7. BENT ELEMENTS

BENT ELEMENT

- LINEAR: JOIST / BEAM / GIRDER (US)
- SLAB

	WIKIPEDIA	CAMBRIDGE DICTIONARY	BBC DICTIONARY	OXFORD DICTIONARY
Joist SE grinda	Horizontal supporting members that run from wall to wall, wall to beam, or beam to beam to support a ceiling, roof or floor	A long thick piece of wood, steel or concrete which is used in a buildings to support a floor or ceiling	Long , thick piece of wood, metal or concrete that is used in buildings or other structures, especially to support a floor or ceiling	A length of timber or steel supporting part of the structure of a building, typically arranged in parallel series to support a floor or ceiling
Beam SE grinda	Structural element that is capable of withstanding load primarily by resisting bending	A long thick piece of wood, metal or concrete, especially used to support weight in a building or other structure	Long thick bar of wood, metal or concrete, especially one which is used to support the roof of a building	Long, sturdy piece of squared timber or metal used to support the roof or floor of a building
Girder ME rigla	The main horizontal support of a structure which supports smaller beams	A long thick piece of steel or concrete, etc. which support a roof, floor, bridges or other large structure	Long thick piece of steel or iron that is used in the frameworks of building and bridges	Large iron or steel beam or compound structure used for building bridges and the framework of large buildings

SE - secondary element
ME - main element

7. BENT ELEMENTS

BEAM

$\ell \geq 3\mathrm{h}$; usual $\ell/\mathrm{h} = 8...10$

STATIC ANALISYS $\rightarrow$ M_{Ed}, N_{Ed}, V_{Ed}

M_{Ed} & N_{Ed} $\rightarrow$ BENDING WITH AXIAL FORCE

SR EN 1998 & P100: $N_{Ed} \leq 0{,}1 A_c f_{cd}$ $\rightarrow$ axial force may be neglected

SLAB

$\ell_{\min} \geq 5\mathrm{h}_{\text{slab}}$

7. BENT ELEMENTS

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

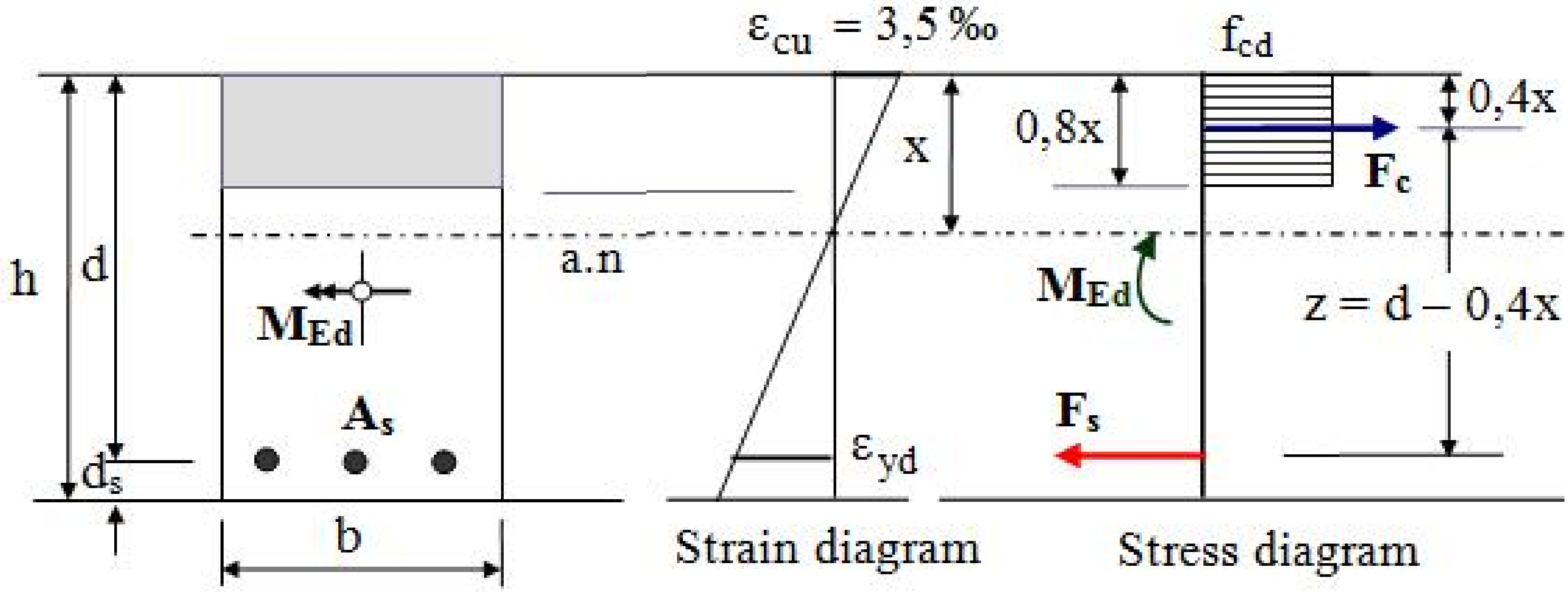
7.2. DOUBLE REINFORCED RECTANGULAR SECTION

7.3. SIMPLE REINFORCED FLANGED SECTION

7.4. DOUBLE REINFORCED FLANGED SECTION

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

7.1.1. SECTION ANALISYS



- stress block -

$$F_s = A_s f_{yd}$$

$$F_c = 0{,}8\, b x\, f_{cd}$$

d – useful depth

z – internal lever arm

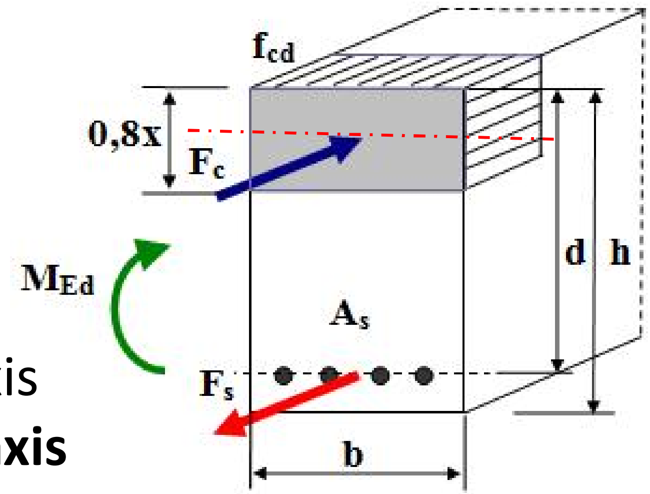
7.1. SIMPLE REINFORCED RECTANGULAR SECTION

EQUILIBRIUM CONDITIONS WILL BE ACHIVED BY THE EQULISATION OF THE ACTION EFFECTS WITH THE RESISTING INTERNAL FORCES

$\Sigma F = 0$

$\Sigma M = 0$

Bending moment can be related to any axis as for instance to the A_s **axis** or to the F_c **axis**



7.1. SIMPLE REINFORCED RECTANGULAR SECTION

$\Sigma F = 0$

$$F_c = F_s \rightarrow 0{,}8bxf_{cd} = A_s f_{yd}$$

$$x = 1{,}25 \frac{A_s f_{yd}}{bf_{cd}}$$ with $\xi = \frac{x}{d}$ $\rightarrow$ $\xi = 1{,}25 \frac{A_s f_{yd}}{bdf_{cd}}$

$$\xi = 1{,}25 \frac{A_s}{bd} \cdot \frac{f_{yd}}{f_{cd}} = 1{,}25\rho \frac{f_{yd}}{f_{cd}}$$ with $\rho = A_s / bd$ - reinforcement ratio

$\xi \rightarrow$ relative value of neutral axis depth

$$\omega = \rho \frac{f_{yd}}{f_{cd}}$$ - mechanical ratio of reinforcement

$$\xi = 1{,}25\omega \rightarrow \omega = 0{,}8\xi$$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

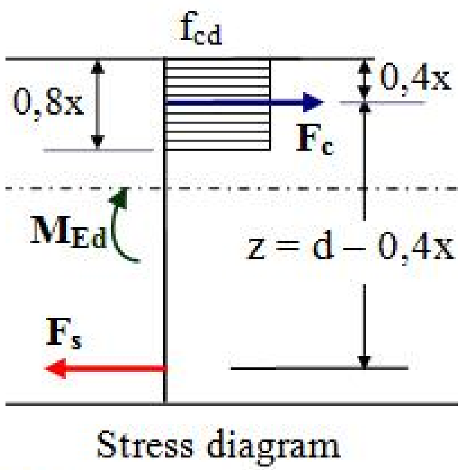
$\Sigma M = 0 \rightarrow$ related to the $\mathbf{A_s}$ **axis**

$$M_{Ed} = F_c\, z$$

$$z = d - 0{,}5(0{,}8x) = d - 0{,}4x$$

$$M_{Ed} = 0{,}8\, b\, x\, f_{cd}(d - 0{,}4x)$$

with $x = \xi d$



$$M_{Ed} = 0{,}8\, b(\xi d) f_{cd}\left[d - 0{,}4(\xi d)\right] = b\, d^2 f_{cd}\, 0{,}8\, \xi(1 - 0{,}4\xi)$$

with $\mu = 0{,}8\xi(1 - 0{,}4\xi)$; but using $\xi = 1{,}25\omega \;\rightarrow\; \mu = \omega(1 - 0{,}5\omega)$

(*) $$M_{Ed} = \underbrace{\mu\, b d^2 f_{cd}}_{M_{Rd}}$$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

$\Sigma M = 0 \rightarrow$ related to the **A_c axis**

$$M_{Ed} = F_s z$$

$$M_{Ed} = A_s f_{yd}(d - 0{,}4x)$$

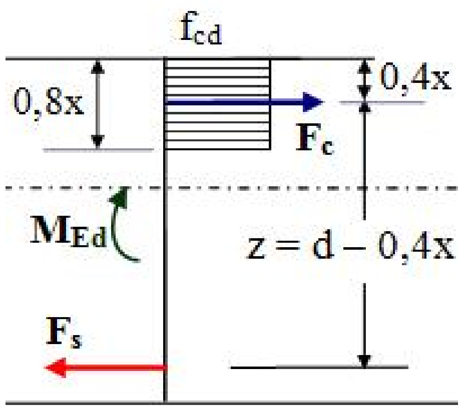
$$M_{Ed} = A_s f_{yd}(d - 0{,}4\xi d) = A_s f_{yd} d(1 - 0{,}4\xi)$$

with $\zeta = \frac{z}{d} = 1 - 0{,}4\xi$

already knowing $\xi = 1{,}25\omega$

$\zeta = 1 - 0{,}5\omega \rightarrow$ relative value of the lever arm

$$M_{Ed} = \underbrace{\zeta d A_s f_{yd}}_{M_{Rd}}$$



Stress diagram

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

In conclusion, one of the following relationships may be used for resisting bending moment calculation

$$M_{Rd} = \mu b d^2 f_{cd}$$

$$M_{Rd} = A_s f_{yd} \zeta d$$

WAYS TO INCREASE RESISTING BENDING MOMENT			
h	h ↗ 2h	100% same as d ↗ ≈110%	110%
p	1% ↗ 2%	100%	(60…80%)
f_{yd}	PC52 ↗ PC60	45%	37%
f_{cd}	20 MPa ↗ 40 MPa	100%	6%
b	b ↗ 2b	100%	6%

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

ALL PREVIOUS COEFFICIENTS ARE RELATED BETWEEN THEM BY ρ, f_{cd} & f_{yd}

TWO TYPES OF TABLES MAY BE USED FOR CALCULATIONS:

Table ①: any type of steel & concrete with $f_{ck} \leq 50$ MPa

Table ②: steel PC52, PC60, S400, S500 & concrete with $f_{ck} \leq 50$ MPa

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Table ①

Calculation of bent elements with rectangular or flanged section

$f_{ck} \le 50$ MPa & any steel

	μ	ω	ξ
	0,05	0,051	0,064
	0,06	0,062	0,077
	0,07	0,073	0,091
	0,08	0,083	0,104
	0,09	0,094	0,118
	0,10	0,106	0,132
	0,11	0,117	0,146
	0,12	0,128	0,160
	0,13	0,140	0,175
	0,14	0,151	0,189
	0,15	0,163	0,204
	0,16	0,175	0,219
	0,17	0,188	0,234
	0,18	0,200	0,250
	0,19	0,213	0,266
	0,20	0,225	0,282
	0,21	0,238	0,298
	0,22	0,252	0,315
	0,23	0,265	0,331
	0,24	0,279	0,349
	0,25	0,293	0,366
	0,26	0,307	0,384
	0,27	0,322	0,402
	0,28	0,337	0,421
	0,29	0,352	0,440
	0,30	0,368	0,459
	0,31	0,384	0,479
	0,32	0,400	0,500
limit values for steel:	0,33	0,417	0,521
	0,34	0,434	0,543
	0,35	0,452	0,565
	0,36	0,471	0,589
S500	**0,372**	**0,490**	**0,617**
S400	**0,392**	**0,531**	**0,668**
PC60	**0,395**	**0,553**	**0,676**
PC52	**0,407**	**0,569**	**0,710**

Formulas

$$\mu = \frac{M_{Ed}}{b\,d^2 f_{cd}}$$

$$\omega = \frac{A_s}{b d f_{cd}}$$

$$A_s = \omega b d \frac{f_{cd}}{f_{yd}}$$

$$M_{Rd} = \mu\, b\, d^2 f_{cd}$$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Table ②a

Calculation of bent elements with rectangular or flanged section

PC52 & $f_{ck} \leq 50$ MPa

$f_{yd} = 300$ MPa; $\xi_{max} = 0{,}710$

$$\mu = \frac{M_{Ed}}{b\,d^2 f_{cd}}\ ;\ \omega = \frac{A_s}{b\,d f_{cd}};\ A_s = \omega b d \frac{f_{cd}}{f_{yd}} = \frac{p}{100} bd\ ;\ M_{Rd} = \mu\, b\, d^2 f_{cd}$$

μ	ω	ξ	C12	C16	C20	C25	C30	C35	C40	C45	C50
			reinforcement percentage p = 100A_s/bd								
0,02	0,020	0,025	0,054	0,072	0,090	0,112	0,135	0,157	0,180	0,202	0,224
0,04	0,041	0,051	0,109	0,145	0,181	0,227	0,272	0,318	0,363	0,408	0,454
0,06	0,062	0,077	0,165	0,220	0,275	0,344	0,413	0,482	0,550	0,619	0,688
0,08	0,083	0,104	0,223	0,297	0,371	0,464	0,557	0,649	0,742	0,835	0,928
0,10	0,106	0,132	0,282	0,375	0,469	0,587	0,704	0,821	0,938	1,056	1,173
0,11	0,117	0,146	0,312	0,415	0,519	0,649	0,779	0,909	1,038	1,168	1,298
0,12	0,128	0,160	0,342	0,456	0,570	0,712	0,855	0,997	1,140	1,282	1,425
0,13	0,140	0,175	0,373	0,497	0,621	0,776	0,932	1,087	1,242	1,398	1,553
0,14	0,151	0,189	0,404	0,539	0,673	0,842	1,010	1,178	1,346	1,515	1,683
0,15	0,163	0,204	0,436	0,581	0,726	0,907	1,089	1,270	1,452	1,633	1,815
0,16	0,175	0,219	0,468	0,624	0,779	0,974	1,169	1,364	1,559	1,754	1,949
0,17	0,188	0,234	0,500	0,667	0,834	1,042	1,251	1,459	1,668	1,876	2,084
0,18	0,200	0,250	0,533	0,711	0,889	1,111	1,333	1,556	1,778	2,000	2,222
0,19	0,213	0,266	0,567	0,756	0,945	1,181	1,417	1,654	1,890	2,126	2,362
0,20	0,225	0,282	0,601	0,801	1,002	1,252	1,503	1,753	2,004	2,254	2,504
0,21	0,238	0,298	0,636	0,848	1,060	1,325	1,589	1,854	2,119	2,384	2,649
0,22	0,252	0,315	0,671	0,895	1,119	1,398	1,678	1,957	2,237	2,517	2,796
0,23	0,265	0,331	0,707	0,943	1,178	1,473	1,768	2,062	2,357	2,652	2,946
0,24	0,279	0,349	0,744	0,992	1,240	1,549	1,859	2,169	2,479	2,789	3,099
0,25	0,293	0,366	0,781	1,041	1,302	1,627	1,953	2,278	2,603	2,929	3,254
0,26	0,307	0,384	0,819	1,092	1,365	1,707	2,048	2,389	2,730	3,072	3,413
0,27	0,322	0,402	0,858	1,144	1,430	1,788	2,145	2,503	2,860	3,218	3,575
0,28	0,337	0,421	0,898	1,197	1,496	1,870	2,245	2,619	2,993	3,367	3,741
0,29	0,352	0,440	0,938	1,251	1,564	1,955	2,346	2,737	3,128	3,519	3,910
0,30	0,368	0,459	0,980	1,307	1,634	2,042	2,450	2,859	3,267	3,675	
0,31	0,384	0,479	1,023	1,364	1,705	2,131	2,557	2,983	3,409	3,836	
0,32	0,400	0,500	1,067	1,422	1,778	2,222	2,667	3,111	3,556	4,000	
0,33	0,417	0,521	1,112	1,482	1,853	2,316	2,779	3,243	3,706		
0,34	0,434	0,543	1,158	1,544	1,930	2,413	2,895	3,378	3,861		
0,35	0,452	0,565	1,206	1,608	2,010	2,513	3,015	3,518			
0,36	0,471	0,589	1,256	1,674	2,093	2,616	3,139	3,662			
0,37	0,490	0,613	1,307	1,743	2,178	2,723	3,267	3,812			
0,38	0,510	0,638	1,360	1,814	2,267	2,834	3,401	3,967			
0,39	0,531	0,664	1,416	1,888	2,360	2,950	3,540				
0,40	0,553	0,691	1,474	1,965	2,457	3,071	3,685				
0,407	0,569	0,710	1,517	2,022	2,528	3,160	3,791				

Table ②b

Calculation of bent elements with rectangular or flanged section

PC60 & $f_{ck} \leq 50$ MPa

$f_{yd} = 350$ MPa; $\xi_{max} = 0{,}676$

$$\mu = \frac{M_{Ed}}{b\,d^2 f_{cd}}\ ;\ \omega = \frac{A_s}{b\,d f_{cd}};\ A_s = \omega b d \frac{f_{cd}}{f_{yd}} = \frac{p}{100} bd\ ;\ M_{Rd} = \mu\, b\, d^2 f_{cd}$$

μ	ω	ξ	C12	C16	C20	C25	C30	C35	C40	C45	C50
			reinforcement percentage p = 100A_s/bd								
0,01	0,010	0,013	0,023	0,031	0,038	0,048	0,057	0,067	0,077	0,086	0,096
0,02	0,020	0,025	0,046	0,062	0,077	0,096	0,115	0,135	0,154	0,173	0,192
0,03	0,030	0,038	0,070	0,093	0,116	0,145	0,174	0,203	0,232	0,261	0,290
0,04	0,041	0,051	0,093	0,124	0,156	0,194	0,233	0,272	0,311	0,350	0,389
0,05	0,051	0,064	0,117	0,156	0,195	0,244	0,293	0,342	0,391	0,440	0,489
0,06	0,062	0,077	0,142	0,189	0,236	0,295	0,354	0,413	0,472	0,531	0,590
0,07	0,073	0,091	0,166	0,221	0,277	0,346	0,415	0,484	0,553	0,623	0,692
0,08	0,083	0,104	0,191	0,254	0,318	0,398	0,477	0,557	0,636	0,716	0,795
0,09	0,094	0,118	0,216	0,288	0,360	0,450	0,540	0,630	0,720	0,810	0,900
0,10	0,106	0,132	0,241	0,322	0,402	0,503	0,603	0,704	0,804	0,905	1,005
0,11	0,117	0,146	0,267	0,356	0,445	0,556	0,668	0,779	0,890	1,001	1,113
0,12	0,128	0,160	0,293	0,391	0,488	0,611	0,733	0,855	0,977	1,099	1,221
0,13	0,140	0,175	0,319	0,426	0,532	0,666	0,799	0,932	1,065	1,198	1,331
0,14	0,151	0,189	0,346	0,462	0,577	0,721	0,866	1,010	1,154	1,298	1,443
0,15	0,163	0,204	0,373	0,498	0,622	0,778	0,933	1,089	1,244	1,400	1,556
0,16	0,175	0,219	0,401	0,534	0,668	0,835	1,002	1,169	1,336	1,503	1,670
0,17	0,188	0,234	0,429	0,572	0,715	0,893	1,072	1,251	1,429	1,608	1,787
0,18	0,200	0,250	0,457	0,610	0,762	0,952	1,143	1,333	1,524	1,714	1,905
0,19	0,213	0,266	0,486	0,648	0,810	1,012	1,215	1,417	1,620	1,822	2,025
0,20	0,225	0,282	0,515	0,687	0,859	1,073	1,288	1,503	1,717	1,932	2,147
0,21	0,238	0,298	0,545	0,727	0,908	1,135	1,362	1,589	1,817	2,044	2,271
0,22	0,252	0,315	0,575	0,767	0,959	1,198	1,438	1,678	1,917	2,157	2,397
0,23	0,265	0,331	0,606	0,808	1,010	1,263	1,515	1,768	2,020	2,273	2,525
0,24	0,279	0,349	0,637	0,850	1,062	1,328	1,594	1,859	2,125	2,390	2,656
0,25	0,293	0,366	0,669	0,893	1,116	1,395	1,674	1,953	2,232	2,511	2,789
0,26	0,307	0,384	0,702	0,936	1,170	1,463	1,755	2,048	2,340	2,633	2,926
0,27	0,322	0,402	0,735	0,981	1,226	1,532	1,839	2,145	2,452	2,758	3,064
0,28	0,337	0,421	0,770	1,026	1,283	1,603	1,924	2,245	2,565	2,886	3,206
0,29	0,352	0,440	0,804	1,073	1,341	1,676	2,011	2,346	2,681	3,017	3,352
0,30	0,368	0,459	0,840	1,120	1,400	1,750	2,100	2,450	2,800	3,150	3,500
0,31	0,384	0,479	0,877	1,169	1,461	1,826	2,192	2,557	2,922	3,288	3,653
0,32	0,400	0,500	0,914	1,219	1,524	1,905	2,286	2,667	3,048	3,429	3,810
0,33	0,417	0,521	0,953	1,271	1,588	1,985	2,382	2,779	3,176	3,573	3,971
0,34	0,434	0,543	0,993	1,324	1,655	2,068	2,482	2,895	3,309	3,723	
0,35	0,452	0,565	1,034	1,378	1,723	2,154	2,584	3,015	3,446	3,877	
0,36	0,471	0,589	1,076	1,435	1,794	2,242	2,691	3,139	3,587		
0,37	0,490	0,613	1,120	1,494	1867	2,334	2,801	3,267	3,734		
0,38	0,510	0,638	1,166	1,555	1,943	2,429	2,915	3,401	3,886		
0,395	0,553	0,676	1,238	1,651	2,064	2,580	3,096	3,612			

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Table ②c

Calculation of bent elements with rectangular or flanged section

S400 & $f_{ck} \leq 50$ MPa

f_{yd} = 348 MPa ; ξ_{max}=0,668

$$\mu=\frac{M_{Ed}}{b\,d^2 f_{cd}}\;;\;\omega=\frac{A_s}{b\,d f_{cd}}\;;\;A_s=\omega b d\frac{f_{cd}}{f_{yd}}=\frac{p}{100}bd\;;\;M_{Rd}=\mu\, b\, d^2 f_{cd}$$

μ	ω	ξ	C12	C16	C20	C25	C30	C35	C40	C45	C50
			reinforcement percentage p = $100A_s/bd$								
0,02	0,020	0,025	0,046	0,062	0,077	0,097	0,116	0,136	0,155	0,174	0,194
0,03	0,030	0,038	0,070	0,093	0,117	0,146	0,175	0,204	0,234	0,263	0,292
0,04	0,041	0,051	0,094	0,125	0,157	0,196	0,235	0,274	0,313	0,352	0,391
0,05	0,051	0,064	0,118	0,157	0,197	0,246	0,295	0,344	0,393	0,443	0,492
0,06	0,062	0,077	0,142	0,190	0,237	0,297	0,356	0,415	0,475	0,534	0,593
0,07	0,073	0,091	0,167	0,223	0,278	0,348	0,418	0,487	0,557	0,627	0,696
0,08	0,083	0,104	0,192	0,256	0,320	0,400	0,480	0,560	0,640	0,720	0,800
0,09	0,094	0,118	0,217	0,290	0,362	0,453	0,543	0,634	0,724	0,815	0,905
0,10	0,106	0,132	0,243	0,324	0,405	0,506	0,607	0,708	0,809	0,911	1,012
0,11	0,117	0,146	0,269	0,358	0,448	0,560	0,672	0,784	0,896	1,008	1,120
0,12	0,128	0,160	0,295	0,393	0,492	0,614	0,737	0,860	0,983	1,106	1,229
0,13	0,140	0,175	0,321	0,429	0,536	0,670	0,804	0,938	1,072	1,205	1,339
0,14	0,151	0,189	0,348	0,465	0,581	0,726	0,871	1,016	1,161	1,306	1,452
0,15	0,163	0,204	0,376	0,501	0,626	0,783	0,939	1,096	1,252	1,409	1,565
0,16	0,175	0,219	0,403	0,538	0,672	0,840	1,008	1,176	1,345	1,513	1,681
0,17	0,188	0,234	0,431	0,575	0,719	0,899	1,079	1,258	1,438	1,618	1,798
0,18	0,200	0,250	0,460	0,613	0,767	0,958	1,150	1,342	1,533	1,725	1,917
0,19	0,213	0,266	0,489	0,652	0,815	1,019	1,222	1,426	1,630	1,834	2,037
0,20	0,225	0,282	0,518	0,691	0,864	1,080	1,296	1,512	1,728	1,944	2,160
0,21	0,238	0,298	0,548	0,731	0,914	1,142	1,371	1,599	1,828	2,056	2,285
0,22	0,252	0,315	0,579	0,772	0,965	1,206	1,447	1,688	1,929	2,171	2,412
0,23	0,265	0,331	0,610	0,813	1,016	1,271	1,525	1,779	2,033	2,287	2,541
0,24	0,279	0,349	0,641	0,855	1,069	1,336	1,604	1,871	2,138	2,405	2,673
0,25	0,293	0,366	0,674	0,898	1,123	1,403	1,684	1,965	2,246	2,526	2,807
0,26	0,307	0,384	0,707	0,942	1,178	1,472	1,766	2,061	2,355	2,649	2,944
0,27	0,322	0,402	0,740	0,987	1,233	1,542	1,850	2,159	2,467	2,775	3,084
0,28	0,337	0,421	0,774	1,032	1,291	1,613	1,936	2,259	2,581	2,904	3,226
0,29	0,352	0,440	0,809	1,079	1,349	1,686	2,024	2,361	2,698	3,035	3,373
0,30	0,368	0,459	0,845	1,127	1,409	1,761	2,113	2,466	2,818	3,170	3,522
0,31	0,384	0,479	0,882	1,176	1,470	1,838	2,205	2,573	2,941	3,308	3,676
0,32	0,400	0,500	0,920	1,227	1,533	1,917	2,300	2,683	3,067	3,450	3,833
0,33	0,417	0,521	0,959	1,279	1,598	1,998	2,397	2,797	3,196	3,596	3,995
0,34	0,434	0,543	0,999	1,332	1,665	2,081	2,497	2,914	3,330	3,746	
0,35	0,452	0,565	1,040	1,387	1,734	2,167	2,601	3,034	3,467	3,901	
0,36	0,471	0,589	1,083	1,444	1,805	2,256	2,707	3,159	3,610		
0,37	0,490	0,613	1,127	1,503	1,879	2,348	2,818	3,288	3,757		
0,38	0,510	0,638	1,173	1,564	1,955	2,444	2,933	3,422	3,911		
0,392	0,531	0,668	1,231	1,641	2,052	2,565	3,078	3,591			

Table ②d

Calculation of bent elements with rectangular or flanged section

S500 & $f_{ck} \leq 50$ MPa

f_{yd} = 435 MPa ; ξ_{max}=0,668

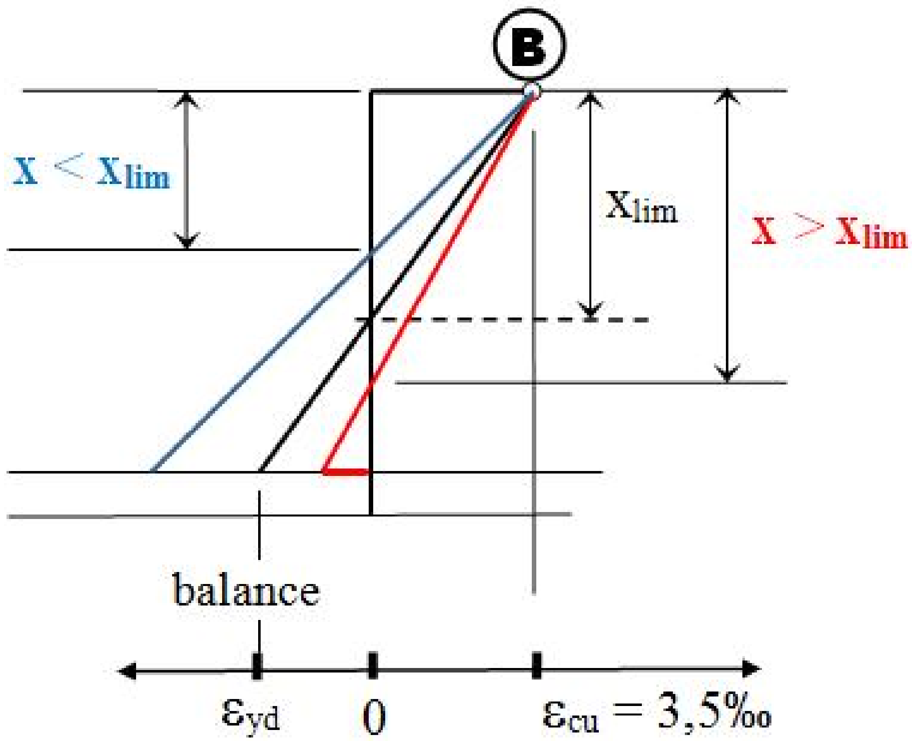
$$\mu=\frac{M_{Ed}}{b\,d^2 f_{cd}}\;;\;\omega=\frac{A_s}{b\,d f_{cd}}\;;\;A_s=\omega b d\frac{f_{cd}}{f_{yd}}=\frac{p}{100}bd\;;\;M_{Rd}=\mu\, b\, d^2 f_{cd}$$

μ	ω	ξ	C12	C16	C20	C25	C30	C35	C40	C45	C50
			reinforcement percentage p = $100A_s/bd$								
0,02	0,020	0,025	0,037	0,050	0,062	0,077	0,093	0,108	0,124	0,139	0,155
0,03	0,030	0,038	0,056	0,075	0,093	0,117	0,140	0,163	0,187	0,210	0,234
0,04	0,041	0,051	0,075	0,100	0,125	0,157	0,188	0,219	0,250	0,282	0,313
0,05	0,051	0,064	0,094	0,126	0,157	0,197	0,236	0,275	0,315	0,354	0,393
0,06	0,062	0,077	0,114	0,152	0,190	0,237	0,285	0,332	0,380	0,427	0,475
0,07	0,073	0,091	0,134	0,178	0,223	0,278	0,334	0,390	0,446	0,501	0,557
0,08	0,083	0,104	0,154	0,205	0,256	0,320	0,384	0,448	0,512	0,576	0,640
0,09	0,094	0,118	0,174	0,232	0,290	0,362	0,435	0,507	0,579	0,652	0,724
0,10	0,106	0,132	0,194	0,259	0,324	0,405	0,486	0,567	0,648	0,728	0,809
0,11	0,117	0,146	0,215	0,287	0,358	0,448	0,537	0,627	0,717	0,806	0,896
0,12	0,128	0,160	0,236	0,315	0,393	0,492	0,590	0,688	0,786	0,885	0,983
0,13	0,140	0,175	0,257	0,343	0,429	0,536	0,643	0,750	0,857	0,964	1,072
0,14	0,151	0,189	0,279	0,372	0,465	0,581	0,697	0,813	0,929	1,045	1,161
0,15	0,163	0,204	0,301	0,401	0,501	0,626	0,751	0,877	1,002	1,127	1,252
0,16	0,175	0,219	0,323	0,430	0,538	0,672	0,807	0,941	1,076	1,210	1,345
0,17	0,188	0,234	0,345	0,460	0,575	0,719	0,863	1,007	1,151	1,294	1,438
0,18	0,200	0,250	0,368	0,491	0,613	0,767	0,920	1,073	1,227	1,380	1,533
0,19	0,213	0,266	0,391	0,522	0,652	0,815	0,978	1,141	1,304	1,467	1,630
0,20	0,225	0,282	0,415	0,553	0,691	0,864	1,037	1,210	1,382	1,555	1,728
0,21	0,238	0,298	0,439	0,585	0,731	0,914	1,097	1,280	1,462	1,645	1,828
0,22	0,252	0,315	0,463	0,617	0,772	0,965	1,158	1,351	1,544	1,737	1,929
0,23	0,265	0,331	0,488	0,651	0,813	1,016	1,220	1,423	1,626	1,830	2,033
0,24	0,279	0,349	0,513	0,684	0,855	1,069	1,283	1,497	1,711	1,924	2,138
0,25	0,293	0,366	0,539	0,719	0,898	1,123	1,347	1,572	1,796	2,021	2,246
0,26	0,307	0,384	0,565	0,754	0,942	1,178	1,413	1,649	1,884	2,120	2,355
0,27	0,322	0,402	0,592	0,789	0,987	1,233	1,480	1,727	1,974	2,220	2,467
0,28	0,337	0,421	0,619	0,826	1,032	1,291	1,549	1,807	2,065	2,323	2,581
0,29	0,352	0,440	0,648	0,863	1,079	1,349	1,619	1,889	2,158	2,428	2,698
0,30	0,368	0,459	0,676	0,902	1,127	1,409	1,691	1,972	2,254	2,536	2,818
0,31	0,384	0,479	0,706	0,941	1,176	1,470	1,764	2,058	2,352	2,647	2,941
0,32	0,400	0,500	0,736	0,981	1,227	1,533	1,840	2,147	2,453	2,760	3,067
0,33	0,417	0,521	0,767	1,023	1,279	1,598	1,918	2,237	2,557	2,877	3,196
0,34	0,434	0,543	0,799	1,066	1,332	1,665	1,998	2,331	2,664	2,997	3,330
0,35	0,452	0,565	0,832	1,110	1,387	1,734	2,080	2,427	2,774	3,121	3,467
0,36	0,471	0,589	0,866	1,155	1,444	1,805	2,166	2,527	2,888	3,249	3,610
0,372	0,490	0,617	0,905	1,207	1,509	1,886	2,263	2,641	3,018	3,395	3,772

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

7.1.2. FAILURE CONDITION

REINFORCEMENT YIELDING BEFORE CONCRETE CRUSHING



¶ á ¶$_{lim}$

$$\xi_{lim} = \frac{x_{lim}}{d} = \frac{3,5}{3,5 + 1000 f_{yd} / E_s}$$

← chp.6: slide 17

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Maximum Bearing Capacity Corresponds to the Balance Situation

Starting formula: $M_{Rd} = \mu b d^2 f_{cd}$

$\xi = \xi_{lim} \rightarrow \mu = 0,8\,\xi(1-0,4\xi)$

$\mu_{lim} = 0,8\xi_{lim}(1-0,4\xi_{lim})$

$$\boxed{M_{Rd,max} = \mu_{lim} b d^2 f_{cd}}$$

The Corresponding Tension Area

Starting formula: $A_s = \dfrac{M_{Rd}}{z f_{yd}}$

$\xi = \xi_{lim} \rightarrow z = d - 0,4x = (1 - 0,4\xi)d$

$z_{lim} = (1-0,4\xi_{lim})d = \zeta_{lim}d$

$$\boxed{A_{s,max} = \frac{M_{Rd,max}}{\zeta_{lim} d f_{yd}}}$$

Whatever is $A_s > A_{s,max}$:

- no yielding of the steel

- bearing capacity remains the same $M_{Rd,max}$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

7.1.3. CROSS SECTION DESIGN

DESIGN PURPOSE:

• set the dimensions b and h of the concrete cross section

• calculate the reinforcement, according to the distribution of bending moments

• detailing of the element

STEP 1: CROSS SECTION DIMENSIONS

- by estimation based on robustness
- by calculation according to the bending moment

STEP 2: REQUIRED REINFORCEMENT

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

CROSS SECTION DIMENSION BASED ON ROBUSTNESS (STIFFNESS)

Slab thickness

Floors with	$h_{f\,min}$
- one way continuous slab - two ways continuous slab	l_{min} / 35 l_{min} / 45
Slab thickness must be multiple of 10 mm	

Beam cross section dimension

		Recommended dimensions
Cross section depth	h_{min}	l /12 – girder of antiseismic frames
		l /15 – main elements
		l /20 – joist; beam
	h_{optim}	l /(8..12) – girder of antiseismic frames; main elements
		l /(12..15) – joist; beam
Cross section width, b		$b = h$ /(1,5..3) – rectangular section
		$b = h$ /(2..3) – flanged section b = 120, 150, 180, 200 mm, afterwards mutiplu of 50 mm
Additional recommendations for cast-in-situ elements		h - multiple of 50 mm for h ≤ 800 mm h - multiple of 100 mm for h > 800 mm

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

CALCULATION OF THE DIMENSIONS ACCORDING TO BENDING MOMENT

Input data	Output data
M_{Ed} ; f_{cd} ; f_{yd} ; c_{nom}	b, h, A_s, x

there is chosen:

b - low influence on section resistance

p - it is a link between three unknowns (b, h, A_s)

usual values: 0,25 … 0,60% for slabs

0,80 … 1,30% for beams

$$\omega = \frac{p}{100}\frac{f_{yd}}{f_{cd}} \qquad \mu = \omega(1 - 0{,}5\omega)$$

ω → table ① → μ

useful depth $d_{rqd} = \sqrt{\frac{M_{Ed}}{\mu b f_{cd}}}$

d = d_{rqd} + d_s → rounded according to slide 17

to check ratio *h*/*b* → slide 17

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

CALCULATION OF THE REINFORCEMENT AREA

$d = h - d_s$

$$\mu = \frac{M_{Ed}}{b\,d^2 f_{cd}} \qquad \omega = 1 - \sqrt{1 - 2\mu}$$

table ①

$$A_s = \omega\, b\, d \frac{f_{cd}}{f_{yd}}$$

$p = 100A_s/bd$

NOTE:

1. Using table ① the check ¶ á ¶$_{\mathbf{lim}}$ is implied
2. To check $p \geq p_{min}$ from slide 24

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

7.1.4. CROSS SECTION CHECK

Input data	Output data
$M_{Ed};\ f_{cd};\ f_{yd};\ b;\ h;\ A_s;\ c_{nom}$	$M_{Rd};\ x$

M_{Rd} calculation by equilibrium conditions

$$x = \frac{A_s f_{yd}}{0{,}8 b f_{cd}} \le \xi_{lim} d$$

NO
- too much reinforcement
- crushing of concrete without yielding of reinforcement

$$M_{Rd} = M_{Rd,max} \text{ (slide 15)}$$

YES

$$M_{Rd} = 0{,}8 b x f_{cd}(d - 0{,}4x)$$
$$M_{Rd} = A_s f_{yd}(d - 0{,}4x)$$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

M_{Rd} calculation by using table

$d = h - d_s$

$\rho = A_s/bd$

$$\omega = \rho \frac{f_{yd}}{f_{cd}} \quad \xrightarrow{\text{table ①}} \quad \mu = \omega(1 - 0{,}5\omega)$$

$\mu \le \mu_{lim}$

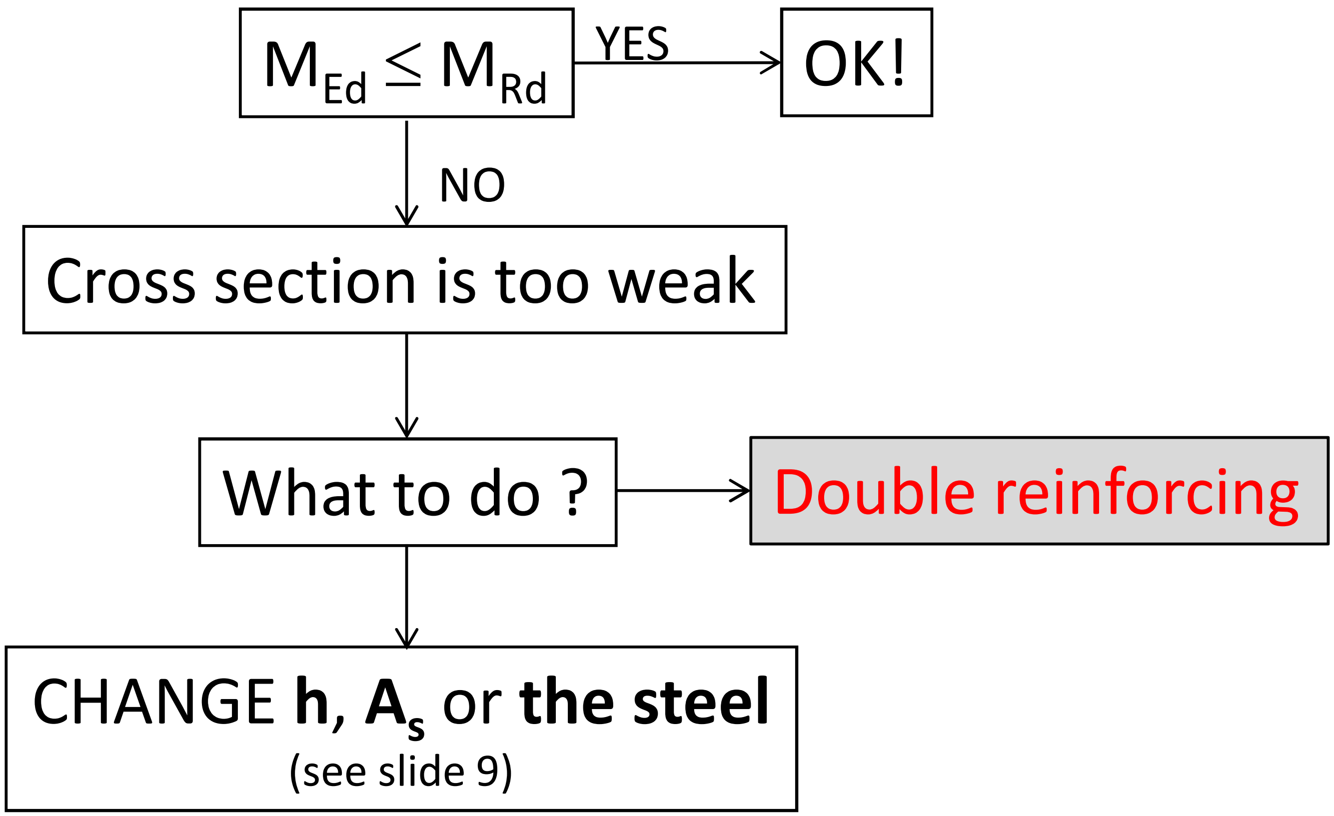
NO → $M_{Rd} = M_{Rd,max}$ (slide 15)

- too much reinforcement
- crushing of concrete without yielding of reinforcement

YES → $M_{Rd} = \mu b d^2 fcd$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Checking the bearing capacity



7.1. SIMPLE REINFORCED RECTANGULAR SECTION

7.1.5. PROVISIONS FOR REINFORCEMENT AREA

Maximum reinforcement percentage corresponds to balance situation

Starting formula: $\xi = 1{,}25\rho \frac{f_{yd}}{f_{cd}}$ $\quad \xi = \xi_{lim} \rightarrow$ $\rho = 0{,}8\xi \frac{f_{cd}}{f_{yd}}$

$$\downarrow$$

$$\rho = 0{,}8\xi \frac{f_{cd}}{f_{yd}}$$

$$\rho_{max} = 0{,}8\xi_{lim} \frac{f_{cd}}{f_{yd}}$$

$$p_{max} = 100\rho_{max} = 80\xi_{lim} \frac{f_{cd}}{f_{yd}}$$

p_{max} values

- in table ②
- EC2: 4%

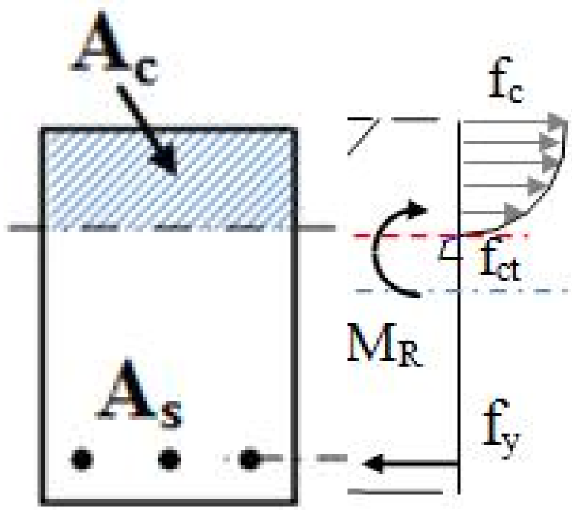
Whatever is $p > p_{max}$:

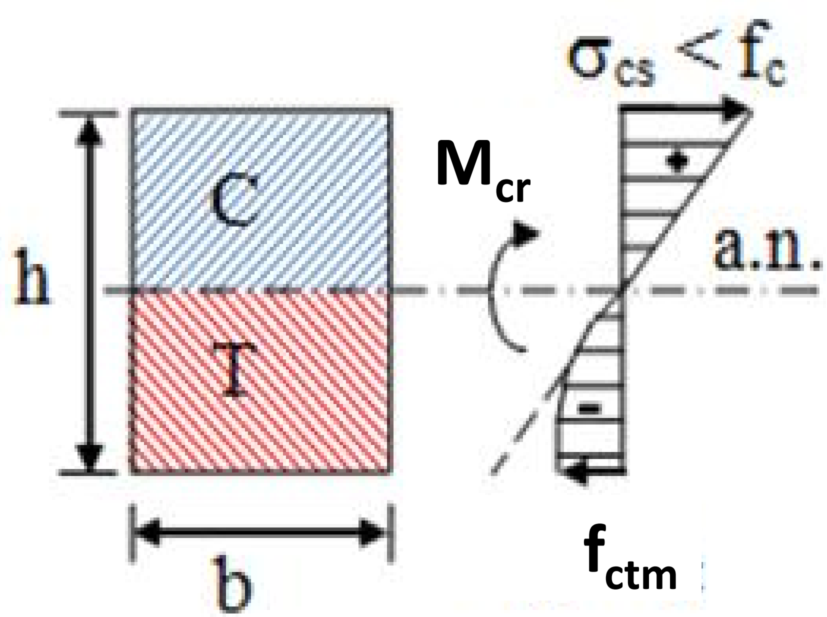
- no yielding of the steel

- bearing capacity remains the same $M_{Rd,max}$

7.1. SIMPLE REINFORCED RECTANGULAR SECTION

Minimum reinforcement percentage is obtained equalizing M_{Rd} with M_{cr}





$M_{Rd} = f(A_s) \longrightarrow M_{Rd} = f(p)$

$M_{cr} = f(f_{ctm})$

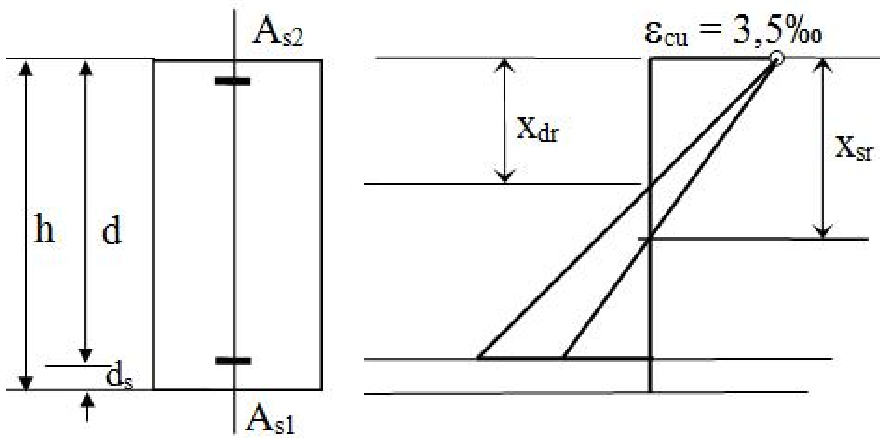
$M_{Rd} = M_{cr} \rightarrow p_{min}$

EC2: $p_{min} = 26 \frac{f_{ctm}}{f_{yk}} \geq 0{,}13\,\%$

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

COMPRESSION REINFORCEMENT LEADS TO:

- INCREASING OF BEARING CAPACITY
- DECREASING OF COMPRESSED CONCRETE
- INCREASING OF SECTION ROTATION, RESULTING A HIGHER DUCTILITY



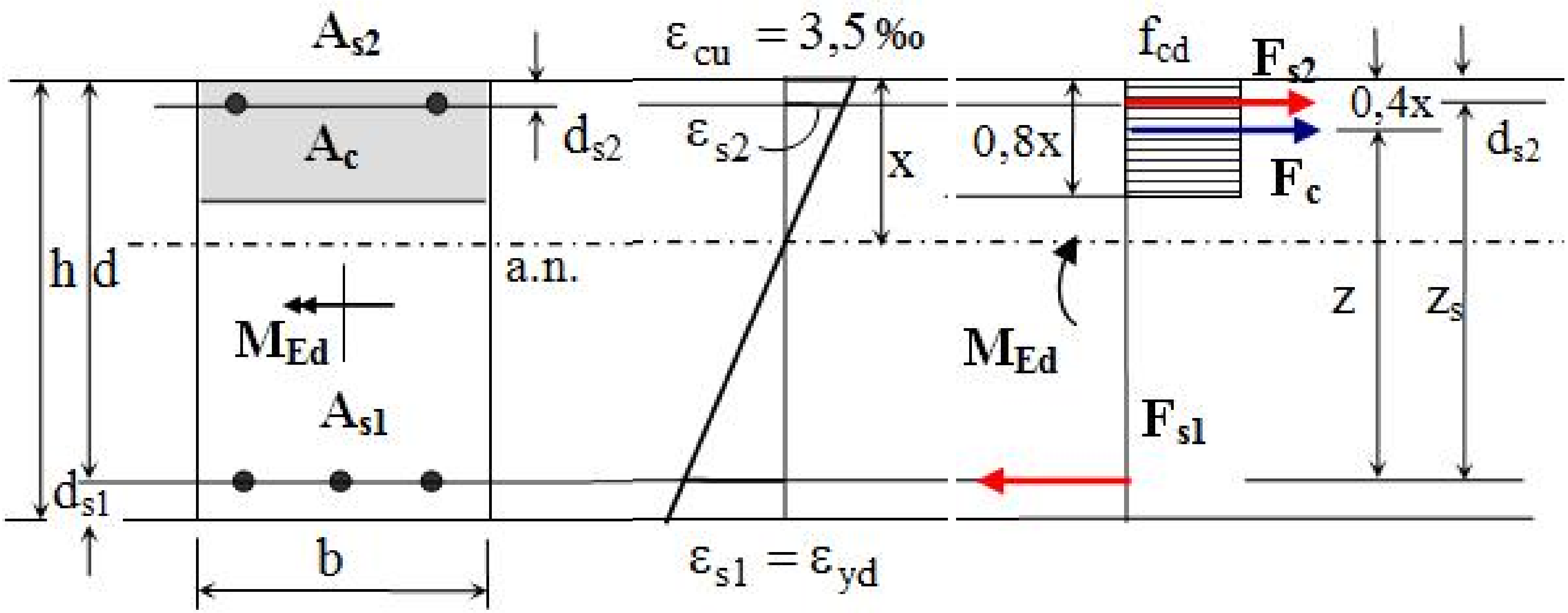
sr – simple reinforced
dr – double reinforced

DOUBLE REINFORCEMENT IS USED IN THE FOLLOWING SITUATIONS:

- SIMPLE REINFORCED SECTION IS TO WEAK & NOTHING CAN BE CHANGED
- THERE ARE ALTERNATING BENDING MOMENTS
- SOMEHOW THERE IS REINFORCEMENT IN COMPRESSED AREA
- IN ANTISEISMIC STRUCTURE EVEN THOUGH NO ALTERNATING BENDING MOMENTS

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

7.2.1. SECTION ANALISYS



$F_{s1} = A_{s1}f_{yd}$

$F_{s2} = A_{s2}\sigma_{s2}$!

$F_c = 0,4bxf_{cd}$

$z = d - 0,4x$

$z_s = d - d_{s2}$

$$\varepsilon_{s2} = \varepsilon_{cu} \frac{x - d_{s2}}{x}$$

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

TENSION REINFORCEMENT YIELDING BEFORE CONCRETE CRUSHING

¶ á ¶$_{lim}$

STRESS IN COMPRESSION REINFORCEMENT

There is yielding of compression reinforcement if $\varepsilon_{s2} \geq \varepsilon_{yd}$

$$\varepsilon_{s2} = \varepsilon_{cu} \frac{x - d_{2s}}{x} \geq \varepsilon_{yd} \qquad x \geq \frac{\varepsilon_{cu}}{\varepsilon_{cu} - \varepsilon_{yd}} d_{s2} \rightarrow x_y$$

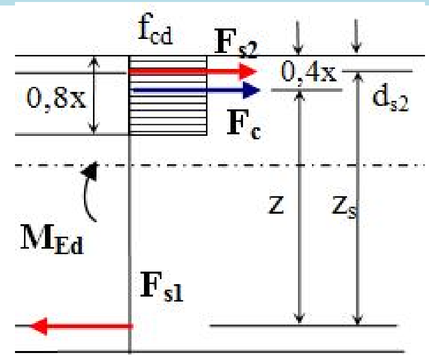
Steel	PC52	PC60	S400	S500
x_y	$1{,}69d_2$	$1{,}91d_2$	$1{,}98d_2$	$2{,}64d_2$
STAS 10107/0-97	$2{,}0d_2$			

$x \geq x_y$ $\quad \sigma_{s2} = f_{yd}$

$x < x_y$ $\quad \sigma_{s2} < f_{yd}$

- no yielding of compression reinforcement
- procedure in the chapter 6.4 (slide 12) applies
- simplified approach: F_c is acting at the level of F_{s2}

7.2. DOUBLE REINFORCED RECTANGULAR SECTION



Let's assume $\pm_{s2} = f_{yd}$

$$\Sigma F = 0$$

$$F_c + F_{s2} = F_{s1}$$

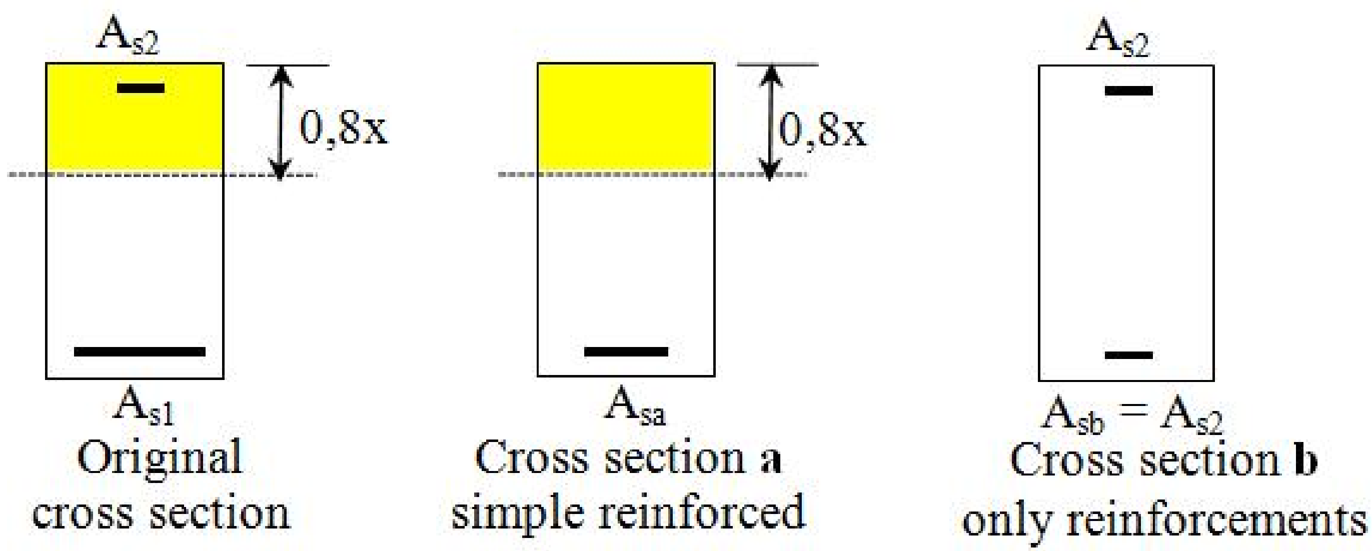
$$0{,}8b\,x\,f_{cd} + A_{s2}f_{yd} = A_{s1}f_{yd}$$

$$x = 1{,}25\frac{(A_{s1} - A_{s2})f_{yd}}{bf_{cd}}$$

$$\xi = 1{,}25\frac{(A_{s1} - A_{s2})f_{yd}}{bdf_{cd}}$$

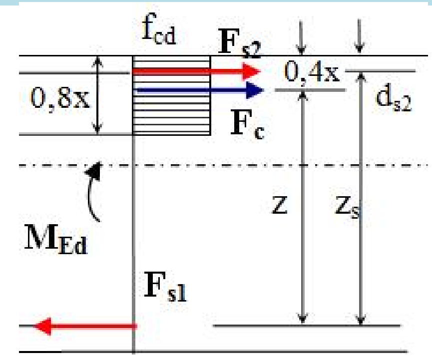
7.2. DOUBLE REINFORCED RECTANGULAR SECTION

$\Sigma M = 0 \rightarrow$ related to the **A_{s1} axis**



M_{Ed}	=	M_a	+	M_b
A_{s1}	=	A_{sa}	+	A_{sb}
A_{s1}	=	A_{sa}	+	A_{s2}

7.2. DOUBLE REINFORCED RECTANGULAR SECTION



Let’s assume ±$_{s2}$ = f_{yd}

$$M_{Ed} = F_c z + F_{s2} z_s$$

$$M_{Ed} = 0{,}8\,b\,x\,f_{cd}(d - 0{,}4x) + A_{s2} f_{yd}(d - d_{s2})$$

$$M_{Ed} = b\,d^2 f_{cd}\,0{,}8\,\xi(1 - 0{,}4\xi) + A_{s2} f_{yd}(d - d_{s2})$$

$$M_{Ed} = \underbrace{\mu\,b\,d^2 f_{cd}}_{M_a} + \underbrace{A_{s2} f_{yd}(d\text{-}d_{s2})}_{M_b}$$

$$M_{Rd} = \mu\,b\,d^2 f_{cd} + \underbrace{A_{s2} f_{yd}(d - d_{s2})}_{\text{aM}}$$

a**M**

increasing of the bearing capacity due to compression reinforcement

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

7.2.2. CROSS SECTION DESIGN

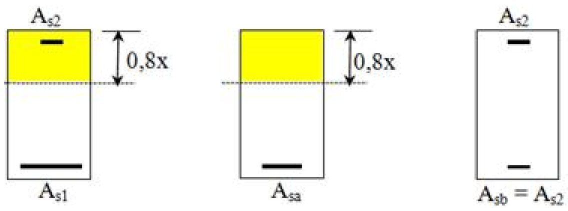
CASE ①
CONSEQUENCE OF WEAK RECTANGULAR SIMPLE REINFORCED SECTION

CASE ②
THERE IS REINFORCEMENT IN THE COMPRESSION ZONE

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

CASE ① - WEAK RECTANGULAR SIMPLE REINFORCED SECTION

Input data	Output data
M_{Ed} ; f_{cd} ; f_{yd} ; b, h ; c_{nom}	A_{s1}; A_{s2}



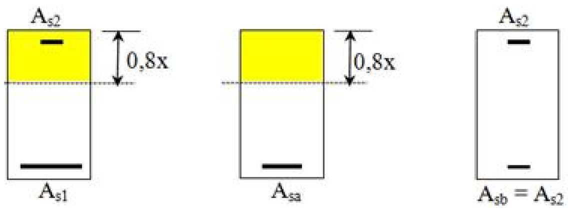
- $d = h - d_{s1}$
- $\mu = \dfrac{M_{Ed}}{b d^2 f_{cd}} > \mu_{lim} \rightarrow$ section does not resist to M_{Ed}
- simple reinforced cross section can withstand bending moment $M_{lim} = \mu_{lim} b d^2 f_{cd}$
- $\Delta M = M_{Ed} - M_{lim}$
- compression bars A_{s2} are required to increase resisting bending moment
- $A_{s2} = \dfrac{\Delta M}{f_{yd}(d - d_{s2})}$
- for equilibrium of internal forces $\rightarrow$ a corresponding amount of steel must be added to the tension reinforcement A_{slim} (provided for M_{lim})
- $A_{s1} = A_{slim} + A_{s2}$
- $A_{s1} = \dfrac{M_{lim}}{z_{lim} f_{yd}} + \dfrac{\Delta M}{(d - d_{s2}) f_{yd}} = \dfrac{1}{f_{yd}}\left(\dfrac{M_{lim}}{z_{lim}} + \dfrac{\Delta M}{(d - d_{s2})}\right)$; $z_{lim} = (1 - 0{,}4\xi_{lim})d$

NOTE: $\xi = \xi_{lim}$ & $x = x_{lim} > x_y$ $\rightarrow$ both reinforcements yield

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

CASE ② - THERE IS REINFORCEMENT IN THE COMPRESSION ZONE

Input data	Output data
M_{Ed}; f_{cd}; f_{yd}; A_{s2}; b; h; c_{nom}	A_{s1}; x



- $d = h - d_{s1}$
- $\mu = \dfrac{M_{Ed} - A_{s2} f_{yd}(d - d_{s2})}{b d^2 f_{cd}}$
- a) $\mu \leq \mu_{lim}$ is the same like $\xi \leq \xi_{lim} \rightarrow A_{s1}$ yields
- from table ① $\rightarrow \xi$; ω
- if $x = \xi d \geq x_y$ $\rightarrow$ A_{s2} yields; $A_{s1} = A_{sa} + A_{s2} = \omega b d \dfrac{f_{cd}}{f_{yd}} + A_{s2}$
- if $x = \xi d < x_y$ $\rightarrow$ A_{s2} does not yield

  simplified approach: F_c is located at the level of A_{s2}

  $\Sigma M = 0 \rightarrow$ related to the **A_{s2} axis**:

  $$M_{Ed} = A_{s1} f_{yd} z_s = A_{s1} f_{yd}(d - d_{s2}) \qquad A_{s1} = \frac{M_{Ed}}{f_{yd}(d - d_{s2})}$$

- b) if $\mu < 0$ $\rightarrow$ A_{s2} is too strong (similar to $x < x_y$); previous relation applies
- c) if $\mu > \mu_{lim} \rightarrow A_{s2}$ is too is weak; calculation according to CASE ① is required

7.2. DOUBLE REINFORCED RECTANGULAR SECTION

7.2.3. CROSS SECTION CHECK

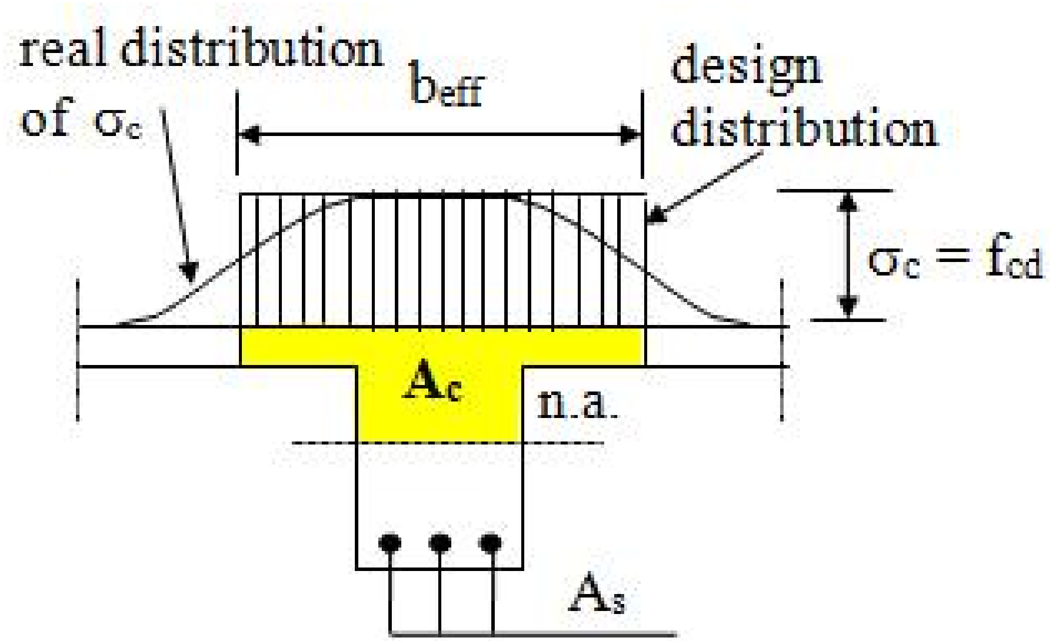
Input data	Output data
M_{Ed}; f_{cd}; f_{yd}; A_{s1}; A_{s2}; b; h; c_{nom}	M_{Rd}; x

- $x = \dfrac{(A_{s1} - A_{s2})f_{yd}}{0{,}8bf_{cd}} \le \xi_{lim} d$
- if $x_y \le x \le x_{lim}$ $\rightarrow \xi = x/d$ $\rightarrow$ table ① $\rightarrow \mu$: $M_{Rd} = \mu b d^2 f_{cd} + A_{s2} f_{yd}(d - d_{s2})$
- if $x < x_y$ $\rightarrow A_{s2}$ does not yield $\rightarrow$ simplified approach: $M_{Rd} = A_{s1} f_{yd}(d - d_{s2})$
- if $x > x_{lim}$ $\rightarrow A_{s1}$ is too strong: $M_{Rd} = \mu_{lim} b d^2 f_{cd} + A_{s2} f_{yd}(d - d_{s2})$
- $M_{Ed} \le M_{Rd}$?

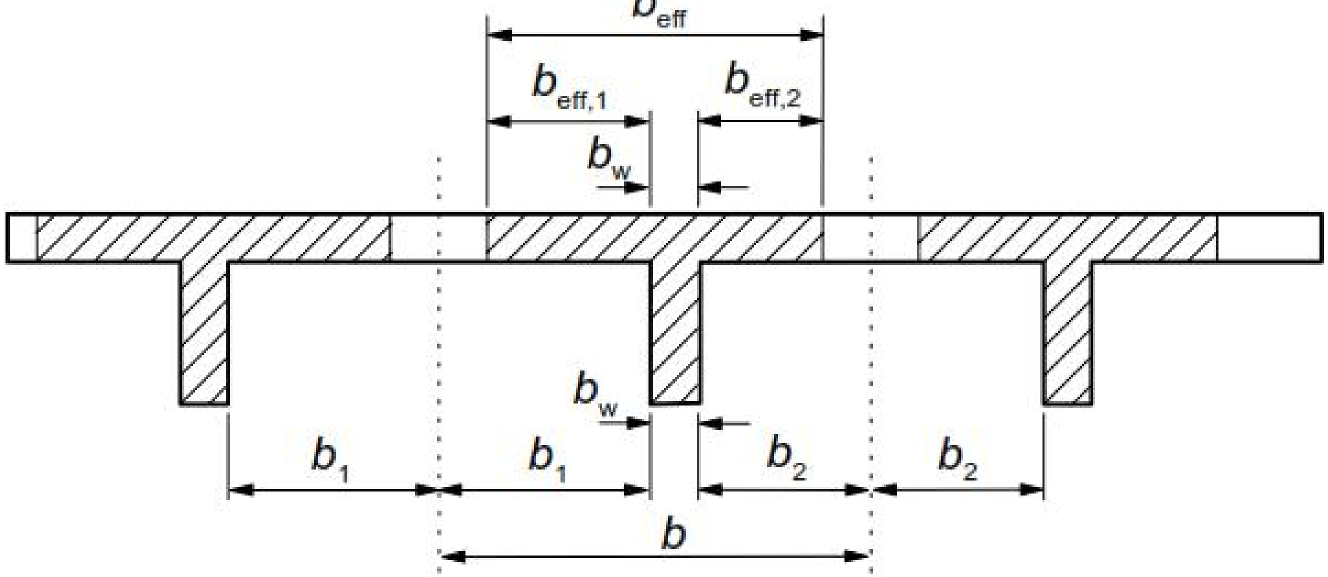
7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.1. EFFECTIVE WIDTH OF FLANGES

THE DIFFERENCE IN THE RIGIDITIES OF THE WEB AND FLANGES LEADS TO NONUNIFORM DITRIBUTION OF COMPRESSIVE STRESSES



7.3. SIMPLE REINFORCED FLANGED SECTION



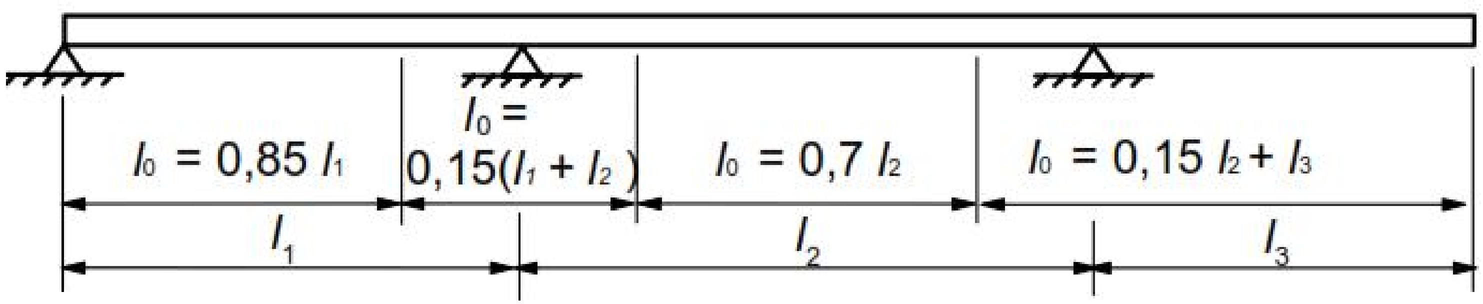
$b_{eff} = b_{eff1} + b_w + b_{eff2} \leq b$

$b_{eff1} = 0,2b_1 + 0,1\,\ell_0$

$b_{eff2} = 0,2b_2 + 0,1\ell_0$

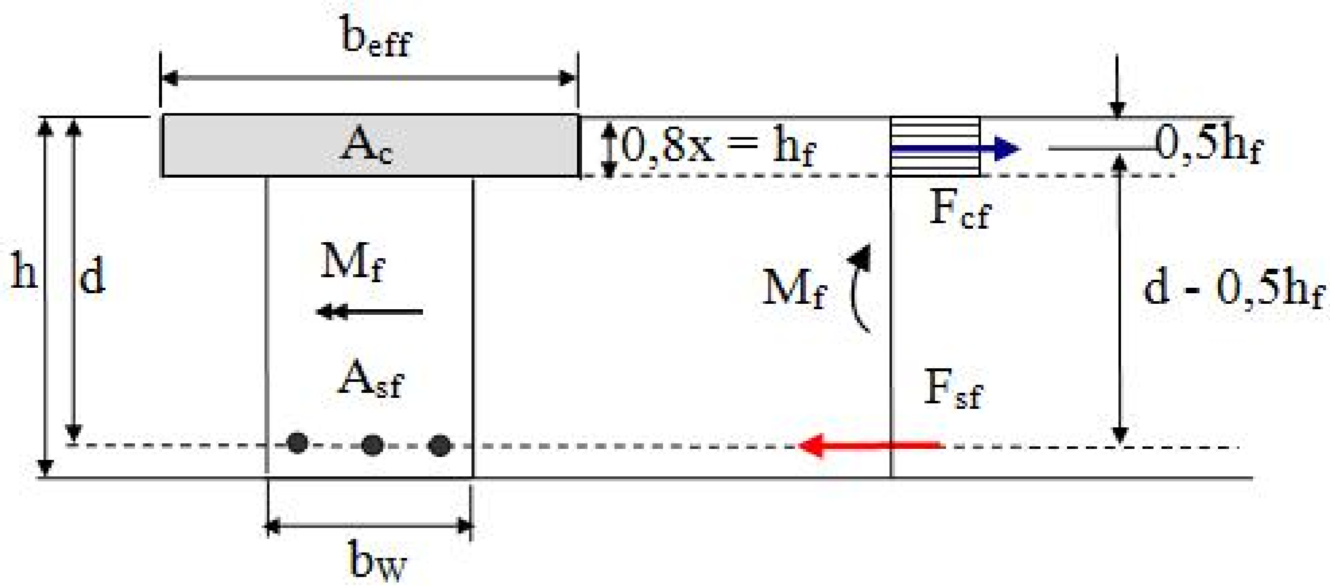
$b_{eff1} \leq b_1$

$b_{eff2} \leq b_2$



7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.2. EXTENSION OF THE BLOCK STRESS



$\Sigma F = 0$

$$F_{cf} = F_{sf}$$

$$F_{cf} = b_{eff} h_f f_{cd}$$

$$F_{sf} = A_{sf} f_{yd}$$

$$A_{sf} = b_{eff} h_f \frac{f_{cd}}{f_{yd}}$$

$\Sigma M = 0 \rightarrow$ related to the **A_{sf} axis**

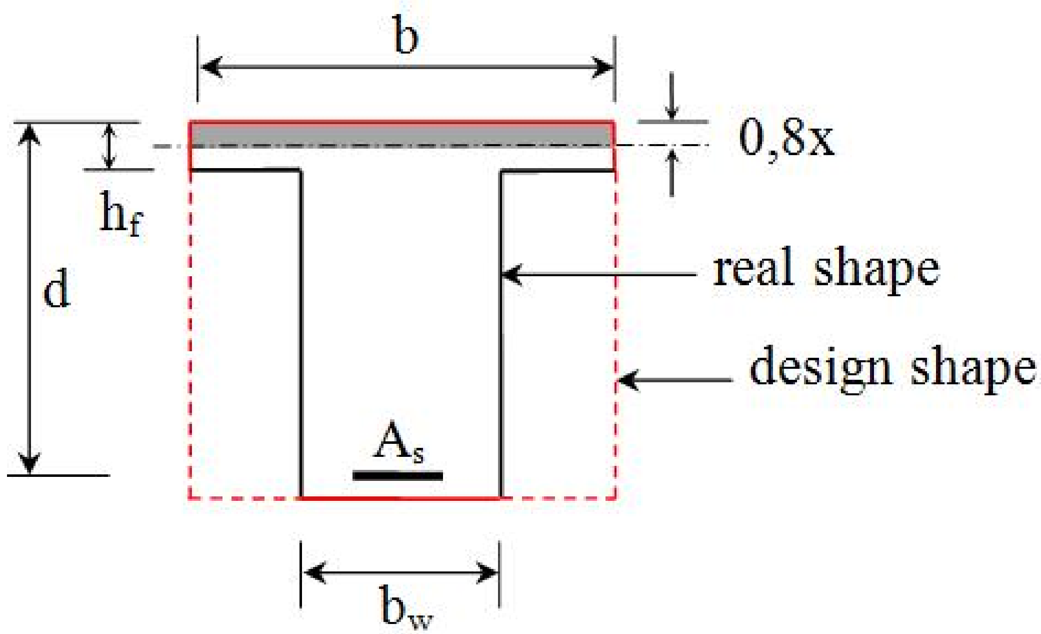
$$M_f = b_{eff} h_f f_{cd} \left(d - 0,5h_f\right)$$

7.3. SIMPLE REINFORCED FLANGED SECTION

Design	Check	
$M_{Ed} \leq M_f$	$A_s \leq A_f$	**Block stress in the flange** $0,8x \leq h_f$
$M_{Ed} > M_f$	$A_s > A_f$	**Block stress in the web** $0,8x > h_f$

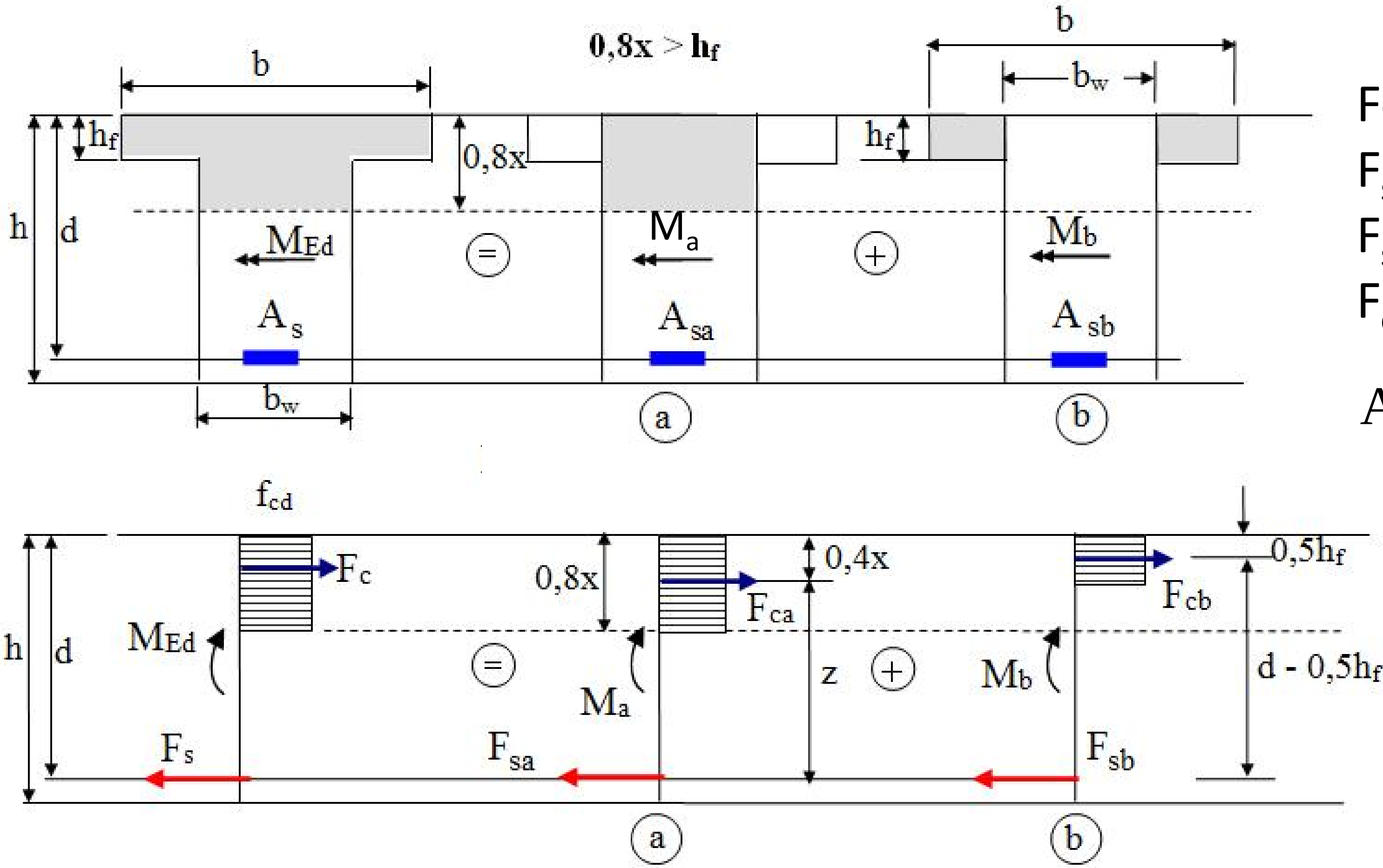
7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.3. CROSS SECTION WITH BLOCK STRESS IN THE FLANGE



- concrete below the neutral axis is cracked
- real shape does not matter
- calculation → rectangular section b & h

7.3.4. CROSS SECTION WITH BLOCK STRESS IN THE WEB



For section b:

$F_{sb} = F_{cb}$

$F_{sb} = A_{sb} f_{yd}$

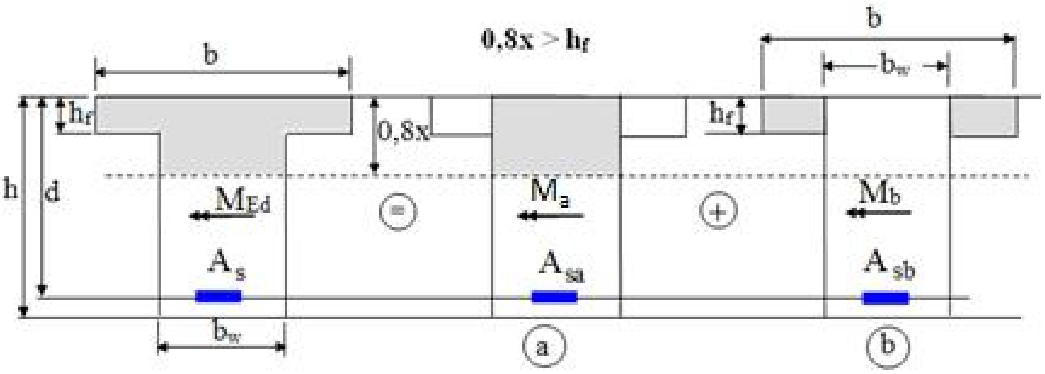
$F_{cb} = (b - b_w) h_f f_{cd}$

$$A_{sb} = (b - b_w) h_f \frac{f_{cd}}{f_{yd}}$$

7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.4. CROSS SECTION WITH BLOCK STRESS IN THE WEB

$\Sigma F = 0$



$$F_c = F_s$$

$$F_c = F_{ca} + F_{cb} = 0{,}8bxf_{cd} + (b - b_w)h_f f_{cd}$$

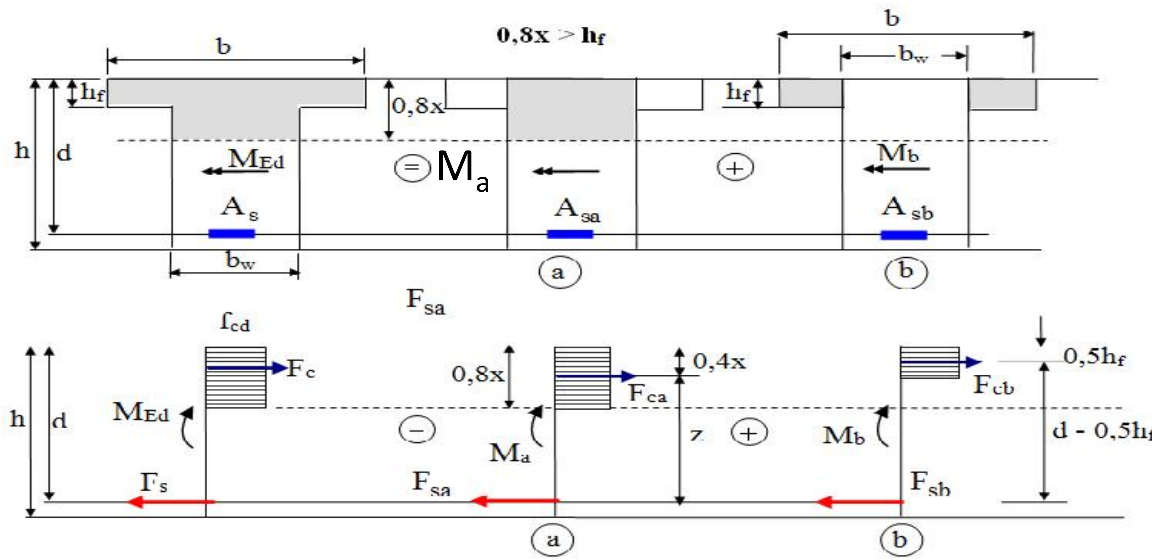
$$F_s = F_{sa} + F_{sb} = (A_{sa} + A_{sb})f_{yd} = A_s f_{yd}$$

$$x = \frac{A_s f_{yd} - (b - b_w)h_f f_{cd}}{0{,}8 b_w f_{cd}} \quad \rightarrow \quad x = 1{,}25\left(\frac{A_s f_{yd}}{b_w f_{cd}} - \frac{b - b_w}{b_w} h_f\right)$$

$$\xi = 1{,}25\left(\frac{A_s f_{yd}}{b_w d f_{cd}} - \frac{b - b_w}{b_w d} h_f\right)$$

7.3. SIMPLE REINFORCED FLANGED SECTION

$\Sigma M = 0 \rightarrow$ related to the $\mathbf{A_s}$ **axis**



$$M_{Ed} = F_{ca} z + F_{cb}\left(d - 0,5h_f\right)$$

$$M_{Ed} = \underbrace{\mu b_w d^2 f_{cd} + (b - b_w) h_f (d - 0,5h_f) f_{cd}}_{\text{Resisting bending moment}}$$

$$M_{Rd} = \mu b_w d^2 f_{cd} + (b - b_w) h_f (d - 0,5h_f) f_{cd}$$

7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.4.1. CROSS SECTION DESIGN

Input data	Output data
M_{Ed}; f_{cd}; f_{yd}; b_w; b; h; h_f	A_s; x

$$A_{sb} = (b - b_w)h_f \frac{f_{cd}}{f_{yd}}$$

$$M_b = (b - b_w)h_f (d - 0{,}5h_f)f_{cd}$$

$$M_a = M_{Ed} - M_b$$

$$\mu = \frac{M_{Ed}}{\mu b_w d^2 f_{cd}} \quad \text{table ① } \rightarrow \omega \rightarrow \quad A_{sa} = \omega b_w d \frac{f_{cd}}{f_{yd}}$$

$$A_s = \omega b_w d \frac{f_{cd}}{f_{yd}} + (b - b_w)h_f \frac{f_{cd}}{f_{yd}}$$

NOTE: if $\mu > \mu_{lim}$ double reinforcing is required

7.3. SIMPLE REINFORCED FLANGED SECTION

7.3.4.2. CROSS SECTION CHECK

Input data	Output data
M_{Ed}; f_{cd}; f_{yd}; b_w; A_s; b; h; h_f	M_{Rd}; x

$$A_{sb} = (b - b_w)h_f \frac{f_{cd}}{f_{yd}}$$

$$M_b = A_{sb} f_{yd} (d - 0{,}5h_f)$$

$$A_{sa} = A_s - A_{sb}$$

$$\omega = \frac{A_{sa}}{b_w d} \frac{f_{yd}}{f_{cd}}$$ table ① $\rightarrow \mu \rightarrow$ $$M_a = \mu b_w d^2 f_{cd}$$

$$M_{Rd} = \mu b_w d^2 f_{cd} + A_{sb} f_{yd} (d - 0{,}5h_f)$$

$$M_{Ed} \leq M_{Rd} \ ?$$

NOTE: if $\mu > \mu_{lim}$ $\rightarrow$ $M_a = M_{lim}$

7.4. DOUBLE REINFORCED FLANGED SECTION

7.4.1. EXTENSION OF THE BLOCK STRESS

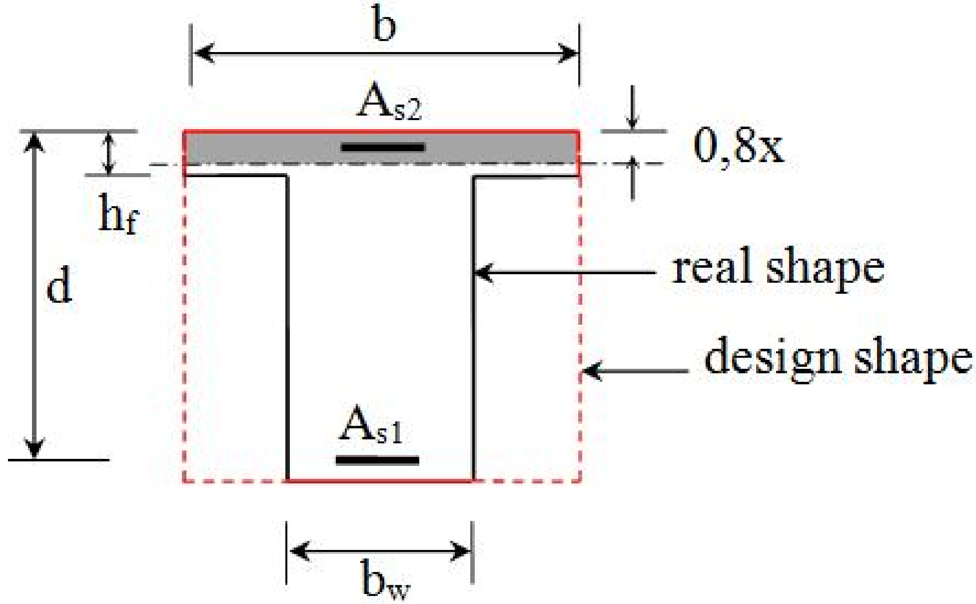
Formulas from slide 37 are completed with contribution of compression reinforcement A_{s2}

$$A_{sf} = b h_f \frac{f_{cd}}{f_{yd}} + A_{s2}$$

$$M_f = b h_f f_{cd} \left(d - 0{,}5 h_f\right) + A_{s2} \left(d - d_2\right)$$

7.4. DOUBLE REINFORCED FLANGED SECTION

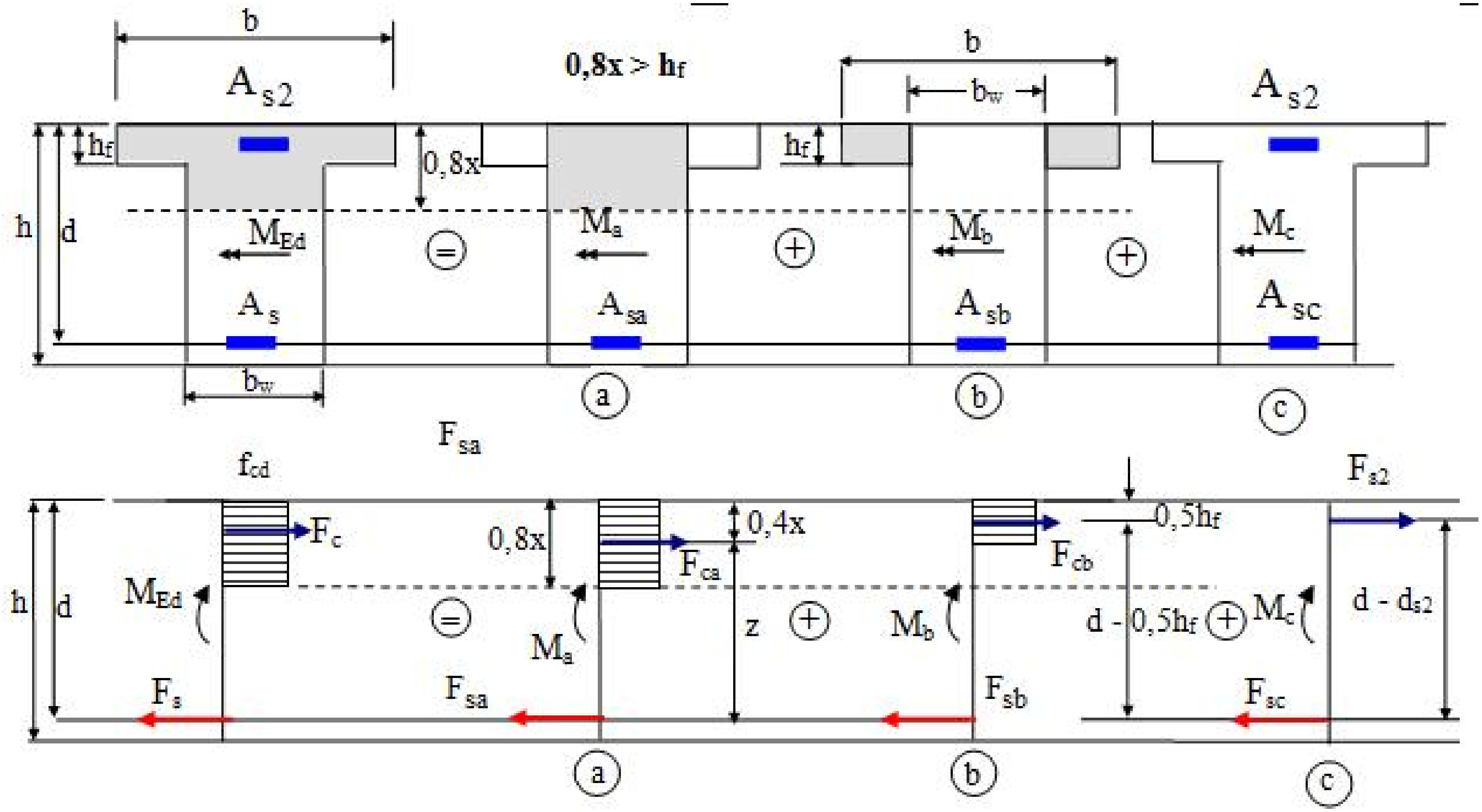
7.4.2. CROSS SECTION WITH BLOCK STRESS IN THE WEB



- concrete below the neutral axis is cracked
- real shape does not matter
- calculation $\rightarrow$ rectangular section b & h

7.4. DOUBLE REINFORCED FLANGED SECTION

7.4.3. CROSS SECTION WITH BLOCK STRESS IN THE WEB



COMBINATION OF THE PROCEDURES OF CHAPTERS 7.2 AND 7.3