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Comparative Study of Flexural Strength for Steel-Concrete Composite beams from the point of view of different codes

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الملخص العربى

يتناول هذا البحث دراسه مقارنه لقدره تحمل قطاعات الكمرات المركبه من الحديد والخرسانه للعزوم الموجبه لكل من الكود المصرى للمنشآت الحديديه (ECP 205-2001,2007) و الكود الأمريكى للمنشآت الحديديه (AISC 360-10) من خلال طريقتين للتصميم وهما طريقه معامل الحمل والمقاومه و طريقه الاجهادات المسموحه. حيث تناولت الدراسه حساب قدره العزوم لعدد ٢٧ قطاع وكانت قطاعات الحديد عباره عن IPE, HE-B,HE-A و Cوالبلاطه الخرسانيه بسمك ١٥٠مم. وخلصت الدراسه الى ان الزياده في قدره مقاومه العزوم الموجبه في كل من قطاعات IPE وHE-B,HE-A تكون من القطع المكافئ بينما قطاع C تكون الزياده فيه خطيه. ايضا اوصت الدراسه ان لا تقل مساحه الخرسانه عن ٩ مرات مساحه الحديد.

Abstract

In this study, the specifications aspects of steel-concrete composite beams using recently adopted design provisions were reviewed. Design provisions reviewed included the load and resistance factor design (LRED) and allowable stress design (ASD) of Egyptian and American Specification for structural steel building. The design moment strengths of composite beams were calculated according to each design specification. The study compared the capacity of different composite beam sections under positive moment.

Keywords: composite beam, flexural strength, load and resistance factor method, allowable stress design.

1- Introduction

As the used composite construction is particularly competitive for medium- or long-span structures where a concrete slab or deck is needed for other reasons, where there is a premium for rapid construction.According to the review of existing design standards, such as Egyptian Code of Practice for steel construction (ECP 205-2001,2007) and American Institute of steel Construction (AISC 360-10), the calculation methods for design strength of steel-concrete composite members can be divided into the load resistance factor design method (LRFD) and the allowable stress design (ASD). For ECP and AISC 361-10, using LRFD, the design strength of composite members is determined by multiplying the nominal member strength and the resistance factor φ, which is not greater than 1.0. For adopting ASD, the safety factor γ of not less than 1.0 is applied directly to material characteristic strengths rather than to the member strength. This difference in the calculation format between the LRFD and ASD can result a notably differences in the design strength of composite members, even though the material and section have the same properties.

In this study, the provisions for flexural design of composite beams specified in ECP 205 and AISC 360-10 were reviewed in terms of design format, resistance and safety factors, and the method of section analysis. For a quantitative comparison, the design moment of fully composite beams was calculated according to the provisions specified in each design code.

2- Provisions for Flexural Design

2-1 Design format and Material Strength

The characteristic strength, design strength, and safety factor for materials shown in Table (1) are denoted as f_k, f_d and γ, respectively. For example, f_{ck}, f_{cd}, and $\gamma_c$are the characteristic compressive strength, design compressive strength, and safety factor for concrete, F_{yk}, F_{yd}, and γ_s are the characteristic yield strength, design yield strength, and safety factor for structural steel, and f_{yrk}, f_{yrd}, and γ_r are the values for reinforcing steel bars. Additionally, $M(f_k)$ and $M(f_d)$ denote the ultimate moment strengths of composite beams calculated by using the characteristic and design material strengths, f_k and f_d, respectively. In table 1 M_d is the design moment strength including a safety margin against the nominal strength, and φ is the resistance factor used for LRFD.

Table (1)compares between two methods of design formats and material strength specified in ECSC and AISC360-10. For both provisions which use LRFD as design format, the design moment strength of composite beams is calculated by multiplying the nominal strength M_n and the resistance factor φ. Thus, the LRFD can ensure a constant safety margin for bending, regardless of behavior of composite beam. On another hand, the use of allowable strength design as a design format, the design moment strength is directly calculated from the reduced material strength $f_d$divided by the safety factor for concrete, steel and reinforcing bar.

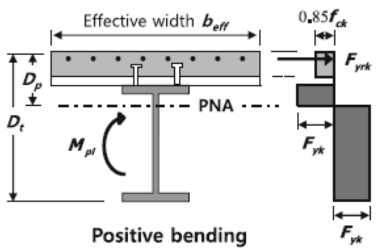
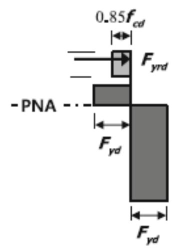
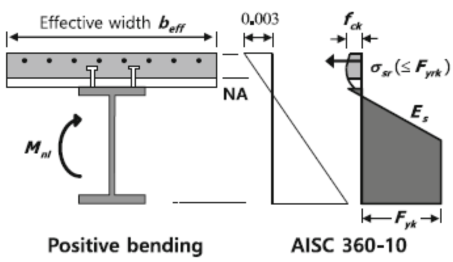
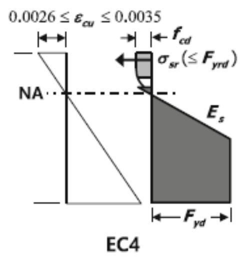
Table1: Comparison between Egyptian and American provision in design format

	ECSC		AISC	
Design format	load and resistance factor design(LRFD)	Allowable stress deign(ASD)	load and resistance factor design(LRFD)	Allowable stress deign(ASD)
Design moment strength M_d	$M_d = \varphi M_n$	$f_d=f_k/\gamma$ and $M_d=M(f_d)$	$M_d = \varphi M(f_k)$	$M_d = M_n / \Omega$
Resistance factorφ or safety factorϒ for materials	φ=0.80or 0.85	Concrete γ=1.5 Steel γ_s=1.0 Reinforcing bar γ_r=1.5	φ=0.9	Ω= 1.67
Characteristic material strength fk(MPa)	concrete $25 \leq f_{ck} \leq 50$	concrete $25 \leq f_{ck} \leq 50$	concrete $21 \leq f_{ck} \leq 70$	concrete $21 \leq f_{ck} \leq 70$
	Steel $F_{yk} \leq 360$	Steel $F_{yk} \leq 360$	Steel $F_{yk} \leq 525$	Steel $F_{yk} \leq 525$

2-2 Design Moment strength

The ultimate moment strength of composite beam sections can be calculated using the plastic stress distribution method (PSDM) and strain-compatibility method (SCM). Table (2) demonstrate the comparison between stress distribution of concrete, steel and reinforcing bars over a composite section required for PSDM prescribed in Egyptian and American specification. The stress distributions illustrated in Table (2)are for positive bending, as the concrete flange is subjected to compression. For LRFD design format the plastic stresses of concrete, steel, and reinforcing bars are defined as $0.85f_{ck}$, F_{yk}, and f_{yrk}, respectively. The plastic moment M_{pl} and the depth D_p of plastic neutral axis are then calculated from the force equilibrium between internal resultant forces produced by the plastic stresses $0.85f_{ck}$, F_{yk}, and f_{yrk}. In contrast with the ASD as a design format define the design plastic stresses of concrete, steel, and reinforcing bars as $0.85f_{cd}$, F_{yd}, and f_{yrd}, respectively. Because the design plastic stresses are decreased by dividing by the safety factors γ_c, γ_s, and γ_r (≥ 1.0), the values of M_{pl} andD_p determined from ASDspecifiedin ECSC and AISC 360-10 are not equivalent.In fact, the plastic stress distributions shown in Table 2 are different from the actual stress distributions at the ultimate limit state. Furthermore, a composite beam may suffer a premature failure due to crushing failure in the concrete slabeven before the plastic stress is fully developed in the steel section. This is more likely to occur when high-strength steel is used.

Table2: Design moment strengths by plastic stress distribution method and strain compatibility

	AISC 360-10	ECP 205
		LRFD
Plastic stress	Conc. $0.85f_{ck}$, steel F_{yk}, and reinforcing bar f_{yrk}	Conc. $0.67f_{cd}$, steel F_{yd}, and reinforcing bar f_{yrd}
Stress distribution		
Design strength M_d	$M_d = \phi M_{pl}$ and $\phi = 0.9$	$M_d = M_{pl}$ or βM_{pl}
		ASD
Conc. σ–ε curve	Not specified Maximum compressive strain = 0.003	Not specified Maximum compressive strain = 0.003
Steel σ–ε curve	Not specified	Not specified
Stress and strain distributions (positive bending)		
Design strength M_d	$M_d = \phi M_{nl}$ and $\phi = 0.9$	$M_d = M_{nl}$

3. Design Resistance by ASD and LRFD methods

In this section, the design moment strength of cross section calculated by LRFD and ASD accoriding to the Egyptian and American provisions. the design format, resistance factor, and plastic stress of the material refer to Table (1 and 2). The study calculates the momemt stength for IPE, HE-B,HE-A and C with different cross section with total number 27 section. The cross section isshown in Fig. 1

Table (3): Design results : interior beams under positive bemding (kNm)

section	ECP 205			AISC360		
	M_n	M_d(LRFD)	M_d (ASD)	M_n	M_d(LRFD)	M_d (ASD)
IPE200	46.68	68.27	34.23	33.05	29.75	19.83
IPE300	108.87	168.35	84.05	95.49	85.94	57.30
IPE 360	168.01	258.38	131.68	155.39	139.85	93.24
IPE 400	211.41	320.99	166.67	201.46	181.31	120.88
IPE500	345.21	523.51	274.53	362.52	326.27	217.51
IPE600	541.26	631.09	433.15	456.31	410.68	273.79
HE_B200	119.38	184.93	89.89	63.46	57.12	38.08
HE-B300	304.57	481.16	239.12	166.91	150.22	100.14
HE-B360	425.12	665.94	337.02	290.47	261.42	174.28
HE-B400	506.41	787.52	403.51	391.06	351.95	234.64
HE-B500	735.76	1130.60	591.36	649.03	584.13	389.42
HE-B600	969.23	1474.45	782.84	954.30	858.87	572.58
HE-B700	1252.44	1885.49	1014.62	1343.73	1209.35	806.24
HE-B1000	2202.26	3270.56	1786.21	2677.15	2409.43	1606.29
C200	38.55	61.74	30.01	45.44	40.90	27.27
C260	65.79	110.32	53.63	89.44	80.49	53.66
C 300	97.34	160.27	77.91	124.15	111.74	74.49
C 350	157.27	245.54	119.36	196.81	177.13	118.09
C400	208.41	329.32	160.09	264.93	238.44	158.96
HE-A200	82.96	127.82	62.14	36.13	32.52	21.68
HE-A300	228.39	352.84	179.21	104.94	94.45	62.97
HE-A360	332.94	514.92	264.19	205.22	184.70	123.13
HE-A400	402.55	620.70	320.97	288.89	260.01	173.34
HE-A500	605.17	922.61	487.05	500.36	450.32	300.22
HE_A600	807.76	1222.12	653.55	761.70	685.53	457.02
HE-A700	1054.49	1586.01	854.56	1098.99	989.09	659.40
HE-A1000	1495.15	2812.53	1544.97	2261.23	2035.11	1356.74

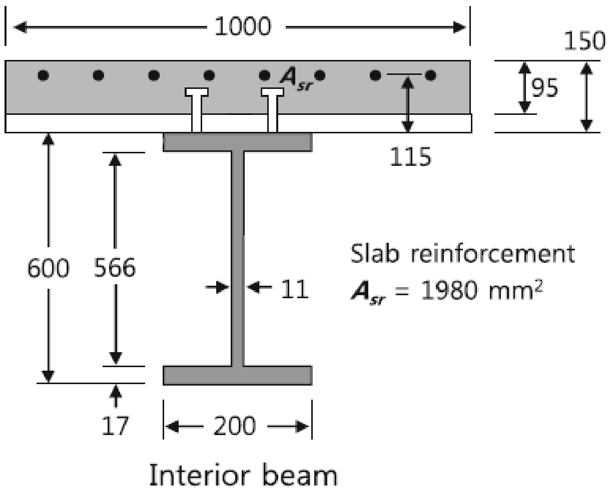
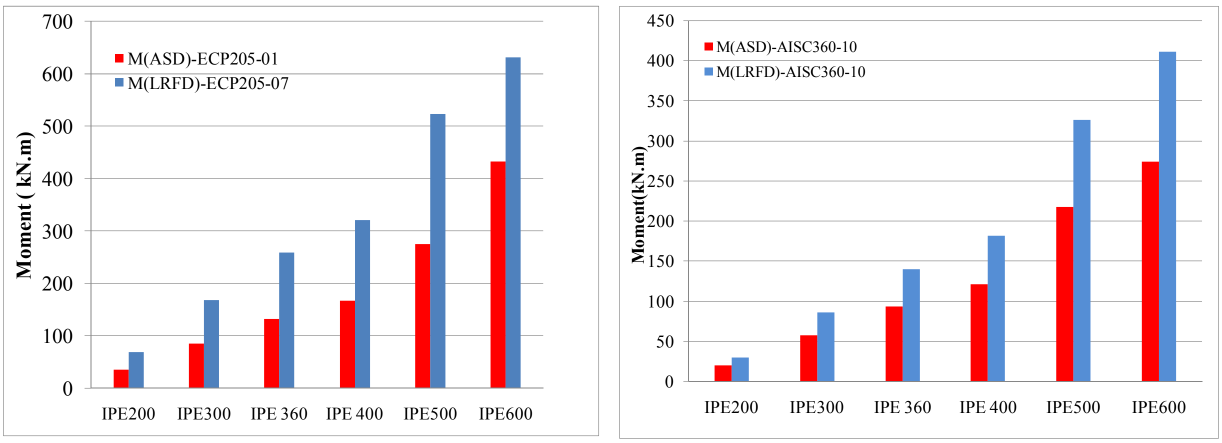


Fig.(1): Cross section of composite beams (mm)

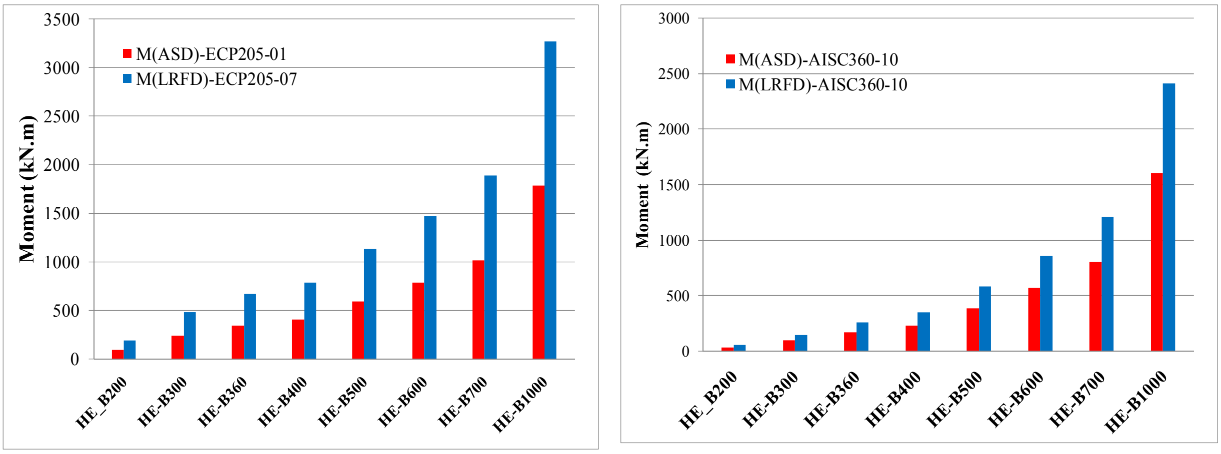
4-Result Analysis

This section discuss the resulte of each type of section with respect to the design moment getting by ASD or LRFD methods according to Egyptian and Amrican specification . For the IPE section it is notice that the prabolic increse for ASD and LRFD. While the ECP205 gives more design values than AISC360 as seen in Fig.2(a&b). with respect to the HE-B section shown in Fig.3(a&b) the design moment increase in prabolic trend in the presence of marked diffrence between ASD and LRFD in both Egyptian and Amrican spcifications. According to the C section as shownin Fig.4(a&b), it seen that the linear increse in the design moment strength whether using ASD or LRFD in both sepcinfications ECP and AISC. The HE-A section gives similar trend as HE-B section as clarified in Fig. 5



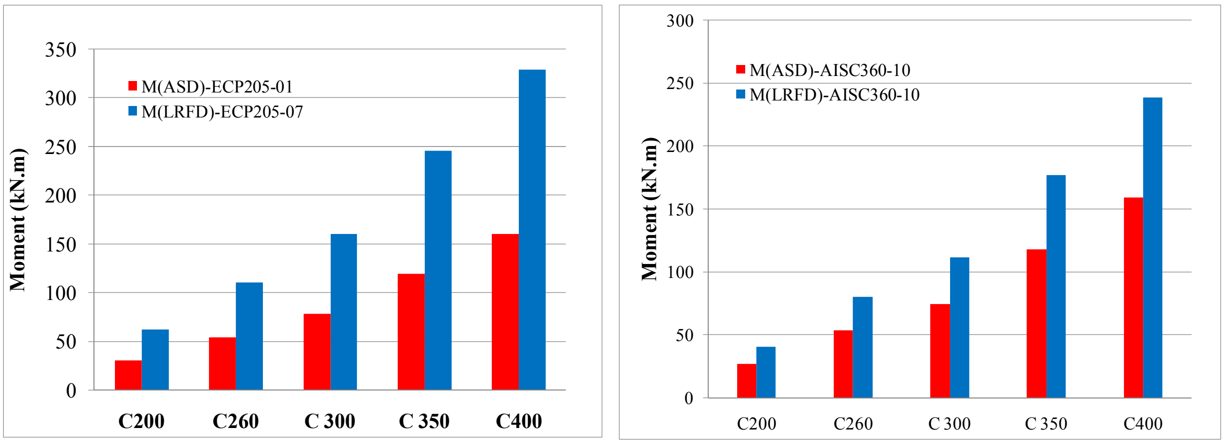
(a) (b)

Fig.2: Design moment calculated from ECP and AISC for IPE section



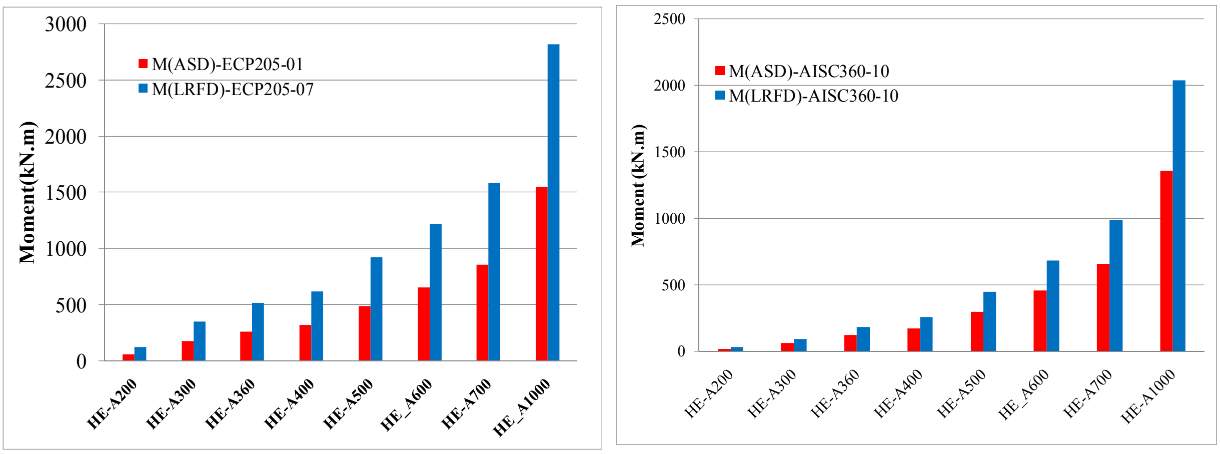
(a) (b)

Fig.3: Design moment calculated from ECP and AISC for HE-B section



(a) (b)

Fig.4: Design moment calculated from ECP and AISC for C section



(a) (b)

Fig.5: Design moment calculated from ECP and AISC for HE-A section

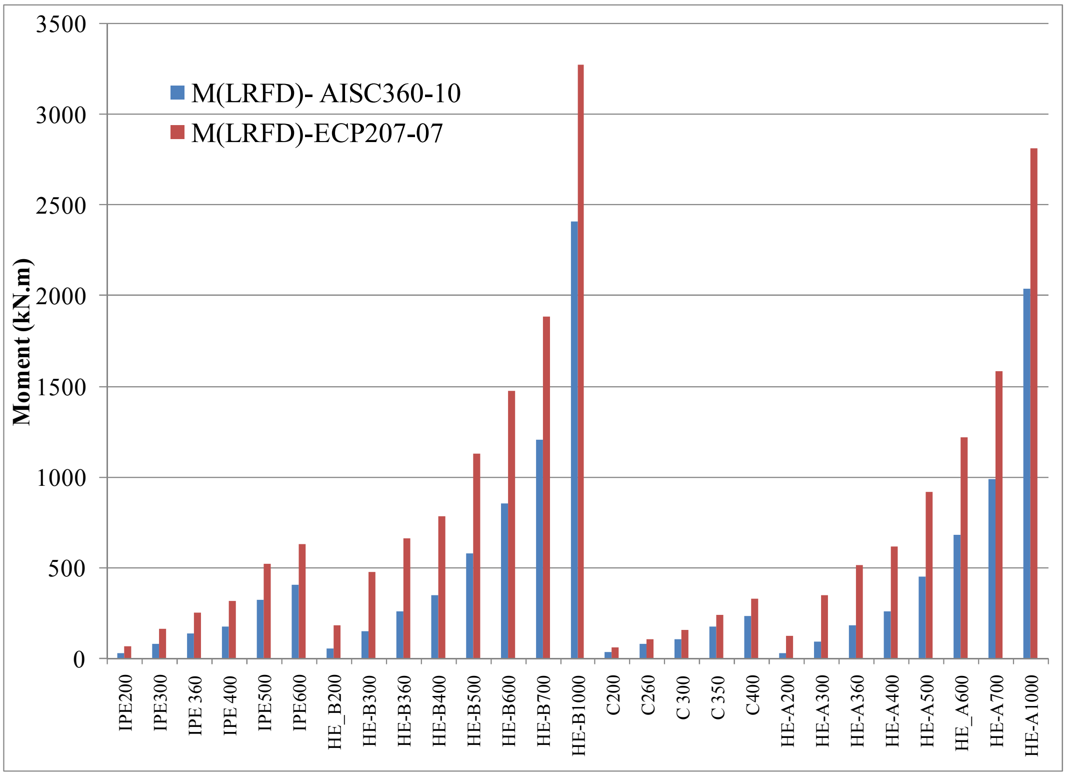


Fig.6: Comparison between ECP and AISC in term of LRFD

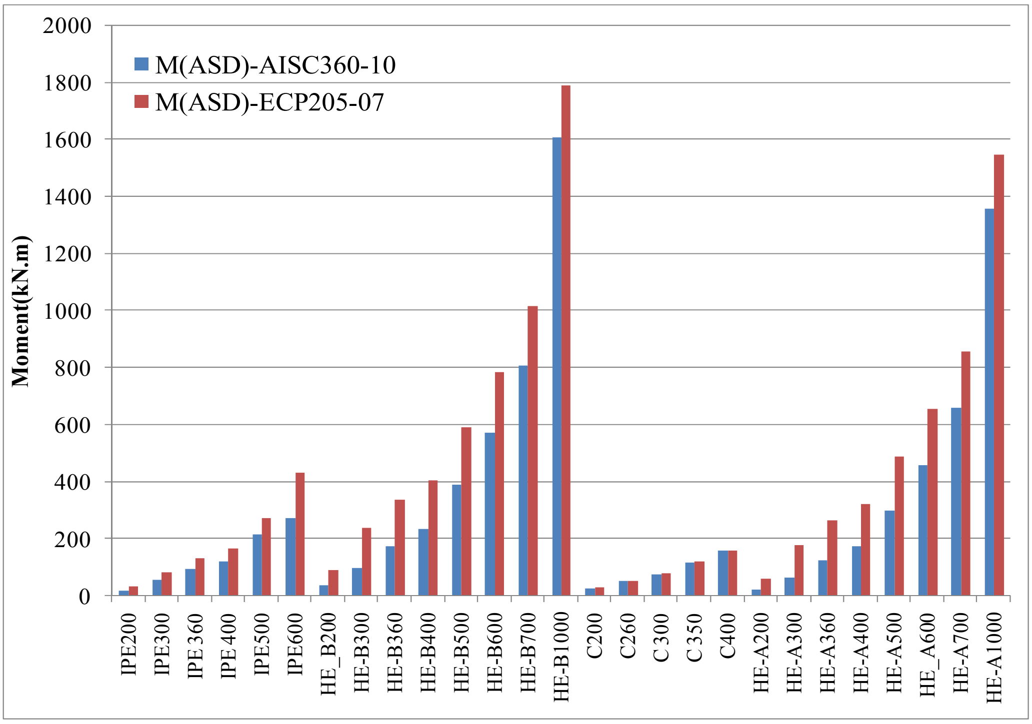


Fig.7: Comparison between ECP and AISC in term of ASD

From Fig.6 and Fig.7 it is notice that the Egyptian specification in more conservative than the American specification in both LRFD and ASD design format. The results indicate that, thecomposite steel section is weaker by decreasing the concrete area with respect to area of steel section. It is recommended that the area of concrete not less than 9 times of steel section area.

Conclusion

In this study, provisions for flexural design of composite beams specified in ECP 205 and AISC360-10 were compared based on LRAD and ASD in terms of the design format, material strength, and resistance safety factor. The major finding of this study can be summarized as follows:

1- The increase in the design moment by ASD and LRFD methods are in a parabolic trend in IPE, HE-A and HE-B and a linear increase for C section.

2- Egyptian specification is more conservative than American specification in both methods of design.

3- It is recommended the area of concrete not less than 9 times the area of steel section.

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