; mixed frame (reinforced concrete and steel); stone bearing walls with different cover options. Practically all surveyed workshops had hoisting equipment in the form of overhead cranes and overhead cranes of capacity from 2 to 280 tons with different modes of operation: from repair to heavy. The degree of aggressiveness of the environment of the investigated productions was defined mainly as non-aggressive or slightly aggressive, less often as moderately and strongly aggressive.

During data collection, the object, operating time, hoisting equipment, aggressive workshop environment, structure, structural element, damage type and location, damage magnitude and frequency as well as the probable cause were recorded. Frequency characteristics for the main types of damage and defects were then plotted. The frequency of damage was defined as the ratio of damaged structures (elements) to their total number at a given facility.

3 Results

The types and frequency of damage to reinforced concrete columns are shown in Fig. 1.

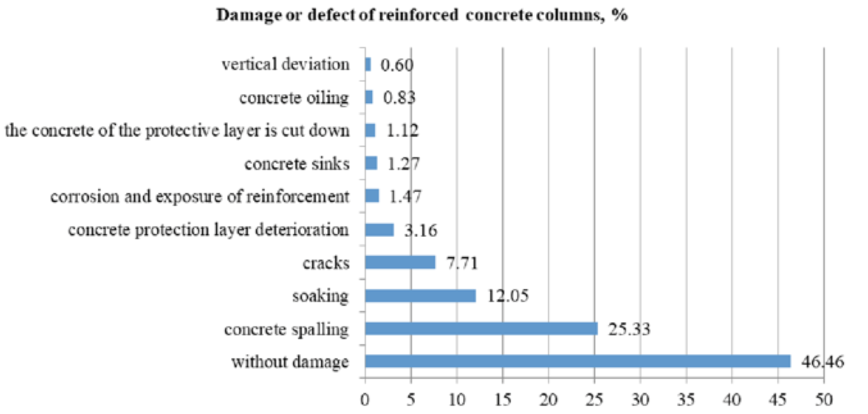

Fig. 1 Damage (defects) to reinforced concrete columns

As can be seen from the presented graph, the most common defect of reinforced concrete columns is spalling of concrete 25.3% and soaking of structures 12.1%. The least common are oiling of concrete and deviation of columns from the vertical.

Types and distribution of damage to metal columns are shown in Fig. 2.

For metal columns, corrosion of 41.8% and local bends of 10.1% can be distinguished as the most common, the least typical defect is the bending of the wall of the I-beam. Such a defect as the vertical deviation is also found in this type of structure, but less often than columns made of reinforced concrete.

The distribution of damage to reinforced concrete trusses is shown in Fig. 3.

As can be seen, for reinforced concrete trusses the number of defects encountered is quite small, which is explained by their massiveness and durability. The most typical defects for this type of structures are minor spalling of concrete 29.6%, and soaking of elements 28.9%.

The list of detected defects and damages of steel trusses are shown in Fig. 4.

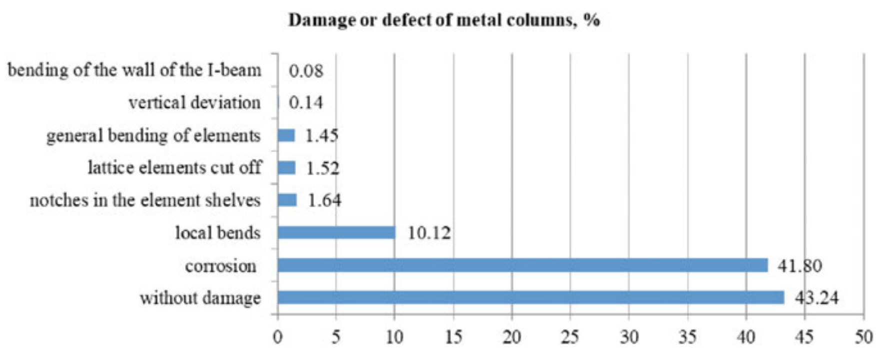

Fig. 2 Damage (defects) to metal columns

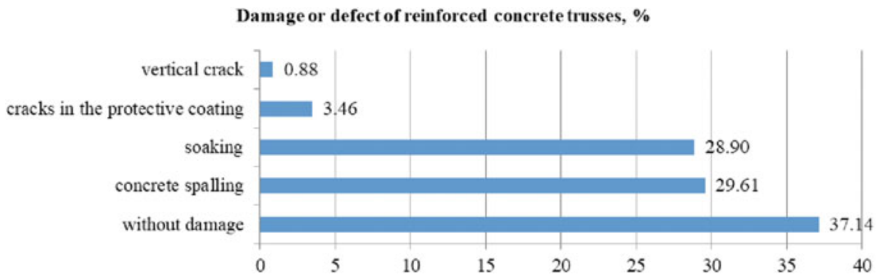

Fig. 3 Damage (defects) to reinforced concrete trusses

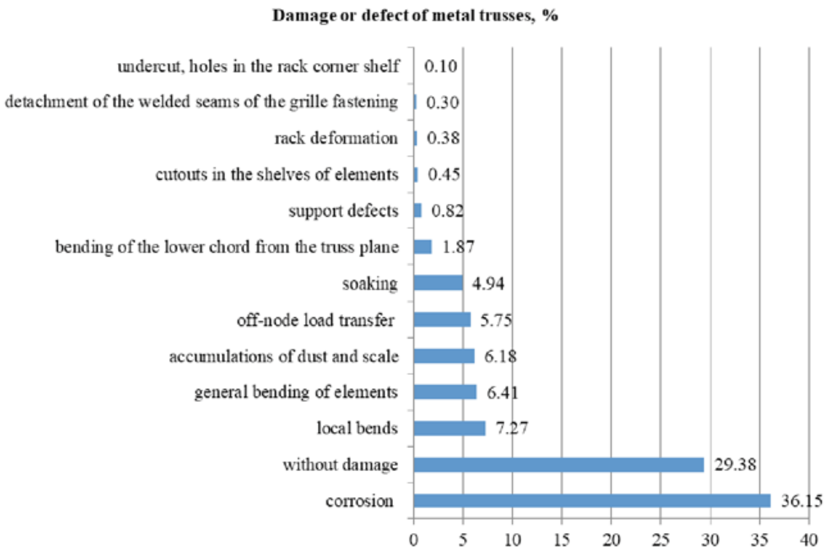

Fig. 4 Damage (defects) to metal trusses

The graph above shows that more than one third of the metal trusses are characterised by corrosion 36.2%. The next highest frequency are local bends 7.3% and general bending of truss components 6.4%. Rare are detachment of the welded seams of the grille fastening as well as various undercuts, holes in the element flanges.

Types and frequency of damage to trusses and columns are shown in Figs. 5, 6.

In the case of linking elements, the list of defects encountered does not depend on whether they are used for columns or trusses. Damage (defects) characteristic of links are as follows: corrosion, cutouts in elements, local bends, absence of communication elements, general bending of elements. However, the incidence of damage (defects) differs depending on the location of the structures. For example, more than half of the truss connections are susceptible to corrosion, but among the column connections this defect occurs in less than 4% of cases. This is due to the location of the ties and roof leaks. The opposite situation is due to mechanical damage to the structures,

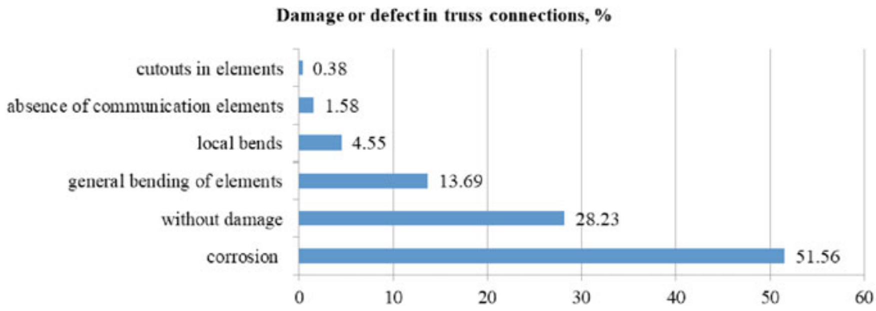

Fig. 5 Damage (defects) to truss connections

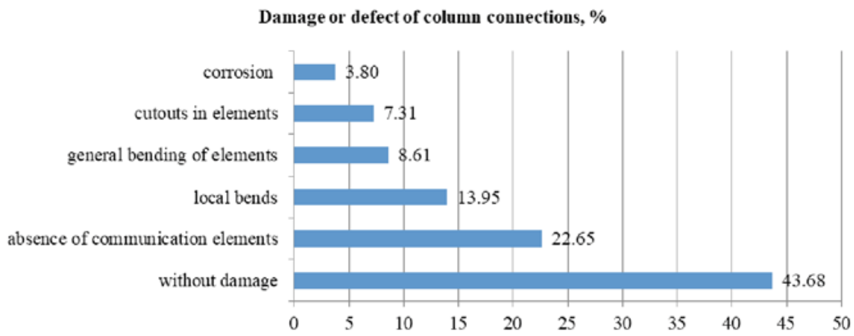

Fig. 6 Damage (defects) to column connections

namely notches in the ties. This damage occurs in 7.3% of column connections and in less than 1% of truss connections. This is due to the positioning of utilities and equipment.

Types and distribution of damage to prefabricated floor and roof slabs are shown in Fig. 7.

Note that more than half of the roof and floor slabs are subject to soaking 57.6%. This defect is the most frequent in this type of construction and is associated with leaks in roofs and gutters. The next most frequent defect is concrete corrosion in 7.7% as a consequence of leaks. Most defects which are not caused by leaks and concrete corrosion occur in no more than 3% of structures. The absence of any damage (defects) is characteristic only for a quarter of the surveyed structures.

The distribution of damage to brick walls is shown in Fig. 8.

The most characteristic damages to brick walls are atmospheric erosion, cracks and soaking. These defects occur in 10–23% of brick walls. Rare ones include spalling, peeling of protective coatings and biological damage to structures.

The types and frequency of damage to steel crane beams are shown in Fig. 9.

As can be seen, the most frequent defect is structural corrosion 29.6%. A fifth of beams (19.2%) have disorder of bolted and riveted joints due to dynamic loads from

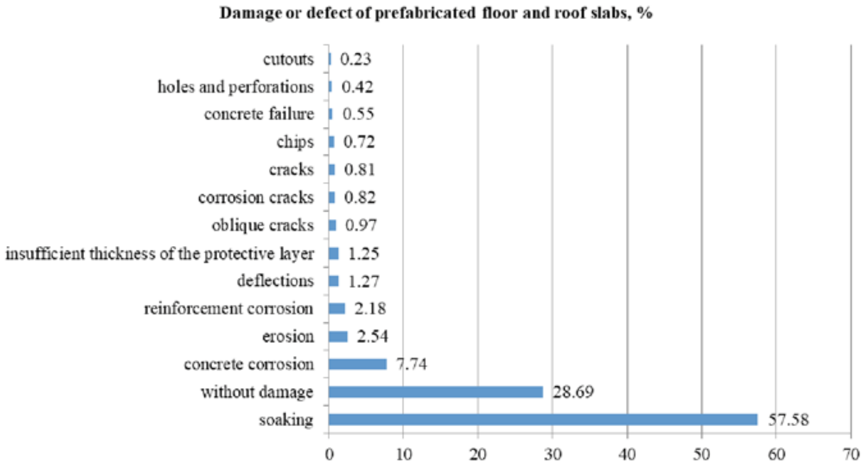

Fig. 7 Damage (defects) to prefabricated floor and roof slabs

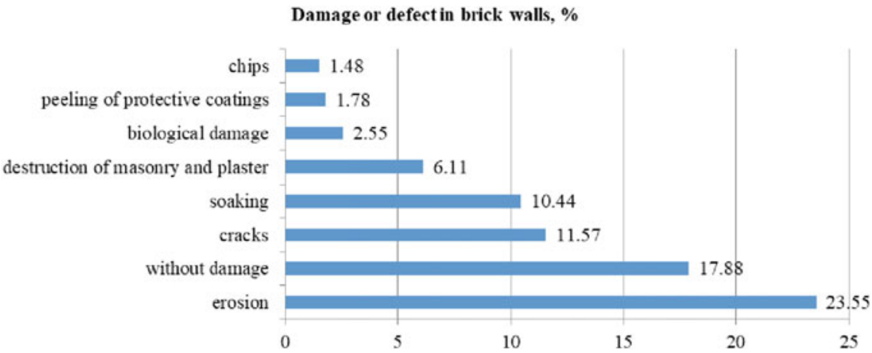

Fig. 8 Damage (defects) to brick walls

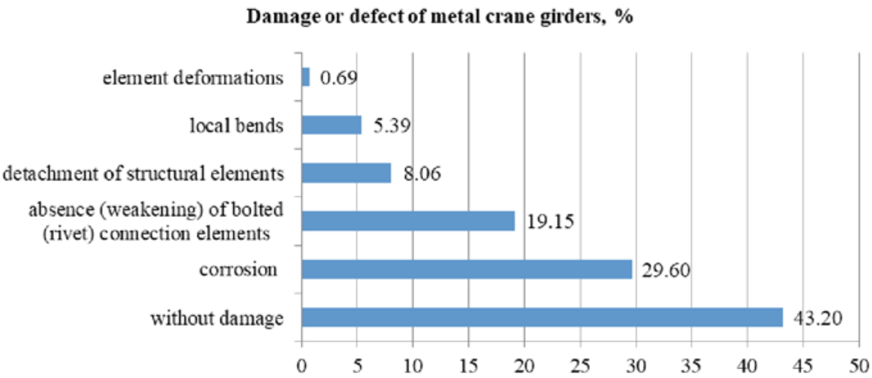

Fig. 9 Damage (defects) to metal crane girders

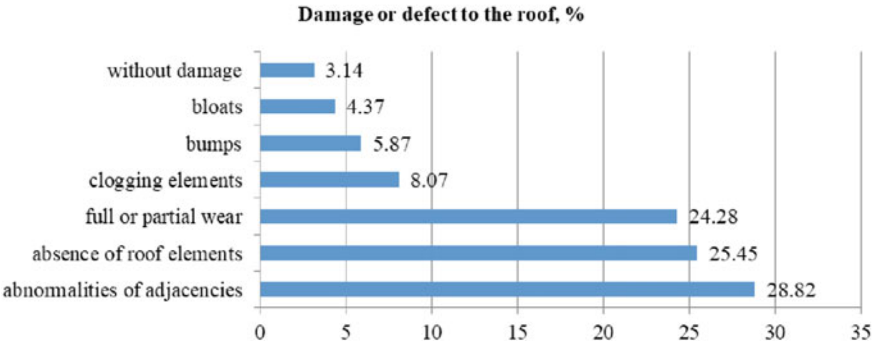

Fig. 10 Damage (defects) to roofs

the hoisting equipment of the workshops. Deformations of elements as well as local bends can be attributed to rare occurrences.

The types and distribution of roof damage are shown in Fig. 10.

As can be seen, the percentage of roofs without damage is quite small at just over 3%. The most characteristic defects in the roof structures are joint failures in 28.8% and missing roofing elements in 25.5% (aprons, parapet protection, expansion joints etc.).

4 Conclusion

Based on the foregoing, the following conclusions can be drawn. The absence of defects is characteristic for about 45% of reinforced concrete and metal columns, while the most significant defect was soaking and spalling of concrete for reinforced concrete columns, corrosion and local bends for metal columns. The proportion of reinforced concrete and metal trusses without damage is approximately 33%. Damage-free linking elements are found in 29% of cover elements and in more than 40% of column connections. The most frequent defect in column connections is a missing connection element in 23%, while corrosion is a characteristic defect in truss connections and is found in more than half of the examined structures. For prefabricated floor and roof slabs, no defects are found in only a quarter of the structures, and the most frequent defect is soaking, which occurs in almost 2/3 of the structures. A large proportion of external brick walls are subject to atmospheric erosion. The proportion of crane beams with damage is 57%. The most common damage to crane girders is corrosion and loose bolted connections. Almost 97% of the roofs have some kind of defects and damage: broken joints, complete or partial wear and tear, missing individual elements as well as clogged gutters, uneven and swollen roof mats. The main causes of damage are impacts during operation: corrosion, deformations from impacts, dynamic loads from cranes, atmospheric erosion.

The results obtained provide more information on the types and frequencies of damage in typical industrial building structures, which is important for ensuring their safe operation and improving the efficiency of production. Further research will focus on the application of neural networks to process damage data for objective assessment and management decision-making in the operation of industrial buildings.

References

1. SP 255.1325800.2016. Buildings and structures. Rules of operation. General provisions. Moscow (2016)
2. Classifier of the main types of defects in the construction and building materials industry. Gosstroi Russia, Moscow (1993)
3. Albrecht, R.: Defects and Damage to Building Structures. Stroyizdat, Moscow (1979)
4. Analysis of the causes of accidents and damage to building structures. Stroyizdat, Moscow (1973)
5. Baiburin, A.K.: Ensuring the Quality and Safety of Constructed Civil Buildings. ASV, Moscow (2015)
6. Grozdov, V.T.: Defects in building structures and their consequences. kN+ Publishing, St. Petersburg (2001)
7. Dobromyslov, A.N.: Diagnosis of Damage to Buildings and Engineering Structures. ASV, Moscow (2008)
8. Yeremin, K.I.: Atlas of faults and damage to building structures in operation. VELD, Magnitogorsk (2010)
9. Narkevich, M.Y.: Visual inspection as the basis for the development of automated systems for remote monitoring and quality assessment of buildings and structures at hazardous industrial facilities. Proceedings of Tula State University. Technical Sciences. 5, 570–575 (2021).
10. Kuzmishkin, A.A.: Classification of defects in the inspection of metal structures. Bull. Grad. School. **12**(39), 95–97 (2014)
11. Solovyov, V.G.: Analysis of defects and damages of reinforced concrete structures, typical for underground structures, by the example of civil defense structures. News Higher Educ. Inst. Invest. Constr. Real Estate. **9**(1), 124–133 (2019)
12. Guseva, K.B.: Peculiarities of the inspection of metal structures. Sci. J. **5**(39), 23–25 (2019)