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Assessment of Reinforced Concrete Half Joint According to EN -1992-1-1

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Abstract. A half-joint is a particular type of RC structure .When using precast beams in reinforced concrete frame structures, dapped beams ends are often required in the bearing area to keep the floor structure as thin as possible. The arrangement and detailing of the reinforcement is an important factor in the performance of a half-joint. For pre-tensioned members, the prestressing force and tendons should be ignored, but for post-tensioned members the prestressing force should be considered as an external force acting on the half-joint. This paper aims to calculate dapped beam ends according to the EN 1992-1-1.

Keywords: Half-joint, Reinforcement, Strut-and-tie model, Tensile force

1. Introduction

When using precast beams in reinforced concrete frame structures, dapped beams ends are often required in the bearing area to keep the floor structure as thin as possible. Because anchorage of the diagonal tie Zs is difficult due to the geometrical conditions in strut-and-tie models with an inclined reinforcement portion of 100 %, a combined strut-and-tie model comprising perpendicular and inclined suspension reinforcement is selected under normal conditions.

This paper aims to calculate dapped beam ends or a half-joint according to the EN 1992-1-1.[1]

2. Half-joint calculation in accordance with EN 1992-1-1

The calculation is based on a strut-and-tie model combined of perpendicular and inclined suspension reinforcement in accordance with DAfStb¹ Booklet 399.[2]

The equilibrium in the strut and-tie model is determined by iterative addition of the required stirrups and the recalculation of the centres of gravity of the reinforcement.
Strut-and-tie model consisting of inclined suspension reinforcement.

The inclined model is always used in combination with the model of perpendicular suspension reinforcement to prevent shearing of the half joint along the inclined bars. This model is more suitable for mapping the actual load-bearing behaviour of higher beam corbels.

¹ German Committee for Reinforced Concrete

$$F_{ZV} = (F_{ed} - F_{1ed}) \cdot \text{inclined reinforcement portion} \quad (1)$$

2.2. Strut-and-tie model consisting of perpendicular suspension reinforcement

While the model of inclined suspension reinforcement results directly from the support geometry, the geometry of the model of perpendicular reinforcement is determined through the dimensioning of the nodes 1 and 2 of the inclined strut (D1), see Figure 2.

Fig. 1. Strut-and-tie model a) and an alternative Strut-and-tie model b)

It is assumed that the stress limit in node 2 (stress σ_{cd2} depends on a_4) is complied

$$\sigma_{Rdmax} = k_2 \cdot v' \cdot f_{cd} \quad (2)$$

with; k_2 and v' are assumed in accordance with the selected National Annex (NA).

$$\text{- for Germany: } k_2 = 0.75, v' = 1.1 - f_{ck} / 500 \leq 1.0 \quad (3)$$

$$\text{- for Austria: } k_2 = 0.9, v' = 1.0 - f_{ck} / 250 \leq 1.0 \quad (4)$$

The exact compression strut position with the dimensions of the nodes 1 and 2 is determined in the above expressions and the given border conditions such as the concrete cover and the centre of gravity of the suspension reinforcement and the horizontal reinforcement. By defining unfavourable half joint dimensions and/or if a high number of reinforcement layers is required, an inclination of the compression strut below 30° can result.

Fig. 2. The geometry of the strut-and-tie model

2.3. Tensile force in the vertical suspension reinforcement:

$$F_{ZV} = (F_{ed} - F_{1ed}) \cdot (1 - \text{inclined reinforcement portion}) \quad (5)$$

Compression strut inclination:

$$\Phi_1 = \arctan\left(\frac{h_c}{l_c}\right) \quad (6)$$

$$\sigma_{cd2} = \frac{F_{ZH}}{(b_k \cdot a_4)} \quad (7)$$

$$b_k = \text{half-joint width}; F_{ZH} = F_{ZV} \cdot \frac{l_c}{h_c} \quad (8)$$

$$\text{Compressive strut force: } F_C = F_{ZV} / \sin(\Phi_1) \quad (9)$$

2.4. Horizontal forces due to the compressive strut geometry that are to be anchored:

$$F_{ZH} = (F_{ZV} + F_{1ed}) \cdot \left(\frac{l_c}{h_c}\right) + H_{ed} \quad (10)$$

2.5. Verification of the load-bearing capacity of the compressive concrete strut:

Compliance with the following condition must be verified

$$F_{ed} \leq V_{rd,max} \quad (11)$$

$$V_{rd,max} = \alpha_{cv} \cdot b_v \cdot z \cdot v_1 \cdot f_{cd} / (\cot \theta + \tan \theta) \quad (12)$$

Where:

α_{cv} is a coefficient taking account of the state of the stress in the compression chord

b_v is the minimum width between tension and compression chords

z is the inner lever arm, for a member with constant depth, corresponding to the

bending moment in the element under consideration, the approximate value $z = 0.9 \cdot d$ may normally be used. International Journal of Business and Technology, Vol. 5, Iss. 1 [2016], Art. 3
 v_1 is a strength reduction factor for concrete cracked in shear
 f_{cd} is design value of concrete compressive strength
 θ is the angle between the concrete compression strut and the beam axis perpendicular to the shear force, The angle θ should be limited

$$1 \leq \cot \theta \leq 2.5 \quad (13)$$

2.6. Verification of node 1 (bearing stress):

The verification of the compressive stress underneath the load plate is based on EN 1992-1-1: With the following conditions underneath the load plate:

$$\sigma_{ld} = \frac{F_{ed}}{(l_p \cdot b_p)} \leq \sigma_{rd} = k_2 \cdot v' \cdot f_{cd} \quad (14)$$

k_2 and v' in accordance with the applicable National Annex (NA)

- for Germany: $k_2 = 0.75$, $v' = 1.1 - f_{ck}/500 \leq 1.0$

- for Austria: $k_2 = 0.9$, $v' = 1.0 - f_{ck}/250$

and in node 1:

$$a1(1) = 2 \cdot d_1 \quad (15)$$

$$a2(1) = \left(a1(1) \cdot \left(\frac{l_c}{h_c} \right) + l_p \right) \cdot \sin(\Phi_1) \quad (16)$$

$$\sigma_{cd} = \frac{F_c}{a2(1) \cdot b_p} \leq \sigma_{rd} = k_2 \cdot v' \cdot f_{cd} \quad (17)$$

k_2 and v' as with node 1 for bearing stress, σ_{ld} and σ_{cd} can be limited to $0.85 \cdot f_{cd1}$ in accordance with Schlaich/Schäfer.

Fig. 3. Model for the back anchorage of the horizontal force

The tensile force of the vertical suspension reinforcement:

$$F_{ZV} = (F_{ed} - F_{1ed}) \cdot (1 - \text{inclined reinforcement portion}) + H_{ed} \cdot \frac{h_c}{z} \quad (18)$$

3. Worked example Design of Half Joint Using Strut-Tie Model

Multiphase Assessment of Reinforced Concrete Half Joint According to EN-1992

The beam in fig.4. is 7.0 m simply supported. The beam is 140cm x 75 cm broad. The height of the half joint h_k is 65 cm while the length of the half joint l_k is 50 cm at each end. The beam supports a uniformly distributed load of 200 Kn/m. Assume C30/37 Mpa and B500B Mpa.[3]

Fig. 4. A reinforced concrete “Half Joint” beam

Analysis:

$$A = p \times (L/2 + 0.5/2) = 200 \times 3.75 = 750 \text{ Kn} \quad (19)$$

$$\text{Bending moment at mid-span} = 750 \times 3.50 - 200 \times 3.75^2/2 = 1218.75 \text{ Knm} \quad (20)$$

$$d_1 = c + \phi/2 = 4.0 + 2.0/2 = 5.00 \text{ cm} \quad (21)$$

$$d = h - d_1 = 140 - 5.25 = 135 \text{ cm} \quad (22)$$

CROSS SECTION

$$\text{cross section values } z_u = 70 \text{ cm} \quad A_c = 1.0500 \text{ m}^2 \quad I_c = 0.17150000 \text{ m}^4 \quad (23)$$

$$\text{BENDING DESIGN } k_d \text{- method } (x/d < 0.448), \quad M_{yd} = 1218.80 \text{ kNm} \quad (24)$$

$$\epsilon_{1s} = -2.85 \text{ o/oo} \quad \epsilon_{2s} = 45.00 \text{ o/oo} \quad x/d = 0.07 \quad z/d = 0.97 \quad k_d = 3.35 \quad (25)$$

$$\text{required Bottom longitudinal reinforcement } (A_{sb}) = 19.85 \text{ cm}^2 \quad \mu = 0.19 \% \quad (26)$$

$$\text{Provide: } 7R \phi 20 = 21.98 \text{ cm}^2 \quad (27)$$

$$\text{Top longitudinal reinforcement } (A_{s'}) : 4 \phi 20 = 12.57 \text{ cm}^2 \quad (28)$$

Table 1. Pulled up bearing by EN 1992-1-1:2004 C 30/37 B500B

support force	$F_{ed} = 750.0 \text{ kN}$
horizontal force (UK)	$H_{ed} = 150.0 \text{ kN}$
dist. axis of support - front edge notch	$e_1 = 25.0 \text{ cm}$
cross section of	$b_0 = 75.0 \text{ cm}$ $h_0 = 140.0 \text{ cm}$
console	$l_k = 50.0 \text{ cm}$ $h_k = 65.0 \text{ cm}$
dimensions of sup bp	$b_p = 36.0 \text{ cm}$, $l_p = 27.0 \text{ cm}$, concrete cover $c = 5.0 \text{ cm}$
distance upper and lower reinforce. (UE- and LE-centroid)	$d_o = 6.6 \text{ cm}$

pressure strut D1 inclination $\phi_1=37.63$ degr.

node 1 (below) $a_1=18.0$ cm $a_2=32.9$ cm

node 2 (above) $a_4=13.2$ cm $d_4=6.6$ cm

tied arch Zh (horizontal reinforcement) :

distance to upper edge beam $h_1 = 49.8$ cm

tied arch Zv (suspension reinforcement) :distance to front edge notch $d_1= 28.0$ cm

distance from axis of support $d_a = 53.0$ cm

Tie ZV2 (suspension reinforcement 2):distance to front edge notch $d_2=111.6$ cm

Internal forces

for vert. stirrups ZV1 (with contribution $Z_v = 819.1$ kN

for vert. stirrups ZV2 $Z_v = 972.9$ kN

horizontal tensile force $Z_h = 1175.7$ kN

Design

carrying capacity $F_v=750.00$ kN < $V_{rdmax} = 1406.23$ kN

trans. tens.force $F_{td}=86.25$ kN

pressure at supp. $\sigma_{ld} = 7.72$ N/mm² < $\sigma_{rdmax}=12.72$ N/mm²

inpressure strut $\sigma_{cd}=10.36$ N/mm² < $\sigma_{rdmax}=12.72$ N/mm²

suspens.stirr ZV1 $A_{c,req}=18.84$ cm² < $A_{c,exis} = 20.34$ cm²

suspens.stirr.ZV2 $A_{c,req}=22.38$ cm² < $A_{c,exis} = 22.60$ cm²

horizont.stirrups $A_{c,req}=27.04$ cm² < $A_{c,exis} = 31.40$ cm²

reinforcement

Fig. 5. A reinforcement of concrete "Half Joint" beam[4]

Conclusions

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The EC2 model avoid any unsafe predictions in the shear strength. Adequate anchorage should also be provided for the tensile steel reinforcement at the supports to prevent premature reinforcement slip failure. As shown in fig.5. the following stirrups are provided: ZV1 ϕ 12 2- set in 9 layers with 20.34 cm², for ZV2 ϕ 12 2- set in 10 layers with 22.60 cm² and for horizontal stirrups ϕ 20 2- set in 5 layers with 31.40 cm². The Eurocode 2 strut-and-tie model can be unsafe when a_v/d ratio is in between 1 and 2.

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