STATIC AND FATIGUE TESTS OF CRANE BRACKET JOINTS

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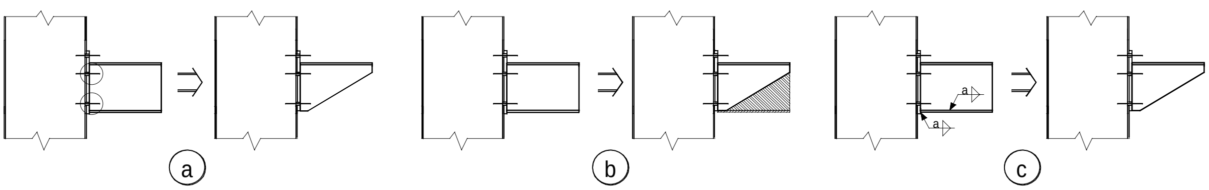
ABSTRACT

The paper presents the details and results of a monotonic and cyclic experimental study on bolted crane bracket joints of industrial type steel buildings. Most of these buildings include cranes of hoisting capacity below 200 kN. Generally, these cranes transmit the loads to the column of the main frame through crane brackets. For the cranes mentioned above the bolted crane bracket joints have significant advantages comparing to the usually applied welded brackets because of the simplicity in structural details and installation. The aim of the experimental study was to determine the static and fatigue behaviour and strength of the new type of bolted brackets without lower flanges. The investigation showed that brackets without compression flange and joints with backing plates instead of stiffeners are efficient alternatives in case of light cranes.

INTRODUCTION

Cranes, and therefore crane brackets, have become essential in today's industrial buildings. This calls for an interest in the effective design of these crane brackets.
There is a logical way of achieving better structural solution of crane brackets by omitting the compression flange. As compared to the traditional design, this solution offers the following advantages, as shown in Figure 1: (a) ease of installation, by ensuring better access to the bolts; (b) lower self-weight, by the omission of one of the flanges; (c) less welds and ease of their preparation.
In the current research the static and fatigue behavior of the modified crane brackets are studied by experiments.



(a) ease of installation (b) light construction (c) reduced length of welds

Fig. 1 Crane bracket design advantages

In the experimental programme 20 full scale specimens were included and covered six different bracket arrangements. The various bracket shapes and designs examined are shown in Figure 2.

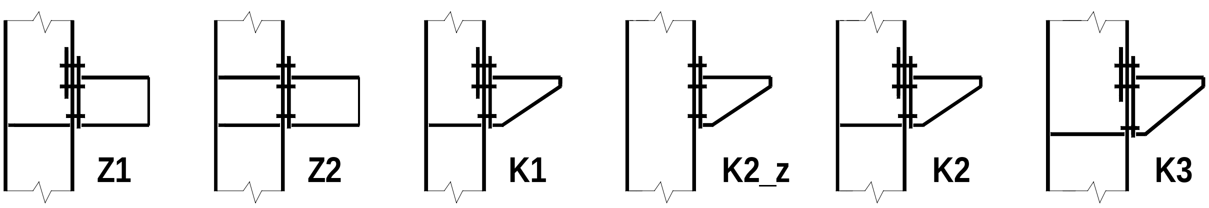


Fig. 2 The investigated details

The arrangements tested correspond to that used with overhead mobile cranes with a maximum capacity of 200 kN. Eight of the specimens were subjected to monotonic loading, whereas the remaining twelve, to cyclic loading. The main dimensions were identical in all tests.
The aim of the experimental study was, first, to determine the failure mode and the load bearing capacity of the brackets under static loads; and second, to study the behaviour of the crane brackets under fatigue loading. The arrangements examined belong to cranes of different load bearing capacities.

TEST SPECIMENS

Figure 3 shows the test specimens K1, K2 and K3 with their main plate dimensions.

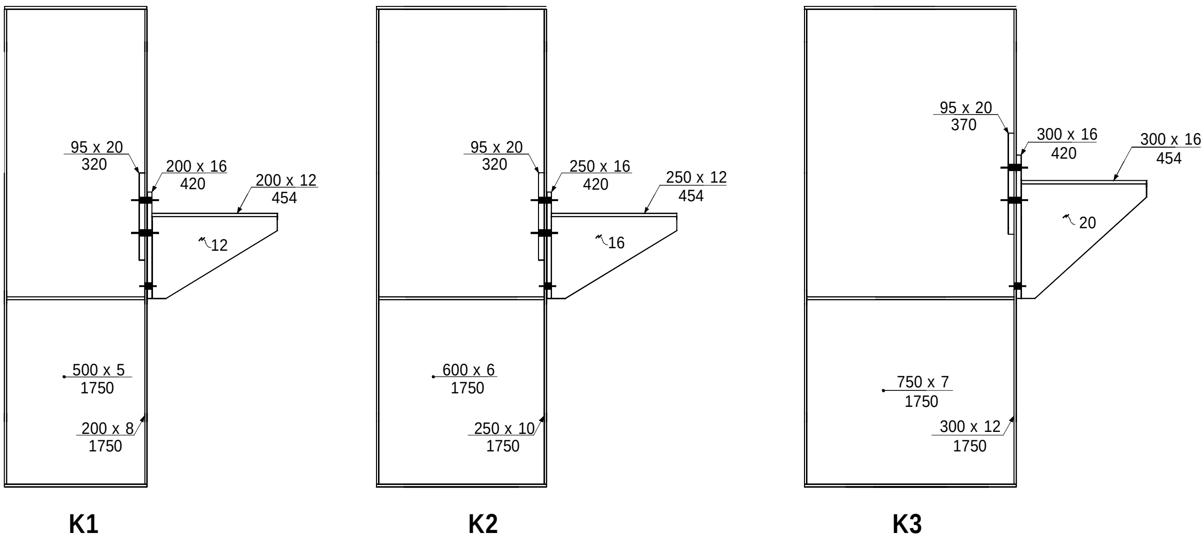


Fig. 3 The test specimens

The following dimensions were identical for all brackets: column height, 1770 mm; free bracket length, 470 mm; application point of the load (i.e. height and lever arm) on the crane bracket.
The steel grade of the test specimens was S355. The bolts were of 10.9 steel; the bolt diameters were M20 and M24 with normal clearances and washers; all bolts were preloaded (DIN 18 800: M20 by a preload of 160 kN; M24 by 220 kN). In all cases the brackets were fixed to the column with three bolt rows. All welds on the test specimens were double-side fillet welds. Table 1 shows a summary of the testing programme.

Table 1 Testing programme

Test specimen	Bolt M20	Bolt M24
Z1	-	static and fatigue
Z2	-	static and fatigue
K1	static and fatigue	static and fatigue
K2_z	-	static and fatigue
K2	static and fatigue	static and 2 times fatigue
K3	fatigue	static and 3 times fatigue

TEST ARRANGEMENT

A test frame was used so as to find a simple arrangement which is flexible (i.e. easy to install and suitable for all tests) enough to test all specimens under all load histories. Figure 4 shows the test frame used.

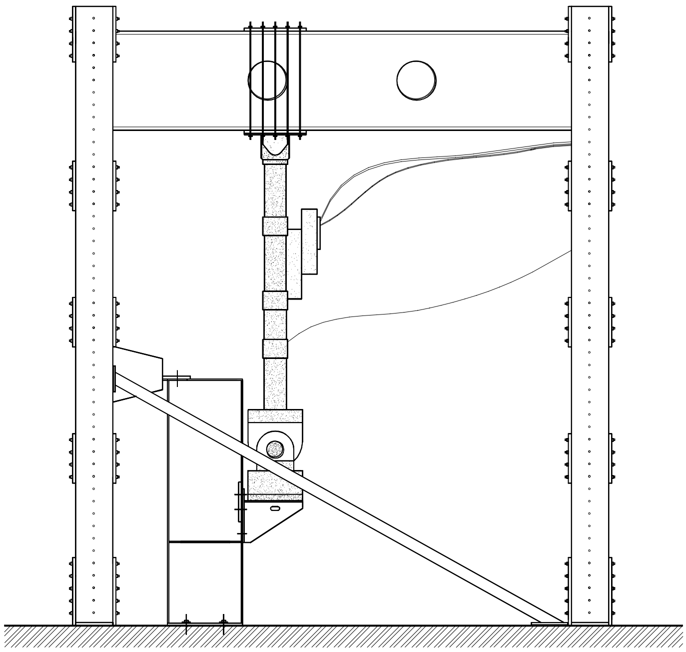


Fig. 4 The test frame

In the test arrangement the column-bracket sub-assembly is modelled by a fixed column base and a pin at the top of the column. The bracket is loaded in the vertical axis of the crane girder by downward and uplift forces using a loading system with one hydraulic actuator. In all tests the typical displacement are measured by transducers and the strain distribution is investigated by 12 gauges in average.

To prevent lateral torsional buckling the upper flange of the crane bracket was restrained by a plate as shown in Figure 5. This lateral support modelled the effect of the crane runway girder which effectively prevents lateral-torsional buckling.

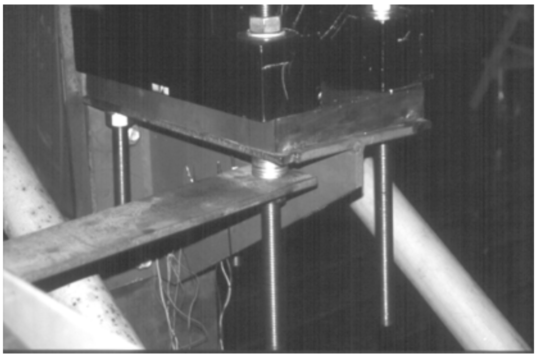


Fig. 5 Lateral support of bracket

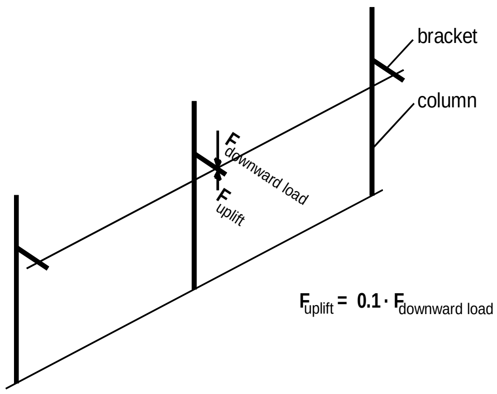


Fig. 6 Illustration of uplift load

In the case of continuous beams, there is uplift as well as downward force and we also simulated this uplift. In the fatigue tests this uplift load was equal to 10% of the downward vertical load, as shown in Figure 6.

STATIC TESTS

A total of eight static tests were carried out. For all static tests the load bearing capacity and failure mode was also calculated on the basis of a non-linear FEM model. After the tests, these models were re-evaluated using the actual material properties.
In all tests data were collected on a continuous basis with DMC Lab plus (Hottinger Baldwin Messetchnik). The collection tact was 1 second. A summary of the load-displacement diagrams is shown in Figure 7.

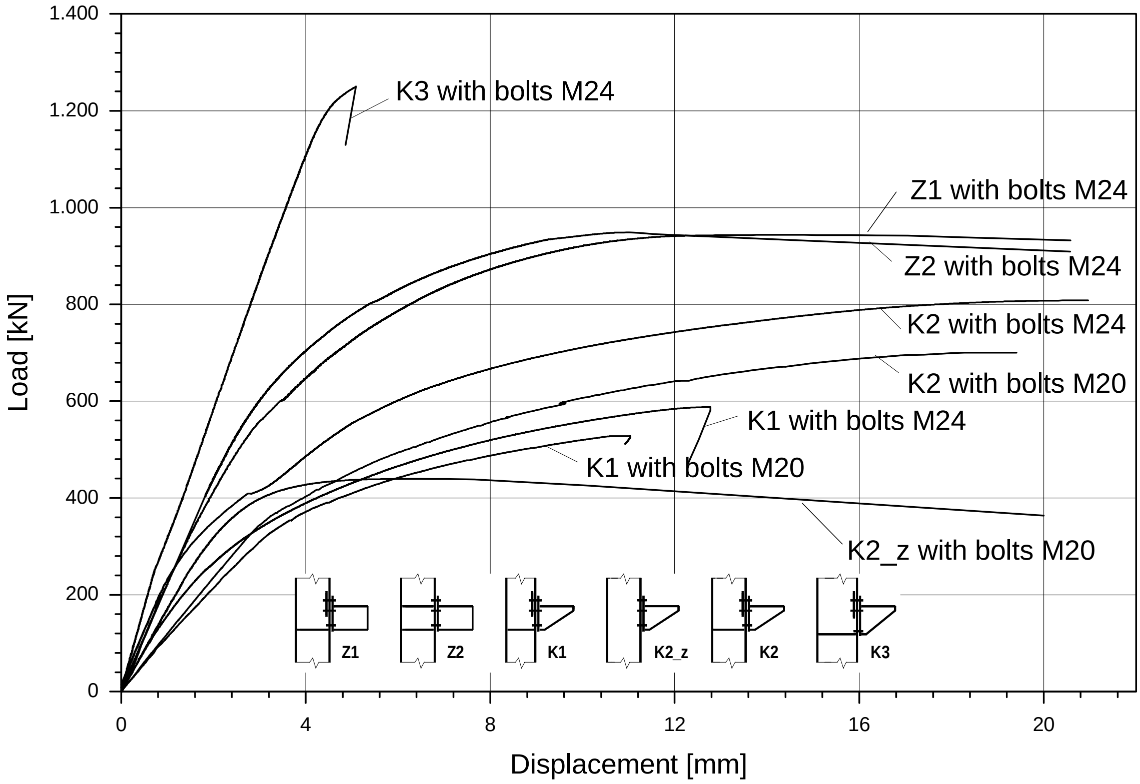


Fig. 7 Summary of load-displacement diagrams

The diagrams confirm the results of the FEM calculations. The load capacity and the initial stiffness of the brackets is nearly the same and does not depend on the bolt diameter, because of the collapse mode of the brackets.

Test specimens K1 and K2 failed by web buckling (Figure 8); specimen K2_z, by column web buckling; and specimens Z1 and Z2, by rupture in the end-plate. Test K3 was interrupted because the loading equipment reached its capacity (1250 kN). For further tests, therefore, the static load bearing capacity was assumed to be 1350 kN.

The FEM calculations show that the diameter of the bolts has only a slight effect on the load bearing capacity and the stiffness of light crane brackets. The FEM calculations also showed that the load bearing capacity and stiffness of the joint was nearly the same in both cases. The tests confirmed these calculations. This explains the failure mode observed in test items K1 and K2 caused by stability failure in the web, as shown in Figure 8.

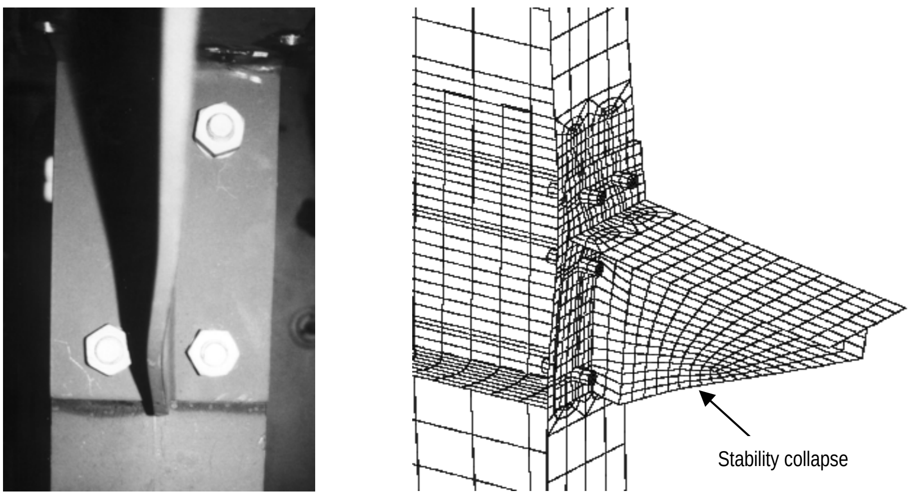


Fig. 8 Bracket web after stability failure in test specimen K1 and the FE model under ultimate load

For all static tests the load bearing capacity and the initial stiffness of the joints was also calculated on the basis of an analytical model. The applied model was the Eurocode 3 component model as modified for the particular case. This modification included, on one hand, that the cross-section of the bracket was always classified as class 4, and so the calculation was done on the basis of an effective cross-section (with the buckling part of the web and all bolts within omitted); secondly, a new stiffness coefficient to bracket web in compression, in a manner analogous to that of the column web in compression, was introduced. Figure 9 shows the load-displacement diagram as well as the "original" and the modified EC3 and FEM curves.

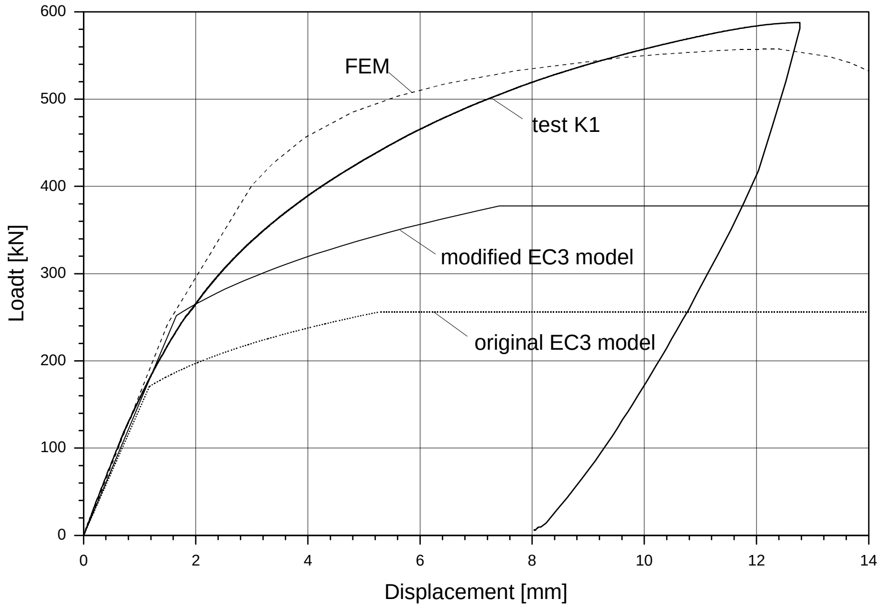


Fig. 9 Load-displacement diagram for test K1 with bolts M24

FATIGUE TESTS

The maximum fatigue load was equal to 70% of the static load bearing capacity. Figure 10 shows the load spectrum curve chosen, according to the recommendation of the DIN 15 018 standard. This curve was simplified by a four step approximation as shown in Figure 10. These steps were introduced so as to avoid difficulties of test control.

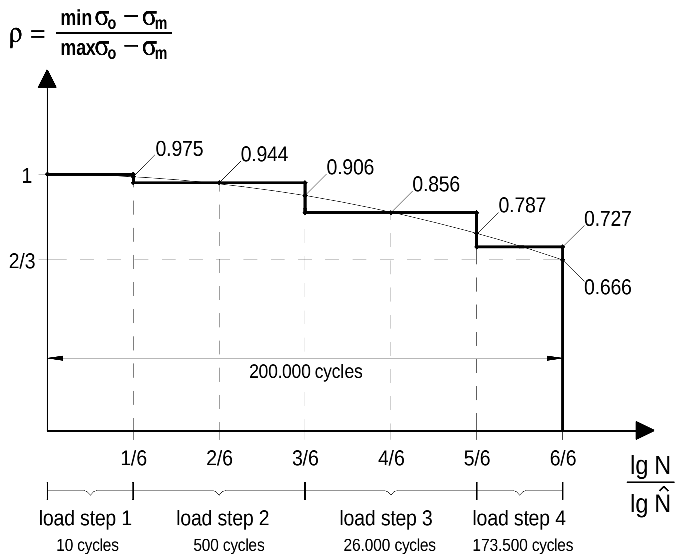


Fig. 10 Load spectrum curve and its step-like approximation

The fatigue tests simulated the continuous beam behaviour of the crane brackets. Therefore, the bracket flanges were subjected to both vertical downward loading and uplift (this latter equal to 10% of the downward load). The test specimens were loaded between 1 and 2 Hz.

Under the first and second load steps (10 cycles and 500 cycles) the collection of data was continuous at 20 Hz. In steps three and four, however, there was too much data to handle. This is the reason why we switched from continuous to sequential data collection, according to a rule shown in Figure 11. During each load cycle measurements were taken at least 10 times so as to facilitate post test evaluation. That is, the double requirement of both a sufficient degree of accuracy at the evaluation stage and a reasonable extent of data collection has been achieved by a 20 Hz data collection system. This system, contrary to what was applied in the case of static tests, was not continuous; it was restricted to the collection of data within intervals distributed periodically within the timeframe of the test, see Figure 11. This system proved to be accurate enough from the point of view of post test evaluation, and at the same time, ensured a reasonable amount of data.

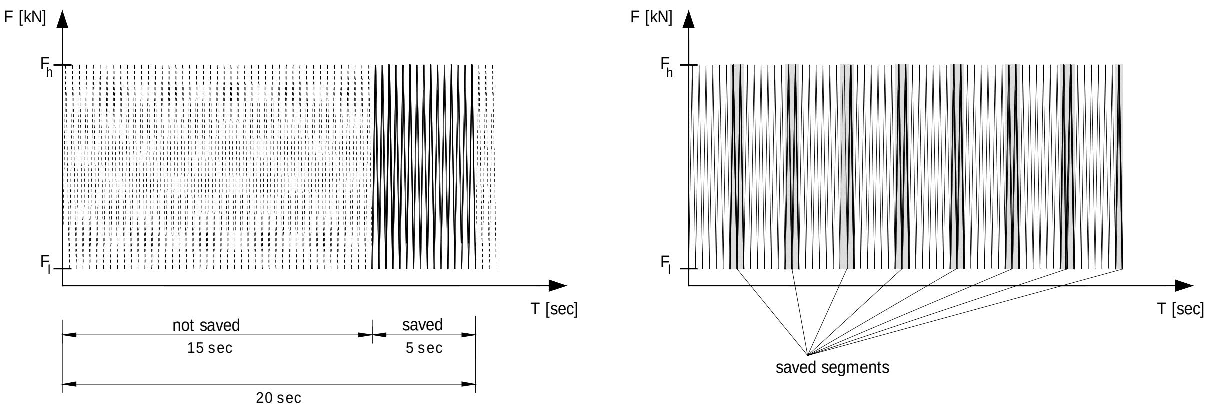


Fig. 11 Principle of the saving the measured data

Table 2 Summary of test results under repeated loading

test	static load bearing capacity from test [kN]	stiffness according to EC3 [kNm/rad]	maximum fatigue load. / static load bearing capacity [%]	load steps [kN]	load cycles achieved
Z1, M24	950	29.063	70	665 / 628 / 569 /	ca. 13.000
Z2, M24	950	46.653	70	665 / 628 / 569 / (483)	ca. 8.000
K1, M20	530	8.914	70	371 / 350 / 318 / 270	ca. 109.000
K1, M24	590	9.078	70	413 / 390 / 354 / 300	ca. 42.000
K2, M20	700	13.897	70	480	ca. 13.000
K2, M24	805	14.237	70	560 / 529 / 480 / (407)	ca. 22.000
K2, M24	805	14.237	41	334 / 316 / 286 / 243	ca. 293.000
K2_z, M24	437	3.680	70	306 / 289 /262 / 222	ca. 170.000
K3, M20	840	23.406	70	585 / 518 / 451	ca. 26.000
K3, M24	1.350	24.042	70	945 / 892 / 809 / (687)	ca. 13.000
K3, M24	1.350	24.042	53	715 / 675 / 612 / 520	ca. 154.000
K3, M24	1.350	24.042	35	468 / 442 / 401 / 340	ca. 589.000

( )* - load step not reached

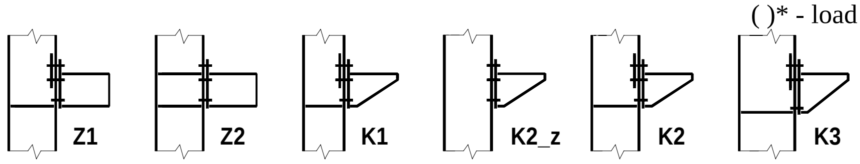


Table 2 shows a summary of test results under fatigue loading. The results show that the bracket load spectrum, and therefore the whole design concept, has significant influence on the fatigue behaviour of light brackets. The fatigue test of the arrangement K2 with bolts M24 was carried out twice. When subjected to lower load steps (initiated at 41% of the load bearing capacity), the specimen achieved 293.000 load cycles; the same design when subjected to higher load steps (initiated at 70%), achieved 22.000 load cycles only. The test specimens K2_z and K2 have the same geometry, but in specimen K2_z the stiffener in the compression zone and the backing plate was omitted. Subjected to the same load spectrum, the "flexible" arrangement K2_z achieved 170.000 load cycles against the 22.000 of K2.
Figure 12 shows load histories form test K3 with bolts M24 for three different load spectra. The diagram shows the difference in fatigue behaviour. The higher the load steps of cyclic loading as compared to the static load bearing capacity (i.e. the closer actual stresses are to the yield strength), the lower the number of cycles that causes the failure of the joint. When the joint was subjected to 70% and 53% of the static load bearing capacity respectively in the first step, joint failure was due to the rupture of the end plate at the height of the upper flange; when the same joint was initially subjected to 35% of the static load bearing capacity, testing was stopped at 589.000 cycles.

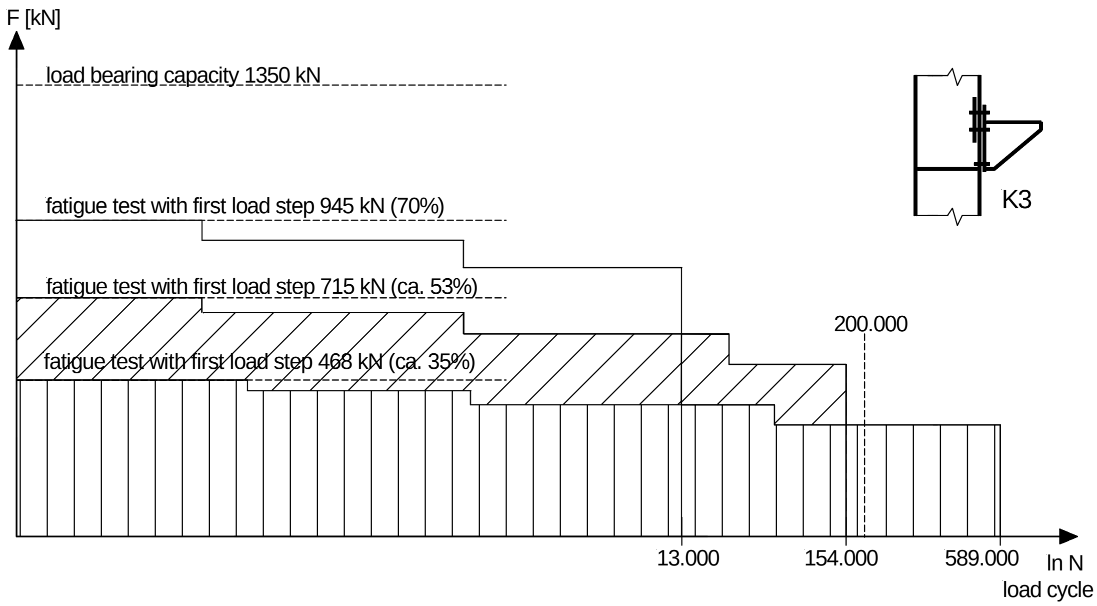


Fig. 12 Test specimen K3 under repeated loading with different load spectra

In tests Z1 and Z2 the achieved number of load cycles was significantly lower than in the case of test K2 (which was the nearest light bracket design according to its geometry). In both tests, failure was due to rupture in the end-plate at the height of the tension flange, see Figure 13.

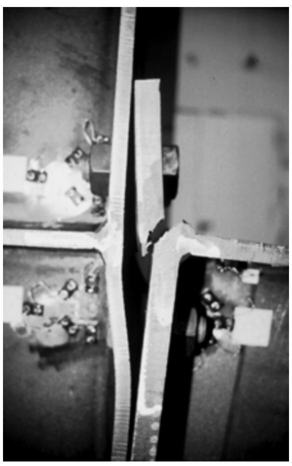


Fig. 13 Failure by rupture in the end-plate, test Z2

Failure occurred the “classical way”, i.e. at low load cycles (13.000 and 8.000, respectively), at the stress concentrations along the welds. The apparently poor fatigue behaviour of this arrangement is explained by its “excessive” rigidity which prevents the development of elastic response when subjected to such loading.

SUMMARY AND CONCLUSION

The experiments showed that brackets without compression flanges and joints with backing plates rather than stiffeners are competitive alternatives for use with light cranes.

For practical applications, the following conclusions are drawn.

- The load bearing capacity and stiffness of a bolted joint subjected to static loading can be enhanced (even without modifying the overall geometry of the joint) with no danger within certain limits. When there is fatigue loading, however, stiffness should be increased by applying larger overall dimensions rather than by introducing additional stiffeners.
- In joints under fatigue loading, abrupt premature failure such as bolt failure should be avoided by innovative solutions.
- In joints under fatigue loading, joint ductility is an important consideration; it is to ensure adequate behaviour under repeated loading.
- It is better not to stiffen the joint under fatigue loading. The tests show that specimens with higher stiffness fail earlier, i.e. under lower load cycles.
- Backing plate design has advantages against the use of welded stiffeners as its behaviour is more favourable with respect to load capacity and ensure better behaviour under fatigue loading, while easier to install and thus cheaper.
- For light cranes brackets without compression flanges are useful and economical alternatives. If the web thickness is chosen adequately, one can save the compression flange and the corresponding welding length, and at the same time such brackets are easier to install.

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REFERENCES

Pasternak, H., Katula, L. (1999). “Crane bracket-to-column joints for light overhead travelling cranes” (in German) *Bauingenieur*, 10/99, 432-437.

Standards
Eurocode 3, Part 1.1 Revised Annex J, Joints in Building Frames, Edited approved draft, January 1997
Eurocode 3, Design of Steel Structures, Part 1 General rules and Rules for Buildings, Edited draft, Brussels, April 1990
DIN 15 018 Teil 1: Krane; Grundsätze für Stahlbauwerke, Berechnung, 11/84, Teil 2: Krane; Stahlbautragwerke, Grundsätze für die bauliche Durchbildung und Ausführung, 11/84
DIN 18 800 Stahlbauten; Teil 1: Bemessung und Konstruktion, 11/90, Teil 2: Stabilitätsfälle, 12/90