New Applications of Headed Studs

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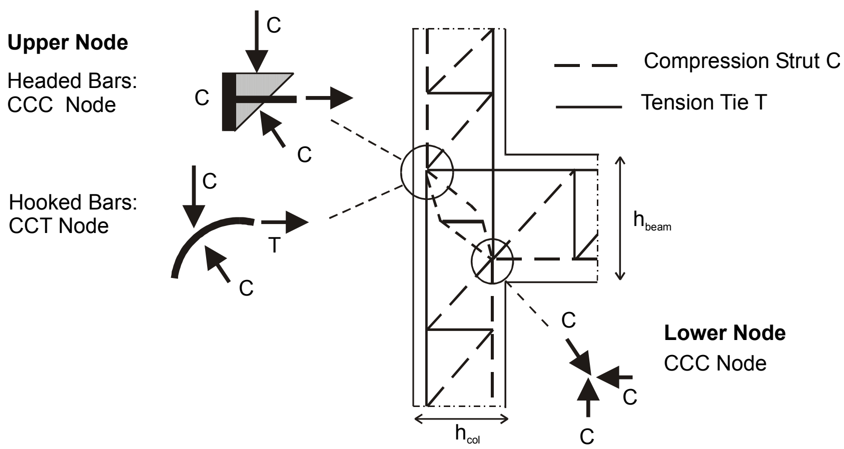
Summary

The anchorage of headed studs shows a negligible slippage of the reinforcement and is superior with respect to the load bearing capacity, the detailing, and the handling on site. In combination with threaded reinforcement and keyed concrete joints the industry of the concrete technology will be improved by this innovative reinforcement technology. The paper describes the experiments and numerical investigations, which were the basis for a new technical approval by the German DIBt. Furthermore, the applications of headed studs in concrete structures like parking structures are discussed.

Keywords: anchorage, beam column joints, corbels, headed studs, parking structures, threaded reinforcement.

1. Introduction

Tests on beam column-joints [1, 2] and corbles [3] with headed bars show an improved load bearing capacity. The strut-and-tie model shown in Fig. 1 can explain this. In the upper nodal zone of a beam column-joint, two different types of nodes may develop: a CCT node (two compression struts C and one tension tie T) in the case of hooked bars and a CCC node (3 compression struts C) in the case of headed bars. Due to confinement action, the strength of a CCC node is higher than a CCT node.



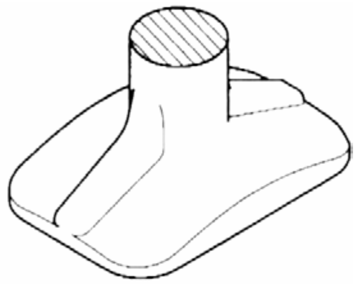


Fig. 1 Strut and tie model beam-column joint, new developed HDB-E headed anchor

2. Test-Specimens

In order to obtain a technical approval by the DIBt for the newly developed HDB-E anchor shown in Fig. 1, the Consulting Office Hegger and Partner carried out two test series with Halfen headed studs as tension ties in beam column joints (series RH in Table 1) and corbels (series KH in Table 2). In test KH 4 a precast column was tested with supplemented corbels. Two types of joints between the precast column and the corbels were investigated: a smooth joint and a keyed joint (see Fig. 2).

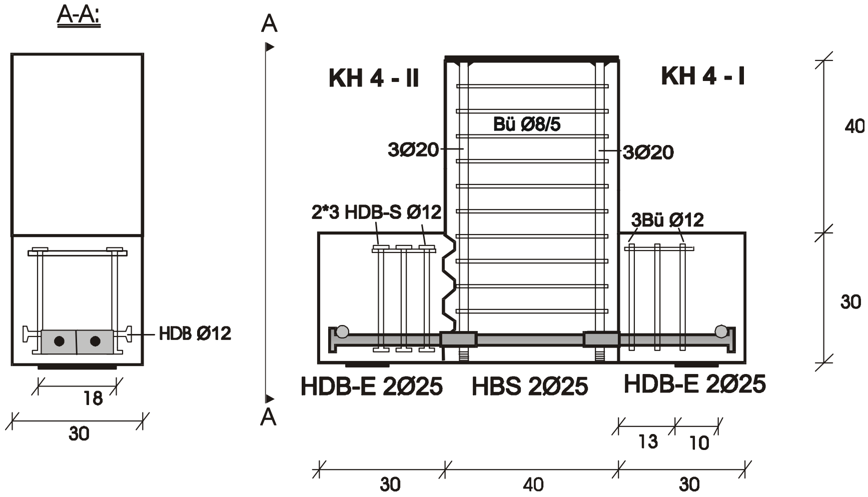


Fig. 2 Test specimen KH 4 with precast column

Table 1: Test Series RH (Beam Column Joints)

Test	$f_{c,cyl}$ *[MPa]*	h_{beam}/h_{col}	*Beam Tension Reinforcement*	N_{col} *[kN]*	ω *[-]*	*Joint Stirrups*	M_{Test} *[kNm]*	M_{Test}/M_{calc} η
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
RH 1	32,0	1,5	2·HDB-E ∅20	-100	0,26	4 Bü ∅10	90,2	1,10
RH 2	32,0	1,5	2·HDB-E ∅20	-750	0,26	4 Bü ∅10	67,2	0,82
RH 3	26,0	1,5	2·HDB-E ∅16	-500	0,19	3 Bü ∅10	59,4	1,13
RH 4	40,0	2,0	2·HDB-E ∅20	- 500	0,15	4 Bü ∅10	117,5	0,98
RH 5	50,5	1,5	2 HDB-E ∅20	-500	0,16	4 Bü ∅8	99,2	1,15
RH 6	50,5	1,5	2·HDB-E ∅25	-500	0,27	6 Bü ∅10	128,6	0,97

$f_{c,cyl}$ = concrete strength; joint slenderness h_{beam}/h_{col}; h_{beam} = depth of the beam; h_{col} = depth of the column; beam reinforcement with Halfen HDB-E-anchors; N_{col} = column normal force; ω = mechanical reinforcemnt ratio = $A_{S,HDB-E}\, f_y / (h_{beam}\, b_{beam}\, f_c)$; Joint stirrups = closed stirrups with 135° hooks; M_{Test} = Ultimate Beam Bending Moment in Test; Efficiency index η: M_{Test}/M_{calc}

Table 2 Test Series KH (Corbles)

		KH 1	KH 1-II	KH 2	KH 3	KH 4[1]	KH 4-II[2]
concrete	$f_{c,cyl}$ [MPa]	26,7	26,7	38,4	25,7	22,2	22,2
anchors	n	2	2	4	5	2	2
	$\varnothing_{HDB-E}$ [mm]	25	25	25	16	25	25
	f_y [MPa]	533	533	533	551	533	533
	A_s [cm^2]	9,81	9,81	19,62	10,05	9,81	9,81
Test	V_{Test}[MN]	**0,45**	**0,44**	**0,79**	**0,51**	**0,23**	**0,43**

[1] = smooth joint; [2] = keyed joint

$f_{c,cyl}$ = concrete strength, f_y= yield strength HDB-anchor; n = number of anchors

3. Test-Results

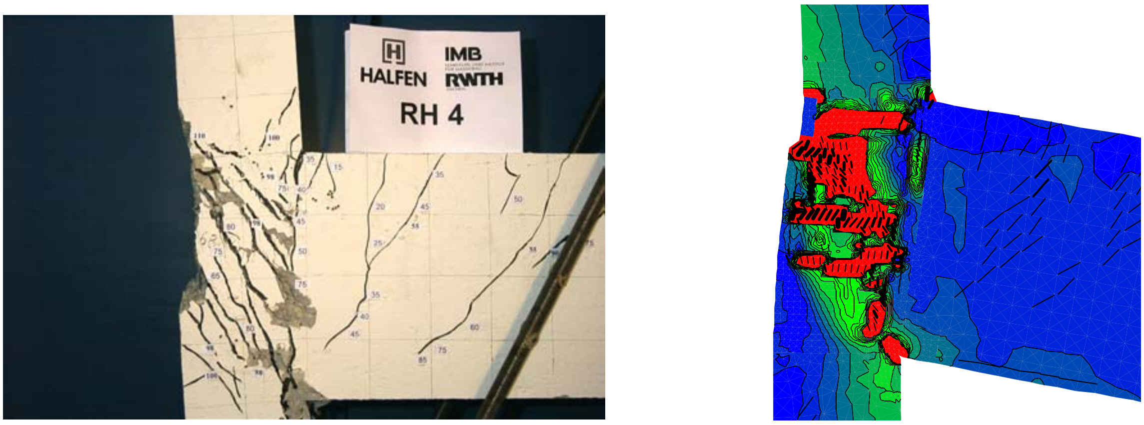


Fig. 3 Test specimen RH 4 and Finite Element Analysis

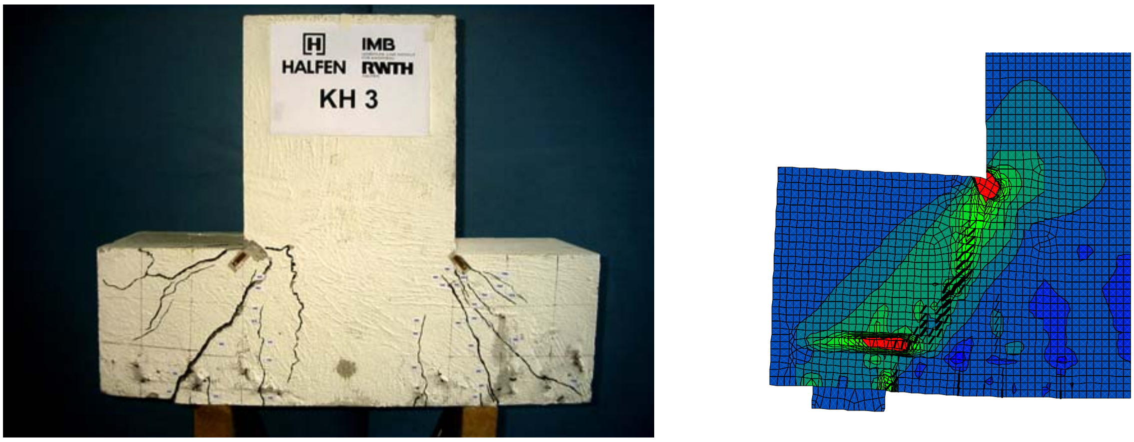


Fig. 4 Test specimen KH 3 and Finite Element Analysis

Tests on the beam column joints show two different failure modes, which can be distinguished by the design concept of Roeser [1, 4]:

a) **Bending failure** with a ductile load-deflection behaviour. The ultimate bending moment capacity of the beam is reached and the beam reinforcement is yielding. This type of failure is anticipated when designing beam-column joints.

b) **Joint failure** in which the ultimate bending moment capacity of the beam cannot be reached and a characteristic crack is observed inside the joint. The shear stress and the type of anchorage of the beam reinforcement influence the crack formation. Both are interrelated. At the ultimate limit state, the crack develops into the compression zone of the upper column. The ultimate strength depends on the quality of the anchorage. Using headed bars the anchorage capacity is increased by 20 % in comparison with bent bars [4].

In none of the current tests anchorage failure has been observed. In all cases the slippage of the anchor was less than 0.1 mm at a measured stress of σ_s = 500 MPa in the reinforcement indicating the superior anchorage behaviour of the headed bars.

Figure 3 shows test specimen RH 4 at failure. The results listed in Table 3 indicate the high efficiency of the anchorage of the reinforcement. The theoretical failure moment of the beam (bending failure) could be achieved. In some tests even exceeded.

All tests on corbels failed in pure shear indicating the efficiency of the anchorage of the flexural reinforcement. Figure 4 shows test specimen KH 3 at failure. The corble KH 4-II with a keyed joint shows nearly the same shear capacity as the monolithic corbels, whereas the smooth joint reached only 50% of the capacity (see Table 2).

In addition to the tests, extensive numerical investigations were carried out [5]. The failure mechanisms and the ultimate failure loads obtained from the FE-analysis agreed well with the ones observed in the experiments (see Figs. 3 and 4).

4. Applications

The high efficiency of the new anchorage system in addition to the simplicity achieved in the reinforcement detailing opens up a whole range of applications. In the field of beam-column joints in precast construction this system shows its superiority compared to traditional reinforcement detailing. Figures 5 and 6 shows the application of headed studs in innovative concrete parking structures. The prestressed beams of high strength concrete shows a remarkable slenderness of l/d = 16.5/0.55 = 30. The beams are connected to the columns by headed studs eliminating congestion of the reinforcement in the beam column joint and ease construction.

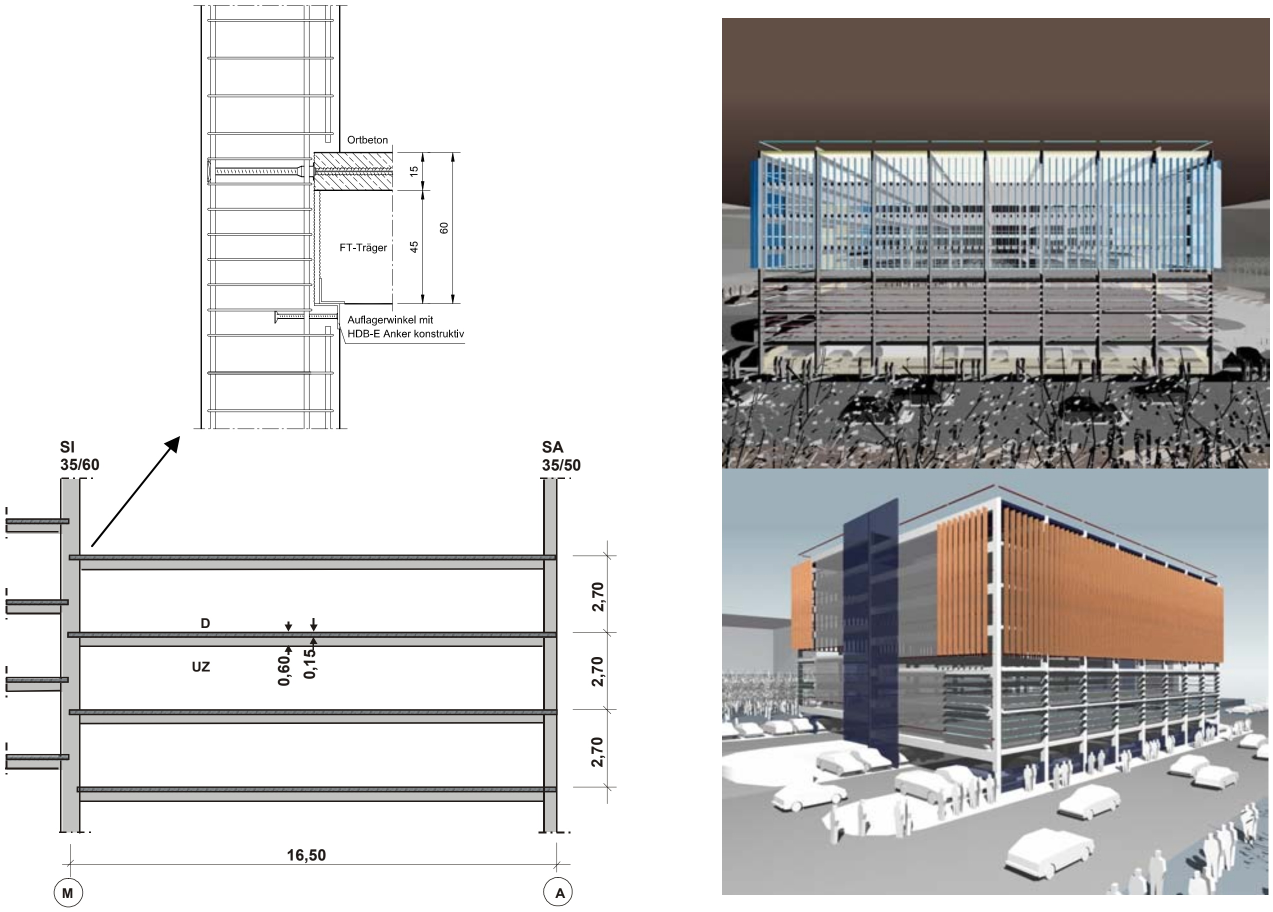


Fig. 5. Parking Structure I: structural detailing and architectural view [7]

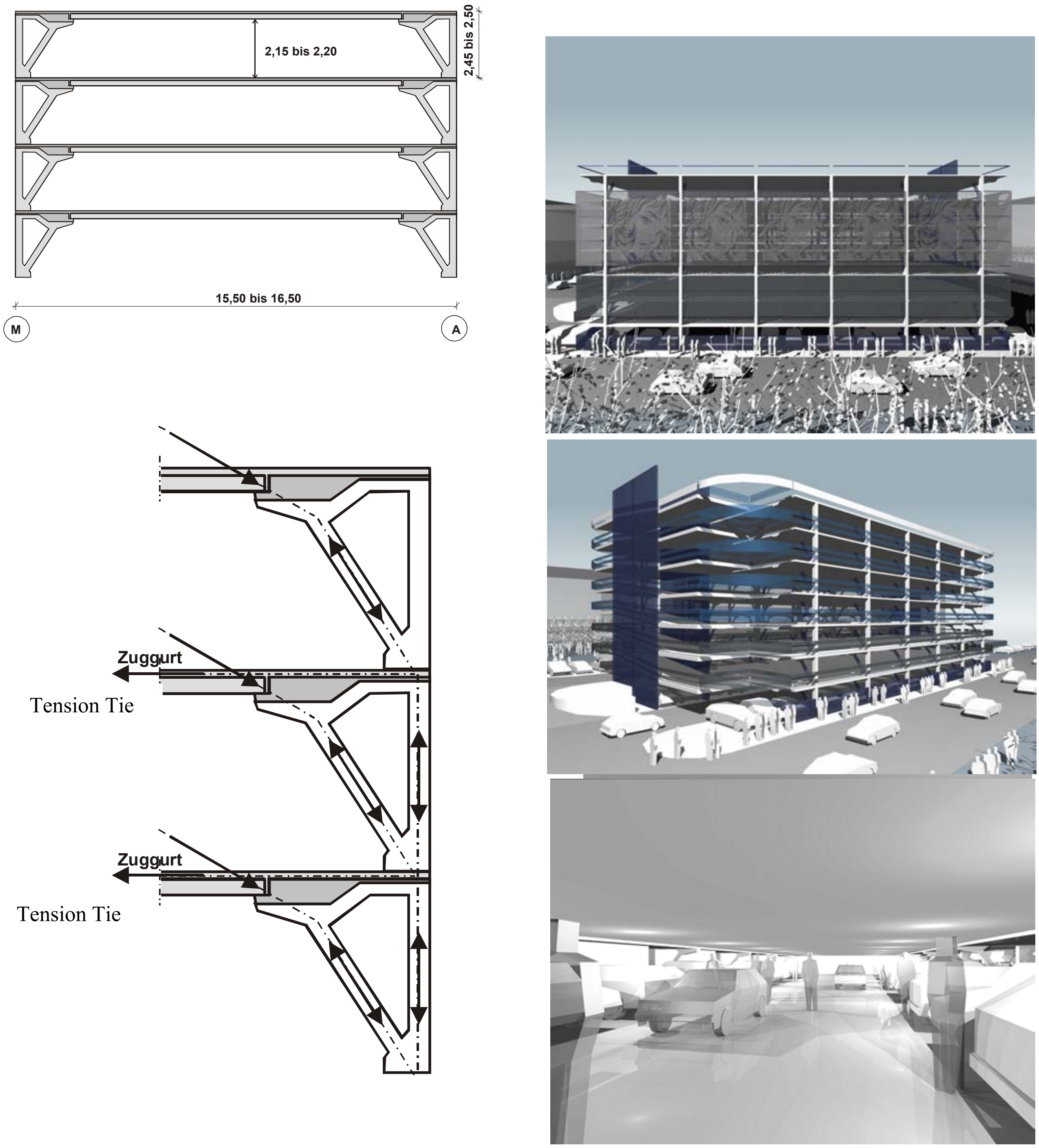


Fig. 6. Parking Structure II: structural detailing and architectural view [7]

5. Conclusions

The anchorage efficiency of headed bars as reinforcement in beam-column joints and corbels has been demonstrated. With the new developed rectangular headed studs it is possible to detail beam-column joints and corbles in an easy and effective way. With this innovative reinforcement layout elegant structures of cast in situ as well as precast concrete can be designed.

6. References

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