

RESIDUAL LIFE OF EXTERNAL STEEL CONSTRUCTIONS

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Resume

The contribution is focused to the aspects of prevention untimely damage of exterior steel constructions at variable climatic conditions. The aspects for assurance of continual service of strategic steel constructions (bridges, pipelines, pylons, pressure vessels, containers, frameworks, cranes, chimneys, towers, etc.) is by action of severe climatic conditions in our climatic zones deteriorative. The service safety of construction mentioned is decreasing and could cause preterm damages. To avoid preterm damage there are two ways. First is to create conditions excluding the damage and second is proposal of construction safety also after expected limit state. During the lifetime is needed to assure failure free service of external steel constructions stressed by variable loading. At the same time is needed to calculate with action of aggressiveness of external environment as well as worsen atmospheric conditions. From load and conditions analysis could be calculated the residual life of external steel constructions.

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1. Introduction

Determining criteria of operation of steel constructions is their reliability what in praxis means that it is needed to provide required function for defined period. Generally we speak about robust investment units as bridges, pylons, reservoirs, pressure and pipeline systems, frameworks of buildings etc. Operator is fixed to pay attention to keep reliability of own investments. Nowadays is calculated about utilizing of diagnostic methods and monitoring of exposed nodal points together with mathematics modeling of ageing. It enables to define the residual life of particular components using on line system. The residual life is relevant to plan maintenance and repair which guarantee safety and failure free operation of modern steel constructions.

2. Analysis of operational stress

Decisive part of external steel constructions are in service loaded by dynamic loading simultaneously with activity of climatic conditions. Dynamical loading causes a response

in the critical locality of structure by accumulation of damage. In beginning phases this is an event without visible signs on material surface, when the incubation phase of fatigue failure on the level of structure and substructure takes place, mainly by growth in density of dislocations. This stage of development of fatigue cracks is usually affected by the stress concentration from notches and also by residual stresses, mainly in the zone of welded joints. After incubation stage of fatigue process, the stage of fatigue crack growth follows. The damage process terminates by rupture of the remaining cross section. In case of existence of surface defects (crack, lack of fusion, cold lap, etc.) the incubation phase is abandoned and the entire process of fatigue consists only in the fatigue crack growth.

The resistance of material against formation of brittle fracture depends from ability of plastic deformation. In the root of crack is the stress theoretically extremely high. In real life is formed in this place the plastic zone. The size of plastic zone depends on limit of elasticity R_e of

material, Fig. 1. Steels with higher limit of elasticity create smaller plastic zone. The risk of brittle fracture is therefore higher by using high strength steels, where the radius of plastic zone r_p is already very small. Increasing of the risk is caused in the region of welded joints and in using of high thickness of material, where plane strain is dominant [1].

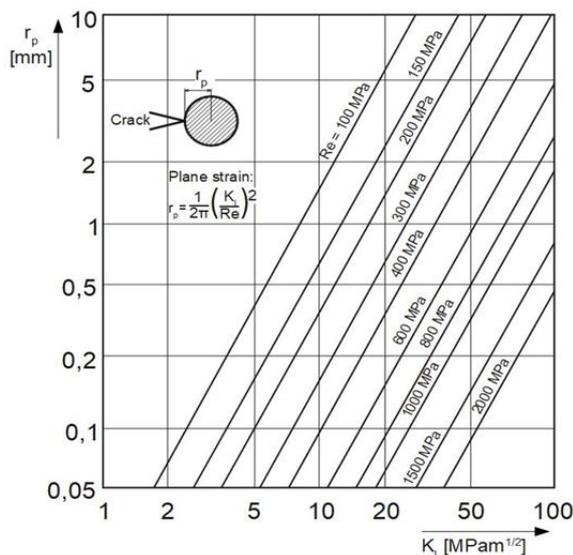


Fig. 1. Size of radius of plastic zone for different steels.
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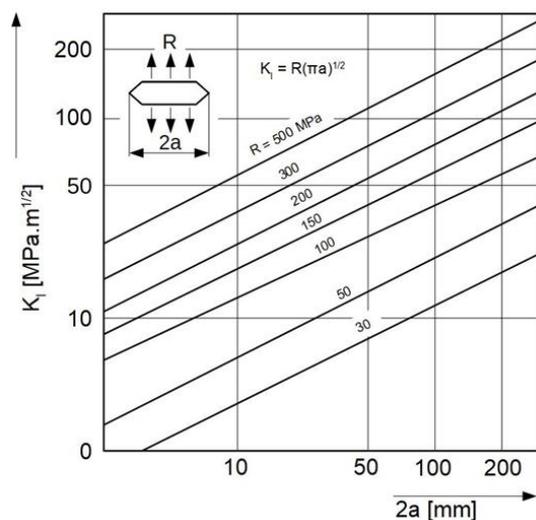


Fig. 2. Setting of strain greatness for constructional steel
(full colour version available online)

The steel constructions loading is composed of external dynamic loading, corrosion, and internal influences as residual

stresses and stress concentration factors. Final loading is superposition of all internal and external loadings on critical cross section of steel construction. Critical point is regularly on the surface of the body. Here is anticipated also initiation of eventual fatigue crack. The evaluation of total stress σ , that subject limit state of construction is depends on stress intensity factor K_I , and critical defect size $2a$ in regarded cross section [1], [2], Fig. 2.

3. The integrity of steel constructions and residual life

During the operation of external steel constructions comes to degradation of their utility properties. Therefore there is need to estimate residual life continuously. For minimizing of the risk of failure is needed to realize the maintenance of construction in defined intervals of inspection. The structures dynamically loaded in service may be loaded either by high-cycle fatigue, low- cycle fatigue, or by irregular fatigue loading. Theoretical background for determining the growth rate of fatigue cracks is sufficiently mastered at present. For crack growth rate at high cycle fatigue, the Paris - Erdogan's (1936) relationship is used, whereas for the strain fatigue the Manson - Coffin's (1954) relationship is applied and at irregular fatigue, the cumulative hypotheses are employed, whereas the most widely used seems to be the Palmgren - Miner's (1945) criterion in conjunction with Wohler's (1860) curve [3]. Present direction in the field of design, manufacture, service, repairs and liquidation of structures is governed by the approaches making use of the theoretical and practical knowledge of the „Fitness For Service - FFS" approach. (This method was conceived and developed within IIW - International Institute of Welding, in Commission XV - „Design, analysis and fabrication of welded structures "(1990). Following proceedings at present became the contents of Commission X - Structural Performances of Welded Joints - Fracture Avoidance. The „Fitness For Service" theory

may be used actually in all fields of fabrication and service of metallic but also non-metallic (plastics, composites, ceramics, concrete etc.) structures and products. Documents from this field are accessible on the web site: www.eurofitnet.org.

The limit state may occur from several reasons, for example from the material loss of the bulk structure, caused by surface corrosion or by gap corrosion. Material degradation may occur due to ageing, distortion of crossbars and due to defect growth by fatigue process, most often by loading caused by the sharp atmospheric influences. Optimum solution of maintenance and repairs supposes determination of suitable inspection intervals. Their determination follows from the analysis of damage risks (Risk Based Inspection - RBI) [4], as shown in Fig. 3. The structure must be capable to tolerate the failures formed between the two inspection intervals. Thus, in spite of existence and growth of damage caused by corrosion and/or dynamic loading, the structure must be safe and functional up to the next planned inspection. Determination of interval of diagnostic inspections directly depends on the admissible probability of failure.

The system of diagnostics measurement is destined for an objective determination of factual state of steel construction material from the viewpoint of its damage during the service. Modern non-destructive and destructive diagnostic methods used for determination of factual stage of steel construction damage allow obtain a complex picture about the internal and external defects in the critical cross sections, as well as the measure of material damage due to ageing. The damage process of steel structure progresses in the course of life separately in its individual components (corrosion, ageing, defect growth, distortions of crossbars etc.) but the resultant effect of damage is

represented summarily. The degradation process is governed by actual physical and chemical laws, which allow to predict their expected further development and to predict residual life.

Residual life generally depends on the state in structure damage, on acceptable damage size and on the supposed service conditions in the course of time form diagnostics performance till the end of safe life. Four significant modes of damage may occur on steel structures which alter during the course of life and affect the residual life of construction: material ageing, corrosion, fatigue crack growth and distortion of crossbars.

Determination of supposed residual life is an engineering problem, which solution consists in unimpeachable estimation of time during which construction may be utilised and met requirements for service safety. Residual life of construction is thus considered till termination of a safe service and not up to reaching the emergency (limit) state. Each of the mentioned damage modes may separately cause the termination of service period, due to exceeding the critical damage size (CDS). The time courses of assessment properties can be obtained on the basis of long-term monitoring of individual damage modes. This allows to achieve the life function of studied property. At individual damage modes, attention should be mainly paid to the two issues. First is course of the life function at individual damage modes, and second is critical degree of degradation (CDS) of an actual damage. Regarding the fact that the development of individual damage modes, as well as the admissible degree of degradation mutually differ, since they are of different physical or chemical essence, it is necessary to approach to individual damage modes separately.

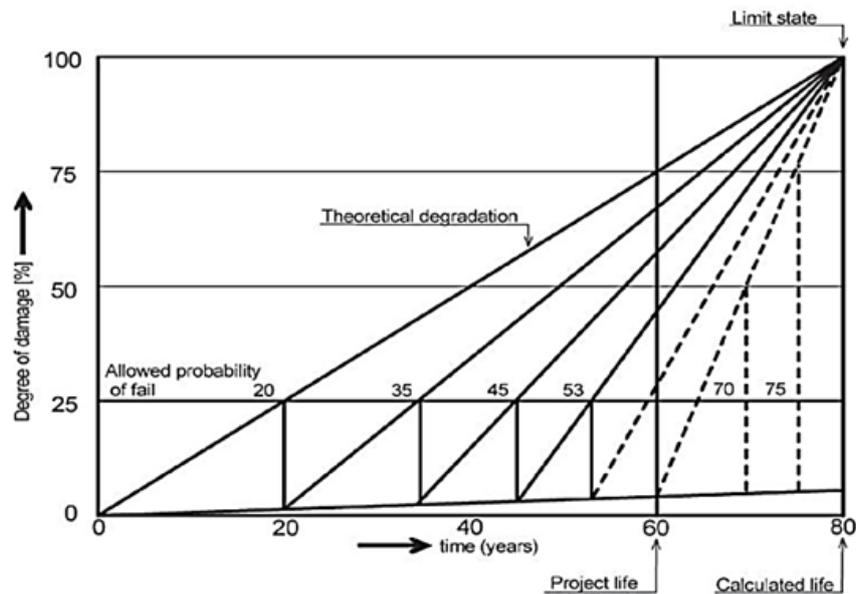


Fig. 3. Intervals of structure inspection by the Risk Base Inspection theory. (full colour version available online)

4. Controlled ageing of steel constructions

Integrity of steel constructions must be ensured continually. The quality systems have introduced the principle of responsibility of manufacturer and operator for the safety of products during the entire period of their technical life. This requirement can be ensured by the method of controlled ageing of constructions. Principle of controlled ageing consists in the fact that a complex diagnostics with subsequent maintenance (eventually also repairs) of all defective points is performed in the intervals defined in advance. After such action the structure gets to its „initial” state. However, the material degradation caused by ageing will remain a permanent change that cannot be removed. These intervals are determined by the RBI (risk based inspection) method. Controlled ageing has a direct effect upon two most important performance criteria, namely the service reliability and Life Cycle Cost (LCC) [5]. However, also time of safe service is prolonged. On the side of expenditures, the costs for diagnostics, maintenance and repairs are involved, whereas on the side of savings a prolonged time of safe life of constructions is obtained. Practice have shown, that the cost for

controlled ageing are considerable lower, than the savings obtained by prolonged time of safe service with postponing of new investment.

In design of steel constructions was supposed that theoretical development of degradation will be linear and finish by limit state. Research indicates that theoretical trend of degradation of steel construction is in real conditions modified above all by effect of damage accumulation and local disorders as corrosion or wearing. Development of the life cycle of steel constructions with three times inspection and repair is plotted in Fig. 4. Assessing of risk probability index for lack integrity of construction is in Tab. 1.

Realisation intervals for inspection tests and consistent repairs or maintenance are defined to keep the probability of damage under 30%. Parallel the propagation of damage is in zone of very low risk of fail. Heavy line represented development of lifetime of real steel construction with three inspections and three repairs (1, 2 and 3). After repairs is not possible to come to original degradation because of ageing process of material. This advance makes possible to ensure that 76% of lifetime will the construction work in low risk of damage.

In the case of next inspection and repair the lifetime will be prolonged. The operator could make a decision either to repair the construction or make a new investment.

Consecutive degradation of steel constructions causes also changes of original mechanical properties of material. The damage accumulation is decisive especially on critical

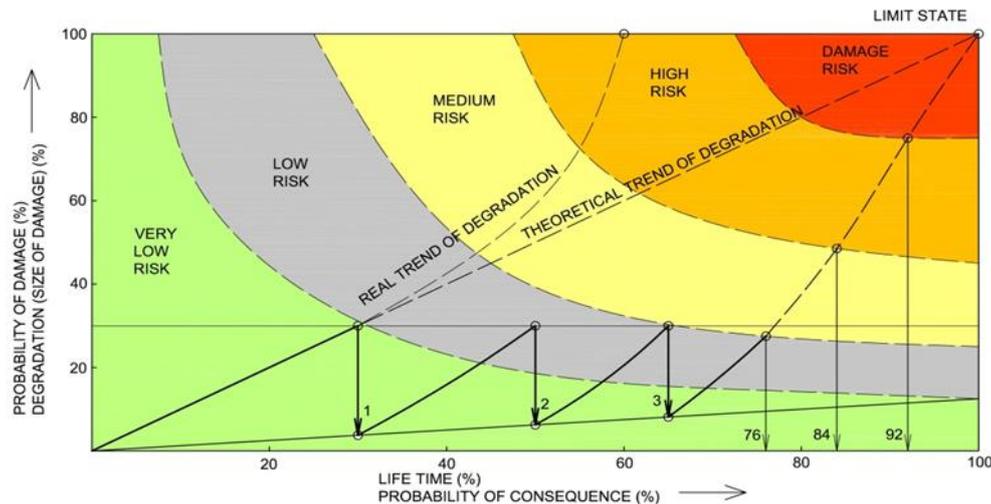
nodal points of construction. In this places are peaks of loading from notches mainly in welded joints [6]. The factors of damage collection are loading, surroundings, changing temperature and ageing process. For avoiding of limit state of construction is needed to fulfill three conditions, namely proper material, precise dimensioning, and quality of production and inspection.

Table 1

Setting of index of probability of risk lack integrity of construction.

Risk index	Probability of damage	Probability of outcome	Probability of risk
1	any	any	right low
2	little	improbable	low
3	average	eventual	average
4	significant	probable	big
5	serious	much probable	emergency

Fig.



4.

Development of life cycle of construction (3 times inspection and repair).
(full colour version available online)

5. Discussion and Conclusions

Research in scope of controlled ageing has shown the possibilities for optimizing of intervals of inspection and maintenance or repair of steel constructions to obtain optimal operational conditions and safety. In order to assure the service reliability as well as the optimum economical usage of construction it is advisable to elaborate and implement the program of controlled ageing of real steel construction. This will allow monitoring and assess the effect of service and degradation processes on individual bearing components of steel constructions. Systematic solution and attention to service safety of steel constructions

consist of sophisticated attempt to individual segments of cycle of development, production, construction, service and clearance of investments. The information resource about development of damage consists in completion of inspection measurements and analysis of degradation feedbacks.

Fundamental effect for long period of service is surface shielding of steel construction. The quality of surface shielding should be monitored regularly and have to be renovated as soon as possible during whole life of construction [7]. By exploitation of diagnostic inspection derived from risk analysis and fracture mechanics supported by fitness for service

method is possible to propose maintenance and repair processes to assure safe life of construction during whole life. This is the basis of controlled ageing of steel constructions. The assessment of residual life makes possible to realize prognosis of safe life and determine either new inspection or new investment. The technics described enable also to prolong lifetime of steel constructions.

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References

- [1] Vlk, M., Florian, Z.: Limit States and Reliability, VUT Brno 2007 (in Czech).
- [2] A.F. Hobbacher: Recommendations for Fatigue Design of Welded Joints and Components, 1st edition, Springer Int. Publishing, Switzerland 2009.
- [3] M. Kocak: Welding in the World 51 (5-6) (2009) 95-105.
- [4] J. Sinay: Risk of technological plants, TU Košice 1997.
- [5] D. Daniš: AT&P Journal 10 (55-56) (2005).
- [6] I. Hrivňák: Welding and Weldability of Materials, STU Bratislava 2009 (in Slovak).
- [7] P. Polak: Corrosion Cracks Propagation Velocity, Welding Research Institute, Bratislava 1998.