STEEL News & Notes
SINGAPORE STRUCTURAL STEEL SOCIETY

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Contents

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The President's Corner

The structural steel industry is facing a tough and rapidly changing construction environment. Over the last two years we experienced the softening of residential and commercial markets, and have to face with the slowdown of the oil and gas and marine industry due to depressing oil prices, causing many of the companies to cut down or halt their infrastructure spending. This has resulted in cut backs in the procurement and usage of structural steel related services. Many of our members have been affected by this economic downturn and saw their volume of work reduced.

On a more optimistic note the outlook for construction demand continues to be strong, according to Building and Construction Authority recent forecast. The annual construction demand for 2016 and 2017 will be between S$26 billion to S$33 billion. This is a good sign for the construction industry and hopefully there will be substantial quantities of structural steelwork for projects in the pipeline.

The construction industry continues to pay emphasis on productivity and quality. The rapidly changing method of construction from an on-site base to an off-site manufacturing method augurs very well for the structural steel trade. The Building and Construction Authority is leading the built environment to move forward and embrace Design for Manufacturing and Assembly (DfMA).

In a factory environment, emphasis will be on mechanised equipment and less labour. With less reliance on labour and high on productivity and quality it may well become the standard way to fabricate and assemble our structural components and building units.

Members are encouraged to keep abreast with the latest construction technologies available and seek assistance when needed from the various government related agencies to tap on their expertise and guidance. Hopefully, members can progress with various newly acquired methods of construction, and position themselves in a more competitive environment.

On behalf of the council, I would like thank you for the support you have given to the society and look forward to seeing you at our society functions.

To a fruitful year ahead

Anthony Tan

President, Singapore Structural Steel Society

May 2016

SSSS New Ordinary & Associate Members as of 4 Jan 2016

Member Code	Last Name	First Name	Member Grade	Date Joined
OM-1027	Yan	Nyein	Ordinary	12-Apr-2012
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OM-1038	Cheong	Chee Keong	Ordinary	14-Jun-2012
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OM-1055	Wong	Kok Fann	Ordinary	13-Sep-2012
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OM-1077	Wu	Dai Hai	Ordinary	20-Feb-2013

SSSS New Ordinary & Associate Members as of 4 Jan 2016

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OM-1100	Ganeshananth	Kumarasamy	Ordinary	09-Jan-2014
OM-1101	Sivaganeshan	Sathasivam	Ordinary	09-Jan-2014
OM-1102	Suvarnarajah	Thangarajah	Ordinary	09-Jan-2014
OM-1103	Tran	Chi Trung	Ordinary	09-Jan-2014
OM-1104	Kannadasan	Arumugam	Ordinary	09-Jan-2014
OM-1105	Min	Win Kyaw Kyaw	Ordinary	13-Feb-2014
OM-1106	Chen	Yi Chun	Ordinary	13-Feb-2014
OM-1107	Chong	Qin Xian	Ordinary	13-Feb-2014
OM-1108	Kumar	Athisekaran Krishna	Ordinary	13-Mar-2014
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OM-1111	Eduria	Jonathan Sanado	Ordinary	08-Apr-2014
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OM-1116	Ma	Ni Ni Myint	Ordinary	05-Jun-2014
OM-1117	Choong	Raphael Yeein Chern	Ordinary	05-Jun-2014
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OM-1119	Eng	Nona	Ordinary	05-Jun-2014
OM-1120	Tan	Wei Kwang	Ordinary	05-Jun-2014
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OM-1122	Jayalal	Koswatte Gedara Ranjan	Ordinary	09-Jun-2014
OM-1123	De Silva	Pituwala Liyanage Nirosha Udayanga	Ordinary	09-Jun-2014
OM-1124	Sien	Michael Hay Wah	Ordinary	09-Jun-2014
OM-1125	Yoon	Wing Yen	Ordinary	10-Jul-2014
OM-1126	Chai	Chong Her	Ordinary	10-Jul-2014
OM-1127	Tseng	Hui Yen Clement	Ordinary	14-Aug-14
OM-1128	Yap	Lee Yu Leelyn	Ordinary	14-Aug-14

SSSS New Ordinary & Associate Members as of 4 Jan 2016

Member Code	Last Name	First Name	Member Grade	Date Joined
OM-1129	Liew	Kuo Huei	Ordinary	14-Aug-14
OM-1130	Cheong	Wai Keong Justin	Ordinary	14-Aug-14
OM-1131	Jayasinghe	Herath Jayasinghe Amila Prabuddha	Ordinary	14-Aug-14
OM-1132	Saminathan	Gunasekaran	Ordinary	14-Aug-14
OM-1133	Gao	Song	Ordinary	14-Aug-14
OM-1134	Hiew	Siaw Ling	Ordinary	14-Aug-14
OM-1135	Chua	Koh Hee	Ordinary	14-Aug-14
OM-1136	Ong	Toon Lian	Ordinary	28-Aug-14
OM-1137	Sheldon	Rick John	Ordinary	11-Sep-14
OM-1138	Chuan	Yeong Soon	Ordinary	11-Sep-14
OM-1139	Lau	Kien Fah	Ordinary	11-Sep-14
OM-1140	Braza	Vicente Gardin	Ordinary	9-Oct-14
OM-1141	Vinothan	Puveneswaran	Ordinary	9-Oct-14
OM-1142	Murali	Kaliyamoorthy	Ordinary	9-Oct-14
OM-1143	Guo	Qianli	Ordinary	9-Oct-14
OM-1144	Eng	Lye Huang, Isaac	Ordinary	9-Oct-14
OM-1145	Fong	Chee Keong	Ordinary	9-Oct-14
OM-1146	Chong	Seng Lai	Ordinary	9-Oct-14
OM-1147	Teoh	Kok Hean	Ordinary	9-Oct-14
OM-1148	Kyi Min Htet	Kyi Min Htet	Ordinary	13-Nov-14
OM-1149	Chockaiya	Raja Rajan C.	Ordinary	13-Nov-14
OM-1150	Geethan	Singarayar Cleetruse	Ordinary	8-Jan-15
OM-1151	Ng	Pin Yuan	Ordinary	8-Jan-15
OM-1152	Edison	Ivan K	Ordinary	12-Feb-15
OM-1153	Soh	Kian Siang	Ordinary	12-Feb-15
OM-1154	Rahman	Md Habibur	Ordinary	12-Feb-15
OM-1155	Nguyen	Trong Hieu Robert	Ordinary	12-Feb-15
OM-1156	Chua	Yina	Ordinary	12-Feb-15
OM-1157	Sathasivam	Manoharan	Ordinary	12-Mar-15
OM-1158	Zhao	Zhe	Ordinary	12-Mar-15
OM-1159	Pak	Ming Wee	Ordinary	9-Apr-15
OM-1160	Wong	Cai Ching	Ordinary	9-Apr-15
OM-1161	Lee	Yen Fong	Ordinary	7-May-15
OM-1162	Wu	Xiao Feng	Ordinary	11-Jun-15
OM-1163	Sim	Wee Keat	Ordinary	11-Jun-15
OM-1164	How	Gim Hooi	Ordinary	11-Jun-15
OM-1165	Wong	Wai Kit	Ordinary	11-Jun-15
OM-1166	Han	Yinzheng	Ordinary	11-Jun-15
OM-1167	Gunawan	Irsan	Ordinary	11-Jun-15
OM-1168	Ong	Bang Hui	Ordinary	11-Jun-15
OM-1169	Tang	Koon Guan	Ordinary	2-Jul-15
OM-1170	Zhao	Shuliang	Ordinary	2-Jul-15
OM-1171	Choo	Kim Thong	Ordinary	2-Jul-15
OM-1172	Kiran	R K	Ordinary	2-Jul-15
OM-1173	Andalis	Sonny Galoso	Ordinary	2-Jul-15
OM-1174	Martinez	Nolan Malinao	Ordinary	2-Jul-15
OM-1175	Lor	Chee Seng	Ordinary	10-Sep-15
OM-1176	Alvaro	Henry Amigable	Ordinary	13-Aug-15
OM-1177	Wan	Yong Kwong	Ordinary	13-Aug-15
OM-1178	Sundaramoorthy	Gunaseelan	Ordinary	10-Sep-15
OM-1179	Durairaj	Raja	Ordinary	13-Aug-15

SSSS New Ordinary & Associate Members as of 4 Jan 2016

Member Code	Last Name	First Name	Member Grade	Date Joined
OM-1180	Lim	Swee Chin	Ordinary	13-Aug-15
OM-1181	Selvan	Thomas Panneer	Ordinary	10-Sep-15
OM-1182	Chua	Huat Hin	Ordinary	10-Sep-15
OM-1183	Thaung	Myint Oo	Ordinary	10-Sep-15
OM-1184	Mohamed	Shukor Bin Ahmad	Ordinary	8-Oct-15
OM-1185	Wong	Chee Fei	Ordinary	8-Oct-15
AS-126	Ang	Cheng Leong	Associate	12-Apr-2012
AS-127	Tin	Myo Lwin	Associate	12-Apr-2012
AS-128	Lim	Chang San	Associate	12-Apr-2012
AS-129	Chai	Chong	Associate	12-Apr-2012
AS-130	Ang	Eng Kang	Associate	10-May-2012
AS-132	Song	Khong Kit	Associate	12-Jul-2012
AS-133	Jeyaraman	Jagen S/o	Associate	12-Jul-2012
AS-134	Hein	Thu Myint	Associate	7-Aug-2012
AS-135	Chng	Thien Chuan	Associate	13-Sep-2012
AS-136	See	Boon Huat	Associate	11-Nov-2012
AS-137	Chew	Yi Yuan	Associate	20-Feb-2013
AS-138	Chong	Chong Kiat	Associate	11-Apr-2013
AS-139	Sivasubramanian	Krishnan Pillai Gananathan	Associate	13-Jun-2013
AS-140	Vigneswaran	Rethinasamy	Associate	09-Jan-2014
AS-141	Tan	Thai Heng, Dominic	Associate	09-Jan-2014
AS-142	Sivasubramanian	Krishnan Pillai Gananathan	Associate	13-Jun-13
AS-143	Venugopal	Venugopal Mahendran	Associate	12-Mar-15
AS-144	Au	Yean Loy	Associate	12-Mar-15
AS-145	Subbiah	Alagappan	Associate	10-Sep-15
AS-146	Venkatachalam	Prasath	Associate	13-Aug-15

SSSS New Corporate Members as of 4 Jan 2016

Company Name	Address 1	Date Joined	Member Grade	Member Code
YLS Contracts Pte Ltd	No. 33 Defu Lane 9, Singapore 539273	11-Sep-14	Corporate	CM-239
Harico Construction (S) Pte Ltd	1015 Geylang East Ave 3 #04-121, Singapore 389730	11-Sep-14	Corporate	CM-240
Mutiara (FE) Pte Ltd	258 Woodlands Industrial Park E5, Singapore 757311	9-Oct-14	Corporate	CM-241
Stallion Development Pte Ltd	15/17 Rochdale Road, Singapore 5335829	9-Oct-14	Corporate	CM-242
Lim Teck Yong Building Construction Pte Ltd	55 Yunnan Drive 3, Singapore 637948	13-Nov-14	Corporate	CM-243
TET Engineering and Metalworks Pte Ltd	34 Sungei Kadut Loop, Singapore 729488	13-Nov-14	Corporate	CM-244
Ngee Hong Metal Engineering (S) Pte Ltd	10 Admiralty Street #02-17 Northlink Building, Singapore 757695	19-Nov-14	Corporate	CM-245
Zhejiang Jiangnan Steel Structure Co., Ltd	No. 62 Yashan West Road, Zhapu Jiaxing, CHINA	8-Jan-15	Corporate	CM-246
Topmast Engineering Pte Ltd	2 Balestier Road, Balestier Hill Shopping Centre #04-643, Singapore 320002	12-Feb-15	Corporate	CM-247
Zingametall (S) Pte Ltd	3 Coleman Street #03-09 Peninsula Shopping Centre, Singapore 179804	12-Feb-15	Corporate	CM-248
Nippon Steel & Sumitomo Metal Southeast Asia Pte Ltd	16 Raffles Quay #17-01 Hong Leong Building, Singapore 048581	12-Mar-15	Corporate	CM-249

SSSS New Corporate Members as of 4 Jan 2016

Company Name	Address 1	Date Joined	Member Grade	Member Code
HH Engineering & Services Pte Ltd	52 Sungei Kadut Street 1, Sungei Kadut Industrial Estate, Singapore 729355	12-Mar-15	Corporate	CM-250
Eyota Engineering Pte Ltd	No. 8 Boon Lay Way #07-21 Tradehub 21, Singapore 609964	12-Mar-15	Corporate	CM-251
Kirby South East Asia	Nhon Trach Iz3 Phase 2, Nhon Tract District, Dong Nai Province	11-Jun-15	Corporate	CM-253
Premium - Rich Engineering Pte Ltd	6 Woodlands Walk, Singapore 738398	11-Jun-15	Corporate	CM-254
ANR Construction & Engineering Pte Ltd	Block 38 Woodlands Industrial Park E1 #02-07, Singapore 757700	2-Jul-15	Corporate	CM-255
Creative Engineering Pte Ltd	22 Woodlands Link #03-08, Singapore 738734	2-Jul-15	Corporate	CM-256
Kai Engineering & Construction Pte Ltd	Blk 148 Potong Pasir Ave 1 #02-29, Singapore 350148	2-Jul-15	Corporate	CM-257
THI Engineering & Construction Pte Ltd	14 Kian Teck Way, Singapore 628737	13-Aug-15	Corporate	CM-258
Citi Construction & Engineering Pte Ltd	21 Bukit Batok Crescent #07-81 WCEGA Tower, Singapore 658065	10-Sep-15	Corporate	CM-259
Jian Man Construction Pte Ltd	6 Ubi Road 1 #08-10 Wintech Centre, Singapore 408726	13-Aug-15	Corporate	CM-260
Dongguan City Laigang Steel Structure Co. Ltd	Long Jian Tian Private Industrial Zone, Huang Jiang Town, Dong Guan City, GuangDong Province, China	10-Sep-15	Corporate	CM-261
Aik Lian Metal & Glazing Pte Ltd	705 Sims Drive #03-18 Shun Li Industrial Complex, Singapore 387384	8-Oct-15	Corporate	CM-262
NKH Metal & Engineering Pte Ltd	29 Sungei Kadut Loop, Singapore 729469	12-Nov-15	Corporate	CM-263

Courses: Structural Steel Supervisor (StS) and Structural Steel Engineer (StEr)

Arising from the success of the joint BCA/SSSS Structural Steel Fabricators Accreditation Scheme, the SSSS further embarked on providing the above training courses to site engineers and site personals who may be directly involved in the design, planning and construction of structural steelwork. These instructional training courses focus on practical aspects of construction work and would lead to recognition and accreditation under the Singapore Structural Steel Society as Steel Inspectors to supplement the accreditation scheme.

The SSSS has recently appointed a course organiser to administer and manage registration of both the Structural Steel Supervisor (StS) and the Structural Steel Engineer (StEr) training courses. The venue has been adjourned to Singapore Polytechnic at Dover Road to better serve members and the construction industry. Recent intake (26th batch) for the Structural Steel Supervisor course which commenced on 11th September 2014 began well with Euro-code updates to the course notes.

Line-up for both courses, StS and StEr, has been planned for year 2015 and is ready for registration with our course organiser. Further details can be found at our webpage *www.ssss.org.sg*, or you may send your enquires to *paulinezee@avconsultants.com.sg*.

Impact of Structural Eurocodes on Composite Steel & Concrete Structures

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The introduction of Structural Eurocodes to replace the existing British Standard design codes will benefit the construction industry in the long run. However, in the short term, to help our engineers migrate over to the new Eurocodes, it is useful to conduct a comparative study on both Eurocodes and British Standards to identify some of the key changes and impact on the performance of the composite structures. In this connection, this paper investigates three key design aspects comprising material properties, shear resistance of headed studs and lateral-torsional buckling of composite beam. It is found that the buckling resistance and lateral-torsional buckling resistance determined from Eurocode 4 are much larger than those from BS5950-3.1. However, for shear resistance of headed stud, Eurocode 4 produced a lower value compared to BS5950-3.1.

Keywords: Eurocode 4, BS5950-3.1, material property, shear resistance, headed studs, lateral-torsional buckling.

1. Introduction

Eurocodes are a set of harmonized technical design rules established by the European Committee for the standardization of design of structures and structural components in the European Union. The main objective of drawing up these set of harmonized technical specifications for building and civil engineering works is to eliminate technical barriers and to promote trades across member countries. Each Eurocode contains provisions which are open for national choice. Such provisions contain country specific data on those parameters, known as Nationally Determined Parameters, and such data could include weather aspects, seismic zones, geo-informatics, etc. in a relating National Annex. The National Standard implementing Eurocodes must comprise the full, unaltered text of that Eurocode, including all annexes. All European countries are required to develop their own National Annexes. Although a non-European country, Singapore has chosen to adopt the Eurocodes as her national design codes and after an initial 2 year co-existence period, the Eurocodes will be fully implemented in Singapore by 1 April 2015.

Although many of the Eurocodes design rules are based on the same design concepts as the British Standards (BS), the Eurocodes have incorporated more up-to-date research on many respects of structures behavior. The Eurocodes clauses are structured slightly differently in which they specified principles that must be satisfied first and followed by application rules that offer a way of satisfying the principles. The Eurocodes are also less prescriptive than the British Standards, with more design aspects left open to the engineers to decide. Consequently, for this reason, it is useful to discuss the design approaches and compare the results obtained by both codes to assess the impact of making some of the key changes.

In this paper, the key changes for three design aspects using both Eurocodes and BS5950 are investigated in details. The material properties of the concrete and steel materials, shear resistance of headed stud shear connectors are and lateral-torsional buckling resistance of composite beam are investigated.

2. Materials

Compared to BS5950, Eurocodes provide a wider range of both concrete strength and steel strength. For structural steel, the yield strength should not be taken as being more than 460 N/mm^2 in BS5950-1, whereas steel grades with nominal yield strength up to 690 N/mm^2 can be used according to EC3. Similarly, concrete with cylinder strength up to 60 N/mm^2 can be adopted in EC4, while maximum 50 N/mm^2 of concrete cube strength is given in BS5950-3.1. These ranges in BS5950 are narrower than those given in Eurocodes because there is limited knowledge and experience of the behaviour of structures with high strength steel and strong concrete. The key changes in material properties between BS5950 and Eurocodes are summarized below.

2.1 Ductility of structural steel

For the property of structural steel, EC3 has additional ductility requirements compared to BS5950 in terms of stress ratio, elongation and strain ratio. The limiting values of the ratio f_u/f_y, the elongation at failure and the ultimate strain ε_u may be defined as following:

(1) For normal strength steel (f_y < 460 N/mm^2):
- a) $f_u/f_y \geq 1.10$;
- b) elongation at failure not less than 15%;
- c) $\varepsilon_u \geq 15\varepsilon_y$, where ε_y is the yield stain.

(2) For high strength steel (460 N/mm^2 < f_y < 690 N/mm^2):
- a) $f_u/f_y \geq 1.05$ (EC3-1-12), $f_u/f_y \geq 1.10$ (UK NA to EC3-1-12),;
- b) elongation at failure not less than 10%;
- c) $\varepsilon_u \geq 15\varepsilon_y$.

However, some product standards only have requirements on the nominal yield and tensile strength, or their minimum values. The stress ratio calculated according to these nominal values cannot comply with the EC3 ductility requirement, as shown in Table 1. In composite slab, the profiled steel sheeting manufactured from these product standards may face the problem with EC3 ductility requirement, for example, the stress ratio of a type of profiled steel sheeting which is manufactured from G550 steel in accordance with AS 1397 can not comply with the EC3 ductility requirement, as shown in Figure 1. Therefore, the yield strength of profiled steel sheeting should be amended to satisfy the ductility requirement.

Table 1: Stress-ratio of some product standards

Standard	Grade	Nominal yield strength (MPa)	Nominal tensile strength (MPa)	Stress ratio
AS 1397	G450	450	480	1.07
	G500	500	520	1.04
	G550	550	550	1.00
AS 1595	CA 500	500	510	1.02
EN 10326	S550GD	550	560	1.02
ISO 4997	CH550	550	550	1.00

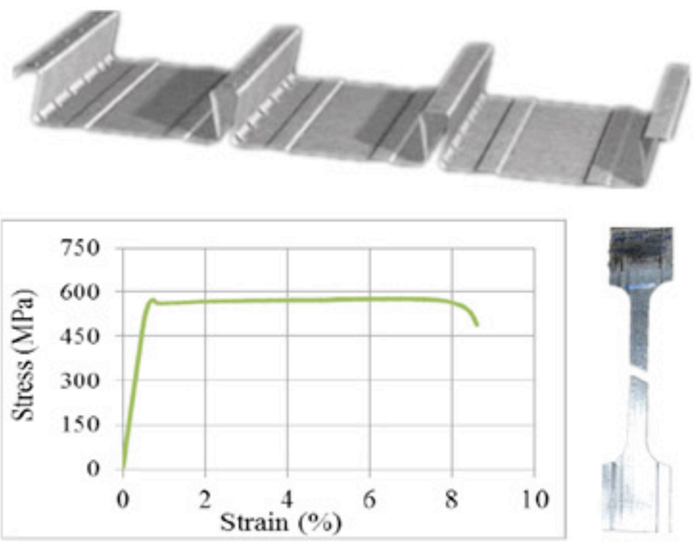
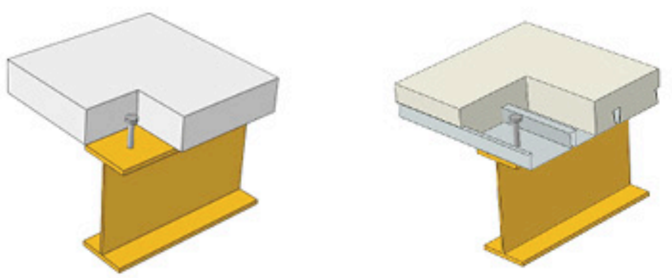


Figure 1: Stress-strain curve of a typical profiled steel sheeting

3. Shear resistance of headed studs

Shear connectors are used for providing the composite action between steel and concrete. This connection which is referred to as shear connection is provided mainly to resist longitudinal shear. The most common shear connector used in construction is the headed studs. It can be welded to the upper flange of steel beams either directly or through profiled steel sheeting, as shown in Figure 2.



(a) Solid slab (b) Composite slab

3.1 Headed studs in solid slab

In BS5950-3.1, the characteristic resistance of headed studs in solid slabs is given for various combinations of height, diameter and concrete strength, but the physics behind the numbers is not presented. The characteristic resistance of a headed shear stud embedded in a solid slab of normal weight concrete should be taken from Table 5 of BS5950-3.1.

In EC4, the resistance of headed studs in solid slabs are calculated by design equation. It is influenced by some factors, such as a shank diameter d and an ultimate strength fu of headed stud, a characteristic strength fck and a mean secant modulus E_{cm} of concrete, and failure either in the steel alone or in the concrete alone.

For a solid concrete slab, the design shear resistance of a headed stud should be determined from:

$$P_{Rd} = \frac{0.8 f_u \pi d^2 / 4}{\gamma_V} \quad (1)$$

$$P_{Rd} = \frac{0.29 \alpha d^2 \sqrt{f_{ck} E_{cm}}}{\gamma_V} \quad (2)$$

Whichever is smaller,with:

$$\alpha = 0.2(h_{sc}/d + 1) \leq 1 \quad (3)$$

The two equations represent different failure modes. Equation (1) is based on failure of the shank of headed stud, while equation (2) is based on failure in concrete.

The characteristic resistance of headed stud determined by BS5950-3.1 is different from that calculated by EC4. The comparison of characteristic resistance of different types of headed stud and various concrete strength used in the BS5950-3.1 and EC4 is shown in Figure 3. It is found that the characteristic resistance of headed studs calculated by EC4 is lower than those determined by BS5950-3.1. The resistance of headed studs is mainly influenced by the types of headed studs and the concrete strength. The larger the values of diameter and height of headed stud, the smaller the difference between BS5950-3.1 and EC 4 becomes. Additionally, with the decreasing of concrete strength, the resistance of headed stud also decreases significantly compared to BS5950-3.1.

Taking a headed stud with 19 mm diameter and 100mm height for example, the exact value of characteristic resistance determined by BS5950-3.1 and EC4 is given in Table 2. EC4 leads to a 15% maximum reduction of characteristic resistance of headed stud compared to BS5950-3.1.

3.2 Headed studs in composite slab

If profiled steel sheeting is used, headed stud connectors are located in the trough of sheeting. Based on the information from tests, it shows that the shear resistance of headed studs in composite slab is lower than the resistance in a solid slab for materials of the same strength. This is because that local failure of the concrete rib occurs. For this reason, reduction factors are applied to the resistance P_{Rd} according to EN 1994-1-1.

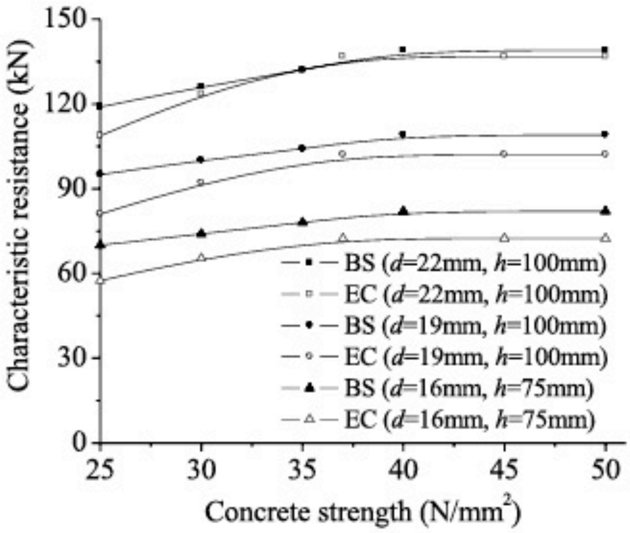


Figure 3: Comparison of characteristic resistance of headed studs in solid slabs

Table 2: Comparison of characteristic resistance of headed studs

Characteristic resistance of headed stud P_{Rk} (kN)				
Headed stud in solid slab	Characteristic strength of concrete strength (N/mm^2)			
	25	30	35	40
BS5950-3.1	95	100	104	109
EC4	81	92.1	100.6	102.1
(BS-EC4) / BS %	15%	8%	3%	6%

The load-slip relationship of headed stud connector in profiled steel sheeting is more complex than in a solid slab. It is influenced by the following factors:

a) The direction of the ribs relative to direction of span of the composite beam;
b) The mean breadth b_0 and depth h_p of profiled steel sheeting;
c) The diameter d and height h_{sc} of the headed shear stud;
d) The number n_r of the headed studs in one trough;
e) Whether or not a headed stud is central within a trough.

Base on testing and experience, reduction factors *k* are given to calculate the shear resistance of a headed stud connector in composite slab with profiled steel sheeting. There are two situations should be considered in the calculation of reduction factor *k*.

(1) For profiled steel sheeting with ribs parallel to the supporting beams, the reduction factor, k_l is taken as:

$$k_l = 0.6\frac{b_0}{h_p}\left(\frac{h_{sc}}{h_p}-1\right) \le 1.0 \tag{4}$$

In BS5950-3.1, the reduction factor is calculated using the same equation given in EC4.

(2) For profiled steel sheeting with ribs transverse to the supporting beams, the reduction factor, kt is taken as:

$$k_t = \frac{0.7}{\sqrt{n_r}}\frac{b_0}{h_p}\left(\frac{h_{sc}}{h_p}-1\right) \le k_{t,max} \tag{5}$$

Where n_r is the number of stud connectors in one rib at a beam intersection, not exceed 2. The factor k_t should not be taken greater than $k_{t,max}$ given in Table 3.

In BS5950-3.1, the reduction factors that are applied to the resistance of the shear connector are calculated using identical equations to those EC4, but with a different constant coefficient applied. For re-entrant trough profiles, the constant coefficient is 0.85 and 0.6 for singles and pairs respectively, and for open trough profiles, 0.63 and 0.34 for singles and pairs respectively. However, the constant coefficient is 0.7 and 0.5 for singles and pairs respectively in EC4, as shown in Equation (5).

Table 3: Upper limits $k_{t,max}$ for the reduction factor k_t

Profiled steel sheeting	Number of stud per rib	Thickness (mm)	EC4	BS
Re-entrant trough	n_r=1	≤1.0 >1.0	0.85 1.0	1.0
	n_r=2	≤1.0 >1.0	0.70 0.8	0.8
Open trough	n_r=1	≤1.0 >1.0	0.85 1.0	0.82
	n_r=2	≤1.0 >1.0	0.70 0.8	0.45

Compared to BS5950-3.1, EC4 leads to a 17% reduction for re-entrant trough profiles if the deck geometry is such that the limiting values do not apply, whereas an increase for open-trough profiles. However, most decks commonly used in the UK are designed such that the limiting value dominates, so the reduction factor is independent of the geometry and is based only on the number of studs and the orientation of the deck. For re-entrant trough profiles, these values of EC4 are the same as the BS for decks thicker than 1.0 mm, but about 15% lower than BS5950 for decks with a sheet thickness of 1.0 mm or thinner. However, for open trough profiles, these values of EC4 are higher than that of BS.

In composite slab with profiled steel sheeting, the resistance of headed stud (d=19mm and h=100) determined by BS5950-3.1 and EC4 are compared in Table 4. The values of headed stud resistance is the product of the resistance of headed stud in solid slab and the reduction factor $k_{t,max}$ in Table 3. From Table 4, it is found that the resistance of headed stud in EC4 is lower than that in BS5950-3.1, except for open trough profiled steel sheeting with two headed studs per rib.

Table 4: Comparison of resistance of headed studs

Headed stud in composite slab with profiled steel sheeting			Characteristic strength of concrete strength (N/mm^2)			
			25	30	35	40
BS5950-3.1	Re-entrant	n_r=1	95	100	104	109
		n_r=2	76	80	83.2	87.2
	Open trough	n_r=1	77.9	82	85.3	89.4
		n_r=2	42.8	45	46.8	49.1
EC4	Any type	n_r=1	68.9	78.3	85.5	86.8
		n_r=2	56.7	64.5	70.4	71.5

In general, for both solid slab and composite slab, the resistance of headed studs determined by EC4 is lower than that given in BS5950-3.1. Therefore, for a composite member with identical dimension and material, more headed studs are needed in the construction according to EC4.

4. Lateral-torsional buckling of composite beams

In composite beam, the upper flange of steel section attached to slab by shear connection may be assumed to be laterally stable. Generally, the profiled steel sheeting is assumed to prevent any lateral-torsional buckling in the design situation of construction. Therefore, the composite beam can be taken as fully restrained against lateral buckling, though lateral-torsional buckling can occur before fixing the profiled steel sheeting. The bottom flange of steel section is in compression in hogging moment regions of continuous composite beams. The region of hogging moment at the internal supports may be considerable when only the dead loads act on one of the spans. In this situation, the lateral-torsional buckling of the bottom flange may easily occur at internal supports, as shown in Figure 4. Therefore, the slab is usually assumed to prevent the upper flange of the steel section from lateral-torsional buckling. But, the stability of bottom flange should be checked in the hogging moment region.

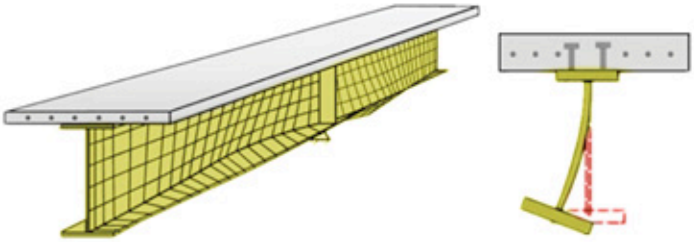


Figure 4: Lateral-torsioning of continuous composite beam

In BS5950-3.1, no equation is provided to calculate the lateral-torsional buckling resistance of continuous composite beams. When checking the lateral-torsional buckling, the method given in BS5950-1 is used. However, EC4 provides equation to check lateral-torsional buckling. According to BS5950-3.1, when checking the lateral stability of the bottom flange in negative moment regions, the methods given in appendix G of BS5950-1 may be used. For a uniform member with one flange laterally restrained and a non-restrained compression flange, the buckling resistance moment is determined by the following equation:

$$M_{b,Rd} = p_b S_x \tag{6}$$

Where p_b is the bending strength; S_x is the plastic modulus about the major axis. The bending strength p_b for the relevant values of λ_{TB} and the yield strength of steel p_y should be obtained from Table 16 or Table 17 of BS5950-1. For a uniform member, the equivalent slenderness λ_{TB} is determined by the following expression:

$$\lambda_{TB} = n_t u v_t \lambda \tag{7}$$

with:

$$v_t = \left[\frac{4a/h_s}{1+\left(2a/h_s\right)^2 + 0.05\left(\lambda/x\right)^2} \right]^{0.5}$$

$$n_t = \left[\frac{R_1+3R_2+4R_3+3R_4+R_5+2\left(R_s-R_E\right)}{12R_{max}} \right]^{0.5}$$

Where u is the buckling parameter, u = 0.9 for rolled sections; is taken as L_y/r_y; a is the distance between the reference axis and the axis of restraint; h_s is the distance between the shear centres of flanges; x is the ratio of the section depth to flange thickness; R1 to R5, RE and RS can be determined from the G.4.3 of BS5950-1.

According to EC4, the design buckling resistance moment of a laterally unrestrained continuous composite beam should be taken as:

$$M_{b,Rd} = \chi_{LT} M_{Rd} \tag{8}$$

With:

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \bar{\lambda}_{LT}^2}}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{M_{Rk}}{M_{cr}}}$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0.2\right) + \bar{\lambda}_{LT}^2\right]$$

Where: M_{Rd} is the design resistance moment under hogging bending at the relevant internal support; is the imperfection factor related to the buckling curve; M_{Rk} is the resistance moment of the composite section using characteristic material properties; M_{cr} is the elastic critical buckling moment at an internal support of a continuous beam.

According to EN1994-1-1, the calculation of the elastic critical moment M_{cr} is based on a rather complex approach called "continuous inverted U-frame" model. This model takes into account the lateral displacement of the bottom flange causing bending of the steel web, and the rotation of the top flange that is resisted by bending of the slab. The elastic critical buckling moment at an internal support of a continuous beam is given by:

$$M_{cr} = \left(k_c C_4 / L\right)\left[\left(G_a I_{at} + k_s L^2 / \pi^2\right) E_a I_{afz}\right]^{1/2} \quad (9)$$

where: k_c is a property of the composite section; C_4 is a property of distribution of bending moment within length L; G_a is the shear modulus for steel, ; I_{at} is the torsional moment of area of the steel section; k_s is the rotational stiffness; L is typically, the span length; I_{afz} is the minor-axis second moment of area of the steel bottom flange,

A worked example of a two-span continuous composite beam is given to compare the lateral-torsional buckling resistance calculated according to EC4 and BS5950-3.1. In the worked example, the span of composite beam is 9m, and the thickness of composite slab with profiled steel sheeting is 130 mm. A steel section 406 × 178 UB 67 with steel strength f_y = 355 N/mm^2 is adopted. The cylinder compression strength of concrete used in the beam f_{ck} and the strength of reinforcement f_{sk} is 25 N/mm^2 and 500 N/mm^2 respectively. The result is illustrated in Table 5.

It is found that value of the lateral-torsional buckling resistance determined by EC4 is larger than that calculated from BS5950-3.1. EC4 leads to 14 % increase of the resistance compared to BS5950-3.1. As mentioned above, BS5950-3.1 adopted the method given in BS5950-1 for steel beam with one flange laterally restrained and a non-restrained compression flange. The influence of concrete is not considered in the calculation. However, in EC4, although the upper flange of steel section attached to slab by shear connection is assumed to be laterally stable and the bottom flange of steel section is non-restrained, which is similar to the assumption of BS5950-1, the contribution of concrete slab is considered in the calculation of the bending moment resistance M_{Rd} and the elastic critical buckling moment M_{cr}. This is the reason why the value of the lateral–torsional buckling resistance obtained from EC4 larger than that determined from BS5950-3.1.

Table 5: Comparison of lateral-torsional buckling resistance

	EC 4	BS5950-3.1	(EC 4- BS)/ BS
$M_{b,Rd}$ (kN)	546	479	14%

5. Conclusions

The impact of Eurocodes on composite structures is investigated in this paper. The study of material property, shear resistance of headed studs and lateral-torsional buckling resistance of continuous composite beams is conducted according to EC4 and BS5950-3.1. Based on the results of analysis, the following conclusions can be drawn.

(1) Some product standards only have requirements on the nominal yield and tensile strength, or their minimum values. The stress ratio calculated according to these nominal values cannot comply with the EC3 ductility requirement. Therefore, the yield strength should be amended to satisfy the ductility requirement.

(2) For both solid slab and composite slab, the shear resistance of headed studs determined by EC4 is lower than that given in BS5950-3.1.

(3) The value of lateral-torsional buckling resistance of continuous composite beams determined by EC4 is larger than that calculated from BS5950-3.1. This is because that the contribution of concrete is considered in EC4, while not taken into account in the design of BS5950-3.1.

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Very Large Floating Structures

FIG 1

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Managing Director
Floating Solutions LLP.

Very large floating structures (VLFS) are of course nothing new. From ships to offshore oil rigs and FPSOs, Singapore has built a fair share of them. Until recent years the principles of buoyancy remain almost exclusively in domain of the marine industry. However, in the past two decades, global issues have arisen that have prompted engineers to look to the sea for solutions to meet the challenges these issues present.

These issues are interelated. Its source is the 7.3 billion people on this planet spewing about 30 billion tons of carbon dioxide annually. It results in global warming and rising sea levels and salination and loss of coastal lands. El nino events such as typhoons and flash floods coupled with deforestation result in stripping the nutrient rich top soil necessary for life.

As much of the world's population lives around the coast, the consequence of the effect of climate change is dire. VLFS offers ways to overcome these challenges. Innovations in this field include floating airports, ports, wind and solar energy farms, nuclear power plants, bridges abodes and even launch pads for space exploration.

For Singapore, land reclamation is no longer a viable option. Export of sand is ecologically and hence politically incorrect. The next option is the creation of floating "islands". Its life cycle cost is attractive. Government agencies are offering grants to investigate their use.

Given the limited land, the government policy is design to maximise land yield. It favours industries, which contributes to the GDP with minimal use of land and labour. Steel fabrication is unfortunately not one and is dispensable.

Relocating production to Indonesia, Vietnam, Malaysia or any such countries, has several cost advantage but is not without risks to the shareholders. Incidents of strikes, riots, government policy reversals, and religious violence are all too common. Every dollar sunk into foreign soil is a dollar at risk.

VLFS offers another option, which hitherto has never been considered.

An entire fabrication facility erected on a float has many advantages. It does not occupy land. It is free of the risk of escalating rentals. It is a movable asset and like a ship, may be moored in Singapore waters or the waters of any country. Its ownership can be transferred across national borders and production can be located at wherever the international market justifies it to be. For instance if there is a major project in Bangkok, which requires 30,000 tons of fabrication work, the facility may be moved there and operate in a lower cost environment as well as lower cost of shipping bulky finished products. To overcome Thai laws, the facility may be sold to a Thai for a period until the project is completed with a pre-agreement for the Thai to sell it back under stipulated conditions.

Is it stable and safe? How big can it be? Rather than answer these questions herewith words, I suggest the reader google on line for videos and images of VLFS (search words: floating runway Tokyo; floating breakwater Monaco video; floating bridge lake Washington; floating nuclear plant Russia; floating rig in heavy storm video; floating city national geographic 2015 video; floating solar power plant)

Clustering always confer benefits for industries. Steel fabrication is no exception. A group of steel fabrication plants in close proximity promotes the growth of supporting industries such as steel stockists, galvanisers, steel basting and painting services, suppliers of welders, fitters and painters, scaffoldings. This is so on land and will be in the sea too. In addition, a cluster of floating fabrication plants can use a common power plant, fuel storage facility, workers amenities such as food and recreation centres and dormitories. Water is collected from precipitation and stored beneath the deck of each floating facility. Any short fall may be bought from water boats, which service ships in the harbour. A cluster may compose of stand-alone floats or abutting floats as shown in the Fig. 1.

Being afloat, one may take advantage of the many floating cranes in Singapore, which have lifting capacity up to 5000 tons (unlikely to be needed for structural steel fabrication). The erection of a floating theatre (Seoul) on a floating platform is depicted in Fig. 2.

The author welcomes any enquiries from those wishing to explore the subject further.

Fig. 2

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