Valuation of Doubly Reinforced Beam Design under Working Stress Vis-a-Vis Limit State Method

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1-**Abstract:-**

The valuation means the costing of doubly reinforced beam with reference to steel used during designing under working stress cum limit state method. As the steel cost is more by 70 times to concrete, hence valuation is based on the sum of steel requirement in tension and compression zone of beam. Through illustration, this technical paper revealed that less steel is required, while designing of beam by Limit state method. The study demonstrates that by using of higher grade of steel, requires its lesser quantity with reference of using higher grade of concrete. Fe-415 grade of steel requires its less quantity, if using Fe-250 grade and similarly using of higher grade of concrete, requires not much more less steel. This technical paper highlights to use limit state design as well as better grade of concrete and better grade of steel, rather than working stress design and lower grade of concrete and steel as well for economical valuation. 40% cost variation occurs during changing of grades of materials from WSM to LSM. Therefore recommendation exists with LSM, to design the structure as well as to use higher grade of steel and slight higher grade of concrete as well. The study reveals that using of higher grade of concrete sets less economy than using of higher grades of steel.

2-Key Words:-Factored bending moment, Steel in tension zone, Steel in compression zone, M_{ulimit}, X_{umax}, beam effective depth, beam breadth, valuation and limit state versus working stress.

3-Introduction:-

Since more than three decades, the designing of structures either steel or reinforced structures are being designed through Limit State than Working Stress method. Though ultimate limit of design method is also there, however it is not in vogue. At the time of collapse of structure, margin of safety approaches rationally in limit state method of design. In ultimate design, the structure leads excessive deflection and cracking, whereas elastic method is over safe in deflection and cracking as well. In between only limit state method exists for design of reinforced structures, wherein acceptable limit of safety under collapse and serviceability under deflection/cracking exists. The structure collapse is limited to bending, shear, compression and torsion. The previous technical paper titled Valuation of Methods for Designing of RCC Structures-A Case Study with Working Stress v/s Limit State vis-a vis Ultimate Load published by the author indicates the cost base ratio of working stress to limit state 1.24 : 1.00, steel base ratio respectively 1.00 : 3.00 and concrete base ratio by 1.67:1.00. It means that limit state method is economical, even having steel much more for singly reinforced beam. Keeping this point of view, the matter came in mind the happening of this in doubly reinforced beam will be of

which type. Then the case study make started and after the illustration, confined result has been outlined by using below methodology.

4-Methodology:-

The title of paper is clear to get the cost of doubly reinforced beam under elastic and limit state method of design. As through the cited references, elastic method has incoming bending moment(M), coefficient of critical neutral axis(X_1=m.cbc/(m.cbc+st), coefficient of lever arm(Z_1=1 - X_1/3), moment resisting factor(Q=0.5xcbcxX_1xZ_1), resisting moment (M_r=Qbd^2), critical area of steel for singly reinforced(Ast_1= M_r /st.Z_1d), remaining moment(M_2=M-M_1), area of steel for remaining moment in tension{Ast_2= M_2/st (d-d^1)} and compression{(Asc= M_2/(1.5m-1)cbc^1(d-d^1)} etc.

In limit state factored moment (Mu=1.5xM), permissible stress of steel in compression(fsc), limiting moment of resistance {M_{ulimit}= 0.36 fck.b.X_{umax} (d-0.42X_{umax})}, area of steel in tension for singly reinforced{Ast1=M_{ulimit} /0.87 fy.(d-0.42X_{umx})}, remaining moment(Mu_2=Mu-M_{ulimit}), area of steel in tension due to remaining moment {Ast2= Mu_2/0.87 fy (d-d^1)} and area of steel in compression due to remaining moment {Asc= Mu_2/fsc(d-d^1)} are calculated.

Finally total area of steel in tension Ast=Ast_1+Ast_2 is calculated and then Total steel required for beam which includes Asc too in Ast is determined. As the steel is the costlier item than concrete and concrete section is of same size, hence the valuation will only be dependent on steel required for beam. More the steel, more the cost and less steel has less valuation as well as economical. The value of fsc is taken from table according as d^1/d to the steel grade.

5-Example:-

A doubly reinforced beam has been limited to size 250 mm by 550 mm (effective) and bearing factored moment 300,00,00,00 N-mm. The compression steel is 50 mm below to the top fiber of concrete. Comparing study table by changing the grades of concrete as well as reinforcement and methods of designing by working stress versus Limit state is as under.

WSM M-20,Fe-250,m=13, Moment M=200000000 N-mm, d^1=50 mm.	LSM M-20,Fe-250,Factored Moment=300000000 N-mm d^1=50 mm
1-X_1=0.39,Z_1=0.87,Q=1.187 N/mm^2 2-Bending Moment M=200,00,00,00 N-mm 3-Bending Moment due to singly reinforced beam M_1=(1.187)(250)(550)(550)=89766875 N-mm 4-Remaining moment M_2=200,00,00,00-89766875=110233125	1-fsc=217 N/mm^2, X_{umax}=0.53 d=291.5 mm. 2-Factored Moment=300,00,00,00 N-mm 3- Bending Moment due to singly reinforced beam Mulimit=(0.36)(20)(250)(291.5){550-(0.42)(291.5)} =224345979 N-mm

N-mm **5-Tensile Steel in tension zone due to Singly reinforced beam** **Ast_1=** **89766875 N-mm/(140)(0.87)(550)=1340 mm^2** **6-Tensile Steel due to remaining M_2 Ast_2=110233125/(140)(550-50)=1575 mm^2** **7-Compression Steel in compression zone due to remaining M_2** **Asc=110233125/(18.5)(500)(5.37)** **=2220 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=1340+1575+2220=5135 mm^2**	**4- Remaining moment Mu_2=300,00,00,00-224345979** **=75654021 N-mm** **5-Tensile Steel in tension zone due to Singly reinforced** **Beam Ast_1=** **224345979/0.87(250){550-(0.42)(291.5)}** **=2412 mm^2** **6-Tensile Steel due to remaining Mu_2** **Ast_2=** **75654021/(0.87)(250)(550-50)=695 mm^2** **7-Compression Steel in compression zone due to** **remaining Mu_2** **Asc=7560421/(217)(550-50)** **=693 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=2412+695+693=3801 mm^2**
WSM **M-20,Fe-415,m=13, Moment M=200000000 N-mm, d^1=50mm**	**LSM** **M-20,Fe-415,Factored Moment=300000000 N-mm, d^1=50 mm**
1-X_1=0.28,Z_1=0.90,Q=0.88 N/mm^2 **2-Bending Moment M=200,00,00,00 N-mm** **3-Bending Moment due to singly reinforced beam** **M_1=(0.88)(250)(550)(550)=66550000 N-mm** **4-Remaining moment M_2=200,00,00,00-66550000=133450000** **N-mm** **5-Tensile Steel in tension zone due to Singly reinforced beam** **Ast_1=** **66550000 /(230)(0.88)(550)=598 mm^2**	**1-fsc=353 N/mm^2, X_{umax}=0.48d =264 mm.** **2-Factored Moment=300,00,00,00 N-mm** **3- Bending Moment due to singly reinforced beam** **M_{ulimit}=(0.36)(20)(250)(264){550-(0.42)(264)} =208669824 N-mm** **4- Remaining moment Mu_2=300,00,00,00-208669824=91330176 N-mm** **5-Tensile Steel in tension zone due to Singly reinforced beam** **Ast_1=** **208669824/0.87(415){550-(0.42)(264)}**

6-Tensile Steel due to remaining M_2 **Ast_2=133450000/(230)(550-50)=116 mm^2** **7-Compression Steel in compression zone due to remaining M_2** **Asc=133450000/(18.5)(500)(4.73)** **=3050 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=598+116+3050=3764 mm^2**	**=1316 mm^2** **6-Tensile Steel due to remaining Mu_2** **Ast_2=** **91330176/(0.87)(415)(550-50)=506 mm^2** **7-Compression Steel in compression zone due to remaining Mu_2** **Asc=91330176/(353)(550-50)** **=518 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=1316+506+518=2340 mm^2**

WSM **M-25,Fe-250,m=11, Moment M=200000000 N-mm, d^1=50mm**	**LSM** **M-25,Fe-250,Factored Moment=300000000 N-mm, d^1 =50 mm**
1-X_1=0.40,Z_1=0.87,Q=1.48 N/mm^2 **2-Bending Moment M=200,00,00,00 N-mm** **3-Bending Moment due to singly reinforced beam** **M_1=(1.48)(250)(550)(550)=111925000 N-mm** **4-Remaining moment M_2=200,00,00,00-111925000=88075000N-mm** **5-Tensile Steel in tension zone due to Singly reinforced beam** **Ast_1=** **111925000 /(140)(0.87)(550)=1671 mm^2** **6-Tensile Steel due to remaining M_2** **Ast_2=88075000/(140)(550-50)=1259 mm^2** **7-Compression Steel in compression zone due to remaining M_2**	**1-fsc=217 N/mm^2, X_{umax}=0.53d =291.5 mm.** **2-Factored Moment=300,00,00,00 N-mm** **3- Bending Moment due to singly reinforced beam** **M_{ulimit}=(0.36)(25)(250)(291.5){550-(0.42)(291.5)}=280432473.75 N-mm** **4- Remaining moment Mu_2=300,00,00,00-280432473.75=19567526.25 N-mm** **5-Tensile Steel in tension zone due to Singly reinforced beam** **Ast_1=** **280432473.75/0.87(250){550-(0.42)(291.5)}** **=3016 mm^2** **6-Tensile Steel due to remaining Mu_2** **Ast_2=** **19567526.25/(0.87)(250)(550-50)=180 mm^2** **7-Compression Steel in compression zone due to remaining Mu_2**

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Asc=88075000/(15.5)(500)(6.57) **=1730 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=1671+1259+1730=4660 mm^2**	**Asc=19567526.25/(217)(550-50)** **=181 mm^2** **8-Total Steel in Beam** **Ast_1 + Ast_2 +Asc=3016+180+181=3377 mm^2**

6-Comparative Valuation in Tabulated Form :-

Point of Compariso n	WSM M-20,Fe-250, m=13, Moment M=20000000 0 N-mm, d^1=50 mm.	LSM M-20,Fe-250 , Factored Moment= 300000000 N-mm d^1=50 mm	WSM M-20,Fe-415, m=13, Moment M=200000000 N-mm, d^1=50mm	LSM M-20,Fe-415, Factored Moment= 300000000 N-mm, d^1=50 mm	WSM M-25,Fe-250 , m=11, Moment M =200000000 N-mm, d^1=50mm	LSM M-25,Fe-250 , Factored Moment =300000000 N-mm, d^1=50 mm
Ast_1	1340	2412	598	1316	1671	3016
Ast_2	1575	695	116	506	1259	180
Ast_1 + Ast_2	2915	3107	714	1822	2930	3196
Asc	2220	693	3050	518	1730	181
Ast_1 +Ast_2 + Asc	5135	3800	3764	2340	4660	3377
% age benefit under valuation	(5135-3800)(100)/5135=26		(3764-2340)(100)/3764=37.8 3		(4660-3377)(100)/4660=27.53	
Choice	3rd		1st		2nd	

7-Conclusion:-

The technical paper title in tabulated form results that steel requirement in limit state method of design is very much less than design through working stress. The case study 1st, where steel saving remained 26% for LSM standing for f_y 250 grade and M_{20} grade. 37% and 27.5% steel saving occurred in LSM for M_{20} with fy $_{415}$ and M_{25} with f_y 250. The valuation of doubly RCC beam has been taken on the basis of total steel area required for tension as well as compression zone. As the concrete has same area of beam, because of using same sectional area in all three case studies, hence only steel

has variation due to using of various grades of concrete as well as steel. The result concludes to use of higher grade of steel rather than concrete, sets better economy than vice versa.

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