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DAMAGES INVOLVING PLASTIC DEFORMATION OF STRUCTURES RELATED TO MAINTENANCE COST REDUCTION

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ABSTRACT
This paper presents some aspects of the correlation between maintenance cost reduction and accidents—specifically, damages due to plastic deformation in steel constructions at production companies in Bosnia and Herzegovina. In the theoretical part, a tension testing diagram for typical structural steels (I, U, T, etc.) is used to explain the nature of failures in the discussed support constructions. The practical part includes a series of photographs taken during forensic examinations following accidents, providing evidence of prior plastic deformation. This section is complemented by data on corresponding maintenance costs. It is emphasized that using loads above 60% of the yield stress, even if within the elastic range, is a dangerous practice for steel constructions in Bosnian manufacturing companies, let alone exceeding the yield point into the plastic deformation range. The most common causes for this practice, i.e., 'overloading' that results in plastic deformation or structural accidents, include poor quality of planned-preventive maintenance and a policy of reducing maintenance costs. These accidents often lead to injuries among workers, partial or complete destruction of structural components, or the decommissioning of entire facilities, thereby causing technological delays and triggering enormous costs due to lost production. These total costs are further increased due to the necessity to remedy the state of equipment and/or production technology.

1. INTRODUCTION AND THEORETICAL APPROACH
Figure 1 [1] illustrates a typical stress-strain curve obtained from a tensile test of a steel used in construction, conforming to EN 10024 standards for hot-rolled sections such as I-beams, U-channels, and T-bars. The diagram highlights three critical points in the testing process: the yield point, ultimate stress point, and fracture point. These points are essential for understanding the mechanical properties of steel under tensile loading.

The tensile test is a fundamental mechanical test in material testing. This simple test is often conducted using advanced, computer-controlled machines, which enhance the flexibility to adjust the speed and accuracy of the test based on the specific requirements of the material's application. The tensile test involves using a sample piece, which must be broken to measure its resistance to applied force. The results are typically represented in a stress-strain curve, which clearly delineates critical mechanical properties such as the yield strength or proof strength and ultimate tensile strength.

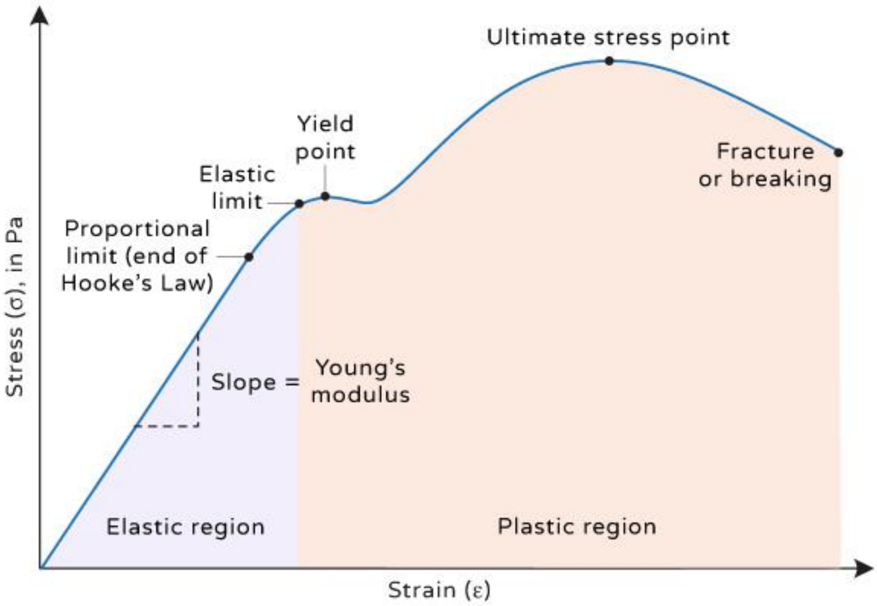

Figure 1. Typical tensile test diagram [1]

The Elastic region in Figure 1, which represents the region of elastic deformation, is considered safe under experimental conditions. However, in the long-term application of these steel constructions in B&H industrial companies, this safety can be compromised due to factors such as improper construction, inadequate maintenance, harsh winter conditions, chemically aggressive environments, and vibrations.

The yield point on the stress-strain curve, where plastic deformation initiates, marks the transition from elastic behavior. This point, where the curve flattens, is often challenging to identify precisely. An 'offset yield point,' also known as proof stress, is commonly used in practice. This offset is typically defined arbitrarily at a plastic strain of 0.1% or 0.2%.

In materials science and the theory of plastic deformation, the critical resolved shear stress is defined as the component of shear stress, resolved in the direction of slip, necessary to initiate slip within a grain of the material. This resolved shear stress is the shear component of an applied tensile (or compressive) stress resolved along a slip plane—the most closely packed plane—which is neither perpendicular nor parallel to the stress axis. The relationship between the applied stress and the resolved shear stress is quantified by a geometric factor, typically known as the Schmid factor, which reaches its maximum value on slip planes at a 45° angle to the direction of the applied force. Therefore, even the Elastic region depicted in Figure 1, which represents a region of presumed safety under elastic deformation, is not entirely secure. The onset of plastic deformation, which ideally should not occur in industrial structures and facilities, can still potentially initiate within this zone [2].

Preventive maintenance (PM) generally refers to maintenance activities carried out at predetermined intervals or according to specific criteria, with the aim of reducing the likelihood of failure or the degradation of an item's functionality. When designing maintenance policies for complex systems, a common approach is to adopt a top-down methodology. This process typically involves selecting a maintenance strategy—such as Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), or Risk-Based Maintenance (RBM)—followed by the choice of a maintenance policy, such as condition-based maintenance or PM. Within this framework, PM models play a critical role. They are used not only to estimate the effectiveness of preventive maintenance (PM) but also to evaluate key reliability indices, such as time to failure. The literature offers a wide range of PM models, each designed to measure PM effectiveness across various applications.

Additionally, preventive maintenance involves planned maintenance activities aimed at enhancing equipment lifespan and preventing unplanned repairs. These activities include tasks such as lubrication, cleaning, and minor repairs, with the primary goals of minimizing breakdowns, maximizing production efficiency, and extending equipment life.

The importance of preventive maintenance has grown due to factors such as increased automation, the need to reduce downtime, and the demand for improved product quality. The advantages of preventive maintenance include enhanced safety, reduced costs, fewer equipment failures, extended equipment lifespan, and improved reliability. However, there are some disadvantages, such as slightly higher maintenance expenses, potential breakdowns at inconvenient times, reduced output during maintenance, and the risk of performing unnecessary maintenance on certain components [3,4,5,6].

2. PRACTICAL APPROACH TO THE CORRELATION BETWEEN MAINTENANCE EXPENDITURES AND DAMAGE DUE TO PLASTIC DEFORMATION IN STRUCTURES

Figures 2 through 8 in the practical section of this paper illustrate significant plastic deformations that resulted in structural failure in a metallic material production plant. Similarly, Figures 9 through 12 depict notable plastic deformations that have not yet resulted in structural failure in a non-metallic material production plant. These cases were derived from court expert judicial proceedings involving various companies in Bosnia and Herzegovina.

Figure 2. An example of the broken portal crane

Figure 3. Western layout view from a broken portal crane

Figure 4. Eastern layout view from a broken portal crane

Figure 5. Detailed view of a severely plastically deformed (bent) section of a broken portal crane

Figure 6. Detailed position of a deeply corroded section of a broken portal crane

Figure 7. Detailed position of a welded and deeply corroded section of a broken portal crane

Figure 8. Detailed position of ductile fracture of a broken portal crane section

Figure 9. Position of the wooden and steel construction supports to plastically deformed sections

Figure 10. Another location of the wooden and steel construction supports to plastically deformed sections

Figure 11. Position of the wooden construction supports to plastically deformed sections & roof

Figure 12. Detailed position of plastically deformed sections & roof

All these issues (structural failures and damage resulting from significant plastic deformation), as visible in Figures 2 through 12, are primarily caused by inadequate maintenance. These failures often stem from compromises in proper maintenance practices, particularly preventive maintenance (PM), in an effort to reduce maintenance expenditures. This conclusion is supported by an analysis of the maintenance accounting records from the companies involved [2,7,8,9,10]. Furthermore, an overview of the annual maintenance expenses in KM versus production quantity in tonnes (t) is presented in Table 1 and Figure 13.

Table 1. Overview of total yearly maintenance expenses in (KM) v.s. production quantity in (t)

Facility	2017. (KM) Tot. expen. / Quantity- t	2018. (KM) Tot. expen. / Quantity- t	2019. (KM) Tot. expen. / Quantity- t	2020. (KM) Tot. expen. / Quantity- t	2021. (KM) Tot. expen. / Quantity- t	2022. (KM) Tot. expen. / Quantity- t
No. 1.	18.053 KM / *	21.075 KM / *	12.249 KM / 11.571 t	14.661 KM / 12.503 t	8.201 KM / 6.801 t	4.493 KM / 7.051 t
No. 2.	76.005 KM / *	89.345 KM / *	50.457 KM / 387.514 t	42.795 KM / 312.044 t	53.619 KM / 313.993 t	50.944 KM / 121.553 t
* Data were not available						

The data from Table 1 are visually represented in Figure 13, where the consequences of reduced maintenance costs become very apparent.

Figure 13 clearly illustrates a decline in maintenance expenses. This decrease becomes even more pronounced when depreciation is considered, though that is beyond the scope of this article. The occurrence of plastic deformation in the construction elements, as ominously shown in Figures 9 through 12, serves as a clear indication of inadequate preventive maintenance (PM). This insufficient PM ultimately led to structural issues in the production facility. Furthermore, standard operating procedures (SOPs) had not yet been implemented at the production facility.

For staff at the production facility with connections to metallurgy, materials, or mechanical engineering faculties or institutes, it would be highly advisable to establish collaboration with specialists from these fields. Combined teams of such experts could organize visits to metallic and non-metallic production factories across Bosnia and Herzegovina. These visits would aim to convey critical advice and raise awareness about the dangerous consequences of plastic deformation in structures and machinery. They could also point at the correlation between total maintenance expenditures and the occurrence of structural failures or damage, including those associated with plastic deformation.

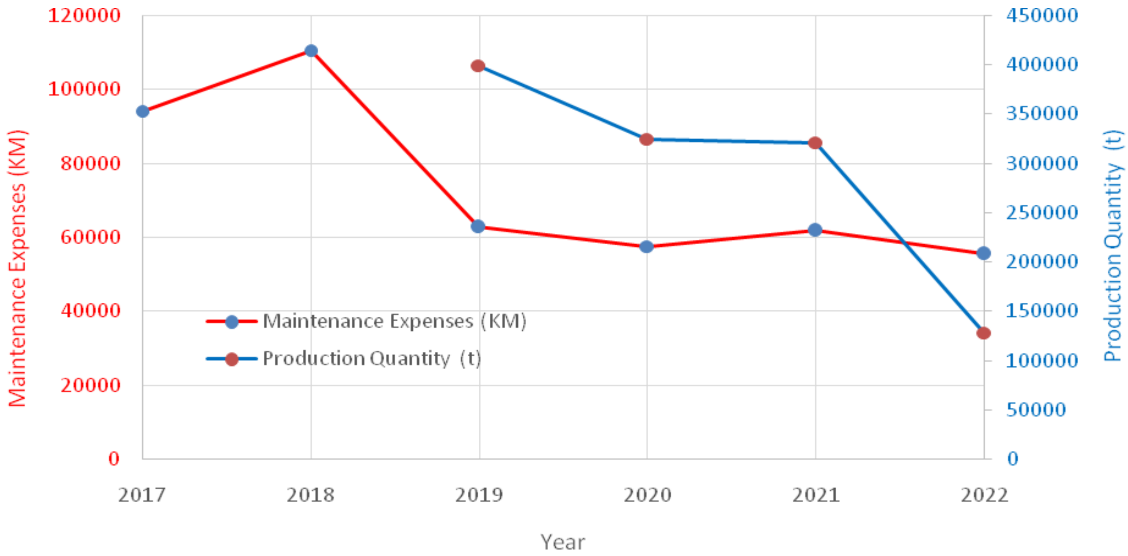

Figure 13. Annual Maintenance Expenses (red line) vs. Production Quantity (blue line)

Special attention during these proposed visits should be directed toward identifying potential causes of dangerous plastic deformation. These may include:

A) Insufficient safety coefficients in design
B) Overloading
C) Improper treatment of welding spots
D) Inadequate or irregular corrosion protection
E) Exposure to chemically aggressive environments
F) Extreme heating and freezing conditions, particularly at welding spots
G) Vibrations and shocks
H) Other contributing factors.

Addressing these issues during the visits can help enhance understanding and mitigate risks associated with plastic deformation in structures and machinery.

The aim of this article is not to address the aforementioned issues (A to H) from the perspective of metallurgy or material science, which can contribute to dangerous plastic deformation in various steel structures. Rather, it seeks to encourage more frequent visits by teaching staff to industrial facilities. During these visits, brief on-site reviews of the issues listed from A to H can be presented, providing valuable insights and urging owners and management to adopt proper, planned, and preventive maintenance practices.

Another area for improvement could involve organizing and monitoring a comparison of maintenance expenditures versus the effectiveness of proper maintenance. Based on my experience as a court expert, many transitioning companies in Bosnia and Herzegovina (B&H) tend to reduce labor forces and maintenance budgets. However, such practices simultaneously increase the risk of structural failures or damage due to insufficient planning and lack of preventive maintenance. Incorporating daily, weekly, and monthly maintenance routines into production schedules is highly advisable, particularly for facilities that date back to the previous century.

3. CONCLUSIONS

1. Plastic deformation causes and maintenance deficiency

Overloading, improperly treated welding spots, insufficient or irregular corrosion protection, exposure to chemically aggressive environments, extreme heating and freezing conditions (particularly at welding spots), vibrations, shocks, and other unexpected factors can lead to plastic deformation in structures. These issues are often the result of inadequate mechanical maintenance, lack of preventive maintenance (PM), or negligence of the early signs of plastic deformation.

2. Risks in industrial transition

While optimizing production during industrial transitions—such as managing operations on high-performing facilities, reducing labor forces, and cutting maintenance expenses—may seem economically sound, it simultaneously increases the risk of structural damage or collapse. This heightened risk is largely due to the absence of proper planned and preemptive maintenance (PM).

3. Teaching staff and expert visits

Regular visits by teaching staff or industry experts to industrial facilities are highly recommended. On-site presentations addressing the aforementioned issues, as highlighted in the first conclusion, can provide valuable insights and practical advice to facility management.

4. Enhancing consulting activities

It is advisable to expand technical and technological consulting services offered by both the Faculty of Mechanical Engineering and the Faculty of Metallurgy and Technology. Based on experience, many transitioning companies in Bosnia and Herzegovina (B&H) prioritize cost-cutting measures, such as reducing labor forces and maintenance budgets. However, this approach significantly increases the risk of structural failures and facility damage due to insufficient planned and preemptive maintenance (PM). Daily, weekly, and monthly maintenance routines should be incorporated into standard operating procedures (SOPs), especially for facilities dating back to the previous century.

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