Zukunft Bau

SUMMARY

Title

Development of assessment methods to avoid brittle failure of riveted and bolted steel structures

Initial situation

In the assessment of existing steel structures, the structural safety has to be considered as well as the safety against brittle failure. The normative regulations in DIN EN 1993-1-10 are not applicable for riveted or bolted structures made of old structural steels. For this reason, a method is developed for assessing the fracture toughness of quasi-statically stressed riveted or bolted components made of mild steel on the basis of fracture mechanics.

Subject of the research project

Serving as a basis for the assessment method, an extensive test program was carried out on components of existing steel structures which were built between 1904 and 1930. Material samples from different buildings, different types of cross sections and all types of old mild steels were investigated. In addition to the determination of material properties in the tensile test, the material toughness of the steels was analyzed. For this, on the one hand instrumented impact tests were performed to determine the transition temperatures T_{27J}. On the other hand, the fracture toughness K_{Jc} was determined in fracture mechanics tests in accordance to ASTM E1820. Subsequently, the reference temperature T_0 was determined by the Master Curve concept. Considering the heterogeneity of all material samples, the fracture toughness was determined according to the multimodal Master Curve concept. Based on this, the characteristic value of the fracture toughness (at 5% probability of failure) depending on the temperature was determined. The results were validated using existing data for fracture toughness of mild steels of old steel bridges. In addition, a possible correlation of the reference temperature T_0 of fracture toughness and the transition temperatures T_{27J} was checked.

In the investigations, the dependence of the material toughness on the chemical composition was clearly identifiable. Partially, the investigated mild steels had above-average contents of impurities. Therefore, the sample selection formed a good basis for determining conservative values of the fracture toughness. A differentiation between the more impure converter steels (e.g. Thomas steel) and the more pure Siemens-Martin steel was not definitely derivable from the amount of data.

Material properties at the hole and component edges were analyzed to investigate the crack initiation and crack size in quasi-statically stressed components made of mild steel. For this, mechanical and metallographic examinations were carried out with components with punched holes and component edges. The depth of the hardened edge zones was analyzed by means of micro-hardness measurements to quantify the degree of material hardening due to punching (local cold forming) and aging.

Typical cross sections and connection configurations were identified as the basis for subsequent fracture mechanic investigations by systematically analyzing the structural design of various steel truss structures. The main focus was on the relatively common connections

of angle sections. A distinction was made between connections with one and with several fasteners (rivets or bolts).

Extensive fracture mechanical FEM calculations were performed taking into account these structural conditions and the knowledge of the hardening of the punched holes. The stress intensity was determined at the crack tip of angle section connections with one fastener and the crack initiation at the edge of the hole. In order to derive an applicable equation for use in "hand calculations", the results of the FEM analysis were approximated by modification of a K-factor solution from the technical literature. Based on this, a solution was derived for angle section connections with several fasteners.

Equations for determining the limit load to avoid brittle fracture were derived for angle profile connections on the basis of fracture mechanics considering the results of the material tests and numerical calculations. In order to validate the equations and the described component failure, numerous tensile tests were carried out. Based on the experimentally determined failure loads, a statistical analysis was carried out according to DIN EN 1990. With this, the design values of the connection load capacity and the partial safety factors γ_M were determined for the application of the fracture mechanics assessment model.

Conclusion

Using the results of this research project, a semi-probabilistic assessment procedure is applicable to perform a safety assessment in order to avoid brittle fracture.

The material tests have verified that the assessment of old mild steels based on the minimum values of the Charpy impact energy in accordance with DIN EN 1993-1-10 is not suitable. The correlation of transition temperatures being valid for current steel grades should not be used for old mild steels. A different correlation could not be derived from the test results.

Key data

Short title: Assessment to avoid brittle failure of old steel structures

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FIGURES:

Figure 1: Lochrandanriss.jpg
Caption: Brittle fracture at the edge of a punched rivet hole

Figure 2: Sanz.gif
Caption: Comparison of the toughness of the investigated mild steels with those of modern structural steels (according to the mod. SANZ-correlation in DIN EN 1993-1-10)

Figure 3: Master-Curve.gif
Caption: Comparison of the fracture toughness of the investigated mild steels according to the Master Curve concept with those of old bridge steels

Figure 4: Mikrohärtemessung.jpg
Caption: Micro hardness measurements on the deformed ferrite-pearlite microstructure at a punched hole edge

Figure 5: Ein-Niet-Anschluss.png
Caption: Geometry definition of a connection with one rivet

Figure 6: Mehr-Niet-Anschluss.png
Caption: Geometry definition of a connection with two or more rivets